Cost Structure of **Historical River Engineering Measures** on the **Viennese Danube**

Andreas Hahmann

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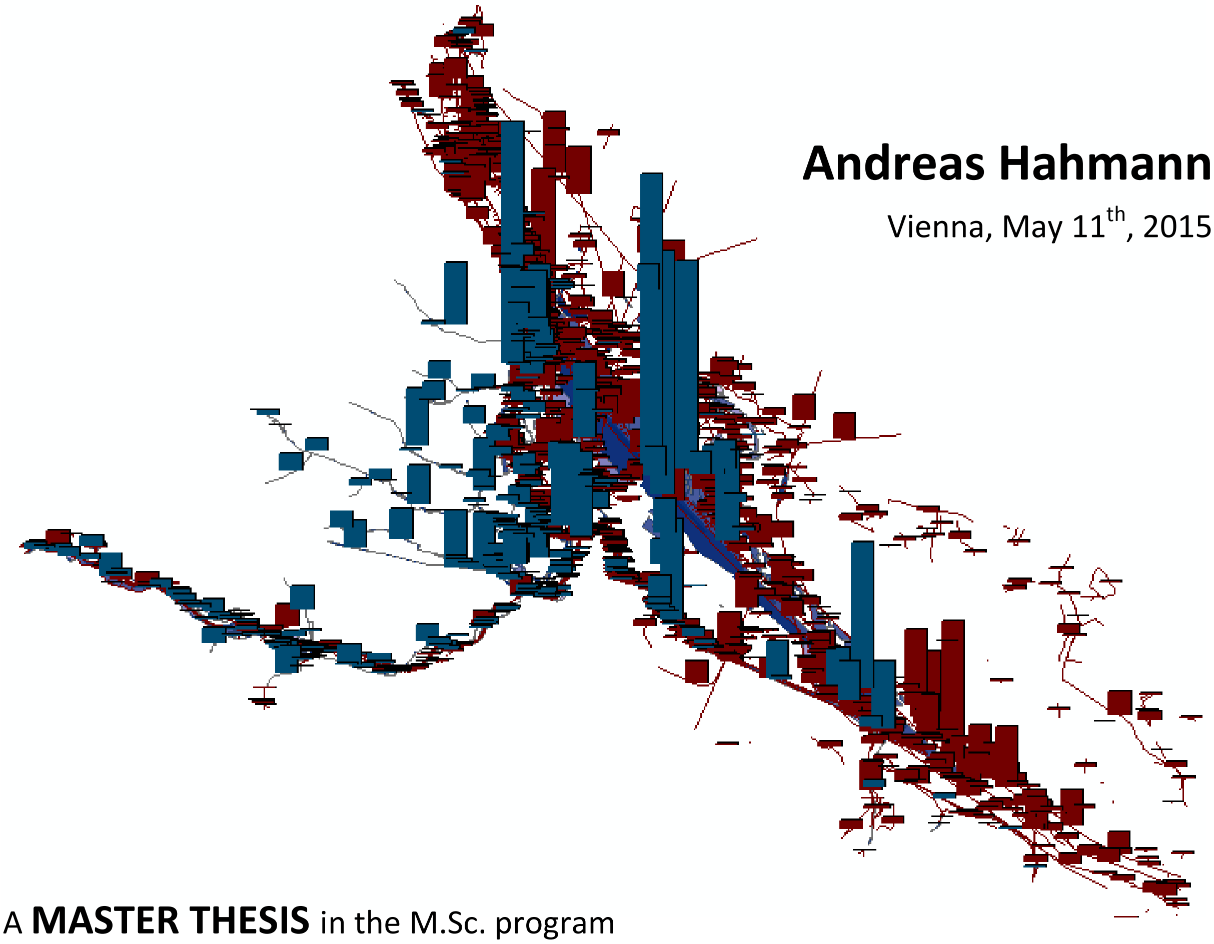

A **MASTER THESIS** in the M.Sc. program

Environmental Science in Europe (ENVEURO)

For the achievement of a double-degree at the *University of Copenhagen (KU)* and the *University of Natural Resources and Life Sciences Vienna (BOKU)*

Supervision: **Severin Hohensinner** and **Herwig Waidbacher** (BOKU), **Brian Jacobsen** (KU) and **Andreas Weigl** (University of Vienna)

English title

Cost structure of historical river engineering measures on the Viennese Danube

German title

Kostenstruktur historischer Wasserbauten an der Wiener Donau

Danish title

Omkostningsstruktur af historiske flodbygningsværker ved Wiens Donau

Supervision and Allocation

Host University: *University of Natural Resources and Life Sciences Vienna (BOKU)*, Austria
Department of Water - Atmosphere - Environment (WAU), Institute of Hydrobiology and Aquatic Ecosystem Management (IHG)
Supervisors: Severin Hohensinner, Herwig Waidbacher

Home University: *University of Copenhagen (KU)*, Denmark, *Faculty of Science, Department for Food and Natural Resource Economics*
Supervisor: Brian H. Jacobsen

From the *Department of Economic and Social History* at the *University of Vienna* as **external supervisor**: **Andreas Weigl**

The study has been supported by **Verena Winiwarter** from the *Centre for Environmental History in Vienna* at the *Alpen-Adria-University Klagenfurt,* based on the project ENVIEDAN 1500-1890 (project no. P25796-G18) and in the context of the project URBWATER (project no. P22265-G18). Both projects were funded by the Austrian Science Fund (FWF).

Declaration of Authorship

I hereby certify that the present thesis, to the best of my knowledge and belief, is original and the result of my own thoughts and investigations. Wherever thoughts and investigations from other sources are used, they are indicated as such. The work has neither been published in any form nor submitted for a degree at any university before.

„If one deals with problems and the solutions of problems […] and if one is willing to approach human problems not already with the blinders of a particular theory, one easily notices that humans, just as animals, have the fatal characteristic to stick to once elaborated, once found solutions stubbornly, namely as well when the environmental conditions have already altered so much, that solutions which potentially have once been the best possible ones, maybe the only possible ones, do not apply any longer and the solution in this way has become a new problem." [1]

Paul WATZLAWICK (1921-2007)

Original quote in German:

„Wenn man sich […] mit Problemen und Problemlösungen befasst und wenn man willens ist an menschliche Probleme nicht bereits mit den Scheuklappen einer bestimmten Theorie heranzugehen, dann fällt einem unschwer auf, dass Mensch wie Tier die fatale Eigenschaft haben, an einmal erarbeiteten, einmal gefundenen Lösungen stur festzuhalten und zwar auch dann, wenn die Umweltbedingungen sich schon so weit geändert haben, dass die Lösungen, die einmal möglicherweise die bestmöglichen, vielleicht die einzig möglichen waren, nicht mehr zutreffen und dass auf diese Weise eben die Lösung dann zum Problem wird."

[1] From: WATZLAWICK (1987), translated from German by the author of the thesis; available at URL: http://www.youtube.com/watch?v=M7aMmiMrYmU (Minute 6:48) [accessed 09 30, 2014]

PREFACE, REMARKS AND ACKNOWLEDGEMENTS

This thesis fulfills several purposes:

- ✓ On a societal level it is a little contribution for present and future generations in Vienna and elsewhere to gain access to past experience in river management and to raise awareness for the great and diverse efforts which have been and will be necessary to enable a city like Vienna to fulfill the "requirements" for its existence and evolution and to safeguard the "functionality" of rivers – like the Danube and its tributaries – in accordance with different societal and environmental goals.
- ✓ On an academic level it is an interdisciplinary experiment with the information hidden in widely distributed and heterogeneous historical data when they are collected, made comparable and, thus, accessible and illustrated in a schematic way over time. This thesis was conducted as independent part of the research project *URBWATER Vienna´s Urban Waterscape 1683-1918 – An Environmental History*, dealing with fundamental changes in the Viennese waterscape from 1683 to 1918 (ZUG, 2013-2015)[2]. It is funded by the Austrian Science Fund (FWF; project no.: P25796-G18; project leader: *Verena Winiwarter*). The research is based on the former FWF-project *ENVIEDAN 1500-1890* (project no. P22265-G18; ZUG, 2012-2014)[3] dealing with the interlinked environmental history of the Viennese Danube, a river landscape which has been entirely regulated and transformed over the centuries and still constitutes the ultimate boundary condition for the existence and functioning of the city of Vienna. The results from "ENVIEDAN" have recently been published in six articles[4] in the journal *Water History* and presented in various Austrian newspapers, e.g. *Die Presse* (KUGLER, 2013[5]; ÖZKAN, 2013[6]).
- ✓ On a personal level the thesis concludes a period of travelling through three different countries and various fields of environmental sciences, meeting many contrasting and interesting people from around the world and getting in contact with a wide range of different ideas and approaches to science and to life, sharing the insight that major transitions of society's practices are required in near future.

Available [accessed 09 30, 2014] at URL:
[2]http://www.umweltgeschichte.uni-klu.ac.at/index,6536,URBWATER.html
[3]http://www.umweltgeschichte.uni-klu.ac.at/index,3560,ENVIEDAN.htm
[4]http://link.springer.com/journal/12685/5/2/page/1
[5]http://diepresse.com/home/science/1429917/Wie-die-Donau-gebaendigt-wurde
[6]http://diepresse.com/home/panorama/donautour/1340303/Wien-und-die-Donau_Eine-Scheinehe

The data collections in this thesis contain specifications for nearly 2,000 historical river engineering measures, more than 500 years and numerous references with price information from historical sources. The following text focuses on the central themes and on a schematic description of the methodology leading to the results. Besides, there is an appendix attached to the thesis containing illustrations, which did not fit in directly into one of the chapters. Many details furthermore hide in the raw data. A basic data selection is available on the DVD attached to the hard copy of the thesis in the library of the *University of Natural Resources* and *Life Sciences* in Vienna and was submitted to the supervisors. A description of the selection on the DVD is attached in appendix V. Please note that these data tables could not be attached to the PDF and online versions of the thesis. A complete version with all raw data, calculations and additional material is available at the *Institute of Hydrobiology and Aquatic Ecosystem Management* and the *Centre for Environmental History* in Vienna.

The processing of data in this study was conducted with two computer programs: *Microsoft Excel 2010* (in the text called *Excel*) and *ESRI ArcGIS 10* (in the text referred to as *ArcGIS* or *GIS*). Research specific illustrations originate from these two programs. *ArcGIS* served both as supporting tool for the initial literature work and for additional illustrations of the final outcome. All steps in between, extensions, rearrangements of the database, calculations etc. were conducted with *Excel*.

Throughout the thesis certain terms appear which are only understandable if they are defined more precisely: A list of definitions and abbreviations is attached at the end of the text to enhance the understanding of such terms. Some terms appear with meanings in the context of this research, deviating from their common meaning, either because they have been translated from German, or because the research asks for specific definitions. Such cases are explained in the respective chapters of the text. Specific expressions (e.g. “unqualified labor“) and important categories (e.g. “water body type”) are highlighted with “quotation marks” whenever it appears appropriate to stress their particular meaning in this context. Terms in *italic letters* apply to names of locations (e.g. *Donaukanal*), people (e.g. *G. Wex*), categories (e.g. *flood dikes*) or research specific units (e.g. *days unqualified labor equivalents*). Underlined letters mark links to figures or tables in the text and to other chapters or appendices or they mark external links to online sources. Direct quotes from other sources are highlighted by the use of both *“quotation marks and italic letters”*. Both for direct quotes and for specific information, such as documented prices for river engineering measures – if possible – the exact page (or archive signature) is mentioned together with the reference in the text.

As the nature of the thesis is highly interdisciplinary, support from many sides was required to realize this project. Hence, **many thanks to**

... *Severin Hohensinner* from the *Institute of Hydrobiology and Aquatic Ecosystem Management*, contributing with detailed knowledge about the history of the Viennese Danube floodplain and relevant historical sources,

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ABSTRACTS

Summary (Abstract in English)

Recently, the evolution of the *Viennese Danube floodplain* in the previous 500 years has been reconstructed and a GIS-database has been established, with approximately 1,850 river engineering measures at the Viennese water bodies from 1100 till 1900 CE, featuring basic information about their extent, durability, primary objectives and physical properties. In the 16th century the navigability of the *Wiener Arm* – a precursor of the present *Donaukanal* which functioned as a supply line from the main branch to Vienna – was threatened due to continuous siltation processes and fluvial dynamics of the Danube. The Viennese opposed these changes with costly but inefficient regulation efforts setting a century-long battle in motion peaking with the *Great Danube Regulation* between the years 1870 and 1875.

In this study, the extents and physical properties of river engineering measures were translated into cost estimates in order to obtain a long-term overview of the undertaken efforts, underlying motivations and changing abilities of society to change the city's water bodies. A framework of existing price indices and documented labor and food prices was used to compare historical values of money. Distinct price categories for different construction types and time periods were derived by data in historical literature as standardized prices per extent.

Adding up the cost estimates resulted in expenses at least equivalent to 60,000 - 400,000 days unskilled labor of a mason in most decades from 1540 to 1700, at least 300,000 - 1,400,000 in all decades between 1700 and 1830, and at least 1,800,000 in all decades from 1830 till 1910, peaking with – potentially – up to 28,000,000 days unskilled labor in the decade 1870-1880. The resulting cost structure shows analogies with natural, environmental and societal changes and historical events in Vienna. The attributes from the database (e.g. water body types, objectives) allow for a wide range of scientific analyses.

Zusammenfassung (Abstract in German)

Kürzlich wurde die Entwicklung der *Wiener Donau-Auen* in den vergangenen 500 Jahren rekonstruiert und eine GIS-Datenbank mit etwa 1.850 zwischen 1100 bis 1900 n. Chr. umgesetzten Wasserbauten, mit Hinweisen zu deren Ausdehnung, Lebensdauer, wasserbaulichen Zielen und physischen Eigenschaften erstellt. Im 16. Jh. wurde die Schiffbarkeit des *Wiener Arms* – einem Vorläufer des heutigen *Donaukanals* und Versorgungsweg zwischen dem Donauhauptarm und Wien – durch andauernde Verlandung und natürliche Verlagerungen der Donau bedroht. Die Wiener antworteten mit teuren, aber ineffizienten Regulierungen, die einen jahrhundertelangen Kampf einleiteten, der mit der *Großen Donauregulierung* von 1870 bis 1875 seinen Höhepunkt fand.

In der vorliegenden Arbeit werden die Kosten historischen Wasserbauten auf Basis ihrer physischen Eigenschaften und des Bauvolumens quantifiziert. Dadurch ist es möglich, einen zeitlichen Überblick über den betriebenen Aufwand, die zu Grunde liegenden Motivationen und die Fähigkeit der Gesellschaft, die Gewässer in der Stadt zu verändern, zu erstellen. Dokumentierte Preisindizes, Löhne und Nahrungsmittelpreise werden zum Vergleich historischer Geldwerte herangezogen. Preiskategorien für verschiedene Bautypen bzw. Zeiträume werden aus historischen Quellen als standardisierte Preise je Bauumfang abgeleitet.

Die aufsummierte Schätzung legt Ausgaben im Wert von mindestens 60.000 - 400.000 Tagen Arbeit eines ungelernten Maurers in den meisten Jahrzehnten von 1540 bis 1700 nahe. Zwischen 1700 und 1830 sind es mindestens 300.000 - 1.400.000 Tage Arbeit in allen Jahrzehnten, 1830 bis 1910 mindestens 1.800.000. Maximal werden im Jahrzehnt 1870-1880 Kosten von bis zu 28.000.000 Tagen Arbeit angenommen. Die Kostenstruktur weist Analogien mit natürlichen, ökologischen und gesellschaftlichen Veränderungen und historischen Ereignissen in Wien auf. Die Attribute in der Datenbank (z.B. Gewässertyp, Ziel der Maßnahmen) ermöglichen eine Reihe weiterführender Analysen.

Sammenfatning (Abstract in Danish)

For nylig blev udviklingen af Wiens Donau flodslette i de foregående 500 år rekonstrueret og en GIS-database blev etableret, med omkring 1.850 flodbygningsværker ved Wiens vandløb fra årene 1100 indtil 1900 e.Kr., som byder på grundlæggende oplysninger om deres omfang, holdbarhed, primære mål og fysiske egenskaber. I det 16. århundrede blev besejlingsforholdene i flodgrenen *Wiener Arm*, en forsyningsledning fra Donaus hovedgren til Wien, som var en forløber for den nuværende *Donaukanal*, truet af kontinuérlige siltations-processer og hovedløbets naturlige dynamik. I Wien reagerede man på de fluviale forandringer med dyre og ineffektive reguleringer, der satte en århundrede lang kamp i gang, som nåede sit højdepunkt med den Store Donau Regulering, mellem 1870 og 1875.

I denne afhandling, er omfanget og de fysiske egenskaber af flodbygningsværker oversat til et omkostningsoverslag, for at få et begreb af den finansielle indsats, de underliggende motivationer og samfundtes skiftende evne til at forandre og vedligeholde byens vandveje. Prisindeks, løn og fødevarepriser blev anvendt til at sammenligne historiske værdisætninger af penge. Priskategorier for forskellige konstruktionstyper og tidsperioder, som standardiserede priser pr omfang, blev afledt af noter i historisk litteratur.

Summeringen af estimaterne resulterede i omkostninger, svarende til mindst 60.000 - 400.000 arbejdsdage, af en ufaglært murer, i de fleste årtier fra 1540 til 1700, mindst 300.000 - 1.400.000 dage i hvert årti fra 1700 til 1830 og mindst 1.800.000 dage i hvert årti fra 1830 til 1910, med et maksimum op til 28 millioner ufaglært arbejdsdage i tiåret 1870-1880. De resulterende mønstre viser analogier med naturlige, miljømæssige, samfundsmæssige forandringer og historiske begivenheder i Wien. Attributterne fra databasen (f.eks vandløbstype, formål) giver mulighed for en bred vifte af yderligere videnskabelige analyser.

TABLE OF CONTENTS

1 INTRODUCTION AND OVERVIEW

An interdisciplinary approach was used to characterize the diverse past interactions of a major European capital – *Vienna* – with its waterscape, consisting of the *Danube River* and its tributaries. This relationship has been examined in the mirror of prices per extent, cost volumes per time period and the cost-efficiency of historical river engineering measures conducted in the present city area of Vienna. Rivers are essential structures of natural environments and fulfill important functions both in socio-economic systems (e.g. as flood risk, transport route, water and energy supply) and for ecosystems (e.g. as riparian and aquatic habitats, ecological pathways or flood retention basins). The health of ecosystems itself has been recognized as being of long-term socio-economic importance in a globalized society, which has identified major limitations in the environmental offer compared to growing societal demands (e.g.: EFTEC, 2005; MEA, 2005). The present constitution of the river network in Vienna is the result of a century-long battle of *the Viennese* with "their" water bodies with changing attention on several societal functions: Battles for permanent and safe navigation, for the gain of urban space, for the protection of agricultural land or urban infrastructure from floods and erosions, for water and energy supply were on top of the agenda. Changing natural, socio-economic and cultural boundary conditions triggered both quantitative and qualitative changes in the societal effort to transform the water bodies by the means of hydraulic engineering (HOHENSINNER et al., 2013b; WINIWARTER et al., 2013). Nowadays, the *European Union* in the *EU Water Framework Directive* urges all member states to *"implement the necessary measures to prevent deterioration of the status"* and *"protect and enhance all bodies of surface water"* and to restore all surface water bodies that are not classified as *"heavily modified"* (EU, 2000, Art. 4§1.a). Thus, water quality and ecological status have become integrated requirements for modern river management on the highest level of European law. These new objectives only start to add to and still compete with other requirements, e.g. power generation, a sufficient water depth for long-distance bulk transport or improved flood protection to defined discharges (WINIWARTER et al., 2013). Besides being biophysical services or threads, running waters are parts of basic human life experience and are emotionally associated with such important terms as life, death, power or happiness (EHMAYER, 2008; BEKESI, 2010). Myths and fairy tales tell about the intrinsic meaning of the water bodies near Vienna, for example, when they are dealing with fishermen dragged under by water necks[7] or with dangerous places near the mill weirs being home of a merman[8] (SAGEN.AT, 2000-2014). Thus, the functionality of running waters is both of short-term and long-term, socio-economic and intrinsic importance for human societies.

Only recently, the "co-evolution" of Vienna and the Danube has been studied (WINIWARTER et al., 2013) in the interdisciplinary research project *ENVIEDAN (Environmental History of the Viennese Danube 1500-1890)* at the *Faculty for Interdisciplinary Studies* of the *Alpen-Adria-University Klagenfurt* in cooperation with the *University for Natural Resources and Life Sciences* in Vienna. Figure 1-1 on the following page may give a good first impression of the overall transformation of the floodplain which has happened between the year 1550 and today. The entire process which turned the Viennese Danube floodplain from a wide natural river landscape into an entirely regulated urban river for the first time has been reconstructed in detail based on numerous historical maps and documents for various time steps back till 1529 (LAGER, 2012; HOHENSINNER et al., 2013a, 2013b). As a byproduct of this project, a database of nearly two thousand historical hydraulic engineering measures between the years 1100 and 1900 has been established (HOHENSINNER et al., 2012) with the program *ESRI ArcGIS*.

Available [accessed 09 30, 2014] at URL:
[7] http://www.sagen.at/texte/sagen/oesterreich/wien/20_bezirk/donauweibchen.html
[8] http://www.sagen.at/texte/sagen/oesterreich/allgemein/vernaleken/wassergeister_3.html

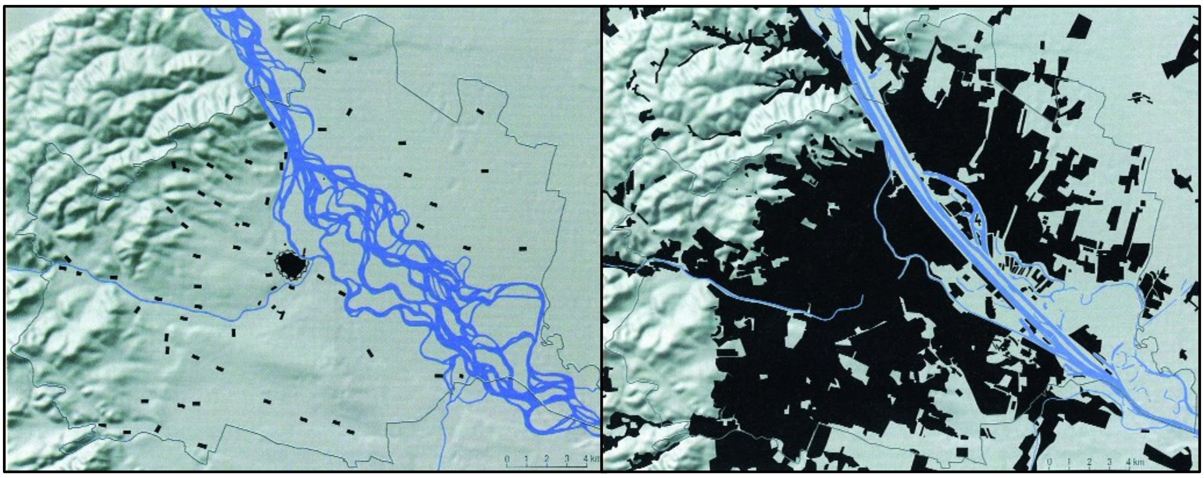

Figure 1-1: Illustrations of the city area of Vienna: "river-dominated" in 1550 (left hand side) and "colonized" in 2010 (right hand side); river branches (blue) and settled areas (black); from: SCHMID et al. (2010), after: BRUNNER & SCHNEIDER (2005).

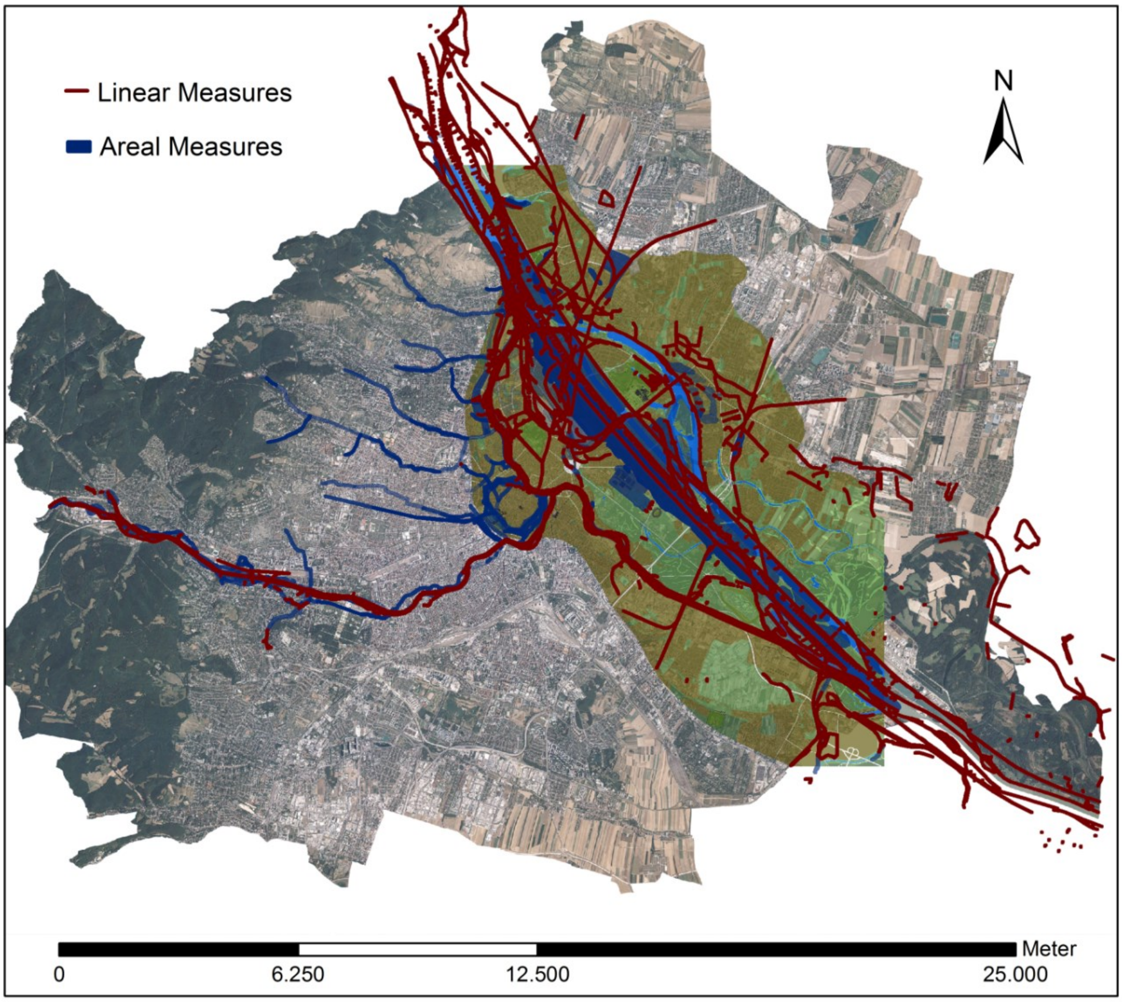

Figure 1-2: Database of historical river engineering measures in Vienna (HOHENSINNER et al., 2012) on top of the reconstructed floodplain (LAGER & HOHENSINNER, 2012a), on top of a satellite image of the city area (MA 41, WIEN, 2007).

Figure 1-2 shows the spatial dimension of the measures in the database (HOHENSINNER et al., 2012) on top of the reconstruction of the Danube floodplain in 2010 (LAGER et al., 2012a) and on top of a present satellite image of Vienna. Continuous natural change in the river morphology and dynamics altered the “functionality” of the channel network and, thus, determined and limited the opportunities of the people living in the area (WINIWARTER et al., 2013). The recognized potential to transform nature by technological means gave rise to the understanding that running waters may be artificially adapted according to particular demands. Following major physical interventions, rivers began to look more alike the ideal images of decision-makers of the respective time periods. A society depending on the caprices of the waterscape, it was using, developed into the active driver of environmental change. Despite major on-going river engineering efforts since the 16th century, the river landscape had been mostly natural till the early 19th century, but has since been rapidly transformed leading to a complete morphological and ecological transformation of the floodplain (LAGER, 2012). Figure 1-3 shows the past Danube floodplain on a map in the late 18th century which was subdivided into many branches covering a wide area northeast of Vienna. The core area of settlements is located on the ancient river terrace and the floodplain itself had been cultivated but hardly settled. A dynamic natural river landscape dominates urban structures which seem to be adapted to and dependent on the natural functionality of water bodies. In contrast, on a modern satellite image (figure 1-4), the Danube appears as a marginal structure in a wide-spread urban landscape. Stable urban infrastructure nowadays clearly “dominates” the natural dynamics of the river. A straight channel has been assigned to the Danube main branch – a result from the *Great Danube Regulation* (*GDR*) from 1870 to 1875. The flood bypass *Neue Donau* (*New Danube*) which was constructed between 1972 and 1987 is visible east of the main channel. Only the *Alte Donau* (*Old Danube*) in the east and the *Donaukanal* in the west appear as obvious remnants of former side branches of the river.

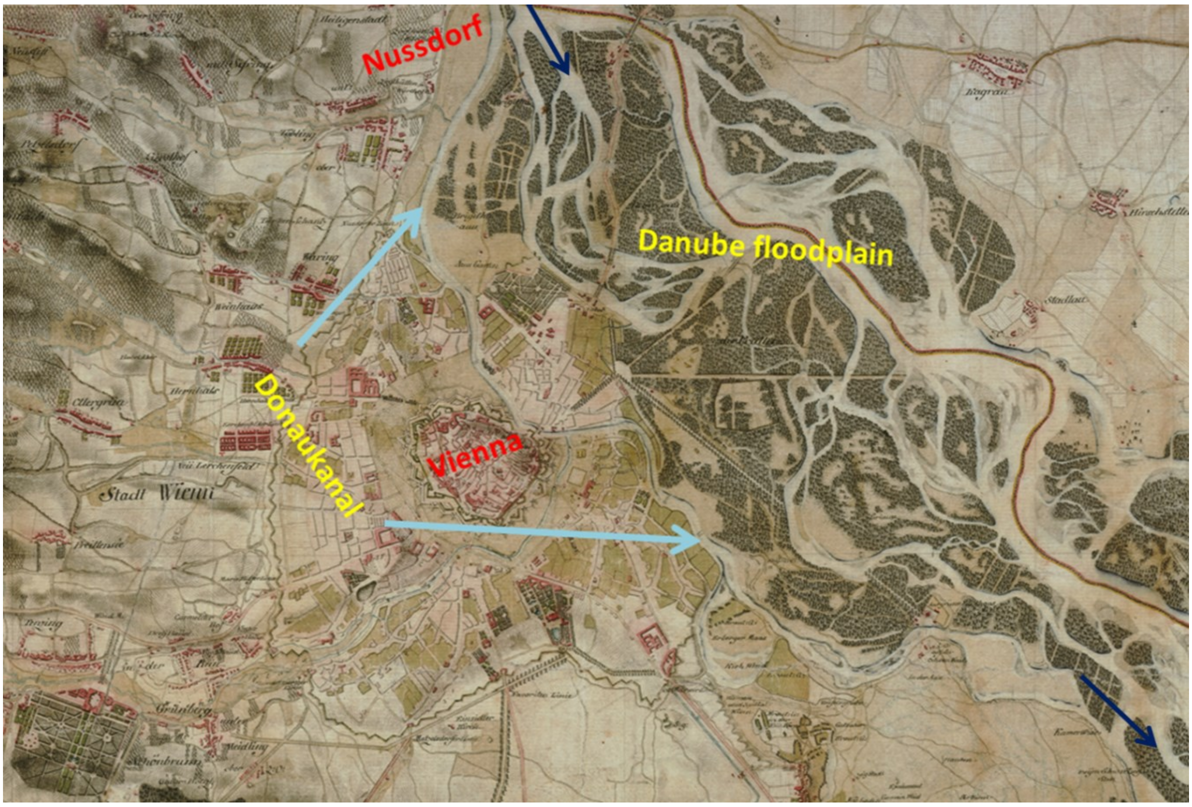

Figure 1-3: Excerpt from a historical map of Vienna next to the Danube from around 1780; 1st MILITARY SURVEY, 1773-1781; OeStA, Kriegsarchiv B IX a 242.

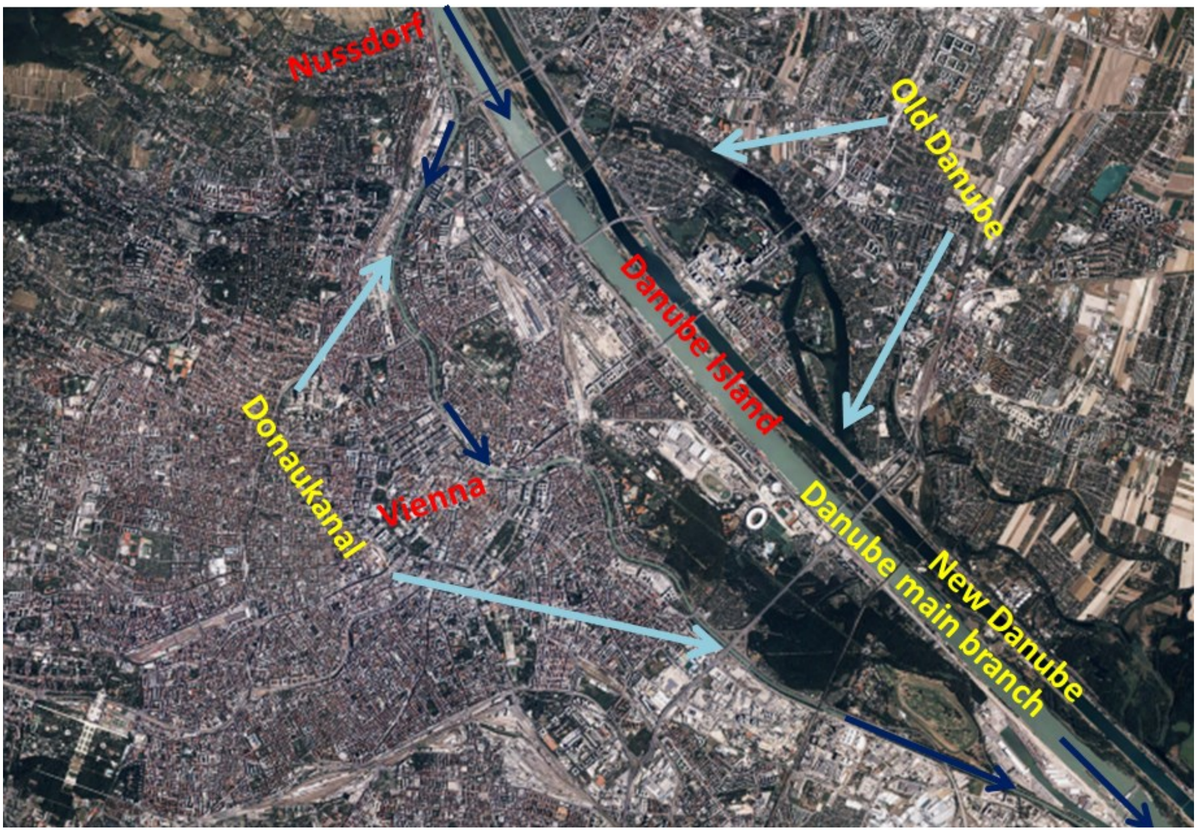

Figure 1-4: Modern satellite image of Vienna next to the Danube; excerpt from MA 41, WIEN (2007).

The extent and complexity of river engineering measures in the database indicate enormous expenses spent continuously on the rearrangement or maintenance of the channel network in Vienna. Information in literature on the extent of those expenses is widely distributed and fragmentary (e.g.: PASETTI et al., 1850; PASETTI, 1862; DRC, 1868, 1898; THIEL, 1904, 1906; SONNLECHNER & HOHENSINNER, 2011). The central motivation behind this thesis is to collect and analyze historical data in a schematic way and to identify temporal patterns in the regulation history of the river network in Vienna from a societal perspective. Financial means spent on river engineering measures are seen as indicators for the societal effort undertaken to adapt the functionality of water bodies for societal requirements and for the relative importance given to the improvement of particular river functions in different time periods. Society is in fact represented by particular actors (such as emperors, governments, the estates, mill owners or citizens) and costs are not necessarily reflecting "democratic" preferences within society as a whole but the priorities of those who were in charge of making decisions. The awareness of society in every decision-making step is one important factor defining the functionality of the running water system and changes fundamental boundary condition for the existence and functioning of future societies and ecosystems. Thus, the study may support historically informed decisions today and in future by making past relationships visible and aware. The project was approached step by step and aims on finding satisfying answers to the following research questions:

(1) What prices per meter, hectare or cubic meter were typical for different construction types of hydraulic engineering measures in the area of Vienna and the close surrounding in different time periods? How do the prices differ for different construction types and do they change evidently over time?
(2) What financial means were spent on river engineering in Vienna per time interval (quantitative effort) and which river functions were addressed by those expenses (qualitative effort)? How were the efforts distributed on different water body types or river sections in the city area?

(3) How has the societal ability to transform the floodplain changed over time, expressed by the cost-efficiency of measures in the database as prices per extent (meter or hectare) and duration of functionality (in years)?
(4) How did the societal motivation change over time reflected by the efforts per capita (inhabitants of Vienna) and compared to the Austrian gross domestic product (GDP)?

The following chapter 2 provides an overview of conclusions from previous studies on the history of Vienna and the Danube. The research will in this way be related to natural and socio-economic or socio-ecological developments, trends and events that may have influenced the cost structure in multiple ways or vice versa have been triggered themselves by particular river engineering projects and the transformation of the floodplain. Hydraulic engineering efforts are assumed to be reactions of societal actors to changing natural conditions (climate change, floods, meandering etc.), cultural preferences or societal demands (power structures, laws, population growth, industrialization etc.), technical or economic abilities (phases of technical progress and economic growth or stagnation and recession), environmental impacts of previous human activities (hydraulic barriers, loss of the riparian zone, sinking water levels, loss of ecological connectivity etc.). Subsequently, the question arises how side-effects of earlier rearrangements of the waterscape with particular priorities have influenced or caused the necessity for later rearrangements of the waterscape, possibly with different priorities.

The key research (methodology and results) is then subdivided into four major parts which are described and explained in the chapters three to six: Part 0 (described in chapter 3) refers to the characteristics of the database of historical river engineering measures in Vienna. It is described in this part how the database has been prepared for the purpose of the research. Schematically the structure of the existing database from Vienna (HOHENSINNER et al., 2012) is described and key characteristics (extents, construction types, primary objectives of measures) are illustrated. Meaningful categories of measures are defined and a scheme of river functions addressed by each measure or project has been carved out. Part A (described in chapter 4) does provide a central methodological tool in the research and aims on developing a framework of indicators for historical values of money in Vienna. The questions is how the effect of changes in the actual value of nominal money over time (inflation / deflation) can be eliminated in such a way that both predictions, about how prices in Vienna may have developed over shorter time intervals, and comparisons of amounts of money over longer time intervals, will be possible. As there is not one single absolute and "right" method, several methods have been used and compared based on available historical price indices, food prices and wages on a yearly level. Part B (described in chapter 5) is all about the documented prices for river engineering measures in historical literature and the selection of likely price ranges for different measure types and time periods in the database. The focus is in particular on that historical data for which information on prices per meter or hectare of a river engineering measure of a distinct construction type were derivable. For the interpretation and time-independent comparison of the meaning of the historical data the documented prices are deflated with the method(s) developed in part A and brought to the price levels of selected reference years. Similar prices from comparable construction types in each time period were grouped into a category with a defined price range. The measures in the database were then assigned to these price categories and a method has been developed according to which the quality of each estimate was specified. The individual cost estimates were interpreted using various "value-of-money"-indicators from part A. In Part C (chapter 6) results with respect to the central research questions were summarized. The financial means spent per time interval (mostly decades) were calculated by accounting individual cost estimates resulting from Part B for the different money equivalents derived in part A. Besides, the overall data quality, the distribution of expenses on different parts of the waterscape and the addressed river functions were illustrated. Major changes in average prices per extent and the cost-efficiency related to the durability of measures were detected over time.

As a starting point several very basic hypotheses may come up, at first:

- The years 1540 (= start of major Danube regulations), 1700 (= start of the systematic creation of the *Donaukanal*), 1830 (= extension of regulation efforts to the entire Danube floodplain after the ice jam flood in 1830) and 1875/1905 (= Viennese Danube floodplain/tributary network are regulated nearly entirely) are striking steps in the cost structure.
- Because the capacities of society have constantly increased over time, due to population growth and a greater economic productivity per capita, a gradual increase of expenses on river engineering can be expected to be amplified by the industrialization and by new technology in the 20th century.
- The industrialization in the 19th century is assumed to lead to decreasing prices and increasing cost-efficiencies of river engineering measures when fossil fuels replaced biomass as main energy source.
- Phases of economic growth are times of innovation, enhance the realization of river engineering projects, and correlate with high expenses per capita. The opposite applies to phases of crises.
- Extreme flood events causing great damage in the city lead to resignation and or trigger new motivation by demonstrating either the failure or the insufficiency of river engineering efforts. Thus, they trigger rapid jumps or drops in the cost structure.
- Climatic conditions leading to periods with a huge number of flood events and several severe floods are reflected in a great need for the repairing and the renewal of structures and thus higher efforts per inhabitant of Vienna compared to previous or following decades
- The side-effects of earlier expenses at least partly determine the necessity for later expenses.

These general statements are specified in <u>the following chapter</u> and <u>chapter 7</u> discusses to what degree such relationships can be verified and the system of causes and effects will be discussed in a simple and schematic way. Conclusions of the research will then be summarized in chapter 8.

2 THE STUDY AREA AND ITS HISTORY

2.1 Natural dynamics of the Viennese (river) landscape and its transformation in the last 500 years

Vienna is located at the eastern end of *the Alps* and at the western edge of the sediment-filled *Viennese Basin* – a part of the Alps which started to subside several kilometers deep 17 million years ago. A climatic change at the end of the tertiary in the *Pleistocene* between cold periods ("ice ages") and warm ("interglacial") periods lead to strongly changing flow conditions along the Danube River and to the formation of different stages of river terraces which can still be observed on the present city area. During the latest stage in those climatic cycles – the Holocene – which has started c. 11,700 years ago, the course of the Danube has been alternating within the recent Viennese floodplain while the land on the ancient terraces except for temporary erosion at the edges remained mostly stable and untouched by the river's movement. One should consider that significant human interactions with the river in this area have taken place under Holocene boundary conditions. The situation of the historical center of Vienna on the stable Pleistocene terrace and embedded in the geological environment is shown in figure 2-1. (GRUPE & JAWECKI, 2004)

The Danube River crosses the Viennese basin on a length of around 60 km between Vienna in the West and *Bratislava* in the East. Situated at the upper river course, the stretch needs to be considered as Alpine river entailing a relatively steep slope and high kinetic energy of the flow, a flow regime which is changing both strongly and rapidly and which allows for the transport of huge quantities of material, in particular as well coarse material (WINIWARTER et al., 2013, p. 105).

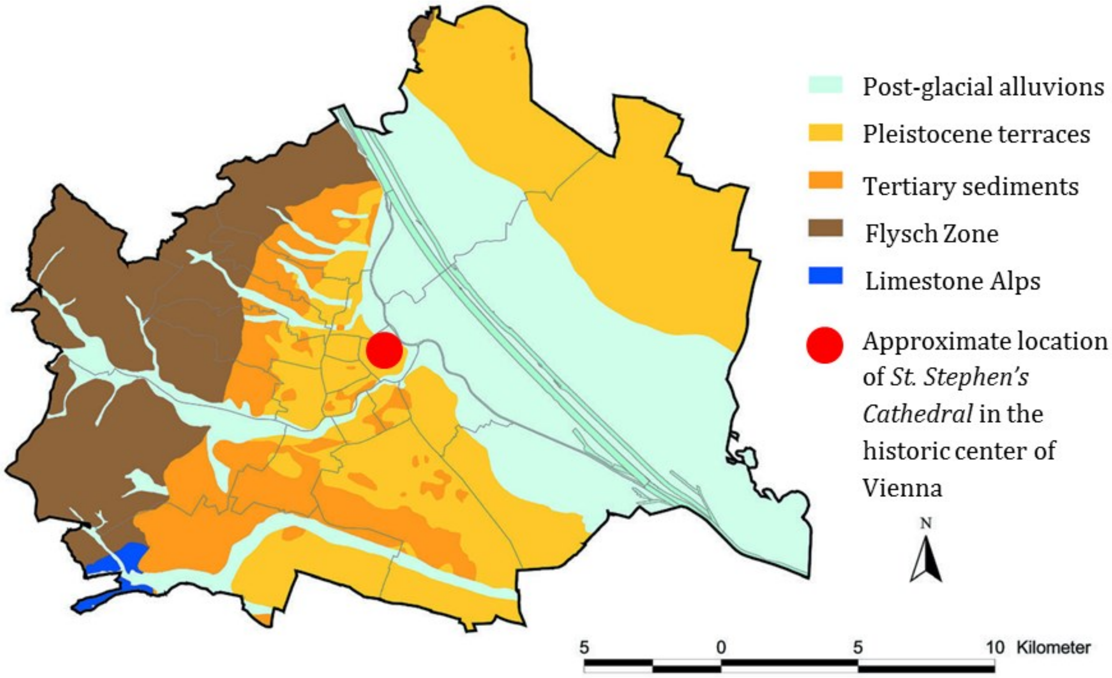

Figure 2-1: Geological basement of Vienna; from GRUPE & JAWECKI (2004), after BRIX (1970).

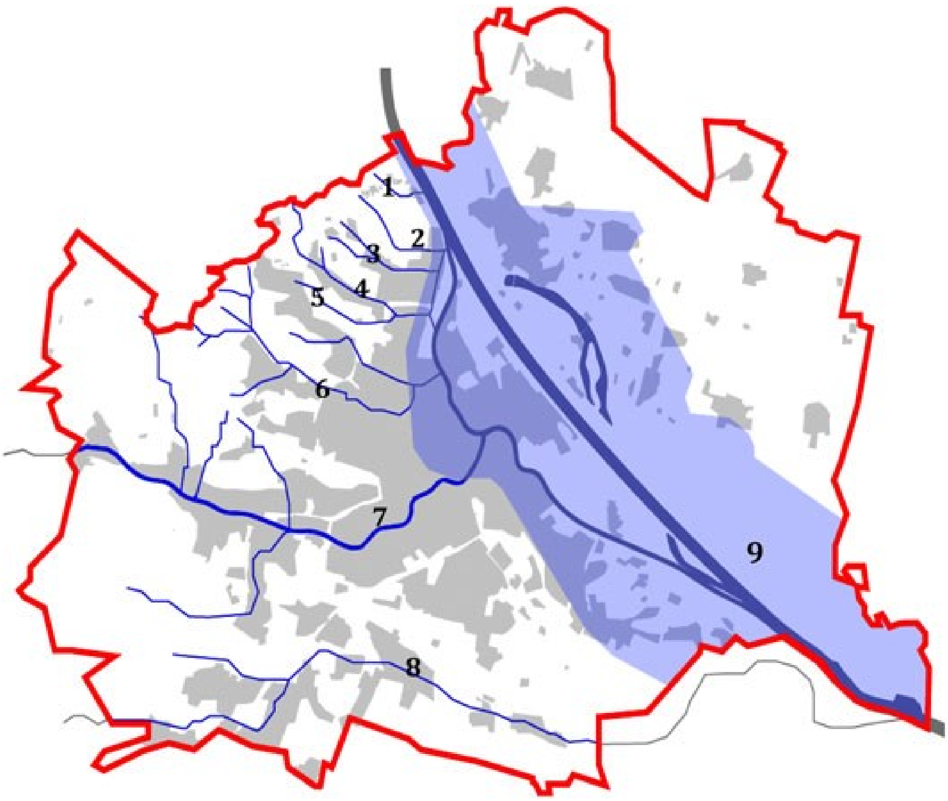

Figure 2-2: Arrangement of Vienna's waterscape after the *Great Danube Regulation*; 1 *Waldbach*, 2 *Schreiberbac*h, 3 *Nesselbach*, 4 *Arbesbach*, 5 *Krottenbach*, 6 *Alserbach*, 7 *Wien River*, 8 *Liesing River*, 9 *Danube River*; the *Danube floodplain* is shaded in blue; from WINIWARTER et al. (2013).

North of Vienna the Danube is encompassed by mountains and it is therefore forced into a relatively narrow bed. The river enters the basin in the northwest through the so-called *Wiener Pforte* (= *Viennese Gate*) between the mountains *Bisamberg* and *Leopoldsberg*. Prior to regulation the Danube could alter its course across a floodplain of around six kilometers width and showed both characteristics of a braiding and meandering river. The Viennese Danube was subdivided into several branches and continuously accumulating and eroding islands; river bends were continuously developing and straightened again. Floods may occur in all seasons – after heavy rainfalls in summer and autumn; ice jam floods in the winter were of particular importance throughout the city’s history. Considering longer time periods there has more or less been a dynamic equilibrium between erosion and accumulation of sediments in the floodplain. (HOHENSINNER et al., 2008, 2013b; WINIWARTER et al., 2013)

Figure 2-2 shows the channel network of Vienna consisting of the *Danube River* and major *Danube tributaries*. The latter ones are mostly coming down from the *Wienerwald Mountains* in the West. The discharges of those *Wienerwald streams* can change very heavily and fast during periods of rain in the catchment. This property played an important role as well for the development of the city, making it necessary to regulate them. (ATZINGER & GRAVE, 1874; GANTNER, 1991; BEKESI, 2010)

The reconstructions of the morphology of the Viennese Danube floodplain for eleven time steps from 1529 till 2010 are based on evidence from numerous textual and cartographic historical sources from Vienna both depicting changing natural conditions and changing perceptions of nature, a logical consideration of a river-morphological succession of events and the impacts of historical river engineering. Figure 2.3 shows little excerpts of the reconstructions allowing for comparisons between the earliest time step from 1529, the reconstructed morphology before (1849) and directly after (1875) the *Great Danube Regulation* and the present situation in 2010. (LAGER, 2012; LAGER & HOHENSINNER, 2012a, 2012b)

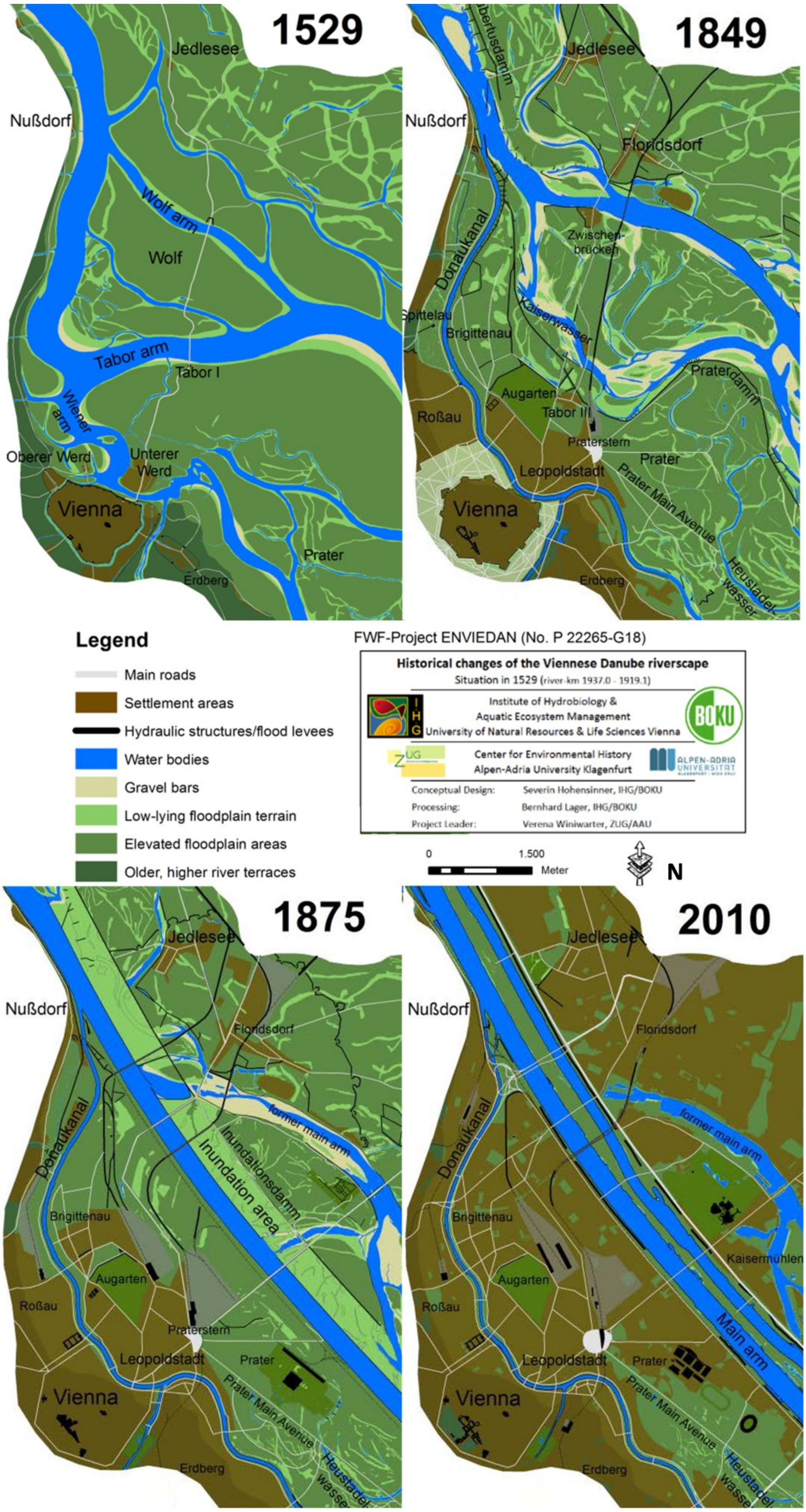

Figure 2-3: Reconstructions of the Viennese Danube floodplain from LAGER & HOHENSINNER (2012a): Four excerpts from the years 1529, 1849, 1875 and 2010**.**

The database of historical river engineering measures in Vienna (HOHENSINNER et al., 2012) – together with a flood event database and a database with more than 200 geo-referenced historical maps – has been a side-product of and a tool for the reconstructions (HOHENSINNER et al., 2013a). Four of the reconstructions LAGER (2012) from the years 1570, 1726, 1817 and 1912 have been attached in appendix I.1.
In Roman times, several sources assume that Vienna was directly situated at the main branch of the Danube which did reach to the Pleistocene terrace in the west. However, it is evident that, by the year 1455, the so-called *Tabor Arm*, as the nearest main branch, was situated around 3.5 km north of the city while the city was only supplied by a side branch which was called *Wiener Arm*, the precursor of the present *Donaukanal* (HOHENSINNER et al., 2013b). Repeatedly, the main branch did move closer to the city and away again. Over many centuries, however, there has been a gradual movement of the Danube away from the city – which has been explained both by tectonic movements in the Viennese Basin and increased sediment transport due to land use change in the catchment of the Viennese Danube. The beginning of major river engineering activities in the Danube floodplain coincides with the formation of the *Wolf Arm*, a natural straightening of the Danube main branch *Tabor Arm* which had come very close to the city in the 16th century (around 1.5 km in 1529). Pre-industrial hydraulic engineering measures in the Viennese floodplain usually only had a local impact. Only since 1700 the *Donaukanal* was increasingly channelized and regulated. Furthermore, the ice jam flood around 1830 marked an important turning point. Around that time, large-scale transformations in the entire floodplain have taken place, resulting in a smaller water surface in the floodplain, the loss of connectivity of many former side branches and the transformation of the riparian zone of the river into urban land. The natural dynamic equilibrium had been lost and during the 19th century terrestrialization of water bodies more and more dominated the evolution of new water bodies. The regulation between 1870 and 1875 has strongly reduced both processes. (LAGER, 2012; LAGER & HOHENSINNER, 2012a, 2012b; HOHENSINNER, 2012; HOHENSINNER et al., 2013a, 2013b)

2.2 Vienna and the Danube as a socio-natural study site

Following the concept described by WINIWARTER et al. (2013), river landscapes are socio-natural sites. The history of nature and society is seen as a co-evolutionary dynamic process, implying that human interventions are not seen as disturbances of an idealized pristine environment. The central idea of this concept has been described as follows: *"The concept of socio-natural sites emphasizes legacies in river history. Human practices in the past changed material arrangements in the riverscapes and these changed arrangements became constraints for later practices. Arrangements are inherited; they offer options for some and make other practices impossible."* and *"Nature, society and technology are transformative to each other: if one realm changes, the other two change as well."* (SCHMID et al., 2010, p. 2). This concept has been adapted for the co-evolutionary study on the history of Vienna and the Danube assuming that the evolution of socio-ecological systems needs to be both looked at in terms of changing arrangements and practices (WINIWARTER et al., 2013). Practices and arrangements unavoidably determined and influenced each other. Practices and arrangements are characterized as both "natural" and "cultural" and both are considered as "*socio-natural hybrids*". (FISCHER-KOWALSKI et al., 1999; HABERL et al., 2006; SCHMID et al., 2010; WINIWARTER et al., 2013, pp. 107-110).

Human practices had a strong impact on the Viennese river landscape even before the first hydraulic engineering efforts in the area: GRUPE & JAWECKI (2004) mention that the removal of loess did destabilize the river terrace, making it vulnerable to erosion. HOHENSINNER et al. (2013b), stress that already the Viennese Danube floodplain in 1500 has not been pristine anymore due to the land use upstream and due to forestry in the floodplain. Since the earliest times, the settlements and the waterscape in the area of Vienna have shared a common history. Already the location of Roman legion camp *Vindobona* has not been chosen arbitrarily: The situation between the *Danube* in the East, the *Ottakringerbach* in the North and a minor creek in the South provided excellent military shelter (BUCHMANN et al., 1984). On the higher Pleistocene terrace the Roman camp and later the medieval town which was founded “on top” of the roman camp was protected even against higher floods from the Danube and the tributaries. For the medieval town the riparian forests provided timber, herbs, mushrooms, berries and medication and served as the city’s hunting ground. Furthermore, the water bodies served as a rich source of fish (an important fish market existed from at least 1400 onwards), and the provisioning of the city was largely dependent on the functioning of the river as a navigation route to the city. Ship mills on the Danube and stable mills along Wien River since the 12th century were an important part of the food supply system of Vienna. Freshwater supply from the western hilly regions was guaranteed by water pipes and several hundred wells in the city area. Very early a main sewer for waste and wastewater existed. (HOHENSINNER et al., 2013b; SONNLECHNER et al., 2013; WINIWARTER et al., 2013)

Rather than a clearly defined spot on the map, Vienna needs to be thought of as a network with a flux of matter, energy, money, people and ideas across the city’s boundaries. Since the 12th century, the importance of Vienna had increased first under the Babenberg dukes and later under Habsburg reign. From the 16th century onwards Vienna was residence and seat of many central institutions in the Habsburg Empire. In 1526, a charter ended the autonomous development of Vienna and the interests of potential river engineering stakeholders and decision-makers were further on often lying outside the city’s boundaries. As a major capital in the Habsburg Empire the importance of the Danube role for provisioning and transport increased as well as the role of the urban stream network for military protection. After the first Ottoman siege in 1529 conflicts between the Habsburgs and the Ottomans concerning the control of land downstream of Vienna turned the Danube into a “*theatre of war for centuries”* (WINIWARTER et al., 2013, p. 106) which as well inhibited trade towards the east and restricted the economic importance of Vienna. The ban of this thread for Vienna after the second Ottoman siege in 1683 did enable Vienna to flourish, now situated at an important navigation route. In the 18th century, on the one hand the growth of the city into the floodplain lead to new conflicts with the river, on the other hand the rivers were perceived as trade routes safeguarding the power of the Empire as political player. While the pre-industrial interest in rivers was multifunctional and rivers fulfilled many functions, the transformation of water bodies after industrialization was done according to few major objectives: Along the Danube SCHMID et al. (2010, pp. 2-4) have identified four major drivers of systematic large-scale regulation after industrialization: Steam navigation (since the 1830s on the Danube), land reclamation, flood protection of growing urban agglomerations since the 19^{th} century and electricity generation since the 20^{th} century. (SCHMID et al., 2010; HAIDVOGL et al., 2013; SONNLECHNER et al., 2013; WINIWARTER et al., 2013, p. 105-107)

Urban growth into the Danube floodplain in Vienna happened in three major phases (HAIDVOGL et al., 2013): The earliest stable settlements in the floodplain were erected on the comparably stable island *Untere Werd* (today parts of *Leopoldstadt*) opposite to Vienna across the *Donaukanal*. From 1704 till 1837 urban growth mainly proceeded within those already settled areas. Partly the settlements were secured with embankments and local flood dikes. A large-scale expansion over the entire island was observed between 1837 and 1875. The *Great Danube Regulation* then enhanced and safeguarded the growth of new urban areas, by stabilizing the river bed, separating the aquatic zone and flood-safe terrestrial zones and lowering the groundwater table. Today the former *Danube floodplain* covers around one fifth of the city area. 35 km² or 24 % of Vienna's urban area is situated in the former Danube floodplain (HAIDVOGL et al., 2013, p. 196). The *municipality of Vienna* before 1850 covered an area of 2.8 km² (the 1^{st} district), but a defense wall (= *line wall*) was constructed in 1704 around the suburbs covering an area of 60 km² which today covers the 3^{rd} till 9^{th} and parts of the 2^{nd} district (GIERLINGER et al., p. 223). Officially, this area became a part of Vienna in 1850. The outer suburbs of Vienna were mostly incorporated in the later 19^{th} century and the area increased to 178 km² by 1890 and to 278 km² by 1913. (KORTZ, 1905; GINGRICH et al., 2012; GIERLINGER et al., 2013; HAIDVOGL et al., 2013)

The population is the most reliable and available long-term measure for the size of Vienna. In the context of this research the population is for example related to:

1. The number of locals which can be recruited as workers for the construction of hydraulic structures and the city's capacities to implement them.
2. The number of consumers which are both depending on the provisioning with water, energy, goods and producing sewage water and waste.
3. The need for space, infrastructure and the protection of urban area against floods and erosion.

Figure 2-4 shows the assumed number of inhabitants in absolute numbers and the reconstructed *real Austrian gross domestic product (GDP) per capita* as percentage of the value in 2011 for the time intervals defined in chapter 3.1.

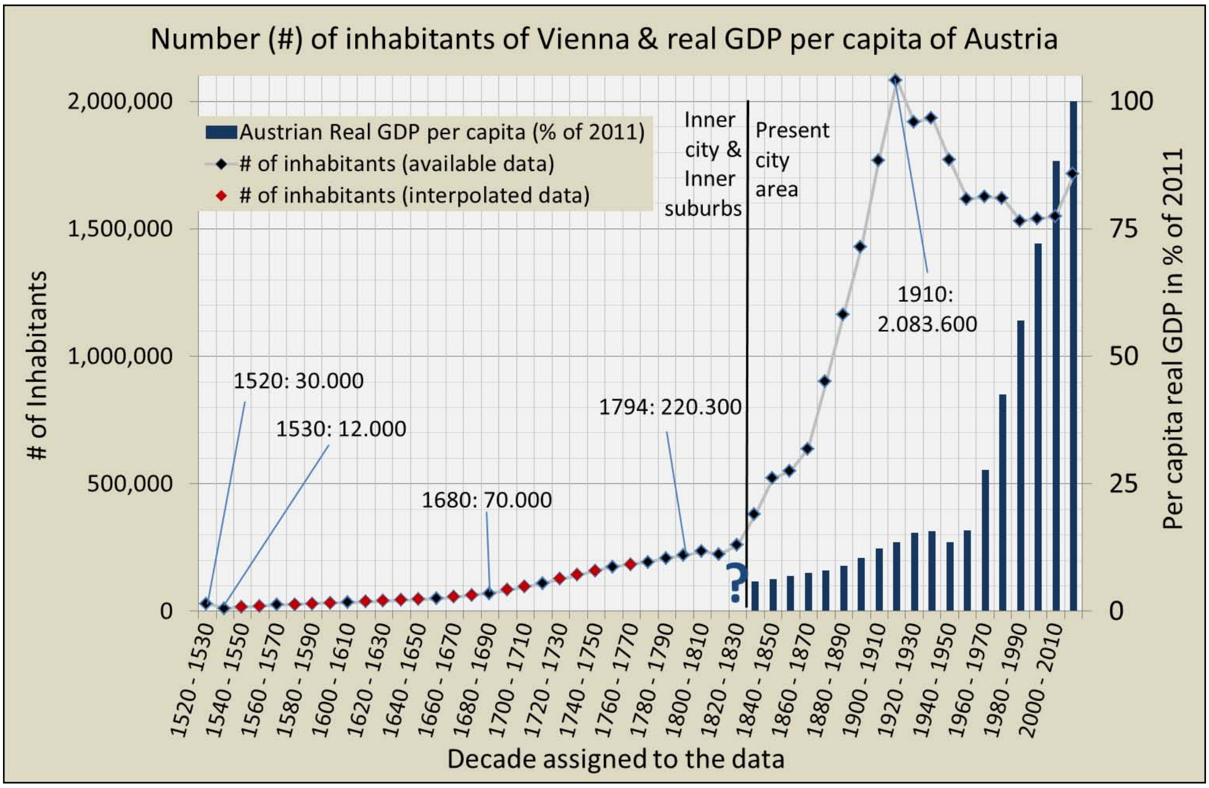

Figure 2-4: Growth of the population of Vienna and the GDP per capita of Austria (in its present boundaries); sources: 1.) Number of inhabitants: WEIGL (2003); BUCHMANN & BUCHMANN (2006); STATISTIK AUSTRIA (2014); 2.) Real GDP per capita: KAUSEL et al. (1979); BUTSCHEK (1998); STATISTIK AUSTRIA (2014); compare the population diagram by WINIWARTER et al. (2013, p. 106).

The number of inhabitants of Vienna was around 12,000 in 1530 after the 1st Ottoman siege and multiplied by the factor 10 from c. 200,000 to around 2,000,000 people between the late 18th century and the early 20th century (SCHIMMER, 1875; WEIGL, 2003; BUCHMANN et al., 2006; STATISTIK AUSTRIA, 2014). The real Austrian GDP per capita (calculated after: KAUSEL et al., 1979; BUTSCHEK, 1998; STATISTIK AUSTRIA, 2014) indicates a strong increase in the economic productivity since 1830, when the value was approximately 5 % of that in 2011. The derived values from literature are supposed to represent roughly the conditions at the beginning of each time interval. In chapter 6.1 these assignments were used to calculate expenses on river engineering in Vienna per capita and as share of the Austrian GDP. For time intervals before 1800 with no assigned population data, a linear interpolation was applied.

The tremendous growth of the population in the 19th century occurred parallel to a complete transition of the socio-ecological system. The bio-physical dimension of the relationship of the city of *Vienna* related to the *Danube* may be described by the concept of the "urban metabolism", which describes society as a unit which requires and releases certain amounts of material, water and energy with certain qualities. Since 1830, the energy use had multiplied rapidly and there was a qualitative shift from biomass-based energy to fossil fuels as main energy source. As summarized by GINGRICH et al. (2012, p. 3): "*The increasing use of non-renewable energy carriers in the course of industrialisation (...) loosened the area-dependency of energy provision, and allowed for entirely new patterns of land use, a process described as a socio-ecological or socio-metabolic transition".* The first railroad in Austria was constructed near Vienna in 1837, steam boats replaced row boats; these changes initiated rapid industrialization and the upcoming of machine factories, which let the capacities and abilities of society rise to new levels. An enormous increase of wastewater and waste made the rearrangement of the entire urban waterscape urgent, in order to enable fast discharge of the polluted and disease-bearing waters out of the city area. (GIERLINGER et al., 2013; GINGRICH et al., 2012).

2.3 An overview of Vienna's battle with "its" waterscape

The term *Viennese Danube*, in this text stands both for the Danube floodplain and the Danube tributaries on the present city area of Vienna. As stated previously, "*the city's inhabitants were able to cope with the river's characteristics only due to the ability of the city and its rulers to invest heavily into river engineering measures over the centuries*" (WINIWARTER et al., 2013, p. 104). Several documents from the time before, during and after the *Great Danube Regulation (GDR) from 1870 to 1875* give detailed insights into plans, motivations and the conduction of the Danube regulation in the 19th century (e.g. PASETTI et al., 1850; PASETTI, 1859; BAUMGARTNER, 1862; DRC, 1868, 1886, 1898; WEX, 1870a, 1870b, 1876a, 1876b). Besides, the demolition of several earlier regulation measures which had become obstacles for navigation in the Danube main branch during the GDR raised questions about their historical origins and properties (PROKESCH, 1876). THIEL (1904, 1906) did work through a wide range of historical literature and wrote a history of the Danube regulation in Vienna far back in time. New insights were added by SLEZAK (1977, 1978, 1980). The *Donauatlas* (MOHILLA & MICHLMAYR, 1996) contains a collection of historical maps of Vienna back to 1600 with a specific attention to historical regulation efforts at the Viennese Danube. In the recent research, documents from the 16th century emerged and were reinterpreted by *C. Sonnlechner* and *S. Hohensinner* (SONNLECHNER & HOHENSINNER, 2011) contributing to the profound image which we now have of the relationship between the Viennese and their waterscape at least since the 1540s and which is best described in the recent publications in the journal *Water history* (GIERLINGER et al., 2013; HAIDVOGL et al., 2013; HOHENSINNER et al., 2013a, 2013b; SONNLECHNER et al., 2013; WINIWARTER et al., 2013).

The reason behind every single decision to implement hydraulic engineering projects might either be the economic expectation of an overall benefit for the budget of the state, the city or a private actor or there were other intrinsic motivations such as the emperor's reputation and power, the protection of lives or possibly even an unbearable smell in the city area (e.g.: THIEL, 1904, 1906; WEX, 1880; BEKESI, 2010). Hydraulic measures are constructions with a physical impact in the landscape and they are cultural symbols. Each implementation of a measure can be interpreted as a preliminary outcome of an on-going societal communication process and represents a decision for certain preferences between different societal uses and interpretations of water bodies. A set of hydraulic measures from each time period is an expression of a limited and characteristic set of idealized expectations concerning the functionality of the running waters. On a long term hydraulic measures may adapt the physical arrangement of the landscape for the requirements of human practices and alter the stocks and flows in the landscape often irreversibly. (FISCHER-KOWALSKI et al., 1999; HOHENSINNER et al., 2013b; WINIWARTER et al., 2013)

The earliest known attempts to protect Vienna against the power of the Danube are wooden weirs close to what is now *Schwedenplatz* from the 12th or 13th century, which were found in the 18th century (THIEL, 1904, p. 122, HOHENSINNER et al., 2012). The so-called *Wiener Arm*, which flew directly to Vienna for a long time, has very likely been a navigable and water-rich branch of the Danube. Already in 1377 and 1455 the measures to keep the *Wiener Arm* navigable appear in the town bills of Vienna (THIEL, 1904, pp. 129-130). The engineer *Kasper Hartneid* was imprisoned in 1462 after his costly works had been destroyed by the next flood and he could only safe his life by assuring to leave Vienna with no return (THIEL, 1904; HOHENSINNER et al., 2013b). Major and ongoing regulation efforts aiming on a physical transformation of major Danube branches are documented since the 1540s (THIEL, 1904; SONNLECHNER & HOHENSINNER, 2011). Initially the most important river engineering activities were a response to the natural straightening of the highly sinuous Danube main branch. As a consequence the river shifted away from the city of Vienna and the *Wiener Arm* – the side branch which was central for the provisioning of the city via navigation – showed terrestrialization tendencies in the 16th century. Regulation commissions were trying desperately to find ways for redirecting the main branch back towards the city and preventing a break-through of the Danube towards the left banks. But despite of those pioneer works and the gain of valuable experience for later efforts they remained widely unsuccessful and finally the enterprise was given up. The following projects aimed instead only on the maintenance of the Wiener Arm as navigation route to the city. Due to siltation the navigability in the 17th century was only temporarily given in the Wiener Arm. The change between 1529 and 1570 is shown in the figure 2-5: Despite a movement of the river bend towards the city (1.6 km north of the city in 1529, 1.3 km in 1570), the straightening *Wolf arm* replaced the Danube bend *Tabor Arm* as main branch. Till 1663 the flow direction had moved further away from the city and navigation could only be maintained due to continuous efforts. (HOHENSINNER et al., 2013b)

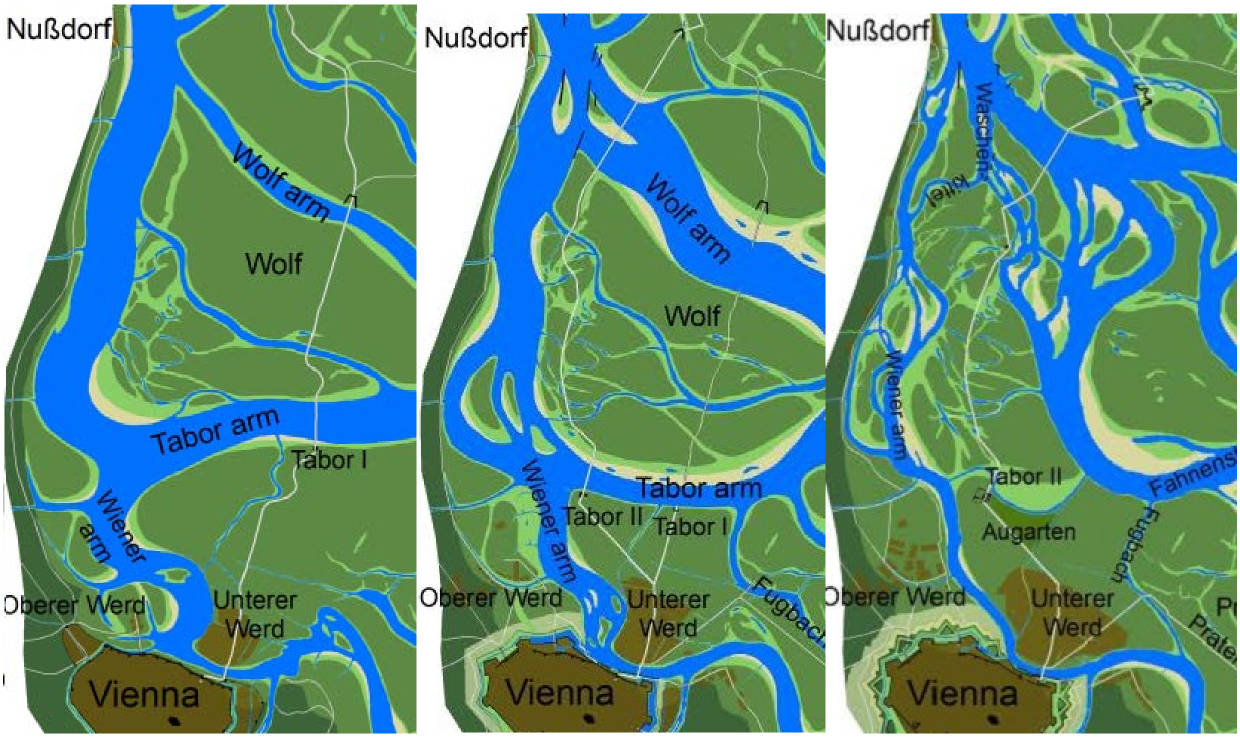

Figure 2-5: Evolution of the upper Wiener Arm from 1529 (left) to 1570 (center) and to 1663 (right); excerpts from the reconstructions LAGER & HOHENSINNER (2012a).

Since 1700 the Wiener Arm – which was then subdivided into two branches on its upper section – has been called *Donaukanal*. This change is marked by the closure of the right side branch (*Nussdorfer Arm*) and by the construction of a new guide wall at the branch-off from the Danube and a major cut-off in the left side branch (so called

Waschenkittel). These measures could not prevent the further accumulation of sediments and expensive excavations were necessary for many years (SLEZAK, 1978). More cut-offs were excavated throughout the 18th century and altered the course of the Donaukanal significantly. In the 17th and 18th century several water engineers and cartographers from Italy were employed in Vienna and contributed with influential regulation concepts (SLEZAK, 1977). The relationship between the length of river sections, flow velocity and siltation was increasingly recognized and the guide walls dividing the two branches were constantly moved upstream to reduce the angle and to prevent the accumulation of sediments. Increasingly concerns caused by the growing population, in particular the need for urban space and disease prevention had become important issues. First ideas came up to combine solutions for navigation and flood protection in a general solution for the Danube. Figure 2-6 shows an excerpt of one of the earliest preserved plans for a Danube regulation by *T. Clausniez*. Figure 2-7 shows the pioneer suggestion by *N. v. Spallart* for a major Danube cut-off. In the late 18th century the first large-scale flood protection system was implemented combined with a large-scale system of spur dikes (figure 2-8) by the engineer *I.E. Hubert* to concentrate the flow in the main channels. The flood protection system failed during the flood in 1787 and major dikes remained unrepaired for a long time period. *Hubert* lost support and realized only few projects afterwards. A general solution integrating all major concerns of that time was still too expensive and responsible engineers never agreed on one concept. Nevertheless, the river engineering activities had reached a new level by 1830. The banks were systematically stabilized with stone embankments. Due to the use of fossil fuels and new means of transport parallel structures along the banks made of stone had become preferable to the combination of embankments and spur dikes made both of wood and stone as used in the previous decades (SCHREY, 1899). Since 1836, regular excavations of accumulated sediments on the river bed were conducted using a new steam machine both in the Donaukanal and in the Danube (THIEL, 1906). (MOHILLA & MICHLMAYR, 1996; HOHENSINNER et al., 2013b)

Figure 2-6: One of the earliest maps of planned regulation measures near Nussdorf from around 1600; excerpt from CLAUSNIEZ (1601); OeStA, Finanz- u. Hofkammerarchiv, Herrschaftsakten Nr. 27/B, Fol. 1122, F 245.

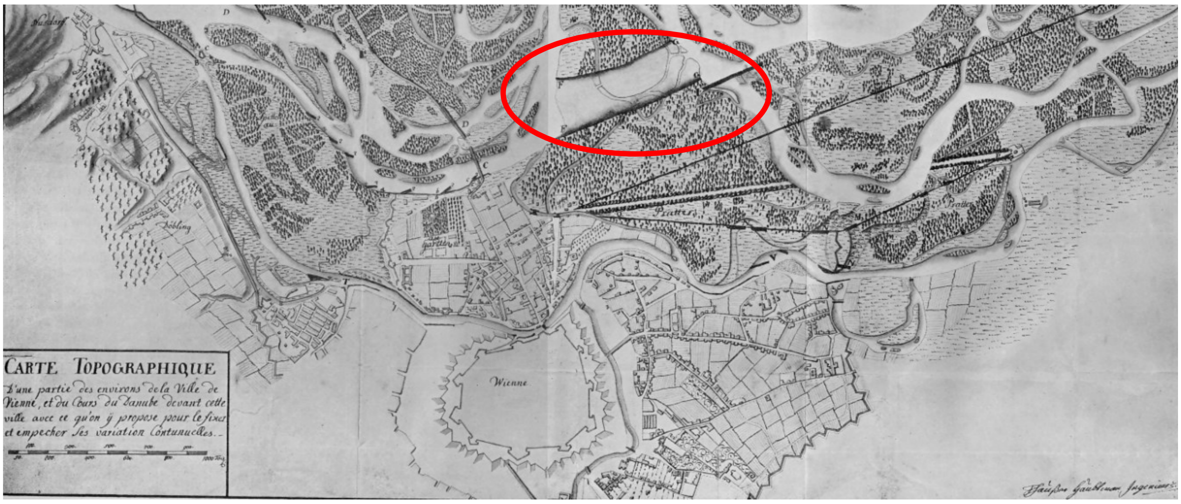

Figure 2-7: Suggested cut-off in the Danube floodplain from the 18th century; excerpt from SPALLART (1765); OeStA, Haus-, Hof- u. Staatsarchiv, Handschriften Weiß 713, fol. 69a.

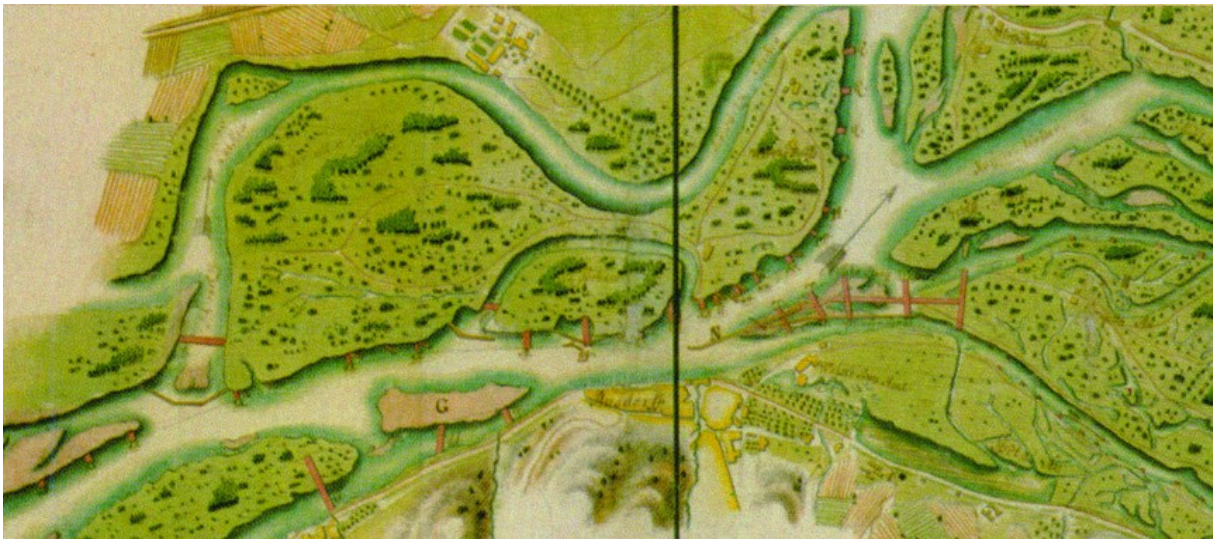

Figure 2-8: Suggested system of spur dikes near Nussdorf, at the branch-off of the Donaukanal from the Danube in the 1760s; excerpt from HUBERT (1769); OeStA, Finanz- u. Hofkammerarchiv, F329.

The 19th century is characterized by the quest for a master solution to gain control over the Danube. The irregular course of the river complicated navigation and inhibited the discharge of ice loads in winter. Ambitious suggestions aimed on the construction of a stable permanent bridge over the Danube, the achievement of "all time" flood control, a deepening of the river bed and closure of most side branches (HOHENSINNER et al., 2013b). The solution should lead to narrower navigation routes, safeguard the existing trade and traffic conditions at low costs and as practical as possible, stabilize and heighten the floodplain for the gain of permanent and flood-safe urban space, prevent the accumulation of sediment, open the Donaukanal for steam navigation, create new landing places for steam ships of all types and allow short transport distances from the ports to the city and the railroad (PASETTI et al., 1850; DRC, 1868). The *Great Danube Regulation in Vienna between 1870 and 1875 (GDR)* both contributed to successful flood control and enhanced navigation, but as well it proved to be insufficient regarding both aspects and pre-defined the characteristics of later expenses on river engineering (HALTER, 1902). In the 1890s the channels were adapted by new groynes enhancing navigation at low-water conditions. Some contemporary engineers supposed that the *GDR* had almost been an ultimate solution, such as *G. Wex*: "*The floods in Vienna and in the Marchfeld will by all means be eliminated entirely [...]"* and *"[a] dike has been constructed, which the floods may doubtlessly never exceed"* (WEX, 1876a, p. 122, translated by the author). Floods in the 1890s questioned this statement and in 1908 the hydrological central office reported a historical discharge maximum of around 14,000 m³ per second which would exceed the supposed maximum from the *GDR* engineers of 11,900 m³ per second and the quest for an improved flood protection became issue of discussion (HCB, 1908). As a consequence, a flood bypass, separated from the main branch, by the newly-elevated, 21 kilometer long, *Danube Island*, was realized between 1972 and 1987 (MOHILLA & MICHLMAYR, 1996). While hundred thousands of people live today in the area of the former floodplain and are dependent on maintained flood control, the *Marchfeld*, one of Austria's most fertile agricultural landscapes, and the biodiversity in the *Nationalpark Donau-Auen* east of Vienna, one of Europe's last free flowing river sections, still are struggling with fast bed erosion, sinking groundwater levels and a loss of the lateral hydrological connectivity.

By the 16th century some of the Western tributaries of the Danube had already been strongly rearranged (BRAUNEIS, 1974; HOHENSINNER et al., 2012): the *Alserbach* and the *Ottakringerbach* were feeding the town moat of medieval Vienna with water and served the city both for water supply and military protection. Around 1000 AD a new technology came up when hand-mills were largely replaced by water mills since then playing an important role in the food supply system in Austria (SANDGRUBER, 1995). Along the *Wien River* mill streams were excavated and mill weirs constructed for this purpose. They were continuously entertained with great efforts till they became dispensable in the 19th century (ATZINGER & GRAVE, 1874; LOHRMANN, 1980; BEKESI, 2010). Likewise, the energy of the Danube was used with the installment of ship mills (LOHRMANN, 1980) along the stream. The regulation of tributaries was dominated for a long time by these motivations till during the late 18th century increasingly the risks of floods, erosion and disease became an obstacle for the growing city and were addressed by respective regulation measures. Only around 1830 the urban stream network started to be systematically regulated as part of the urban sewage system, first the inner suburbs of Vienna and later in the 19th century as well the outer suburbs. By 1905, the entire urban water landscape had been transformed completely with main sewers along the Donaukanal and the Wien River and many creeks redirected, channelized and vaulted – since then flowing belowground. For the *Wien River* as the most prominent Danube tributary in the growing city a solution was required to ban the flood, erosion and disease risk for newly settled areas. In the end the *Wien River* was widely regulated between 1891 and 1915 from its source to the mouth (KORTZ, 1905; MILDE, 1993-2014). In the 20th century the flood discharge capacities of tributaries had to be improved and maintained. Today, restoration aspects and their future role in the town picture of Vienna have begun to be addressed (e.g. SEIDL, 2006; RH, 2007).

3 PART 0: THE DATABASE OF HISTORICAL RIVER ENGINEERING MEASURES IN VIENNA

3.1 The database of historical hydraulic measures in Vienna

The original *database of historical river engineering measures in Vienna* (HOHENSINNER et. al., 2012; see appendix V and *file 0.1* on the DVD) – which is still updated – contains all presently known hydraulic measures from *Vienna* (in the *Danube floodplain* and at *Danube tributaries*) which were constructed between 1100 and 1900. The largest part is situated within the present administrational area of Vienna while few reach outside the city's boundaries: in the north approximately till *Korneuburg,* in the south in particular including the right Danube banks opposite to *Lobau* (including the mouth of the *Schwechat River* in *Lower Austria*). Each measure is represented by a GIS-feature with one distinct construction type. Features are characterized by a position and shape in the GIS either as polyline ("linear") or as polygon ("areal") with a precise extent (length or area): Construction types such as embankments, flood protection and infrastructure dikes, weirs, guide walls and spur dikes are characterized by a defined length while channels, bed excavations, ditches etc. are characterized by a defined area. Beyond this, all features in the database are described by a wide range of attributes such as the potential construction period, durability, diverse remarks and comments, references in historical maps and literature, their objectives and likely purpose. At present, there are 1,403 linear and 450 areal measures documented in the database. The documentation of river engineering measures from the Danube floodplain between around 1540 and 1900 is a result of a systematic and comprehensive study based on numerous historical maps and documents (see HOHENSINNER et al., 2013a, 2013b). Since the 1540s on-going

Danube regulation efforts are evident and the existing documentation from the earliest regulation period has been carefully analyzed and integrated into the database (SONNLECHNER & HOHENSINNER, 2011; HOHENSINNER et al., 2012). Before 1540 only few measures are known from the Danube floodplain and no systematic study is available due to the lack of references. Documentation for the Danube tributaries in the area is still in progress and might be extended during the FWF-project *URBWATER* (ZUG, 2013-2015). For the 20th century, the documentation is yet incomplete as the focus of the FWF-project *ENVIEDAN* has been on the time period from 1500 till 1900 (HOHENSINNER et al., 2013b; WINIWARTER et al., 2013). The database has been prepared for the analysis in *Microsoft Excel* in several steps. This process, which is leading to an extended database file (*file 0.2* on the DVD, see appendix V), is described in chapter 3.2.

Figure 3-1 and 3-2 show the number and size of measures in the database. In contrast to a similar illustration by HOHENSINNER et al. (2013b), all measures in the database were considered (including those from Danube tributaries) and a large-scale regular dredging between 1830 and 1875 in the Donaukanal (on c. 45 ha) and in the Danube (on c. 10 ha) was separately accounted for each single decade from 1830 to 1870. The greatest number of measures was constructed in the decade 1840 till 1850 during which more than 160 individual measures are documented. In each single decade between 1830 and 1880 more than 100 measures were implemented. In the same period more than 50 km of linear measures and areal measures covering an area of more than 100 hectare were constructed in each decade. The maximum extents of implemented measures were reached in the decade of the GDR (1870-1880) when almost 1,500 hectare (ha) of areal measures (channels, excavations, etc.) and 160 kilometer (km) of linear structures (embankments, dikes etc.) were constructed. Already between 1550 and 1560 linear measures of more than 4 km length and areal measures with more than 9 ha were implemented. The decade 1770-1780 should be highlighted with 42 km of constructed linear measures and the decades 1640-1650, 1700-1710 and 1720-1730, with c. 12 - 14 ha of constructed areal measures.

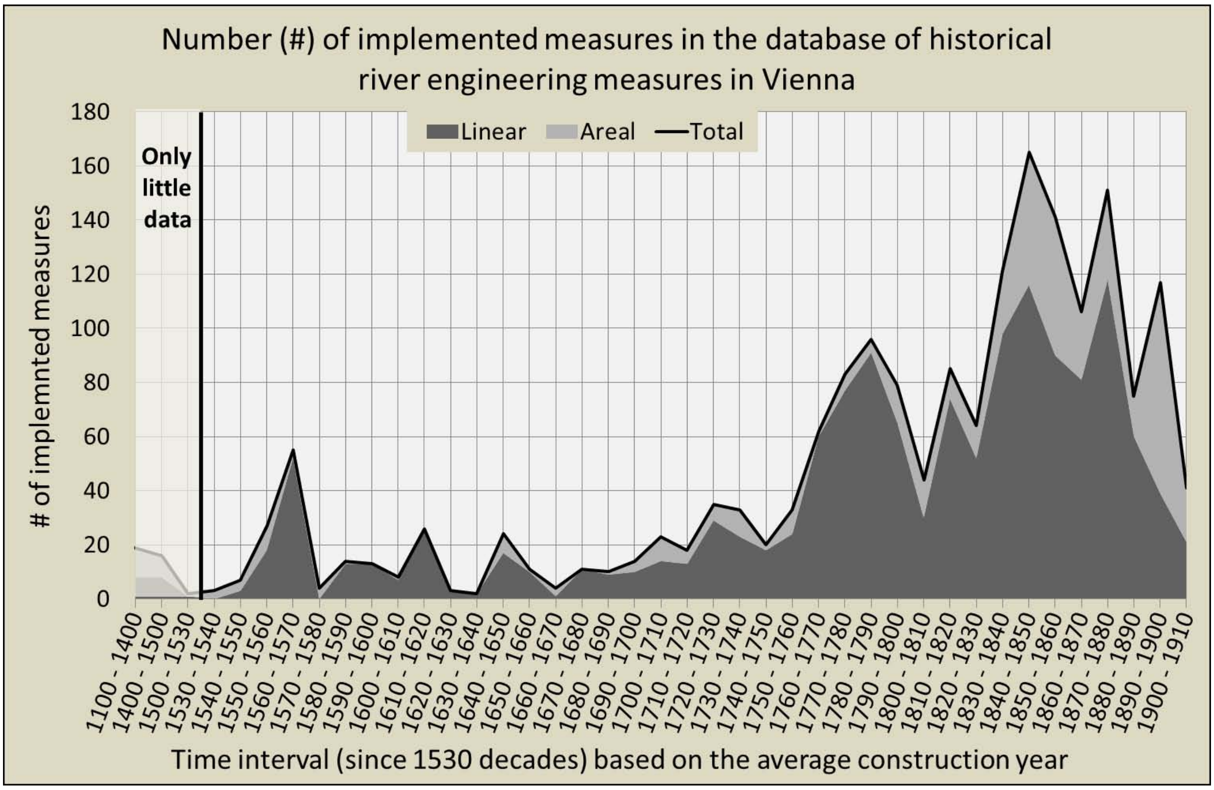

Figure 3-1: Number of implemented river engineering measures in the (extended) database; based on the database by HOHENSINNER et al. (2012).

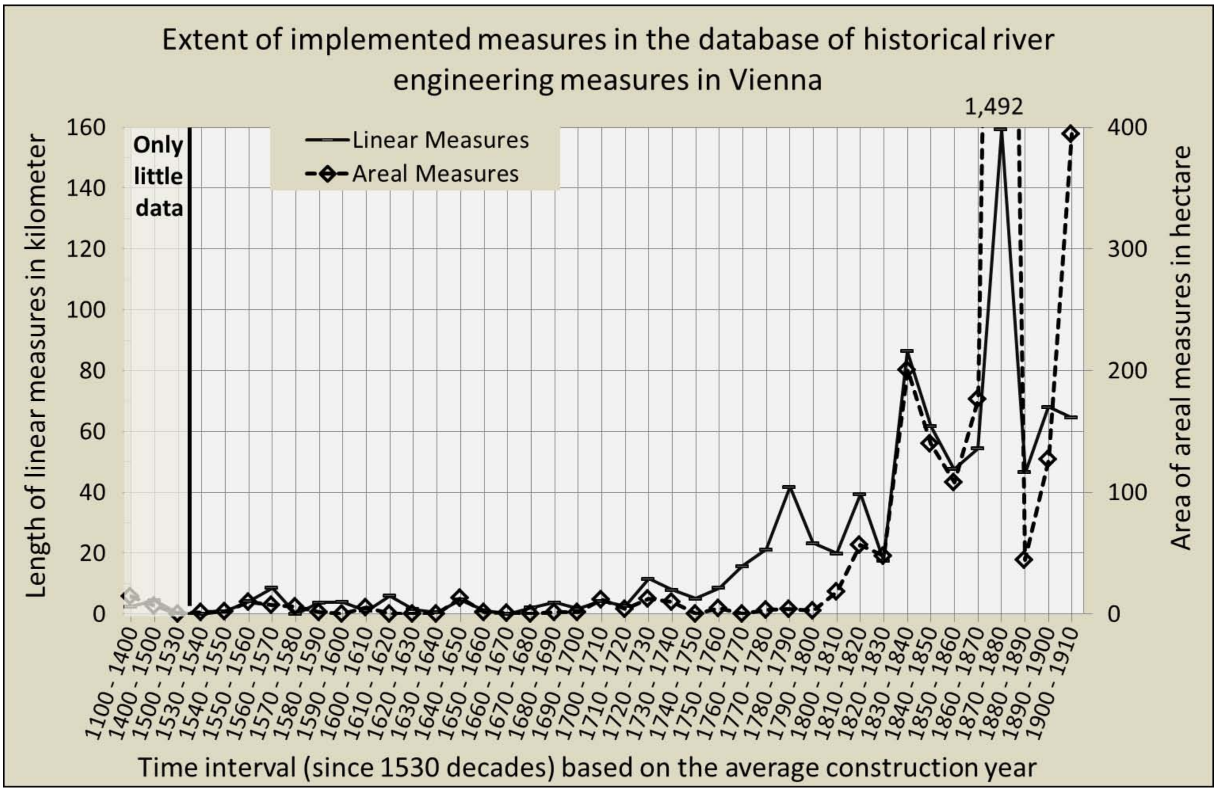

Figure 3-2: Size of measures in the database adapted for this thesis; based on the database by HOHENSINNER et al. (2012).

The graphs do not show numbers and extents from the 20th century, when the newly excavated *Neue Donau* and the elevated *Danube Island* from the 1970s and 1980s together covered an area of around 1,300 hectare.

A variety of information is given on the physical characteristics of all measures. The "construction type" of each individual measure is specified, linked to a more or less detailed description for each measure and furthermore, the name of the water body, the name of the engineer (if known) and a project name are available. The following construction types are distinguished in the database of linear measures:

> *Embankments* (German: *Uferdeckwerke*) were constructed to protect the banks of the river from erosion by increasing the resistibility of the material at the banks; the term refers to parallel measures along the banks in contrast to *spur dikes*.

> *Spur dikes* (German: *Sporne* or *Buhnen*) reach into the river at a certain angle to the banks and are built to redirect the flow to the center of the river during mean water conditions and minor floods. The size and appearance varies from minor bank protection measures to exposed massive constructions at branch-offs.

> *Closure dams* (German: *Abdämmungen*) are constructed at the "entry" of a side or main branch to close the branch and prevent the flow of water to the branch.

> *Guide walls* (German: *Leitwerke*) aim on redirecting the flow of the river and are usually more massive than embankments and closure dams.

> *Low water regulations* (German: *Niederwasserregulierungen*) refers to special groynes safeguarding a sufficient water depth at low water conditions.

> *Flood protection dikes* (German: *Hochwasserdämme*) are elevated levees usually parallel to the running waters to protect the surrounding land against inundations.

> *Infrastructure dikes* (German: *Infrastrukturdämme*) are elevated dikes in the floodplain for flood-safe traffic on streets and railroad.

> *Transverse structures* (German: *Querbauwerk*) refer to structures vertical to the flow direction of the rivers or streams (e.g. weirs, locks and power stations).

In the database of areal measures the following types exist:

> *Terrestrialization measures* (German: *Verlandungswerke*) are constructions within side branches of the Danube aiming on a reduction of the flow velocity and enhancing the aggradation process in those branches.
> *Channels* (also referred to as *straightening* or *cut-off*, in German: *Durchstiche*) shorten the course of the river, increase the flow velocity and bed erosion and therefore lower the water level compared to the surrounding land; the flow of the river is concentrated and the water depth rather increased
> *Ditches* (German: *Bachumleitungen*) refer to artificially excavated ditches to redirect minor streams in the city area.
> *Bed excavations* (or *dredging*, in German: *Sohlbaggerung*) are all excavations for cleaning the stream or river bed from accumulated sediments or branches etc.
> *Fillings* (German: *Verfüllungen*) were applied to elevate the banks and the floodplain in the close surrounding of rivers or to fill abandoned river arms; often excavated material from new ditches, channels or bed excavations was used.
> *Piping and covers* (German: *Einwölbungen*) refer to stream sections vaulted with cement constructions (usually minor and major Danube tributaries).

Figure 3-3 shows the relative use of construction types of implemented measures over time. The time intervals as defined in chapter 3.2 were used. Before 1550 the ditches and bed excavations are most frequent among the documented measures. Since 1550, regulation measures (embankments, closure dams, guide walls, spur dikes) had become the most frequent types. The relative number of embankments increased in the 18th century, compared to the other types. At the beginning of the 18th century and during the 19th century, there were greater proportions of excavations, fillings and channels implemented. Flood dikes became important only since the late 18th century and infrastructure dikes mostly occur in the 19th century.

Figure 3-4 shows the temporal pattern of the occurrence of the primary objectives of new measures. The database distinguishes the following objectives: *water supply*, *energy supply*, *military functions*, *flood protection*, *flood-safe traffic routes, wastewater disposal, regulation*, and *gain of space*.

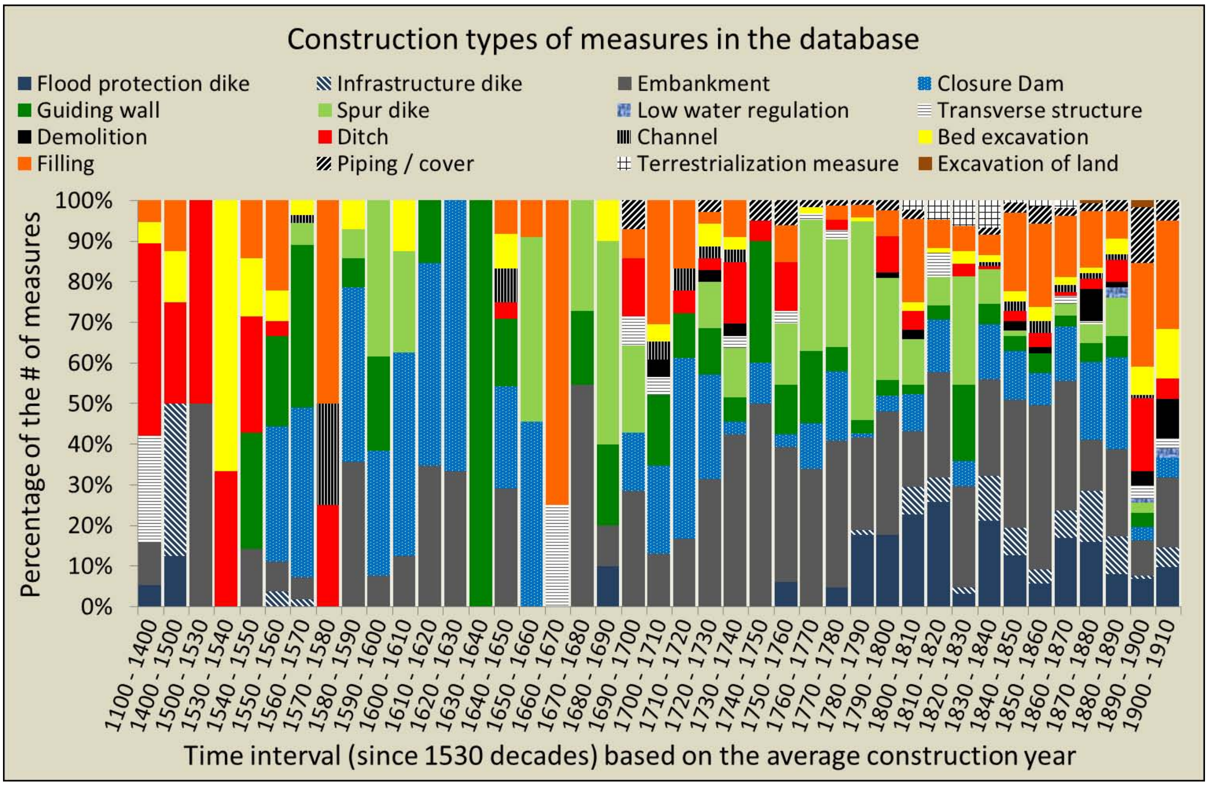

Figure 3-3: Temporal pattern of construction types in the database of historical river engineering measures in Vienna – Percentage of the number of measures per time interval.

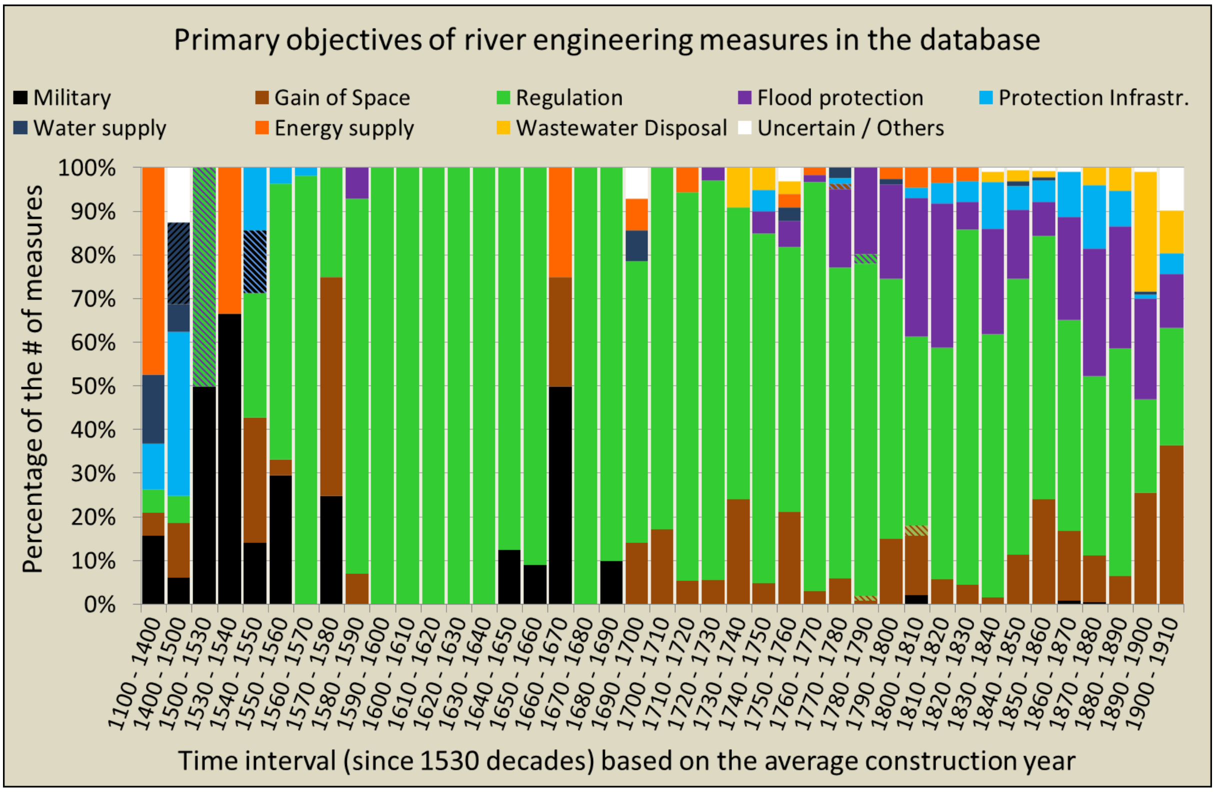

Figure 3-4: Temporal pattern of primary objectives in the database of historical river engineering measures in Vienna – Percentage of the number of measures per time interval.

The largest part of implemented measures between 1540 and 1650 aimed on a *regulation* of Danube branches referring to the stabilization of the banks against erosion and the increase of the water depth for navigation. Till the middle of the 16th century the transformation of tributaries for the purpose of water supply, energy supply and military issues dominated. Energy supply had some importance till the first half of the 19th century and military functions stopped being an issue with the 2nd Ottoman siege in 1683. Starting around 1700, new objectives became more important: first the gain of urban space, later the wastewater disposal, flood protection, and the protection of urban infrastructure competed with or added to the pure objective of regulation. A short remark with additional information on the motivation behind each implemented measure is given in the database under the label: “purpose of the measure”. Many of the known river engineering measures aimed on improvements for Vienna itself. A minor part does aim on the protection of villages and agricultural land surrounding Vienna. The growth over time of the city is reflected by measures which occur at increasing distance from the historical city center.

Each measure is assigned to a distinct “construction period”. HOHENSINNER et al. (2012) used combined information from both historical documents and the non-existence and first appearance of measures in historical maps of Vienna. Thus, the implementation of all measures can be assigned to a reliable time frame. The efficiency of hydraulic measures is expressed in the database by their durability: The “duration of physical existence” can be distinguished from the “duration of functionality” with respect to the intended purpose(s). While the duration of existence indicates how long a structure had existed physically (possibly not fulfilling any purpose and potentially still causing unintended side-effects in the arrangement), the duration of functionality aims on an estimate of how long the structure had fulfilled the intended purpose. In fact, “success” and “failure” are insufficient terms to describe the effect of hydraulic measures and have to be seen relative to a context as the evaluation depends on different perspectives of stakeholders from different time periods. The terms “efficient” or “inefficient” are preferable as both potential positive and negative effects are contained. A long duration of functionality implies a great potential of a measure both for a successful regulation and for causing unintended side-effects and thus, is the best available measure for the efficiency of the structures in the database. The construction period, duration of functionality and the duration of existence of all measures has been plotted in figure 3-5. It appears that for many early measures the functionality was given only till one of the next floods, often less than a year or two. Nevertheless a few of the early measures physically existed till the 19th century when they became an obstacle for the new regulation efforts (PROKESCH, 1876). In contrast, after the *Great Danube Regulation (GDR)* a majority of measures which were implemented have lasted till today. Looking carefully at the duration of measures, years can be identified which ended the existence or at least the functionality of many measures. This applies to the very destructive floods in 1787 and 1830 and to the *GDR* from 1870 till 1875.

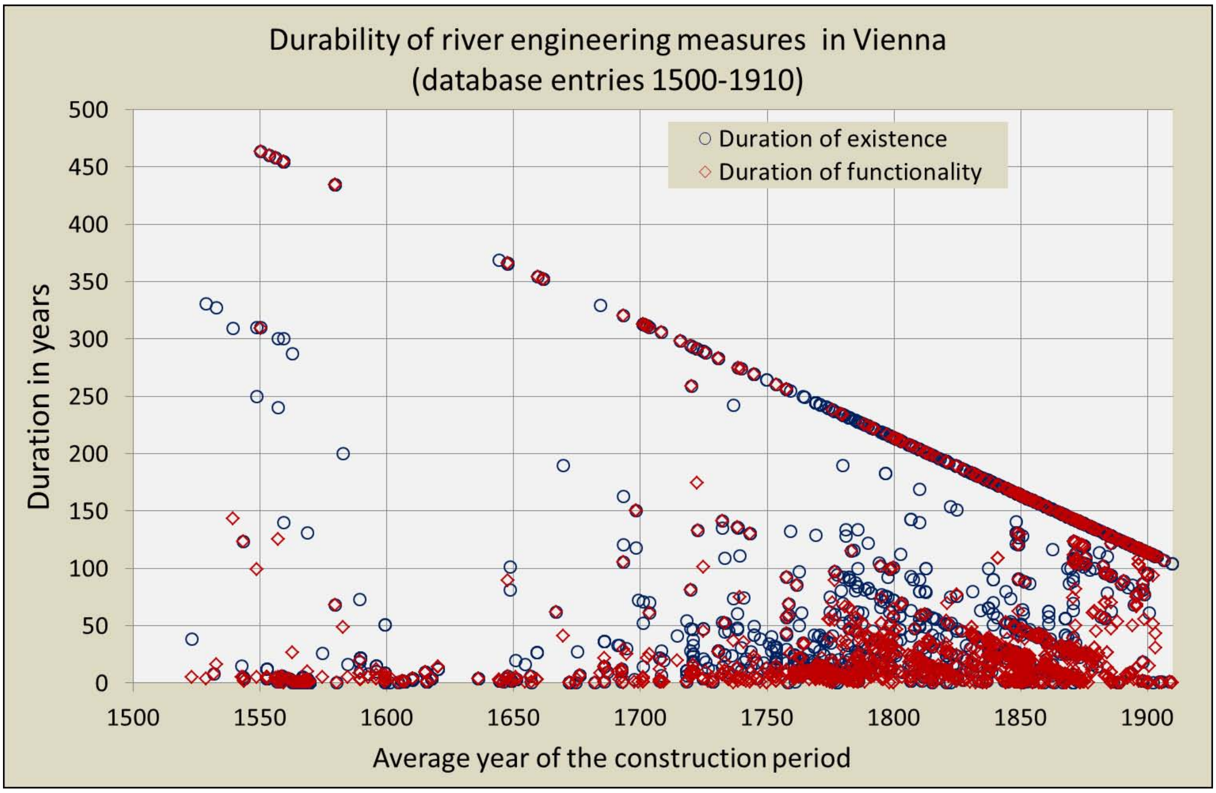

Figure 3-5: Construction time vs. duration of functionality and duration of existence of river engineering measures in Vienna. After the database by HOHENSINNER et al. (2012)

3.2 Re-structuring, specifying and extending the database

In a first step both geodatabases (of linear and areal river engineering in Vienna) have been merged to one single database with *Microsoft Excel* (hereinafter: *DB*) including both “linear” and “areal” measures in one table. Fifty-two time intervals were defined: The interval “1” stands for the years from 1100 to 1400, “2” refers to the time period 1400 to 1500, “3” to 1500-1530, the interval 52 stands for years after 2010, and the intervals with the numbers “4” to “51” represent the decades from 1530-1540 till 2000-2010 in chronological order. Thus, the intervals “10”, “20”, ..., ”50” correspond to the years 1590-1600, 1690-1700, ... , 1990-2000 etc. Each DB entry was assigned to a time interval based on the average year of the given potential construction period. The earliest and the latest possible construction year (according to the present state of documentation) were extracted for each entry and the average year calculated. Subsequently, each entry in the DB is linked to one distinct time interval while the actual construction time might have been in the earlier or following interval or spread over more than one decade. If the average construction year was a round number (e.g. 1570) the measures was assigned to the previous interval (in this example to the decade 1560-1570). Assigning all measures to distinct time intervals allows focusing on methodological uncertainties on historical values of money, price categories and extents of measures in the database, rather than on the temporal uncertainty on the exact date of the expenses.

The extent of implemented structures in the database in each time interval can be understood as an approximation to the real extent of implemented measures in this time interval. As both historical documents and maps have been used, there is in many cases a relatively detailed knowledge and reference for the location of structures, the approximate width of river arms and distances being relevant for assumption of the location and extents. Some historical sources even provided actual distances. The difficulty in estimating the real extent of implemented measures has been approached by assigning an uncertainty on the extents of measures in the DB.

While this uncertainty on the extent cannot be quantified exactly, it is for each measure indicated in the original DB, whether the extent should be considered uncertain or not. In our calculation, an uncertainty on all lengths and areas was assumed: +/ - 50 % if it was indicated that the extent was uncertain and +/ - 10 % for all other measures where this was not indicated. Those assumptions allow a better approximation to reality than by just using the original and precise GIS-extents.

A value for the efficiency as integral number between 1 and 100 was derived based on the estimated mean duration of functionality for each measure. The efficiency "1" stands for one year or less. "100" stands for 100 years or more. In this way the efficiency for all measures before 1913 is weighted equal and the efficiency of two (hypothetical) measures with duration of functionality till today and implemented in 1500 and in 1913 would be interpreted as 100 years. Figure 3-6 is derived of the data from figure 3-5 now only plotting the efficiency values for different construction types:

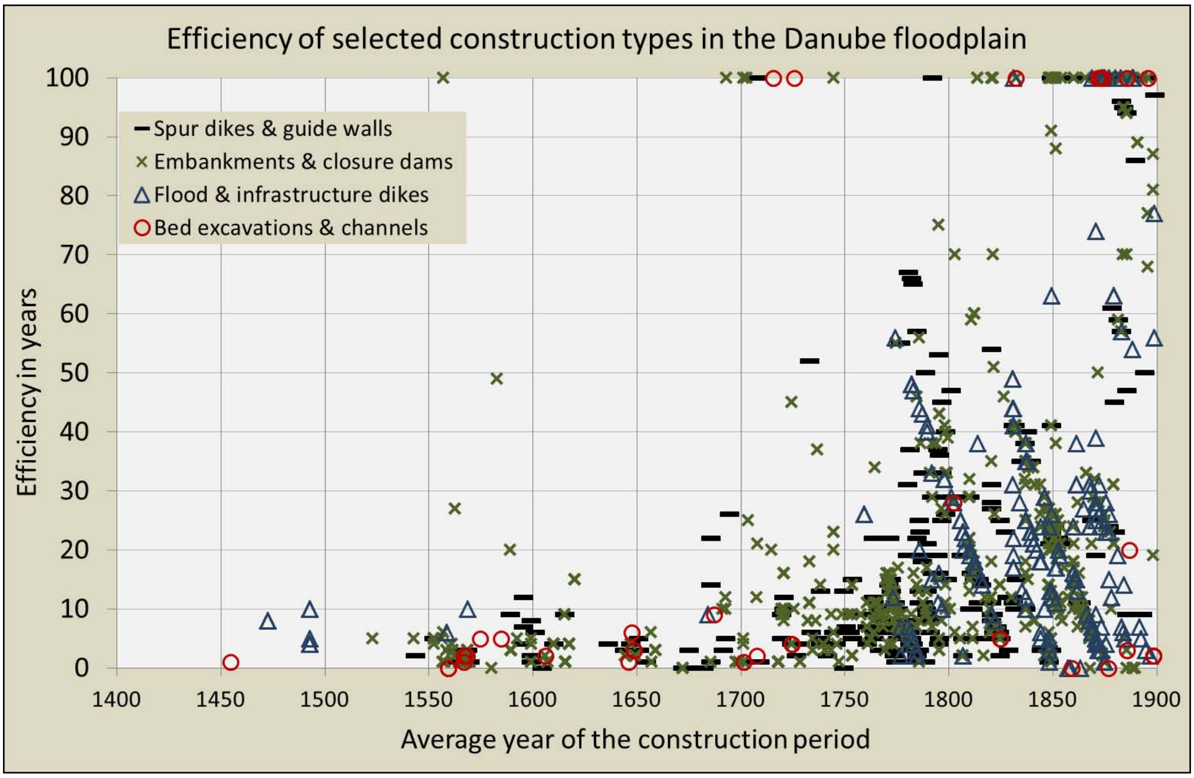

Figure 3-6: Derived efficiency of selected types of river engineering measures in the DB in years.

The so-defined efficiency of implemented structures before 1700 rarely exceeded a value of ten years. A gradual increase of the efficiencies can be observed in the following decades and since the end the 18th century, there were many measures which lasted for several decades. Since around 1830, an efficiency of 100 years could be assumed for numerous measures (which means, their functionality lasted for 100 years or more). A description of the median and average durability of implemented measures in different time periods is given by HOHENSINNER et al. (2013b, p. 165).

The categorizations in the database (DB) were further processed by adding three more attributes to the DB: the construction material, the chronology and the water body type. The attribute “construction material” uses information given in the “description of the measure” in the database. The following categories could be distinguished: *wood*, *stone* (referring to rocks broken in quarries), wood and stone (labeled as *wood / stone*), *soil & gravel* (referring to loose excavated material), furthermore excavations, which are characterized as *extraction of material*. Other types have been labelled as *mixed and others* referring to such different, but few, cases where steel works or plantations of trees (as terrestrialization measures) were used. When the information was uncertain and only derived from the most common construction type of the time period a question mark has been added to the above mentioned labels. Some measures were labelled as *unknown* if no assumption at all was possible.

The attribute “chronology” of a measure describes if a structure has been implemented entirely new (*primary*), or if it is a *subsequent* measure either as *extension*, *renewal*, *removal* or *repairing* of a structure. If a specification was impossible according to the information in the description of the measure in the DB, the chronology has been described as *unknown*. While the term renewal implies the replacement of an existing structure in a new fashion, the repairing of damages is rather conducted after floods to restore the functionality of the structure in the same fashion. The repairing will most certainly be cheaper than a renewal, extension or primary measure, because parts of the material is already at its place and can be integrated in a repaired structure. Separately, for linear and areal measures, the temporal occurrence of construction types, construction materials and chronologies of measures is illustrated in the figures in appendix I.3 as proportion of the length or area of implemented structures in each time interval and respective absolute numbers in kilometers and hectare per time interval are given in the *file 0.3* on the DVD (see description in appendix V).

The attribute "water body type" roughly follows the water body type classification for the river network in the Danube floodplain which was carried out by LAGER (2012). Danube branches with permanent flow were characterized either as *main branch* or *anabranch*. Their distinction follows the description of the reconstructions by LAGER (2012, pp. 23-49) and uses the assigned water body name and construction period in the database (HOHENSINNER et al., 2012). The name "Danube" always refers to the main branch. Besides, various Danube branches were temporarily considered as main branches: the *Tabor Arm* till 1566, the *Wolf Arm* since 1566, and in the following centuries, in particular the *Fahnenstangenwasser* and the *Kaiserwasser*. Other permanently flooded branches in the floodplain were considered as anabranches. Structures (e.g. closure dams) at the branch-off between a main branch and an anabranch were understood as part of the main branch. Branches which were not permanently flooded or cut off from the river were labelled as *oxbow* (= dead or abandoned arms). Port basins, flood-bypasses and canals have been labelled as *artificial water body* (e.g. the *Neue Donau*). For practical reasons, and giving some weight to their different regulation history, major and minor tributaries in Vienna were distinguished. Major tributaries are *the Rivers Wien, Liesing and Schwechat*. They were referred to as *tributaries (rivers)*. All other Danube tributaries were labelled as *creeks and ditches*. Mill weirs and streams in this classification were understood as part of the tributaries they belong to (most of them in the city area were constructed along the Wien River). The spatial patterns of the water body types assigned to the measures from the database were illustrated in figure 3-7 (linear measures) and figure 3-8 (areal measures). (HOHENSINNER et al., 2012; LAGER, 2012)

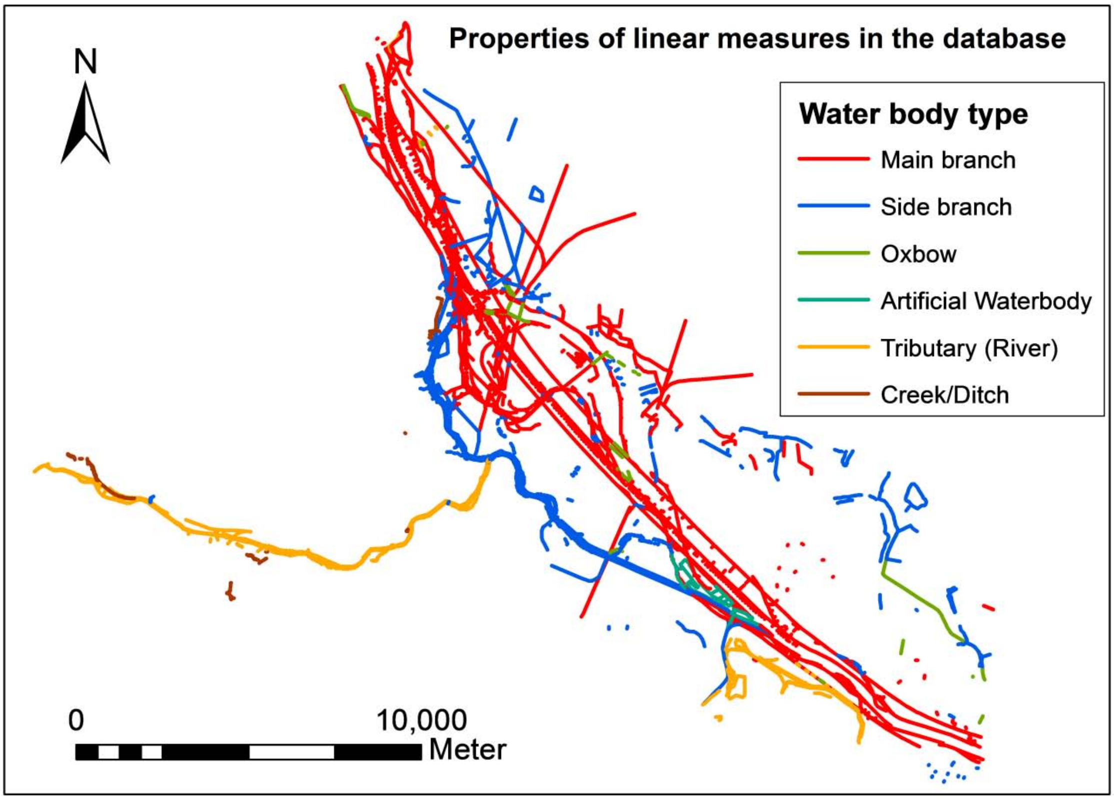

Figure 3-7: Spatial distribution of linear historical river engineering measures and related water body types at the time of implementation of the measures.

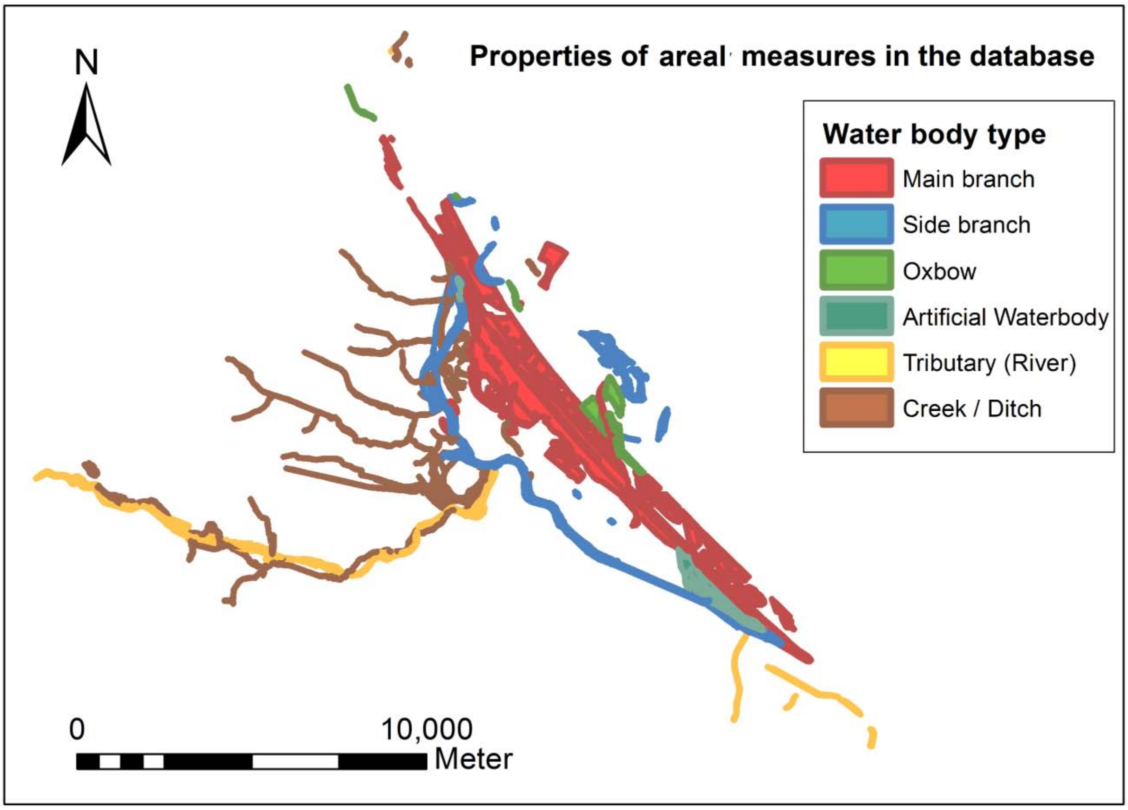

Figure 3-8: Spatial distribution of areal historical river engineering measures and related water body types at the time of implementation of the measures.

The research both relies on the identification of realistic price categories (cost indices) per meter or hectare for different construction types in different time periods and on documented money amounts spent on hydraulic engineering projects in Vienna. Subsequently, cost information was integrated in two different ways either by assigning prices per extent to "individual measures" or by integrating known expenses of "projects" into the database. The individual measures in the database till 1900 are a synthesis of the areal database and the linear database described above (chapter 3.1). They are characterized by all the specific information in the database e.g. time interval, construction type, chronology, material, water body type, objective etc. Projects only require cost information for a whole hydraulic project from literature and are assigned at least to a water body type and a time interval.

Database entries can be included in the analyses of this work in four different combinations: They were accounted:

1.) Both as project and individual measure (applying to most measures)
2.) only as individual measure (when total expenses are better expressed by a hint for a project in literature which cannot be split up on individual measures)
3.) only as project replacing several individual measures in the project list
4.) Neither as project, nor as individual measure

It depends on the given information which of these cases applies: In several cases "projects" for which expenses were documented could not directly be assigned to the individual measures in the database. The integration of cost estimates for these projects – while the exact distribution on individual measures is unknown – can increase the quality and precision of the estimate of cost volumes per time period (quantitatively). For this latter case it was necessary to integrate new entries into the database. In few cases this applies to measures implemented before 1900, while the 20th and 21st century is represented mainly by selected major projects such as the *Neue Donau* and *Donauinsel* and the *Hydropower Plant Freudenau*. These were both listed as projects and individual measures. It has been started to specify their individual elements which were often both excluded from the list of projects and the list of individual measures as neither the distribution of expenses nor their extent and other database properties are verified yet in the DB. The 20th century is therefore thought as preliminary addition and link to the present while in particular the period between 1540 and 1900 will be examined in detail. Among 1,995 entries, 1,853 entries are linear (1,403) and areal (450) measures from the original DB, while 142 entries were added during this research not all of which were accounted either as projects or individual measures. In total, 1,731 entries were accounted as "projects" and 1,904 entries were accounted as "individual measures".

Based on a combination of existing categorizations in the DB, all entries (projects and/or individual measures) were assigned to 31 project categories according to characteristic common meanings, objectives and construction types. They allow analyzing the cost structure separately for these specific groups. Minor tributaries were referred to as *creeks & ditches* and major tributaries just referred to as *tributaries*. *Mill weirs & streams* (along the *Wien River*) were considered as own category. In the Danube floodplain it was distinguished between dikes – namely *infrastructure dikes* and *flood dikes* – and *regulation works* within the channels (including embankments, spur dikes, guide walls and closure dams, mostly made of hard materials as wood, stone or both) and "excavations and fillings" (describing a transfer of loose material, as in *bed excavations*, *fillings* or *channels*). These groups of measures were furthermore grouped based on time periods: In the Danube floodplain measures implemented during the *Great Danube Regulation* (*GDR*, between 1870 and 1884) were distinguished from measures implemented between 1830 and 1870 and before the great flood in 1830, and from measures implemented subsequent to the GDR (labelled "Post GDR"; since around 1882). For regulation measures and flood dikes the measures *between 1787 and 1830* and *before the flood in 1787* are separate categories. The historically important measures implemented by the engineer *I.E. Hubert* between 1770 and 1790 were assigned into extra categories. For "regulation measures" implemented before 1700 it was distinguished between the ones *between 1540 and 1650 near Nussdorf*, other regulation measures *before 1650* and those implemented *between 1650 and 1700*. Major projects from the 20th and 21st century were grouped as *hydropower* (the plants at *Freudenau* and *Nussdorf*), the on-going *improved flood protection* since the 1970s (including the *Danube Island* and *Neue Donau* from 1972 till 1987) which aimed on the protection of Vienna from Danube floods for discharges up to 14,000 m³ per second, and *correction* projects of negative impacts of the *GDR* (e.g. the *Marchfeldkanal* east of Vienna). Every DB entry was assigned to one distinct project category.

In order to make changes in societal priorities visible, certain centers of attention (referred to as “river functions”) were identified, which are repeating motives or ideals in the present documentation of historical river engineering measures in Vienna. Rather than exact terms, they are clusters in past communication about and motivations related to the water bodies. In different times a “navigation route” has been something different for the inhabitants of Vienna (e.g. today requirements for navigation are fundamentally different than for navigation before industrialization) – still it is always distinctly different perceiving the river as navigation route than looking at the river as a “flood risk”, a “military barrier” or an “ecosystem”. Each measure marks the intended manipulation of the water body according to one or more of these ideals. Based on the information given by the “objective” and “purpose” in the original database each individual measure has been linked with one or more of those “river functions” that were addressed by the expenses on this measure: “military barriers”, “gain of urban space”, “navigation routes”, “navigation port”, “sewage system” (for the fast disposal of wastewater), “biodiversity” (only relevant recently) energy supply either by traditional “water mills” or for the generation of electricity (“hydropower”), water supply both for “households and industry” and for “groundwater and agriculture”, furthermore various risks: “disease prevention”, “flood protection”, “erosion protection”, “infrastructure protection” (flood-safe traffic routes).

On the following pages, basic specifications of the extended database were demonstrated for three exemplary measures in the tables 3-1 to 3-5:

1. The linear measure named *Gegenschlacht* (ID, linear DB: 28), a major guide wall among the early measures near Nussdorf which aimed on redirecting the current of the Danube to the right banks (and the course of the river towards the city).
2. The areal measure *Weidenhaufen-Durchstich* (ID, areal DB: 278) is one of two major cut-offs from the GDR.
3. The entry referring to the *New Danube / Donauinsel* (Name: IFP_0)

Table 3-1 shows the basic identity in the DB and the assignment to time intervals, table 3-2 refers to the extent of the measures and table 3-3 interpretation of the durability given in the database.

The “origin” is either from the original database (*DB*) or an additional/new entry (*Add*), the shape is either *linear* or *areal,* or the entry represents a cost sum of a project known from literature (“SUM”). Time intervals assigned based on the average construction years (see above) were listed in two separate lines for projects and individual measures. If the entry was either excluded from the list of projects or from the list of individual measures the time interval was set into brackets (which will exclude the entry from later calculations in excel which will either refer only to the list of “projects” or only to the list of “individual measures”). Extents were usually only assigned to linear (only length) or areal individual measures (only area). The integration of information about volumes, cross sections, width and height is only at the beginning, optional and not systematically possible. If possible, time frames for the durability of measures were extracted from the information in the DB. However, only the mean assumption for the duration of functionality was used for the calculation of the efficiency of measures (see above within this chapter).

Table 3-4 refers to the basic categorizations of DB entries and table 3-5 shows the assignment of the river functions which were addressed by the measures, as described above.

Table 3-1: Identification, construction time and assigned time intervals of measures in the database (DB); in Black: Original DB entries by HOHENSINNER et al. (2012), in red: New entries in the DB

OBJECTID *		28	278	IFP_0
Origin		DB	DB	Add
SHAPE *		Linear	Areal	SUM
Year		1548-1558	1874-1875	1972-1987
Remarks construction year	(German)	none	none	-
Construction year	Average	1553	1875	1980
	Minimum	1548	1874	1972
	Maximum	1558	1875	1987
# of the time interval	Individual	6	38	(48)
	Project	(6)	38	48
	Minimum	5	38	48
	Maximum	6	38	49
Century		16.	19.	20.

Table 3-2: Extents of measures in the database (DB); in Black: Original DB entries by HOHENSINNER et al. (2012), in red: New entries in the extended DB

OBJECTID *		28	278
Length_DB	in m	538	
Width_DB (Linear measures)	Width categories	10	
Assumed length (in meter)	Mean	538	
	Minimum	269	
	Maximum	807	
Area_DB	in m²		466,034
Circumference_DB	in m		5,975
Assumed area (in square meter)	Mean		466,034
	Minimum		419,431
	Maximum		512,637
Volume	in m³		3,300,000
Cross section	in m²		
Width	in m		
Height	in m		

Table 3-3: Durability of measures in the database as "duration till ..." and "duration in years"; in black: original DB entries by HOHENSINNER et al. (2012), in red: new entries in the extended DB.

OBJECTID *		28	278	IFP_0
Duration of existence (years)	Database	5	till today	till today
	Mean	4	140	35
	Minimum	1	139	27
	Maximum	10	140	42
Remarks duration of existence		ca. (not later than 1556 till 1558 partly destroyed)	none	till today
Existence till ...	Mean	1557	2014	2014
	Minimum	1556	2014	2014
	Maximum	1558	2014	2014
	Time period	6	52	52
Duration of functionality (years)	Database	5	till today	till today
	Mean	5	140	35
	Minimum	?	139	27
	Maximum	?	140	42
Remarks duration of functionality		ca.	River bed partly rebuilt during the construction of *Kraftwerk Freudenau* 1992-1998	till today
Functionality till ...	Mean	1558	2014	2014
	Minimum	?	2014	2014
	Maximum	?	2014	2014
	Time period	6	52	52
Duration of existence minus duration of functionality		0	0	0

Table 3-4: Categories of measures in the database (DB); in black: original DB entries by HOHENSINNER et al. (2012), in red: new entries in the extended DB.

OBJECTID *	28	278	IFP_0
Project name (German)	Gegenschlacht	Weidenhaufen-Durchstich, Unterer Durchstich	Neue Donau / Donauinsel
Project category	Regulation works near Nussdorf before 1650	Excavations & Fillings, GDR	Improved flood protection
Water body name (German)	Donau	Donau	Neue Donau / Donau
Water body type	Main Branch	Main Branch	-
Construction type	Guide wall	Channel	-
Description (German)	Errichtung der "Gegenschlacht" (eine von 2 Hauptschlachten), hölzerne Schlacht mit Wasserbausteinen	teilweiser Aushub eines neuen Flussbettes in Form einer 2.845 m langen u. 170 m breiten Künette entlang des rechten Ufers, 2,5 m unter Null tief, gesamt 4,1 Mio. cbm Material	Gesamtprojekt beinhaltet: Neue Donau / Donauinsel / Dämme / Wehranlagen etc.
Chronology	Primary	Primary	-
Construction Material	Wood / Stone	Extracted	-
Engineer	Potzo	Wex	

Table 3-5: River functions addressed (x) by the database entries; derived from the “objective” and “purpose” given by HOHENSINNER et al. (2012).

OBJECTID *		28	278	IFP_0
Objective		Regulation	Regulation	Flood protection
Purpose of the measure (here translated from German, in the Database in German)		Prevention of erosion at the northern banks and deflection of the stream towards the city	Improvement of the navigability and of the flood discharge; prevention of ice jam floods	Flood protection for suburbs
Military	Military Barrier			
Space	Urban Space			
Navigation	Route	x	x	
	Port			
Thread for land & infrastrastructure	Flood Protection		x	x
	Erosion Protection	x		
	Infrastructure Protection			
Energy supply	Water Mills			
	Hydropower			
Water supply	Households & Industry			
	Agriculture & Groundwater			
Ecological & health functions	Biodiversity			
	Disease Prevention			
	Sewage System			

4 PART A: HISTORICAL VALUES OF MONEY

4.1 Money and currencies in the history of Vienna

Interpreting documented amounts of money from more than 500 years at first requires being familiar with the most common currency units from the history of Vienna. Nominal relationships between these currencies can be traced back to the 12th century (PŘIBRAM, 1938; MÜHLPECK et al., 1979a; OENB, 2014). In 1193/94, the mint of the *Babenberg* dukes moved to Vienna where the so-called *Wiener Pfennig* was coined since then which played a leading role in this region (ALRAM, 1994). 1 *Pfund Wiener Pfennig* (short: tal.) was a count unit equal to 8 *Wiener Schilling* (sol.; count unit) and to 240 *Wiener Pfennig* (den.; silver coins). In 1510/11, the *Gulden* (short: fl.) à 60 *Kreutzer* (short: kr.) was introduced as new currency and 1 *Gulden (fl.)* was set equal to 1 *Pfund* (PŘIBRAM, 1938, p. 3; OENB, 2014, pp. 10, 14-16). Since around 1750 the Gulden is referred to as well as *Gulden Conventionsmünze* (short: fl. CM; OENB, 2014, p. 46). For the purpose of this research, only one currency was defined as reference currency in each year. The term "nominal currency unit" (short: *NCU*) has been introduced for these reference currencies. The *Wiener Pfund* (tal.) has been considered as NCU referring to the time intervals "1" and "2" (1100-1500). The Gulden was considered as NCU for the time intervals "3" to "36" (1500-1860). Several second and less common currencies had been used however: The *Gold-Gulden* before 1510 is not to be confused with the later Gulden. The *Taler* – a silver coin – and the *Dukate*n – a gold coin – had existed for a long time and were related to the *Gulden* currency at changing rates. These rates over time were carefully documented by PŘIBRAM (1938, pp. 28-44). Yet, they only play a minor role in the documentation of river engineering expenses. The most relevant case is that of paper money, which was first printed in 1762 (OENB, 2014, p. 50). The exchange rates between paper and silver money are given by PŘIBRAM (1938, pp. 54-55): The paper money can be referred to as *fl. bank notes (fl. BN)* and lost its value from 1.00 *fl. BN* in 1796 to 4.92 *fl. BN* in 1810, compared to 1 *fl. CM*. After the state bankruptcy of Austria in 1810, between 1811 and 1858 the *Gulden Wiener Währung* (*fl. WW*) was used with a changing rate between 2.0 and 3.5 *fl. WW per fl. CM*. Between 1820 and 1858 this relationship was set to a fix value and 1 *fl. CM* was equal to 2.5 *fl. WW* until both currencies were replaced by the *Gulden Österreichische Währung* (*fl. ÖW*). 1 fl. CM equals 1.05 *fl. ÖW* and 1 *fl. ÖW* equals 100 *Kreutzer* (short: *kr. ÖW*) as documented by OENB (2014, p. 66). The *fl. ÖW* has been replaced by the *Kronen (K)* à 100 *Heller (hlr.)* in the year 1892 at a rate of 1 fl. ÖW to 2 *K* (OENB, 2014, p. 74). The Gulden currencies since 1510 were based on silver, while the *Kronen* was based on gold. The use of the Kronen currency lasted till the great inflation in the 1920s. In 1925, a first *Schilling currency (aS)* replaced the Kronen, which had lost its value nearly entirely. This earlier Schilling is today referred to as *Alt-Schilling (aS, "Old Shilling")* to distinguish it from the *Schilling (S)* introduced after WW II. The official exchange rate (relevant for price indices) in 1925 was 1.44 *(Gold-)Kronen* to 1 *aS* (MÜHLPECK et al., 1979a). The *Reichsmark (RM)* was used between 1938 and 1945 and had replaced the *aS* in 1938 at a rate of 1 *RM* to 1.5 *aS*. The newer Austrian *Schilling* currency *(S)* in 1945 replaced the *RM* at a rate of 1 : 1. At present the *Euro (€)* is the only valid currency in Austria and replaced the *Schilling* at a rate of 1 € to 13.7063 S in 2002. After 1860, the following currencies were considered as "NCU": the *fl. ÖW* for the time intervals "37" to "39" (1860-1890), *K* referring to the time intervals "40" to "42" (1890-1920), *aS* for the time intervals "43" and "44" (1920-1940), *S* in the time intervals "45" to "50" (1940-2000) and € for the recent intervals till today.

Based on the exchange rates, when new currencies were introduced the above mentioned NCU are – hypothetically – related to each other by stable exchange rates: Thus, the term 1 *Gulden (fl.)* – nominally – equals 0.0707 € and 1 € equals 14.153 *fl.* vice versa. This system enables us dealing with all currencies appearing in historical documents and all historical money amounts could theoretically be expressed with all of the *nominal currency units* for each year! Together with price trends indicated by price indices from Vienna or Austria (chapter 4.2 and 4.3), historical values of money are then interpretable. An overview of important currencies is given in table 4-1. Exchange rates between the NCUs (so called "NCU factors") are shown in figure 4-1:

Table 4-1: Historical currencies in Vienna; after PŘIBRAM (1938) and OENB (2014).

Abbre-viation	New currency	Time period	Subunits	Introduced in ...	Rate	Old currency
€	Euro	Since 2002	1 € = 100 Cent (ct.)	2002 (1999)	13.7603	Schilling
S	Schilling	1945-2002	1 S= 100 Groschen (Gr.)	1945	1	Reichsmark
RM	Reichsmark	1938-1945	1 RM = 100 Reichspfennig (Rpf.)	1938	1.5	Schilling
aS	(Alt-)Schilling	1924-1938	1 aS = 100 Groschen (aGr.)	1924/25	1.44	(Gold-) Kronen
K	Kronen	1892-1924	1 K = 100 Heller (hlr.)	1892 (1900)	0.5	Gulden ÖW
fl. ÖW (fl.)	Gulden ÖW ("Österreichische Währung")	1858-1900	1 fl.ÖW = 100 Kreuzer (kr.ÖW)	1858	0.9524	Gulden CM
fl. WW (fl.)	Gulden WW ("Wiener Währung")	1811-1858	1 fl. WW = 60 Kreuzer (kr. WW)	1811	-	Gulden CM
fl. BN	Gulden BN ("Bank notes")	1762-1811		1762	-	Gulden CM
fl. (fl. CM)	Gulden CM ("Conventions-münze")	1510/11- 1858	1 fl. / fl. CM) = 60 Kreuzer (kr. / kr. CM)	1510/11	1	Pfund Wiener Pfennig
tal. (tt.)	Pfund Wiener Pfennig	c. 1193/94-1510/11	1 tal. = 8 sol. (Schilling) = 240 den. (Wiener Pfennig)	c. 1193/94	-	-

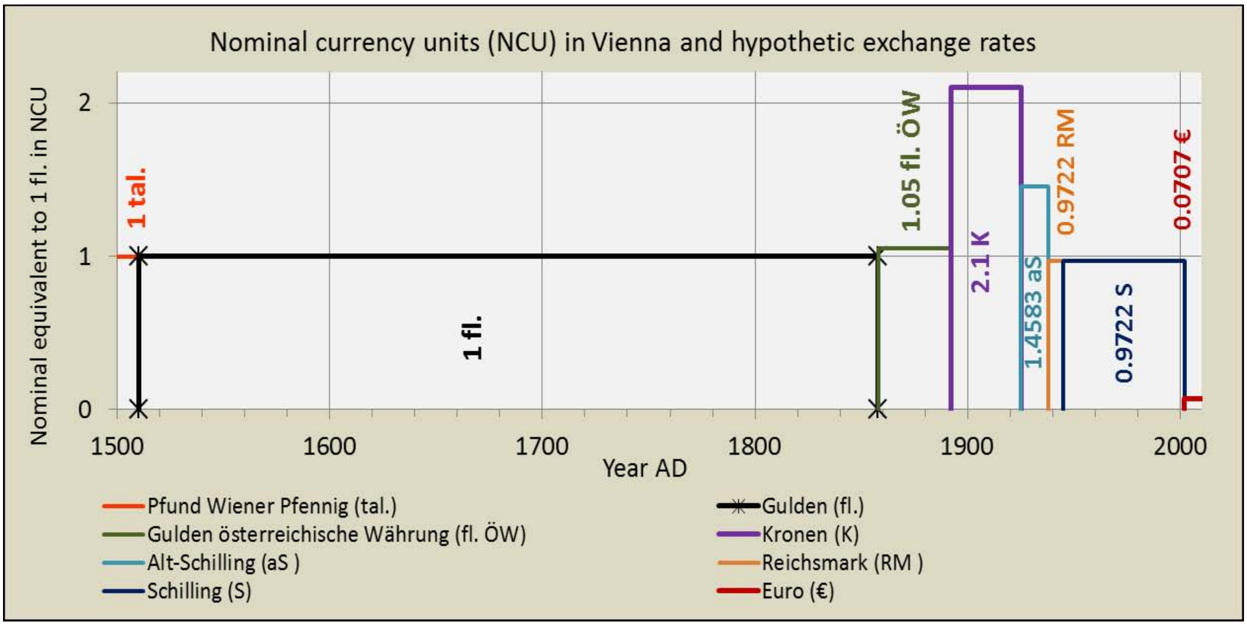

Figure 4-1: Nominal currency units (NCU) in Vienna and hypothetic exchange factors based on the official transfer rates in the years when a new currency was introduced.

4.2 Base data for historical values of money in Vienna

4.2.1 Comparisons of historical values of money

Nominal expressions of money have no or only little meaning looking at them without a socio-economic reference. The use of nominal exchange rates between currencies (e.g. 1 € equals 13.7 *S*) for the transfer of historical amounts of money to present values leads to confusing and usually meaningless results. As the research is dependent both on the long-term interpretation (over several centuries) of the societal significance of historical expenses on river engineering and on predictions of shorter-term price developments (over several decades, or even centuries for early measures), a framework of methods needs to be developed that can give a sufficiently satisfying answers to three questions:

1. How would a price of a river engineering measure per meter or hectare in a time period “A” (e.g. given by a price information in a historical sources) change to another time period “B” for the same construction type (e.g. as represented by another entry in the database)?
2. What is the relative value of amounts of money from year “A” compared to other amounts of money from year “B” according to a clearly defined money equivalent?
3. And how significant is the mismatch between different methods of interpretation?

There is in fact wide agreement that comparing historical worth of money with present worth is not seriously possible (e.g. GERHARDT & ENGEL, 2004; EMMERIG, 2012) due to the fact that the “*relationships between different goods or services have changed tremendously over time”* (EMMERIG, 2012, p. 20, translated from German by the author). Price indices are characterized by a reference year for which the price level is normalized to 100 and a clearly defined bundle of goods and/or services for which the price development over the years is observed. Those indices cannot seriously serve for a reliable long-term comparison of the actual “value” or “worth” of money. For the case of the *United Kingdom* and the *United States*, OFFICER & WILLIAMSON (2010) have previously shown that extreme mismatches of several orders of magnitude may occur, using different price indices for the standardization of money over several centuries and for comparisons of historical with modern prices. Though, price indices may well serve as an adequate short- or medium-term prediction tool. For example, the *GDP price index (= GDP deflator)* and the *consumer price index* are commonly used as “deflators” of money for shorter periods. For interpretations and comparisons over longer time periods, GERHARDT & ENGEL (2004, pp. 40-52) suggest referring to amounts of certain goods or services (e.g. days labor of an unqualified mason, kilograms of bread) one could obtain in a defined time period for a certain amount of money. In the present research, adequate indicators for a comparison of the value of historical amounts of money should as good as possible fulfill the following criteria:

> They are goods and services which are documented on a yearly level for a long time period, in the best case the entire time period from 1530 to 2012 (e.g. mason wages and prices of cereal, bread, flour, beef, peas, lard or wine).

> They are goods and services having a great importance in daily life and in the economy over the entire time period (e.g. rather bread, beef, cereal, labor etc. than nails, carps or peas etc.).

> They are goods and services for which prices are available in an at least rather homogeneous and comparable unit (e.g. one week labor of an unqualified construction worker; 1 kg beef etc.). Therefore, the “weights”, prices refer to should both be documented and clear in their meaning for the entire time period.

None of such indicators qualifies as absolute measure of a historical value of money, as both the quality and the socio-economic importance of observed goods and services change over time: The quality of the oat contained in a liter sold at the market changes over time due to different regulations or practices. Due to technological progress, the labor of a mason in 2012 is more productive than in 1530 and the working conditions are better. The socio-economic weight of one day labor has strongly increased since the beginning of the industrialization (see appendix II).

4.2.2 Value-of-money indicators and available registers in Vienna

Looking at a time span of around 500 years in total, it was required using already existing data collections and combining them to one synthesis of various indicators for the entire time period from at least the years 1530 to 2012 AD. There is a variety of data that can be used in Austria and more specifically in Vienna and – to the knowledge of the author – they have not been digitized together for this entire time period, before. Rather, they were used separately for studies focusing on shorter time periods of interest (e.g. LANDSTEINER, 2001; CASUTT et al., 2009).

The selection and digitization of adequate data in particular, for the pre-industrial period, was very time-consuming: For Vienna, a comprehensive collection of prices of numerous food and other products and different types of labor has been laid out by PŘIBRAM (1938): The price registers include data from the *Viennese market protocols* (German: *Wiener Marktprotokolle*) with prices for cereal (wheat, rye, barley, oat), different grain-sized flour, four types of bread, beef and legumes (peas, beans, lentils) between 1690 and 1913. Beyond, prices and wages for a wide range of products and services are documented based on the conditions at two institutions the *Stift Klosterneuburg* – a monastery near Vienna – and the *Bürgerspital* – an important social institution in Vienna, where purchases, sells and wages were documented from the 14th century to c. 1780 (PŘIBRAM, 1938). Back till around 1530, there is rather complete documentation without major gaps for some products. Food prices from 1800 to 1913 are documented on a yearly level by MÜHLPECK et al. (1979b). SANDGRUBER (1994) provides fragmentary information on mason wages from the 19th century. From 1900 to 1996, price data on a yearly level were documented by the *Austrian Statistical Central Office* (ÖSTERR. STAT. ZENTRALAMT, 1997).

Data for two common economic price indices are available back to the early 19th century: The *consumer price index* (referred to as *CPI*) has been reconstructed by MÜHLPECK et al. (1979a) for the time period between 1800 and 1913. The study observed the price development of a bundle of goods representing the consumption of a hypothetical average workers' household in the year 1910. In the same volume, the *nominal* and *real gross domestic product (GDP)* of Austria back to the year 1830 has been reconstructed by KAUSEL et al. (1979). Generally, the GDP measures the extent of the entire output of an economy. The *nominal GDP* expresses this extent for a certain year in the nominal currency which is valid in this year. In contrast, the *real GDP* uses price levels from a reference year and eliminates the effect of inflation in the economy, so that the extent of the GDP from different years can actually be compared. The ratio of the nominal GDP divided by the real GDP referring to a defined reference year is the so-called *GDP deflator*, which is hereinafter referred to as GDP price index (GDPPI). Hence, the "GDPPI" mirrors price trends, representing the entire output of the economy, in contrast to the "CPI" which only describes price trends from the perspective of a hypothetic "average household". OFFICER & WILLIAMSON (2010) suggest referring to the CPI rather for projects on a personal or household level, while the GDPPI would be adequate when looking at likely price trends in public investments and government projects (such as hydraulic measures). The two mentioned studies on the price development in Austria provide a missing link between pre-industrial and modern times. BUTSCHEK (1998) has linked those reconstructions with the two corresponding modern price indices which were documented by STATISTIK AUSTRIA (2014) in the late 20th and early 21st century.

4.2.3 Consumer price index and GDP deflator

Data from the above mentioned sources were processed in four separate excel sheets, copies of which are collected in *file A.1* on the DVD (see appendix V). One sheet ("CPI") collects all data for the *consumer price index* (*CPI*) of Austria since 1800: The yearly consumer price index (CPI) by MÜHLPECK et al. (1979) was listed relative to the price level in 1913 which was set to a value of 100. This was done both for the "general index" (CPI) and the "food price index", which is excluding all other goods and services than food products. In the early 19th century these two indices show deviations of up to 25 % from each other, which is relatively little considering the major fluctuations of price levels in this time. The continuation of the CPI by

BUTSCHEK (1998) was listed and serves as primary reference from 1914 till 1958. For the time after WW II the CPI with different base years (1938, 1958, 1966, 1976, 1986, 1996, 2000, 2005 and 2010) from STATISTIK AUSTRIA (2014)[9] were collected: For each base year the observed bundle of goods is adapted to the demands of an average household of that time. These indices were chain-linked according to the price levels in the base years. For example, the indices with the base years 1995 and 2000 were linked by setting the values of both indices equal for the year 2000 and further on following the trend of the index with the base year 2000. This results in one single consumer price index between 1800 and 2012, assigning one distinct value to each year, which means, that the ratio of price levels between two years in the same index does not change, no matter which reference period is used.

Another sheet, labelled as “GDP”, deals with the nominal and real Austrian GDP and with the *GDP Price Index* (*GDPPI*) after 1830. The data both includes the reconstructed historical *nominal GDP* of Austria and a reconstructed *real GDP* at price levels of a given reference year. The values from KAUSEL et al., (1979) referred to the time period 1830 till 1914. BUTSCHEK (1998) provided the link to after WW II and uses several reference years (1937, 1954 and 1976), while newer values were given by STATISTIK AUSTRIA (2014)[10] referring to the real GDP in 2012. All values for the nominal GDP were then expressed in Euro while the real GDP has been chain-linked and expressed in Euro at levels of 2012 for the entire period. For all years from 1830 till 2012 for which both the nominal and real GDP are given the *GDP price index* can be calculated as ratio of the nominal GDP divided by the real GDP multiplied by 100 (the reference value for 2012). As prior to 1910, values for the nominal GDP were only reconstructed for every ten years or even less the gaps in the *GDPPI* were filled by applying the overall trends from the CPI for years in between.

Available [accessed 09 30, 2014] at URL:
[9]http://www.statistik.at/web_de/statistiken/preise/verbraucherpreisindex_vpi_hvpi/zeitreihen_und_verkettungen/index.html
[10]http://www.statistik.at/web_de/statistiken/volkswirtschaftliche_gesamtrechnungen/bruttoinlandsprodukt_und_hauptaggregate/jahresdaten/index.html (values from 1976-1994 are no longer online)

The *CPI* and the *GDPPI* were normalized to three different reference times: The presence is represented by the year 2012. The last year before WW I, 1913, is the year used by MÜHLPECK et al. (1979a) and KAUSEL et al. (1979) for their studies. 1830 to 1838 is a period where the prices are rather stable and the average of these years may well be used for chain-linking the CPI with earlier indices. For the GDPPI only the year 1830 was used for this purpose as it is the only year with primary data. For example, if the year 1913 is used as reference year (price level = 100) the CPI or GDPPI would in 1870 indicate price levels of 86 or 78 %, in 2012 levels of 4,578 or 1,823 % compared to 1913. In other words, considering the nominal exchange rates between the currencies, according to the *CPI*, 100 K 1913 would be equivalent to c. 43 fl. ÖW in 1870 and to 154 € in 2012; according to the *GDPPI*, 100 K would be equivalent to c. 39 fl. ÖW in 1870 and to 61 € in 2012. Because there is no data for the CPI and the GDPPI in Austria before the early 19th century, another way to observe price trends for the earlier centuries had to be developed for Vienna.

4.2.4 Historical wages in Vienna

For the data series in the excel sheet named "wages", the following documented wages have been used: PŘIBRAM (1938) lists wages of workers in *kr. per day* before 1780 at the *Bürgerspital* (pp. 344-350) and at the *Stift Klosterneuburg* (pp. 515-520). Between 1790 and 1913, mason wages are listed by SANDGRUBER (1994) for selected years. Since 1900, the wages refer to those values given by the ÖSTERR. STAT. ZENTRALAMT (1997): Between 1900 and 1914, these were wages of construction workers in *K per day*, between 1914 and 1923 contractual minimum wages of the construction sector in *K per week*. Since 1948 the wages are given in *S per hour* while the working hours per week were listed separately. Generally, a wage given in units per week was considered to correspond to a wage for six working days approaching the situation over more than 500 years and allowing for a simple unit transfer if necessary: Generally two groups of labor were considered (after PŘIBRAM, 1938; SANDGRUBER, 1994; ÖSTERR. STAT. ZENTRALAMT 1997):

1. "Unqualified" or "unskilled" labor: from the 15th century till 1780, represented by *day laborer* wages of *masons* ("Maurer") and *roofers* ("Ziegeldecker"); in the 20th century, by *assistant workers in the construction sector* ("Hilfsarbeiter im Baugewerbe"); SANDGRUBER (1994) refers to wages of an unskilled mason.
2. "Qualified" or "skilled" labor: from the 15th century till 1780 represented by *journeymen* wages of *masons* ("Maurer"), *carpenters* ("Zimmerer") and *roofers* ("Ziegeldecker"); in the 20th century represented by *educated workers in the construction sector* (= "Facharbeiter im Baugewerbe").

Thus before 1780, there are time series for five groups of wages available at present (two for daylaborers: masons and roofers; three for journeymen: masons, carpenters and roofers). Generally, the wages for qualified labor were higher than those for unqualified labor. Both for *qualified* and *unqualified labor*, mason wages are the most complete data series. The wages from SANDGRUBER (1994) were considered as continuation of the series of *unskilled mason wages* and *assistant* and *educated worker wages* for the 20th century were listed under the series of *unskilled* and *skilled mason wages*. Gaps were usually closed, either by assuming a gradual increase or by transferring the overall trends from other series. The most severe gap had to be closed for the wage increase from 1790 (with 1 fl. CM / week) till 1830 (2.5 fl. CM / week), which was overcome by observing overall trends from other indices: When there were only minor fluctuations, the wages were assumed to be stable, while in phases of rapid inflation, a gradual increase of wages was assumed. The overall trends of the GDPPI were used to fill the gaps in the 19th century after 1830 and as the wages from SANDGRUBER (1994) only refer to *unqualified labor* the received price trends were applied over the entire period on the series of *qualified labor*. Yearly data on wages from Vienna in the 19th century should be added in future, in order to verify or adapt the here assumed developments of wages in this period. Before 1530, data only from selected years existed and only rough representations for this time period were given. In this early time, the given wages were food-inclusive and thus, higher wages were assumed following the overall trends and the ratio from years in which both food inclusive and non-inclusive wages were listed. As the wages were given in different units (e.g. kr. / day) the wages were transferred to units of NCU per week (1 week was defined as 6 working days). One wage index for each type of labor before the year 1780 was calculated related to the average wage from the time period 1721-1745 which was set to a value of 100. This reference period was already used by PŘIBRAM (1938) for price trends indicated by different goods or services. After 1780, the mason wage indices were followed till today and referred to as indices for “qualified” and “unqualified” labor. As in the CPI and the GDPPI, the exchange rates between the NCUs were eliminated in the indices.

4.2.5 Historical food prices in Vienna

The most complex collection was made in the excel sheet labelled as “food”. Prices for beef, different types of bread and flour, lard, beer, wine and legumes (peas, beans, lentils) are listed in *K per kg or liters* (depending on the product) by MÜHLPECK et al. (1979a) for the period 1800-1913. Series of flour, beef, bread, wine and beer were followed till today based on prices for these products from ÖSTERR. STAT. ZENTRALAMT (1997) usually given in NCU per liter or kg. The period 1997-2012 has been covered by applying the price trend from the CPI and these trends should be replaced by actual prices for the food products in future, for which STATISTIK AUSTRIA is the first address to contact. Under consideration of the above mentioned requirements the following groups of food products have been considered over several centuries back in time, based on the documentation by PŘIBRAM (1938):

> “Cereal” prices are known from the 14th century till 1913 (PŘIBRAM, 1938, pp. 269-274, 371-373 & 447-452). There are temporary gaps, in particular large gaps before 1530. Yearly prices for four cereals were listed: *wheat* (“Weizen”), *rye* (“Korn” or “Roggen”), *barley* (“Gerste”) and *oat* (“Hafer”).

> “Beer” prices were considered since 1800

> “Flour” prices were available since 1690 based on four different types in the *market protocols* (PŘIBRAM, 1938, pp. 374-380)

- > "Bread" prices are documented since around 1690, as well prices for four kinds of bread in the *market protocols* (PŘIBRAM, 1938, pp. 381-384).
- > For "meat" the most valuable series were beef prices and prices of oxen which are documented most of the time since around 1450 till 1780 from the *Bürgerspital* and Stift Klosterneuburg (PŘIBRAM, 1938, pp. 287-296, 381-384 & 464-476)
- > Prices for the sale of "wine" at the *Bürgerspital* and *Stift Klosterneuburg* are documented back to the 14^{th} century. If several products were sold, the documented prices usually refer to the lower price for the sell in each year in the respective institution. (PŘIBRAM, 1938, pp. 308-311 & 462-463).
- > "Lard" prices were listed after PŘIBRAM (1938, pp. 287-290; 464-470)
- > "Legume" prices of peas, lentils and beans were listed after PŘIBRAM (1938, pp. pp. 384-385, pp. 275 - 279, pp. 452-456)

Volume and weight measures follow the definitions of PŘIBRAM (1938, pp. 85-127): A *Metzen* was a volume measure used till 1875 for cereals, flour and legumes. The exact size differs depending on the institution: The *Viennese Metzen* ("Wiener Metzen") was equal to 41 liter (l) till 1620 and equal to 46.25 l afterwards. The *Lower Austrian Metzen* ("Niederösterreichischer Metzen") corresponded to 59.5 l, from 1589 till 1687, 61 l 1688-1755, and 61.5 l 1756-1875. Both at the *Viennese market* and in the *Bürgerspital* prices till 1751 referred to the *Viennese* and since 1752 to the *Lower Austrian Metzen*, while for the Stift Klosterneuburg the Lower Austrian Metzen replaced the so-called *Stiftsmetzen* (with 43.33 l) in 1589. At the *Bürgerspital* (till 1620: 48.5 l; 1621-1751: 51 l) and *Stift Klosterneuburg* (1589-1687: 71 l; 1688-1751, 77l) a separate "Oat Metzen" was used temporarily. Prices from the market after 1875 till 1913 were given per 100 kg by PŘIBRAM (1938); and 100 kg correspond to c. 132.8 l of wheat, 142.7 l of rye, 156.2 l of barley, 221.4 l of oat, 136.5 l of peas and 124.2 l of lentils/beans. The Stift Klosterneuburg had used the Lower Austrian Metzen since 1589. Flour was often addressed in a measure called *Strich*, which is equal to 40.75 liters. One *Wiener Pfund* (= *0.1 Centner = 10 Achtel*) was used as weight unit, e.g. for lard and beef and 1 kg is equal to 1.7855 *Wiener Pfund*. 1 *Eimer* is a volume measure for liquids (e.g. wine and beer) and was set equal to 58.0037 liter for the entire period. The exchange rates from table 4-2 were used to transfer all currencies into NCUs and the weights of the products were transferred to common units, usually liters for volumes, and kilograms for weights. The currency of the prices used by PŘIBRAM (1938) are kr. (and kr. CM) till 1810, kr. WW 1811-1857, and afterwards subunits of NCUs (kr. ÖW, hlr.). Prices in fl. WW from between 1811 and 1858 were transferred to Gulden CM (fl. CM) in this period. In each of the eight groups of food products, the gaps in the data series were closed in at least one of the data series. E.g. for cereal the series for oat were the most comprehensive and complete data series and minor gaps were filled for oat mainly based on the assumption of a linear increase or decrease of prices in the missing years. In other series the gaps were closed by applying the average price trends of cereal products. In a third step for each food product an index was calculated based on the average prices of the product in the period of 25 years from 1721 till 1745 which was considered as 100 percent. Then, a *cereal price index* was calculated as average of the rye, wheat, oat and barley indices. Equally, average *flour* and *bread price indices* were calculated as average of the four price indices of each group in each year. In the same way, a *legume price index* was derived as average of the yearly indices for peas, lentils and beans. The *beef price index* integrates the trends of oxen prices. *Wine*, *beer* and *lard* were considered as extra indices. The bread and flour price index prior to 1690 were chain-linked to the cereal price index based on price levels between 1721 and 1745, the beer price index before 1800, based on price levels between 1830 and 1838.

4.2.6 Workflow scheme for the derivation of money equivalents

For the year 1870, the following flow chart in an exemplary way draws a sketch of the necessary steps to obtain useful indicators from complex base data. The chapters 4.1 and 4.2 have basically covered the first three steps in the chart, dealing with the preparation of base data. The steps four to six may be understood supported by the chapters 4.3 and 4.4.

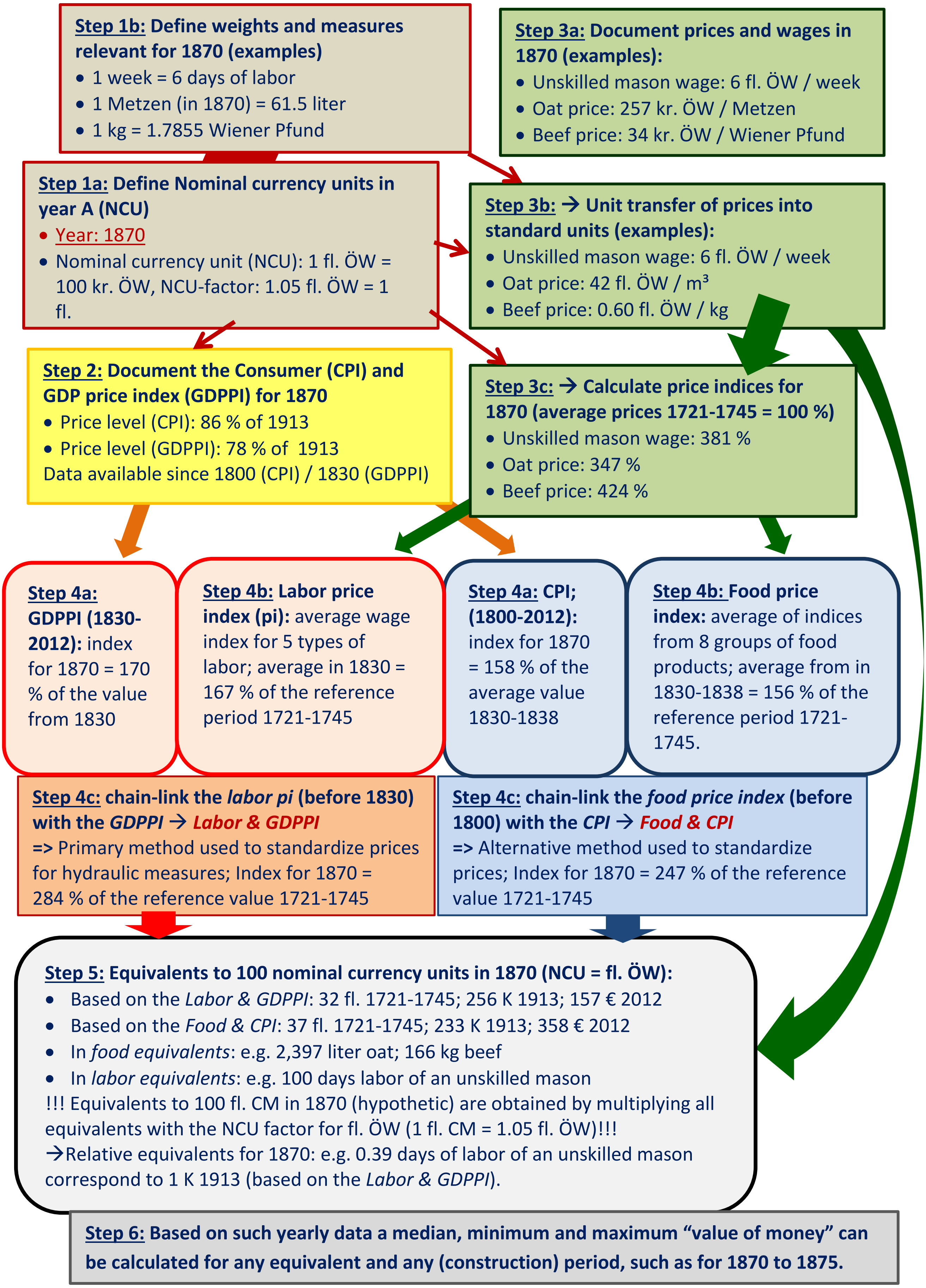

Figure 4-2: Workflow for the year 1870: from different kinds of base data to money equivalents.

4.3 Observation of price trends over several centuries

The averages of all available indices for wages of qualified labor and analogously for wages of unqualified labor (see chapter 4.2.4) were calculated. The calculation was entirely based on the assumption of the average value from 1721 to 1745 as reference value (= 100 %) for all indices. For each year, the wage levels indicated by the indices for unqualified and qualified labor were both weighted equally to generate an average *labor price index*. The primary intention was to give a representation of the wage development in Vienna before 1830, the period before industrialization and before data for a *GDP price index* is available. Till then at least, prices for hydraulic measures are expected to be closely related to the costs of local labor (compare figure 5.1 in chapter 5.2). Subsequently, overall price developments for distinct hydraulic construction types may be reconstructed over time by using the rise and fall of local labor prices as indicator. In the course of the 19th century the economy had become more complex: Enhanced transport over far distances loosened the dependency of river engineering prices from local labor and thus, the *GDP price index (GDPPI)* is considered as the best available tool after 1830 to predict price developments for hydraulic measures because the index explicitly reconstructs the price trends representing the entire output of the economy (see chapter 4.2.3). Considering these aspects the logical consequence was to generate one index, which contains trends of the *labor price index* before the year 1830, while the *GDPPI* covers the period 1830-2012. The two indices were chain-linked (*step 4* in figure 4-2): The values from both indices of the year 1830 were set equal. The *GDPPI* for 1870 is 170 % of 1830, the *labor price index* in 1830 is 167 % compared to the reference period 1721-1745. Thus, the price trends indicated after 1830 by the *GDPPI* could be linked to the trend prior to 1830 based on the *labor price* index which results in a value for 1870 of 100 x 1,67 x 1,7 = 2,84 (284 % of 1721-1745). The new index is hereinafter referred to as “Labor & GDPPI”. Deflated by the *Labor & GDPPI*, 1 Gulden 1721-1745 would correspond to 7.65 Kronen in 1913 and 4.70 Euro in 2012. The *Labor & GDPPI* is considered as primary tool (“deflator”) which can interpret price trends for hydraulic engineering from the perspective of the decision-makers and engineers concerned with hydraulic projects and it is the best available approximation to an actual prediction or reconstruction of price developments in hydraulic engineering.

In order to accommodate the fact that there are other perspectives on the price development, such as the *consumers’ perspective*, an alternative tool has been generated based on the *consumer price index* (*CPI*). As described in chapter 4.2.3 price trends based on a bundle of goods representing the consumption of an average household in 1910 have been traced back to 1800 by MÜHLPECK et al. (1979a). As there is no data about how the consumption of the “average household” looked like before 1800, simple average trends of several groups of food products were used: The separate price indices for the eight groups of food products from chapter 4.2.5 were incorporated: four cereal-based product groups (cereal, flour, beer and bread) and four other food products (wine, beef, lard and legumes). The average of the years 1721-1745 has been considered as reference for the indices for each of these product groups and one average *food price index* was calculated by weighting each product group equally. Analogously to the generation of the *Labor & GDPPI*, the CPI from 1800 to 2012 has been linked to the food price index covering the time before 1800. Average values of both indices from period 1830 till 1838 were equalized and used to chain-link the two indices. These years were used because the price levels were relatively stable for most products in these years, as opposed to the prices in the first decades of the 19th century. The one resulting index from at least 1530 till 2012 was hereinafter only referred to as “Food & CPI”. For the *Food & CPI*, 1 Gulden 1721-1745 would correspond to 6.26 Kronen 1913 and 9.65 Euro 2012.

Interpreting their actual meanings one could summarize that the *Food & CPI* is supposed to eliminate price developments in the economy from a consumers’ perspective, while the *Labor & GDPPI* rather approaches the perspective of decision-makers and engineers to trace price developments in the entire economy (after 1830) and of local labor prices (before 1830). As stated above, the *Labor & GDPPI* is seen as the more adequate tool to predict and reconstruct price developments in hydraulic engineering over time. However, for comparisons of the actual value of amounts of money from different centuries both indices should only be understood as two out of many methods, each having a particular informative value. Various such value-of-money indicators were finally derived in chapter 4.4.

Instead of linking the *labor price index* with the *GDPPI* and the *food price index* with the *CPI*, the average *labor price index* and the average *food price index* can equally be followed till today. Furthermore, the index for each single food product group could be looked at separately, observing price trends only based on the *cereal price index*, the *beef price index* etc. which all tell their very own history. In order to obtain an idea of the overall trends which are indicated by these different price indices, the figure 4-3 shows trends from 1550 to 1913. For this figure, average values from the reference period 1721-1745 were normalized to 100 for all price indices. Over many centuries before around 1850 the long-term trends are apparently rather similar for different indices: In 1600 the indicated price levels are already higher than one half of those from 1721-1745. In 1850 the indicated price levels are still only 2 to 2.5 times above those from 1721-1745. Each index shows characteristic fluctuations over shorter time intervals. Prices for food products change rapidly from year to year, while wages develop more continuously over longer periods. In the 17th and 18th century the increase of wages did not keep up with the increase of food prices, which means the "real" wages actually decreased. Only in the 19th century the indices really begin to diversify: following the *labor* or the *beef price index*, the price levels would be seven times above those from 1721-1745, while according to the *wine price index* they would only be two times above. Figure 4-4 adds the trends over the 20th century and here, the values from the reference year 1913 were normalized to 100 for all indices. Compared to the price levels in 1913, there is a strong diversification in the 20th century. While the indicated price level in 2012 is up to 400 times higher than in 1913 based on the *labor price index*, the *GDPPI* only indicates an increase of prices till 2012, by the factor 20.

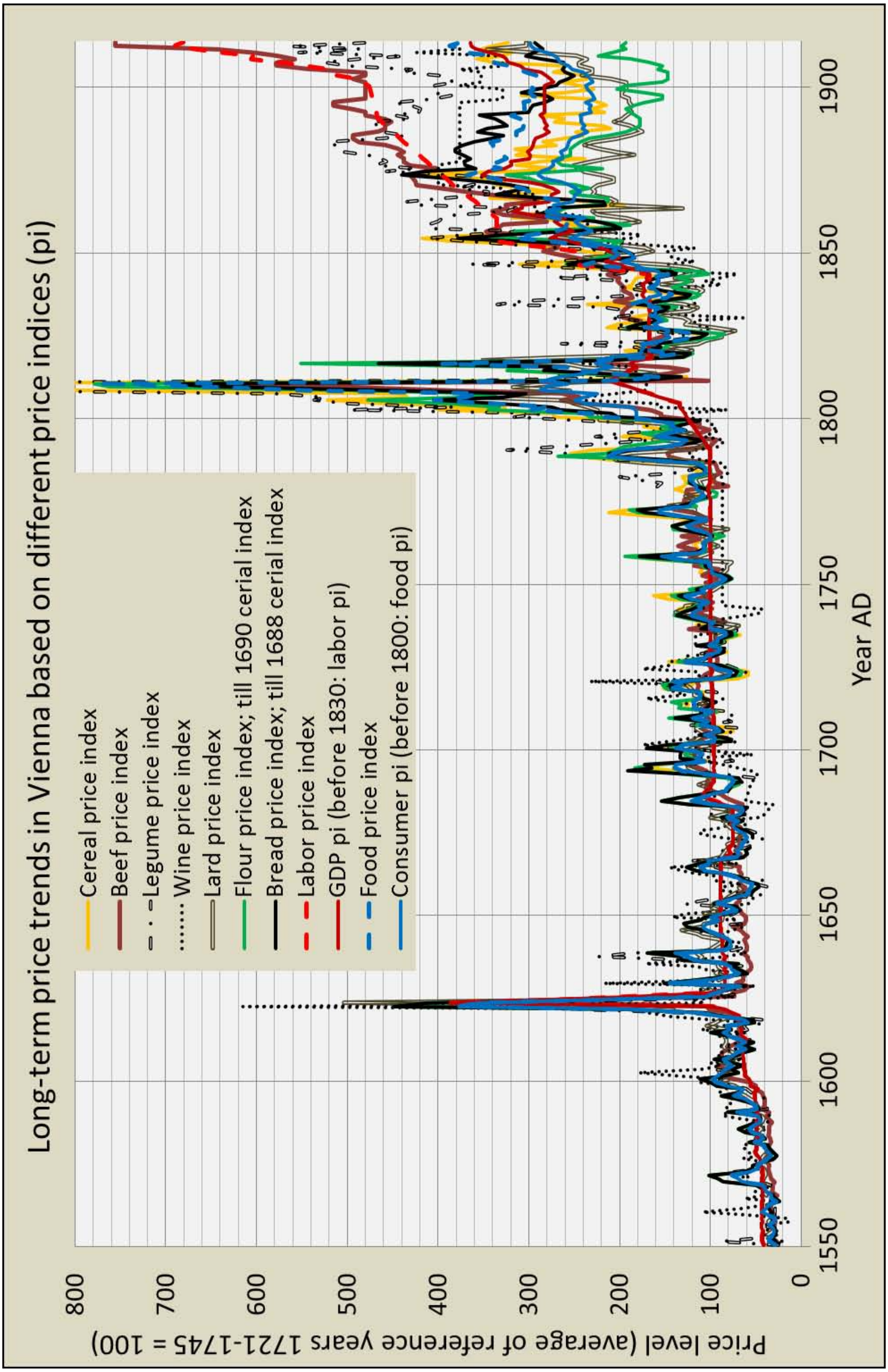

Figure 4-3: Historical price trends in Vienna 1550-1913 according to different indices relative to the average price levels 1721-1745 which were normalized to a value of 100.

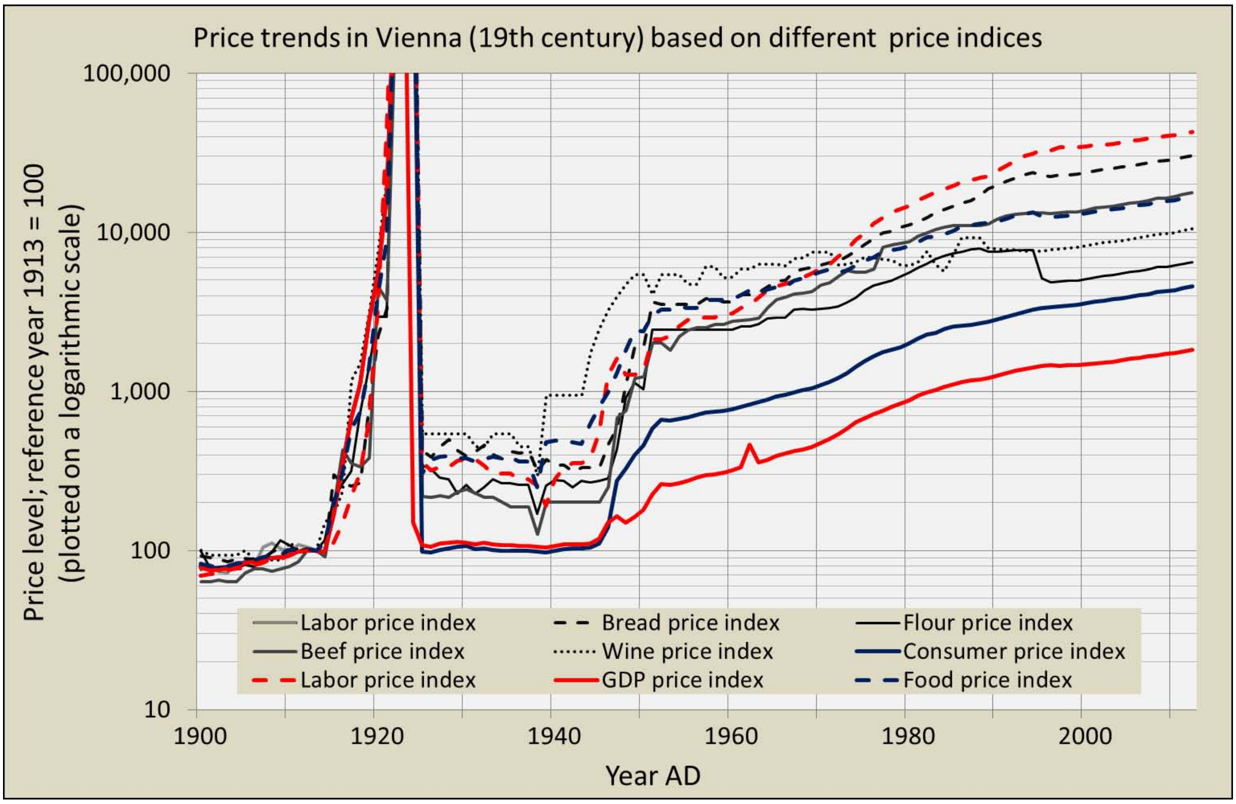

Figure 4-4: Historical price trends in Vienna from 1900 to 2012 plotted on a logarithmic scale according to different price indices compared to the price level in 1913.

Table 4-2: Mismatch / accuracy of different price indices for three reference times (1721-1745, 1913, 2012); the values indicate the deviation of the indicated price level relative to the *Labor & GDPPI* (which was set to 100 % all over the time).

Average mismatch of different indices in % of the Labor & GDPPI (Reference years: 1721 - 1745)					
Time period	Food	Food & CPI	Labor	Cereal	Beef
1548 - 1558	-	72	-	68	68
1721 - 1745	-	100	-	100	100
1830 - 1838	96	96	99	99	114
1870 - 1875	105	84	120	102	128
1913	61	82	187	117	257
1972 - 1987	1,000	187	3,158	-	2,015
2012	986	205	4,379	-	2,010

Average mismatch of different indices in % of the Labor & GDPPI (Reference year: 1913)					
Time period	Food	Food & CPI	Labor	Cereal	Beef
1548 - 1558	65	88	54	76	360
1721 - 1745	121	122	54	113	48
1830 - 1838	98	117	53	111	55
1870 - 1875	107	103	64	115	62
1913	100	100	100	100	100
1972 - 1987	948	228	1,690	-	973
2012	924	251	2,344	-	970

Average mismatch of different indices in % of the Labor & GDPPI (Reference year: 2012)					
Time period	Food	Food & CPI	Labor	Cereal	Beef
1548 - 1558	-	35	2	-	-
1721 - 1745	19	49	2	7	5
1830 - 1838	16	47	2	7	6
1870 - 1875	18	41	3	9	6
1913	14.2	39.8	4.3	6.0	10.3
1972 - 1987	119	91	72	78	100
2012	100	100	100	100	100

Good accuracy	80 - 125 %
Acceptable accuracy	50 - 80 % or 125 till 200 %
Severe mismatch	10 - 50 % or 200 - 1000 %
Extreme mismatch	< 10 % or > 1000 %

The diversification in the late 19th and even more in the 20th century are interpreted as consequence of the industrialization in the 19th century, and further modernization of the economy in the late 20th century. The changes lead to an increase of the productivity and the value of labor in the economy due to technological progress, accompanied by a higher per capita income and a relative increase of the prices of basic consumer goods compared to price trends in the entire economy. The economy has become much more complex and diverse, which influences the prices for many products and services relevant for the *CPI* and *GDPPI*.

The selection of the reference period fundamentally changes the perspective on the price development indicated by different indices. For illustrating this statement, in table 4-2 the indices obtained for the reference years 1721-1745, 1913 and 2012 based on the *Labor & GDPPI* were for selected years (1548-1558, 1721-1745, 1830-1838, 1870-1875, 1913, 1972-1987 and 2012) compared with the values obtained from five other price indices: the *Food & CPI*, the *food* and the *labor price index*, the *beef* and the *cereal price index*. For example, the *food price index*, referring to the price levels 1721-1745, on average indicates a value for the years 1830 to 1838, which is 96 % compared to the value indicated by the *Labor & GDPPI*. This value has been considered as *accuracy* or *mismatch* for the food price index with the *Labor & GDPPI*. The accuracy, with 98 %, is even better if the reference year 1913 is used while there is a huge mismatch – with only 16 % – if the indices refer to the year 2012. Accuracies of more than one half (50 %) and less than double (200 %) were considered as “acceptable accuracy” and accuracies between 80 and 125 % were described as “good accuracy”. Mismatches of more than an order of magnitude (< 10 or > 1,000 %) were considered as “extreme mismatch”, and values between the “extreme mismatch” and “acceptable accuracy” were considered as “severe mismatch”. As demonstrated in table 4-2, referring to the years 1913 and 1721-1745, there would at least be an “acceptable accuracy” of most indices in the selected periods before 1913 and at least a “severe mismatch” afterwards. Thus, both the reference to the period 1721-1745 and to the year 1913 leads to rather non-ambiguous interpretations of historical prices from around 1540 to 1913, the time period which is most interesting for the present research: In this time, for most of the indices, the overall price levels which are indicated will not exceed or go below those, which are indicated using the *Labor & GDPPI*, by the factor 2. In contrast, for modern prices referring to the year 1913 the price trend is amplified by factor 23 (!) looking at the *labor price index* instead of the *Labor & GDPPI*. Vice versa, the normalization of historical prices to price levels in 2012 is highly ambiguous for the entire time period before 1913, but leads to accurate results at least for prices from the last 50 years: For example at least an "acceptable accuracy" can be obtained for all indices for the interpretation of values of money in the time period 1972-1987 in € 2012.

The present chapter 4.3 approaches answers to the first of the three questions from chapter 4.2.1: If a price index says that a price level in year B is 200 % of that in year A, then a price of for example, 1 fl. from year B is only considered half as high compared to 1 fl. from year A. Vice versa a hydraulic structure (e.g. one meter embankment of a certain type) which costs 1 fl. in year A would cost 2 fl. in year B. The *Labor & GDPPI* is seen as the most adequate deflator to make such predictions / reconstructions for hydraulic engineering measures in Vienna. Regardless of likely price developments for hydraulic engineering prices which were looked at mostly over shorter timer intervals (rather years or decades than centuries), the actual interpretation of the value of historical money amounts from different centuries is a different story which is addressed in the next chapter. Furthermore, referring to the third question from chapter 4.2.1, the accuracy and mismatch of the price trends indicated by other indices compared to the *Labor & GDPPI* were discussed in this chapter. One needs to be aware that this accuracy and mismatch between different methods is particularly important for the interpretation of the "value" of historical money amounts rather than for the prediction of price trends over short time intervals, for which the *Labor & GDPPI* has been considered as the most adequate of the available tools. Certainly, there is not one indicator which provides an absolute measure for the comparisons of the actual value of historical money amounts.

4.4 Framework of historical values-of-money in Vienna and its application on the database

This chapter describes the selection and transformation of available price data in a way that 100 *nominal currency units* for each single year can be expressed by a framework of money equivalents. Such a framework of methods approaching an answer to the second question from chapter 4.2.1 is required for the long-term comparison of the relative value of historical money amounts from different time periods. For this purpose, three types of money equivalents have been defined:

> "Standardized money equivalents" are money amounts related to price levels of a certain reference year or period (e.g. K 1913) corresponding to a nominal money amount in a certain year and deflated by clearly defined price indices.

> "Labor equivalents" are days of labor of a certain type (e.g. the labor of an unskilled mason) one could pay in Vienna for a money amount in a certain year.

> "Food equivalents" are amounts of a particular food product (e.g. kg bread) one could buy in Vienna for a money amount in a certain year.

The *standardized money equivalents* were derived from the *Labor & GDPPI* and the *Food & CPI* (chapter 4.3). For both indices the reference points in time 2012, 1913 and 1721-1745 were used. For both indices amounts of *Gulden (fl.) 1721-1745*, *Kronen (K) 1913* and *Euro (€) 2012* were calculated which would correspond to 100 NCU in each single year (for NCU compare figure 4-1). In the reference year 1913, 100 *K 1913* (deflated money) would correspond to 100 K (nominal money). For example, in the year 1870, fl. ÖW is the NCU: 1 fl. ÖW equals 2 K and the GDPPI or CPI project a general price level of 78 or 86 %, respectively, compared to 1913. That means prices for the same good or service in 1913 would be 1.16 or 1.28 times higher than in 1870. Thus, 100 fl. ÖW in 1870 correspond to 256 K 1913 based on the *Labor & GDPPI* (1.28 * 2 K 1913 per fl. ÖW * 100 fl. ÖW) and 233 K 1913 based on the *Food & CPI* (1.16 * 2 K 1913 per fl. ÖW * 100 fl. ÖW). In this way for each year six *standardized money equivalents* were calculated: based both on the *Labor & GDPPI* and the *Food & CPI* for three reference periods. The resulting pattern over time is shown in figure 4-5. The ratios between the two indices change over time, while the ratios between the reference years for the same index are constant (see chapter 4.3).

The *labor equivalents* were calculated both based on the series of unskilled and skilled mason wages, described in chapter 4.1.4. For each year the days of labor corresponding to 100 NCU were calculated based on the wage lists. For example, in 1870 100 fl. ÖW would correspond exactly to 100 days of "unqualified labor". In the same way, *food equivalents* were calculated using four single food products (chapter 4.1.4) which qualified as indicators by being both common goods and well-documented complete over the entire time period: Thus, 100 NCU were expressed for each year in *liters of oat* (only till 1913), representing the most complete cereal price list, *kilograms of bread* (only since 1690), *kilograms or beef* and *liters of wine*. In 1870 one could buy 166 kg of beef in Vienna for 100 fl. ÖW (the NCU at this time). The food and labor equivalents of 100 NCU over time are depicted in figure 4-6. In both figures (4-5 & 4-6) one has to consider that the NCUs change in 1858 (fl. → fl. ÖW) and in 1892 (fl. ÖW → K). Furthermore, all money equivalents were for each year expressed relative to 1 fl. 1721-1745 deflated by the *Labor & GDPPI*. This applies to the corresponding number of fl. 1721-1745 based on the *Food & CPI*, and on the four food (beef, oat, wine, bread) and two labor equivalents (qualified, unqualified). The result from 1550 to 1910 is illustrated in figure 4-7. A short study on the characteristics of these relationships is attached in appendix II using 10-year average values to illustrate the changing ratios between different value-of-money indicators.

For eight selected years (1548, 1600, 1704, 1787, 1830, 1875, 1913 and 2012) the value of money is given in table 4-3 expressed with all 12 money equivalents, which are now available. For example, 100 fl. (as NCU) in 1600 corresponded to c. 1,044 kg beef, 600 days unqualified labor or either 175 or 103 fl. related to the reference period 1721-1745 for the standardization either with the *Labor & GDPPI* or with the *Food & CPI*. In 1787, 100 fl. (as NCU) corresponded to only c. 574 kg beef, 400 days unqualified labor and 469 or 368 fl. 1721-1745.

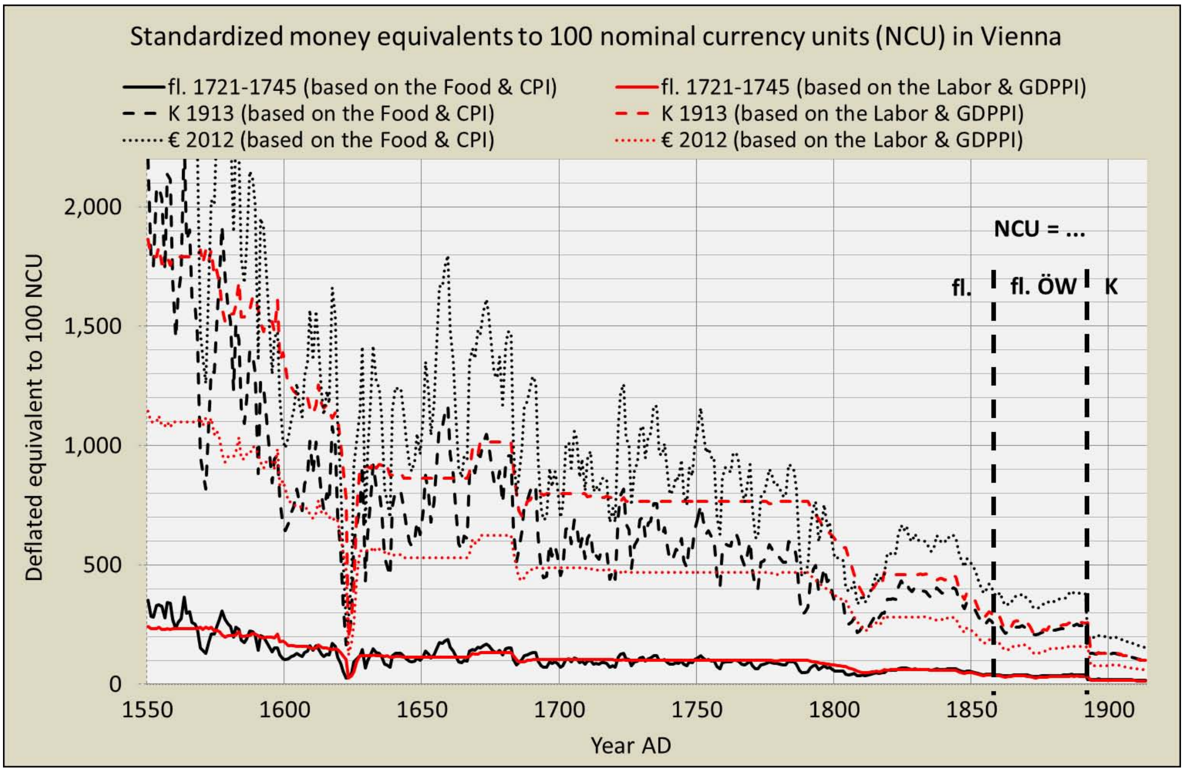

Figure 4-5: Standardized money equivalents to 100 nominal currency units based on yearly data for the two deflation methods, *Labor & GDPPI* and *Food &* CPI, and three reference time periods (1721-1745, 1913 and 2012) as described in this chapter.

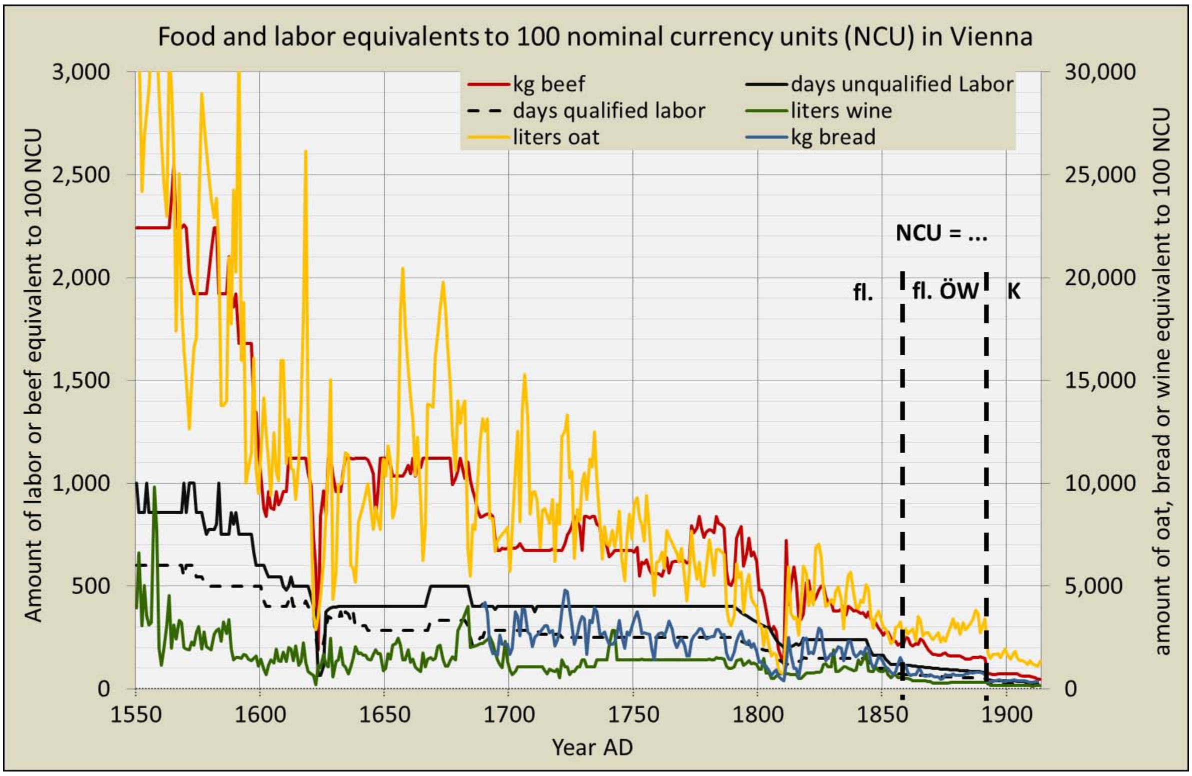

Figure 4-6: Food and labor equivalents to 100 nominal currency units based on yearly data; the value of 100 NCU (nominal currency units in each year) is plotted on the y-axis for six different goods and services.

Table 4-3: Historical values of money from selected years standardized with different methods. Equivalents to 100 NCU (Nominal currency units) and nominal transfer rate to 1 fl.

Value-of-money indicators for Vienna		Selected years							
Method	Equivalent	1548	1600	1704	1787	1830	1875	1913	2012
Labor & GDPPI	fl. 1721-45 / 100 NCU	239	175	104	100	60	29	13	21
Food & CPI	fl. 1721-45 / 100 NCU	405	103	94	59	63	34	16	10
Labor & GDPPI	K 1913 / 100 NCU	1,827	1,338	798	765	457	223	100	163
Food & CPI	K 1913 / 100 NCU	2,539	643	587	368	393	215	100	65
Labor & GDPPI	€ 2012 / 100 NCU	1,121	821	490	469	281	137	61	100
Food & CPI	€ 2012 / 100 NCU	3,912	990	905	567	605	331	154	100
Unqualified labor	days / 100 NCU	923	600	400	400	240	95	28	2
Qualified labor	days / 100 NCU	600	500	286	250	149	59	17	1
Beef price	kg / 100 NCU	2,240	1,044	707	574	377	175	47	8
Bread price	kg / 100 NCU	-	-	2,575	1,750	1,660	690	323	46
Oat price	liter /100 NCU	31,966	11,376	8,104	4,037	4,113	2,317	1,321	-
Wine price	liter / 100 NCU	4,936	1,450	1,061	1,115	1,909	294	156	44
Nominal currency unit (= NCU)		fl.	fl.	fl.	fl.	fl. (CM)	fl. ÖW	K	€
Nominal transfer rate	NCU per 1 fl.	1	1	1	1	1	1.05	2.1	0.071

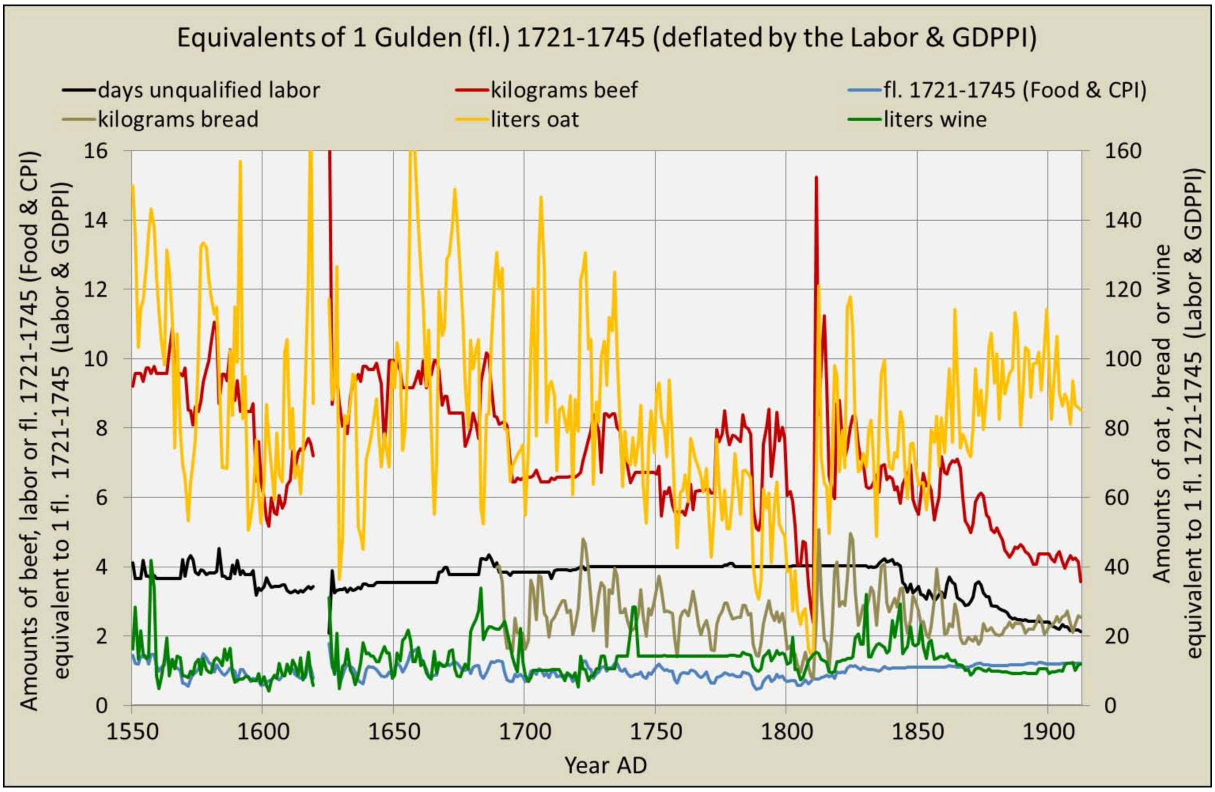

Figure 4-7: Various money equivalents over time relative to 1 Gulden (fl.) 1721-1745 deflated with the *Labor & GDPPI*.

From figure 4-5 it may be concluded that 100 fl. (nominal money) from around 1650 to around 1800 are almost equal to 100 fl. 1721-1745 deflated by the *Labor & GDPPI*. This is due to the rather stable wages in this time. In 1550 around 200 fl. 1721-1745 and in 1850 c. 50 fl. 1721-1745 correspond to 100 nominal fl. The equivalents based on the *Food & CPI* shows similar trends but stronger yearly fluctuations. Looking more closely at figure 4-7, the data documented at present indicates comparably stable ratios of different money equivalents compared to 1 fl. 1721-1745 deflated by the *Labor & GDPPI*. Till around 1830, 1 fl. 1721-1745 would correspond to around 4 days unqualified labor and 6 - 10 kg beef and till 1913 moves down to around 4 kg beef or 2 days unqualified labor. Oat equivalents mostly move in a range between 60 and 120 liter per fl. 1721-1745 (with an exception around 1800) and show major changes on a yearly level, which raises the uncertainty strongly for this method.

Based on the stable nominal exchange rates between the reference currencies the money equivalents per 100 NCU can as well be expressed as money equivalents per 100 fl. for the entire time period till 2012. Based on the exchange rates given in chapter 4.1, 100 Gulden would – nominally – correspond to 97.22 Schilling and for 7.07 € after 2002 (figure 4-1). The use of equivalents to 100 fl. (instead of 100 NCU) for the entire time period enhances the application of the money equivalents to the DB, as equivalents may be assigned to DB entries, regardless of the introduction of new currencies.

After all, the scheme of historical values of money in Vienna has been applied to the database of historical river engineering measures in Vienna. The construction period of each database entry has been assigned to the respective values of money (table 4-4). The yearly equivalents to the nominal unit of 100 fl. have been used in such a way that a measure which has been implemented between year "A" and year "B", is described for each method by *a minimum* (*MIN*), a *maximum* (*MAX*) and a *median* (*MDN*) value of money in the time frame between "A" minus one year and "B" plus one year. For a measure implemented in the year 1567 the years 1566 and 1568 are taken into account. The construction time of the measures was used and the program was automatically looking for the median, minimum and maximum in each construction period. This process was repeated for each database entry and for each of the twelve indicators leading to a scheme of 3 x 12 "values of money" for each DB entry. For the time period 1870 to 1875, the *beef equivalents* between 1869 and 1876 were taken into account and vary between 172 and 188 kg per 100 fl. while the median would be per 174 kg per 100 fl. Based on the *Labor & GDPPI* 100 fl. would correspond to 28 - 36 fl. 1721-1745 (median 31 fl. 1721-1745).

Table 4-4: Application of the twelve defined value-of-money indicators on the construction periods of river engineering measures in the database (three examples): Equivalents to 100 nominal currency units (NCU); median of the yearly data in the period = MDN.

Money equivalents to 100 Gulden (fl.) nominal money				
Construction period		1548 - 1558	1870 - 1875	1972 - 1987
Nominal currency units (NCU)	NCU = …	fl.	fl.ÖW	S
	NCU / fl.	1.00	1.05	0.97
"Gulden 1721-1745" deflated by the Labor & GDPPI / 100 fl.	MDN	234	31	3.20
	MIN	229	28	2.31
	MAX	244	36	5.46
"Gulden 1721-1745" deflated by the Food & CPI / 100 fl.	MDN	333	36	1.72
	MIN	271	35	1.25
	MAX	405	40	2.93
"Kronen 1913" deflated by the Labor & GDPPI / 100 fl.	MDN	1,792	237	24.50
	MIN	1,754	218	17.71
	MAX	1,865	279	41.82
"Kronen 1913" deflated by the Food & CPI / 100 fl.	MDN	2,084	228	10.77
	MIN	1,694	216	7.82
	MAX	2,539	252	18.35
"Euro 2012" deflated by the Labor & GDPPI / 100 fl.	MDN	1,099	145	15.03
	MIN	1,076	134	10.86
	MAX	1,144	171	25.66
"Euro 2012" deflated by the Food & CPI / 100 fl.	MDN	3,210	351	16.59
	MIN	2,610	333	12.05
	MAX	3,912	388	28.27
Days of unqualified labor / 100 fl.	MDN	857	102	0.36
	MIN	857	99	0.23
	MAX	1,000	106	0.81
Days of qualified labor / 100 fl.	MDN	600	63	0.30
	MIN	600	61	0.20
	MAX	600	66	0.69
Kilograms of beef / 100 fl.	MDN	2,240	174	1.13
	MIN	2,240	172	0.89
	MAX	2,240	188	2.03
Kilograms of bread / 100 fl.	MDN	-	639	9.01
	MIN	-	500	5.79
	MAX	-	724	15.29
Liters of oat / 100 fl.	MDN	31,358	2,648	-
	MIN	24,169	2,379	-
	MAX	36,512	2,864	-
Liters of wine / 100 fl.	MDN	3,683	309	4.88
	MIN	1,990	309	3.52
	MAX	9,803	375	5.77

For the *Labor & GDPPI* itself, the three currencies fl. 1721-1745, K 1913 and € 2012 were each defined as reference currency for the time period they may represent best: all DB entries before the industrialization (1830) were primarily related to cost estimates in fl. 1721-1745. From 1830 till 1925, during the industrialization, K 1913 was preferred as primary reference, and from 1925 till today € 2012 was used as reference currency. Analogue to the NCU (nominal currency units) these currencies were referred to as "deflated currency units" (*DCU*) for the respective years because they consider a deflation (= standardization) for overall price developments in the economy. As the exchange rates between the three years are constant, the cost estimates can easily be transferred from one DCU to the other for each single year. However, as described above, the Euro will be the least adequate tool to actually interpret a value from the 16th century, but the price trend indicated between two years is the same for all three DCUs. The same reference currencies deflated by the *Food & CPI* were considered as *alternative deflated currency units (ADCU)*. Thus, the ratio *fl. 1721-1745 (Food & CPI) / 1 fl. 1721-1745 (Labor & GDPPI)* for each year can be rewritten as *ADCU / 1 DCU*. For the construction period 1870-1875 (the years between 1869 and 1876) the ratio of the amount of beef equivalent to 1 fl. 1721-1745 (*Labor & GDPPI*) varies between 4.98 and 6.13 kg (median 5.68 kg). Here one needs to consider, that cost estimates between 1830 and 1925 are primarily using K 1913 as reference currency and 1 K 1913 following the *Labor & GDPPI* always equals 0.1306 fl. 1721-1745.

In table 4-5, yearly money equivalents are related directly to fl. 1721-1745, based on the *Labor & GDPPI*. The median, minimum and maximum ratios per fl. 1721-1745 (*Labor & GDPPI*) were specified for the food and labor equivalents and in fl. 1721-1745 based on the *Food & CPI*. The difference between the two tables results from the reference either to *nominal* (table 4-4) or *deflated currency units* (table 4-5). For example, from 1548 to 1558 100 fl. (NCU) corresponded to c. 857 days of unskilled labor of a mason. 100 fl. in this time would, however, correspond to 234 fl. 1721-1745 (DCU) according to the *Labor & GDPPI* (median value). Thus, the ratio between the two equivalents is 3.72 (875 / 234) days labor per fl. 1721-1745. Or in other words for the time period 1548 to 1558, the money amount corresponding to 100 fl. 1721-1745 deflated by the *Labor & GDPPI* is equivalent to 372 days unqualified labor.

Table 4-5: Application of the framework of historical values of money on the construction periods of river engineering measures in the database (three examples): Ratios of various equivalents to 1 fl. 1721-1745.

Equivalents to deflated currency units (DCU) based on the Labor & GDPPI				
Construction period		**1548 - 1558**	**1870 - 1875**	**1972 - 1987**
Deflated currency unit (DCU) standardized with the Labor & GDPPI		Gulden (fl.) 1721-1745	Kronen (K) 1913	Euro (€) 2012
DCU per 100 fl. (nominal)	MDN	234	237	15.03
	MIN	229	218	10.86
	MAX	244	279	25.66
Exchange rates based on the Labor & GDPPI	fl. 1721-1745	1.0000	0.1306	0.2130
	K 1913	7.6547	1.0000	1.6302
	€ 2012	4.6957	0.6134	1.0000
Alternative deflated currency unit (ADCU) based on the Food & CPI		Gulden (fl.) 1721-1745	Kronen (K) 1913	Euro (€) 2012
ADCU per 1 DCU	MDN	1.41	1.17	0.54
	MIN	1.16	1.10	0.52
	MAX	1.70	1.21	0.55
Exchange rates based on the Food & CPI	fl. 1721-1745	1.0000	0.1597	0.1037
	K 1913	6.2630	1.0000	0.6492
	€ 2012	9.6476	1.5404	1.0000
Days of unqualified labor / 1 fl. 1721-1745 (Labor & GDPPI)	MDN	3.72	3.20	0.11
	MIN	3.66	2.91	0.10
	MAX	4.17	3.58	0.15
Days of qualified labor / 1 fl. 1721-1745 (Labor & GDPPI)	MDN	2.56	1.98	0.09
	MIN	2.46	1.80	0.09
	MAX	2.62	2.21	0.13
Kilograms of beef / 1 fl. 1721-1745 (Labor & GDPPI)	MDN	9.57	5.68	0.36
	MIN	9.20	4.98	0.34
	MAX	9.78	6.13	0.44
Kilograms of bread / 1 fl. 1721-1745 (Labor & GDPPI)	MDN	-	19.28	2.81
	MIN	-	17.59	2.50
	MAX	-	23.67	2.99
Liters of oat / 1 fl. 1721-1745 (Labor & GDPPI)	MDN	134	82	-
	MIN	103	72	-
	MAX	150	97	-
Liters of wine / 1 fl. 1721-1745 (Labor & GDPPI)	MDN	15.12	10.19	1.49
	MIN	8.50	8.81	0.80
	MAX	41.88	10.86	2.26

Relating all money equivalents directly to the *Labor & GDPPI* makes sense, because the cost estimates later on will mostly (if not direct expenses for a DB entry were documented in literature) be expressed based on the *Labor & GDPPI*. If these estimates would be first transferred into nominal money and then to the different money equivalents the uncertainty might strongly increase, in particular for longer construction periods, because fluctuations of the *Labor & GDPPI* and the respective money equivalent – if they are parallel over time – would be integrated twice into the calculation. Thus, the food and labor equivalents were expressed relatively as the amount of labor in days or the amount of the food product in kilogram or liters per fl. 1721-1745 (deflated by the *Labor & GDPPI*).

Appendix II uses 10-year average values to illustrate changing relationships between different value-of-money indicators. The yearly money equivalents based on the twelve indicators in 100 NCU and their 10-year average are as well part of *file A.2* on the DVD. Their application on all construction periods of entries in the river engineering database – both referring to *nominal* and to *deflated currency units* – is shown in *file A.3*. These files are shortly explained in appendix V.

5 PART B: COSTS AND PRICES OF HISTORICAL RIVER ENGINEERING MEASURES

5.1 Protocol of historical expenses and prices per extent

A selection of local historical documents has been examined for information either about expenses on realized river engineering projects or single measures in Vienna ("costs") or for prices per length, surface area or volume for different construction types ("prices") from different time periods, which were planned or realized in the close surrounding of Vienna. A selection of documents emerging during the previous *ENVIEDAN* project was prepared in advance by *S. Hohensinner* – this present research in mind. Table 5-1 on the following page lists the most important sources and pages and outlines the type of information obtained from them. A protocol of the documentation process was set up, allowing for an unfiltered inclusion of different kinds of available data. At the end of this research this collection is neither finished – as more information is hidden in archives and further documents – nor could all of the entries be used for the purposes of the thesis. This chapter can only draw a sketch of the procedure because the base data and the conducted steps are very comprehensive. A copied version of the entire protocol has been attached on the DVD (in the *file B.1*) and is explained in appendix V.

The overall structure of the protocol is demonstrated in table 5-2 with one exemplary entry based on CAMESINA (1886, p. CXXXIII): It describes a ditch to lead Danube water around the entire town ("*Graben mit dem Wasser der Donau um die ganze Stadt durchzubringen*") which was planned in 1597 but apparently not realized (HOHENSINNER et al., 2012).

Table 5-1: Selected historical sources with relevant information on (total) costs and prices (per extent) for river engineering measures near Vienna.

SOURCE (PAGE / ARCHIVE-SIGNATURE): TYPE OF INFORMATION
SONNLECHNER & HOHENSINNER, 2011 (WStLA (Wiener Stadt- u. Landesarchiv), Bürgerspital, Spitalmeisterrechnungen, 1548-1572; OeStA, FHKA (Finanz- u. Hofkammerarchiv), W 61/c/7/a (823), N 27/b/1 (460), W 61/c/87/a (875), W 61/c/87/b (876), W 61/c/3/a&b): Communication about the implementation of and estimated expenses on various early regulation measures near Nussdorf in the 16th century
SCHLAGER, 1835 (pp. 159-199): Some early expenses on regulation and excavation measures from the town bills in the 15th and 16th century mainly concerning water supply for the town moat
PASETTI et al., 1850 (pp. 47-50, 110-119): Overview of the regulation history of Vienna in the first half of the 19th century + the expenses on selected structures; early suggestions for a *Danube Regulation* including detailed cost estimates with prices for different construction types
PASETTI, 1862: Expenses on the regulation of different Danube sections in the Danube monarchy (Upper & Lower Austria, Hungary, Serbia etc.) prior to 1862
BAUMGARTNER, 1862 (pp. 155-158): Suggestions for a *Great Danube Regulation* including cost estimates with prices for different construction types
DRC, 1868 (pp. 197-213): Official cost estimate for the *Great Danube Regulation* in Vienna from 1868. Common prices for many construction types; expected extent of expenses of the project
ATZINGER & GRAVE, 1874: A suggestion to make the *Wien River* navigable including a description of the regulation history of the Wien River and few hints about the costs for regulation projects
WEX, 1876a (pp. 120-122): Overall expenses and extents of different categories of measures (e.g. excavations, regulation measures) in the GDR
CAMESINA, 1886 (p. CXXXIII): Hints concerning the regulation of creeks / ditches in the 16th century
DRC, 1898 (in particular: pp. 79-84): A comprehensive overview of the operation of the *Danube Regulation Commission* in the late 19th century including comprehensive cost estimates and overviews from 1868 and 1881
SCHREY, 1899: Overview of expenses on hydraulic engineering at the Danube and other rivers in different parts of Austria from the 19th century and from the Danube regulations in Vienna
KORTZ, 1905 (pp. 193-199 & pp. 311-343): Expenses on the sewage system 1830-1903, the Wien River Regulation 1891-1915, the ports *Freudenau* and *Kuchelau* (1895-1903) and several other projects
THIEL, 1904, 1906: Comprehensive history of Danube regulations in and around Vienna and many expenses on constructions and projects from the 16th, 17th, 18th and 19th century
SLEZAK, 1977, 1978, 1980: Historical studies on actors, important steps and few expenses on projects from the 17th and 18th century
BUCHMANN et al., 1984: Costs, among others for the construction of the weir and lock at Nussdorf in the 1890s and their repairing in the 1960s
GANTNER, 1991: Regulation of the *Alserbach* in the 19th century including the costs for its drainage and piping in the late 19th and early 20th century.
HOHENSINNER et al., 2012 (= the DB): GIS-Database of historical river engineering measures in Vienna providing estimates about extents, location and construction types of documented measures

The grey-shaded area in the following table 5.2 provides basic information about the exemplary protocol entry. In the database, the entry has the name *Ditch_9* and it refers to the year *1597*. There is no related database entry in the historical river engineering database (HOHENSINNER et al., 2012) which is herinafter only referred to as "DB"; hence, the fields "Shape_DB" (usually stating either *Linear* or *Areal*) and "Link_DB" (for the Object-ID) are empty. The "group" is referred to as *Planned_VIE* indicating that the measure was planned (and not realized) on the city area of Vienna (and not outside). The "water body name" is referred to as *Stadtgraben* (= town moat) and the "location" as *Vienna*. A description in German and English and the reference for the entry follows. The white area makes specifications on the type of the measure: The categories "construction type", "construction material", "chronology" and "water body type" reappear from chapter 3. This entry features a *ditch*, material was *extracted*, the project would have been *primary* and the water body type has been referred to as *Ditch / Creek*. Another field for "further remarks" on the measure type was introduced. *1 klafter (kl)* is a length unit equal to approximately 1.8 meter in the 16th century (see below). Thus, one cubic klafter equals a volume of around 5.8 cubic meters (m^3). The ditch was planned with a length of 794 *kl*, a width of 7.5 *kl*, and a depth of 2 *kl.,* corresponding to metric measures of 1,429 m x 14 m x 3.6 m. Subsequently, the extents of the measure could be specified exactly and respective prices per length in meter (m), per surface area in hectare (ha) and per volume in cubic meter (m^3) in *Gulden (fl.)* were calculated (see table 5-2). The yellow area features basic information on the costs of the project: The "unit price" documented is *1 fl. / cubic klafter (cb-kl)* for the transfer of material which implies a range for the price with a MIN of 0.75 and MAX of 1.25 *fl. / cb-kl*. By applying this unit price on the volume of the measure 11,910 *Gulden (fl.)* were projected in total on this measure. The "source for the cost" is the same source as above and the costs refer to a *single measure*, the *municipality of Vienna* might have been the "carrier of the cost" (this latter type of information has however not been systematically integrated for other protocol entries).

Table 5-2: Structure of a protocol entry (One example from 1597)

Project	Cost estimate for a new town moat	**Name of the entry**	Ditch_9
Shape DB	-	**Year(s)**	1597
Link DB	-	**Cost**	11,910
Group	Planned_VIE	**Currency**	Gulden
Water body name	Stadtgraben	**MIN**	8,930
Location	Vienna	**MAX**	14,890
Description (German)	Graben um Wasser aus der Donau in den Stadtgraben zu leiten	**Unit Price**	1
Description English	Ditch to supply water from the Danube for the town moat	**Curr. / Size**	fl. /cb.- kl.
Reference	Camesina 1886, p. CXXXIII	**MIN**	0.75
C (= Cost info?)	-	**MAX**	1.25
P (= Price info?)	x	**Source cost**	Camesina 1886, p. CXXXIII
Type of Measure	Ditch	**Carrier of costs**	Vienna
Building Material	Extracted	**Cost type**	Single measure
Chronology	Primary	**Remarks Cost**	-
Stream type	Ditch / Creek	**Source Size**	Camesina 1886, p. CXXXIII
Remarks Building Type / Method	-	**Extent (Remarks)**	-

(Mean) Length	794	**(Mean) Volume**	11,900	**(Mean) Surface area**	5,955
Unit	kl.	**Unit**	cb.-kl.	**Unit**	sq.-kl.
MIN	794	**MIN**	11,900	**MIN**	5,955
MAX	794	**MAX**	11,900	**MAX**	5,955
Factor	1.8	**Factor**	5.83	**Factor**	3.2400
Length / m	1,429	**Volume / cbm**	69,401	**Surface Area / sqm**	19294
MIN	1,429	**MIN**	69,401	**MIN**	19,294
MAX	1,429	**MAX**	69,401	**MAX**	19,294
Price / m	8.33	**Price / m³**	0.17	**Price / ha**	6,173
Curr.	fl./ m	**Curr.**	fl. / cbm	**Curr.**	fl. / ha
MIN	6.2	**MIN**	0.13	**MIN**	4,628
MAX	10.4	**MAX**	0.21	**MAX**	7,717
Cross section	15	**Width**	7.5	**Heigth**	2
Unit	sq-kl.	**Unit**	kl.	**Unit**	kl.
Factor	3.24	**Factor**	1.8	**Factor**	1.8
Area / sqm	48.6	**Width / m**	13.5	**Height / m**	3.6

In the same fashion several hundred hints from literature were processed. Usually, there was less information than in the given example, for example only a price per length or only the total extent of expenses on an entire project. One *Wiener Klafter (kl. or °)* à 6 *Wiener Fuß (ʻ)* was technically defined in 1871 as being equal to 1.896 m. This exchange rate can be supposed back till 1760 according to ROTTLEUTHNER (1985, pp. 25-26). From 1588, 1657 and 1673, 1.872 m / kl. are given as exchange rates and for 1547, 1.728 m / kl. (WELLISCH, 1898, p. 563; ROTTLEUTHNER, 1985 pp. 25-26). As most hints on costs and prices between around 1600 and 1830 refer to DB entries with already metric lengths and areas, and as there are two different exchange rates from the 16th century, an exchange rate of c. 1.8 m / kl. was assumed for this early period. Another length unit – 1 *Austrian mile (=* "Österreichische Meile"*)* – equals a length of c. 7,586 m. As the protocol has been developed over the entire process, there are many entries which are incomplete, e.g. when expected prices or costs were not available for entries, or when the documented expenses included significant external expenses which cannot be related to hydraulic engineering measures or projects in the DB. Under the title "C" entries were marked with an "x" when they contain useful cost information on a realized project or single measure in Vienna. Under the title "P", entries were marked with an "x", when they provide prices per meter, hectare or volume. Entries can be *parts of a measure*, *groups of measures*, *single measures*, *side information*, *administrational cost, price information*, or expenses on entire *projects* (possibly including external expenses beyond river engineering). They refer either to *realized* or *planned* projects, either to measures from Vienna ("VIE") or to measures lying outside of Vienna ("external" or "EXT"). Sources for costs and extents are listed extra in the protocol entry, mainly when they differ from the source for basic information about the entry. Many times, extents of DB entries could directly be used to transform cost information from literature into prices per meter or hectare. In accordance with the specifications in chapter 3.2 the same uncertainties (10 % or 50 %) on these extents were considered for such price calculations. Parallel to establishing a protocol of price information, the DB itself has been extended by cost information referring particularly to measures in the DB, or new entries were added to the DB for safely documented money amounts for specific years, time periods or projects. If hints in literature referred to more than one measure, they were distributed equally on their length or area in the DB – if no other specification was available. In few exceptional cases, when different construction types were involved – they were simply equally distributed on the number or measures. If a reasonable hint allowed for it, prior to the direct distribution in the DB, a weighting according to different properties was conducted: e.g. two-row structures were weighted double as much compared to one-row structure in the 16th century, or the material from the area of an excavations was assumed to be distributed with excavated material on the area of a related filling and the same money amount was applied to both parts, despite the different size of the areas. The three examples in table 5-3 refer to the already known DB entries from the tables 3-1 to 3-5 in chapter 3.2:

Table 5-3: Direct referencing of cost information from historical literature to selected measures in the DB

OBJECTID *	28	278	IFP_0
Costs	<Null>	1,320,000	7,000,000,000
Currency	<Null>	fl. ÖW	Schilling
Remarks Costs (German)	Bürgerschaft von 1548-1553 13,000 fl. ; Gemeinden zw. 1548-1558 = mindestens 20,000 Gulden	10,900,000 Gulden für Materialtransfer gesamt, aufgeteilt nach geschätzten Volumen und Preisen in Kostenvoranschlag	Entire Material transfer around 30 Mio m³
Reference Costs (German)	Thiel 1904, S. 131 + 133, Hochleitner 1860, S. 115	Wex 1876a, S. 120-122; DRC 1968, S. 197ff	http://de.wikipedia.org/wiki/Neue_Donau#cite_note-Flor-1: referring to: Eintrag „Neue Donau“ in: Raimund Hinkel, Kurt Landsmann: Floridsdorf von A-Z, Der 21 Bezirk in 1.000 Stichworten, Wien 1997, ISBN 3-85447-724-4
Carrier of Costs	Vienna, several municipalities & Viennese citizens	Donau-Regulierungs-Commission	Vienna ???

5.2 Relevant data in historical sources and literature

The price and cost protocol was sub-divided into eleven segments which were documented in eleven separate excel-sheets (*file B.1* on the DVD; see descriptions in appendix V).

The most comprehensive segment in this protocol was labelled "till 1850" in *file B.1* and features all integrated data before 1850. While the documentation for the second half of the 19th century offers several details and first-hand reports, price information before 1850 is less detailed and widely distributed on documents hidden in archives. The most valuable description is provided by THIEL (1904, 1906). PASETTI et al. (1850, pp. 47-50) contains selected expenses of measures from the first half of the 19th century. Some information for the early 18th century has been summarized by SLEZAK (1977, 1978 and 1980). The recent examinations by SONNLECHNER & HOHENSINNER (2011), which were herinafter referred to by the archive signatures as in table 5.1, provide price information for the late 16th century.

5.2.1 Excavation prices prior to 1850

There is limited information on costs and prices per hectare for "excavation measures" prior to 1850: From 1377 expenses of c. 84 *Pfund Wiener Pfennig* (= *tal.*) and from 1455, 800 tal. are evident based on the town bills of Vienna (N.N., 1855; THIEL, 1904) for the earliest known excavations in the Wiener Arm. A project for supplying the town moat with water from the Danube in 1472 did cost 2 tal. (SCHLAGER, 1835, p. 194). Extents on these measures in the DB are hardly reliable, however. Documented costs of 20 fl., 7 fl. and 24 fl. (CAMESINA, 1865, p. CLVIII & 1881, p. 96) from 1532, 1533 and 1568 refer to the "cleaning" of ditches (bed excavations in minor tributaries) and did match with three DB entries. Although only one of them (from 1533) can be considered as really reliable information, they all indicate prices between minimum 16 fl. / ha (in 1568) and maximum 84 fl. / ha (in 1533). For an actual hectare price for bed excavations in Danube branches, there are two references: The *Nussdorfer Graben* (in the upper part of the Wiener Arm) was "cleaned" for 811 fl. between 1580 and 1590 (THIEL, 1904, p. 138) on an area of c. 1.3 - 1.6 ha in the DB (→ 510 - 625 fl. / ha). Between 1567 and 1569, 4,000 Taler (c. 4,533 fl.) were agreed for the successful completion of bed excavations in the Wiener Arm with mechanically improved excavators (THIEL, 1904, p. 134). This sum can be distributed on two "sessions" of repeated excavations in the DB on an area of c. 1.9 - 5.7 ha (→ c. 400 - 1200 fl. per ha and session). In 1569, 300 fl. were spent on a cut-off near *Klosterneuburg* upstream of Vienna (THIEL, 1904, p. 135) which is documented with a mean area of 1,400 m² in the DB (→ c. 2,140 fl. / ha). The above mentioned ditch from 1597, with an estimated price of 4,600 - 7,700 fl. / ha implies that, in this time, a price for a channel and a ditch were on a similar level, indicating an excavation to a similar depth of both construction types. Prices for sewage drains were obviously far more expensive than ditches in the 16th century, due to the stone constructions which were required. From 1565, a section of a major sewage drain in Vienna with stone walls was planned with 3,300 fl. on an area of 890 m², indicating a price of c. 37,000 fl. / ha (CAMESINA, 1886, p.85).

Another hint is related to the years 1700 till 1714 and indicates a much higher (nominal) price of the cut-offs constructed along the Donaukanal in the 18th century: A new channel (1700-1703) at the entry of the Donaukanal covers around 1.1 - 1.4 ha following the DB and there is a contemporary estimate stating that the expenses had become as high as 400,000 fl. till 1714 as a consequence of regular excavations (1704-1712) which were necessary in these years, due to the continuing accumulation of sediments (SLEZAK, 1978, p. 28). As remarked by SLEZAK (1978, p. 28) the value appears rather overestimated, but explains the limited motivation to use such regulation approaches more widely in this time. In order to derive useful price categories in accordance with the DB, simple assumptions were made: As 400,000 fl. is rather a maximum estimate, the half of this value, 200,000 fl., was considered as minimum, and 300,000 fl. as mean value. Subsequent bed excavations were the reason for the unexpected extent of expenses – which did exceed the foreseen river engineering budget for these years (see below) – and as no other hint exists, half of the money amounts were assigned to the original channel and half for the subsequent excavations. For the former one, the material transfer was subdivided with a ratio of 1 : 1 on both the excavation of the channel and the filling of the material in the surrounding. Based on the mean estimate 75,000 fl. remain for both elements which leads to a price for a new channel of 36,200 - 66,500 fl. / ha and a fix cost estimate (mean: 75,000 fl.) distributed on the fillings around the channel in the DB. Assuming that bed excavations were necessary over eight years, they would have required efforts between 9,000 and 17,000 fl. per ha in each year.

There was no other available reference for the price per ha of major cut-offs in the 18th century. In 1831/32 in the *Donaukanal nearby Simmering* a cut-off was realized for 131,000 fl. CM (PASETTI et al., 1850, p. 50), given with a surface area of 20.5 ha in the DB (c. 6,400 fl. / ha); and another cut-off from 1837 in the *Danube near Fischamend* for 108,000 fl. CM is given with a documented length of 170 m and an estimated width (based on the reconstructions of LAGER & HOHENSINNER, 2012) of around 400 m. This would correspond to an area of c. 68,200 ha and a price of c. 15,800 fl. / ha for this cut-off. In the 1830s, new steam machines allowed excavations on much larger areas than before industrialization (THIEL, 1906, p. 72): In 1833, 10,000 fl. CM were spent on a first test, and 20,000 fl. CM can be assigned to a more comprehensive test from 1836 to 1838 during which 234,000 m³ (Price: 0.085 fl. / m³) loose material was excavated from an area of around 45 ha in the *Donaukanal*. Afterwards regular excavations were conducted on the same area – on average 27,300 m³ per year (WEX, 1871, p. 430) and usually every 3 to 4 years, leading to a mean price estimate of c. 52 *fl. / year & ha* and 181 *fl. per excavation & ha* at volume prices from the years 1836-1838. The DB entries referring to these regular excavations from 1839 till 1872 have been split up into separate entries for the addressed time intervals defined in chapter 3-2. The standardized hectare-price per excavation was later assigned to these measures, and respectively the standardized price per year was used to calculate overall cost estimates for these new entries.

5.2.2 Dike prices prior to 1850

There is limited price information on “dikes” before 1850: From 1473, there is uncertain information on a flood protection or military levee (SCHLAGER, 1835, p. 194; price estimate c.: 0.5 - 1.6 tal. / m). It was used as reference for different levees before 1600. More prices for dikes are only available when they were for the first time constructed at larger extents and between 1770 and 1832 six cases were integrated into the study: Three minor dike constructions are documented: in 1786, a flood dike from the *Floridsdorf municipality* (700 fl. CM on 291 m in the DB → 2.4 fl. / m), in 1806, a heightening of an infrastructure dike for the protection of a major traffic route (35,000 fl. CM for 8,068 m in the DB → 4.3 fl. / m), and in 1815, a combined closure of a side branch (55 m) and dike (485 m long) were constructed for 6,495 fl. WW (c. 2,930 fl. CM), leading to a price of c. 4.8 - 5.8 fl. CM / m (SMITAL, 1903, pp. 139 & 658; THIEL, 1904, p. 42; PASETTI et al., 1850, p. 48). Three Danube and Donaukanal flood dikes are documented in 1782/83 with 16,000 fl. along the *Fahnenstangenwasser* with 1,077 m in the DB (→ c. 14.9 fl. / m), from 1807 with 70,000 fl. on 3,433 m length (→ c. 20.4 fl. / m) and 1831/32 with 80,000 fl. for 2,338 m (c. 34.2 fl. / m) with both primary and renewed sections (PASETTI et al., 1850, p. 47-50; THIEL, 1906, pp. 43). Furthermore, during an economic crisis from around 1847 to 1850, dike constructions were used as economic tool to create employment and trigger economic growth (THIEL, 1906, pp. 81-82). A group of dikes from 1848 to 1850 is documented with 420,000 fl. CM on a length of c. 14 km in the DB (→ c. 30 fl. / m). Additionally, 77,000 fl. CM were spent specifically for a supplementary flood dike along the main Danube branch *Kaiserwasser* with 2.5 km length (→ 30.8 fl. / m) in the DB (compare THIEL, 1906, pp. 81-82).

5.2.3 Prices for regulation measures between 1540 and 1650

Price information on “regulation measures” is much more diverse before 1850: First evidence comes from the early major Danube regulation works in the 16th century between 1548 and 1558: THIEL (1904, pp. 131, 133) and HOCHLEITNER (1860) indicate that around 33,000 fl. was spent for the regulation measures near Nussdorf which aimed on the prevention of a breakthrough of the *Danube* in the *Marchfeld* and a redirection of the main branch towards Vienna. The citizens of Vienna did contribute with 13,000 fl. till 1553, and between 1548 and 1558 Vienna had spent 16,000 fl. and other municipalities in the near surrounding around 4,000 fl. on these regulation works. In the present DB, these expenses distribute on measures with a length of between c. 1,500 - 2,400 m (c. 14 - 22 fl. / m), considering the uncertainty and depending on the measures which were included till 1558. The interpretation of archival material (SONNLECHNER & HOHENSINNER, 2011) allows some basic insights and assumptions: Central elements in these early structures were fascines, long bundles of branches that were bound together. They were often filled with stones in the core and fixated with wooden piles in the river bed. For closure dams and embankments only one row of such constructions was used (”1-row structures”) while guide walls required at least two rows (”2-row structures”) and several spur dikes even more (if not stated different interpreted as “4-row structures”). Spur dikes in this case are very exposed and massive and often short structures at the top of the major guide walls which were installed at the branch-off between the *Tabor Arm* (later the upper *Wiener Arm*) and the *Wolf Arm* (developing as Danube main branch) near Nussdorf (in contrast to those spur dikes in later centuries which rather functioned as bank protection systems and were often less massive than guide walls). The 2,200 m from 1548-1558 would then consist of c. 1,180 m of 2-row (guide walls, double price) and 1,020 m of 1-row structures (closure dams, single price) according to the DB. The price for a 1-row structure would be around 9 - 13 fl. / m a 2-row structure 18 - 26 fl. / m etc. Following this scheme in this early period each documented price can be interpreted as price per row and gives estimates on a hypothetical price of 1-, 2- and 4-row structures. One needs to be aware however, that it is a simplified schematic approximation based on what is known about these structures. In the decade 1560-1570 many floods made a regular renewal or repairing of the then existing structures necessary: Yearly expenses of the *Habsburg Vicegerent* *office* ("Vizedom") and the *Salt office* in Vienna on the works near Nussdorf from these years are known: From archives (OeStA, FHKA, W 61/c/7/a (823) fol. 333r) expenses of the *Habsburg Vicegerent* from 1563 till 1570 are documented safely: 1563: 2,013 fl., 1564: 2,145 fl., 1565: 3,004 fl., 1566: 4,652 fl., 1567: 5,829 fl., 1568: 6,154 fl., 1569: 5,492 fl. and 1570: 6,068 fl. In sum the *vicegerent office* had spent 35,360 fl. from 1563 till 1570. As it remains unclear what exact expenses add to these numbers, they are seen as safe minimum money amounts spent on hydraulic engineering in Vienna and were integrated into the DB as "projects". Furthermore, from 1561 to 1563 the *salt office* paid 3,000 fl. for regulation measures and fix expenses of 5,600 fl. are known for the year 1587 only (ZANGERL, 2003, pp. 27-31). The years 1565 till 1571 are years with an extraordinary flood frequency and it was a flood in 1566 which finalized the evolution of the *Wolf Arm* as new main branch (HOHENSINNER, et al., 2013b, p. 150) bringing the regulation commissions into severe troubles. In 1566, existing regulation works were twice destroyed by floods. A first repairing was planned for a total sum of approximately 5,000 fl. and partly realized before the next flood (OeStA, FHKA, AHK NÖHA, N 27/b/1 (460) fol.166r-168r). The plan spanned constructions with 500 m length and an estimated "row length" of c. 1,700 m leading to a mean prices of c. 3, 6 or 12 fl. / m for a 1-, 2- or 4-row structures (including both primary and renewed measures). 3,000 fl. were spent on another repairing in 1567 (THIEL, 1904, p. 135) at the central regulation measures: They can be related to three realized structures in the DB, thereof, 220 m of guide walls (2-row) and 186 m of a spur dike (4-row). The entire "row length" would be c. 1,184 m which indicates a price per meter of approximately 2.5 fl. / m of a row. A wooden guide wall (named: "Füxl-Schlacht") – 60 m in the DB – was constructed for 600 fl. in 1567 (→ 10 fl. / m; THIEL 1904, p. 139). From 1569, there is a more detailed description of expenses for the planned repairing of regulation works after another flood where expenses were given in detail for four different measures (OeStA, FHKA, AHK NÖHA, W 61/c/87/b (Karton 876), fol. 482-483): The given costs and extents imply prices for 1-row structures of 3.5, 3.5, 3.7 and 1.8 fl. / m. An interesting aspect is the more detailed price for different materials which is given here: One boat load of rocks (providing material for renewed rows of c. 7.5 - 13 m length) from quarries was given with 5 fl. per boat (no size available). Tree trunks were transported to the place with prices between 0.1 - 0.5 fl. per tree trunk, were around 1.3 tree trunks can be assumed for 1 m. A boat load of further wooden material did cost 1.0 - 1.5 fl. per boat and can be related to c. 2.5 - 4.0 m row length. An exceptional project which was planned and possibly as well realized was a filling of large masses of rocks into the Danube trying to close the new main branch in favor of the old course of the Danube. If it was realized it was not successful (see DB), 1,000 boat loads of rocks were projected (= 5,000 fl.) and a price between 16 and 49 fl. / m was estimated based on the length of DB-entries. A 201 m long embankment made of wood & stone in a Danube main branch was planned for 600 fl. in 1571 (OeStA, FHKA, W 61/c/7/a (823), fol. 337-337v), indicating a price of 3 fl. / m for such a measure. There are hints indicating a higher price level of new structure towards the end of the 16th century: GAST (1592) provides cost estimates for planned (2-row?) guide walls (parts of which were realized between 1598 and 1601): 5,000 fl. on 107 m (43 fl. /m) and 11,000 fl. on 284 m (c. 39 fl. / m). In the early 17th century the state's budget was very narrow, but the existing structures had to be renewed and maintained constantly. The estates over the entire century remained very skeptical about their contribution for regulation measures which retarded the realization of many works. As worked out by THIEL (1904, p. 147-162), from the 17th century several supporting payments from the estates in Vienna are documented: 1602: 5,000 fl., 1604: 5,000 fl., 1614: 10,000 fl., 1615: 10,000 fl., 1617: 5,000 fl. before 1646: 5000 fl.; in 1646 another amount was granted (possibly again 5000 fl.?). These "sums" were included into the database and accounted as projects in the cost structure, replacing assigned individual measures, if possible or serving as minimum reference. If the 10,000 fl. from 1602 and 1604 are assigned to the only simultaneous measure in the DB - a renewed spur dike with 105 m length a price range of 87 - 106 fl. / m can be assigned to this structure. Considered like a primary 4-row structure, this is a similar level as the estimates on the two planned guide walls above. The grant from 1615 was assigned to a repairing of selected closure dams in the DB with a length between 632 and 1,895 m – considering the uncertain extents – between 1614 and 1618 (→ Price: 5.3 - 15.8 fl. / m). The use of the 10,000 fl. on different elements of the construction works is described in detail (THIEL, 1904, p. 150) and illustrated in figure 5-1, demonstrating the great dependency of expenses on local labor: 35 % can be related to physical labor directly at the Danube River, 34 % to the purchase of material paying for physical labor in nearby quarries and forests and 21 % to transportation services. Only 10 % were assigned to administrational issues. The money from 1617 was assigned to a renewal of structures of 710 m (mean) length from the year 1618 (→ Price: 4.7 - 14.1 fl. /m). As there was a major interruption during the 30-years war (1618-1648) the siltation in the Wiener Arm continued and navigation on the Arm stopped temporarily. The grant before 1546 was assigned to measures of 1,260 m length in the DB, leading to prices for a repairing after floods of 2 - 8 fl. / m.

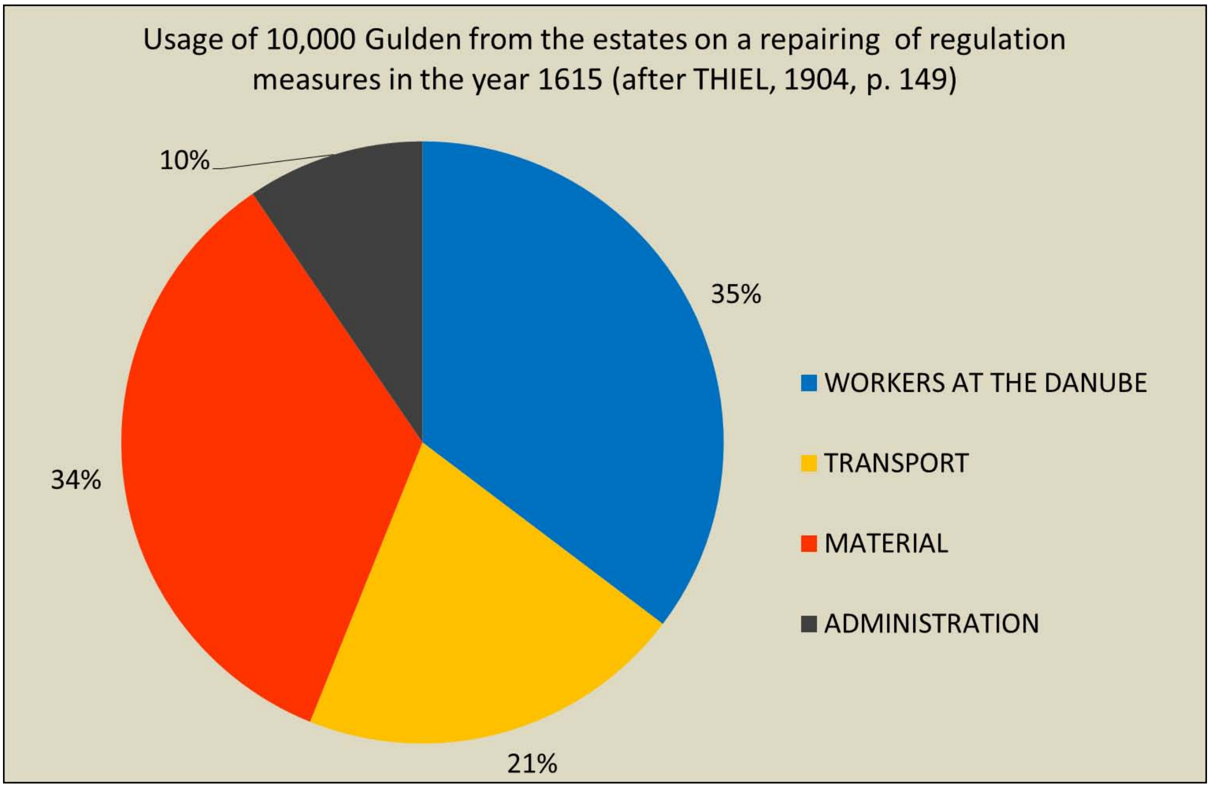

Figure 5-1: Usage of the expenses of the estates on the repairing of structures in 1615.

A commission in 1641 decided that protection measures near the village *Tuttendorf* at the right Danube banks upstream of Vienna were more expensive than the entire village itself – a good example for a purely rational approach to weight costs and benefits for the budget against each other (THIEL, 1904).

5.2.4 Prices for regulation measures between 1650 and 1850

In the second half of the 17th century the estates supported the monarchy with large amounts of money before the 2nd Ottoman siege in 1683 which could however not be linked directly to any measures in the DB. Only little data is available between 1650 and 1770. The few remarks which were available have been interpreted as average prices for common regulation measures of that time based on overall lengths in the DB: In the decade 1670-1680 the separating guide wall at the branch-off had been moved upstream for at least 7,000 - 8,000 fl. (grant of the estates 1672) for 479 m (→ 15.7 fl. / m) and 20,000 fl. were necessary in 1686 (THIEL 1904 pp. 159-161, for several regulation measures at the Danube (1,235 m → 16.2 fl. / m) among them a spur dike at the opposite banks of the Danube ("Gegensporn"). The engineers started to realize that rivers need to be guided over larger distances rather than being only regulated at one critical hotspot (compare THIEL, 1906, p. 7). Regulation measures for the maintenance of the navigation on the *Donaukanal*, started far upstream of the branch-off near *Nussdorf* – e.g. by the closure of many side branches along the left Danube banks – and were distributed along the entire Donaukanal – by the fixation of the banks and an optimization of the course with cut-offs. The financial means assigned to these tasks were since around 1700 organized in a separate river engineering budget (German: *Wasserbaukasse*) taken from wood taxes generating 10,000 - 12,000 Gulden income in a year. Subsequently, in total around 170,000 - 200,000 Gulden were foreseen for the Danube regulation in the period 1700 till 1716, an amount which was probably exceeded only by the expenses for the above mentioned cut-off and following excavations and, thus, cannot be accounted in a meaningful way for the cost structure. The income doubled after 1716 and subsequently around 200,000 - 240,000 fl. were available for the ten-year period 1717-1726. Ambitious plans for closure of several side branches with stone works at the left Danube bank between 1717 and 1726 were not realized in the intended way but major embankments *near Tuttendorf* and hurdle works for the closure of several left Danube side branches at the left bank were constructed in the end. The limitations of the budget may indicate that the available money was entirely used for the regulation measures of that time in the DB. The money amount would then relate to various regulation measure of 10.65 km length between 1717 and 1726 (c. 19 - 23 fl. / m) which is at least a similar level to the prices on different regulation measures from the late 17th century. In 1734, possibly the most massive construction of that time – the separation spur dike at the Donaukanal branch-off – was renewed and 114,000 fl. were spent (SLEZAK, 1978, p. 28) on a length of 946 m in the DB (c. 110 - 134 fl. / m). In the middle of the 18th century, due to several wars, the regulation efforts were limited and rather the most necessary repairing of structures was conducted. In 1729, 3,000 - 4,000 fl. were used (THIEL, 1906, pp. 10) for a minor repairing (c. 1,500 m in the DB, c. 2.1 - 2.5 fl. / m) and in 1761, 6,001 fl. were used for another repairing of regulation measures (THIEL, 1906, pp. 13-14) with 3,500 m in the DB (c. 1.5 - 1.9 fl. / m). The construction with fascines was very common and beneficial (SCHEMERL, 1782) along many rivers. However on upper sections of large rivers, these measures were easily destroyed and rarely used – so as well at the Viennese Danube (HOHENSINNER et al., 2013b). The guide how to estimate prices for different fascine construction types (SCHEMERL, 1782) has not been integrated into the research as it has little relevance for Vienna and as the price estimation has too many variables which are not documented.

More diverse information could be derived for the years 1770 till 1830. In the second half of the 18th century new demands came up leading to a search for more generalist solutions. The spreading suburbs asked for their protection against floods on the one hand, while on the other hand siltation in the Donaukanal continued to endanger navigation (MITIS, 1835; THIEL 1906). Several projects for a Danube regulation were suggested, e.g. by the engineers *Fremaut* (1767: 650,000 fl.), *Hubert* (1776: 334,307 fl.) and *Schemerl* (1.2 million fl. CM in 1811) as described in more detail by THIEL (1906). Many suggestions by *E.I. Hubert* were realized between 1769 and 1787, following the principle to narrow down and deepen the Donaukanal by systems of spur dikes and to elevate major flood dikes for the protection of the *Marchfeld* and the settlements in Vienna. For bank protection systems with many minor spur dikes, the following prices are available (THIEL, 1906, pp. 24-25, 31): In 1785, 2,732 fl. on 225 m (→ 12.1 fl. / m), and 8,000 fl. on 1,412 m (5.7 fl. / m) of the bank protection system are documented. In the years 1791-1793, 28,000 fl., at least, were used on the renewal on the Nussdorf spur dike (1,256 m → 22.2 fl. / m) and another system of spur dikes, guide walls and embankments (together 2,101 m) was renewed and extended for 34,000 fl. (→ 16.8 fl. / m) – while parts of this latter sum might as well be associated on the above spur dike. The distribution is not entirely certain. More exposed and, thus, more massive and expensive spurs were constructed in 1784/85 (32,236 fl. on 508 m → 63.5 fl. /m) and 1785-1787 (14,000 fl. on 504 m → 27.8 fl. / m). By PASETTI et al. (1850, p. 49) a guide wall in the Danube from 1816 (550 m) and a spur dike from 1821 (432 m) – both made of fascines – are given with 104,925 fl. WW (c. 41,970 fl. CM, → 76.3 fl. CM / m) and 54,744 fl. CM (→ c. 126.7 fl. / m). After THIEL (1906, p. 59), 16,000 fl. CM can be assigned to a provisionary stone embankment in the DB (301 m long, → c. 48 - 59 fl. / m) from the Donaukanal from 1825. A system of spur dikes as bank protection implemented between 1827 and 1834 in the Donaukanal covering 1,261 m in the DB did cost 53,176 fl. and a price of 38 - 46 fl. / m was derived (PASETTI et al., 1850, p. 50). A price of 86 - 105 fl. / m was derived for embankments of 2,223 m length from 1849-1852, for which 210,566 fl. were assigned (DIR.ADM.STAT, 1854). The separation wall near Nussdorf was renewed and slightly extended in 1831 for 25,000 fl. (PASETTI et al., 1850, p. 49) on a length of 331 m in total (69 - 84 fl. / m). For a massive guide wall – the *Lobauer Leitwerk* with 1367 m length in the DB – it was documented that a later demolition of the structure would have been as costly as its construction (BUCHMANN, 1984) with

1,000,000 fl. CM in 1850 (c. 730 fl. ÖW / m). This structure was a cornerstone for the suggested new course of the Danube during the *GDR*. Such extraordinary expensive structures were commonly referred to as “major structures” irrespective of their construction type. 27,000 fl. were spent in 1849/50 on an embankment and closure dam in the Danube, downstream of Vienna (902 m → 29.9 fl. / m; PASETTI et al., 1850, p. 50).

5.2.5 Cost estimates for the *Great Danube Regulation* from 1850, 1862 and 1868

The late 19th century is the period of the most intense and well documented regulation efforts and comprehensive price information exists. The three cost estimates for *a Danube Regulation in Vienna* from 1850, 1862 and 1868 are a good starting point and provide detailed information about common unit prices of this time period. The following prices were all given in ancient Viennese units (“klafter”) and here transferred to metric units: A price key and its actual application on suggestions for a major Danube Regulation in Vienna from 1850 were summarized by PASETTI et al. (1850, pp. 110-119) in a protocol of a meeting of the *Danube Regulation Commission (DRC)*, and documented in the sheet “Pasetti 1850” in *file B.1*. Two calculations were distinguished: A conventional calculation based on river engineering practice of that time and an estimate specifically adapted to the conditions for the planned regulation. For the “conventional” prices it is explicitly mentioned, that they follow conventions of previous measures and ignore the potential use of new technical means (PASETTI et al., 1850, p. 115), and thus, they were interpreted in that sense, that these prices are applicable to the conditions prior to 1850 (c. 1830 to 1850). For stone embankments, a price of 42 fl. CM / m is considered based on experience from the Danube close to Vienna. The closure of a side branch was considered with 106 fl. CM / m and of a main branch with 475 fl. CM / m. Their ratios to embankments are 1 : 2.5 and 1 : 11.25. For dikes, a normal cross section of 61 m² was presumed and based on a volume price of 0.59 fl. CM / m³ a price of 36 fl. CM / m was derived. For dike crossings across closed side branches, one third of the dike cross section was considered (→ 12 fl. / m). The adapted calculation used volume prices to estimate the actual prices for realized structures in the considered *Danube Regulation in Vienna*. Those prices may rather serve as reference for the conditions of the following years (c. 1850 till 1870): The price for an excavation without transfer of material was 0.22 fl. / m³. For dikes which were actually planned with different cross sections (here: 86, 88, 110 or 201 m²), depending on the location, prices vary from 0.51 to 0.66 fl. / m³. This leads to prices per meter of 58, 59, 72 or 132 fl. Prices for the transfer of excavated material, e.g. as foundation for embankments, were 0.51 fl. / m³. These bank constructions were planned with c. 26 - 32 fl. / m. The constructed banks were either stabilized with paving or with plantations with areal prices at predictable levels (0.56 vs. 0.26 fl. / m²). Length prices for paving vary strongly (c. 10 - 70 fl. / m) and, thus, actual prices per meter for a complete bank construction are hard to predict in this case. BAUMGARTNER (1862, pp. 57-60) suggests a system of mainly stone constructions (collected in the sheet “Baumgartner 1862”): Excavations of land with area prices of c. 13,900 fl. ÖW / ha and volume prices of 0.73 fl. ÖW / m³, bed excavations in a new port basin with 22,250 fl. ÖW / ha) and trenches of 3.6 m depth with c. 11,100 fl. ÖW / ha and 0.59 - 0.73 fl. ÖW / m³. Flood dikes made of stone with a cross section of 43 m² are projected with 76 fl. ÖW / m. Furthermore, 63.3 fl. ÖW / m were supposed as price for infrastructure dikes. Stone regulation measures were projected with a price of 1.76 fl. ÖW / m³, ripraps as embankments would have cost 28.5 fl. ÖW / m. and paving between 13 and 22 fl. ÖW / m. Excavations of three different types were projected: The official cost estimate from the *Danube Regulation Commission* (DRC, 1868*,* p. 197-213) provides standard prices per length, area and volume and details about the planned constructions (sheet “DRC 1868” in *file B1*): The cost estimate spans 24.6 million fl. ÖW, thereof for excavations 8.6 million, embankments and fillings 3 million, demolitions 1.4 million, flood dikes 1.1 million, guide walls 1.5 million fl. ÖW; for the purchase of land 5.3 and for the administration and unforeseen tasks 2 million fl. ÖW. Prices of 0.29 fl. ÖW / m³ for excavations above the water level and 0.40 fl. ÖW / m³ for excavations below the water level were projected. The suggested section were designed between 1.7 and 3.8 meter high, and based on the given conditions prices for the areal excavations would range from 5,050 and 11,150 fl. ÖW / ha. The main cut-offs were supposed to erode themselves following the line of two excavated trenches. Dike prices per volume excavated material depending on the transport distance between were projected with 0.22 (c. 90 m) - 0.59 (c. 900 m) fl. ÖW per m³. As result of actual distances and actual cross sections of the dikes meter prices on the right side of the Danube of 50 fl. ÖW in the upper and 66 fl. ÖW in the lower part were projected, on the left side of 61 fl. ÖW in the upper section and 100 fl. ÖW in the lower section were documented. Guide walls were indicated with prices between 53 and 137 fl. ÖW / m. Quai walls in the Donaukanal were to be installed for 738 fl. ÖW / m. The prices for paving range between 14 and 42 fl. ÖW per meter length and ripraps with 55 - 72 fl. ÖW / m were documented.

5.2.6 Realization of the *Great Danube Regulation* 1870-1875

WEX (1976a, pp. 120-122) provides the following hints (see sheet "GDR 1870-75"): In total, the realization of the *Great Danube Regulation* in Vienna between 1870 and 1875 did cost 20.26 million fl. ÖW. Thereof, 1.21 million were spent for administrational expenses, 2.7 million on a stable bridge across the Danube, and 0.8 million for two swimming pool areas in the Danube. *1.53 million fl. ÖW* was spent on rail works by the railroad companies *Kaiser-Josefs-Nordbahn* and *Nordwestbahn* – railroad dikes in the DB might have been addressed by these expenses but the extent to which this applies is uncertain. Thus, as expenses on actual river engineering measures 14.01 million fl. ÖW remain between 1870 and 1875. Thereof, 10.9 million fl. ÖW were used on the transfer of 16.4 million m³ loose material (0.66 fl. / m³) – including the excavations, fillings and the elevation of provisionary dikes. In contrast to the original plan, the channels were excavated in their entire extent and not only as trenches which the river erodes itself. The huge masses of material were in particular needed to fill the large area of the former *Kaiserwasser* with loose material, to obtain a new flood-safe settlement area. For now, the costs have been distributed on respective measures in the DB supported by simple assumptions: For the excavation of a floodplain, it has been assumed that it corresponds to the estimated extent (6.15 million m³) and price (0.29 - 0.32 fl. ÖW / m³) from the DRC, 1868 (assigned cost: 1.94 million fl. ÖW). 546,000 m³ were excavated from the Donaukanal (assumed with 0.4 fl. ÖW / m³ → 220,000 fl. ÖW; 4,720 fl. / ha based on the DB). The prices of bed excavations were used (0.4 fl. ÖW / m³) to calculate expenses on the two major cut-offs of the *GDR* which leads to 2.56 million fl. ÖW and 9,988 fl. ÖW / ha for the upper cut-off (m³) and 1.32 fl. ÖW and 27,300 fl. ÖW / ha for the more narrow and deep lower cut-off. Hypothetic dike prices with minor transport distance (0.22 fl. ÖW / m) from the estimate (DRC, 1868) were applied on the elevation of provisionary dikes (→ 590,000 fl. ÖW were assigned to 21.6 km in the DB). The dikes were only elevated in their full size after 1875 (and actual prices from the estimate 1868 for the right and left Danube dikes were applied to them in the DB. The remaining sum (4.27 million fl. ÖW was distributed on the heightening of land in the floodplain and the filling of ancient river arms. Regulation measures (embankments and closure dams) with 1.75 million fl. ÖW are documented for a length of 25.8 km (c. 68 fl. ÖW / m). For those constructions c. 550,000 m³ rocks were used (price: 3.2 fl. / m³) according to WEX (1976a, pp. 121). A special measure type is the "rock blasting" (demolition of solid rocks on the river bed by controlled explosions). In the DB, they however only appear once in the context of the GDR (MAHLER, 1878, p. 131) and were conducted for half the price: 1,470 fl. ÖW were spent on 1,180 m³ (→ 1.1. fl. / m³). New quay walls and landing places in the *Donaukanal* did cost 1.28 million fl. ÖW and the demolition of ancient river engineering measures (made of stone and wood) was conducted with 853,000 fl. ÖW (12,112 m in the DB → 70.4 fl. / m). 5,000 wooden piles were extracted for 1.10 million fl. ÖW (251 fl. ÖW per pile) from old hydraulic measures.

5.2.7 Expenses and prices after the *Great Danube Regulation* (GDR)

A regulation of the Danube sections upstream and downstream of Vienna became necessary subsequent to the GDR in Vienna (Sheet: “DR in NÖ”). A new project spanning 24 million fl. ÖW in Lower Austria (mostly outside of Vienna) was planned. The cost estimate from the year 1881 concerning *the Danube Regulation in Lower Austria* (DRC, 1898, pp. 197-200) lists prices of more than a hundred measures: For each measure the expected expenses, a length, the derived price per length unit and a construction type are given: These prices were grouped based on different construction types leading to the price scheme which is depicted in a box-and-whisker diagram in figure 5-2. The box between the upper and lower quartile contains half of the documented prices for the construction type. The median separates the lower and the upper half of values. Several particularly expensive structures were grouped as own category, labelled as “massive guide walls / spurs”. These were excluded from the other categories. For regulations in Lower Austria and Vienna between 1882 and 1895, 19.5 million fl. had been used – partly for other measures than the projected ones (SCHREY, 1899, pp. 71-80). In total, 54.4 million K were projected for a continuation of the Danube regulation in the time span after 1899 (sheet: “supplementary DR”). The actual use of this money has partly been verified so far: The following “low water regulation” in Vienna was projected with 2 million K for 130,000 m^3 stone works (low water groynes) with 23.85 km in the DB (15.4 K / m^3 and 84 K / m) length and 2 million K for excavations in the Danube (245 ha in the DB) with a transfer of 900,000 m^3 loose material in the Danube on an area of 2.5 million m^2 in the DB (2.2 K / m^3 and 8,000 K / ha). The ports *Freudenau* (4 million K) and *Kuchelau* (2 million K) were contained in the project. A backwater flood dike was implemented in 1893 for 260,000 fl. ÖW (WILETAL, 1897, p. 67) with a length of 5,704 m in the DB (Price: 45.6 fl. ÖW / m). A weir and a lock at the entrance of the Donaukanal near Nussdorf were installed between 1894 and 1899 for 7.96 million K (BUCHMANN, 1984). Quay walls in the Donaukanal were installed (1894-1899) together with a turning basin for ships for 5 million K (BUCHMANN et al., 1984).

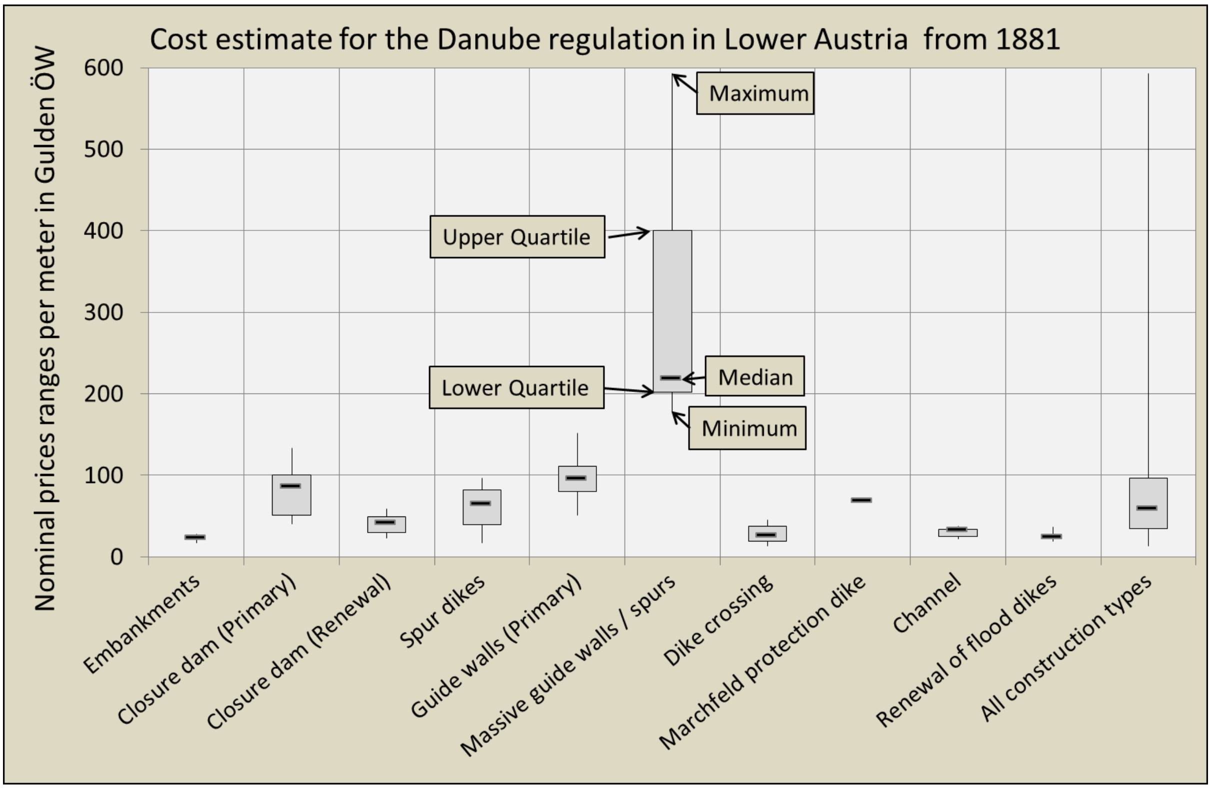

Figure 5-2: Danube Regulation in Lower Austria – Cost estimate from 1881. Distribution of prices for different construction types (after the DRC 1898, pp. 197-200).

For now, as no other documentation was available, the expenses for the ports *Kuchelau* and *Freudenau* were standardized and these values were assumed as range for the costs for the ports *Albern* and *Lobau* around 1939-1941. The lock in Nussdorf was renewed in 1964/65 for 70 million S and the weir was renewed for 135 million S in 1971-1974 (BUCHMANN, 1984). A renewal of the more than 100-year old quay walls in *the Donaukanal* has been started in the recent years and is still on-going, 31 million € are projected from 2012-2022 (BMVIT, 2014) for a length of 3,150 m (→ 9,840 € / m). This price has been standardized and projected to the years 1998 to 2011 when 3,500 m of the existing quay walls had been renewed already.

5.2.8 Prices for regulations along Danube tributaries

Before 1850 there is only one evidence from the *Wien River*, addressing a complete renewal of a mill weir in *Gumpendorf* (176 m wide in the DB) in 1809, constructed for 96,000 fl. BN (ATZINGER & GRAVE, 1807, pp. 9-11), equivalent to c. 43,800 fl. CM (c.

226 - 277 fl. per m width) and a section of the Wien River had been regulated 1814-1817 for 247,914 fl. WW (= c. 107,800 fl. CM) by bed excavations, fillings of excavated material and a bank protection system made of both wooden embankments and a stabilization of the banks by the plantations of trees, (ATZINGER & GRAVE, 1807, pp. 17-18). As the expenses distribute on three measures in the DB and no other distribution is possible, one third of the cost has been assigned to each of the measures: This leads to a price of 3.6 - 4.4 fl. CM / m for the embankments (c. 9,063 m long) and an average price of 3,950 - 4,830 fl. / ha on an area of 1.65 ha on which either loose material was excavated (1.08 ha) or filled in (0.57 ha). For further plantations for the stabilization of the banks in 1821-1822, 40,000 fl. CM were used on an area of 1.68 ha (ATZINGER & GRAVE, 1807, pp. 17-18) indicating a price for such an effort with 0.22 - 0.27 fl. / m².

Expenses after 1830 at Danube tributaries, in particular for the systematic construction of a modern sewage system were collected in the sheet “tributaries”. Between 1830 and 1843 main sewers along the Wien River and redirected and vaulted sections along the Alserbach and Ottakringerbach of 14.3 km length were constructed for c. 2.89 million K (after KORTZ, 1905, p. 194; in NCU: 1.37 million fl. CM). On average this leads to a price of c. 202 fl. CM / m. If the costs are distributed according to the length the different elements the main sewers along the Wien River would make up for around 930,000 fl. CM and the section along Ottakringerbach (1837-1840, 2.4 km, vaulted area in the DB: 10,113 m²) and Alserbach (1840-1843, 2.2 km, vaulted area in the DB: 16,766 m²) would make up 228,000 fl. CM (→ 225,000 fl. CM / ha) and 213,000 fl. CM (→ 127,000 fl. CM / ha) respectively. The sewers along the Wien River are not included in the DB, as they are exclusive sewage system efforts, but cannot actually be considered as river engineering measures. For the two other parts, stream sections were redirected, filled or vaulted; thus, they account as hydraulic engineering measures. According to KORTZ (1905, pp. 193-199) the following amounts of money had been spent in Vienna between 1850 and 1905: 1850-1860 1.1 million K mainly for minor street and house channels, 1861-1874 2 million K on a further canalization and piping of the Ottakringerbach and a sewer along the Wien River, and 1870-1880 6.3 million K and 1881-1890 2.6 million K are documented as total expenses on the Viennese sewage system. However, only redirected and vaulted sections of actual streams are part of the DB. As many street and house sewers are included – which are not accounted as hydraulic engineering – the given sums were listed in the DB but excluded from all calculations of a cost structure. Instead, the above hectare-prices were seen as reference for cost estimates in the DB. Further prices for a modernization towards the end of the century were derived from data by GANTNER (1991, p. 26): In 1877/78 400,000 fl. ÖW were spent on a new section of the *Alserbach* (vaulted area in the DB: 4,500 m² → 89 fl. ÖW / m²): Another section was constructed in 1893/94 586,000 K (vaulted area in the DB: 6,750 → 87 K / m²). The *Wien River Regulation* did cost *46.5 Million K* between 1891 and 1903 (MILDE, 1993-2014) and up to *50 million K* in total till 1915 (KORTZ, 1905, pp. 329-343). This amount includes significant other constructions which cannot be referred to as hydraulic engineering.

The two sheets in the protocol labelled as “out of Vienna” and “1848-53” feature many costs from outside of Vienna mainly referring to DIR.ADM.STAT (1854); PASETTI (1862), SCHREY (1899) and BAUMANN (1951) who all list regulation efforts mainly from the 19th century from different countries of the Austrian monarchy. At this place a description of these external data is left aside.

5.2.9 Documented costs for projects in the late 20th and early 21st century

The project “improved flood protection” has been realized since 1972, aiming on the achievement of flood protection up to the historical Viennese Danube discharge maximum of 14,000 m³ per second. According to HINKEL & LANDSMANN (1997) 7 billion S were spent on the entire project till 1987, thereof 4.5 billion S for the excavation of 28.6 million m³ material (*Neue Donau*), and the elevation of the new *Left Danube Dike* and the *Danube Island* from the same material. The rest till 1987 (2.5 billion S) distributes on the *Right Danube Dike*, three weirs in the *Neue Donau*, embankments etc. This project has been continued from 2006 till 2015 (MA 45, 2014) with an estimated extent of expenses in this period of around 76.8 million € spent in Vienna and is going to be continued in the years 2017-2023 with additional projected expenses of 31 million € (RIS-BKA, 2007). Prices per meter for the renewal of flood dikes with new cement constructions could be estimated and lie between 2,400 and 8,200 € / m (BMVIT, 2014; MA 53, 2009; WGM, 2012-2014). In the cost structure for the 20th century expenses for the 18 km long *Marchfeldkanal* (2.86 billion S between 1984 and 1992) were included (BMVIT, 2014) which is actually largely situated in Lower Austria. For the hydropower plant *Freudenau* directly downstream of the Danube island with 172 MW power and a huge reservoir, 15.6 billion € were spent (VERBUND, 2014). The weir in Nussdorf was complemented by a hydropower plant for 15 million € (WIENENERGIE, 2014). Modern prices were provided by *B. Karl* from the *viadonau Österreichische Wasserstraßen-Gesellschaft mbH.* In 2013/14, the price for an excavation and unloading of fine sediment can be assumed to cost 5 - 6 € per cubic meter, the same for gravel would cost around 6 - 9 €, in both cases if there is not more than a short transport downstream. The excavation of material and elevation of new structures made of excavated material cost between 10 and 13 € / m³. For stone structures a price of 25 € / ton can be assumed equivalent to c. 45 € / m³. Embankments are commonly planned with cross sections of 8.5 m² corresponding to a price of c. 375 € per meter if they are pure stone structures. Closure dams (52.5 m²) would cost around 2,350 € / m, guide walls (112 m²) 5,050 € / m, spur dikes (12.5 m²) 550 € / m and low water groynes (42.5 m²) 1,925 € / m. Cross sections and prices can be reduced significantly if for guide walls or spur dikes the stone structure is constructed over an elevated gravel core. According to *O. Jungwirth* from *Werner Consult GmbH,* the volume price for a new dike is 5 € / m³ if the material is already easily available and 8 - 10 € / m³. This would result in prices for a dike of 3 m height 400 € / m length, and for dikes with 2 or 4 m heights to c. 300 or 750 € / m and for a 3 m-dike for which material is already available to a price of c. 225 € / m.

5.3 Standardization and categorization of prices

5.3.1 Standardized total expenses and prices per extent

The money amounts documented in historical sources are meaningless, unless they are made comparable by eliminating ("deflating") the effect of the price increase (inflation) or decrease (deflation). The money equivalents derived in chapter 4.4 were used to calculate standardized (or "deflated") equivalents of these money amounts. For this purpose, based on the protocol described in chapter 5.1 and 5.2 two separate data selections have been laid out: one "project list" of documented total expenses on hydraulic projects in Vienna, and one "price list" with all derived prices per meter, hectare or cubic meter from Vienna and the close surrounding (the *Lower Austrian* Danube). Costs of hydraulic projects were standardized in the following way:

1. Documented nominal expenses in NCU were divided by the "NCU factor" in order to obtain numbers in fl. (see chapter 4.1).
2. The minimum, median and maximum money equivalents per 100 fl. for the construction period were assigned to each entry (see chapter 4.4).
3. These values per 100 fl. were then multiplied with the nominal expenses leading to minimum, mean and maximum estimates for each money equivalent.

Figure 5-3, illustrates a selection of realized hydraulic projects from Vienna for which the total expenses are directly documented. The sums, both as labor equivalents and in K 1913 (deflated by the *Labor & GDPPI*), were plotted on a logarithmic scale and indicate an overall increase of the costs of common projects. For example, from around 1550 to 1850, the documented sums range from 1,000 to 1 million *days unqualified labor equivalents* (*duql*). After 1850 they often exceed 1 million duql.

In the "price list", for prices of individual measures the construction years, properties (construction type and material, water body type, chronology) and nominal prices per length, area or volume for respective references were extracted. They were standardized with selected methods and expressed in deflated money based on both the *Labor & GDPPI* and *Food & CPI.* Furthermore, all prices were transferred into duql and kg beef equivalents. Before 1830 they have been expressed as *fl. 1721-1745,* between 1830 and 1925 in *K 1913* and for the cases of entries after 1925, in *€ 2012*. In order to allow for a long term overview (figure 5-4), all prices were as well expressed in *K 1913*. In this case, the *Labor & GDPPI* is primarily thought as tool to eliminate and predict price developments over shorter time periods (see chapter 4.3). The reference K 1913 could easily be replaced by another reference year and currency (€ 2012, fl. 1721-1745) for this purpose, as the results would be proportional to the result in K 1913. For an actual interpretation to price levels in 1913, one needs to consider that the use of other indices might lead to different results: As shown in chapter 4.3, the reference years 1721-1745 and 1913, in contrast to the year 2012, do qualify for accurate interpretations of the values of money from 1540 to 1913, while there is a severe mismatch in the 20th century between different methods of interpretation as becomes obvious, when looking at the interpretation of the value of documented total expenses after 1950 in duql and K 1913 in figure 5-3.

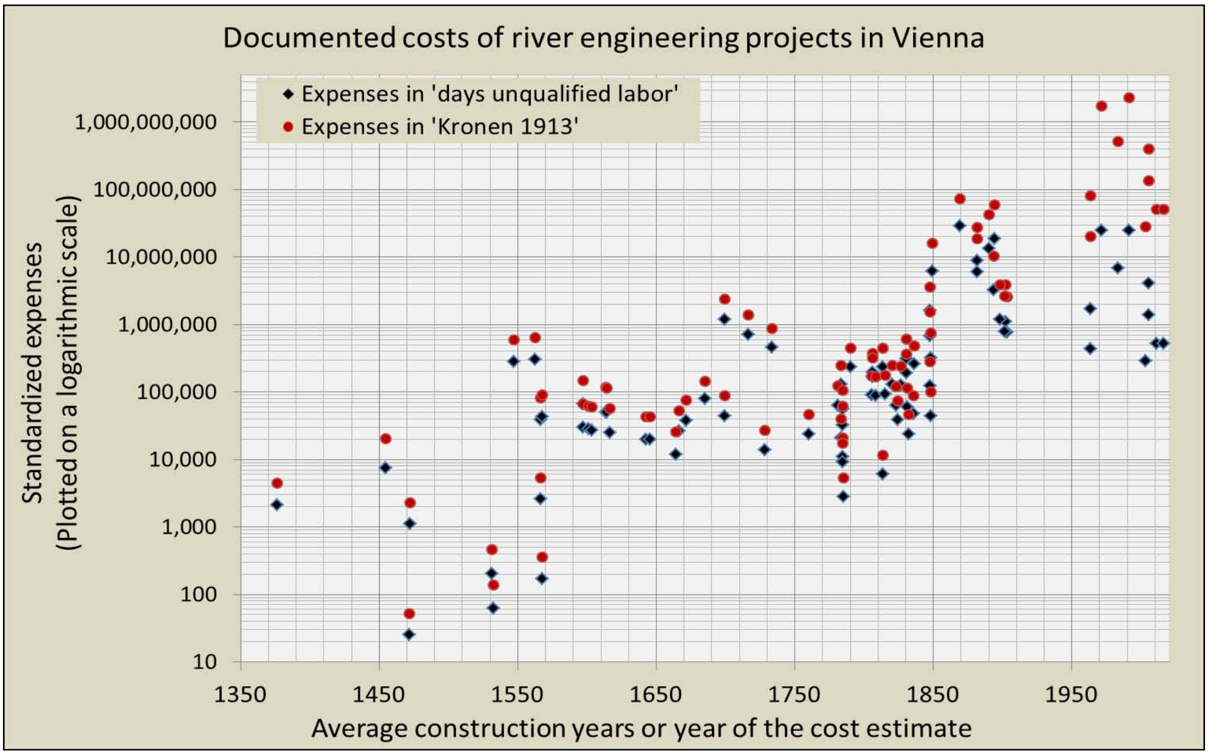

Figure 5-3: Documented expenses on realized river engineering projects in Vienna, the expenses in *Kronen 1913* were standardized with the *Labor & GDPPI*.

Table 5-4: Nominal and deflated price ranges per hectare of the exemplary protocol entry "Ditch 9".

Name:	Ditch_9	Prices per hectare:	MED	MIN	-	MAX	+
Reference year(s):	1597	Nominal in NCU:	6.173	4.628	1.545	7.717	1.545
Measure type:	Ditch	fl. 1721-45 (Labor&GDPPI):	11.916	8.188	3.728	16.225	4.308
Material:	Extracted	fl. 1721-45 (Food&CPI):	9.293	5.743	3.550	11.809	2.516
Chronology:	Primary	days unqualified labor:	41.152	27.770	13.382	57.880	16.728
Water body type:	Ditch / Creek	kg beef:	83.980	62.211	21768	129.665	45686

The above described ditch from 1597, for which a nominal price between c. 4,600 and 7,700 fl. per hectare was derived, after the standardization (table 5-4) corresponds to 8,200 - 16,200 fl. 1721-1745 (deflated by the *Labor & GDPPI*), 5,700 - 11,800 fl. 1721-1745 (deflated by the *Food & CPI*), 27,700 - 57,900 duql and 62,200 - 129,700 kg beef per hectare of the measure.

Based on the list of standardized prices, different groups of measures were illustrated in different colors as prices per meter or hectare in K 1913 in figure 5-4 and in duql in figure 5-5. Each group contains standardized prices (single data points as in chapter 5.2 with their assigned maximum and minimum) within a wide range and further distinction of the construction types and time periods is required to obtain meaningful price categories. But, looking more closely into each data row, there are obviously certain data clusters with two, three or even more data points from the same group in approximately the same price range: For example, in the 19th century for "embankments and closure dams" one cluster of values is far exceeding all other values from this group. If the more detailed documentation is consulted these data points can all be specified as prices for *quay walls.* For other regulation measures between 1650 and 1770, there are three price levels: one for a minor repairing (1729, 1761), one for common regulation prices and one (with only one data point) for the renewal of the Nussdorf spur from 1734. Excavation prices from the channel 1700-1714 are by far exceeding earlier prices for excavations. All excavation prices after 1830 are again significantly lower. For dikes between around 1770 and 1830 a minor and a major price level can be distinguished while after 1830 only the major prices still appear among the available data points.

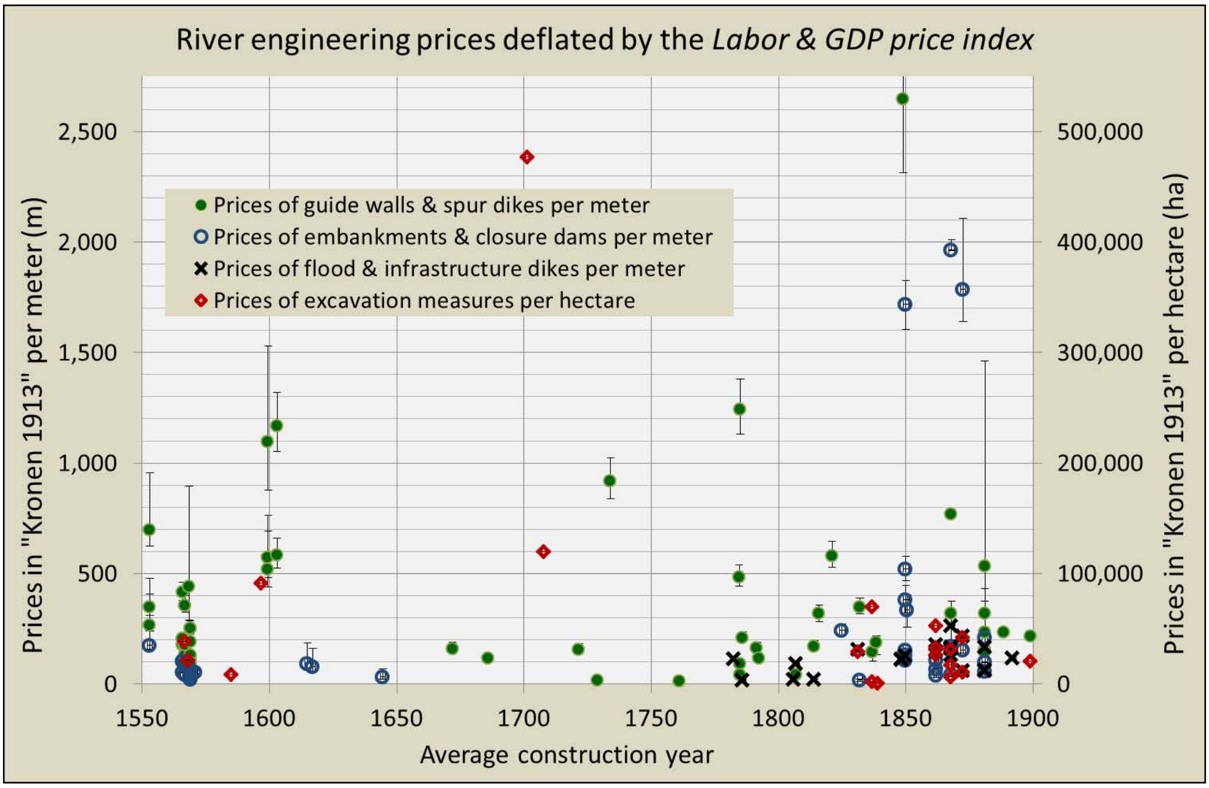

Figure 5-4: Price ranges of river engineering measures in Vienna expressed in *Kronen 1913* (deflated by the *Labor & GDPPI* with the assigned uncertainty (minimum, maximum) for every single data point.

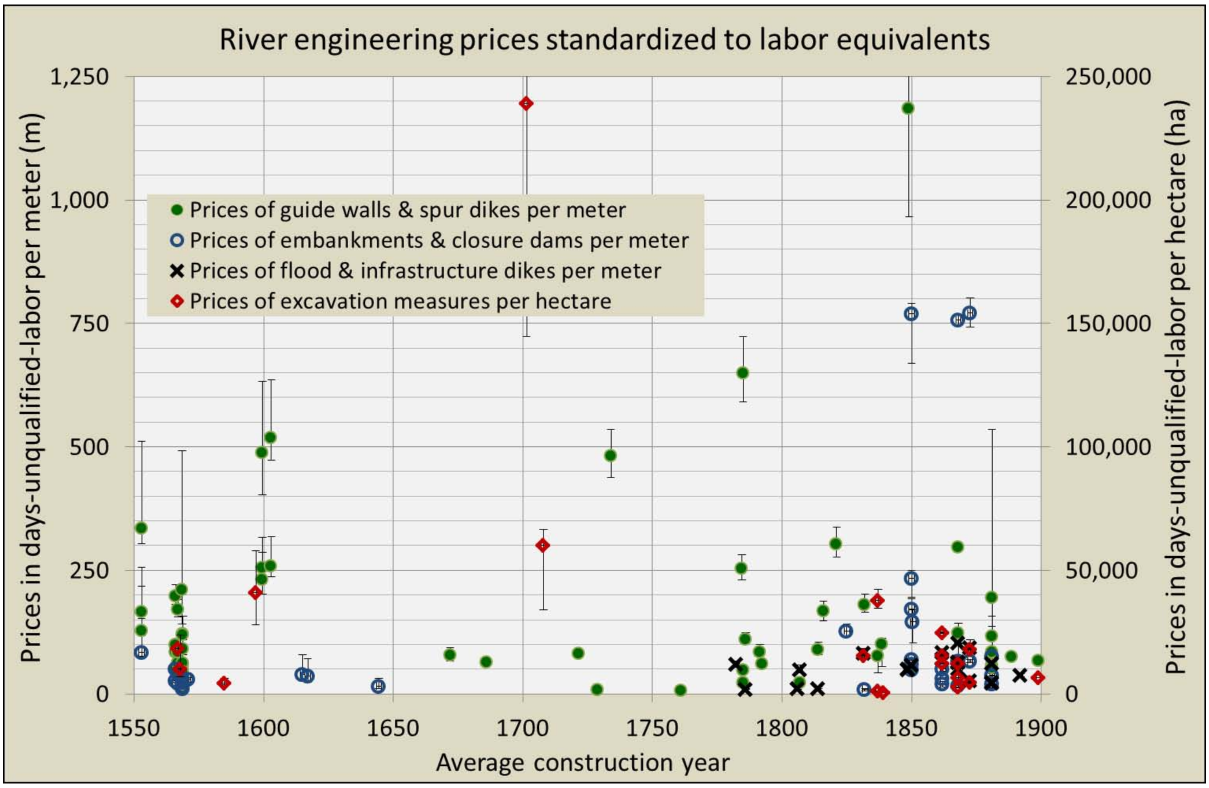

Figure 5-5: Price ranges per extent of river engineering measures in Vienna expressed as *days unqualified labor* with the assigned uncertainty (minimum, maximum) for every single data point.

The use of clusters of single price data points to derive price categories (or cost indices) is demonstrated in an exemplary way, here. The price list was restructured and separately tables for “regulation measures”, “dikes” and “excavation measures” were established with years with price data in the rows, and both more general (e.g. bank protection) and more specific labels (e.g. quay wall or riprap) in the columns. In this way standardized price categories for either more general or more specific construction types could be derived, depending on the availability of data in the respective time periods. For example, the categories can be more specific concerning the constructions between 1540 and 1650 and are more general from 1650 to 1770. The considered time periods usually defined themselves based on the structure of available data (see chapter 5.1) from the late 16th century or in the periods 1590-1650, 1650-1770 and 1770-1830, 1830-1850, 1850-1880, 1870-1875 and after 1880 till 1910. Within these periods, relevant cost indices were identified as shown in chapter 5.3.2.

A preliminary correlation for the prices for the transfer of volumes of loose material would indicate a decrease of volume prices after industrialization. For the excavation of the ditch by mechanic tools in 1597, a price of around 1.2 duql / m³ is safely documented. After 1830, excavation prices range mostly between 0.2 and 1 duql / m³ excavated soil and gravel. More data would be required to confirm and specify this observation.

5.3.2 Derivation of price categories (cost indices)

The temporal and qualitative pattern of prices per meter, hectare or cubic meter, built on highly fragmentary and highly heterogeneous historical data, was analyzed separately, rather based on the historical context and specific historical knowledge rather than by an exaggerated statistical interpretation. In fact, it would be inappropriate to understand the sample of documented historical prices as such, as a homogeneous and representative sample for an overall pattern of such prices. As previously demonstrated with figure 5-4 and 5-5 (see chapter 5.2), price data can partly be grouped into clusters of similar prices per length or area for comparable construction types. Carefully, this was done in the data tables for dikes, regulation measures, and excavation measures. As it is not possible to describe all the developed cost indices (table 5-5) in detail, here are some examples in order to illustrate the general approach: The procedure can well be explained by looking at documented dike prices before 1850 in *Gulden 1721-1745* (standardized with the *Labor & GDPPI*) which are illustrated in figure 5-6. The data point from the levee in 1473 ranges between 2 and 6 fl. 1721-1745 per meter length which was used as very uncertain reference for “dikes before 1600”. Then there are six more reliable data points from between 1770 and 1830. Three of them with prices between 2.2 and 3.3 fl. ÖW / m, three others with prices between 10 and 23 fl. 1721-1745. If one goes back to the base data, one may realize that the minor prices originate from infrastructure dikes and municipal dikes while the three major expenses originate from Danube and Donaukanal dikes. Therefore, two categories of dike prices could be distinguished: “Minor dikes 1770 till 1830” and “Major flood dikes 1770 till 1830”. Between 1830 and 1850, no minor dike prices were documented and the focus obviously was on the implementation of major dikes (including infrastructure dikes) which, based on four different data points, all range between 12.6 and 22.9 fl. 1721-1745. Thus, only one category was used for dike prices and labelled “Synthesis dikes 1830-1850”. Another example is the selection of price categories for guide walls before 1650 (all prices considered as two-row prices): In this case primary measures were distinguished from subsequent measures (repairing / renewal). Measures implemented between 1548 till 1590 appeared less expensive than the measures implemented between 1590 and 1650. This leads to four different hypothetic price ranges for 2-row guide walls in Vienna: Primary vs. subsequent and 16th century (till 1590) vs. 1590-1650 (figure 5-7).

The present “project list”, “price list” and price tables for “regulation measures”, “dikes” and “excavation measures” are available in *file B.2* on the DVD as described in appendix V. The resulting table of derived cost indices is attached in chapter 5.3.3.

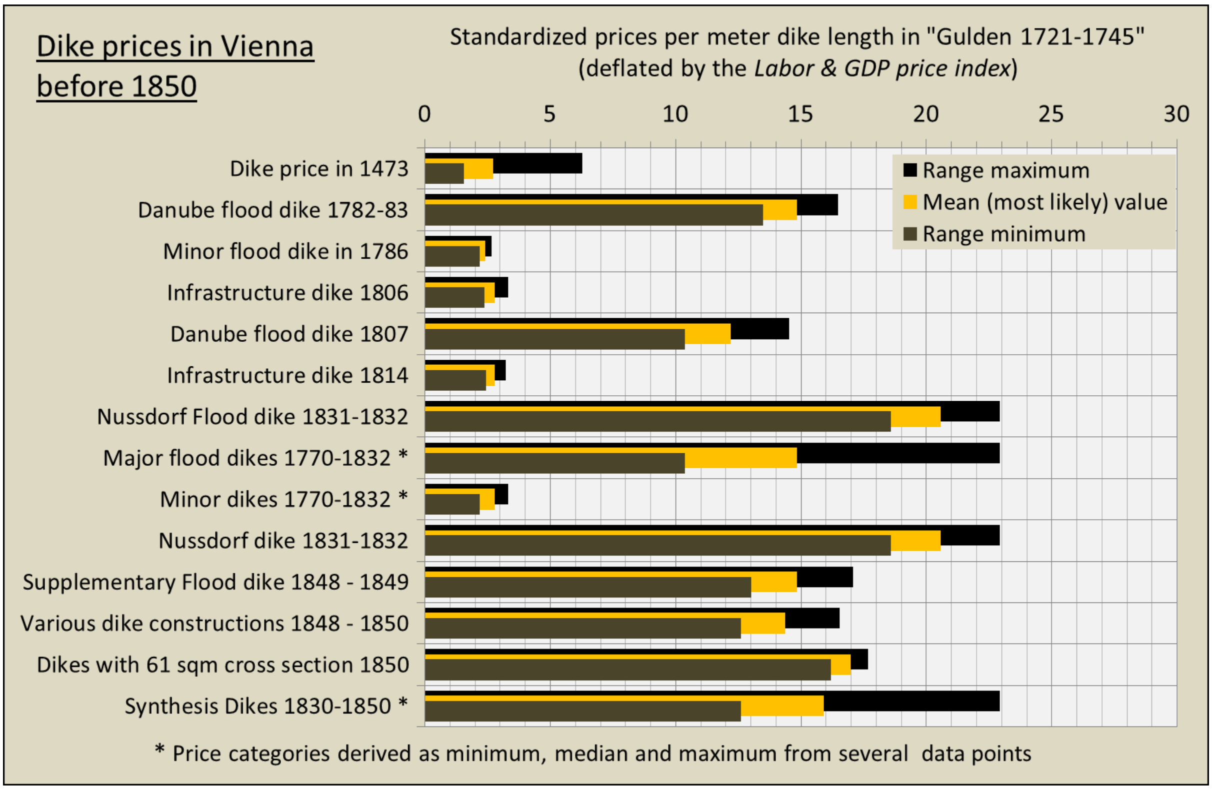

Figure 5-6: Example 1 – Price categories for the construction of dikes in Vienna before 1850.

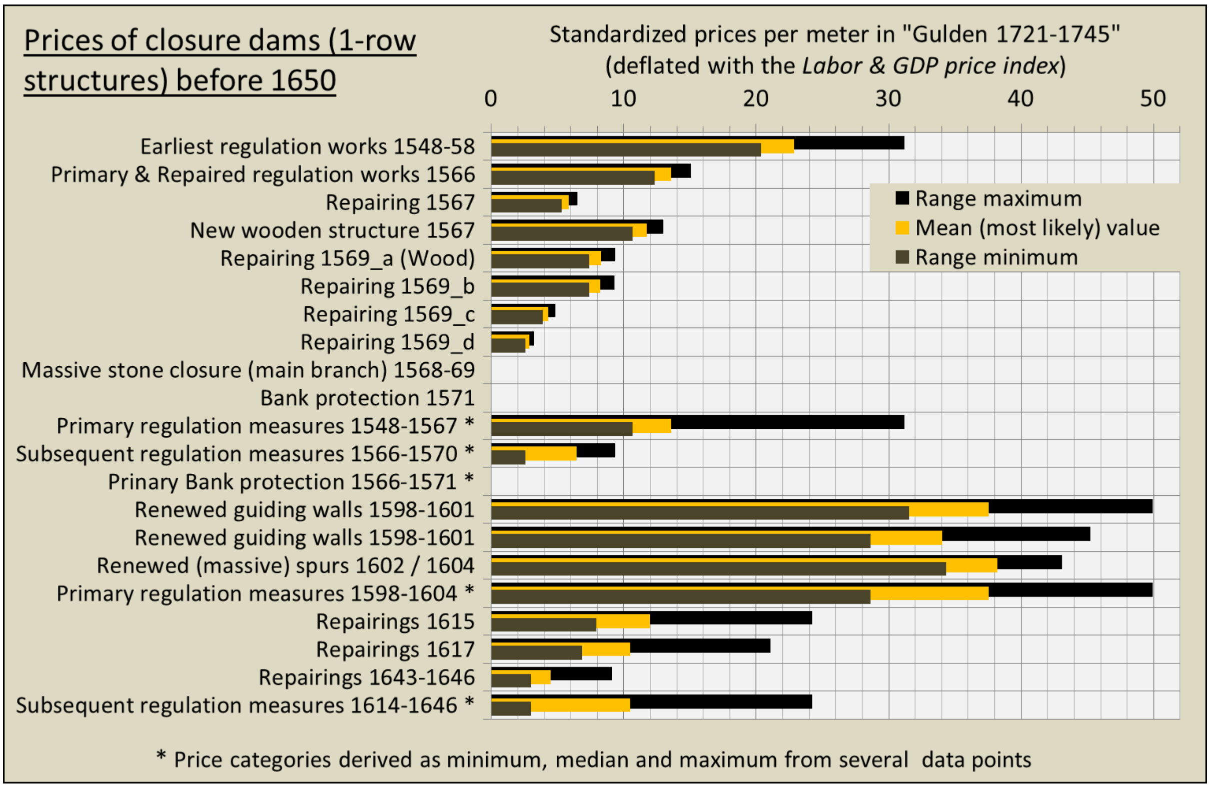

Figure 5-7: Example 2 – Price categories for the construction of guide walls (near Nussdorf) before 1650.

In this way, all standardized prices were processed and a “price key” has been developed, providing reasonable price estimates for common construction types in different time periods. Ideally, every price category would be developed out of three or more documented prices from historical sources / literature and would represent a group of measures in the database, which are described and constructed in exactly the same way. In reality, for some construction types, there is only one hint in literature and the match between the available price information and the properties of measures in the database can only be supported by similarities in the schematic descriptions in the database. The most adequate (= best available) match was used. In future, the methods can always be refined, by including more or better documentation (if available) or by looking more closely at common physical properties of construction types in different time intervals. Thus, at this place the title of the thesis should be modified a little: In fact it is “a first approach to a cost structure of river engineering measures in Vienna over more than 500 years”. Heterogeneities, such as dike heights, channel depths or details concerning the used material were not directly addressed, in the reconstructions, but the pattern of the documented prices themselves in different time periods was used to presume representative standardized cost indices for areal or linear measures which are characteristic in each period. In figure 5-8 and figure 5-9 price keys from two selected time periods – areal prices from the 16th century, and linear prices from 1770 till 1830 – are shown. In the 16th century, there was one data point for a ditch and one for a new channel, three data points each referred to bed excavations in rivers and to cleanings in minor ditches and one data point referred to a sewage drain (“Möhrung”). From 1770 till 1830, cost indices for minor and major dikes and different groups of regulation measures were distinguished. Certainly the cost estimates from 1850, 1862 and 1868 and documented costs from the GDR lead to particularly reliable and detailed price keys. An excellent scheme is that from figure 5-2 which served as direct reference for many measures implemented between 1880 and 1910.

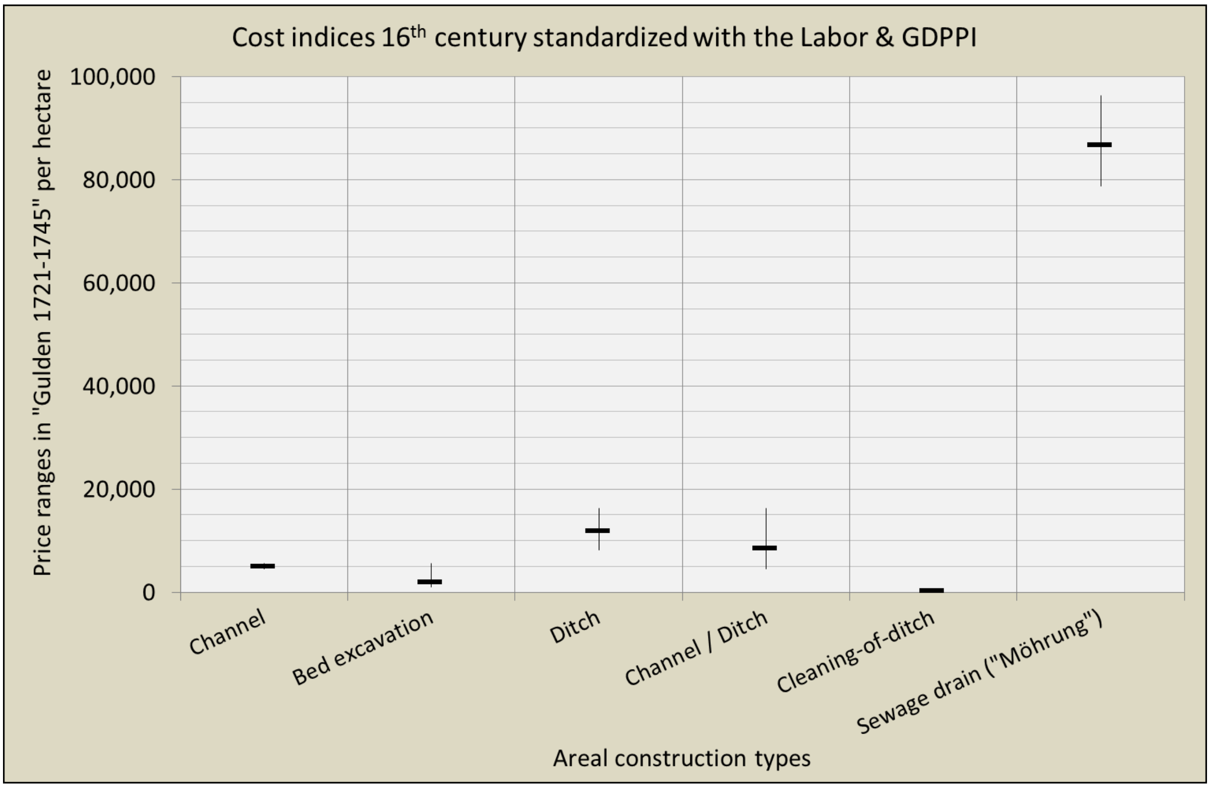

Figure 5-8: Price key for areal measures from the 16th century; the price categories (cost indices) are plotted on a logarithmic scale.

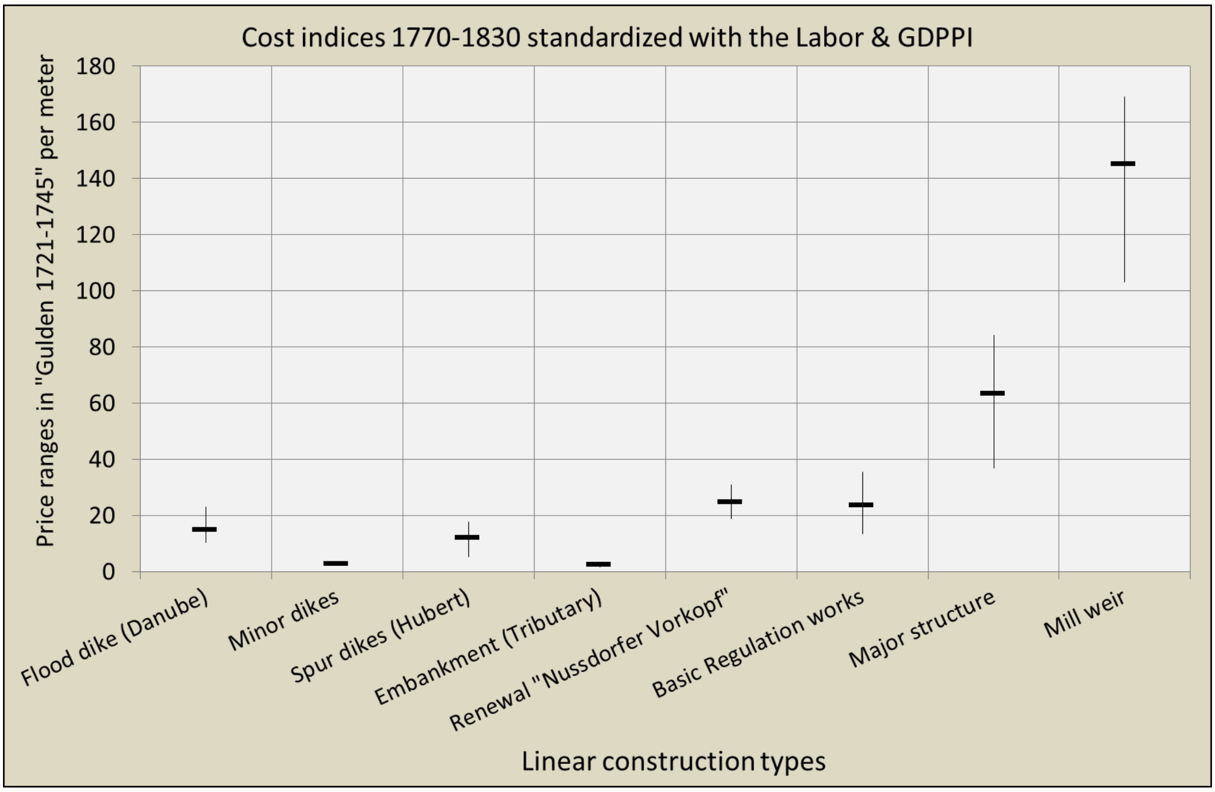

Figure 5-9: Price key for linear measures from the time period between 1770 and 1830; the price categories (cost indices) are plotted on a logarithmic scale.

5.3.3 List of derived cost indices

The cost indices resulting from the standardization and evaluation of historical price data are listed in table 5.5. These price categories per hectare or meter were applied on the hydraulic engineering measures in the DB (chapter 5.4). From left to right the table defines the time period prices refer to ("reference period"), the name of the construction type ("price category") and a medium, minimum and maximum of the derived price range in deflated currency units ("fl. 1721-1745" till 1830, "K 1913" between 1830 and 1925 and "€ 2012" after 1925). In the right column the number of times is listed the category was applied on measures in the DB.

Table 5-5: Applied Cost indices applied cost indices (prices deflated with the *Labor & GDPPI* and grouped into categories for application in the database)

ASSUMED COST INDICES FOR DIFFERENT CONSTRUCTION TYPES					
Standardized prices deflated by the *Labor & GDPPI*		MED	MIN	MAX	# of uses
Prices per meter in fl. 1721-1745					
16th century	Dike	**2.7**	1.6	6.3	10
	Embankment (Primary)	**11.7**	6.3	15.1	8
	Closure dam (primary)	**13.6**	10.6	31.2	13
	Closure dam (prim./wood)	**11.7**	10.6	13.0	1
	Guide wall (primary)	**27.2**	21.3	62.3	9
	Spur dikes (Primary)	**54.3**	42.6	124.7	1
	Closure of main branch (Gasteiger)	**57.7**	37.8	117.0	0
	Bank protection (subsequent)	**6.4**	2.5	9.3	0
	Closure dam (subsequent)	**6.4**	2.5	9.3	5
	Closure dam (subsequent/wood)	**8.3**	7.4	9.3	7
	Guide wall (subsequent)	**12.9**	5.1	18.7	15
	Spur dikes (Subsequent)	**25.7**	10.2	37.4	1
1590-1650	Closure dam (primary)	**37.6**	28.6	49.9	16
	Guide wall (primary)	**75.1**	57.2	99.8	8
	Spur dikes (Primary)	**150.3**	114.4	199.7	6
	Closure dam (subsequent)	**10.5**	3.0	24.2	29
	Guide wall (subsequent)	**20.9**	5.9	48.4	4
	Spur dikes (Subsequent)	**41.9**	11.9	96.8	0
1650-1770	Regulation works	**20.7**	13.6	24.6	183
	Nussdorfer Vorkopf	**120.4**	109.5	133.8	2
	Minor repairing	**2.0**	1.5	2.5	10
1770-1830	Flood dike (Danube)	**14.8**	10.4	22.9	28
	Minor dikes	**2.8**	2.2	3.3	39

	Spur dikes (Hubert)	**12.1**	5.1	17.5	172
	Embankment (Tributary)	**2.3**	1.6	2.7	38
	Renewal *Nussdorfer Vorkopf*	**24.6**	18.8	30.8	5
	Basic regulation works	**23.5**	13.3	35.3	58
	Major structure	**63.4**	36.8	84.1	1
	Mill weir	**145.0**	102.9	169.0	13
1830-1850	Dikes	**15.9**	12.6	22.9	100
	Standard embankment	**20.1**	19.2	20.8	70
	Standard closure dam	**49.9**	42.0	58.1	44
	Standard closure of a main branch	**224.5**	209.8	238.7	0
	Regulation works	**31.8**	12.4	58.1	17
	Major structure	**285.3**	209.8	405.9	0
	Renewal of *Nussdorfer Schere*	**45.5**	41.3	50.6	0
Prices per hectare in fl. 1721-1745					
16th century	Channel	**5,016**	4,560	5,573	0
	Bed excavation	**1,972**	1,014	5,665	5
	Ditch	**11,916**	8,188	16,225	0
	Channel / Ditch	**8,466**	4,560	16,225	64
	Cleaning-of-ditch	**182**	37	209	3
	Sewage drain ("Möhrung")	**86,697**	78,816	96,330	11
1650-1770	Channel	**62,352**	37,745	69,338	2
	Bed excavation	**15,640**	9,286	17,309	3
1770-1830	Material transfer (Wien river)	**2,346**	2,027	2,948	50
	Terrestrialization measure	**800**	681	952	17
	Bank vegetation	**10,922**	9,929	12,135	4
1830-1850	Channel	**6,500**	3,484	10,179	5
	Bed excavation	**182**	94	291	0
	Sewage drain	**130,067**	116,501	147,923	6
	Sewage piping / cover	**117,061**	104,851	133,131	10
	Sewage ditch	**6,503**	5,825	7,396	26
Prices per meter in K 1913					
1830-1850	Dikes	**122**	96	176	100
	Standard embankment	**154**	147	160	70
	Standard closure dam	**382**	321	444	44
	Standard closure of a main branch	**1,718**	1,606	1,827	0
	Regulation works	**243**	95	444	17
	Major structure	**2,184**	1,606	3,107	0
	Renewal of *Nussdorfer Schere*	**348**	316	387	0
1850-1870	Stone dike / guide wall	**180**	174	187	5
	Planned dikes 1850 (Soil / gravel)	**238**	202	498	0
	Infrastructure dike	**150**	145	156	38
	Bank protection (paving + construction)	**170**	95	282	22
	Bank protection (riprap)	**67**	65	70	38
	Bank protection (paving)	**44**	30	158	9

	Bank protection (construction)	**107**	92	123	0
1870-1875	Flood dike	**62**	52	81	0
	Embankment / closure dam	**154**	141	181	4
	Bank protection (quay wall)	**1,788**	1,641	2,106	0
	Demolition	**159**	133	208	2
	Demolition (Piles)	**792**	661	1,036	1
1870-1880	Left Danube dike	**214**	162	272	11
	Right Danube dike	**151**	132	173	7
	Embankment / closure dam	**162**	141	199	19
	Guide wall	**321**	140	374	17
	Bank protection (paving)	**44**	36	115	4
	Bank protection (riprap)	**170**	146	199	0
	Bank protection (quay wall)	**1,876**	1,641	2,106	0
1880-1910	Marchfeld flood protection dike	**169**	166	170	9
	Backwater dike	**117**	105	130	5
	Flood dikes (renewal)	**59**	45	91	3
	Dike crossing	**65**	32	111	3
	Channel	**81**	53	94	2
	Embankment (primary)	**56**	42	69	18
	Closure dam (primary)	**210**	97	328	21
	Guide wall (primary)	**234**	123	373	3
	Spur dikes (primary)	**158**	42	238	8
	Major structure	**536**	430	1,462	2
	Closure dam (subsequent)	**101**	55	146	0
	Low water groynes	**216**	196	240	2
Price per hectare in K 1913					
1770-1830	Material transfer (Wien river)	**18,000**	15,500	22,600	50
	Terrestrialization measure	**6,100**	5,200	7,300	17
	Bank vegetation	**83,600**	76,000	92,900	4
1830-1850	Channel	**49,800**	26,700	77,900	5
	(Regular) Bed excavation	**1,400**	700	2,200	5
	Sewage drain	**995,600**	891,800	1,132,300	6
	Sewage piping / cover	**896,100**	802,600	1,019,100	10
	Sewage ditch	**49,800**	44,600	56,600	26
1850-1880	Channel	**31,750**	20,712	72,604	0
	Excavation of land	**25,099**	7,385	34,281	2
	Bed excavation	**10,663**	6,721	54,849	1
	Bank protection (vegetation)	**6,176**	4,452	7,988	0
	Paving	**23,338**	11,624	46,500	2
	Bed excavation + paving	**34,001**	20,524	60,453	3
1870-1880	Excavation in water (GDR)	**10,663**	8,899	13,953	0
1880-1910	Bed excavation (LW-regulation)	**20,969**	13,979	41,960	0
	Sewage drain	**1,609,000**	1,016,000	2,410,000	0
	Sewage piping / cover	**1,448,100**	914,400	2,169,000	19
	Sewage ditch	**80,450**	50,800	120,500	31

Prices per cubic meter in K 1913					
1830-1850	(Regular) Bed excavation (volume)	**0.38**	0.37	0.38	0
1870-1880	Excavation in water (GDR)	**0.40**	0.40	0.40	0
	Stone works (GDR)	**6.79**	5.74	8.48	0
	Demolitions	**8.13**	7.46	9.57	0
	Demolitions (Price per Pile)	**496**	455	584	0
1880-1910	Bed excavation (LW-regulation)	**2.86**	2.86	2.86	0
	Stone works (LW-regulation)	**19.81**	19.81	19.82	0
Prices per meter in € 2012					
1880-1910	Marchfeld flood protection dike	**104**	102	104	9
	Backwater flood dike	**72**	64	80	5
	Flood dikes (Renewal)	**36**	28	56	3
	Dike crossing	**40**	20	68	3
	Channel	**50**	33	58	2
	Embankment (Primary)	**34**	26	43	18
	Closure dam (Primary)	**129**	60	201	21
	Guide wall (Primary)	**144**	76	229	3
	Spur dikes (Primary)	**97**	26	146	8
	Major structure	**329**	264	897	2
	Closure dam (Subsequent)	**62**	34	90	0
	Low water groynes	**132**	120	147	2
	Left Danube dike	**815**	588	1,431	0
2013	Dikes (Gravel)	**350**	225	750	0
	Flood dikes (Renewal)	**1,559**	951	2,773	0
	Bank protection (Stone)	**375**	375	375	0
	Closure dam (Stone)	**2,350**	2,350	2,350	0
	Bank protection (Spurs; Stone)	**550**	550	550	0
	Guide wall (Stone)	**5,050**	5,050	5,050	0
	Guide wall (Gravel core)	**950**	950	950	0
	Spur (Stone)	**1,925**	1,925	1,925	0
	Spur (Gravel core)	**575**	575	575	0
	Quay wall (Donaukanal)	**9,952**	9,841	10,062	0
Prices per hectare in € 2012					
1880-1910	Bed excavation (LW-regulation)	**12,863**	8,575	25,740	0
	Sewage drain	**987,022**	623,253	1,478,387	0
	Sewage piping / cover	**888,320**	560,928	1,330,548	19
	Sewage ditch	**49,351**	31,163	73,919	31
1972-1987	Material transfer (Neue Donau)	**823,625**	594,286	1,445,100	0
Prices per cubic meter in € 2012					
1880-1910	Bed excavation (LW-regulation)	**1.76**	1.76	1.76	0
	Stone works (LW-regulation)	**12.15**	12.15	12.16	0
1972-1987	Material transfer	**24.00**	17.32	42.11	0
2013	Material transfer	**7.50**	5.00	13.00	0
	Stone works	**45**	45	45	0

5.4 Application of cost indices on measures in the database

The calculations of price and cost estimates for all database entries have been conducted in two different directions: For measures (or projects), for which expenses were documented directly in the DB (or documented expenses which were distributed on several measures based on a reference in literature) the total nominal expenses of the database entry were known at first and the nominal price in NCU was calculated per hectare or meter extent. Vice versa, if no direct estimate was available (which was the case for a large majority of individual measures), the cost indices in deflated currency units (DCU) based on the *Labor & GDPPI* – those described in the previous chapter and listed in table 5-5 – were applied to all other hydraulic measures in the database. That means, the most suitable price category in terms of the time period, construction type, chronology, construction material, and water body type from the list of available price categories was assigned to these measures. Deflated cost estimates were calculated by multiplying the applied price category by the size of the measure in meter or hectare. This leads to cost estimates in fl. 1721-1745 for measures implemented before 1830, in K 1913 for measures between 1830 and 1925 and in € 2012 for measures implemented after 1925 (see chapter 4.4).

The "data quality" of each cost estimate has been qualitatively described by a scheme of five labels: It was distinguished between the following qualities:

> "Safe": Expenses on the individual measure or the project are directly documented in historical sources.

> **"**Good": The price per extent of the same construction type is known OR safely documented expenses on a group of measures have been distributed according to the extents of similar construction types in the database

> "Moderate": Prices per extent of similar construction types are available from the same time period.

> “Poor”: Price information was derived from different but related constructed types in the same period OR from other similar construction types from other time periods.

> “Arbitrary”: No reasonable estimate is possible with the given information. The estimates are a function of the extents in the database in the DB and use price information which appeared somewhat related to the structures.

The spatial distribution of data qualities assigned to individual hydraulic measures has been illustrated in figure 5-10: The data quality in the Danube floodplain appears in many cases at least “moderate” or “good”. In particular along the Wien River many estimates were considered as “poor” or “arbitrary”.

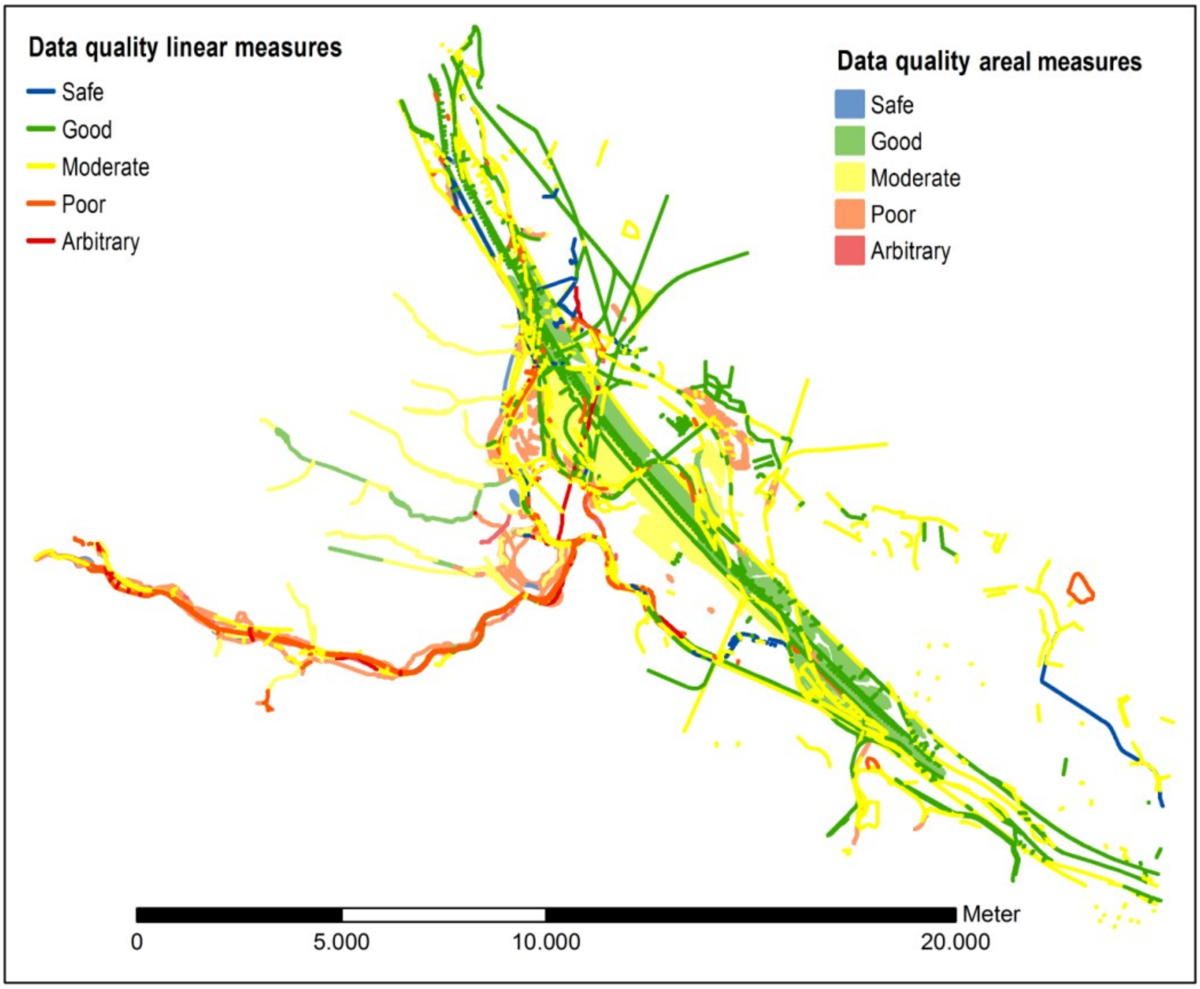

Figure 5-10: Spatial distribution of the data quality of price information on linear and areal measures in the original DB.

The tables 5-6 and 5-7 present in an exemplary way the assumed nominal and deflated prices per extent and total expenses for the three DB entries which are already known from chapter 3.2 (table 5-1 to 5-5): The *Gegenschlacht* (No. 28), a guide wall near Nussdorf from 1548-1558, the *Weidenhaufen-Durchstich* (No. 278) a Danube cut-off from the GDR 1870-1875, and the *Donauinsel / New Danube* (IFP_0) from 1972-1987. If the estimates were based on nominal expenses (as for the entries “278” and “IFP_0”) the nominal money amount was transferred from NCU to fl. for the entire database according to the nominal exchange rates from chapter 4.1. The standardized total expenses and prices (deflated by the *Labor & GDPPI*) per extent were calculated by multiplying the sums in fl. with the assigned median, minimum and maximum money equivalents (assigned as equivalents to 100 fl. in chapter 4.4) to the measures. Vice versa, when deflated price categories were applied, as for the entry “28”, nominal equivalents in NCU to deflated prices and costs were calculated in the opposite direction. The quality of all estimates has been specified using the above described labels. Each measure in the DB, for which a price estimate was used, the related “reference period” from this list (e.g. 1787-1730) and the name of the used “price category” (e.g. *minor dikes*) was stated in the DB. Besides, if available, the exact “reference years” for this price category from the price protocol were stated.

For the interpretation of prices per extent, according to the constant ratios given by the *Labor & GDPPI* all numbers in *fl. 1721-1745* and *€ 2012* were transferred to *K 1913* in order to have one homogeneous measure over the entire time period. Beyond, prices in *days unqualified labor equivalents* (hereinafter: *duql*) per meter or hectare were calculated based on the money equivalents assigned to the DB entries in chapter 4.4. For an actual interpretation of the prices to a level in 1913, the restrictions discussed in chapter 4.3 and 4.4 apply. There is an accuracy or mismatch between different methods of interpretation and the reference time 1913, just as 1721-1745 – which could equally well be used – but as opposed to 2012, allows for quite accurate comparisons of prices over the centuries from 1540 to 1913. For all measures for which an efficiency (duration of functionality in years) is given, a reciprocal measure for the cost efficiency (= effective price) was calculated by dividing the *prices per extent* by the efficiency in years (a value between 1 and 100 as described in chapter 3.2) obtaining *prices per extent (ha or m) & year of functionality*. For now, a reciprocal cost-efficiency based on the prices in duql and in K 1913 (based on the *Labor & GDPPI*) has been calculated. Thus, for the measure "28" an effective price of 34 duql / m & year result from a price of 170 duql / m and an efficiency of 5 years (compare table 5-7). These specifications may well be used for analyzing changes in the cost-efficiency in the entire DB over decades or centuries.

Table 5-6: Estimated total expenses in nominal / deflated currency units (NCU / DCU), data quality and reference of three exemplary measures in the DB; IDs: "28" = guide wall 1548-1558, "278" = cut-off 1870-1875; "IFP_0" = New Danube/Donauinsel 1972-1987; GDR = Great Danube Regulation; the initial nominal cost estimates are marked with bold frame.

Extimated prices and cost efficiencies for three selected measures				
OBJECTID *		28	278	IFP_0
Assumed nominal costs in NCU	Mean estimate	10,510	1,320,000	7,000,000,000
	NCU	fl.	fl.ÖW	S
	Minimum	4,490	1,320,000	7,000,000,000
	Maximum	21,960	1,320,000	7,000,000,000
Assumed deflated costs in DCU (standardized with the Labor & GDPPI)	Mean estimate	24,610	2,868,430	1,082,161,600
	DCU	fl. 1721-45	K 1913	€ 2012
	Minimum	10,940	2,737,290	782,157,830
	Maximum	50,320	3,019,490	1,847,177,010
Quality of the estimate		Good	Good	Safe
Reference year(s)		1548-1558	GDR	
Reference category		(*Guide wall (Primary)*)	-	-
Reference time period		(*16th century*)	-	-

Table 5-7: Estimated prices per meter or hectare (in NCU and DCU, in K 1913 and labor equivalents), assumed efficiency and cost efficiency for two exemplary measures in the DB; the initial deflated cost index is marked with bold frame.

OBJECTID *		28	278	OBJECTID *		28	278
Assumed nominal price per extent in NCU	MED	19.5	28,324	Assumed deflated price in DCU (Standardized with the Labor & GDPPI)	MED	46	61,550
	NCU	fl.	fl.ÖW		DCU	fl. 1721-45	K 1913
	Extent unit	m	ha		Extent unit	m	ha
	MIN	16.7	25,749		MIN	41	53,396
	MAX	27.2	31,471		MAX	62	71,990
Price in K 1913 (deflated with the Labor & GDPPI)	MED	350	61,550	Price in days unqualified labor (duql)	MED	170	27,030
	MIN	311	53,396		MIN	149	21,918
	MAX	477	71,990		MAX	260	33,623
Assumed efficiency	in years	5	100	Expenses per year of functionality	in duql / year	18	13
Cost-efficiency in K 1913 per extent and year of functionality	MED	70	615	Cost-efficiency in duql per extent and year of functionality	MED	34	270
	MIN	62	534		MIN	30	219
	MAX	95	720		MAX	52	336

As a final step, the cost estimates were transferred into different money equivalents (see table 4-4 and 4-5 in chapter 4.4). In sum, twelve value-of-money indicators were defined in chapter 4.4 for the interpretation of past amounts of money: six standardized money equivalents (Gulden 1721-1745, Kronen 1913, € 2012 each both using the "Labor & GDPPI" and "Food & CPI"), four food equivalents (kg bread, kg beef, liter wine, liter oat) and two labor equivalents (days unqualified / qualified labor). For each method a minimum (MIN), medium (MED) and maximum (MAX) estimate was calculated (table 5-8) by transferring either the cost estimates from NCU or DCU depending on the direction of the calculation into money equivalents: For the guide wall from 1548-1558, the initial estimate on the individual measure in DCU is around 11,000 - 50,000 fl. 1721-1745. 1 fl. 1721-1745 equals around 9.2 - 9.8 kg beef in this time, which leads to an estimate of 101 - 492 tons (1 ton = 1,000 kg) of beef. According to the *Labor & GDPPI*, there is a constant exchange rate over time of 1 fl. 1721-1745 to 7.7 K 1913 which leads to an estimate of 84,000 - 385,000 K 1913 for this entry in the DB (table 5-8). The nominal estimate for the cut-off from 1870-1875 (1.3 million fl. ÖW) would be equivalent to the costs of 2,160 - 2,320 tons beef as 100 fl. correspond to 172 - 188 kg beef, and 1 fl. nominally equals 1.05 fl. ÖW.

Labor equivalents state the amount of labor one might have paid instead of spending the expenses on hydraulic engineering. Food equivalents provide "values of money" from everyday life (how much beef / wine / oat / bread could I buy)? The tools *Labor & GDPPI* (from the perspective of the entire economy) and *Food & CPI* (from the perspective of households) use overall price trends for the comparisons. For example "IFP_0" the *Donauinsel / New Danube* would have cost c. 3 billion K 1913, based on the *Labor & GDPPI*, 82,000 tons of beef and 26 million duql. The lower Danube cut-off from the *GDR* (no. 278 in table 5-6) might be interpreted as 1.3 million duql, 2,200 tons beef and 2.9 million K 1913, the guide wall from 1548-1558 as 140 tons beef, 54,000 duql and 112,000 K 1913. Thus, expenses on the Danube cut-off, for all methods, were valued around 15 to 25 times above the guide wall. The interpretation for the large project from 1972-1987 compared to the former cut-off is highly ambiguous (compare chapter 4.3): the cost of the project is weighted between c. 25 (duql) and 500 (*Labor & GDPPI*) times higher. Due to the increase of the productivity, the "effort" in terms of labor for projects in Modern times appears comparably little. For some documented food prices, there are strong yearly fluctuations in the data. Thus, the uncertainties for the *Food & CPI*, oat or wine equivalents tend to be larger than the uncertainties for the beef and labor equivalents and standardized money equivalents deflated by the *Labor & GDPPI*.

Selected price and cost estimates for entries from the original DB were transferred back to the *ArcGIS* geodatabase. Hence, the spatial distribution of expenses on individual measures could be visualized: figure 5-11 shows the extent of assigned estimates in duql to the database of linear measures as columns, figure 5-12 refers to expenses estimated for the measures in the database of areal measures. More detailed illustrations will follow in chapter 6.3.3 for different project categories. The height of the columns represents the extent of the expenses.

Table 5-8: Cost estimates for three exemplary DB entries based on twelve money equivalents; IDs: "28" = guide wall 1548-1558, "278" = cut-off 1870-1875; "IFP_0" = New Danube/Donauinsel 1972-1987.

Cost estimates for three selected measures interpreted with 12 money equivalents									
OBJECTID *		28	278	IFP_0	OBJECTID *		28	278	IFP_0
1000 fl. 1721-45 (Labor & GDPPI)	MED	25	375	230,459	1000 fl. 1721-45 (Food & CPI)	MED	35	446	123,782
	MIN	11	358	166,570		MIN	13	434	89,910
	MAX	50	394	393,379		MAX	85	460	210,963
1000 K 1913 (Labor & GDPPI)	MED	188	2,868	1,764,092	1000 K 1913 (Food & CPI)	MED	218	2,795	775,250
	MIN	84	2,737	1,275,039		MIN	79	2,718	563,110
	MAX	385	3,019	3,011,186		MAX	535	2,882	1,321,263
1000 € 2012 (Labor & GDPPI)	MED	116	1,760	1,082,162	1000 € 2012 (Food & CPI)	MED	335	4,306	1,194,199
	MIN	51	1,679	782,158		MIN	122	4,187	867,417
	MAX	236	1,852	1,847,177		MAX	824	4,440	2,035,281
1000 days unqualified labor	MED	92	1,259	25,638	1000 days qualified labor	MED	63	778	21,773
	MIN	40	1,239	16,667		MIN	27	767	14,189
	MAX	210	1,278	57,967		MAX	132	791	49,961
tons beef	MED	236	2,201	81,694	m³ oat	MED	3,295	31,871	-
	MIN	101	2,164	64,220		MIN	1,130	29,912	-
	MAX	492	2,316	146,138		MAX	7,543	35,228	-
tons bread	MED	-	7,697	648,370	m³ wine	MED	372	3,882	351,345
	MIN	-	6,292	416,667		MIN	93	3,882	253,623
	MAX	-	9,103	1,100,629		MAX	2,107	3,882	415,430

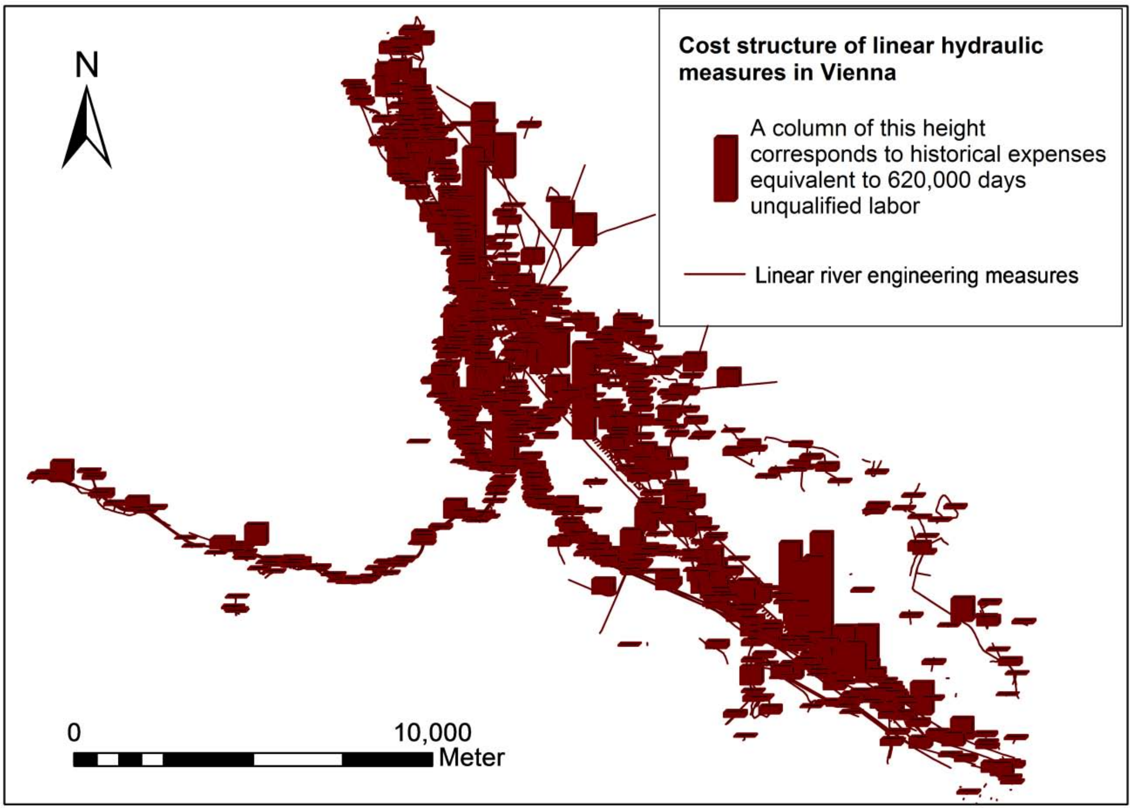

Figure 5-11: Spatial distribution and extent of cost estimates on linear river engineering measures from the original DB in *days unqualified labor equivalents*.

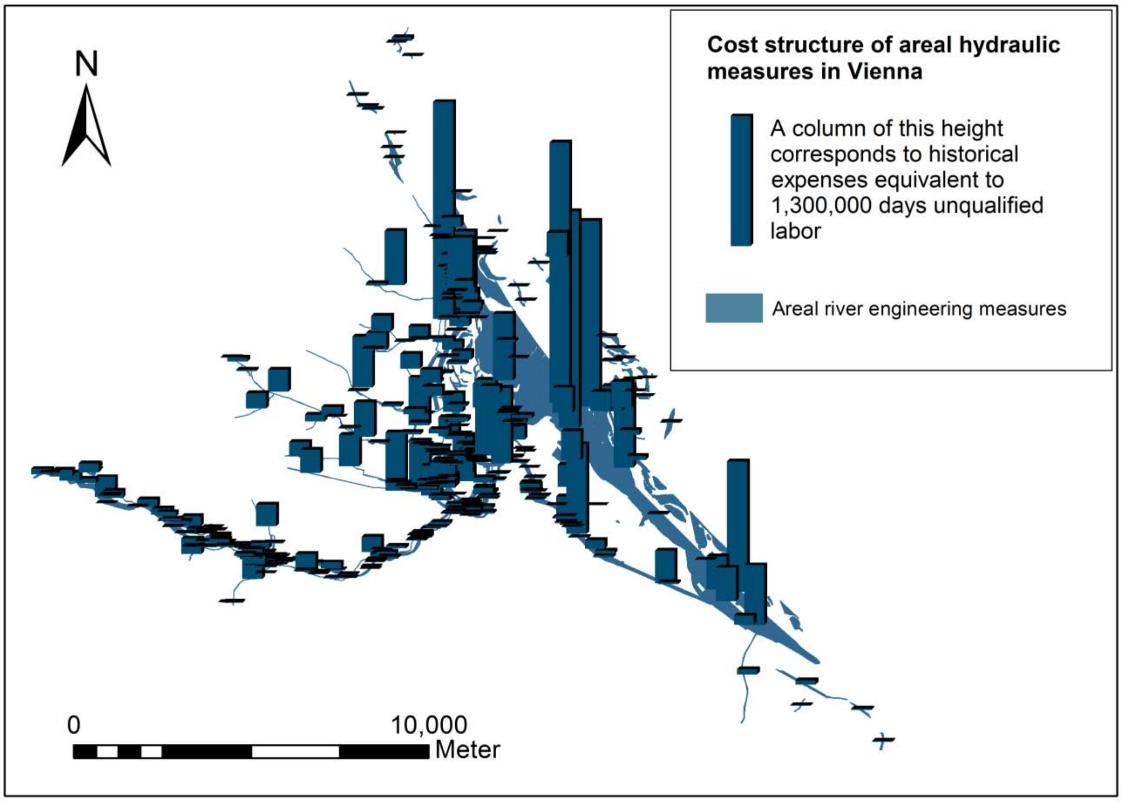

Figure 5-12: Spatial distribution and extent of cost estimates on areal river engineering measures from the original DB in *days unqualified labor equivalents*.

5.5 Temporal patterns of construction prices and cost-efficiencies

This chapter analyses the overall temporal pattern of pooled prices and cost-efficiencies based on an interpretation of prices as *labor equivalents*. In appendix III the temporal pattern and spatial distribution of applied prices in the DB have been illustrated in several figures for prices in K 1913 and in duql.

The derived medium prices in *days unqualified labor equivalents* (*duql*) *per m or ha* and the medium cost-efficiencies (= effective prices) in *duql per m or ha & year* for the measures in the DB (chapter 5.4) were illustrated in *box-and-whisker-diagrams* (figures 5-13 to 5-20). The distribution of assigned values in the database for each time interval is shown: The vertical line is the span from minimum (MIN) to maximum (MAX), the horizontal bar marks the median (MED), separating the upper half of values from the lower half. The box contains the middle half of prices in each decade. Only individual measures from the Viennese Danube floodplain (excluding tributaries) from 1540 till 1910 were considered and four categories of measures have been analyzed separately: “Embankments and closure dams”, “guide walls and spur dikes”, “flood and infrastructure dikes” and “channels and excavations”. The temporal distribution of the prices for certain construction types applied to the river engineering database can be understood as indicator for the change of the actual societal effort which was approximately necessary for a meter or hectare of hydraulic structures according to the chosen value-of-money indicator from chapter 4.4. The effective price is the price for a meter or hectare of a structure functioning for one year without a repairing. The range of the cost-efficiencies of the measures of a time interval can be interpreted as an indicator for the ability of society to transform the riverscape in the intended way by the means of hydraulic engineering. The used unit is in fact reciprocal to the actual efficiency of the expenses (see chapter 6.2.2). Low values stand for great efficiencies and vice versa.

As a method of interpretation of changes in absolute and effective prices over time labor equivalents have been preferred to the *Labor & GDPPI*: All predicted prices are compared to the value of labor of an unqualified mason (compare chapter 4.2). One has to consider that real wages in the late 19th century increased relative to the *GDP price index* as labor is more productive (and more valuable in the economy) at the end than at the beginning of the 19th century. Before 1830, there are only minor differences between the two methods because the *Labor & GDPPI* equals the *labor price index* in this time (see chapter 4.3). As the productivity of labor influences the extent of absolute prices and effective prices in duql, the effort for society and the ability of society to transform the floodplain are approached from an employer's perspective, observing the ratio between hydraulic prices per extent and prices for days of unqualified labor over time. The approach asks: How many day laborers could I hire for one day for the costs of implementing 1 m or ha of a hydraulic measure.

For (figure 5-13) "embankments and closure dams" many values lie between 40 and 140 duql / m. The same applies to "spur dikes and guide walls" (figure 5-15), but in the 19th century where much data is available, the prices are generally above those for the group of "embankments and closure dams". Due to the lack of data from 1650 to 1770, the same price levels were applied to both groups. In accordance with the documentation, prices for renewed spur dikes and guide walls around 1600 appear particularly outstanding (up to 500 fl. / m). The use of more massive structures in the late 16th century might have been a reaction to the little effect the previous measures had shown. Median values of around 100 duql seem intuitively rather high and inappropriate for only 1 m of a regulation measure. However, the documented wages and the documented prices for regulation measures leave no doubt that this relationship is all in all correct: In 1590, 1 fl. nominal money equal around 7.5 days labor of a mason (PŘIBRAM, 1938; unskilled mason wage: 8 kr. / day; 1 fl. = 60 kr.). Thus, 100 duql correspond to around 13 fl. In 1870, 100 days of unqualified labor corresponds to c. 100 fl. ÖW (SANDGRUBER, 1994; unskilled mason wage c. 6 fl. ÖW per week). Not the entire price for a meter or hectare was spent on day-laborers, but beyond well-respected engineers, administrational issues, material, transport and technology were paid from the budget of measures. There were always fewer day-laborers employed for the constructions, than indicated by the following price equivalents. Furthermore, the real day-laborer wages in pre-industrial times were far below the present minimum wages (see appendix II). A meter length of a regulation measures may contain several cubic meters of stone works.

The effective prices (figure 5-14 and 5-16) for the decades were decreasing strongly over time for regulation measures: The decadal median for embankments and closure dams was varying between around 8 and 95 duql / m & year from 1530 to 1730, as opposed to values of 7.6 - 10.4 (1730-1780), 2.1 - 6.7 (1780-1870) and 0.5 - 0.8 duql / m & year (1870-1900). For guide walls the median was mostly 10 - 90 duql / m & year (1530-1750), usually 2.6 - 8.1 (1750-1870) and always 0.9 - 1.5 (1870-1900). That means the cost-efficiency for regulation measures had become more predictable during the 18th century. In the 19th century the increasing use of more expensive stone works, in contrast to the wood constructions or combined wood/stone constructions which were used till then, led to a greater stability and durability of many measures. The cost-efficiency improved again strongly with the *Great Danube Regulation (GDR)* around 1870 which has to do with the use of an overall concept which was more final, in that sense, that the overall configuration of the Danube was maintained since then. In contrast, many constructions from 1830-1870 became invalid during the GDR.

The present data indicates that the prices for "channels & excavations" (figure 5-17) were between 5,000 and 30,000 duql / ha from 1530 to 1700 and in the 19th century. After 1700, for the first time more massive structures were implemented and the applied prices were 65,000 - 150,000 duql / ha. Problems to control continuous siltation were documented for respective efforts. The effective prices (figure 5-18) for excavation measures strongly improved after 1830: The decadal median ranged from 250 to 1,880 duql / ha & year as opposed to mostly 2,500 - 16,000 duql / m & year for the period 1530-1830. After 1830 the material transfer became much easier due to the use of fossil fuels and new steam machines. More data would be required to confirm and specify this pattern over time (see chapter 5.2). A square meter bed excavation (dredging) may contain volumes of few cubic meters, and for excavations of new channels (e.g. cut-offs), much higher volumes of excavated material depending on the elevation of the terrain surface above the Danube water level.

As more massive and higher structures became more common prices for “flood and infrastructure dikes” increased after the great ice-jam flood in 1830 to around 40 - 65 fl. / m for a majority of the implemented dikes (figure 5-19). Before 1830 a majority of the estimated prices ranged from 10 - 60 fl. / m. Although dikes can be considered as more massive structures than embankments, the median prices for embankments – often stone structures after 1830 – in most decades were above the median prices for dikes, mostly made of loose material. Thus, their volume price was cheaper. The greater durability of dikes compensates the price increase and there is no significant change observed in the median of effective prices of (figure 5-20) with 0.8 - 4.8 duql / m & year in most decades from 1770-1900.

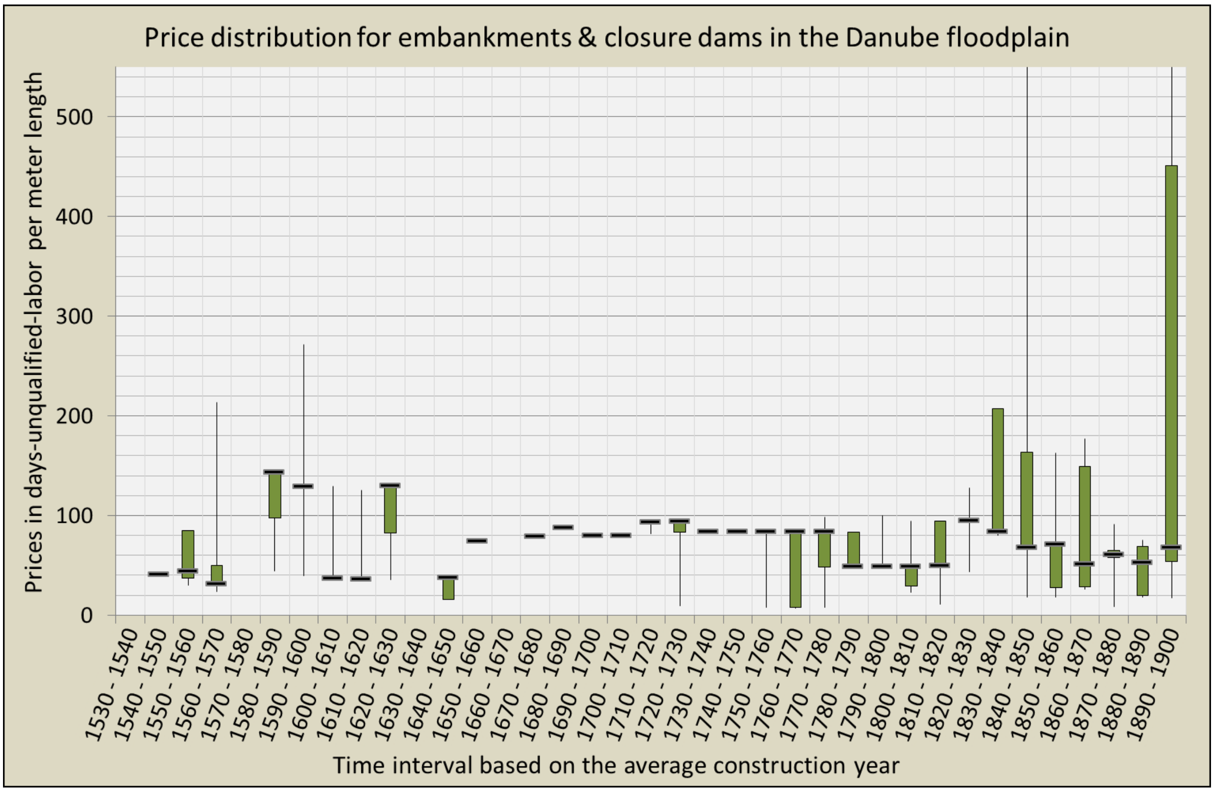

Figure 5-13: Distribution of prices per meter length of embankments and closure dams in the Viennese Danube floodplain in each decade from 1530 to 1900.

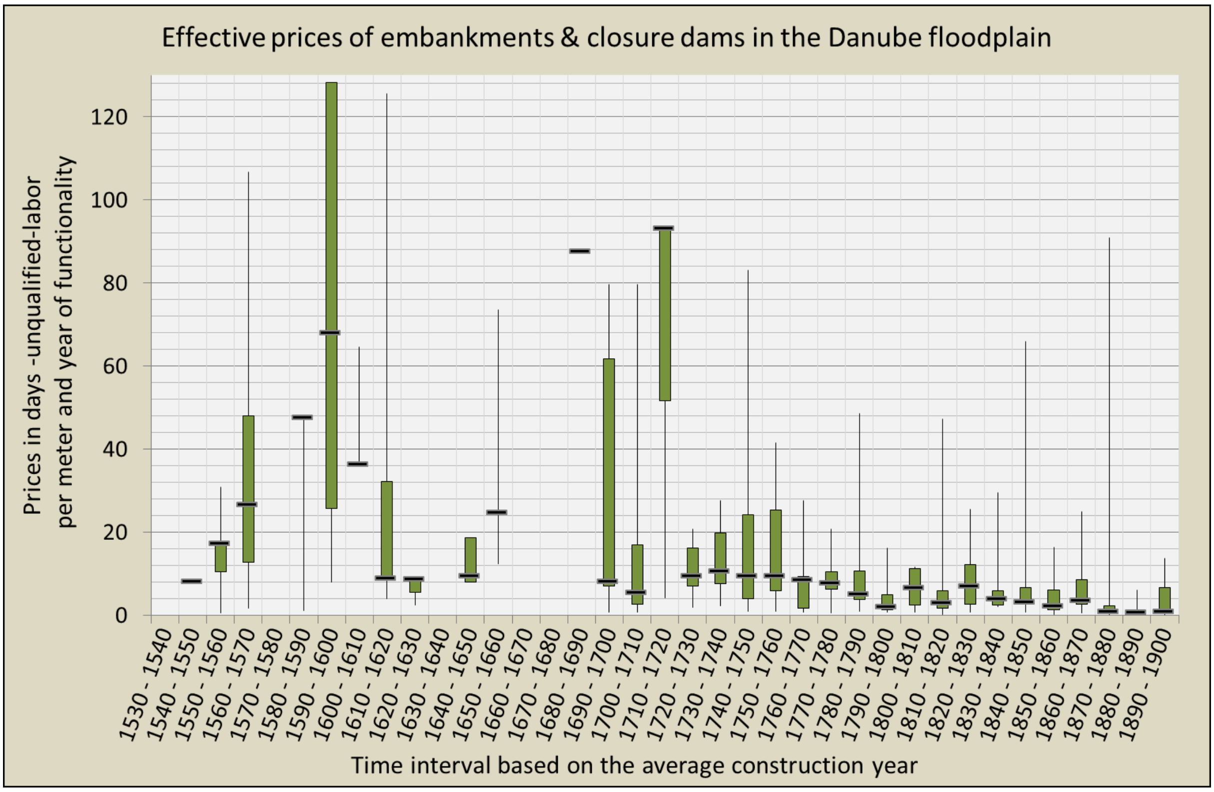

Figure 5-14: Distribution of effective prices per meter length and years of functionality (efficiency) of embankments and closure dams in the Viennese Danube floodplain in each decade from 1530 to 1900.

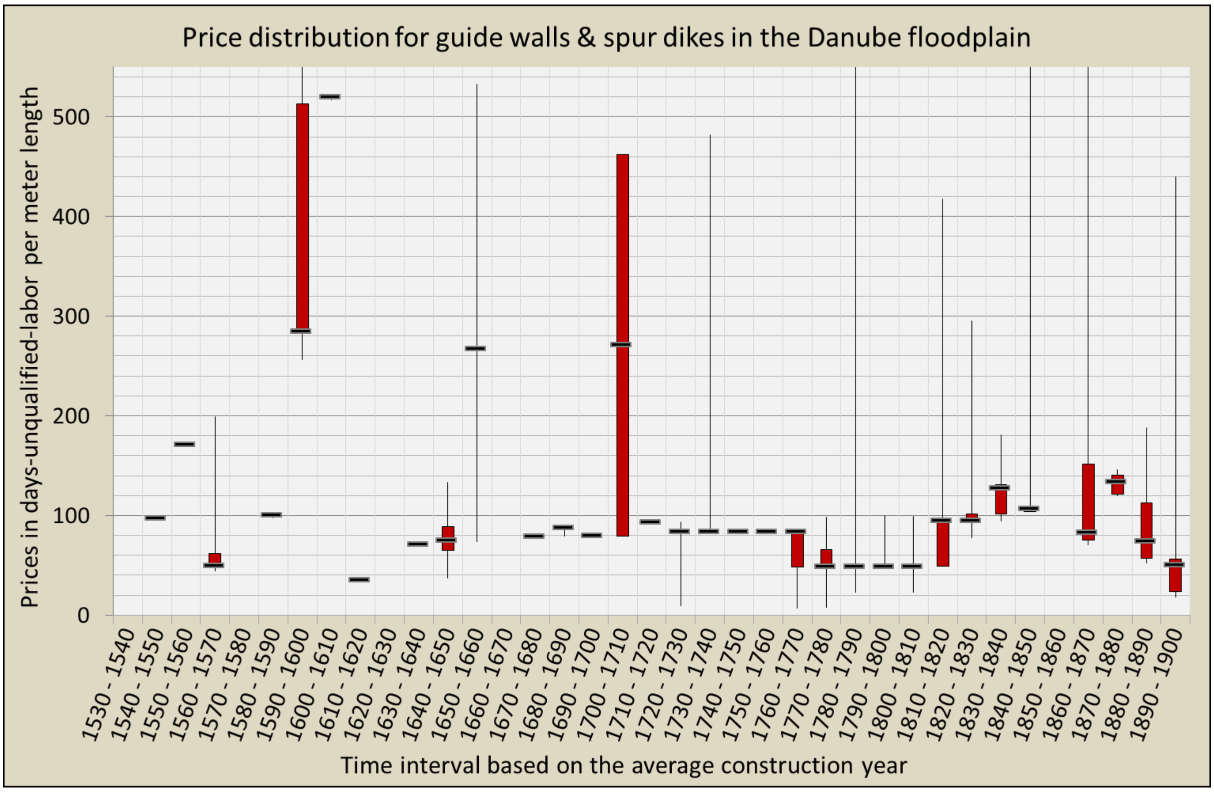

Figure 5-15: Distribution of prices per meter length of spur dikes and guide walls in the Viennese Danube floodplain in each decade from 1530 to 1900.

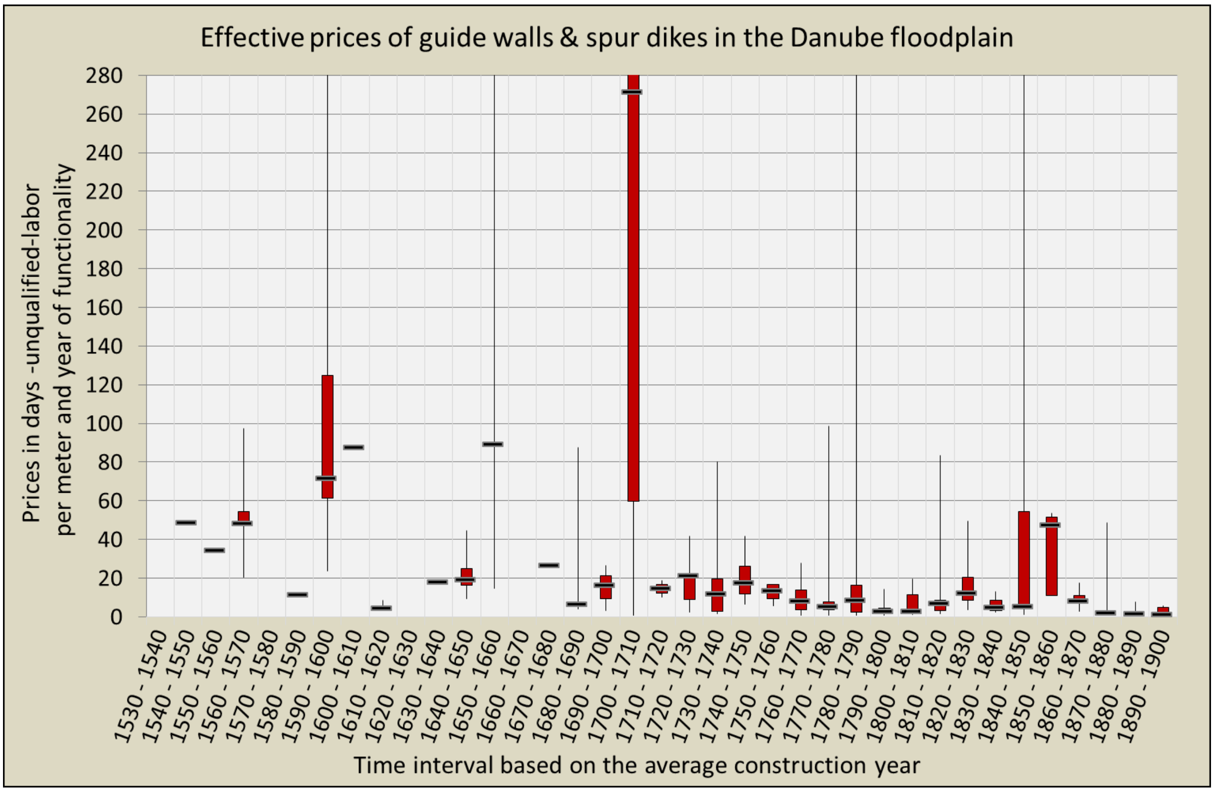

Figure 5-16: Distribution of effective prices per meter length and years of functionality (efficiency) of spur dikes and guide walls in the Viennese Danube floodplain in each decade from 1530 to 1900.

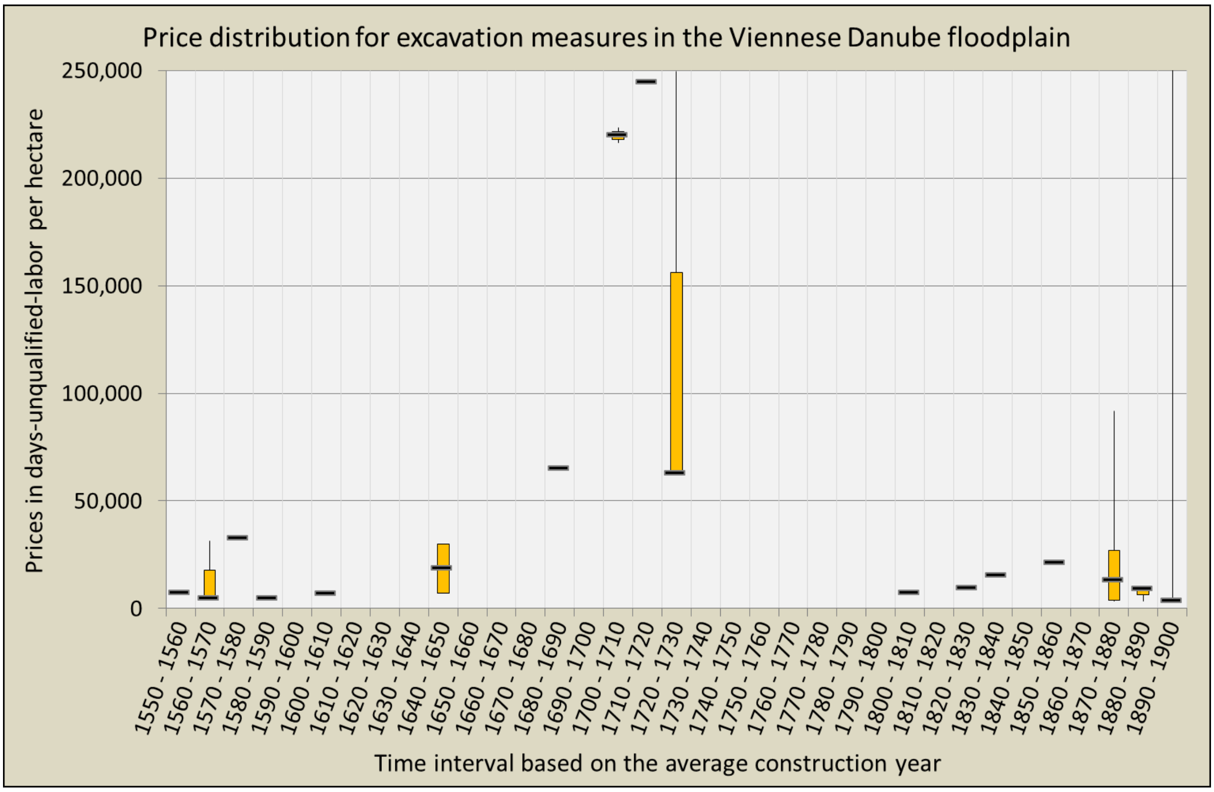

Figure 5-17: Distribution of prices per hectare of new channels and bed excavations (dredgings) in the Viennese Danube floodplain in each decade from 1530 to 1900.

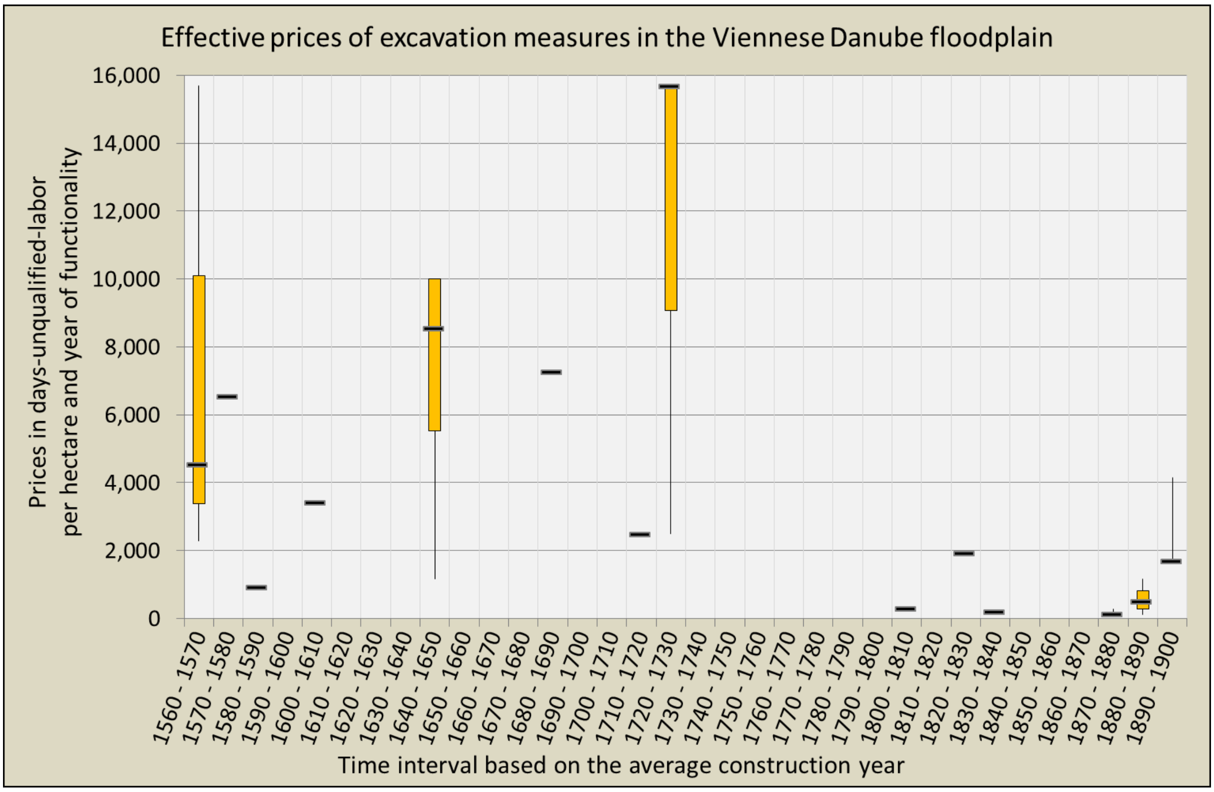

Figure 5-18: Distribution of effective prices per hectare and years of functionality (efficiency) of channels and bed excavations (dredgings) in the Viennese Danube floodplain in each decade from 1530 to 1900.

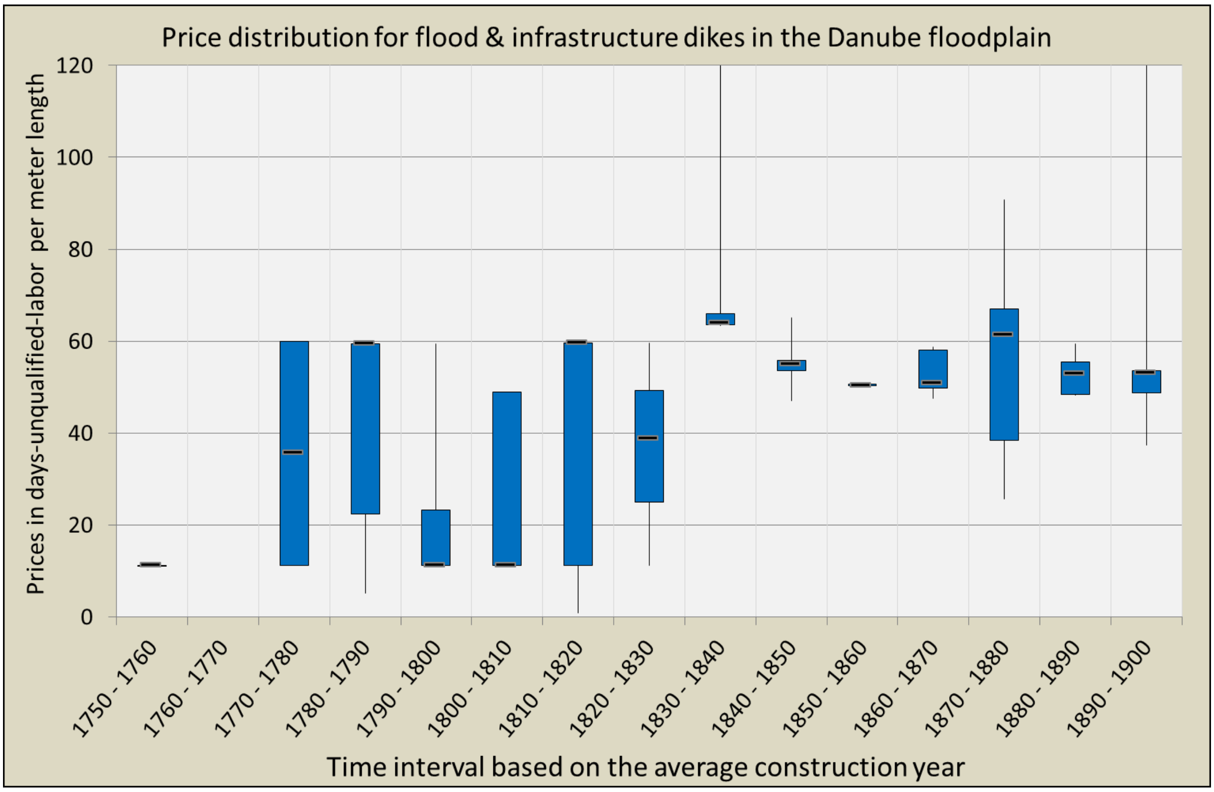

Figure 5-19: Distribution of prices per meter length of new flood and infrastructure dikes in the Viennese Danube floodplain in each decade from 1750 to 1900.

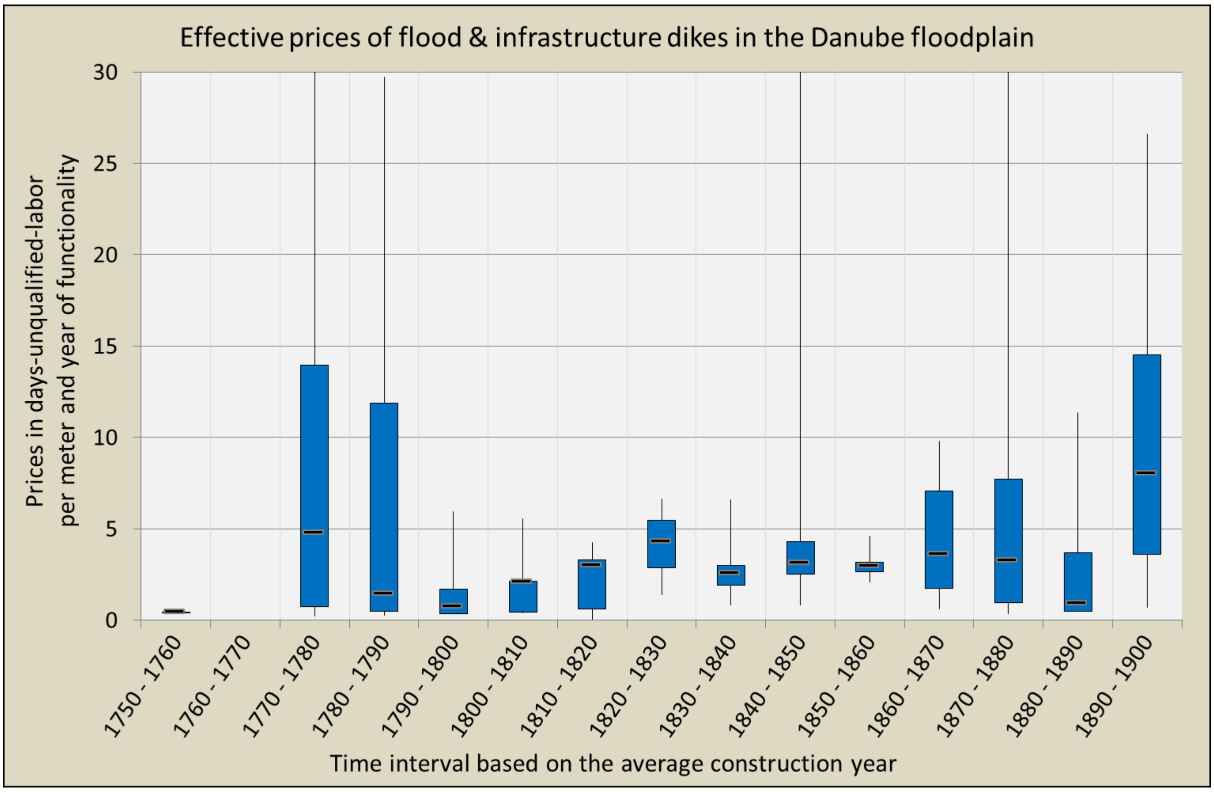

Figure 5-20: Distribution of effective prices per meter length and years of functionality (efficiency) of new flood and infrastructure dikes in the Viennese Danube floodplain in each decade from 1750 to 1900.

6 PART C: HISTORICAL COST DEVELOPMENT OF HYDRAULIC ENGINEERING IN VIENNA

6.1 Estimated expenses on hydraulic engineering in Vienna

6.1.1 Total cost volumes per time interval

Based on the cost estimates for all database entries, sums of the financial means spent on hydraulic engineering in Vienna per time interval were calculated. On the following pages the most central results are presented: The availability of twelve value-of-money indicators from chapter 4 required a selection of particularly illustrative methods for this presentation. A priority was given to provide a sketch of the "big picture" rather than focusing on too many details which might rather be a topic for future studies. The available data allows illustrating results of a systematic study between around 1530 and 1905. Before 1530, the results rely on little information only and after 1905 only selected major projects were included (see chapter 3). Chapter 5 resulted in cost estimates with different qualities for each project and individual measure expressed with the different money equivalents. These cost estimates were added up under different points of view, and using different specifications in the DB entries. First of all, cost volumes per time interval were calculated based on the fifty-two time intervals defined earlier and they refer to the cost estimates for all DB entries from the "project" list (chapter 3.2). Hence, wherever possible, safely-documented money amounts for entire projects were used instead of referring to the price estimates for each individual measure of a project. As the calculation can only contain estimates for documented hydraulic measures (chapter 3; HOHENSINNER et al., 2012) the results should rather be understood as a minimum range. For example, annual maintenance works are usually not known and mostly not part of the database, except for few well-documented cases (e.g. several constructions from the 1560s and the mid-19th century). *Minimum* cost estimates represent in fact an absolute minimum estimate based on the assigned price ranges and based on the documented values of money for the measures. In contrast, the *maximum* estimate represents a maximum potential which can be argued by what is documented at present. The *mean* (= *medium*) estimates can be considered as the most likely estimate which comes closest to the data in historical sources by using median "values of money" and exactly the documented extents, expenses and prices.

Figure 6-1 illustrates the estimated minimum (MIN), the most likely medium estimate (MED) and a maximum potential (MAX) of expenses on hydraulic engineering in Vienna per time interval in *Kronen (K)* at price levels of the year 1913, both based on the standardization with the *Labor & GDPPI* (hereinafter: K $1913_{Labor\&GDPPI}$) and with the *Food & CPI* (= K $1913_{Food\&CPI}$). The *Labor & GDPPI* rather reflects price developments in the entire economy, while the *Food & CPI* takes the consumer's perspective on price trends in the economy (see chapter 4). Alternatively, in figure 6-2, the expenses have been interpreted with the amount of labor equivalent to the expenses, expressed in *days of unqualified labor* (hereinafter only: duql). This method is particularly illustrative due to its intuitively understandable meaning and its relationship to river engineering projects, which are at least partly a result of local labor. For reading the graph, one may imagine a number of "unskilled" masons (in the 20th century low-qualified assistant workers), that could have been employed in Vienna for one day, for the amount of money spent on hydraulic engineering in the respective time interval. The logarithmic scale of the graphs allows grasping a first idea of the overall pattern over the entire time period. For all indicators, the years around 1540, 1700, 1830 and 1910 appear as significant turning points in the cost structure. It is a good starting point to describe the yearly average expenses first for the three time periods in between these years: From 1830 till 1910, the average yearly expenses would range from 1.97 million (MIN) to 3.16 million K $1913_{Labor\&GDPPI}$ (based on the MIN and MAX estimate) while the mean estimate (MED) is 2.43 million

K $1913_{Labor\&GDPPI}$. Alternatively, using the deflation method *Food & CPI*, the estimates range from 1.87 to 3.01 million K 1913 per year (mean 2.31 million K 1913), and, based on labor equivalents from 754,000 to 1.23 million duql / year (mean 941,000 duql). Between 1700 and 1830 the yearly average can be characterized as significantly lower: 159,000 - 363,000 K $1913_{Labor\&GDPPI}$ / year (mean estimate 253,000 K $1913_{Labor\&GDPPI}$), 98,000 - 294,000 K $1913_{Food\&CPI}$ / year (mean 184.000 K $1913_{Food\&CPI}$) and 82,400 - 188,000 duql / year (mean 132,000 duql). The yearly average for the period 1540-1700 lies even below, between 36,000 and 118,000 K $1913_{Labor\&GDPPI}$ / year (64,000 K $1913_{Labor\&GDPPI}$), from 23,000 to 119,000 K $1913_{Food\&CPI}$ / year (52,000 K $1913_{Food\&CPI}$) and within the range of 16,900 to 59,100 duql / year (30,500 duql).

Summing up these numbers, the two price indices and the *days unqualified labor equivalents (duql)* indicate different ratios for the average yearly cost volumes between the three time segments: If the yearly expenses from 1700-1830 are considered as 100 %, based on the deflator *Labor & GDPPI* it would indicate that mean expenses in the years 1540 to 1700 equal only 25 %, while those from 1830 to 1910 are much higher with 960 %. Based on the *Food & CPI* the corresponding values are 29 and 1,260 % and for the estimate in *duql* the values are 23 and 710 %. That means, there is a certain mismatch between different methods. However, acceptable comparisons between 1540 and 1910 are possible. Little information is available before 1540, but the decadal expenses have probably been significantly lower. The so far selected projects for the 20th century indicate a major interruption of efforts after 1910 till about the 1960s. The comparison to present money lacks a non-ambiguous answer: average expenses of c. 150 million K 1913 and 2 million duql per year were estimated for the years 1970 to 2000. Thus, yearly expenses for these three decades would be more than an order of magnitude higher than those from 1870-1880 using the *Labor & GDPPI* for the standardization, which weights modern prices most among the available methods. The *labor equivalent* weights modern prices least among all available methods compared to prices before 1913 as follows logically to chapter 4.3. Yearly expenses from 1870-1880 would even slightly exceed those from 1970-2000!

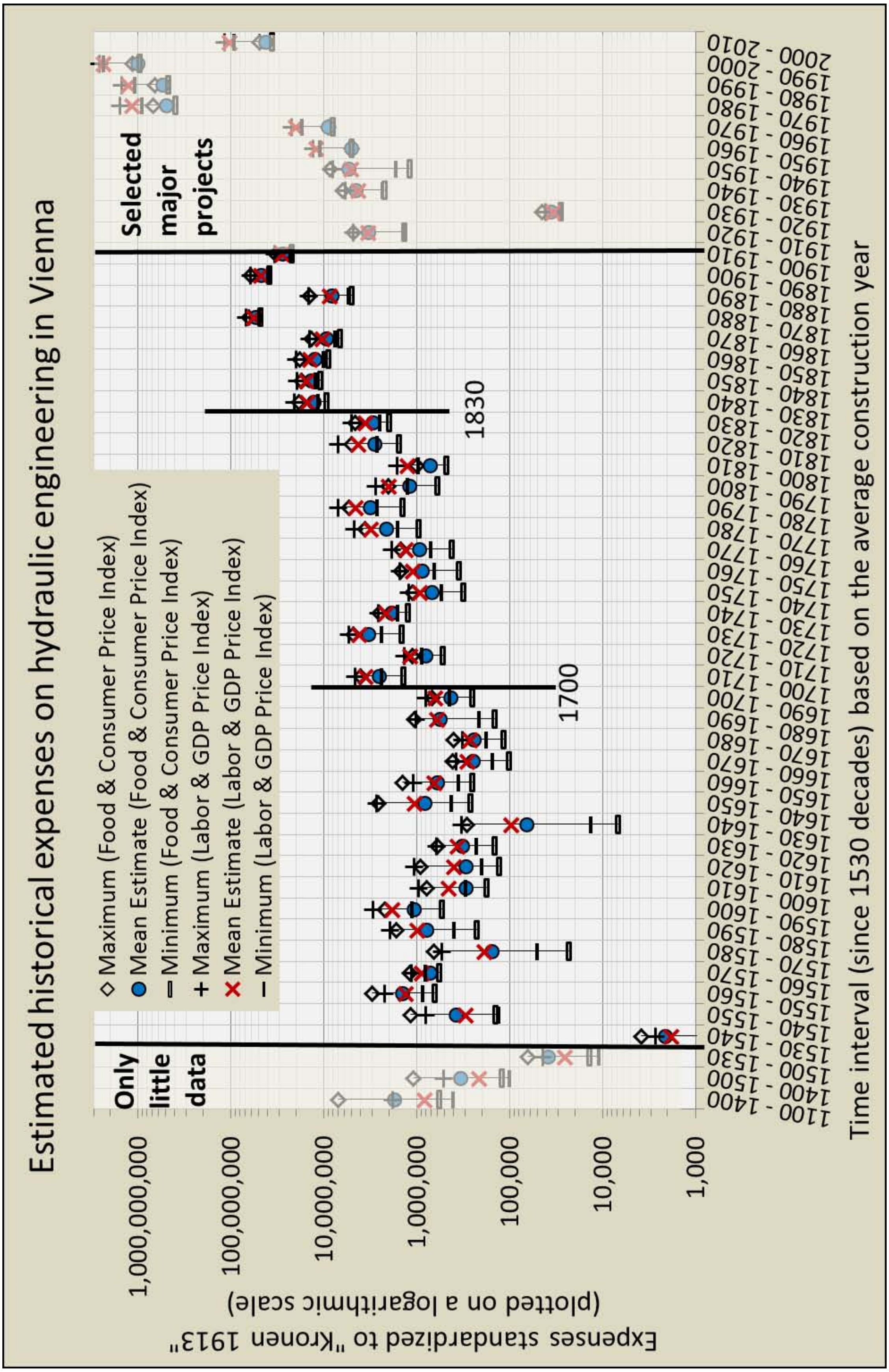

Figure 6-1: Estimated expenses on hydraulic engineering measures in Vienna per time interval standardized to Kronen in the year 1913 (K 1913); the values are deflated by the indices *Labor & GDPPI* and the *Food & CPI*, respectively (see <u>chapter 4.3</u>).

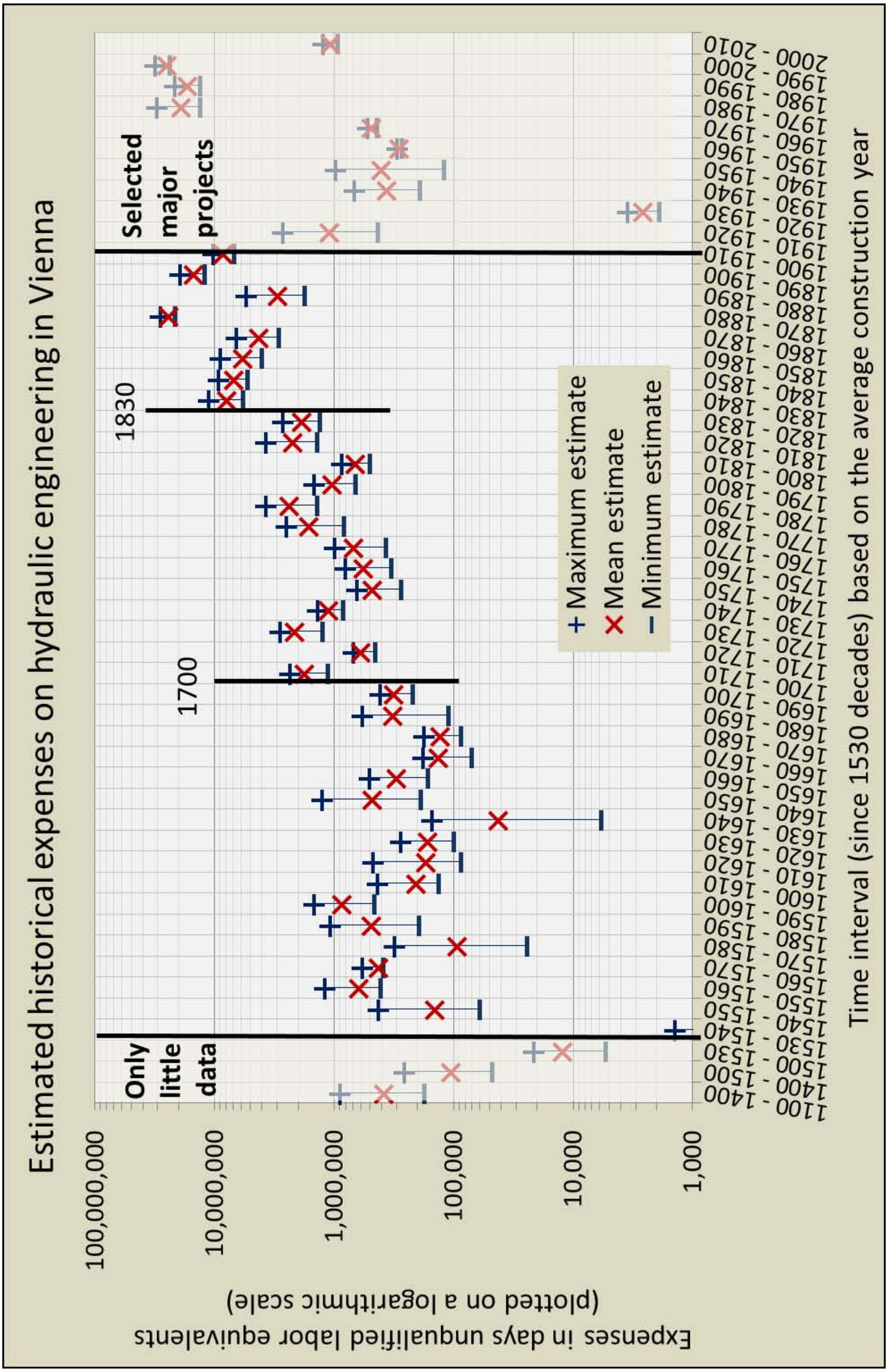

Figure 6-2: Number of days of unqualified labor equivalent to the estimated expenses on hydraulic engineering in Vienna per time interval based on wages in the time of implementation.

As alternative money equivalents the figures 6-3 and 6-5 show the result as amounts of oat or beef which could have been bought in Vienna (in cubic meter) for the expenses per time interval till 1910. The interpretation in “Gulden (fl.) 1721-1745” is attached in figure 6-4. Based on the minimum, maximum and medium the following yearly average values can be expected for three major periods: From 1540 till 1700 an equivalent of 347 - 2,015 m^3 of oat correspond to the average yearly expenses on river engineering in Vienna (mean estimate 791 m^3), from 1700 till 1830 it is 1,100 - 4,570 m^3 oat / year (2.370 m^3) and from 1830-1910 equivalents to 19,800 - 38,400 m^3 oat / year (26,800 m^3) were spent on average. From 1540 till 1700 an equivalent of 37 - 147 tons beef correspond to the average yearly expenses on river engineering in Vienna (mean estimate 72 tons). From 1700 till 1830 the estimate is 130 - 410 tons of beef / year (mean 235 tons). In the period 1830-1910 expenses equivalent to 1,310 - 2,230 tons of beef (mean 1,660 tons) were spent on average per year.

The values correspond to the result in “Kronen (K) 1913” divided by constant factors (for the *Labor & GDPP*: 1 / 7.6, and for the *Food & CPI*: 1 / 6.3). The interpretation to “Euro (€) 2012” is illustrated in figure 6-6 and can be obtained from multiplying the result in *K 1913* with 1.63 (*Labor & GDPP)* and 0.65 (*Food & CPI*). Once again, it is stressed, that the € 2012-reconstruction is not to be confused with a clear answer to the question: How much would the estimated past expenses be, expressed in present money? The large divergence of trends indicated by the *Labor & GDPPI* and the *Food & CPI*, particularly in the 20th century, leads to ambiguous results for most of the time from the perspective of 2012. In € 2012, the interpretations of average yearly cost estimates based on the *Food & CPI* for the three observed time segments (1540-1700, 1700-1830 and 1830-1910) are 1.8 to 2.4 times above the ones based on the *Labor & GDPPI*. In contrast, from the perspective of 1721-1745 (in fl.) and 1913 (in K) the interpretations are more similar and the estimates based on the *Food & CPI* equal those for the *Labor & GDPPI* multiplied by factors between 0.7 and 1.2. As methods of interpretation the reference years 1721-1745 and 1913 provide clearer statements and were preferred to 2012 for comparisons of money amounts from 1540 to 1910.

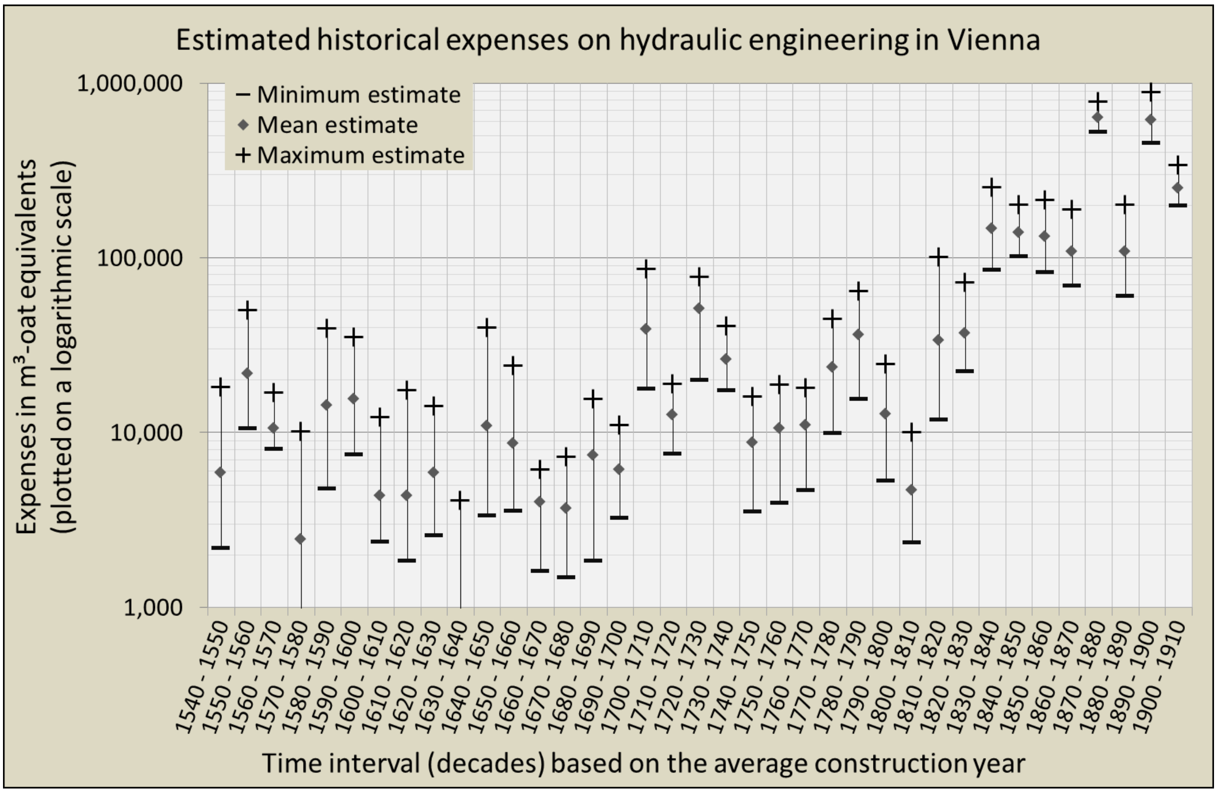

Figure 6-3: The amount of oat in (cubic meters) per decade equivalent to the estimated expenses on hydraulic engineering measures in Vienna at prices in the time of their implementation.

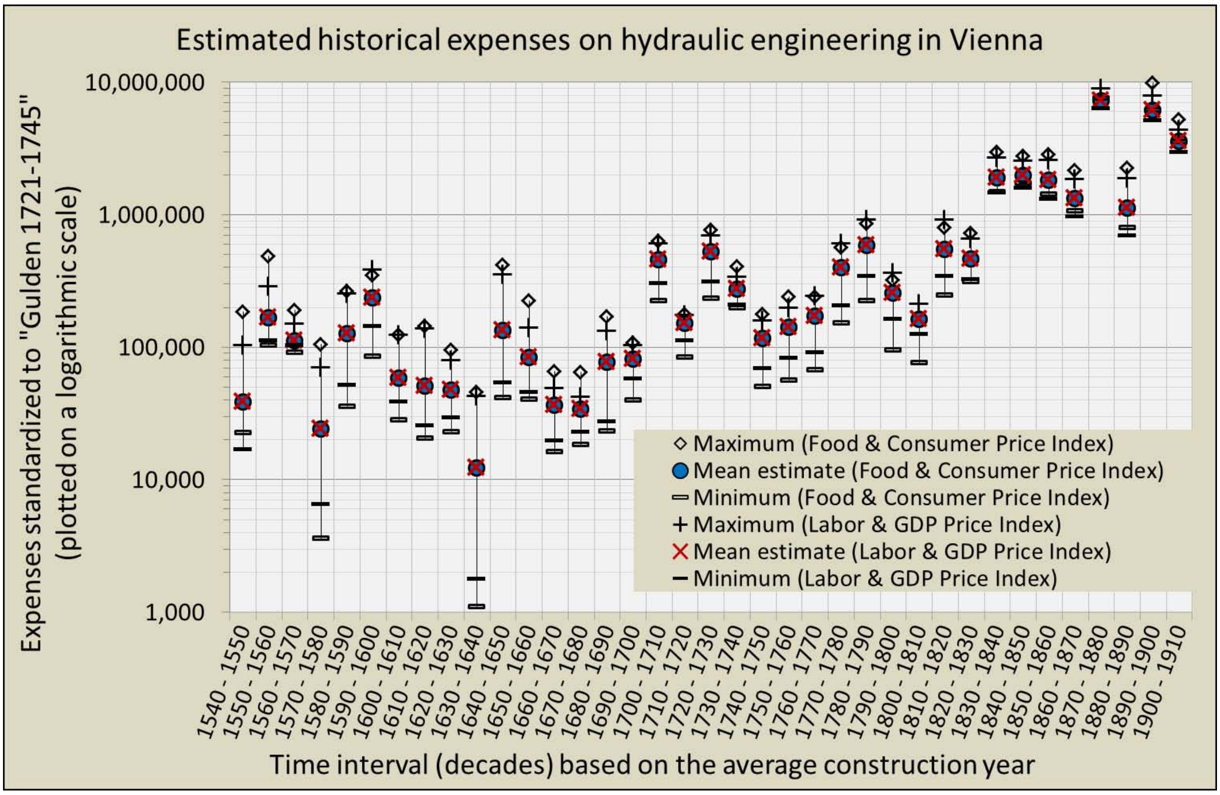

Figure 6-4: Estimated expenses on hydraulic engineering in Vienna per decade standardized to "Gulden (fl.) 1721-1745" with the *Labor & GDPPI* and the *Food & CPI*.

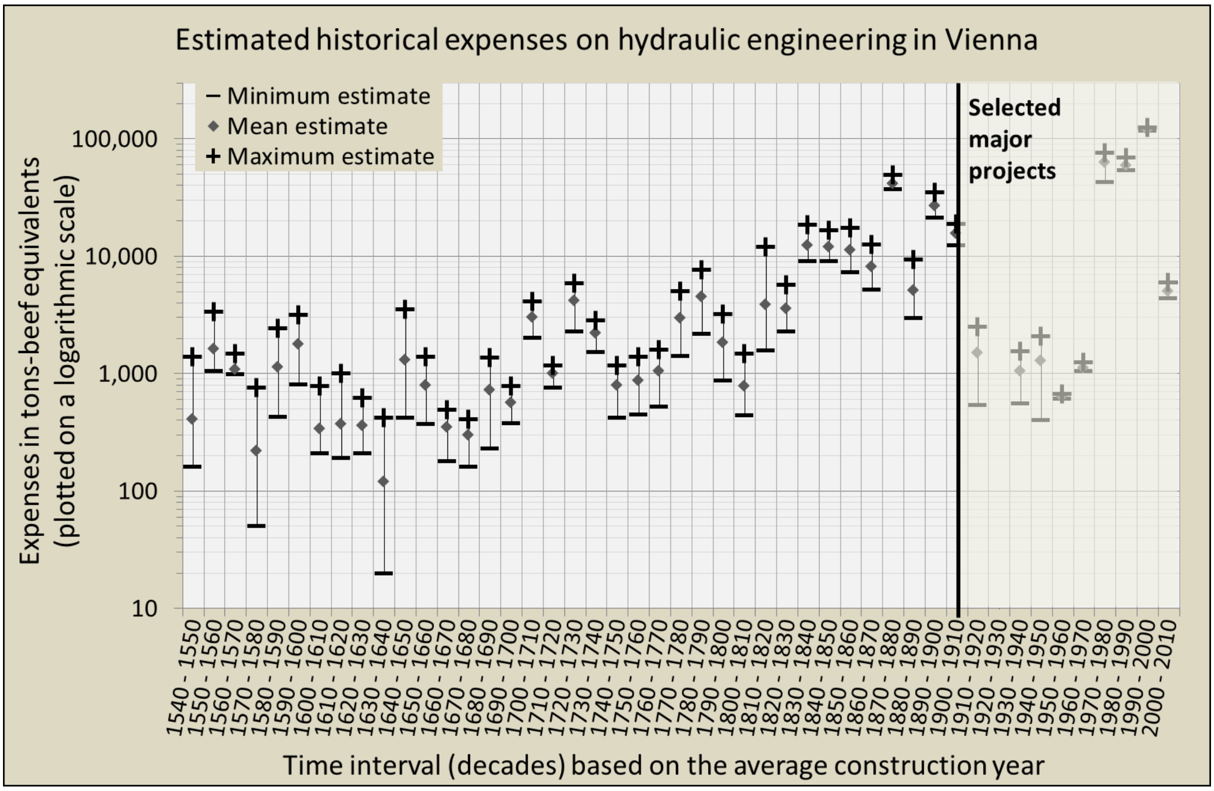

Figure 6-5: The amount of beef (in tons) per decade equivalent to the estimated expenses on hydraulic engineering measures in Vienna at prices in the time of their implementation.

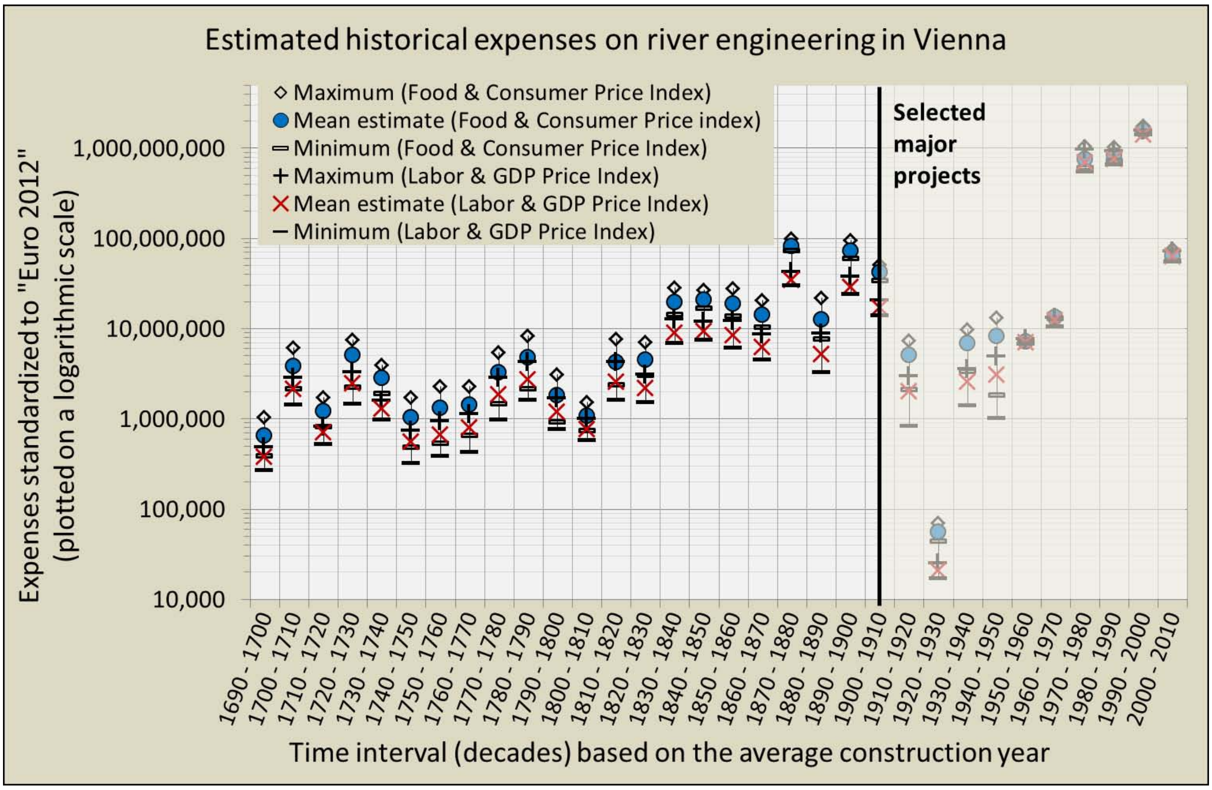

Figure 6-6: Estimated expenses on hydraulic engineering measures in Vienna per decade in standardized to “Euro (€) 2012” with the *Labor & GDPPI* and the *Food & CPI*.

For food equivalents, the yearly expenses in the periods 1540-1700 and 1830-1910 compared to those from 1700 to 1830 would equal 31 and 710 % according to the *tons beef equivalent* and 34 and 1,130 % based on *m³ oat equivalent*. In appendix IV.1 the results for the further methods are illustrated and the cost volumes are expressed in “cubic meters of wine” and “tons of bread”.

Compared to the years 1700-1830, the average yearly expenses, considering mean estimates and based on all available money equivalents, are 7 - 13 times higher in 1830-1910 and 3 - 4 times lower in 1540-1700. An overview of the average cost estimates for the three time periods and based on the twelve value-of-money indicators is given at the end of this chapter (chapter 6.3.3 in table 6-1).

The following diagrams examine the three time periods 1540-1700, 1700-1830 and 1830-1910 more closely. As described in chapter 3.2, each “time interval” represents a distinct number of entries in the DB, even when parts of the construction period may lie in previous or following decades. Hence, peaks in single decades should be interpreted carefully and considering the exact descriptions of DB entries. In figure 6-7 the results from 1540 to 1830 were expressed in “Gulden (fl.) 1721-1745”, in figure 6-8, the *days unqualified labor equivalents* to the expenses were illustrated. The decadal expenses in the late 16th century are generally weighted higher than those from the 17th century: In the periods 1550-1570 and 1580-1600, the mean cost estimates vary between around 380,000 and 860,000 duql or 110,000 to 240,000 fl. $1721\text{-}1745_{\text{Labor\&GDPPI}}$ in each decade. In the 16th century, the uncertainty towards the maximum tends to be amplified by using the *Food & CPI* instead of the *Labor & GDPPI*. The mean estimates from the 17th century were lower with 160,000 to 320,000 duql, or 35,000 to 85,000 fl. $1721\text{-}1745_{\text{Labor\&GDPPI}}$ in most decades. Expenses in the years 1700-1710, 1720-1730, 1770-1790 and from 1810 to 1830 have apparently been significantly higher than those in the decades prior to 1700. The decades 1700-1710, 1720-1730 and 1780-1790 stand out with minimum cost volumes of around 1.2 million duql (300,000 fl. $1721\text{-}1745_{\text{Labor\&GDPPI}}$) and a maximum estimate for 1780-1790 with up to 3.7 million duql (920,000 fl. $1721\text{-}1745_{\text{Labor\&GDPPI}}$).

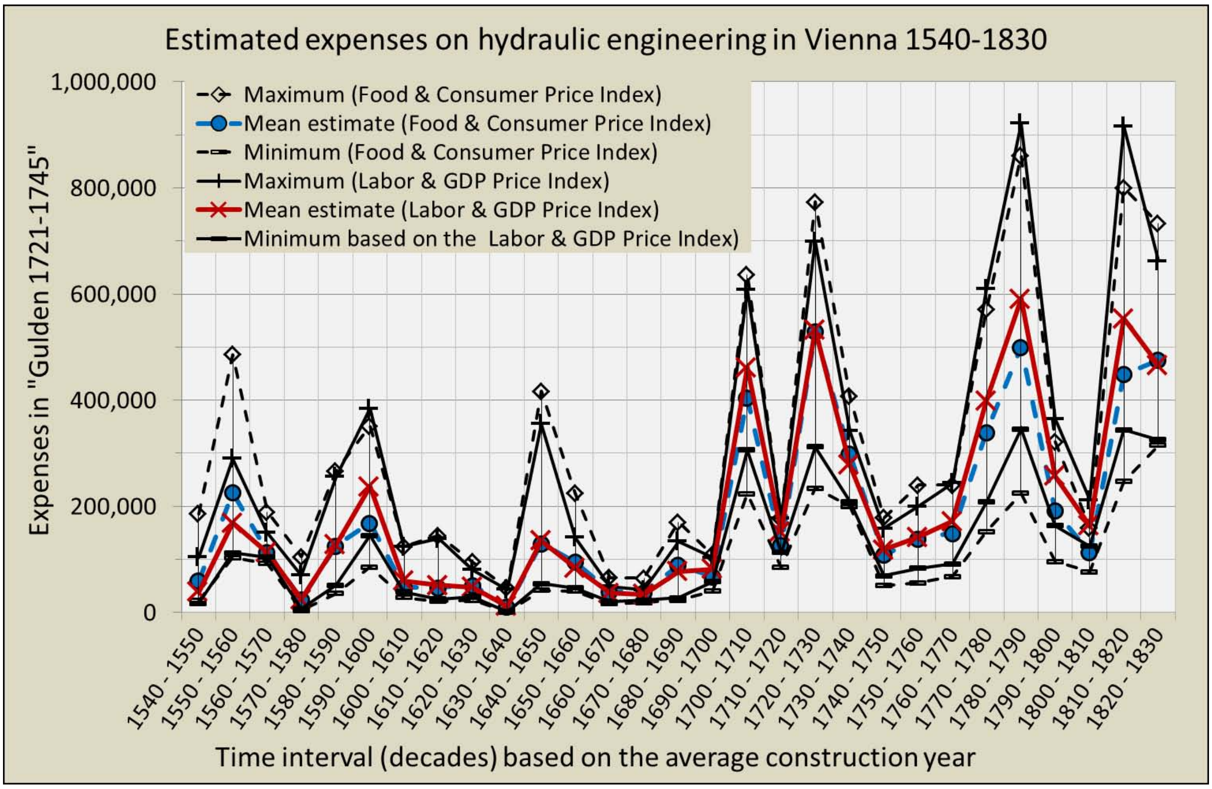

Figure 6-7: Historical expenses on river engineering in Vienna per decade between 1540 and 1830 standardized to "Gulden (fl.) 1721-1745" based on *Labor & GDPPI* and *Food & CPI*.

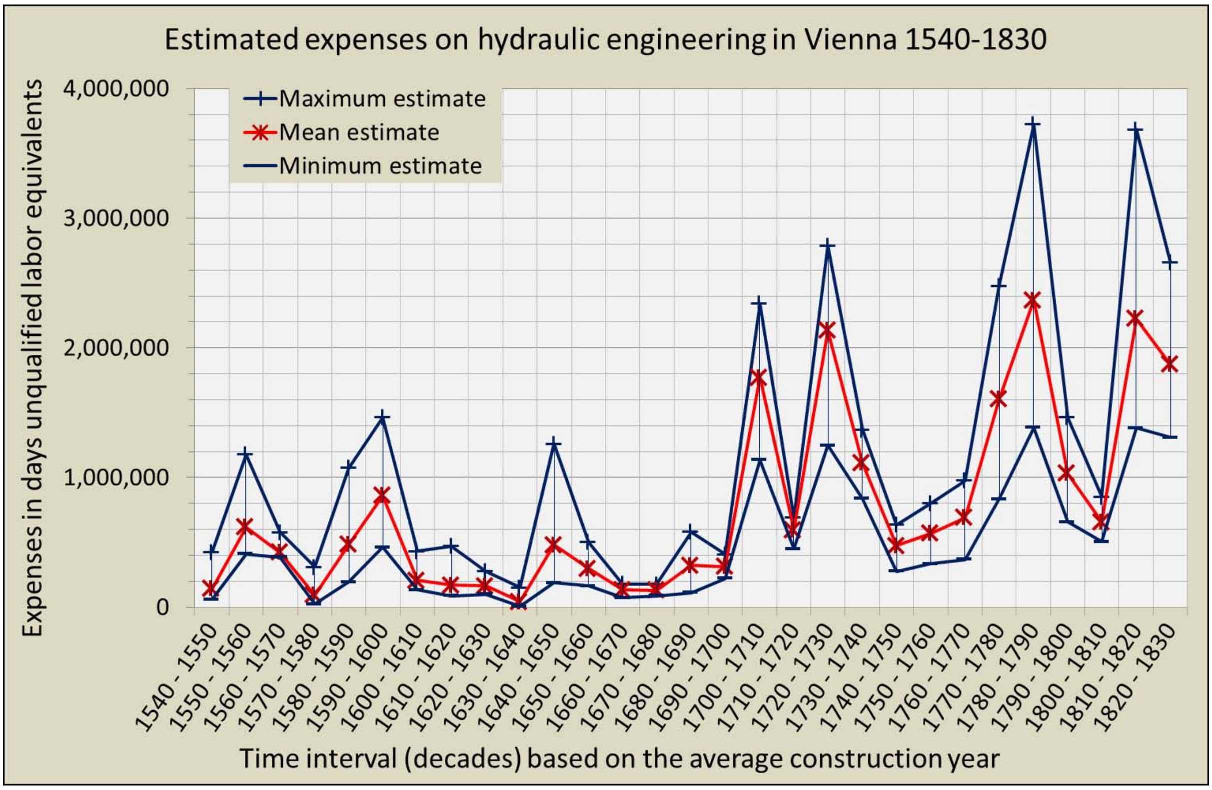

Figure 6-8: Historical expenses on river engineering in Vienna per decade between 1540 and 1830 expressed in days unqualified labor equivalents (duql).

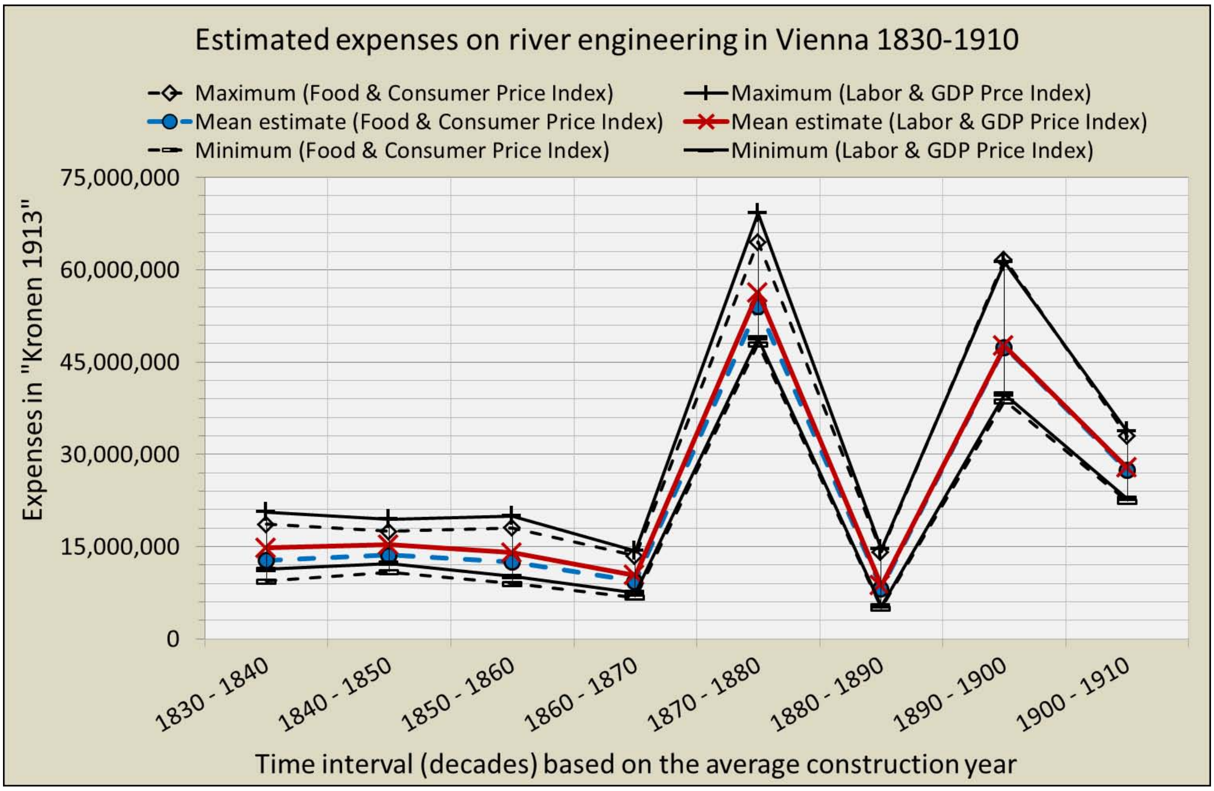

Figure 6-9: Historical expenses on river engineering in Vienna per decade between 1830 and 1910 standardized to "Kronen (K) 1913" based on *Labor & GDPPI* and *Food & CPI*.

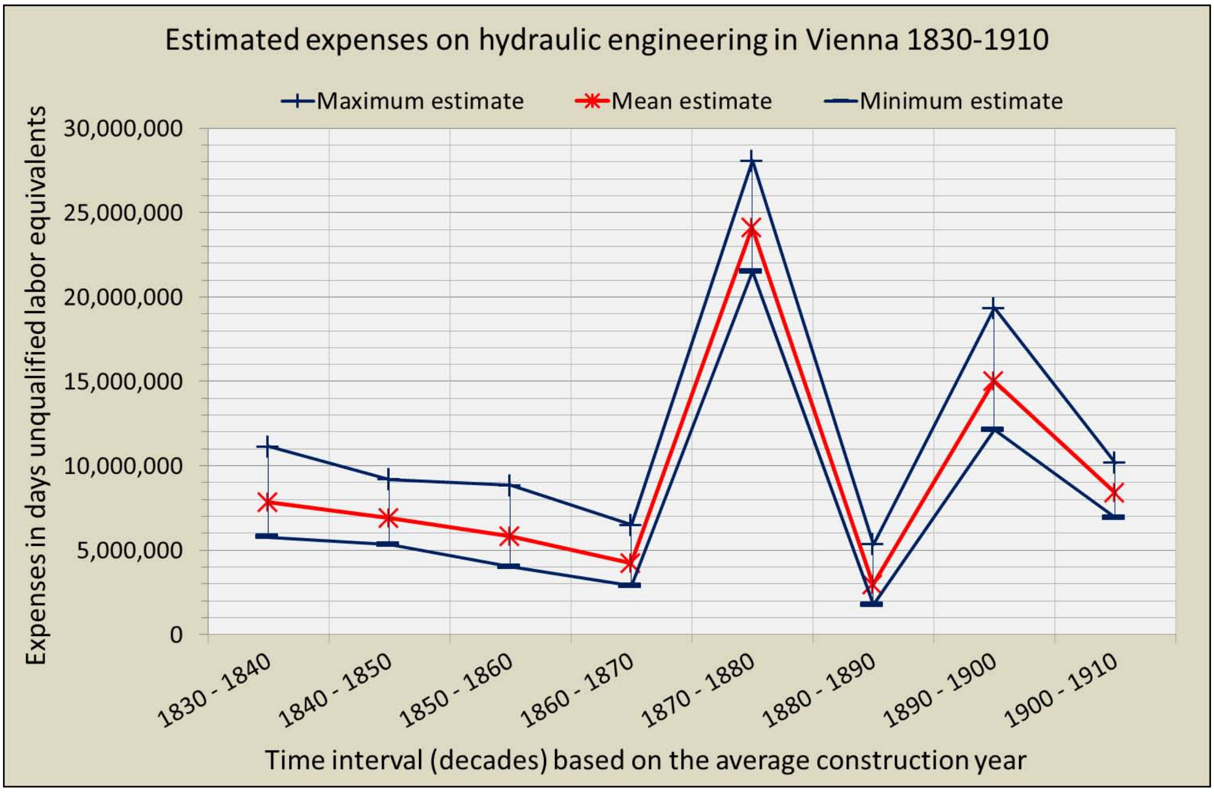

Figure 6-10: Historical expenses on river engineering in Vienna per decade between 1830 and 1910 expressed in days unqualified labor equivalents (duql).

The shift of the main branch away from the city (late 16th century), the beginning of the systematic creation of the Donaukanal (early 18th century) and the change of climatic conditions in the late 18th century are, thus, reflected by particularly intense regulation efforts. The figures 6-9 (in K 1913) and 6-10 (in duql) show the estimated decadal expenses on river engineering in Vienna between 1830 and 1910. There is a rapid jump in the cost structure which reflects the increased regulation activities after the large ice jam flood of 1830. The estimate in the decade 1830-1840 is far exceeding the maxima of all previous decades with at least (minimum) 5.8 million duql or 11.3 million K $1913_{Labor\&GDPPI}$ (= 1.5 million fl. $1721\text{-}1745_{Labor\&GDPPI}$). The maximum was reached during the *Great Danube Regulation (GDR)* in Vienna (1870-1880) when the extent of the expenses was calculated to 22 - 28 million days unqualified labor (duql) or c. 50 - 70 million K $1913_{Labor\&GDPPI}$. From 1840 till 1870 the expenses are estimated less with mean estimates for each decade between 4 and 7 million duql or 14 to 15 million K $1913_{Labor\&GDPPI}$. In 1880-1890, when Danube sections upstream and downstream of Vienna were regulated, the expenses in Vienna were comparably little. They rose again to c. 15 million duql or 47 million K 1913 in the last decade of the century, when supplementary projects as a consequence of the GDR were realized in the Danube floodplain, a major regulation at the *Wien River* was conducted and the tributaries were integrated into the sewage system. The figures 6-7 to 6-10 show that at least from 1540 to 1910 the expenses on hydraulic engineering appear without major interruptions as an important imposition on the budget of the institutions concerned with hydraulic engineering in Vienna's waterscape.

In figure 6-11 the expenses are plotted in the nominal currency units (NCU) as defined in chapter 4.1: In Pfund Wiener Pfennig (tal.) till 1500, in Gulden (fl.) from 1500 till 1860 in Gulden ÖW (fl. ÖW) between 1860 and 1890, in Kronen (K) from 1890 till 1920, in Alt-Schilling (aS) from 1920 till 1940, in Schilling (S) from 1940 till 2000 and in Euro since the year 2000. Comparisons of historical nominal money amounts from different time periods are meaningless, as they ignore the changing purchasing power of the numbers in the developing reference economy (chapter 4).

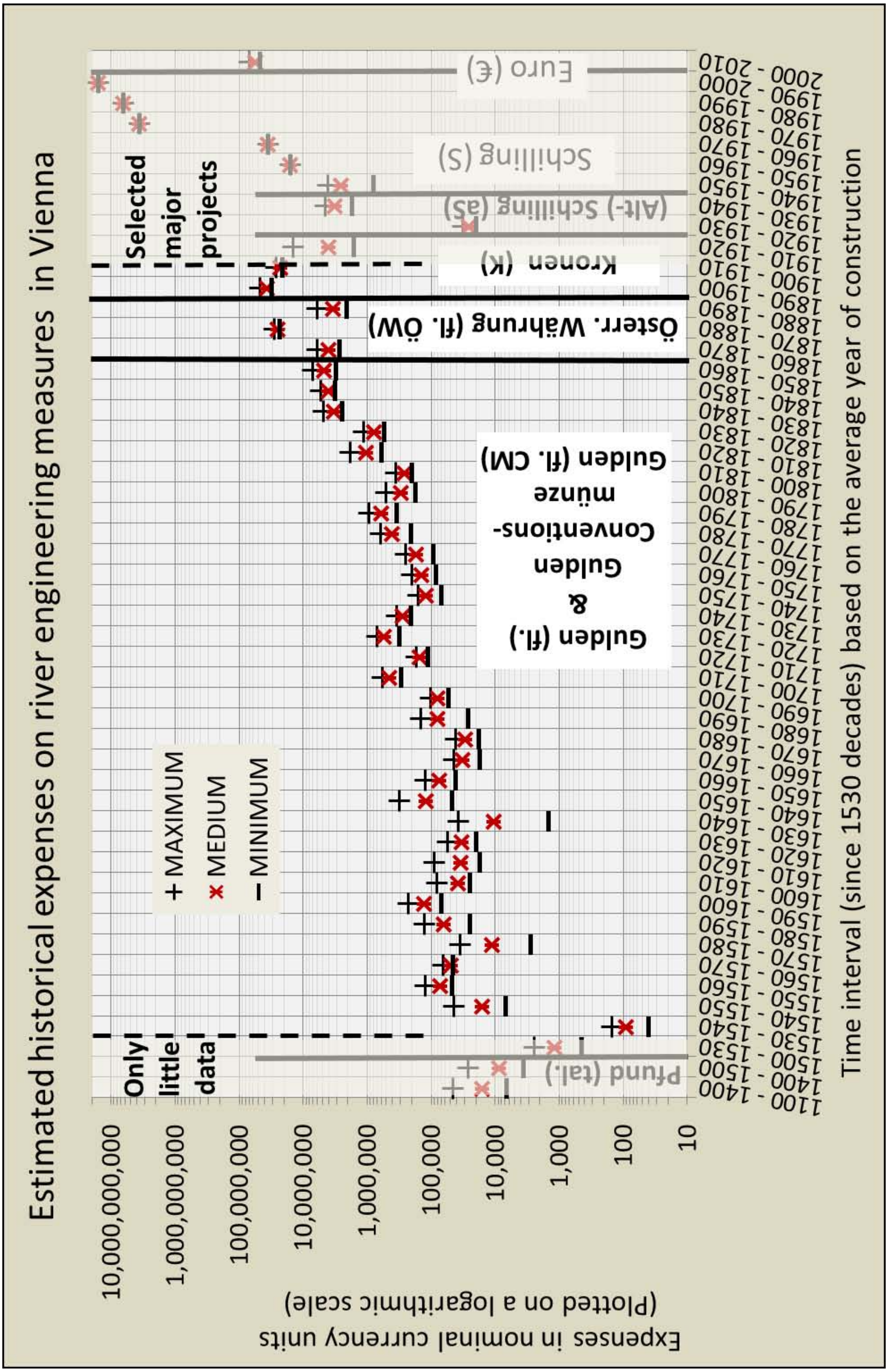

Figure 6-11: Estimated historical expenses on hydraulic engineering in Vienna per decade expressed in nominal currency units (NCU).

However, the sums obtained for each time interval are a good reference when comparing expenses on hydraulic engineering in Vienna with other amounts of money from the same time period. One example: The expenses on the renewal of the town fortification of Vienna between 1529 and 1558 (a period of great military importance) were around 300,600 fl. (10,000 fl. per year) according to HOCHLEITNER (1860, p. 115). In the decades 1540 till 1570 the nominal expenses on hydraulic engineering are estimated with c. 99,000 - 220,000 fl. (c. 3,300 - 7,300 fl. per year). That means the extent of expenses on river engineering measures (mostly near Nussdorf) are in a similar order of magnitude as the amount of money spent on the renewal of Vienna's fortification in that time period.

6.1.2 Efforts as share of the Austrian GDP and per inhabitant of Vienna

The question arises how the calculated expenses can be related to the size of the reference system: One good indicator for this size is the yearly gross domestic product (GDP) of the reference economy. Data on the nominal GDP was available only back till 1830 and only for Austria as a whole (in the present boundaries) after KAUSEL et al. (1979). Based on the nominal expenses on river engineering in Vienna a share of the Austrian gross domestic product (GDP) was calculated based on the minimum, medium and maximum cost estimates for the decades 1830 till 1910. The decadal costs for hydraulic engineering were divided by ten to obtain yearly costs and compared to the yearly GDP at the beginning of the respective decade. This calculation results in figure 6-12. It shows that according to the present documentation from 1830 to 1860 around 0.075 - 0.1 % of the yearly GDP were used on hydraulic engineering measures near Vienna (mean estimates). In 1860-1870, 1880-1890 and 1900-1910 the mean value was between 0,025 and. 0.05 %. The peaks are reached 1870-1880 (during the GDR) and 1890-1900 with around 0.2 till 0.3 % of the Austrian GDP. 1880-1890 a similar share was likely reached for the Danube regulation in Lower Austria (not included in the graph).

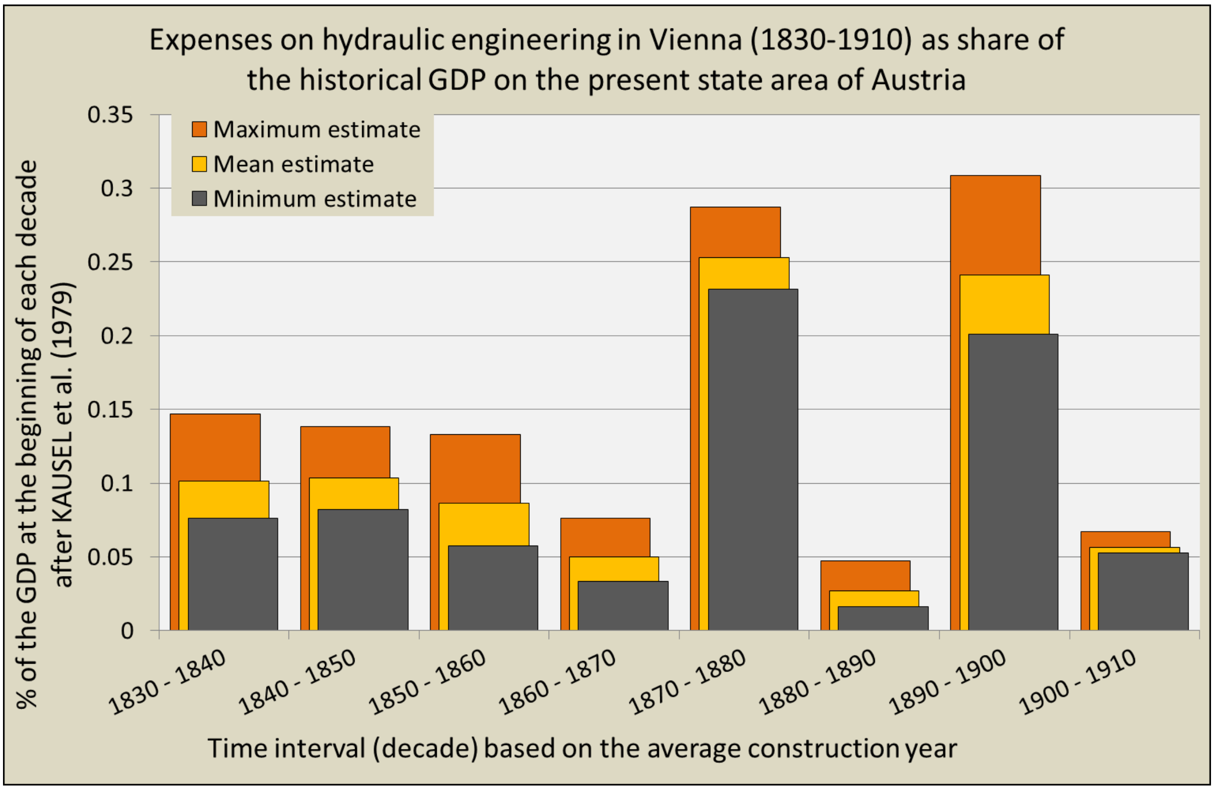

Figure 6-12: Estimated historical effort on hydraulic engineering in Vienna from 1830 till 1910 as share (in %) of the Austrian gross domestic product (GDP) at the beginning of each decade.

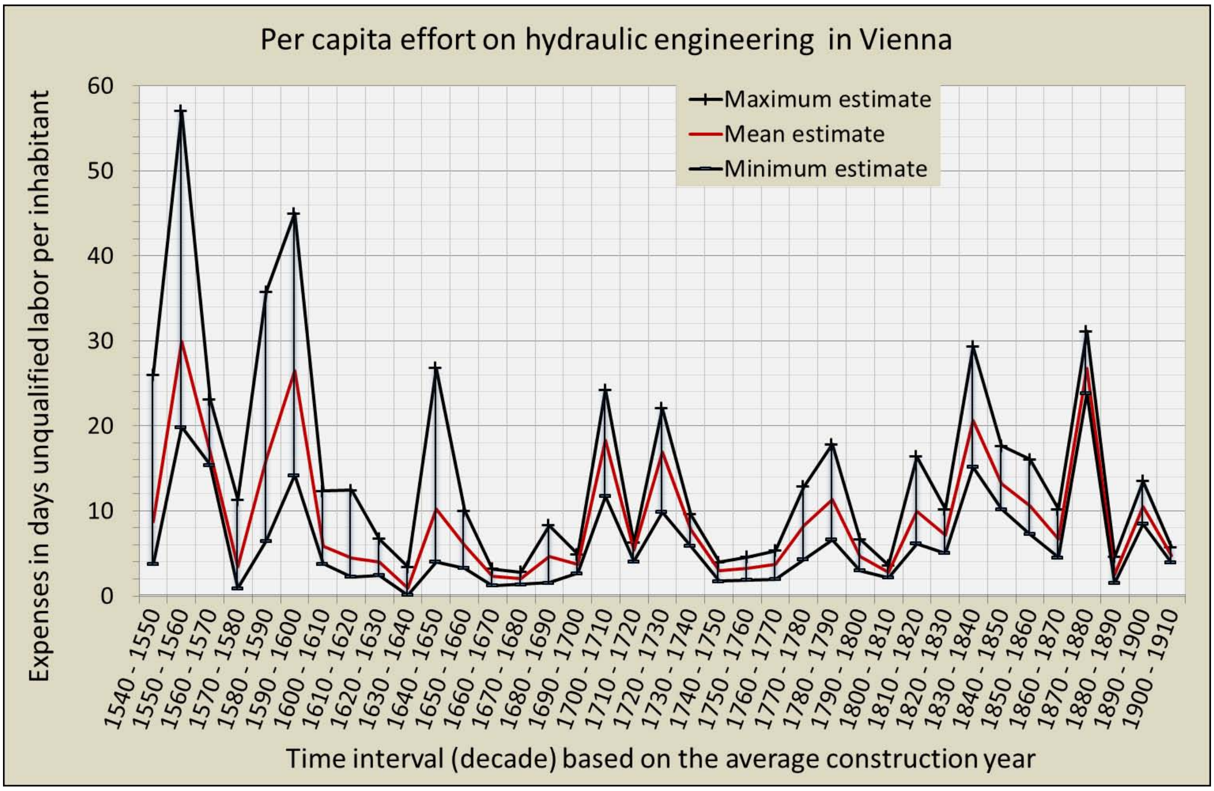

Figure 6-13: Estimated decadal per capita expenses on hydraulic engineering in Vienna from 1540 till 1910 in days unqualified labor equivalents per inhabitant of Vienna.

Furthermore, the "motivation" of the Viennese to invest in hydraulic engineering has been approached by dividing the expenses per time interval expressed in *duql* by the *number of inhabitants of Vienna* at the beginning of the decade (see chapter 2.2). This approach results in a hypothetical *effort per inhabitant for* each decade (figure 6-13). The use of the labor equivalent for this measure extracts the effect of the increase of productivity of labor during the 19th century leading to an appropriate measure of an actual per capita effort for the city. Observing again the above time segments, the results stay in a stable average range of 0.5 - 1.8 duql (1540-1700), 0.5 - 1.1 duql (1700-1830) and 1.0 - 1.7 duql (1830-1910) per inhabitant and year. Thus, there was a constant and important per capita endeavor in Vienna for hydraulic engineering from at least 1540 till 1910 and no significant trend can be observed in this time. In the second half of the 16th century a "motivation" of on average 1.9 duql per inhabitant and year was obtained. For comparison, for the GDR 1870-1880 the value is 2.7 duql. In the decades 1640-1650, 1700-1710, 1720-1730, 1780-1790 1830-1840, and 1890-1900 a mean value of 1 - 2 duql per inhabitant and year was reached.

6.1.3 Differences in extent and data quality for estimates based on "individual measures"

So far, the addition of cost volumes for each time interval was based on the list of projects in the DB. According to chapter 3.2, financial means may be summarized, based on the list of "individual measures" in the DB, either. The overall cost volumes per time interval are supposed to be equivalent, in the sense that estimates based on projects lie within the range of estimates based on individual measures. However, the calculation for projects, which includes safely documented money amounts in literature, is more precise than the estimation based on price ranges per meter or hectare for individual measures. The latter one includes an additional uncertainty for the distribution of, in fact, documented expenses. Figure 6-14 confirms these requirements: The uncertainty could be significantly reduced by integrating project costs directly into the study, as becomes particularly obvious for the late 16th and early 17th century.

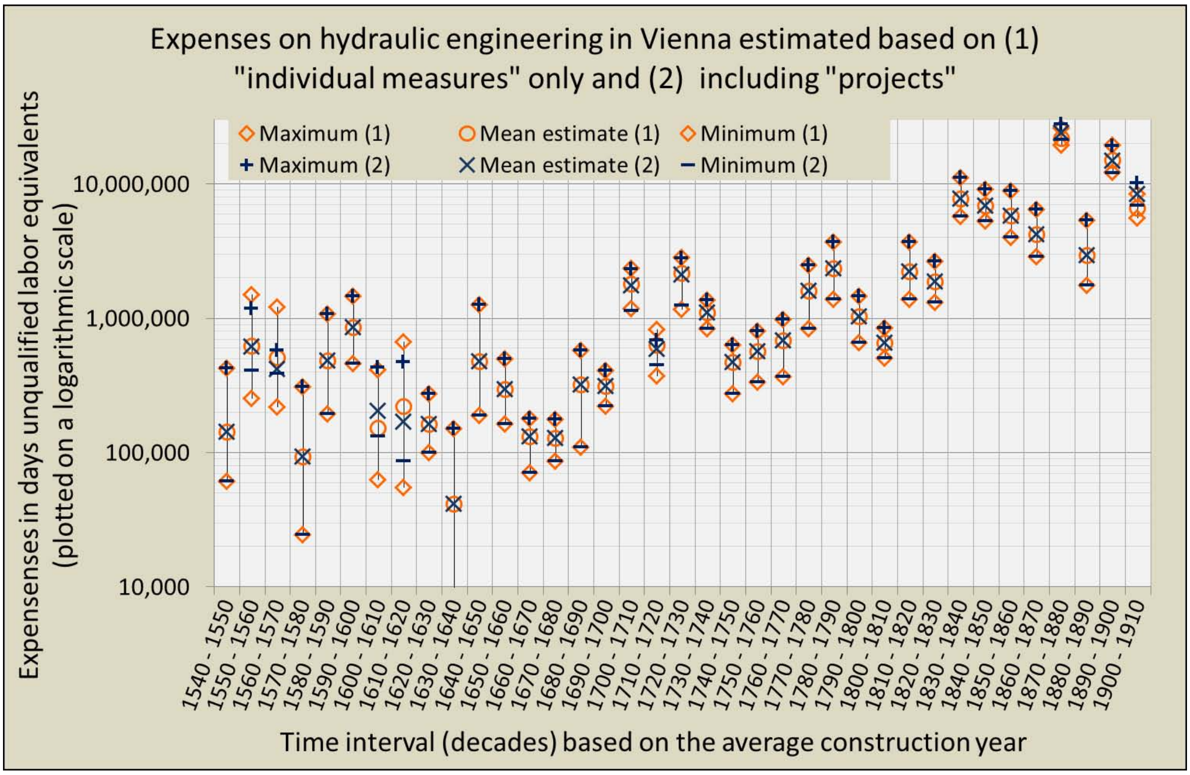

Figure 6-14: Historical expenses on river engineering in Vienna in "labor equivalents" accounted based on individual measures vs. based on projects. The cost volumes based on the estimates for projects are more precise and were used to calibrate the estimates for individual measures.

Another difference between the two approaches lies in the quality of the estimates. For each time interval the proportion of the expenses (medium cost estimate in duql) with the five previously defined "data qualities" ("Safe", "Good", "Moderate", "Poor", "Arbitrary"; see chapter 5.4) was calculated both for "projects" (figure 6.13) and "individual measures" (figure 6.14). The preference for safely-documented money amounts, in contrast to more critical price estimates, raises the data quality and, thus, the overall data quality could be improved significantly, particularly in the 16th, 17th, early 18th and late 19th century by the usage of the "project" list. The time period from 1780 till 1910 and the late 16th and early 17th century mostly show "moderate" cost estimates and beyond numerous "good" and "safe" ones. In particular between 1650 and 1770, there are many estimates classified as "poor" or "arbitrary" and the inclusion of other or better documents would be required. The documentation for the 20th and 21st century is still incomplete, but the included estimates after 1950 were mostly of "good" or "safe" quality. Before 1530 only little data was available.

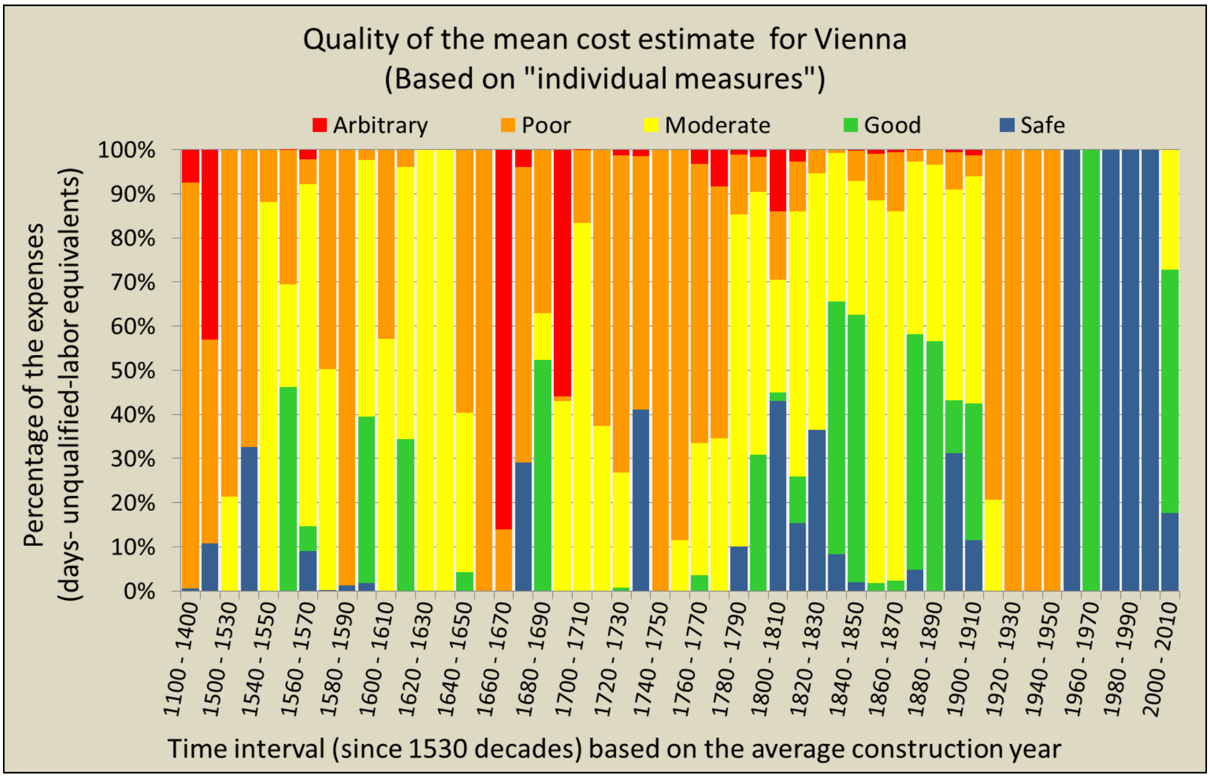

Figure 6-15: Relative data quality for the estimated cost volumes in each time interval based on estimates for each individual hydraulic measures in the database; less precise but more specific estimates.

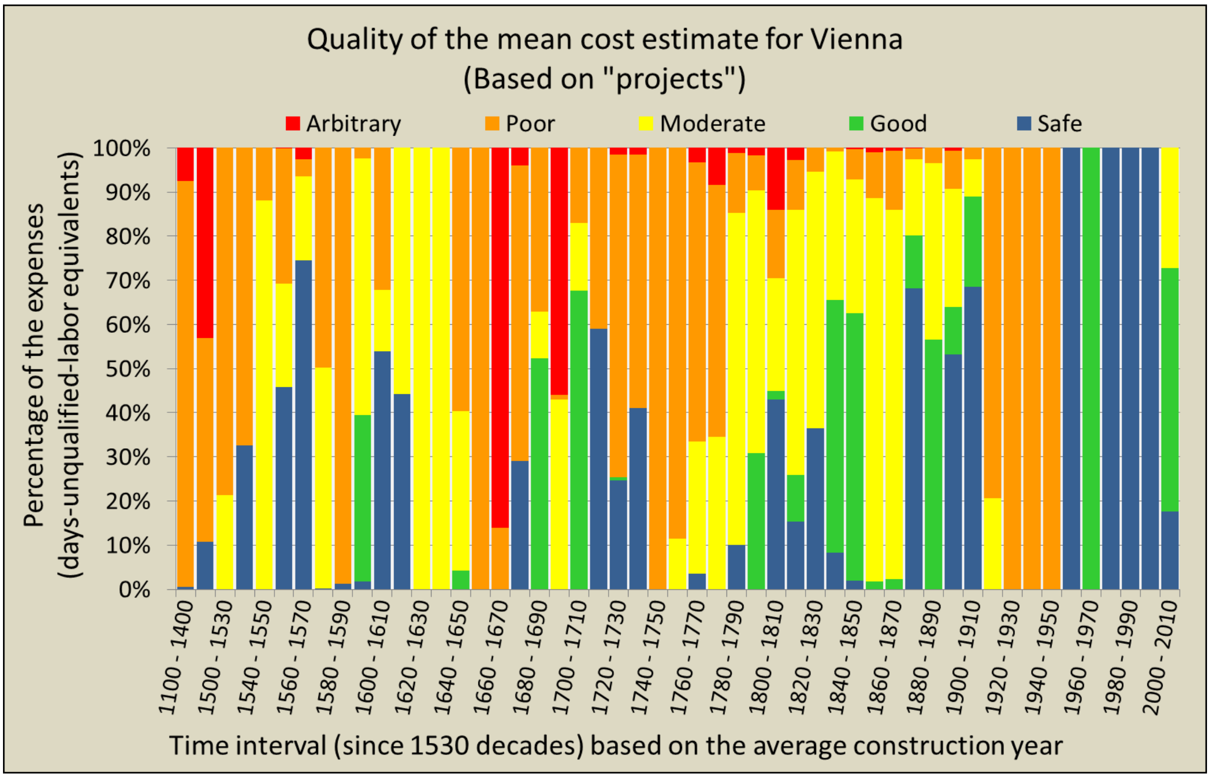

Figure 6-16: Data quality for the estimated cost volumes in each time interval including documented expenses for entire hydraulic projects (spanning several individual measures); less specific and more precise.

6.2 Average prices per extent and overall cost-efficiency

6.2.1 Average prices per extent of hydraulic engineering measures in Vienna

Based on the estimated expenses on hydraulic engineering in Vienna per time interval, the average prices per extent were analyzed separately for individual linear and areal measures in the database: in each time interval the estimated expenses on linear (individual) measures (Figure 6-17) were divided by the length of these measures in meter; for areal measures the expenses were divided by the area in square meter (Figure 6-18). Only the medium estimate was illustrated in these diagrams and three different methods were used: Average prices per meter (m) or square meter (m^2) as *nominal currency units (NCU)*, in *days unqualified labor equivalents (duql)* and in *Kronen 1913* based on the *Labor & GDPPI* were calculated.

The average prices per m were fluctuating in a range of 100 - 250 K 1913 / m and 50 - 125 duql / m in the decades from 1540 and 1750. This appears rather high however one has to consider that a measure of 1 m length often includes several m^3 of volume. Material was transported over distances of many kilometers (including rocks taken from quarries and wood cut from forests). Furthermore, estimates e.g. for weirs, massive spur dikes or guide walls, that caused much higher costs than embankments, are included in this average representation of the price. If the labor equivalents are interpreted intuitively, one should consider that the money was only partly spent on wages of day laborers, but well-respected engineers, administrational issues and technology were paid from the budgets, either. There are peaks exceeding 450 K 1913 and 200 duql in the decades 1590-1600 and 1650-1660. The first peak (1590-1600) is undermined well with data indicating massive primary structures particularly in this time (compare chapter 5.5). The second peak (1650-1660) is based on the same prices as the first peak although the data quality is comparably poor (compare chapter 6.1.3). Yet, these two decades are characterized mainly by the construction of primary structures, while the decades from 1600 to 1650 are more characterized by the cheaper repairing of hydraulic measures (→ appendix I.3).

Generally, it seems, that decades with many primary measures such as 1540-1560, 1580-1610 or 1700-1720 (compare figure I-4 in appendix I.3) are accompanied by particularly high prices. The price range from 1730 to 1900 is lower than before with c. 40 - 100 duql / m. This development could result from the fact, that regulation efforts had become more routine and less pioneer works in this time. Based on the index *Labor & GDPPI* it indicates an increase in the 19th century (140 - 260 K 1913 / m) compared to the 18th century (50 - 160 K 1913 / m): The regular use of massive stone constructions since industrialization and after the huge ice-jam flood in 1830 led to higher real prices of linear hydraulic construction in terms of the price trends in the economy (*Labor & GDPPI*). In terms of *labor equivalents* the increase of real wages (see appendix II), due to the increasing productivity of labor, balances out the increase of (linear) hydraulic engineering prices. Thus, the relationship of hydraulic engineering prices and labor prices stays rather constant from 1730 to 1900.

For areal measures in the late 17th and 18th century average prices of 20 - 45 K 1913 and 10 - 25 duql / m² can be expected. Before 1640 and after 1800 the average prices per ha are much lower (1 - 6 K 1913 or 0.5 - 3 duql in most decades). The ambitious excavation measures without the availability of adequate tools in the 17th century cause the higher average price. Fossil fuels were only used after 1830 allowing for massive structures at lower prices per m². The peak from 1890 to 1900 does correlate with huge areas of vaulted Danube tributaries in this decade, such as Alserbach and Ottakringerbach (The vaulting of large sections of the Wien River prior to 1903 is not yet part of the DB, as they could not purely been identified as hydraulic engineering; compare HOHENSINNER et al., 2012). The excavation of new drains and the vaulting of existing and new drains were separately integrated into the calculations. Beyond, the peak in 1890-1900 still needs to be verified as the known costs for the Nussdorf weir and lock were equally distributed on the respective DB entries leading to extraordinarily high prices per hectare in few cases. Thus, it is required to specify the exact distribution better or to exclude these constructions from the analysis.

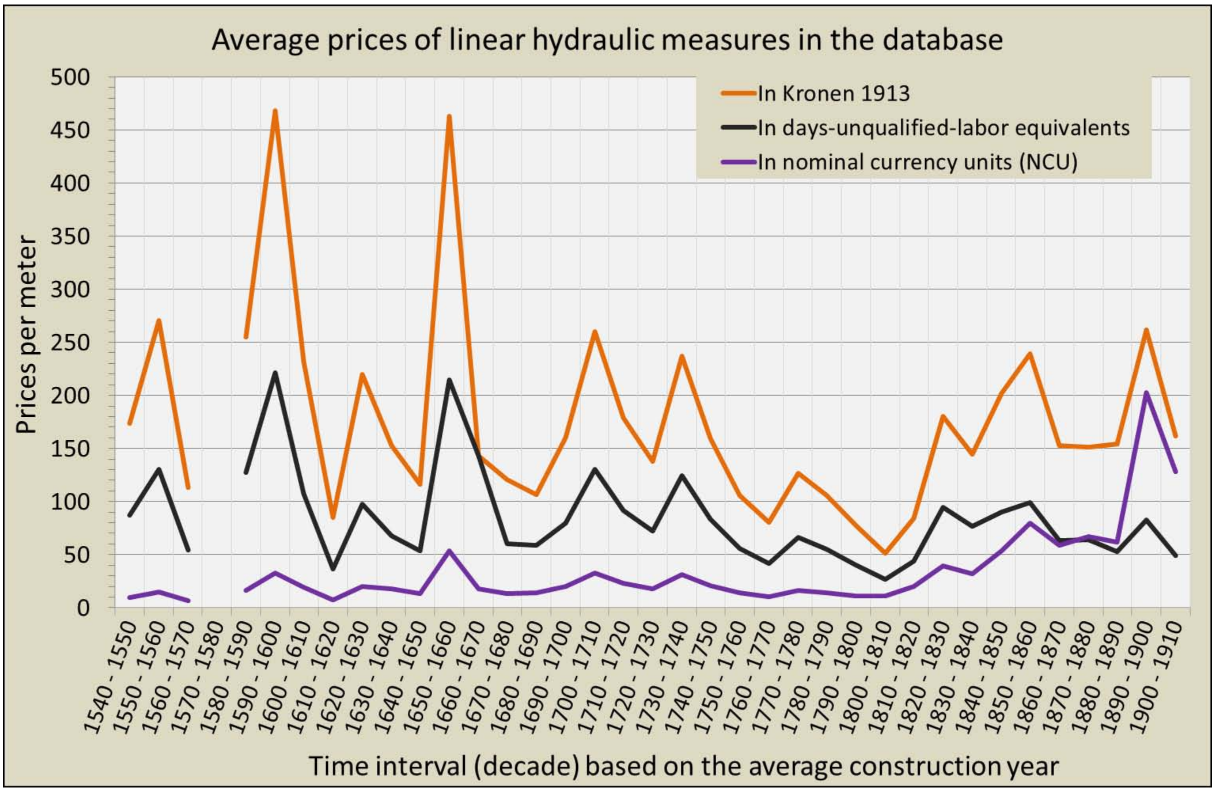

Figure 6-17: Change over time of estimated average prices per meter of *linear* river engineering measures in the database.

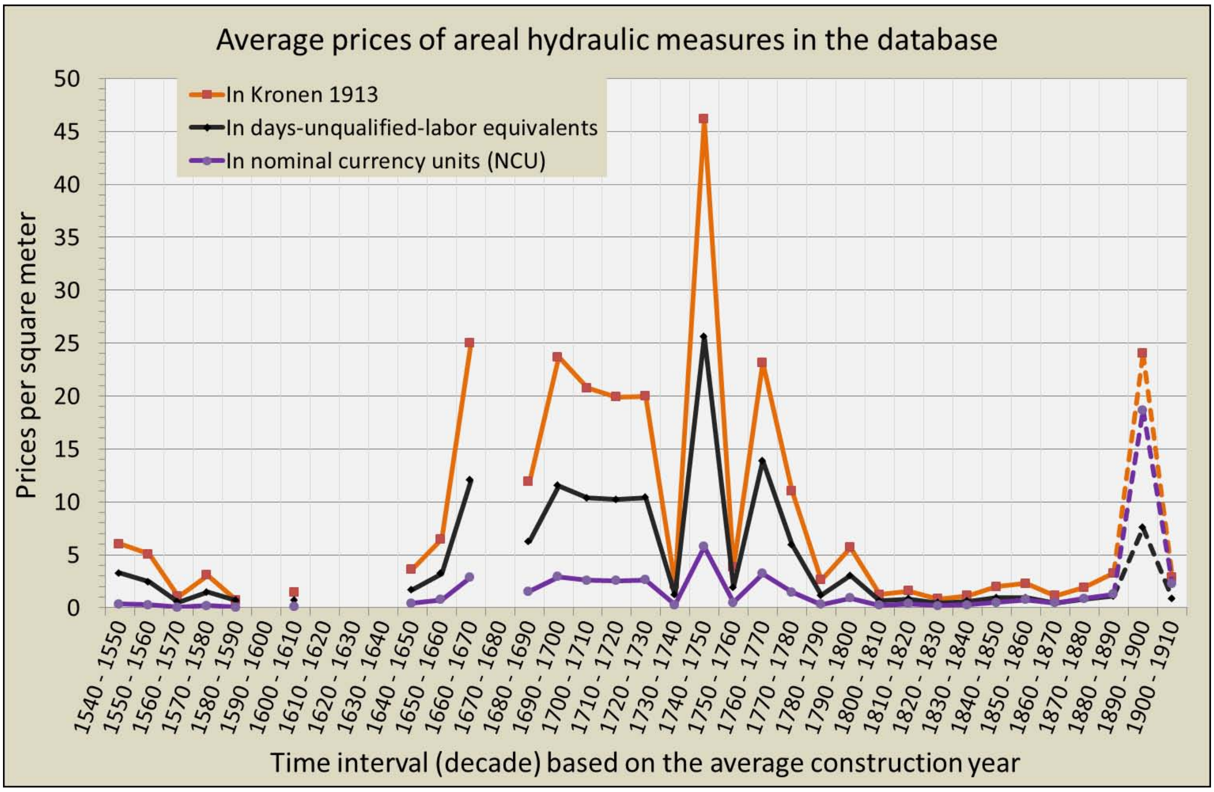

Figure 6-18: Change over time of estimated average prices per hectare of *areal* river engineering measures in the database.

6.2.2 Overall efficiency of the expenses on hydraulic measures over time

For each individual measure in the DB, an effective cost estimate was calculated by dividing the total cost estimate in *duql* by the efficiency in years (i.e. duration of functionality as defined in chapter 3.2; see figure 3-5 and 3-6). The sum of the effective expenses was calculated per time interval. Figure 6-19 shows that the increase of total expenses after 1830 is strongly modified by the greater efficiency of hydraulic measures. The peak in effective expenses from 1870-1880 correlates with the peak in total expenses (figure 6-10). The quotient (in years) of the total costs divided by effective costs has been labelled "overall efficiency" and was illustrated in % in figure 6-20. This is a weighted efficiency based on the calculated expenses (not an average efficiency for the number of measures). Thus, the overall efficiency measures the duration of the period during which expenses do not have to be repeated because the corresponding hydraulic measures function properly. The values were mostly fluctuating between 2 and 10 years from 1540 till 1790. The peaks from the 17th century are not representative as they come from a decade with little regulation activity (1620-1630) or only few minor measures with efficiency 100 are documented which do not represent the typical (Danube) regulation measures of that time (1660-1670). The years 1790 to 1830 appear as a period of transition. From 1830 till 1890 the overall efficiency of the expenses varies from 10 to 25 years in each decade. Peaks are in the decades 1830-1840 and 1850-1860 when large-scale embankments, bed excavations (dredging) and depositions for the uplift of low-lying river banks were conducted. The DB contains several larger projects from 1890-1900 with an efficiency of 100 (present documentation) and the efficiency is much higher (44 years). However, it is required to justify this value more precisely by adding more documentation for the durability in the 20th century. It is suggested to differentiate this analysis more in future, e.g. by observing only linear measures from the Danube floodplain. As shown by figure 6-20 the ability of society to transform the waterscape by the means of expenses on hydraulic engineering has significantly improved during the 19th century in terms of the duration of the intended effect of the constructions.

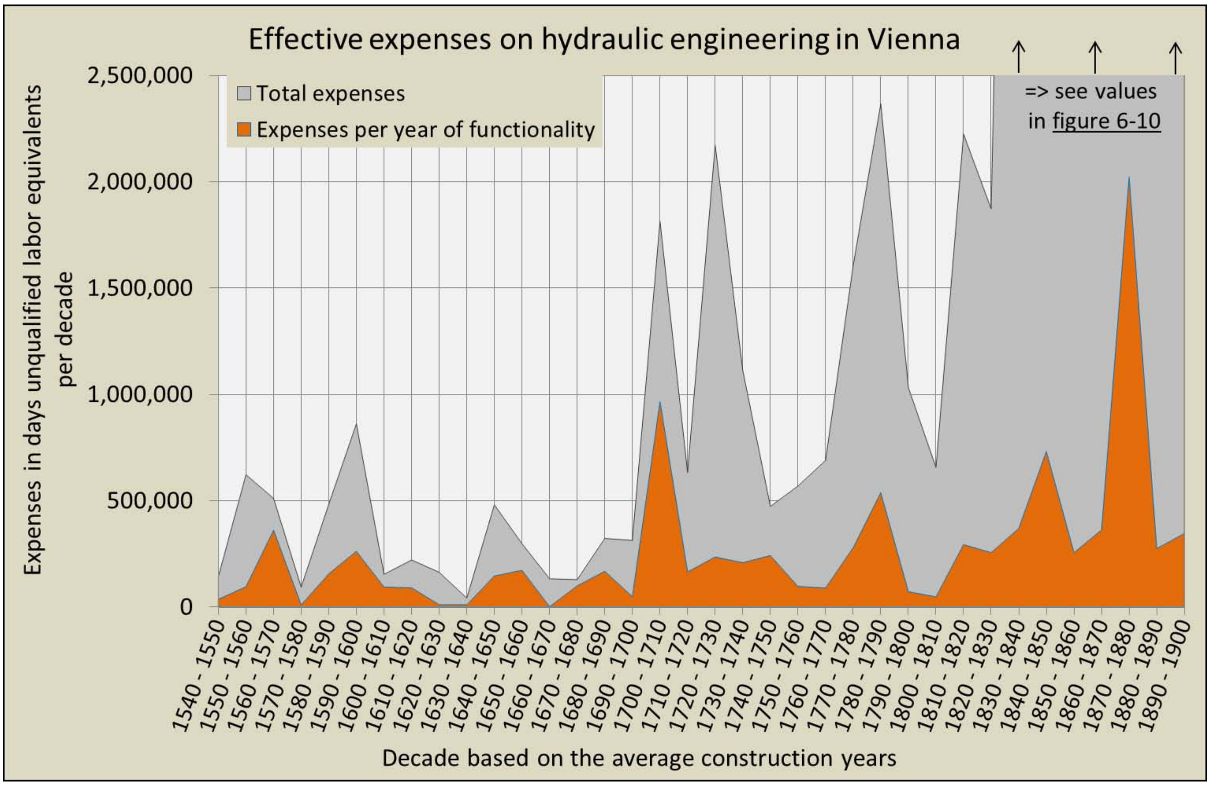

Figure 6-19: Total expenses vs. effective expenses per year of functionality in each decade; the effective expenses of each measure are the total expenses (figure 6.8 and 6.10 in chapter 6.1.1) divided by the efficiency (duration of functionality) in years (figure 3.6 in chapter 3.2).

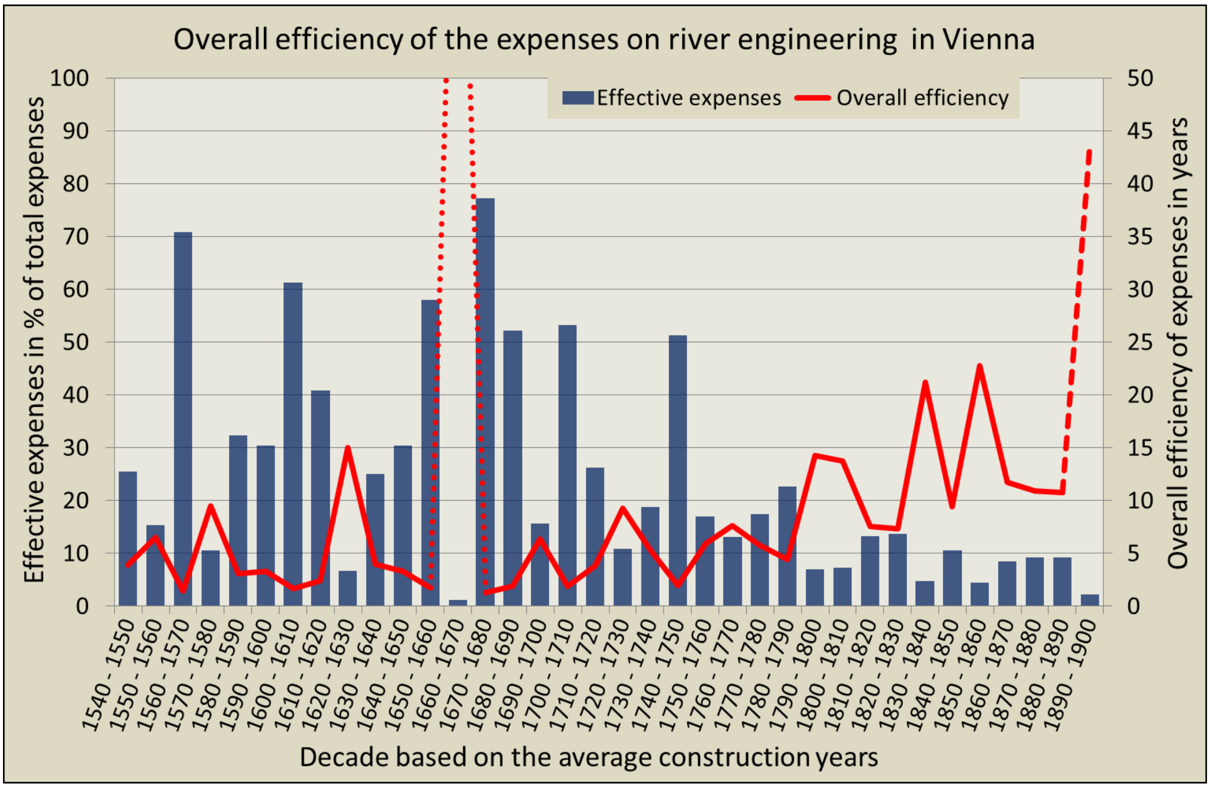

Figure 6-20: Effective expenses as percentage of total expenses per decade and the overall efficiency (= total expenses divided by effective expenses) for each decade in years from 1540 to 1900.

6.3 Distribution and differentiation of the expenses

So far, the cost volumes have been illustrated as amounts of money spent on hydraulic engineering in Vienna by summarizing all available cost estimates in each time interval (chapter 6.1). The project categories defined in chapter 3.2 were used for further specification and illustrations of the results in appendix IV.2. A data selection only based on individual measures from the DB along the *Donaukanal and its precursors*, has been attached in appendix IV.3. A comprehensive overview of the results from this entire chapter 6 is furthermore given in the *file C.3* on the DVD, as described in appendix V.

6.3.1 Distribution on different water body types

The distribution of the expenses on the water body types in Vienna will now be analyzed more precisely. The cost structure can easily be subdivided into the expenses on regulation of the main branches, anabranches, abandoned river arms and artificial water bodies in the Danube floodplain (DF) and the expenses on regulation of Danube tributaries (DT) – both "rivers" and "creeks & ditches". Based on the many specifications in the DB (see chapter 3), the distribution on categories in the DB allows for numerous different analyses. Here, the proportion of expenses on different water body types in each time interval was illustrated (figure 6-21) observing the changing distribution over time: In most decades from 1540 till 1700, a large percentage of expenses did refer to the regulation of main branches. Between 1700 and 1830 the expenses for the regulation of anabranches, in many decades, exceeded those for main branches, corresponding to the start of systematic regulation of the Donaukanal in 1700. Furthermore, from 1830 till 1890 a majority of expenses were dedicated to main branches rather than anabranches, and from 1890 till 1910 the opposite was the case. Tributaries occasionally made up for significant parts of the expenses. From 1730 till 1910 this was regularly the case when around 10 to 30 % in most decades were spent on tributaries as far as this is evident till date.

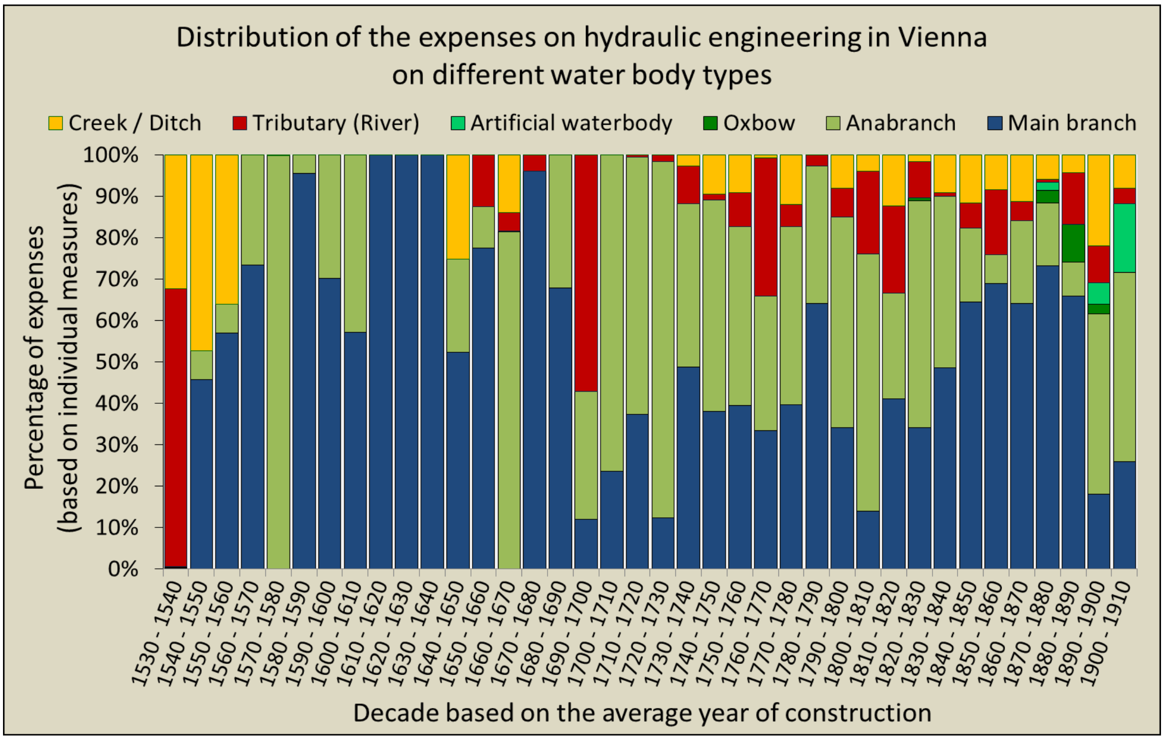

Figure 6-21: Relative proportion of expenses referring to the water body types in each time interval; expenses at "tributaries (rivers)" during the *Wien River Regulation* (1891-1915) are still under-represented because only clear hydraulic measures are accounted, which are not primarily sewage works or urban development measures; price data is still poor for important parts of this extensive regulation (vaulted river sections, weirs, retention basins, stone walls etc.) in the present version of the database.

This percentage might actually be higher as the documentation for the Danube tributaries is still fragmentary and a systematic study is required in future. However – despite of a systematic study – there are certainly historical measures from the Danube floodplain which are not documented.

In figure 6-22, the cost structure has been reduced to "projects" in the Danube floodplain. On a logarithmic scale, expenses in *days unqualified labor equivalents (duql)* are plotted. The overall temporal pattern is similar to that observed for entire Vienna (see figure 6-2 in chapter 6.1.1), but the values from the overall cost structure for Vienna are reduced by the amount spent on the regulation Danube tributaries: In the years 1540-1700 15,000 - 50,000 duql / year (mean 26,300 duql) were spent on average in the Danube floodplain. For the period 1700-1830 a higher average of 72,000 - 163,000 duql / year (mean 115,000 duql) is assumed and 1830-1910 the estimate ranges even from 670,000 to 1.0 million duql / year (mean 800,000 duql).

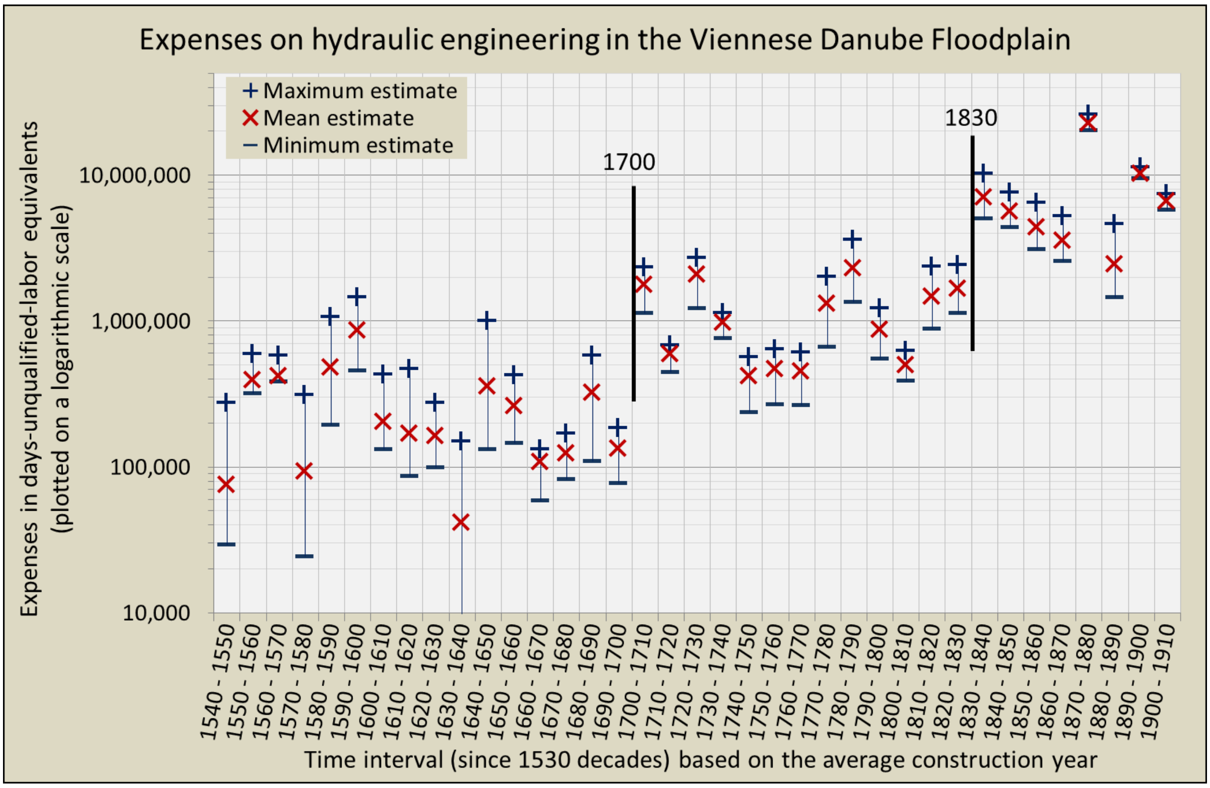

Figure 6-22: Cost volumes of historical river engineering measures in the Viennese Danube floodplain per decade (plotted on a logarithmic scale).

Figure 6-23 shows the separate cost estimates in days unqualified labor equivalents (duql) for all hydraulic projects assigned only to Danube main branches in the DB. The volume of expenses for the regulation of Danube main branches was, already since the 1540s, constantly exceeding a value of 100,000 duql per decade. In the 1590s, when intense pioneer regulation activities at the Danube near Nussdorf reached a maximum, and in the 1780s, when there was a particularly high flood frequency and intensity, the efforts peaked with around 1,000,000 duql. In contrast to the expenses for the regulation of anabranches (see below) there is no major increase in efforts after the year 1700: From 1540 to 1700, 11,900 - 38,900 duql (mean estimate 20,600 duql) were spent on average per year, while 1700-1830 a slightly higher range of 36,100 - 75,000 duql (52,700 duql) was estimated. The yearly average 1830-1910 can be assumed with 435,000 - 675,000 duql (531,000 duql). Thus, the mean estimate 1830-1910 is more than 10 times above the value from 1700-1830 while the mean estimate from 1540-1700 is only 2.5 times below that value. Hence, the level of expenses reached in the cost structure for Vienna since the decade 1830-1840 is obviously mainly a result of an increase of efforts at Danube main branches. After the ice jam flood in 1830 and parallel to the industrialization in Austria, the efforts to regulate main branches in most decades from 1830 till 1910 ranged from c. 2,000,000 to 6,000,000 duql, a range which was usually not reached before. A clear peak lies in the decade 1870-1880 – during the *GDR* – with up to 18,000,000 duql.

Expenses on all projects assigned to anabranches in the Viennese Danube floodplain were illustrated in figure 6-24. The following yearly average values were found for Danube anabranches: From 1540 till 1700 between 2,800 and 12,500 duql / year (mean estimate 6,000 duql) were spent; in the years 1700-1830, the estimated range was much higher with 36,000 - 88,000 duql / year (62,300 duql). The mean estimates are clearly below (1540-1700) and above (1700-1830) those for main branches. The increase around 1700, when the Donaukanal was systematically regulated, is particularly significant at anabranches – the average yearly mean estimate for 1700-1830 exceeds the mean for 1540-1700 by factor 10. As opposed to the main branches, from 1830 to 1910, a range of 205,000 to 288,000 duql / year (237,000 duql) was assumed. Thus the mean estimate is only around 4 times above the one from 1700-1830. In the decade of the GDR, as most of the expenses were assigned with Danube main branches, there is only a minor peak comparable to that in the decade 1830-1840, ranging from c. 2 to 4 million *duql*. This former peak can be explained by large-scale excavation experiments with new steam machines and a systematic creation of embankments in the *Donaukanal*. However, the maximum was reached with more than 7 million duql in the decade 1890-1900, when the *Nussdorf weir* and *lock* were constructed and new quay walls and a turning basin for ships were created in the *Donaukanal*. As the Donaukanal and its precursors is a particularly interesting case, a data selection based on individual measures at this river section has been illustrated in appendix IV.3.

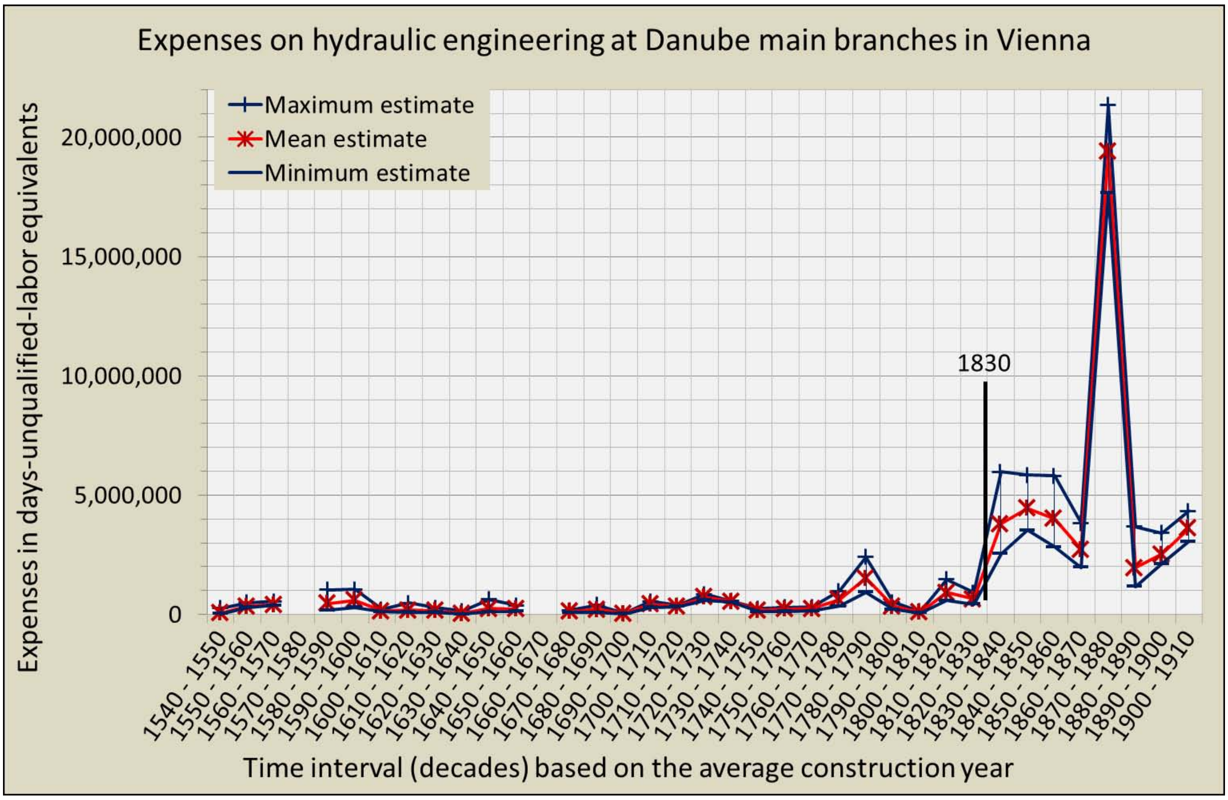

Figure 6-23: Expenses on the regulation of Danube main branches in Vienna per decade, expressed in labor equivalents.

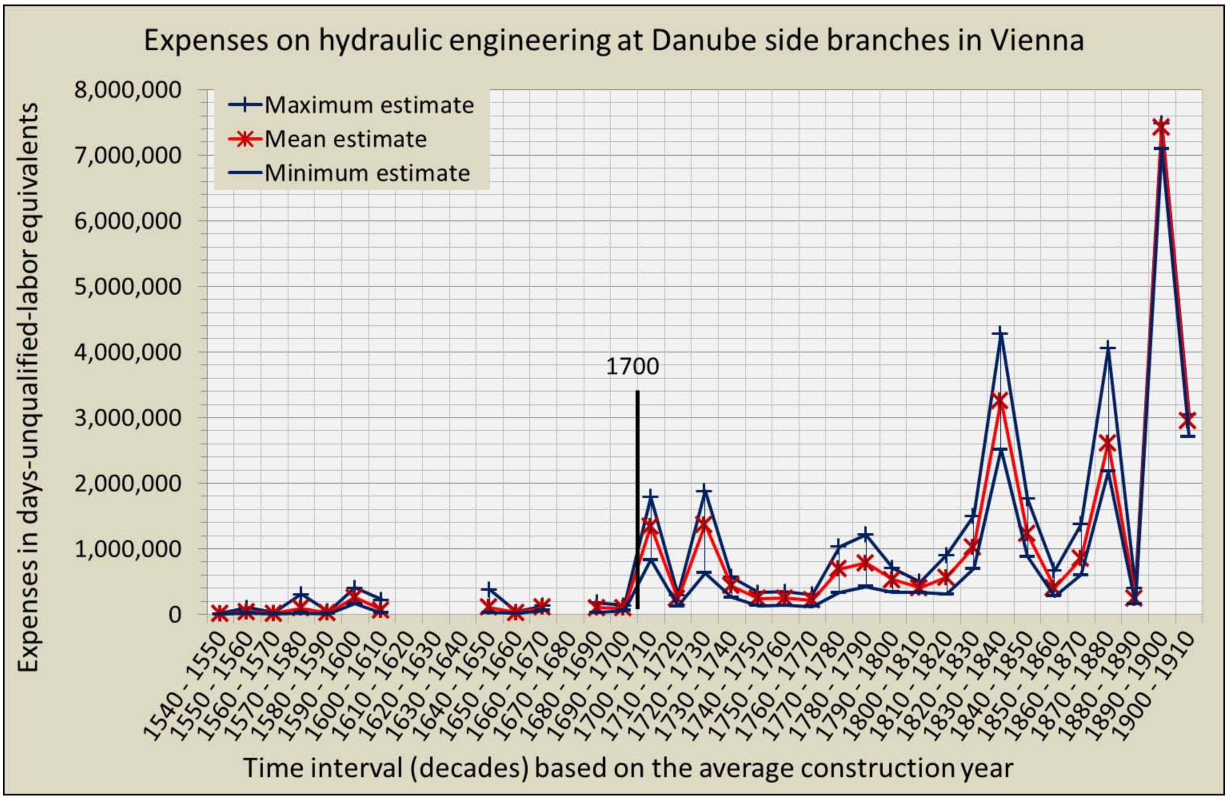

Figure 6-24: Expenses on the regulation of Danube anabranches in Vienna per decade, expressed in labor equivalents.

The documentation for Danube tributaries (DT) is only at the beginning so far, and thus, results for DT need to be understood as a preliminary outcome, based on the documentation till date. Figure 6-25 shows the present cost structure for the Danube tributaries in duql. Before 1700 there are major gaps in the documentation (or/and in the regulation activity?). From around 1730 till 1810 the results fluctuate around c. 100,000 duql per decade. New levels are reached between 1830 and 1910, when expenses were fluctuating around 1,000,000 duql per decade peaking in the decade 1890-1900 during the *Wien River Regulation* and the large-scale regulation of minor tributaries for the creation of a sewage system, with a mean estimate of 5 million duql – as far as an estimate is possible so far.

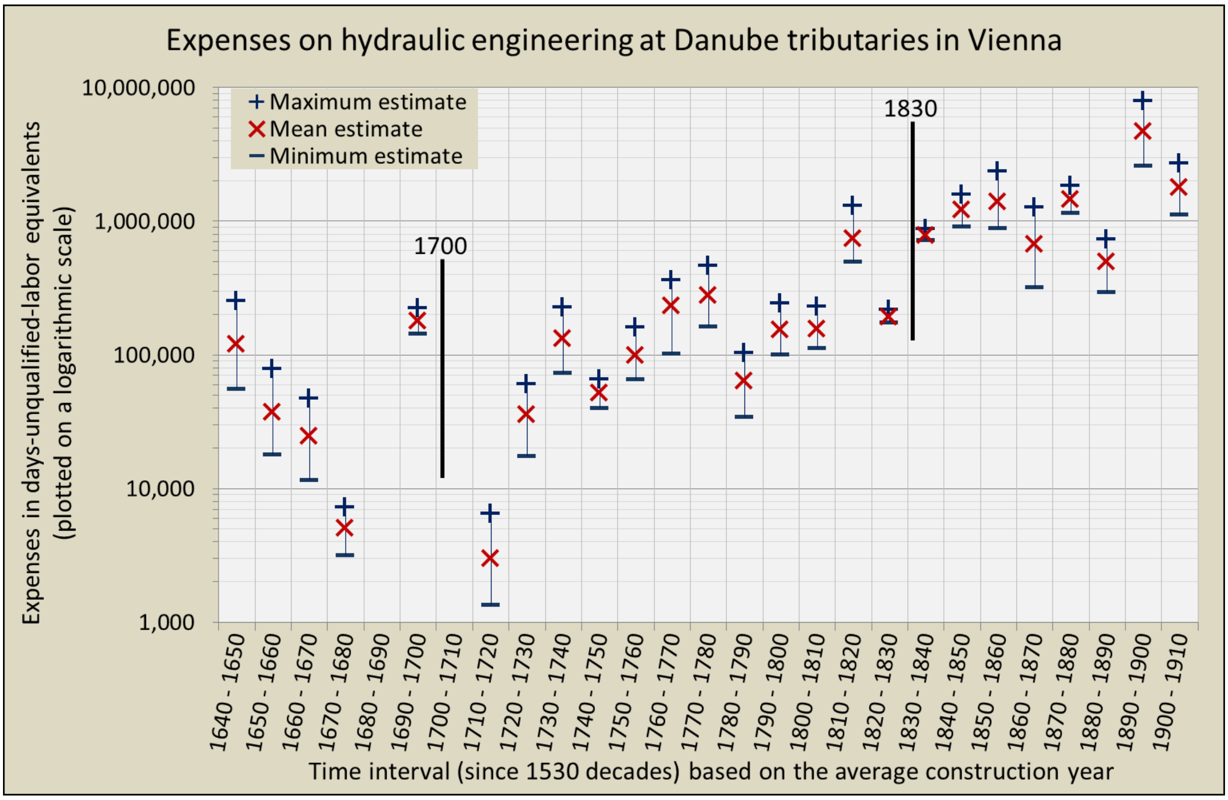

Figure 6-25: Cost volumes of historical river engineering measures at Danube tributaries in Vienna per decade (plotted on a logarithmic scale).

6.3.2 River functions addressed by the expenses

Based on the defined "river functions" for all database entries a qualitative description of the motives of actors over time was derived for the expenses. The amounts of expenses were illustrated which addressed different river functions in each time interval. The medium estimates in *days unqualified labor equivalents (duql)* were used for this analysis and the list of individual measures in the DB was preferred to the list of projects as the differentiation of river functions is much more precise in the way they were assigned to each individual measure. Rather than on the exact quantity in one time interval, the attention is on a long-term scheme, describing the changing importance of certain motives for the regulation of the Viennese waterscape over time. As many database entries were multifunctional, the expenses can count double or several times if more than one river function was addressed by a measure. For example, the measures mostly around Nussdorf aimed on a prevention of the break-through towards east (→ "erosion risk"), but the same measures primarily intended redirecting the flow towards Vienna (→ "navigation route"). Measures for the “sewage system”, nearly always intend to reduce the “disease risk”, either. Hence, multifunctional measures have a higher weight in this overview: One might both argue that this approach distorts the result and that the integration of various river functions justifies a higher weight of the respective expenses. Figure 6-26 on the following page gives an overview for all expenses on hydraulic engineering in Vienna. The following figures separate the schemes for the Danube floodplain and for Danube tributaries: For both parts of the Viennese waterscape there is an illustration of the addressed river functions in absolute numbers (figure 6-27 & 29) and as relative importance in each time interval in percent (figure 6.28 & 30). Alternatively, the usage of transport energy for navigation, military protection, water, energy can be summarized as supply functions of the rivers, and the protection of people, urban area or infrastructure against floods, erosion and disease can be considered as risk functions. Due to the multi-functionality of many efforts, the sums of addressed river functions always equal more than 100 % of the expenses.

In numbers one might summarize for the period 1540-1700 that c. 76 % of the expenses in entire Vienna addressed the issue "navigation route" and 73 % “erosion risk”. "Ports for navigation" (4 %) and "flood risk" (1.5 %) played a minor role. 10 % of expenses addressed streams as "military barrier", 11 % aimed on the gain of urban space. Other functions were addressed by less than 1 %. In the Danube floodplain 88 % of all expenses addressed the issue of the “navigation route” while 85 % addressed the Danube as erosion risk. “Ports for navigation ports” were intended by 5 % and all other functions were minor functions with 1 % or less. The Danube tributaries were addressed as military barrier (67 %) and for the gain of space (81 %), while the flood risk and water supply played a certain role as motives for regulations.

While there has rather been a primary attention on supply functions before 1700, the 18th century appears as period of transition: new issues entered the attention and were further on far more important. This shift entailed a larger primary attention on risk functions (flood, erosion, disease) which were increasingly addressed. The gain of space became more important in the Danube floodplain and in the course of the century the flood risk and the issue of flood-safe traffic routes entered the agenda. Looking at the entire Viennese waterscape, from 1700 to 1830 the river as “navigation route” was addressed only by 41 %, the “erosion risk” only by 51 % of the costs. The “gain of space” (14 %), “flood risk” (27 %), “flood-safe traffic routes” (7.5 %) and “disease risk” (4 %) were increasingly important. Vice versa, the functions “flood risk”, “gain of space” and “disease risk” were particularly addressed at Danube tributaries with 52, 41 and 32 %. The disease risk after 1720 (figures 6-29 and 6-30) refers to the redirection and piping of *Ottakringerbach* and regulation measures to straighten and concentrate the flow of the Wien River, that both enhanced the discharge of floods and waste from Vienna. The energy supply accounted for 15 % at tributaries. In reality the expenses to entertain mill weirs and streams for energy supply might have been much higher from the 12th century onwards (see LOHRMANN, 1980).

In the 19th century, the transformation of the Viennese waterscape is formed by few major motives including both risk and supply functions which appear to be nearly equally important now: navigation, space, floods, erosion, infrastructure, diseases and wastewater. Other issues are widely neglected.

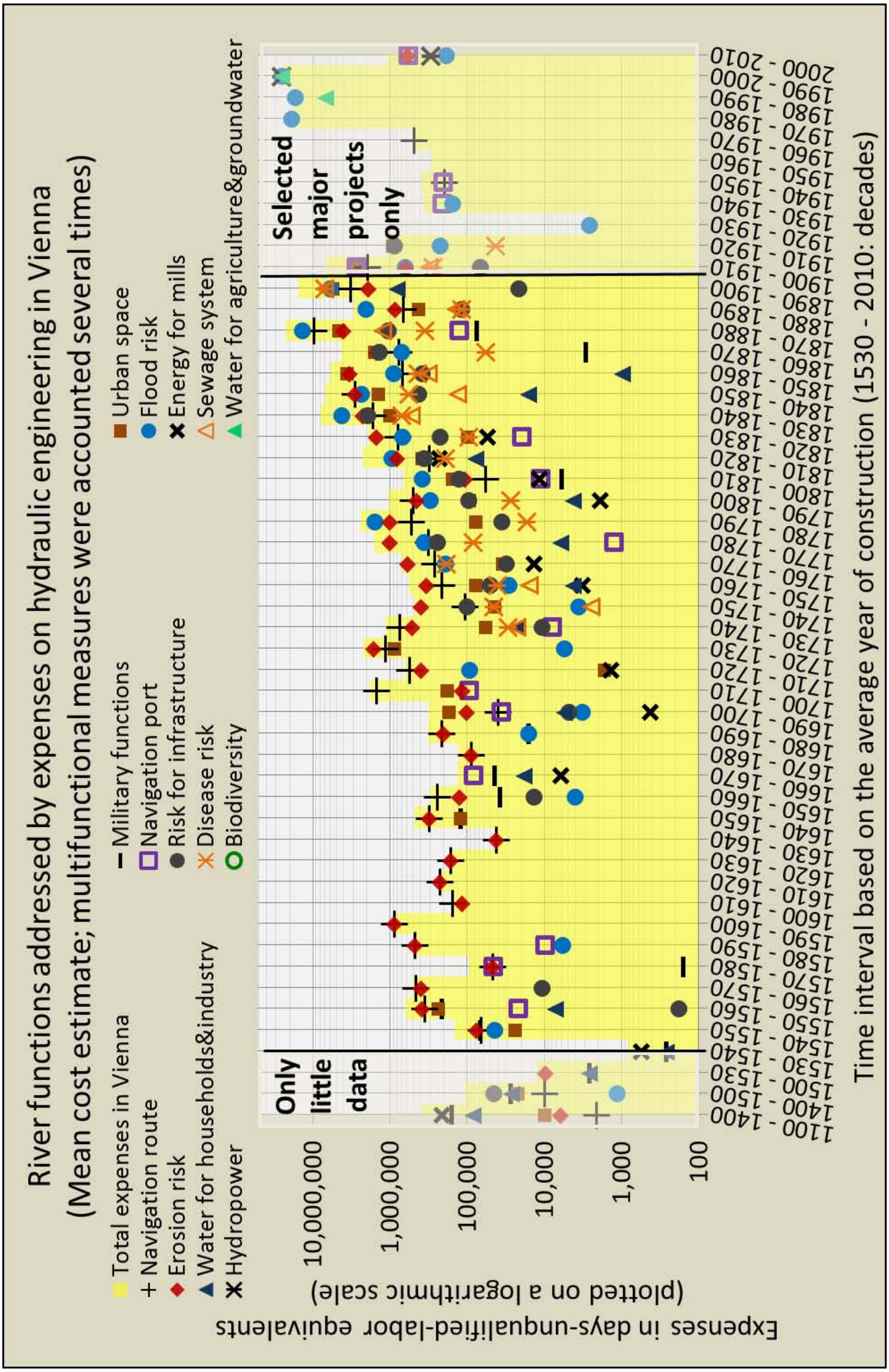

Figure 6-26: River functions addressed by historical expenses on hydraulic engineering in Vienna; overview for the entire city area – *Danube floodplain* and *Danube tributaries* from 1100 till 2010.

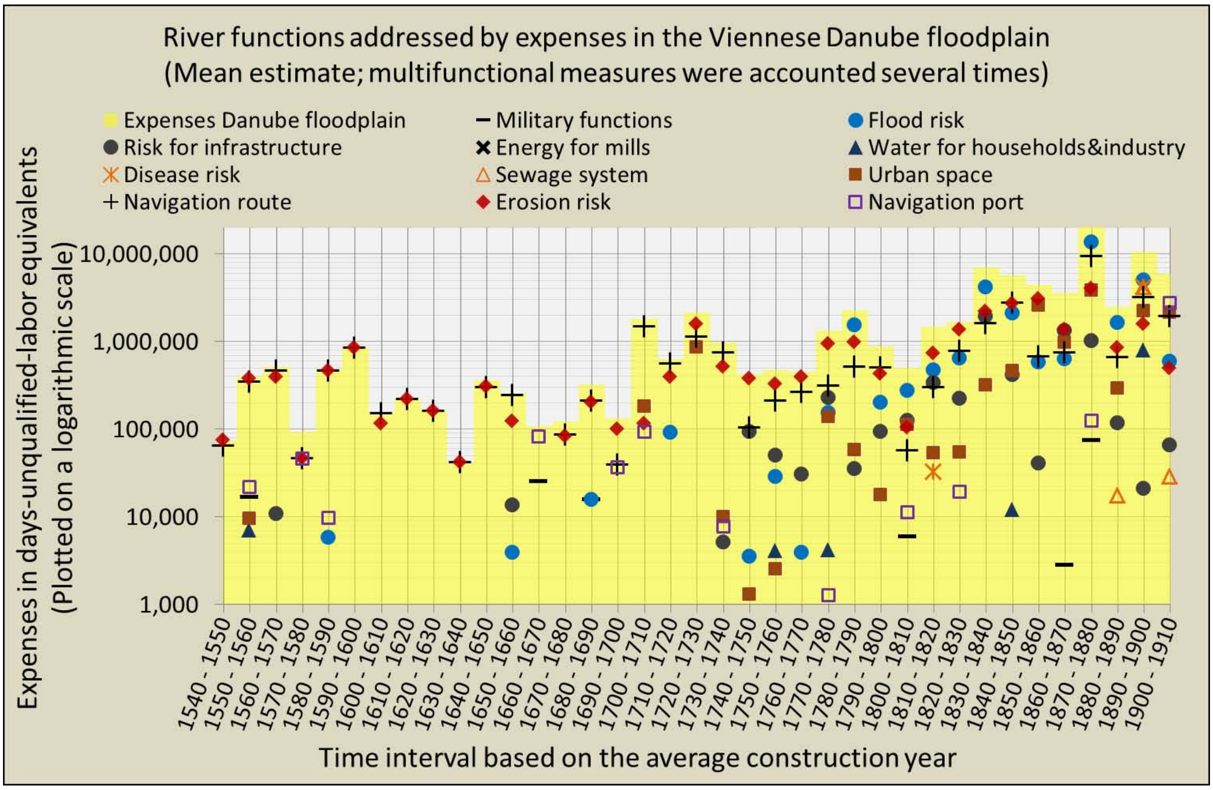

Figure 6-27: River functions addressed by historical expenses on hydraulic engineering in the Viennese Danube floodplain in absolute numbers (plotted on a logarithmic scale).

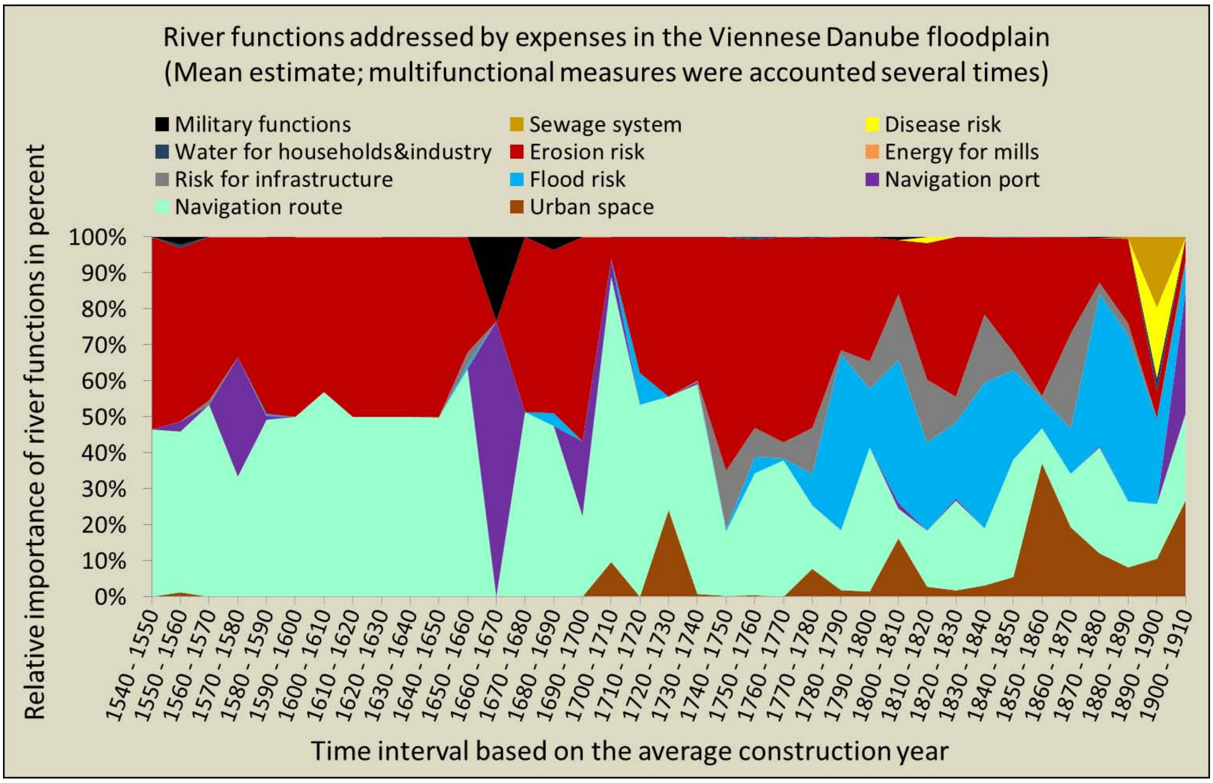

Figure 6-28: Relative importance of the river functions addressed by hydraulic engineering expenses in the Viennese Danube floodplain over time in percent; the expenses of multifunctional measures were accounted manifold for each addressed river function.

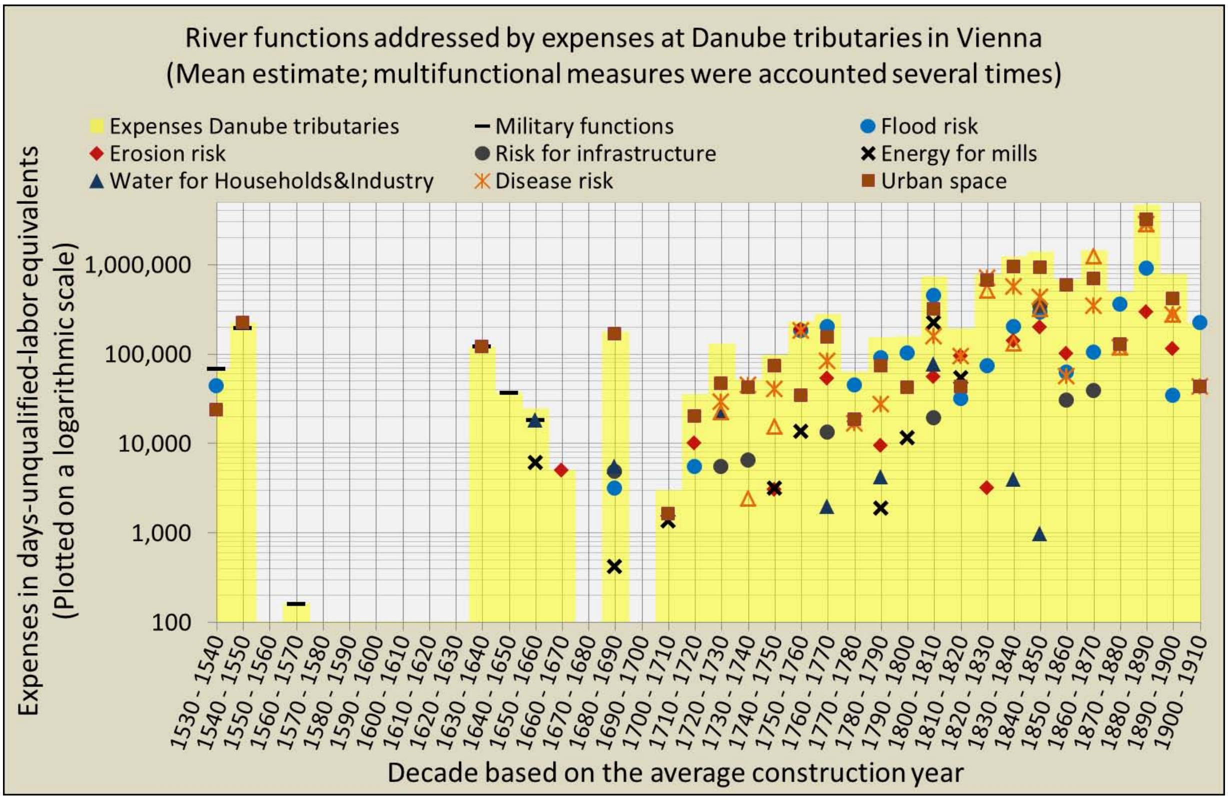

Figure 6-29: River functions addressed by historical expenses on hydraulic engineering at Danube tributaries in Vienna in absolute numbers (plotted on a logarithmic scale).

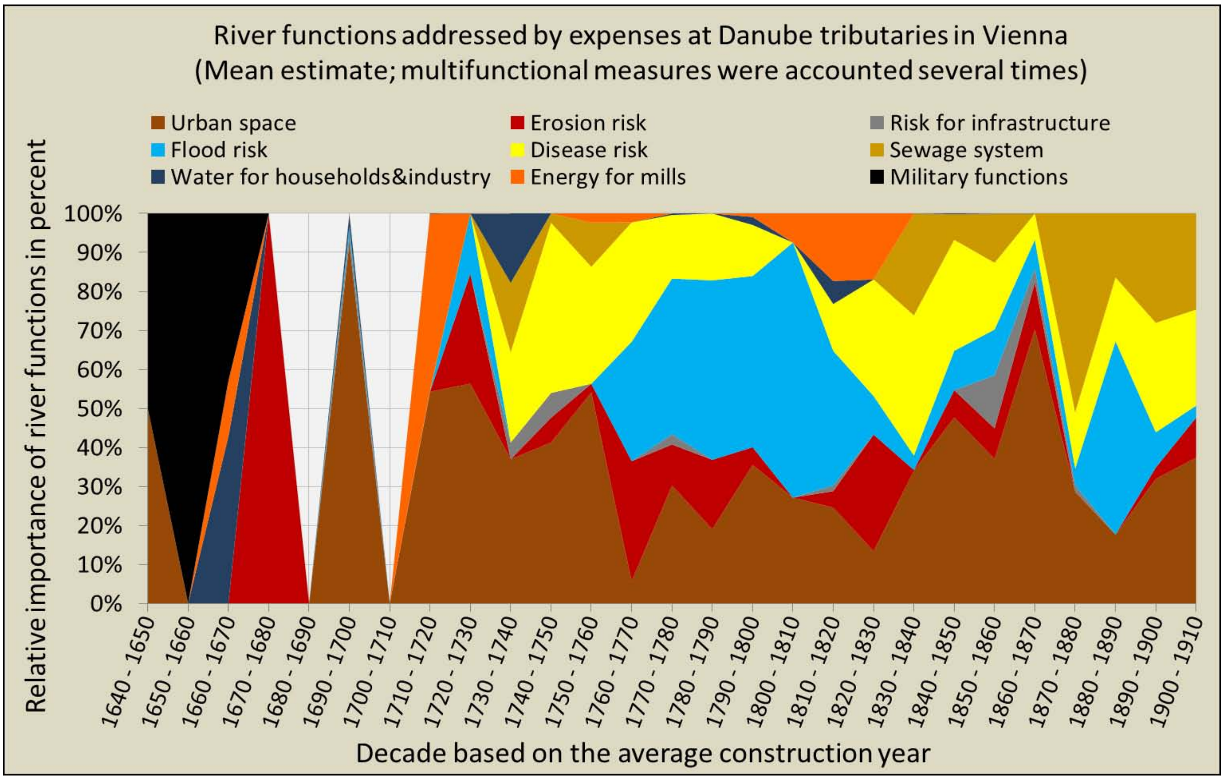

Figure 6-30: Relative importance of the river functions addressed by hydraulic engineering expenses at Danube tributaries in Vienna over time in percent; the expenses of multifunctional measures were accounted manifold for each addressed river function.

From 1830 to 1910 the expenses in Vienna could be assigned to the following motives: navigation routes (28 %), navigation port (4 %), gain of urban space (27 %), flood risk (41 %), erosion risk (23 %), flood-safe traffic routes (7 %), sewage system (13 %); disease risk (13 %) and water supply for households and industry (1 %). In the Danube floodplain, the primary motives were the flood risk with 45 %, the navigation routes with 34 %, the erosion risk (26 %) and the gain of space (21 %). At Danube tributaries the central addressed motives (as far as this is evident at present) were the gain of space with 61 %, the flood risk (16 %), and 43 % each for the two associated functions: the creation of a modern sewage system and the disease risk.

6.3.3 Final overview of expenses and illustrations of the spatial distribution

Table 6-1 summarizes once more central results obtained from this study in one overview: The medium (MED), minimum (MIN) and maximum (MAX) estimate of yearly average cost volumes spent on hydraulic engineering in Vienna (compare chapter 6.1) are listed for the three time periods 1540-1700, 1700-1830 and 1830-1910, both based on different money equivalents and in nominal currencies (NCU). Based on the result in days unqualified labor equivalents (duql) furthermore the effort per inhabitant and year is specified. The cost volumes for the Danube floodplain (DF) and for Danube tributaries (DT) are given and for the DF, separate results for main branches and side arms are presented (compare chapter 6.3). Based on the medium estimate the percentage of expenses addressing different river functions were calculated for each of the three time periods.

The following figures 6-31 to 6-35 visualize the mean cost estimates for individual measures, based on the equivalent amount of "unqualified labor" in days (duql) as map exports from ArcGIS. The height of 3D-columns on top of the structure of the underlying river engineering database from HOHENSINNER et al. (2012) represent the extent of the medium cost estimate for the measure. Different project categories are distinguished by using different colors. Different widths of the columns, and the use of five separate images, allowed integrating expenses within a wide range of values.

Table 6-1: Overview of yearly average expenses in the years 1540-1700, 1700-1830 and 1830-1910 using different money equivalents and percentage of expenses addressing different river functions in Vienna, in the Danube floodplain (DF) and at Danube tributaries (DT).

Average yearly expenses on hydraulic engineering in Vienna							
1540 - 1700	**MED**	**MIN**	**MAX**	**1540 - 1700**	**MED**	**MIN**	**MAX**
in fl. 1721-45 (Labor & GDPPI)	8,320	4,770	15,420	Nominal amounts in NCU	5,400	2,890	10,370
in fl. 1721-45 (Food & CPI)	8,350	3,730	19,040	in duql / inhabitant & year	**0.91**	**0.52**	**1.81**
in K 1913 (Labor & GDPPI)	63,700	36,500	118,000	**% of expenses adressing particular river functions:**			
in K 1913 (Food & CPI)	52,300	23,400	119,300	**1540 - 1700 (%)**	**VIENNA**	**DF**	**DT**
in € 2012 (Labor & GDPPI)	39,000	22,400	72,400	… military barrier	**10.2**	1	67
in € 2012 (Food & CPI)	80,500	36,000	183,700	… gain of urban space	**11.3**	0	82
in m³-oat equivalents	792	347	2,015	… navigation route	**76.4**	88	-
in tons-beef equivalents	72	37	147	… port for navigation	**4.1**	5	-
m³-wine-equivalents	97	37	291	flood risk	**1.5**	1	7
in tons-bread equivalents	-	-	-	… erosion risk	**73.6**	85	1
in days unqualified labor (duql)	**30,500**	**16,900**	**59,100**	… flood-safe traffic routes	**0.6**	1	1
… in the DF in duql	26,400	14,700	50,700	… energy supply	**0.1**	-	1
… thereof at main branches	20,400	11,900	38,300	… water supply	**0.6**	0	4
… thereof at side branches	6,000	2,800	12,500	… disease risk	**0.0**	0	0
… at DT in duql	4,100	2,200	8,400	… sewage system	**0.0**	0	0
1700 - 1830	**MED**	**MIN**	**MAX**	**1700 - 1830**	**MED**	**MIN**	**MAX**
in fl. 1721-45 (Labor & GDPPI)	32,980	20,760	47,040	Nominal amounts in NCU	39,880	24,950	59,920
in fl. 1721-45 (Food & CPI)	29,430	15,620	46,940	in duql / inhabitant & year	**0.79**	**0.50**	**1.10**
in K 1913 (Labor & GDPPI)	252,500	158,900	360,100	**% of expenses adressing particular river functions:**			
in K 1913 (Food & CPI)	184,300	97,800	294,000	**1700 - 1830 (%)**	**VIENNA**	**DF**	**DT**
in € 2012 (Labor & GDPPI)	154,900	97,500	220,900	… military barrier	**0.0**	0	0
in € 2012 (Food & CPI)	283,900	150,600	452,900	… gain of urban space	**13.9**	10	41
in m³-oat equivalents	2,371	1,097	4,568	… navigation route	**41.0**	47	-
in tons-beef equivalents	236	129	410	… port for navigation	**0.8**	1	-
m³-wine-equivalents	407	215	724	flood risk	**26.7**	23	52
in tons-bread equivalents	857	397	1,681	… erosion risk	**51.3**	56	20
in days unqualified labor (duql)	**131,500**	**82,400**	**188,200**	… flood-safe traffic routes	**7.5**	8	2
… in the DF in duql	115,000	71,800	161,600	… energy supply	**1.8**	-	15
… thereof at main branches	52,700	35,800	73,900	… water supply	**0.7**	0	5
… thereof at side branches	62,300	35,900	87,600	… disease risk	**4.2**	0	32
… at DT in duql	16,500	10,600	26,500	… sewage system	**0.2**	0	2
1830 - 1910	**MED**	**MIN**	**MAX**	**1830 - 1910**	**MED**	**MIN**	**MAX**
in fl. 1721-45 (Labor & GDPPI)	317,900	257,900	413,200	Nominal amounts in NCU	1,298,000	1,102,000	1,648,000
in fl. 1721-45 (Food & CPI)	369,900	299,200	480,700	in duql / inhabitant & year	**1.20**	**0.94**	**1.60**
in K 1913 (Labor & GDPPI)	2,433,000	1,974,000	3,163,000	**% of expenses adressing particular river functions:**			
in K 1913 (Food & CPI)	2,317,000	1,874,000	3,011,000	**1830 - 1910 (%)**	**VIENNA**	**DF**	**DT**
in € 2012 (Labor & GDPPI)	1,493,000	1,211,000	1,940,000	… military barrier	**0.1**	0	0
in € 2012 (Food & CPI)	3,569,000	2,887,000	4,637,000	… gain of urban space	**27.4**	21	61
in m³-oat equivalents	26,750	19,810	38,390	… navigation route	**28.2**	34	-
in tons-beef equivalents	1,664	1,310	2,226	… port for navigation	**3.8**	5	-
m³-wine-equivalents	3,714	2,849	5,987	flood risk	**40.6**	45	16
in tons-bread equivalents	7,460	5,290	10,990	… erosion risk	**22.9**	26	7
in days unqualified labor (duql)	**941,300**	**753,900**	**1,232,500**	… flood-safe traffic routes	**7.2**	8	3
… in the DF in duql	784,600	653,400	990,600	… energy supply	**0.0**	-	0
… thereof at main branches	531,000	435,800	678,100	… water supply	**1.1**	1	0
… thereof at side branches	237,200	205,300	288,700	… disease risk	**12.7**	7	43
… at DT in duql	156,300	100,200	241,300	… sewage system	**12.8**	7	43

The background delineations of all measures in the database may be used to identify locations by going back to figure 1-2 which shows the database on top of the reconstructed floodplain and on an aerial photo of Vienna.

Figure 6-31, illustrates the distribution of expenses in the Danube floodplain (DF) before 1830. The greatest expenses are first concentrated near Nussdorf at the branch-off of the Wiener Arm / Donaukanal from the Danube, then more and more along the entire Donaukanal. Several cut-offs in the Donaukanal and the works directly at the branch-off are most significant. Figure 6-32 shows expenses in the DF between 1830 and 1870. Now the expenses are much more distributed over the entire floodplain and one easily notices that it is the main branch of the Danube which had come more intensely into the focus of the efforts. The expenses on flood dikes over the entire DF had been very significant as well. Expenses during the *Great Danube Regulation (GDR)* are shown in the figure 6-33: Besides regulation measures and dikes constructed during the GDR, the excavations of two major cut-offs and areal fillings (deposition of the excavated material in order to create new settlement areas) are the most expensive individual measures from the history of Vienna. Expenses equivalent to more than ten million days of unqualified labor based on contemporary wages were spent only on excavations and fillings. Figure 6-34 shows the distribution of cost estimates from the Danube floodplain in the time directly after the GDR between c. 1880 and 1910. Expenses were mostly dedicated to new ports for navigation, weirs and locks at the upper Donaukanal and the low water regulation of the Danube (supplementary projects to the GDR). In addition, regulation and the construction of flood protection dikes upstream and downstream of Vienna were intensified (Danube regulation in Lower Austria, mostly not part of the DB).

Expenses for the regulation of Danube tributaries – as far as they are known at present – are separately illustrated in figure 6-35. Efforts along the *Wien River* were particularly intense during the *Wien River Regulation* (1891-1915). Expenses on *mill weirs & streams* were certainly much higher than indicated (see LOHRMANN, 1980). The known efforts on minor tributaries before 1830 were mostly close to the center of Vienna, after 1830 is reflected by intense efforts for the sewage system, now spread over the entire urban area.

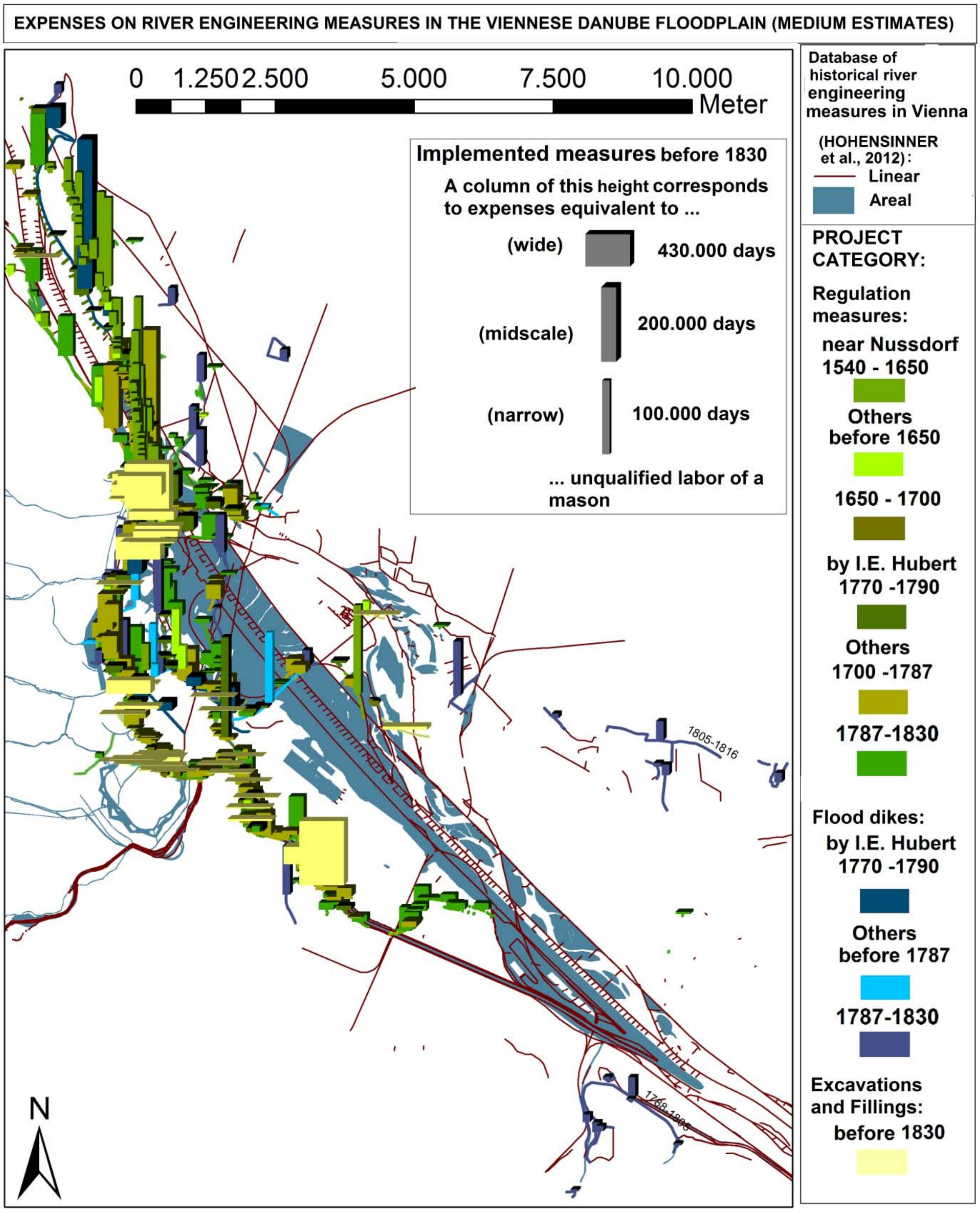

Figure 6-31: Estimated expenses on individual river engineering measures implemented in Vienna before 1830. Due to the highly varying scales of expenses, columns of different width categories were used and represent different scales.

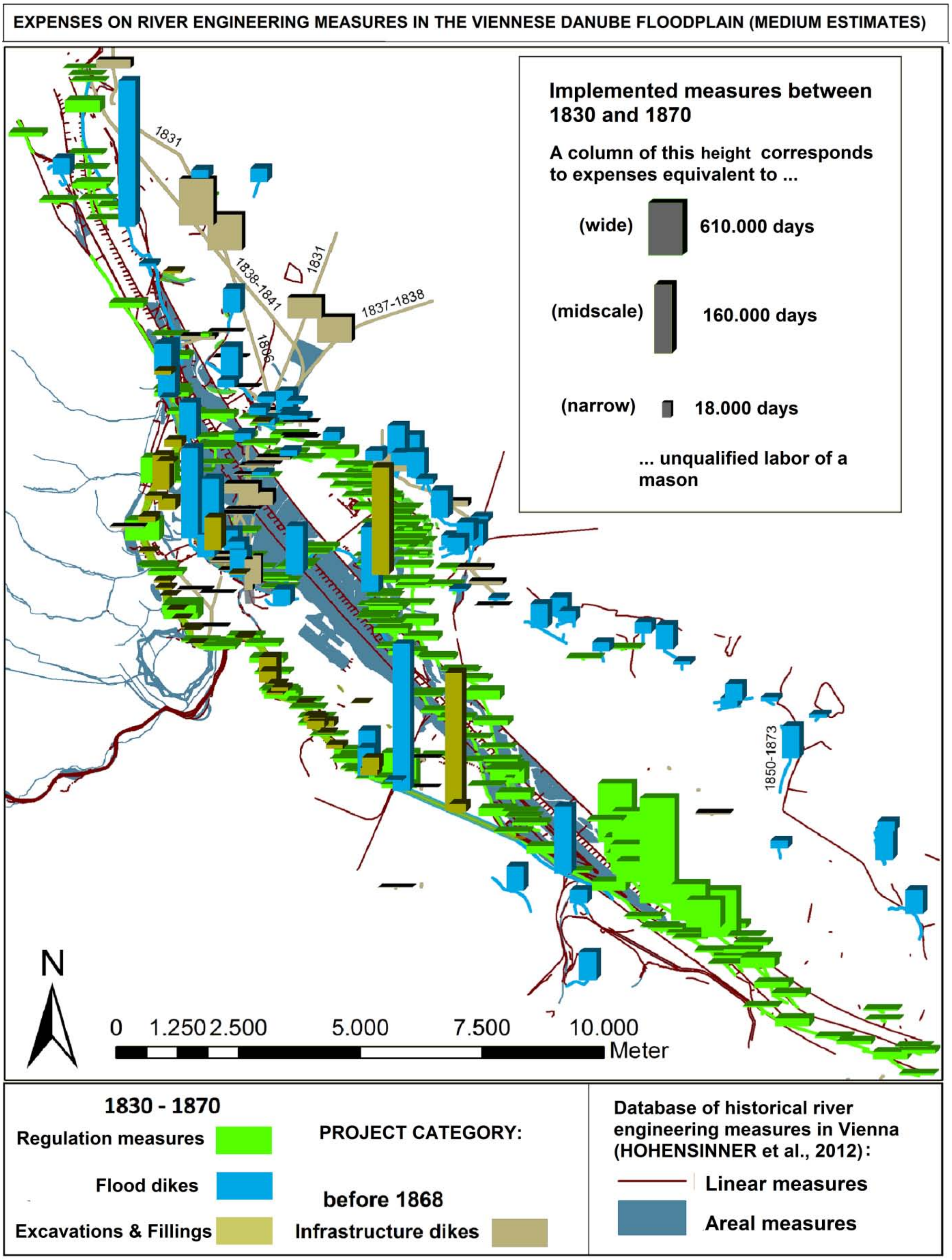

Figure 6-32: Estimated expenses on individual river engineering measures implemented in Vienna between 1830 and 1870. Due to the highly varying scales of expenses, columns of different width categories were used and represent different scales.

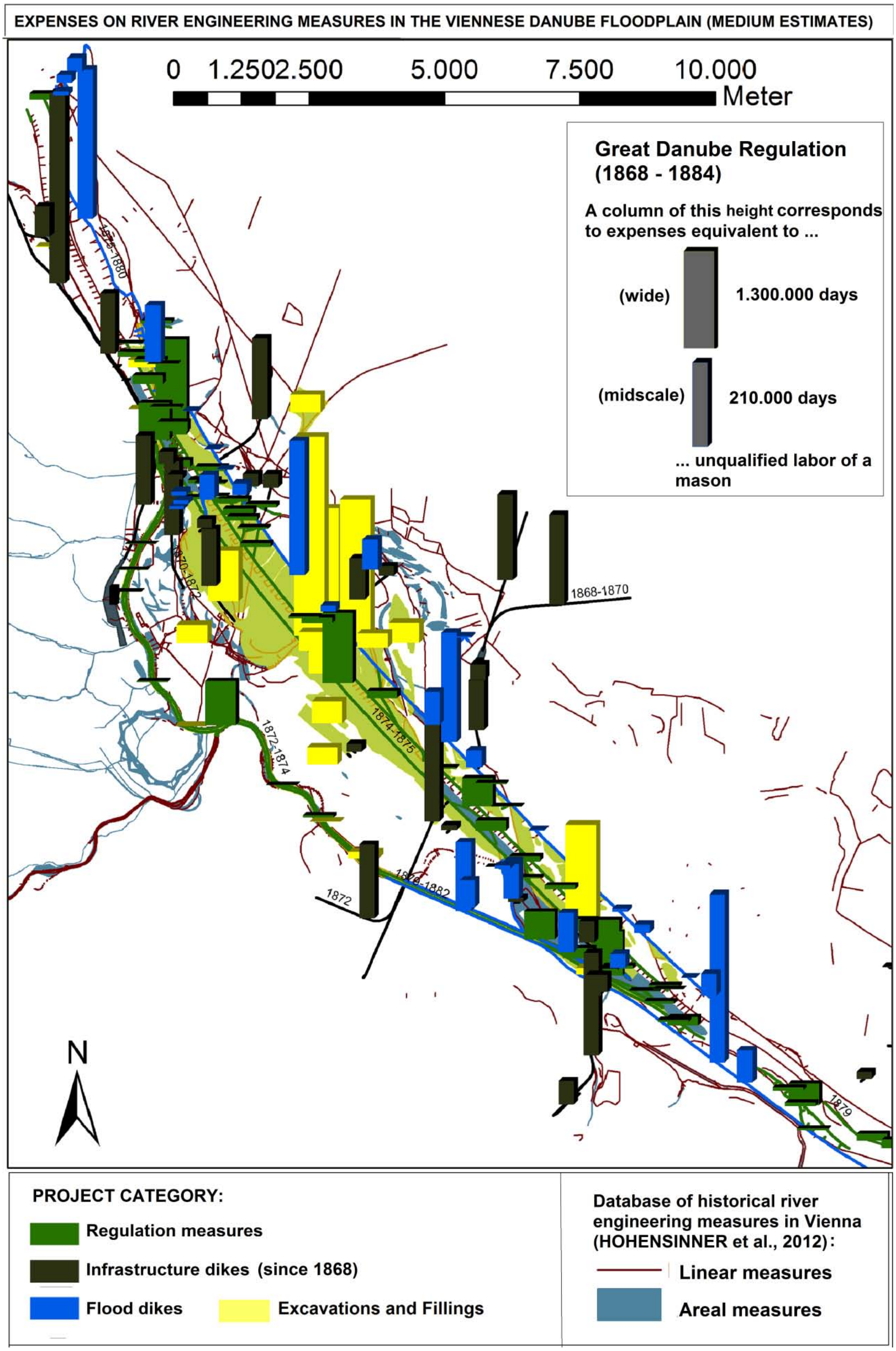

Figure 6-33: Estimated expenses on individual river engineering measures in Vienna during the *Great Danube Regulation (GDR)* between around 1868 and 1884. Due to the highly varying scales of expenses, columns of different width categories were used and represent different scales.

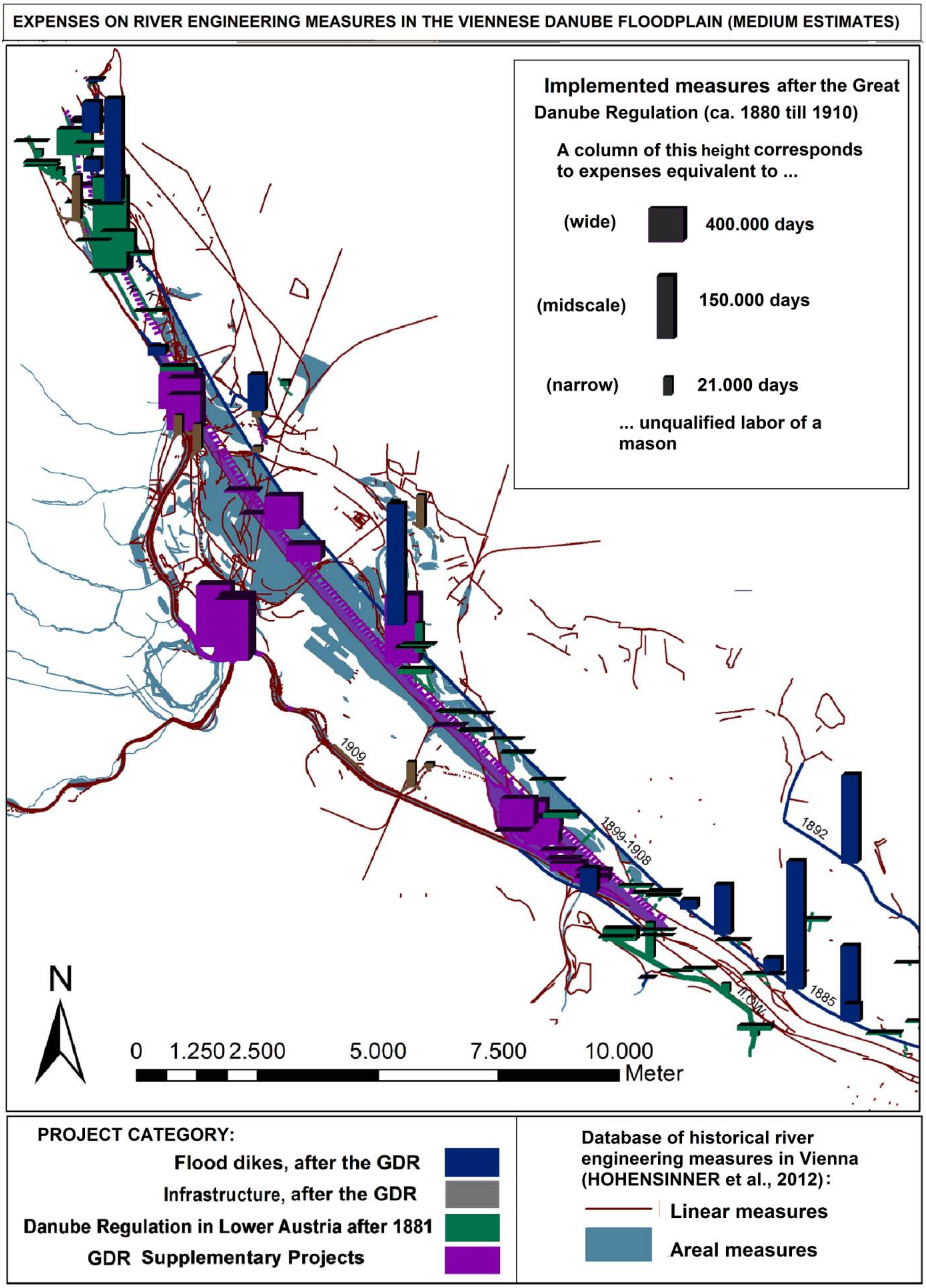

Figure 6-34: Expenses on individual rive engineering measures after the *Great Danube Regulation (GDR)* in Vienna between around 1880 and 1910. Due to the highly varying scales of expenses, columns of different width categories were used and represent different scales.

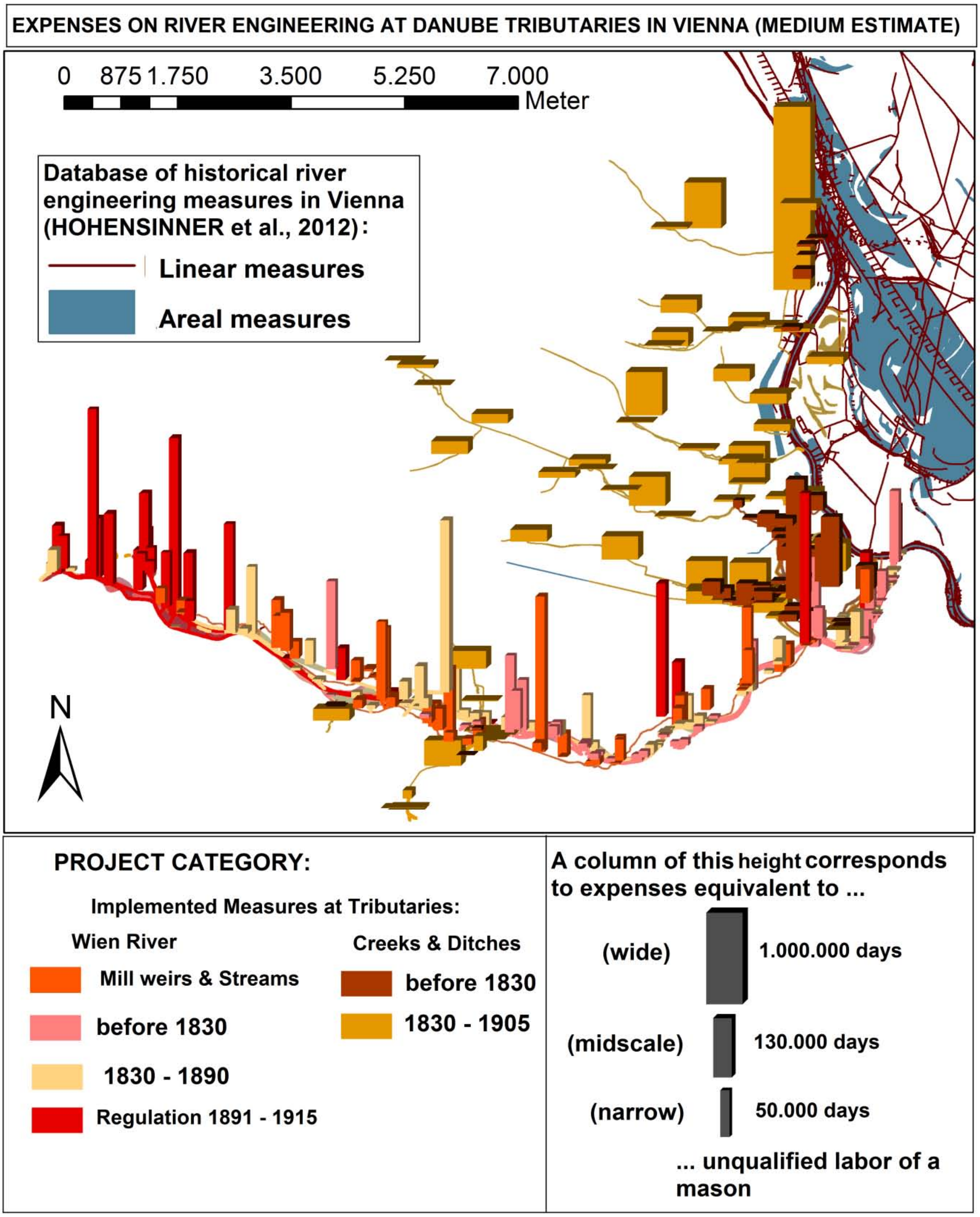

Figure 6-35: Estimated expenses on individual hydraulic measures at Danube tributaries in Vienna between 1100 and 1905 (documentation incomplete, in particular before 1830). Due to the highly varying scales of expenses, columns of different width categories were used and represent different scales.

7 DISCUSSION

7.1 Limitations of the used methodology

The image of a past reality based on the interpretation of fragmentary historical information and not the past reality itself is shown in the illustrations in chapter 6. Various uncertainties on the estimates in the final cost structure are reflected by a minimum and maximum cost estimate for expenses on river engineering measures, projects and sums for time intervals or other categories in the DB. Statistically, this uncertainty covers different aspects and deals with certain difficulties:

1. The uncertainty on the GIS-based estimates on the extents of the measure in the DB (see chapter 3) has been approached based on references in the initial database, stating whether the extents are rather uncertain – assigned as +/- 50 % uncertainty on the extent – or not – assigned as +/- 10 % uncertainty.
2. The changing socio-economic values of nominal (and standardized) amounts of money over time has been approached by a system of money equivalents which were thoroughly documented based on average price indices and prices of goods and services on a yearly level (see chapter 4), while possible price variations within a year were ignored.
3. Prices on river engineering measures were applied as distinct price ranges (cost indices) for different construction types and time periods based on the available documentation (see chapter 5). The range covers all available standardized prices summarized in the category from minimum to maximum and uncertain extents of referred measures from the DB or values in literature.
4. The cost structure over time has been improved by integrating fix amounts of money which were spent on river engineering projects instead of using cost

estimates for the individual measures in the DB, for which the uncertainty was in several cases significantly higher (chapter 6).

Subsequently, there are several systematic problems which need to be considered furthermore, when interpreting the database:

> The label "historical river engineering in Vienna" only covers interpretations and measures referring to the present state of documentation of the restructured, specified and extended DB (chapter 3.2) after HOHENSINNER et al. (2012).

> The standardization and prediction of developments of hydraulic engineering prices was approached by the *Labor & GDP price index*, combining wage trends before 1830 with the *GDP deflator* from 1830 to 2012 (chapter 4.2). A potential systematic error due to the standardization has been reduced by applying prices – if possible – from the same time period on DB measures and by summarizing several standardized prices from different years into one price category.

> There is not one correct indicator available for an interpretation of historical values of money over longer time periods. It has been tested, though, that the accuracy between various used indicators for the entire time period from at least 1530 to 1913 appears acceptable as shown in chapter 4.3. A comparison of these amounts of money with modern prices is complicated, as different indices lead to results which differ by more than an order of magnitude. This difference is interpreted as result of an increase of the productivity of labor and a changing consumer behavior leading to a diversification of products in the economy.

> The price information of historical river engineering measures is fragmentary and the application of cost indices is always based on interpretations. This problem was addressed by the assignment of data qualities to each estimate (chapter 5.4). Good and moderate qualities indicate a reasonable approximation on prices for these measures while poor and arbitrary qualities would definitely require further investigations. The data qualities of the estimates were significantly improved by integrating safely documented expenses for entire projects.

7.2 Expenses on river engineering vs. historical environmental and societal developments

The newly established cost structure over time raises the question what overall developments, trends and events relate to the observed patterns. It was stated earlier that hydraulic engineering projects are understood either as reactions to or triggers of different kinds of configurations, events or developments. The following pages try to approach and identify such correlations in four different ways:

The environmental aspect is addressed in figure 7-1 and illustrates the established cost structure in labor-equivalents compared to important steps in the development of the floodplain as reflected by the reconstructions of the historical morphology of the floodplain (LAGER & HOHENSINNER, 2012a). Important changes in the extent of expenses on the regulation of the water bodies in Vienna are expected to coincide with phases of important environmental transitions in the floodplain and the waterscape of Vienna. The important rise of expenses around 1700 coincides in fact with an important change in the terminology, understanding and morphology of the *Wiener Arm*. Since then, the term *Donaukanal* appears in historical literature for this most relevant Danube branch of that time (THIEL, 1904; SLEZAK, 1978), stressing its regulated and channelized character. In fact, this branch appears fixated near the city of Vienna since then, showing more and more channelized sections and stable banks (LAGER, 2012). As shown previously the rise in expenses is caused by a shift of attention to the regulation of this branch (chapter 6.3). As next major step the expenses on river engineering reach a new level after the momentous ice jam flood in 1830. The following decades are characterized by a massive reduction of the water surface, the cutting-off of side branches, the colonization and settlement of the floodplain and finally the concentration in one major channel after the *Great Danube Regulation* between 1870 and 1875. Around 1905, most of the planned supplementary projects of the GDR in Vienna and Lower Austria had been realized, the urban tributaries were widely channelized, vaulted and hydraulically balanced and the Wien River regulation was nearly finished (KORTZ, 1905). The Viennese waterscape can be considered as nearly entirely regulated and the most urgent questions of the 19th century seemed widely solved from the perspective of the contemporaries. For several decades the regulation activities were reduced to a much lower level. The insufficiency of some solutions from the GDR became obvious in the early 20th century (e.g. HALTER, 1902; HCB, 1908) and in the course of the century new topics, e.g. the generation of electricity came up. The efforts in the late 20th century can therefore be summarized under the label "Improvements and corrections of the GDR and new challenges" and adapt an already irreversibly regulated floodplain to new requirements.

Another way to approach the development of costs is the societal aspect, addressed in figure 7-2. For this purpose some fundamental events in the history of Vienna were superimposed to the illustration: The floods in 1787 and 1830 causing both physical damage and disease had a strong psychological impact on the city's inhabitants and decision-makers. This is reflected by antithetical developments in the cost structure: The flood in 1787 destroyed the expensive and newly established flood protection system of Vienna and the regulation works of the previous years were claimed to be directly responsible for the damage. In fact, the cost structure indicates there is a major interruption in the efforts in the following decades. The experience of the flood in 1830, in contrast, appears as an important trigger to discover and unfold the new potentials based on the industrialization happening at the same time. Periods of war always inhibited or interrupted regulation efforts. The rise of expenses to a new level around 1700 could obviously only happen, after the conflict with the *Ottomans* had ended and the trade on the Danube towards east had been resumed. The state bankruptcy of Austria of 1811 ended a phase with comparably low efforts, while the stock market crash of 1873 had little effect on the on-going GDR.

The much-improved energy transfer after the industrialization leads to lower prices for excavation measures both for transferred volumes and on excavated areas.

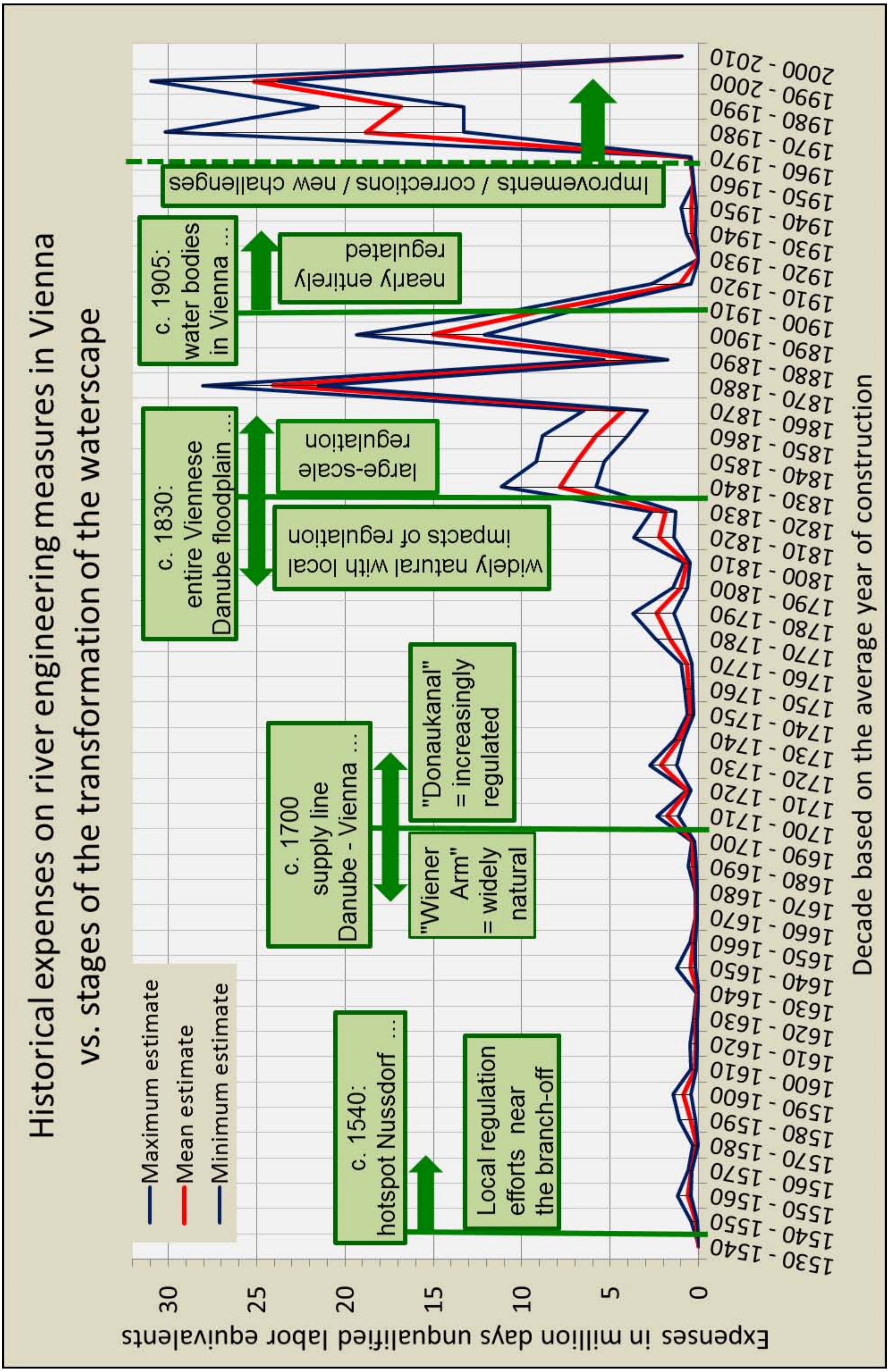

Figure 7-1: Cost development of historical river engineering measures in Vienna vs. important river morphological turning points and transitions in the Viennese waterscape.

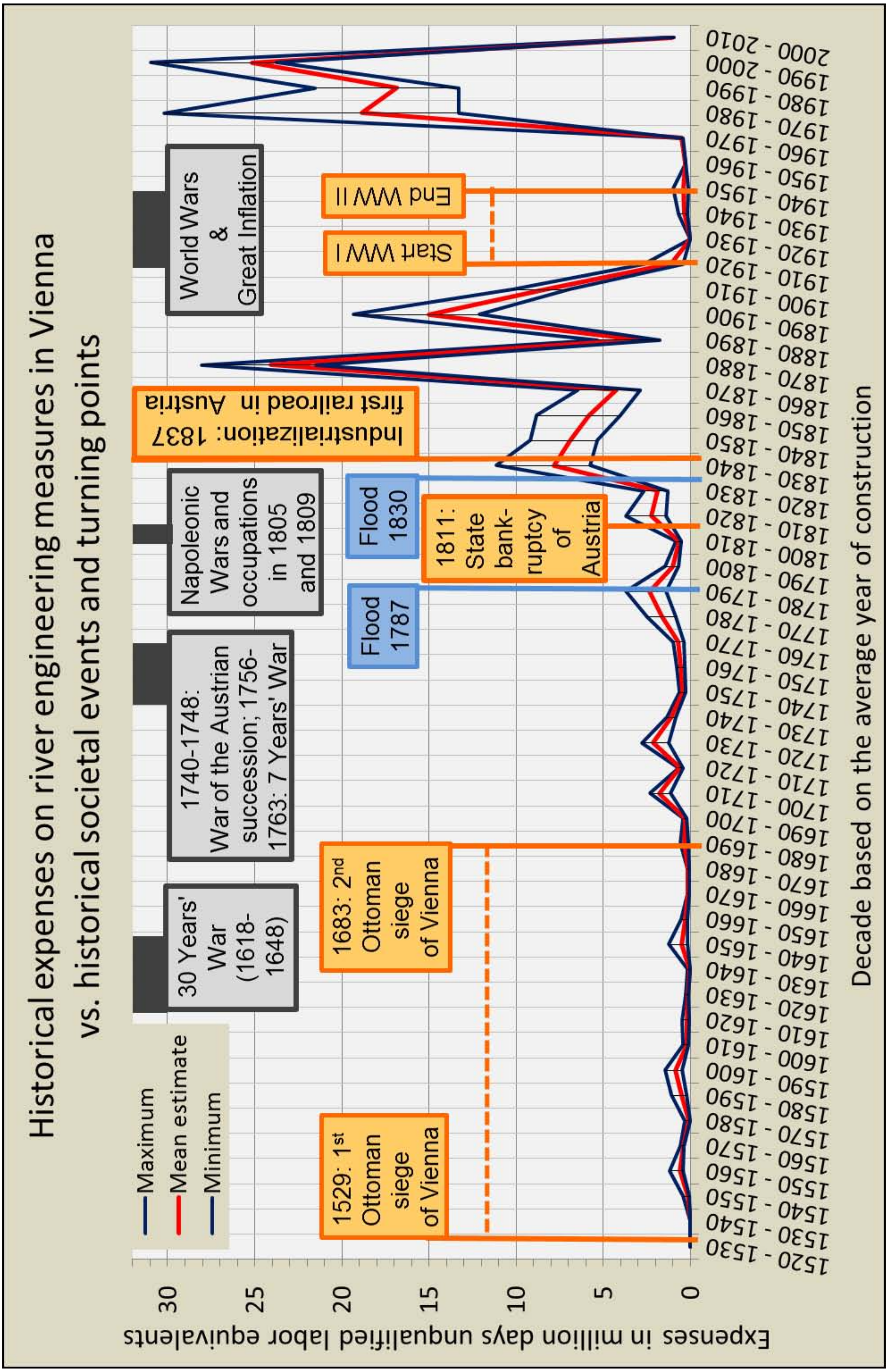

Figure 7-2: Cost development of historical river engineering measures vs. historical societal events and turning points in Vienna.

The strong increase of the efficiency (durability) of river engineering measures in the 19th century leads to a strong improvement of their cost-efficiency. The Viennese were able to transform the Danube floodplain for lower prices and with much greater effect, after 1830. Already in the 18th century, there had been a trend towards a greater cost-efficiency, compared to the earliest regulation works in the 16th century. This pre-industrial change is possibly the result of a gain in routine and know-how compared to early pioneer works and of the different goal to maintain a side-branch instead of deflecting a main branch (HOHENSINNER et al., 2013b).

The correlation of the pattern of the expenses per inhabitant over time with socio-economic phases and the flood frequency was observed: Based on the characterizations by SANDGRUBER et al. (1995) and BUTSCHEK (2011) for the socio-economic history of Austria / Vienna phases were seen – subjectively at this place – as "rather periods of growth and innovation" or "rather periods of crises and wars" (figure 7-3): The 16th and 18th century are largely described as periods of progress while the 17th century had rather been a period of wars and crises. From the 1820s onwards industrialization allowed change and progress while wars in the middle of the 18th century, the Napoleonic wars and the time around the state bankruptcy in Austria from 1811, the 1860s and 1870s are rather characterized as stagnation and inhibition. This characterization is largely represented in the pattern of per capita expenses. The number of flood events and severe flood events has been collected as described by HOHENSINNER et al. (2013b): As figure 7-4 illustrates, a particularly high frequency of severe floods can be considered as trigger for large (per capita) efforts compared to previous or following time intervals in particular around the years 1550-1580, 1640-1660, 1700-1710 and 1760-1790 with partly five or more severe floods per decade). The occurrence of the extreme ice-jam floods from 1830 and 1862 did obviously contribute to stronger regulation efforts in the following years. Beyond the flood events, the river morphological changes played an important role and natural channel changes have actually served as initial trigger for the enormous regulation efforts in Vienna starting around 1540 (see chapter 2.3).

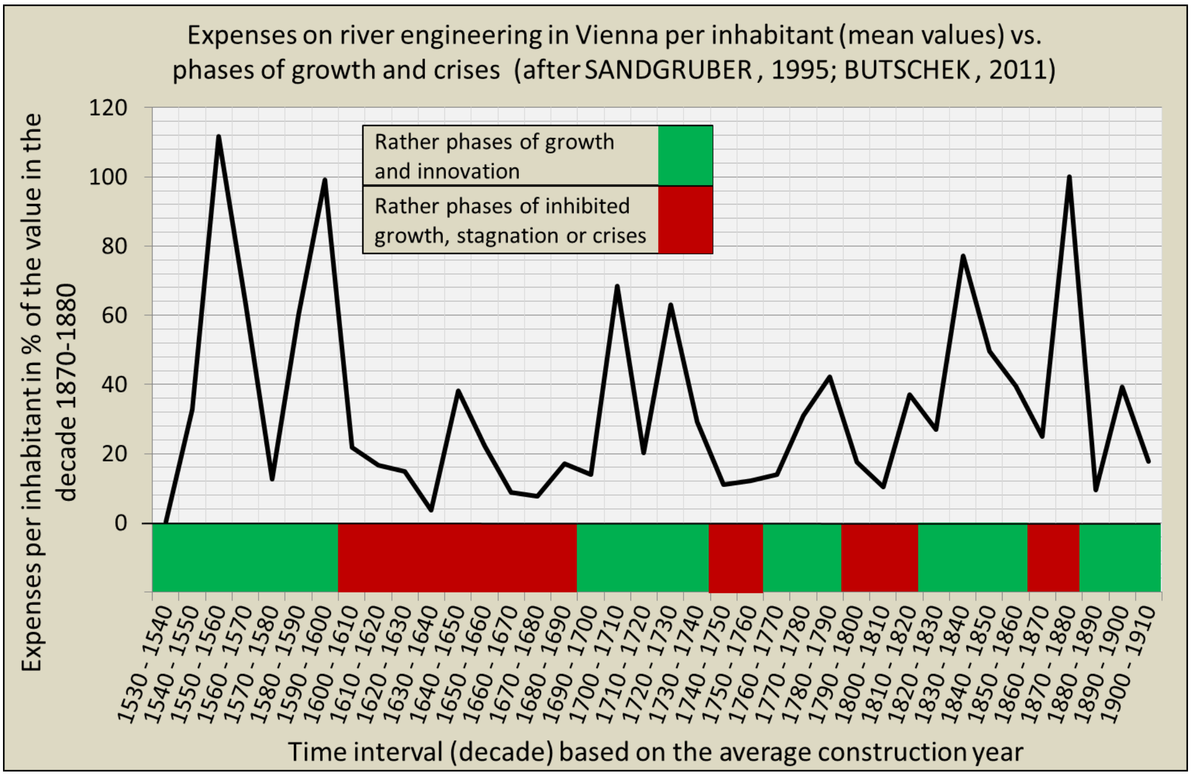

Figure 7-3: Expenses on hydraulic engineering in Vienna per inhabitant and decade from 1530 to 1910 as percentage of the mean value in the decade 1870-1880 vs. phases of growth and crises.

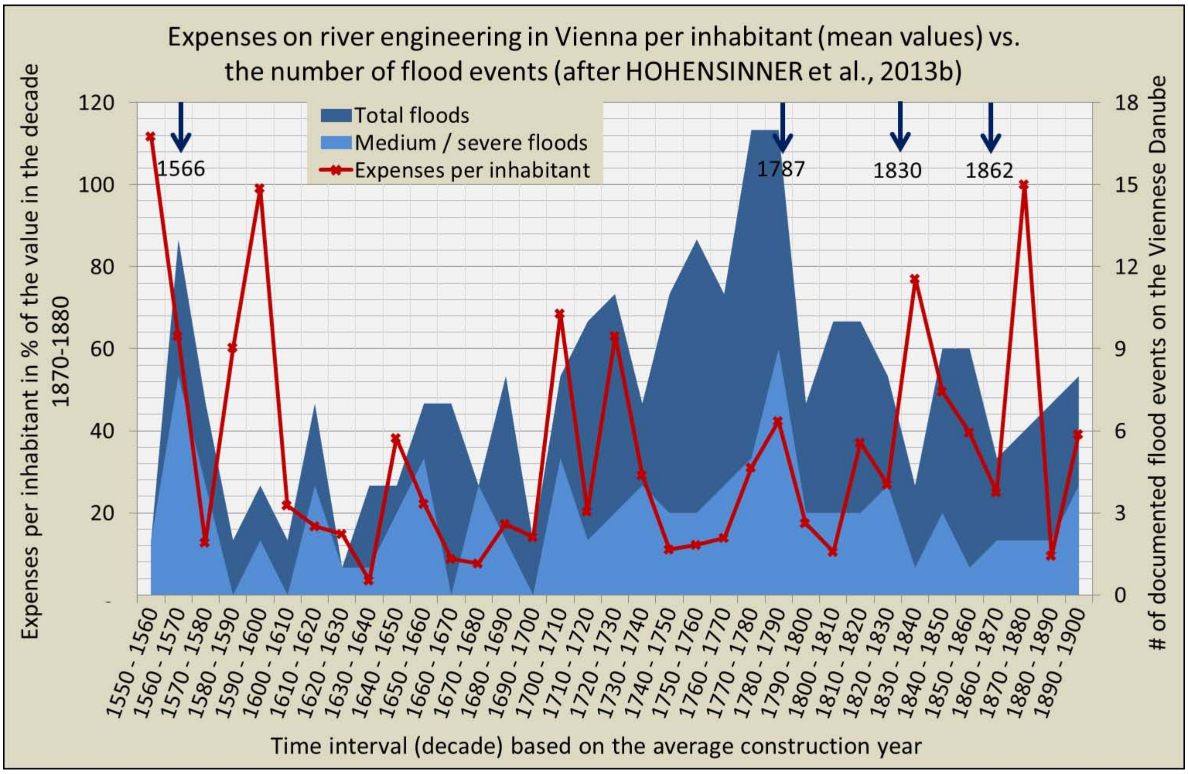

Figure 7-4: Expenses on hydraulic engineering in Vienna per inhabitant and decade from 1550 to 1900 as percentage of the mean value in the decade 1870-1880 vs. flood frequency and selected extreme flood events (1566, 1787, 1830 and 1862).

7.3 Costs and benefits of the expenses on river engineering in Vienna, risk spirals and future prospects

The cost structure invites for being used as a starting point for further investigations: For example, one may ask how the extent of expenses on river engineering measures in a certain time period did relate to corresponding societal benefits and costs obtained from the change of the functionality of the waterscape. River engineering measures were always implemented in order to adapt or maintain the functionality of the floodplain according to the time-specific societal requirements. Different "ecosystem services" the waterscape is offering were in this study considered as "river functions" addressed by the expenses. One might distinguish the intended benefits (on the river functions which were intended to be manipulated) from the unintended societal costs and benefits. Intended changes include the change of the capacity of the river to transport ships, the available space in the floodplain for settlements or industrial or agricultural use, the maximum discharge which can be lead safely through the floodplain. However, unintended changes strongly transformed other services and goods: e.g. the value of the river for fishery or forestry or the biodiversity, the flood prevention or bed erosion in sections downstream of Vienna. Beyond there is a hardly measurable change in intrinsic values (e.g. concerning the value for physical and psychical health, the smell, the biodiversity etc.). And there are long-term benefits such as the gain of experience from possibly unsuccessful pioneer solutions. Questions on the issue of past costs and benefits of river functions have been approached by (SCHOTT, 2007) and changing societal demands and functionalities of the Viennese Danube floodplain were approached in the recent studies (WINIWARTER et al., 2013). The costs and benefits of the *GDR* (1868-1884) have been weighted against each other by WEX (1871a, 1871b), concluding that the benefits outweighed and strongly justified the expenses. Without any doubt benefits for the development of Vienna have been enormous till date. However, based on the here considered expenses on regulation projects, it can at least be stated that, considering a time period of more than 100 years, there are substantial long-term socio-economic costs of the GDR, either. As documented in appendix IV.2 substantial efforts have started in the 1970s which deal with consequences of the *GDR*, labelled as “correction of the GDR”, “improved flood protection” and “hydropower”. On-going and further expenses can be expected for centuries: e.g. for continuous flood protection for hundred thousands of people settling in the former floodplain, routes and for the prevention of bed erosion and sinking groundwater levels and the loss of hydrological connectivity in the *Nationalpark Donau-Auen*, possibly restoration issues and the protection of biodiversity.

From the point of view of environmental history the appearance of material arrangements forming the boundary conditions for present or future practices in socio-natural systems can be considered as legacies of former interventions in the arrangements which were defined by earlier practices (WINIWARTER et al., 2013). Following the concept of risk spirals (e.g. SIEFERLE & MÜLLER-HEROLD, 1996), solutions with respect to one particular problem on a long term, if they are efficient interventions, mark the beginning of a new problem which is possibly only recognized much later. A “risk spiral” unavoidably started with the beginning of efficient transformations in the floodplain. Often new risks arising from side-effects or previous regulation have entered societal awareness only many decades later, as can be observed many times in the Viennese regulation history. The risk spiral started long before regulation by having a growing society in number and demands. In the initial phase of regulation the primary risk was the loss of supply with food, water, energy, goods and the provision of military shelter. These primary concerns were addressed strongly by the expenses on river engineering in the *Danube floodplain* and at *Danube tributaries* as documented in chapter 6.3 for the periods 1540-1700 and less significant for 1700-1830. If energy and water supply, the creation of military barriers and navigation routes and ports are considered as “supply functions” as opposed to “risk functions” which summarize the risk of erosion, flood, disease and the availability of flood-safe urban space and infrastructure, one may state a major shift from supply functions to risk functions as primary motive behind regulations around 1830 (with a period of transition at least since the late 18th century). In other words, the primary concern of the pre-industrial period was to redirect sufficient amounts of water towards Vienna, while in the 19th century the separation of the urban area from the river was primarily important. The *GDR* solved fundamental problems of the time, e.g. concerning the gain of space, a flood protection system, flood safe traffic routes, modern steam navigation routes and ports in some distance to Vienna. Yet, the regulation caused considerable new risks: More people were living in the floodplain as consequence of the regulations and were exposed to the still not entirely banned flood risk. Bed erosion in the straightened and stabilized river lowered the groundwater table which lowered potential benefits from the ecosystem diversity on a long-term threatened water supply for agriculture and today threatens biodiversity in the *Nationalpark Donau-Auen* downstream of Vienna.

Vienna is an interesting spot for examining the structure of expenses of historical river engineering measures and the changing attentions towards different river functions as there is comprehensive documentation of the regulation history far back in time. The cost structure is supposed to and able to capture a temporal pattern of major developments of the quantity and quality of the societal efforts on river regulation over several centuries. The level of detail is necessarily limited and there is a huge potential to replace, extend, improve, correct and refine the data for Vienna and, beyond that, to compare them with data from other spots. For the further usage of the data generated and combined in this research here are various suggestions:

1. An update, double-check and analysis of the time series on historical values of money in Vienna should be considered which might then be used as well for separate socio-economic studies replacing the here-defined preliminary tool. In particular it is suggested to look for additional data on labor prices in the 19th century as they are an important indicator in the research and contain major gaps for which other trends from other indicators had to be used for the time series.

2. Historical studies looking at shorter time windows of the cost structure might contribute a lot to improve and refine the data, and to correct certain interpretations. The integration of hidden price information in additional primary sources can be used to verify / falsify the present price keys. Footnotes given by THIEL (1904, 1906) and SLEZAK (1977, 1978, 1980) might be a good starting point in this context – in particular for the period between 1650 and 1770 for which price information is very rare till date. The research does refer to a simple scheme of documented area and length prices from different time periods. The 3D-extent (e.g. dike height, channel depth etc.) might be more systematically integrated into the cost estimates, given that such systematic information can be sufficiently obtained from the DB or additional historical sources. The time periods 1540-1650, 1650-1770, 1770-1830, 1830-1870 and 1880-1910, and the time of the *GDR* ca. 1868-1884 are suggested for separate studies. For the 20th century the river engineering database needs to be systematically continued. So far, only selected projects were integrated for this time period. Additionally the data quality for Danube tributaries is not that satisfying yet and further historical studies and additional documents might be integrated (HOHENSINNER et al., 2012).
3. Refined analyses of the results for individual water bodies, river branches or other data samples would be a logical subsequent task which can easily be done by making use of the categorizations in the database.
4. Furthermore, an extended study for the Danube sections in *Lower* and *Upper Austria* and examination of the different characteristics compared to the structure for Vienna would be interesting. Several sources (DIR.ADM.STAT., 1854; PASETTI, 1862; DRC, 1898; SCHREY 1899; BAUMANN, 1951) and the protocol in *file B.1* on the DVD may provide a starting point for the 19th century.
5. The results invite for comparisons with other major European capitals or river sections, furthermore, looking in particular on the river functions addressed by river engineering expenses, so that the time periods might be distinguished from site-specific characteristics.

8 CONCLUSIONS

An approximation to a cost structure of historical expenses on hydraulic engineering measures in Vienna has been established (chapter 6). The study refers to an extended, specified and slightly re-structured version of an existing database of historical hydraulic engineering measures in Vienna (chapter 3) which contains a systematic study between 1530 and 1900, selected major projects from the 20th century and occasional information prior to 1530. Documented expenses and standardized prices per meter, hectare and cubic meter of different construction types derived from historical sources served as reference for the study (chapter 5). A labor price index till 1830 and a gross domestic product deflator for Austria since 1830 were used to standardize prices and predict prices over shorter time periods. A framework of money equivalents (e.g. containing oat-, beef- and unqualified-labor-equivalents) has been established, based on prices, wages and price indices in Vienna and Austria, for a comparison of historical nominal and standardized money amounts over the entire time period (chapter 4). Different methods widely have an acceptable accuracy for comparisons between 1530 and 1913 for most methods while a comparison of present amounts of money with amounts before 1913 is very ambiguous, as different methods lead to a severe mismatch, due to a rapid relative increase of ("real") labor and food prices compared to common price indices in the economy shortly after WW II. Going back to the initial research questions from chapter 1, and considering the hypotheses and the issues discussed in chapter 2 and chapter 7, one may draw the following general conclusions:

(1) Based on the analyses of prices per meter of linear measures and per hectare of areal measures in the DB, one may conclude some major changes over time: In particular areal prices of channel excavations are significantly higher from 1700

till 1830 than before, while linear dike prices were more expensive from 1830 till 1910 than before, as more massive and stable structures were used. Areal prices of excavations strongly decreased after 1830 as effect of the strongly improved energy transfer after industrialization. Prices of regulation measures did not show significant (general) trends and need to be looked at more specifically.

(2) Three major phases of regulation could be identified between 1540 and 1910 based on the level of the expenses per time interval spent on hydraulic engineering in Vienna: From 1540 to 1700 a yearly average between 17,000 and 60,000 days unqualified labor-equivalents (duql), from 1700 to 1830, 83,000 - 190,000 duql and 1830-1910 780,000 - 1.3 million duql were estimated. The increase around 1700 could be identified as being a result of increasing efforts along Danube side branches and there in particular along the *Donaukanal*, the increase around 1830 could be identified as result of increased expenses on the regulation of Danube main branches after the momentous ice jam flood in 1830. A growing population and the effect of industrialization have obviously strongly increased the budgets for river engineering in Vienna. Several times, regulation efforts were largely interrupted by political or economic crisis or inhibited by wars. Psychologically important floods had antithetical effects on the river engineering effort of Vienna. While the flood in 1787 did rather lead to resignation as the extremely costly efforts of the previous decades had obviously largely failed, the flood in 1830 triggered a new intensity of investments, both in regulating the Danube branches entirely and in understanding the tributaries mostly as disease risk and part of the sewage system.

(3) The per capita effort is not significantly less in the second half of the 16th century compared to the time of the gross domestic product: On average between 1540 and 1910 the efforts can be considered in the range of 0.5 - 1.8 days unqualified labor equivalents per inhabitant and year. The temporal pattern of expenses per inhabitant clearly correlates with phases of economic growth or inhibited growth and crises. Furthermore, the present data indicate, that phases with an

extraordinary flood frequency are reflected by higher values compared to previous or following decades.

(4) The "ability" of society to transform Danube branches has strongly increased after 1830, when the cost-efficiency per extent and year of functionality – in particular for the excavation of new channels and dredging works – has strongly improved as result of the industrialization. Already in the 18th century the cost-efficiency of regulation measures had become more predictable than in the centuries before.

The study on "river functions" shows well, how regulation measures provided solutions for changing societal motives concerning the functionality of running waters over time. Certain sets of motives are characteristic for each time period. Side-effects of earlier expenses often determined the necessity for later expenses. From 1540 till 1700 provisioning river functions (e.g. water and energy supply, a military barrier and navigation) were addressed primarily by the expenses and regulation efforts aimed to direct water towards the city. Increasingly in the 18th century and constantly in the 19th century, more risks were addressed requiring an improved discharge of water through the channel network and a separation of the floodplain from the river.

The city of Vienna has irreversibly grown into what was once the Danube floodplain. The present waterscape is a legacy or a result of past river regulation in Vienna. A critical awareness on all levels of society on the wide range of functions and values of water bodies and their interrelation in socio-ecological systems might positively affect future interventions in river landscapes. Present and future generations due to the use of information technology are able to model environmental or hydraulic conditions in much more detail and can access huge amounts of data for a reflection about legacies of past interventions. River management appears as an on-going and never-ending task to question existing concepts, adapt prioritizations between environmental, cultural, economic and technological demands of societies and predict potential implications of present regulations on the boundary conditions for future human practices.

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10 LIST OF FIGURES AND TABLES

11 LIST OF DEFINITIONS AND ABBREVIATIONS

Please note that further explanations, definitions and translations of terms are usually given in the text. Categories from the database of historical hydraulic engineering measures in Vienna – such as specific construction types – were left out in this list as they are explained in detail in chapter 3 and in appendix V. The following list is supposed to enhance the understanding of some terms and abbreviations used in the text:

Alternative deflated currency unit (ADCU): refers to the study specific inflation-adjusted currency units *fl. 1721-1745*, *K 1913* and *€ 2012* deflated by the *Food & CPI* (→ chapter 4.4); in contrast to *nominal currency units* and *deflated currency units*

AVRG: acronym for *average*

Average: the sum of values from a sample divided by the number of its elements

Beef equivalent: a food equivalent expressing a historical money amount based on the equivalent amount of beef in *tons* or *kg* which could have been bought by the coevals in Vienna

Bread equivalent: a food equivalent expressing a historical money amount based on the equivalent amount of bread in *tons* or *kg* which could have been bought by the coevals in Vienna

cb: acronym for cubic (e.g. in cubic meter = cbm or cubic klafter = cb-kl.)

CPI: acronym for *Consumer Price Index*

Consumer price index: index observing the change of the prices of a bundle of goods and services which is defined based on the consumption of an "average household" in defined reference years; this index stresses the household's perspective on price developments (→ chapter 4.2)

Danube floodplain: refers to the Danube in Vienna, its main and side branches, abandoned arms and artificial water bodies

Danube tributaries: refers to the tributaries of the Danube in Vienna, mostly flowing down from the *Wienerwald Mountains* in the West

Days unqualified labor (= duql): unit for the *unqualified labor equivalent* in days, in this research used as central unit to weight money amounts from different time periods against each other (→ chapter 6)

DB: acronym for database; if not stated different *DB* refers to the – extended – database of historical river engineering measures in Vienna based on HOHENSÌNNER et al., 2012

DCU: acronym for *deflated currency units* (→ chapter 4.4)

Deflated currency unit (DCU): refers to the study specific inflation-adjusted currency units *fl. 1721-1745*, *K 1913* and *€ 2012* deflated by the *Labor & GDPPI* (→ chapter 4.4); in contrast to *nominal currency units* and *alternative deflated currency units*

Deflated money: refers to all money amounts which are expressed in inflation-adjusted (deflated) currencies referring to price levels of a certain reference year according to clearly defined price indices; e.g. K 1913, fl. 1721-45 or € 2012

Deflator: A method to predict or eliminate short and medium term price developments in historical data on expenses and prices; for hydraulic measures the *Labor & GDPPI* has been considered as best available tool to predict likely price changes for certain construction types over time

den.: *acronym for Wiener Pfennig*

DF: acronym for the *Danube floodplain*

Donau-Reguli(e)rungs-Commission: several commissions which were mandated with the planning and realization in particular of the *Great Danube Regulation (GDR)* in Vienna and with further regulations in the 2nd half of the 19th century.

DRC: acronym for *Donau-Reguli(e)rungs-Commission*

DT: acronym for the *Danube tributaries*

duql: acronym for *days unqualified labor*

Eimer: volume measure equal to 58.0083 liter

ENVIEDAN: "Environmental history of the Viennese Danube 1500 - 1890: Understanding long-term dynamics, patterns and side-effects of the colonization of rivers"; research project funded by the Austrian science fund (FWF); project no.: P22265-G18, project leader: *V. Winiwarter*, *Alpen-Adria-University Klagenfurt*

Euro (€) 2012: a *deflated currency unit* and *standardized money equivalent* based on a standardization of all historical amounts of money to prices in Euro (€) 2012 in the year 2012; either based on the *Labor & GDPPI* (standard) or the *Food & CPI* (alternative)

FHKA: acronym for *Finanz- u. Hofkammerarchiv*, one part of the *Austrian State Archives (OeStA)*

fl. 1721-1745: acronym for the standardized currency *Gulden 1721-1745* (→ chapter 4.4)

fl. / fl. CM: *Gulden / Gulden Conventionsmünze*, main currency in Austria 1510 till 1858 (→ chapter 4.1); based on silver coins; 1 fl. / fl. CM = 60 Kreutzer (kr. / kr. CM)

fl. BN: *Gulden bank notes*; first paper based money in Austria since the late 18th century till the state bankruptcy in 1810 (→ chapter 4.1)

fl. ÖW: *Gulden Österreichische Währung*; currency in Austria from 1858 to 1892 (→ chapter 4.1); based on silver coins; 1 fl. ÖW = 100 Kreutzer (kr. ÖW)

fl. WW: paper based currency 1811-1858 (→ chapter 4.1)

Food & CPI (= Food & Consumer price index): a price index constructed for this research, observing price developments from a consumers' perspective; since 1800 equivalent to the reconstructed *CPI* of Austria; before 1800 average price trends for food prices (see *food price index*) were used to represent the price development in Vienna; the two indices were chain-linked using the price levels in the years 1830-1838 (→ chapter 4.3)

Food equivalent: clearly defined amount of a particular food product one could buy in Vienna for a certain amount of money in a certain year

Food price index: a price index based on the average trends of documented historical food prices in Vienna (→ chapter 4.2 and 4.3)

GDP: acronym for *Gross domestic product*

GDPPI: acronym for *GDP price index* and synonym for *GDP deflator*

GDP deflator: synonym for *GDP price index*

GDP price index (= GDPPI): a price index based on the ratio of the *Nominal GDP* divided by the *Real GDP* at prices of a defined base year; the *GDPPI* measures price trends based on the entire output of the economy (→ chapter 4.2)

GDR: acronym for the *Great Danube Regulation*

GIS: Geographical Information System; here accessed with the program *ESRI ArcGIS 10*

Great Danube Regulation: a huge river engineering project to regulate the Danube in Vienna according to a master plan integrating the major river management concerns of the 19th century; mainly conducted between 1870 and 1875 and completed till around 1884

Gross domestic product (GDP): measure for the extent of the entire output of the economy of a country or area; the *nominal GDP* (expressed in nominal money) and the *real* GDP (standardized to price levels of a reference year) can be distinguished

Gulden 1721-1745: a *deflated currency unit* and *standardized money equivalent* based on a standardization of all historical amounts of money to average prices in Gulden (fl.) in the period 1721-1745; either based on the *Labor & GDPPI* (standard) or the *Food & CPI* (alternative)

Gulden (= fl.): the name of various currencies in Vienna and Austrian (→ chapter 4.1) all abbreviated as fl.; see explanations for fl. / fl. CM, fl. ÖW, fl. BN, fl. WW

kr.: acronym for the currency unit *Kreutzer*

K: acronym for the currency *Kronen*

K 1913: acronym for the standardized currency *Kronen 1913* (→ chapter 4.4)

Kronen (= K): name of the Austrian currency used between 1892 and 1925 (→ chapter 4.1)

Kronen 1913 (= K 1913): a *deflated currency unit* and *standardized money equivalent* based on a standardization of all historical amounts of money to prices in Kronen (K) in the year 1913; either based on the *Labor & GDPPI* (standard) or the *Food & CPI* (alternative)

sol.: acronym for *Wiener Schilling*

ha: acronym for *hectare*

hectare: an area covering 100*100 meter (= 10,000 square meter)

kg: acronym for *kilogram*

kl.: acronym for *klafter*

Klafter: length unit between 1.8 and 1.9 meter depending on the time of its use (→ chapter 5.1)

km: acronym for kilometer (1 km = 1,000 meter)

Labor equivalents: clearly defined wages one would pay in Vienna for certain amounts of money; it was distinguished between *qualified labor equivalents* and *unqualified labor equivalents*.

Labor price index: a price index based on the average trends of documented historical wages in Vienna (→ chapter 4.2 and 4.3)

Labor & GDPPI (Labor & GDP price index): a price index constructed for this study, observing price developments from a decision-makers' perspective; since 1830 equivalent to the reconstructed *GDPPI* of Austria; before 1830 average trends for wages (see *labor price index*) were used to represent the price development in Vienna; the two indices were chain-linked using the price levels in 1830; the index was considered as most adequate "deflator" for hydraulic engineering prices. (→ chapter 4.3)

Liter: volume measure; 1 m^3 = 1,000 liters

m / m² / m³: acronyms for *meter*, *square meter* and *cubic meter*

MAX: acronym for *maximum*

MED: acronym for the *mean* or *medium* reconstruction of prices and cost estimates; always referring to the value which comes closest to historical sources and represents the most likely estimates based on the available documentation

MDN: acronym for *median*

Mean: synonym for *medium*

Median: A statistical value separating a data sample in a higher and lower half, here in particular used for a most likely money equivalent within a time period and for the most likely price out of a sample of several historical price data

Medium: In the context of the research a mean value for price ranges and cost estimates, supposed to represent the most likely reconstruction and the one which comes closest to the available documentation

Metzen: The name of different volume measures with different size (see detailed explanation in chapter 4.2)

MIN: acronym for *Minimum*

Money equivalent: an actual "value" assigned to a defined number of nominal money (here usually 100 *NCU* or 100 *fl.*); the value might be expressed as amount of a food product one could obtain for this money (→ *food equivalent*), the amount of labor one could pay (→ *labor equivalent*) or the corresponding amount of money in a reference year or period following clearly defined price indices (→ *standardized money equivalents*)

NCU: acronym for *nominal currency unit* (→ chapter 4.1)

NCU factor: constant exchange rates between the research specific *nominal currency units* extrapolated to the entire time span based on the exchange rates when new currencies were introduced (for example in 1892, 1 fl. ÖW was replaced by 2 K as nominal currency)

Nominal currency unit (= NCU): refers to the one nominal currency which was defined as reference currency in Vienna for each year (→ chapter 4.1)

Nominal money: amounts of money as documented in historical sources and expressed in historical currencies such as fl. CM, K, € etc.; in contrast to *deflated money*

Nominal price: a price expressed in nominal money

Nominal gross domestic product (= Nominal GDP): the gross domestic product of a country or area expressed for a certain year in the nominal currency of the time

Oat equivalent: a food equivalent expressing a historical money amount based on the equivalent amount of oat in *m³* or *liters* which could have been bought by the coevals in Vienna

OeStA: acronym for *Österreichisches Staatsarchiv* (= Austrian State Archives)

Pfund Wiener Pfennig (tal.): a currency unit in Vienna used from the late 12th century to 1510/11; 1 Pfund Wiener Pfennig (tal.) = 8 *Wiener Schilling* (*sol.*) = 240 *Wiener Pfennig* (*den.*)

Price index: an index observing a trend in historical prices in a certain area compared to defined reference years (set to 100) or periods and based on a defined bundle of goods and services (e.g. consumer price index) or based on one (e.g. oat price index) or few (e.g. cereal price index) goods or services; two indices referring to different reference years may be chain-linked by setting the indices equal for a defined year or period

Qualified labor equivalent: a labor equivalent expressing a historical money amount based on the equivalent amount of days of “skilled” labor of a mason which could have been paid in Vienna in the respective time period

Quartile: the upper/lower quartile separates the upper/lower quarter of the values from a data sample; half of the values of the sample lie in between the upper and the lower quartile

Real gross domestic product (= Real GDP): the *GDP* of a country or area expressed at price levels of a defined reference year

sq.: acronym for *square* (e.g. in square meter = sqm, square klafter = sq-kl.)

tal.: acronym for the currency *Pfund Wiener Pfennig*

Tons: 1 ton = 1,000 kg

Value-of-money indicator: → *money equivalent*

Viennese Danube: refers to the entire Viennese waterscape consisting of both the *Danube floodplain* and *Danube tributaries* in the present city area of Vienna

Wage index: → *Labor price index*

Wiener Pfund: weight measure equal to 1.7855 kg (not to be confused with the currency *Pfund Wiener Pfennig*)

Wiener Schilling: a currency unit from the late 12th to 16th century (→ chapter 4.1)

Wiener Pfennig: a silver coin, coined in Vienna since the late 12th century and used till the 16th century, when it was replaced by the *Kreutzer* (*kr.*) (→ chapter 4.1)

Wine equivalents: a food equivalent expressing a historical money amount based on the equivalent amount of wine in *m^3* or *liters* which could have been bought by the coevals in Vienna

Unqualified labor equivalent: a labor equivalent expressing a historical money amount based on the equivalent amount of days of “unskilled” labor of a mason which could have been paid in Vienna in the respective time period

URBWATER: “Vienna´s Urban Waterscape 1683-1918. An Environmental History”; research project funded by the Austrian science fund (FWF); project no.: P25796-G18, project leader: *V. Winiwarter, Alpen-Adria-University Klagenfurt*

APPENDIX I. PART 0: HISTORICAL RIVER ENGINEERING MEASURES IN VIENNA

Apdx. I.1 Evolution of the Viennese Danube floodplain

Eleven time steps of the reconstructed historical Danube floodplain in Vienna have been described in German by LAGER (2012, pp. 23-49). In the following figures I.-IV., four of these reconstructions are shown, including the names of selected river arms and locations: Figure I-1 depicts the floodplain in the year 1570, from the time when continuous Danube regulation efforts had just begun. The general flow direction of the Danube is from north to south. In 1529 the northern part of the *Wiener Arm*, the present *Donaukanal* has been a part of the Danube main branch. Around 1566 the main flow had shifted to the *Wolf arm* and the regulation efforts desperately tried to prevent this development. The trend continued and till 1632 the *Tabor Arm* had shrunk to a minor side branch while the new *Wolf Arm* conveyed more water. By 1663 this development had evolved and the upper part of the Wiener Arm had split up into two branches and lost its direct connection to the new Danube main branch north of Vienna. The situation in 1726 is shown in figure I-2. Only the left branch (in flow direction) of the upper Wiener Arm was maintained and from now on formed the upper *Donaukanal*, while the right arm had been closed. The branch-off from the Danube and some sections of the Donaukanal appear channelized and straight now, while the Danube main branch continued its movement away from the city. Till 1787, the segregation of the river system was much more developed than in the earlier centuries, which has been explained by effects of climatic change. The reconstruction of the floodplain in 1817 in figure I-3 illustrates the last time step before a systematic rearrangement of the entire Danube floodplain was started. The *Donaukanal* after a century of intense regulation appears fixated while the rest of the Danube branches still appear rather “natural” and free-flowing. Figure I-4 then depicts the situation when the running waters in Vienna had been regulated nearly entirely. Side branches had been cut off and nearly all flow was concentrated in one straight major channel next to which a major inundation area had been designed. By 2010 this inundation area had been replaced by the 21 km long *Danube Island*, and by the flood bypass *Neue Donau* at the left side of the river.

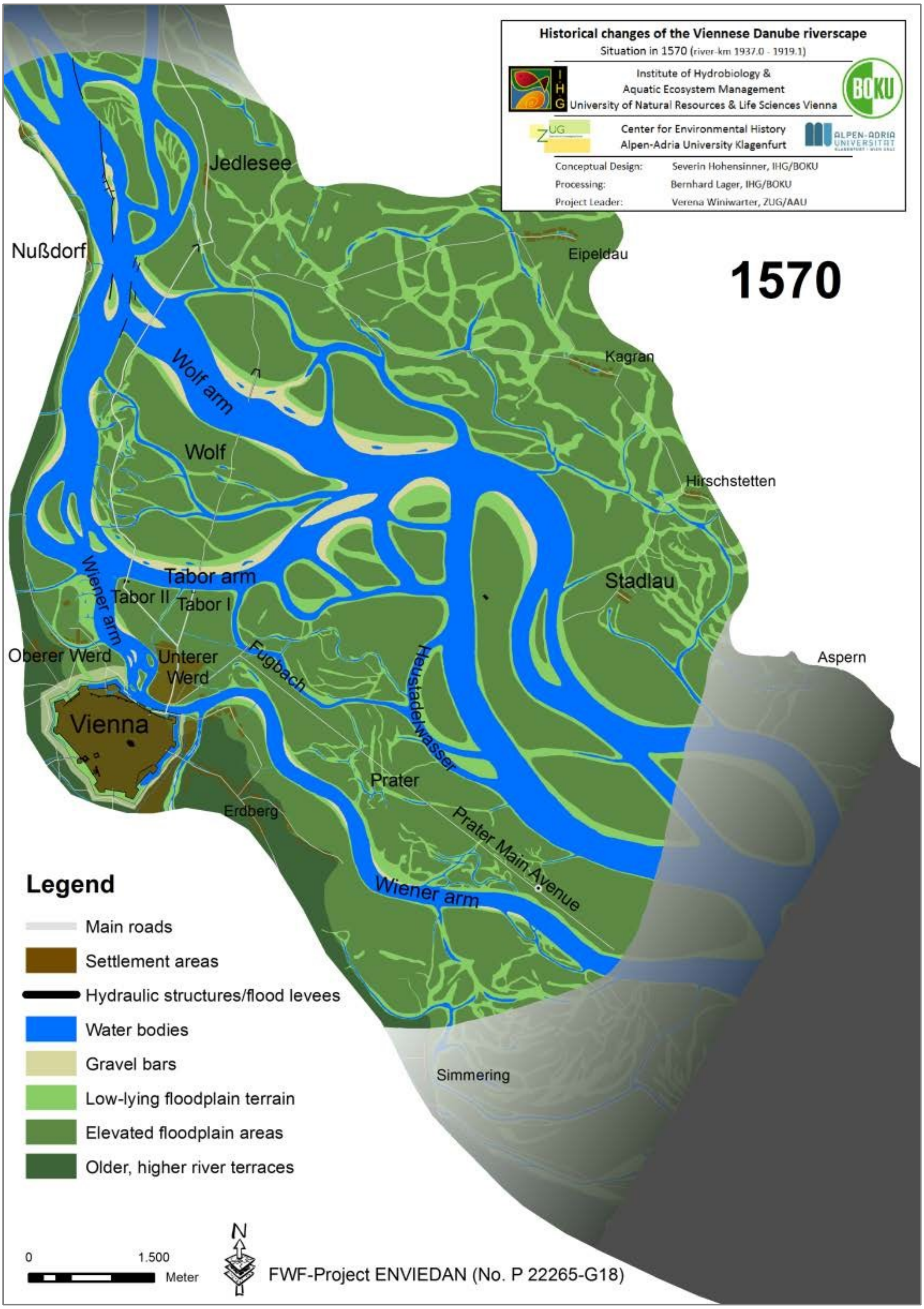

Figure I-1: The Viennese Danube floodplain in the year 1570; reconstruction from LAGER (2012).

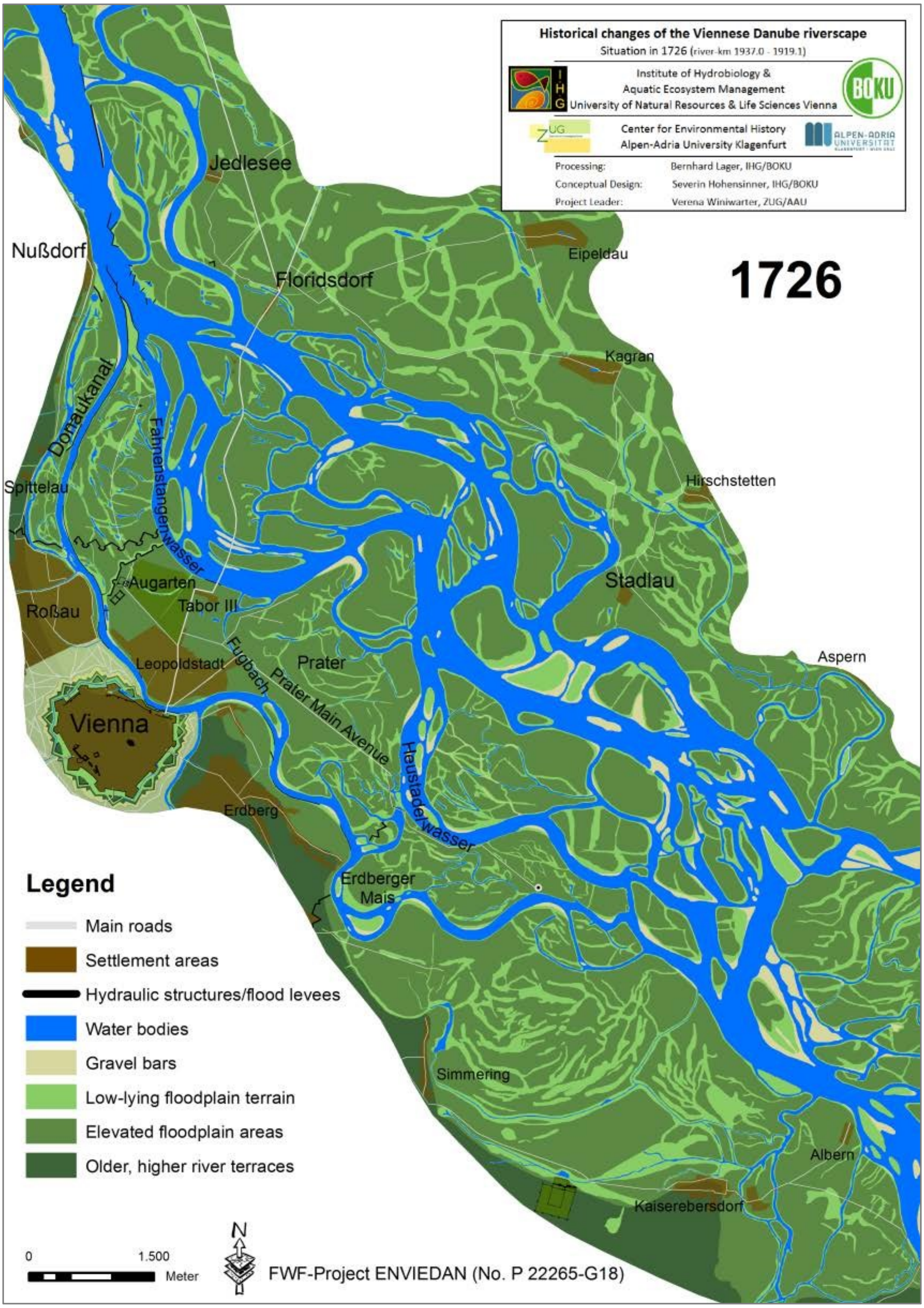

Figure I-2: The Viennese Danube floodplain in the year 1726; reconstruction from LAGER (2012).

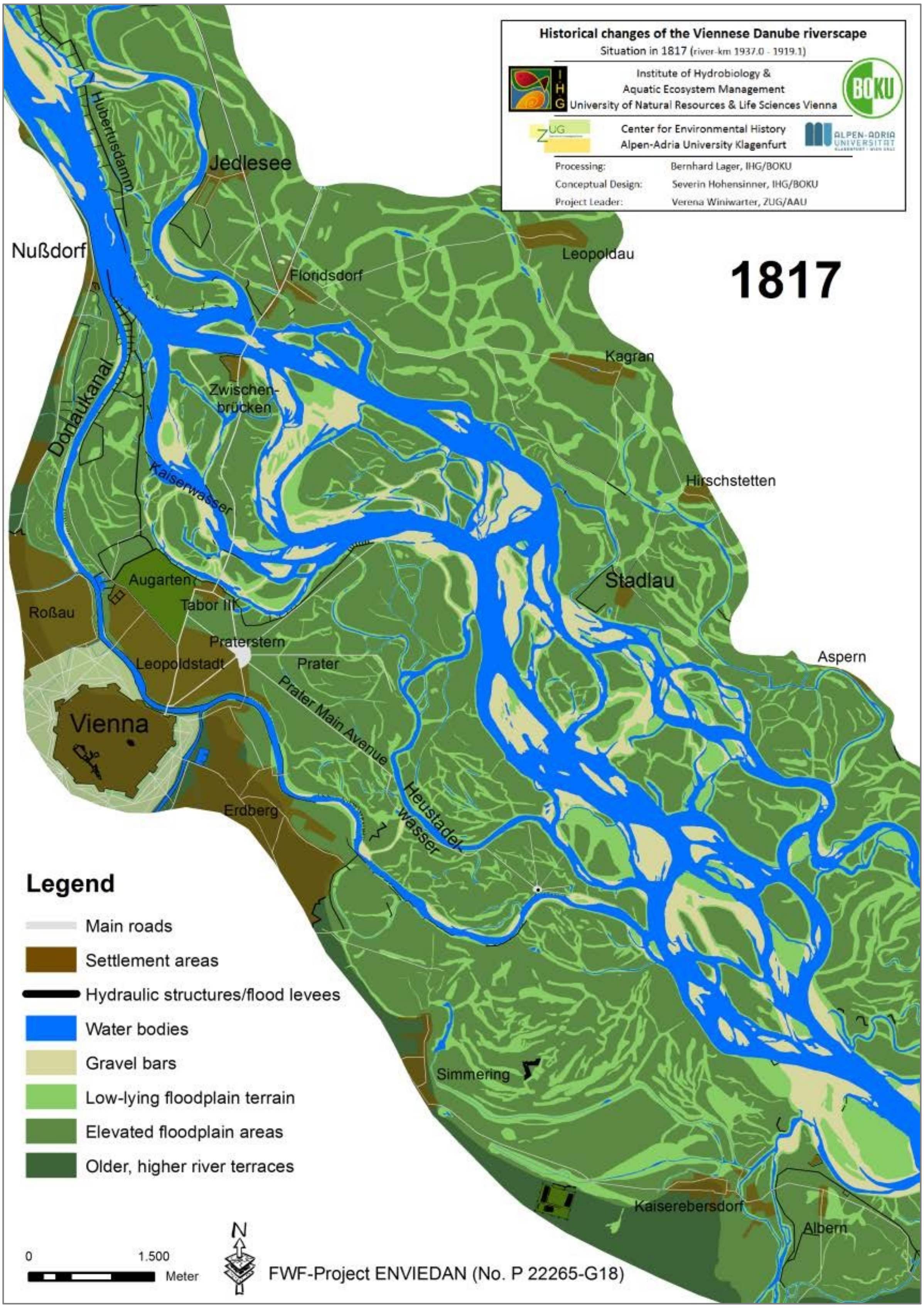

Figure I-3: The Viennese Danube floodplain in the year 1817; reconstruction from LAGER (2012).

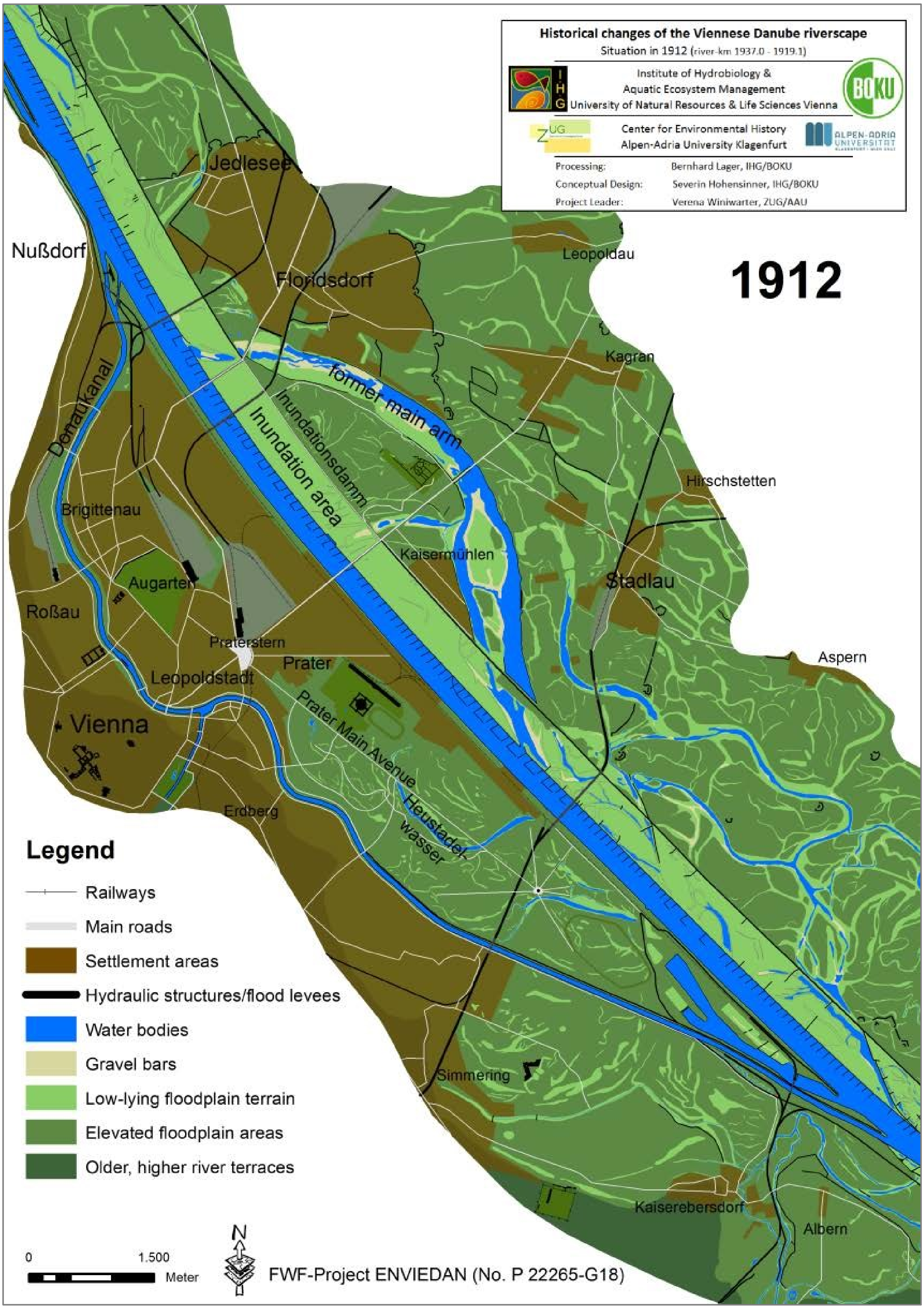

Figure I-4: The Viennese Danube floodplain in the year 1912; reconstruction from LAGER (2012).

Apdx. I.2 The database of historical river engineering measures in Vienna

On the following pages the spatial and temporal distribution has been illustrated with *ESRI ArcGIS* – separately for the three time periods 1100-1700, 1700-1830 and 1830-1910 – based on the database by HOHENSINNER et al. (2012):

Regulation measures from 1100 till 1700 are shown in figure I-5. There were two local regulation hotspots near *Nussdorf* (upstream of Vienna) and near *the city center*. The natural movement of the main branch could not be prevented and only temporary navigation on the *Wiener Arm* was possible. Along the *Wien River*, mill weirs and streams existed and the town moat was fed by minor tributaries.

While major parts of the Danube floodplain remained unregulated, between 1700 and 1830 the implemented hydraulic engineering measures were spread along the entire *Donaukanal,* the *Danube upstream of Nussdorf* and as well along the entire *Wien River* (see figure I-6). Compared to the situation prior to 1700, the regulation activity covered much larger bank lengths and areas. The prevention of further erosion of the Danube to the east and the navigability of the Donaukanal were major goals and systems of flood dikes and spur dikes were constructed in the late 18th century.

Between 1830 and 1910 – as illustrated in figure I-7 – the total Viennese Danube floodplain was entirely rearranged, at first with large-scale embankments and excavations across the entire Viennese floodplain, from 1870 onwards, starting with the *Great Danube Regulation* according to one general concept for urgent issues as the gain of urban space, greater discharge capacities, the safeguarding of the navigation route and modern ports. A complex and modern sewage system was constructed, from the inner city to the outer suburbs of Vienna. The *Wien River Regulation* created retention basins and greater discharge capacities along the major Danube tributary in the city area.

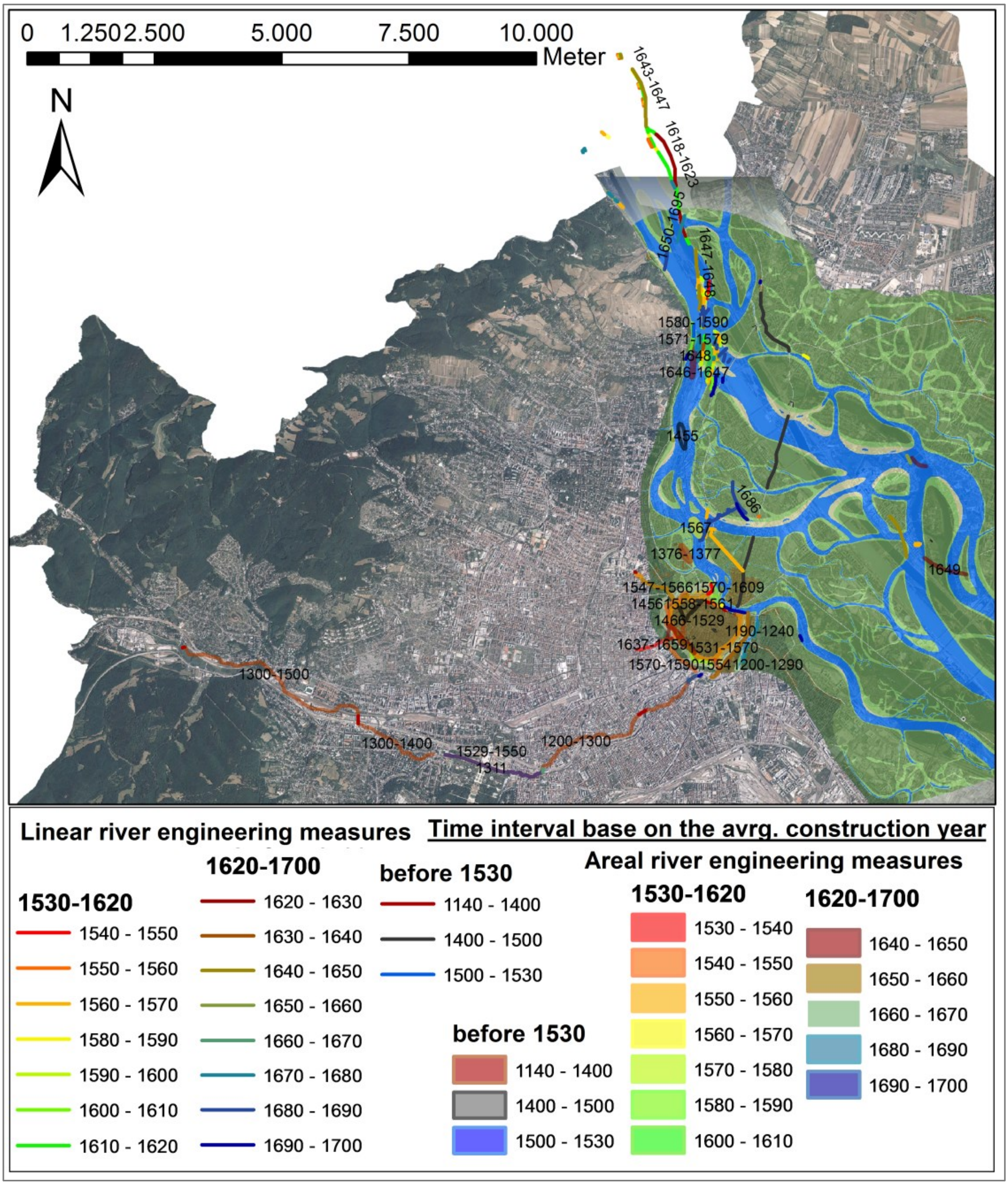

Figure I-5: River engineering measures implemented in Vienna between 1100 and 1700 (HOHENSINNER et al., 2012) on top of the reconstruction of the floodplain from 1570 (LAGER, 2012) and on a modern satellite image of Vienna (MA 41, WIEN, 2007).

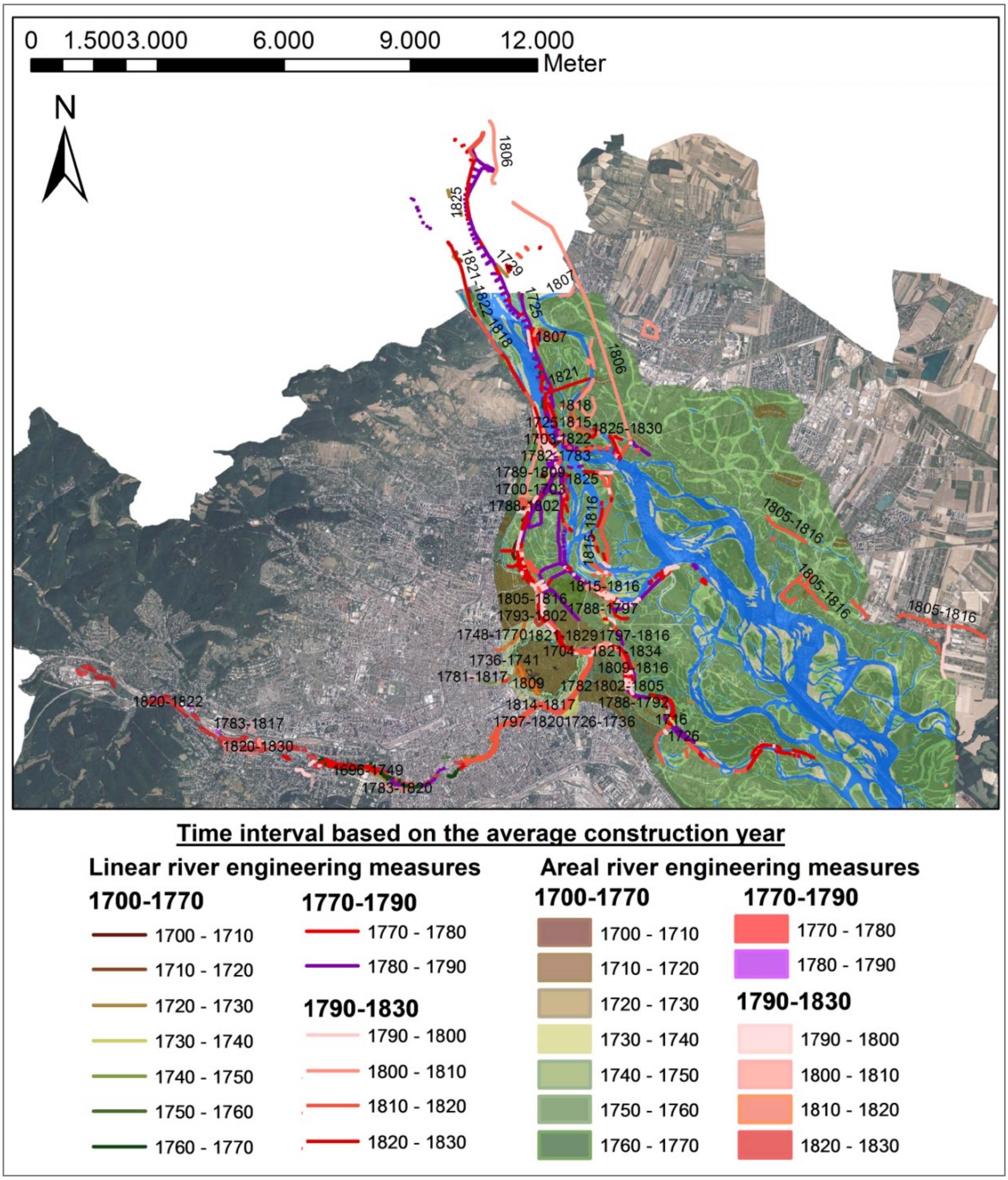

Figure I-6: River engineering measures implemented in Vienna between 1700 and 1830 (HOHENSINNER et al., 2012) on top of the reconstruction of the floodplain from 1787 (LAGER, 2012) and on a modern satellite image of Vienna (MA 41, WIEN, 2007).

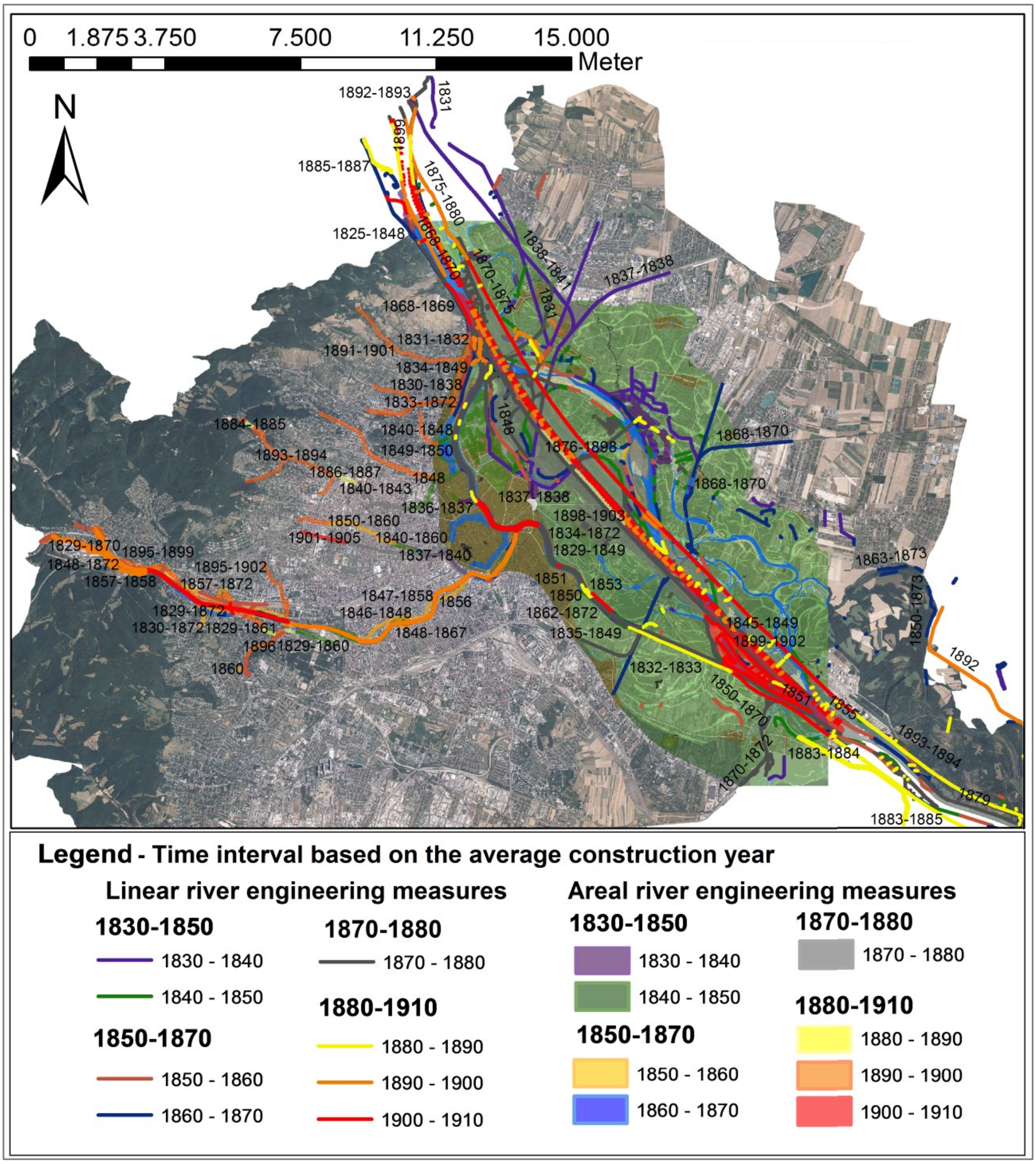

Figure I-7: River engineering measures implemented in Vienna between 1830 and 1910 (HOHENSINNER et al., 2012) on top of the reconstruction of the floodplain from 1875 (LAGER, 2012) and on a modern satellite image of Vienna (MA 41, WIEN, 2007).

Apdx. I.3 Temporal pattern of physical properties of river engineering measures in the database

The occurrences of construction types of linear measures are illustrated in Figure I-8 as proportion of the extent of river engineering measures implemented in each time interval. In the earlier decades in the 16th century and 17th century, guide walls and spur dikes contribute with a large percentage of the length. Embankments at least from 1670 to 1900 make up a large part of the length of implemented structures. Their relative importance peaked between 1730 and 1750, when around 70 - 80 % of the constructed length of linear measures in Vienna consisted of embankments. Flood dikes made up to 50 % of the length in 1780 till 1800 and between 20 and 40 % in most decades of the 19th century. Infrastructure dikes as well contributed a large proportion to the length of hydraulic structures, in particular between 1800 and 1870. Figure I-9 shows the construction types of areal measures: Bed excavations, fillings and ditches occur in most decades, while channels, terrestrialization measure, piping & covers only were used in some decades as construction type.

The occurrence of the chronologies of measures over time is characterized by a more or less cyclic pattern. For linear measures (figure I-10) the periods, with a large percentage of primary measures, alternate with periods, when rather the repairing and renewal of existing structures was conducted. The start of these phases can be dated approximately in the years 1540, 1580, 1680-1700, 1770-1790, 1810 and 1860 and at least partly coincides with phases of innovations and new concepts vs. phases in which existing concepts were maintained and efforts were less ambitious (see chapter 7.2). For areal measures there is a different pattern (figure I-11): before 1530, from 1720 to 1810, 1830 to 1880, and 1890 to 1900 are periods with mainly primary measures.

The used construction materials of linear measures change over time (figure I-12): In the period from 1540 till 1670 the exposed regulation works near Nussdorf were usually constructed in a combination of wood and stone. In the 18th century wooden structures were more and more preferred, but gradually replaced by stone structures between 1770 and 1830. After 1830, stone structures almost exclusively were used while dikes were often elevated with loose material (soil and gravel). Except for wooden structures and planted trees which were used around 1800, and few stone fillings, areal measures (figure I-13) usually either consist of an extraction or elevation of loose material. Further hints concerning the use of different material were summarized by HOHENSINNER et al. (2013b, pp. 133-134).

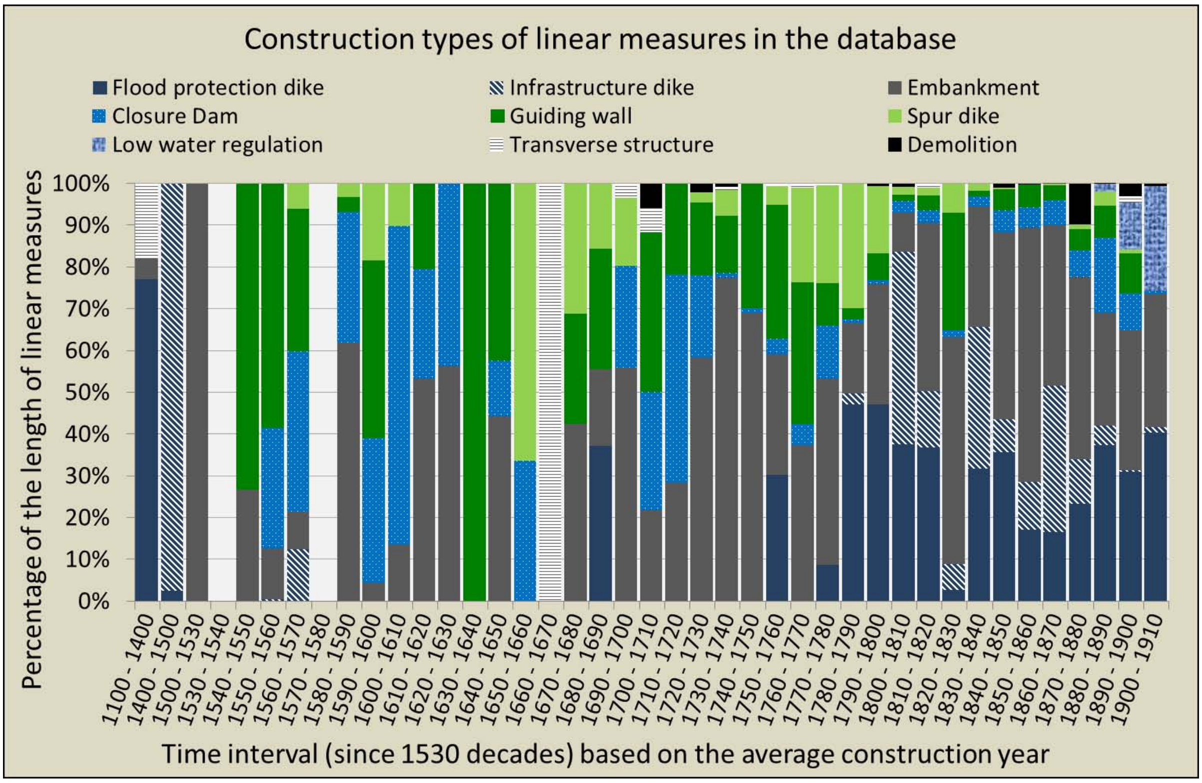

Figure I-8: Temporal pattern of construction types in the database of historical river engineering measures in Vienna – Percentage of the length of linear measures per time interval.

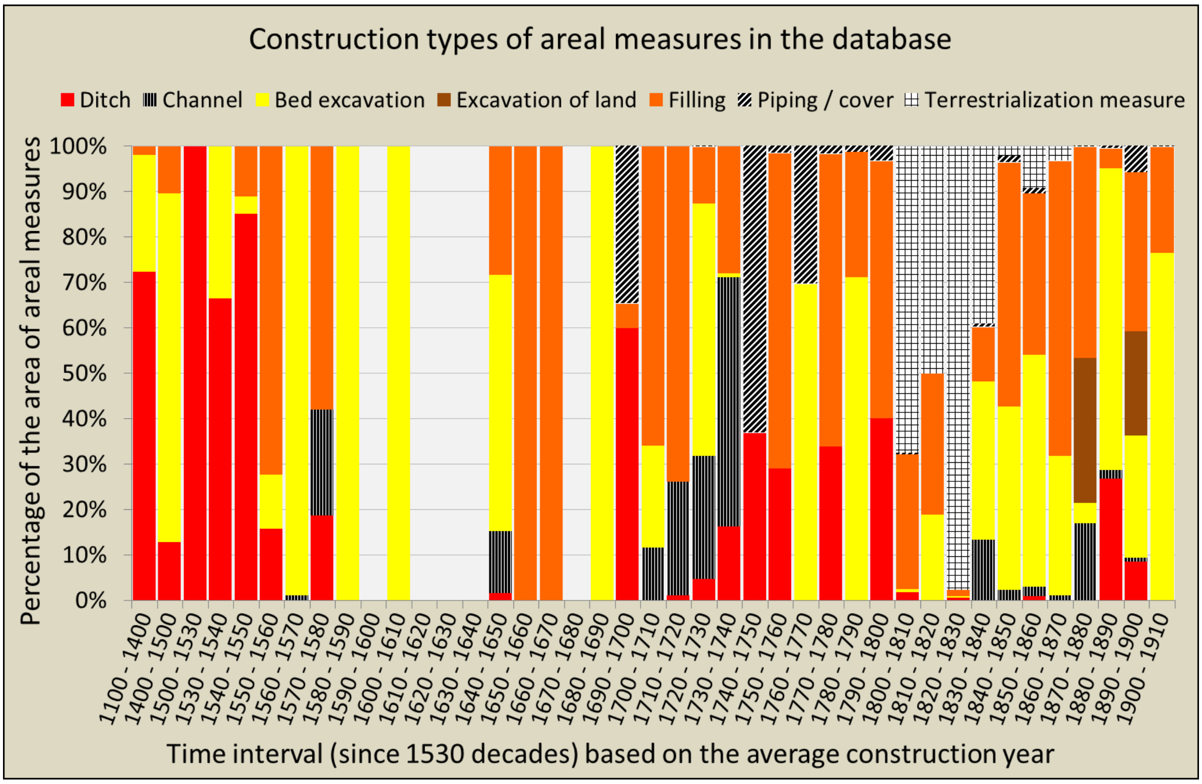

Figure I-9: Temporal pattern of construction types in the database of historical river engineering measures – Percentage of the area of areal measures per time interval.

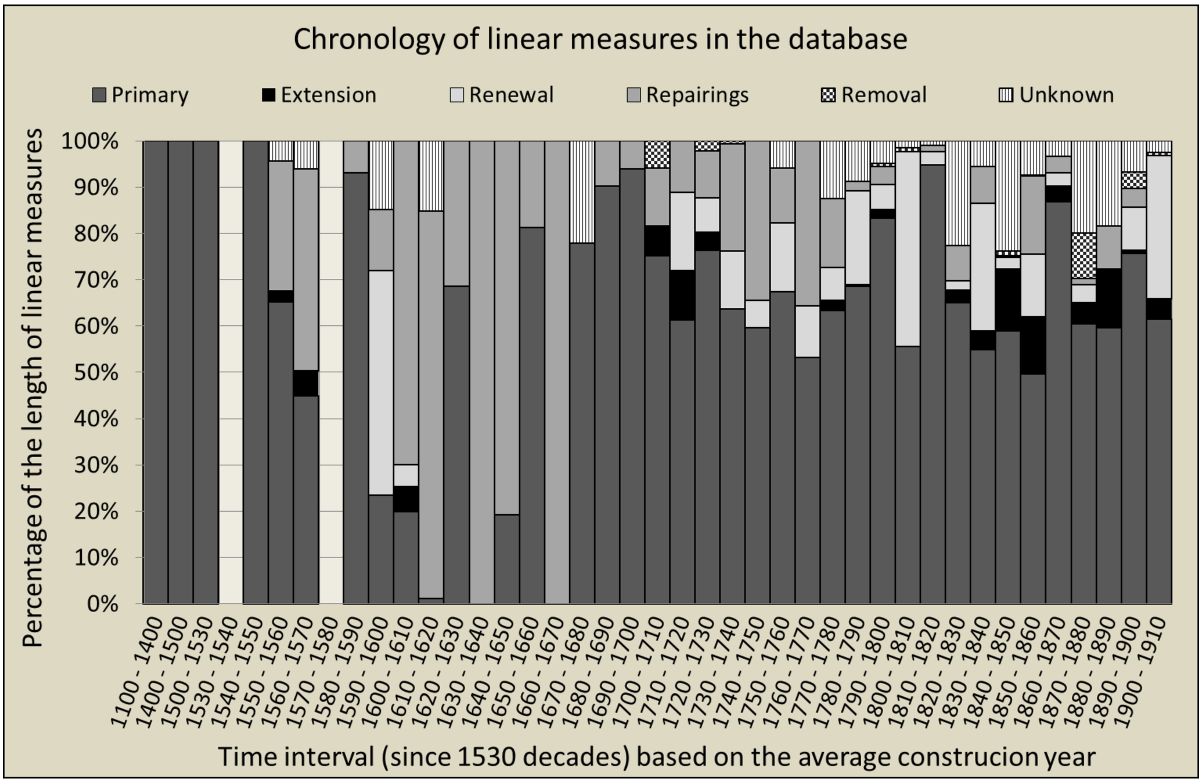

Figure I-10: Temporal pattern of "chronologies" in the database of historical river engineering measures – Percentage of the length of linear measures per time interval.

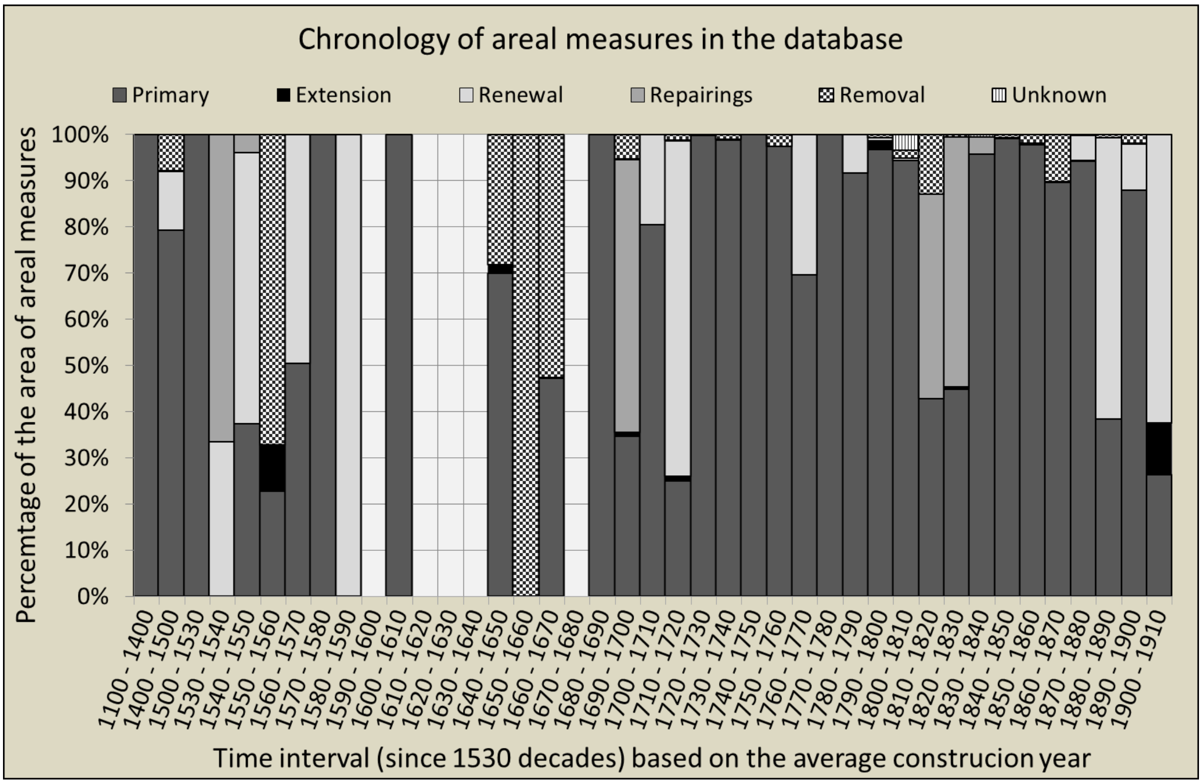

Figure I-11: Temporal pattern of "chronologies" in the database of historical river engineering measures – Percentage of the area of areal measures per time interval.

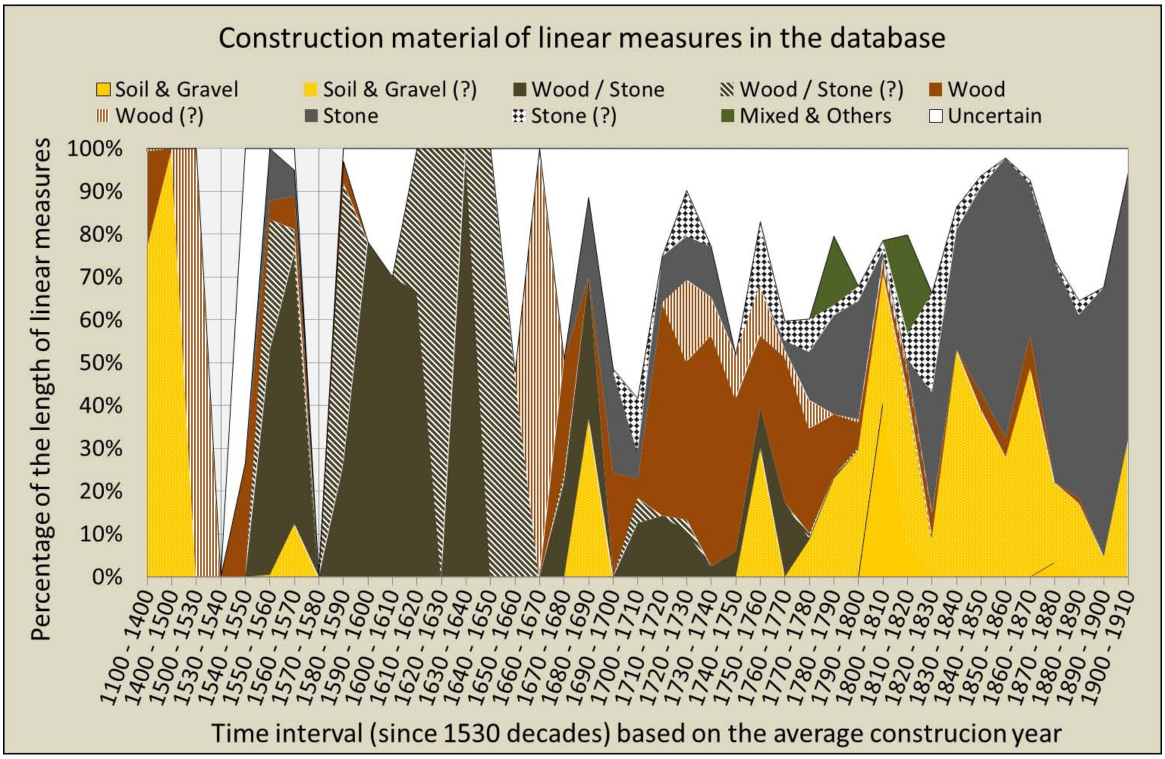

Figure I-12: Temporal pattern of "construction materials" in the database of historical river engineering measures – Percentage of the length of linear measures per time interval.

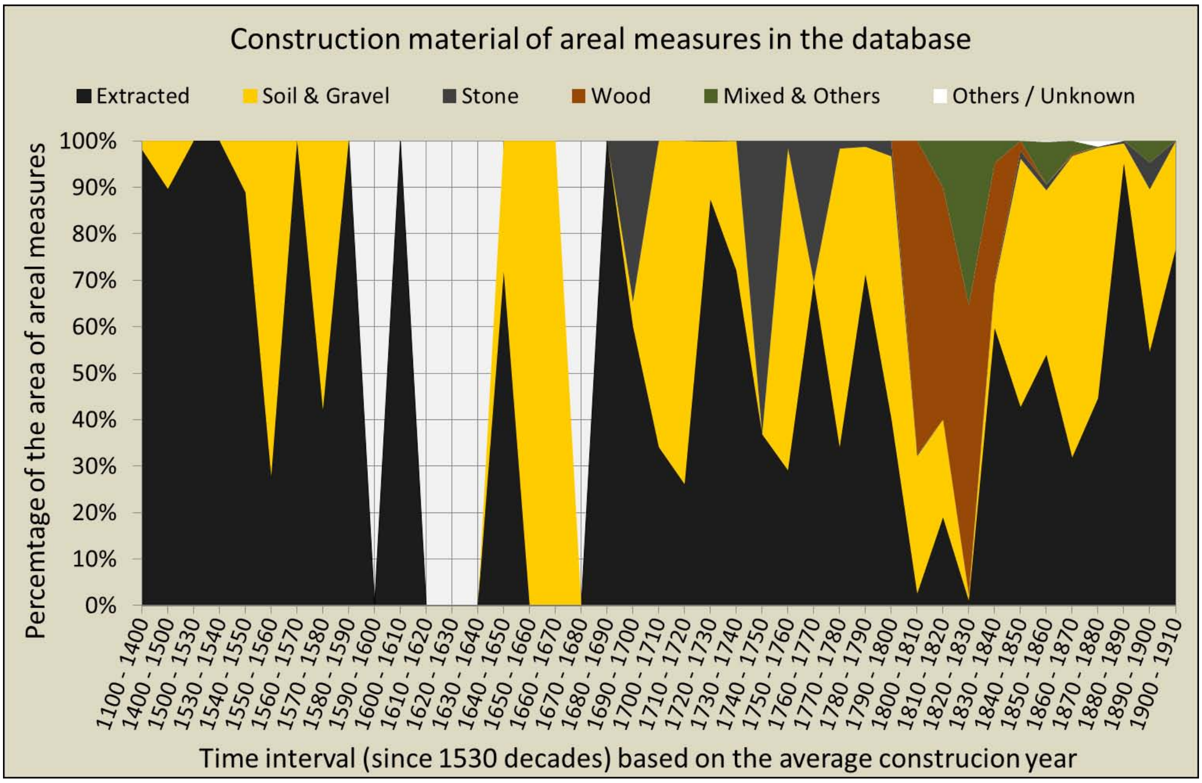

Figure I-13: Temporal pattern of "construction materials" in the database of historical river engineering measures in Vienna – Percentage of the area of areal measures per time interval.

APPENDIX II. PART A: HISTORICAL VALUES OF MONEY IN VIENNA

On the following page, the relationship between different historical value-of-money indicators is illustrated based on average values of money from the years in the decades from 1530 till 2010. Figure II-1 shows the difficulty to interpret historical values of money in Euro in the year 2012. Depending on the used method, tracing different indices the results are completely different – more than one order of magnitude. According to the construction worker wages 0.2 Gulden would approximately be equivalent to 100 € in the 16th century. In contrast the *Labor & GDPPI* indicates that 10 fl. would be equivalent to 100 Euro. This huge difference does reflect the increase in productivity of labor since the industrialization and the impacts of technological progress and the diversification of products and services, the prices of which go into the observed baskets of good and services for the *consumer price index* and the GDP price index.

Accordantly, the real wages (for unqualified masons / construction workers as defined in chapter 4.2) in Vienna have been plotted in figure II-2 as decadal average of the weekly wages expressed as the relative amount in various other money equivalents. Obviously, these "real" wages were rather decreasing in particular in the 17th and 18th century, based on various food products and compared to the *Food & CPI*, and only then, with the industrialization and increasing productivity of labor, the real wages started to increase tremendously over the 20th century.

More such relationships were listed in *file 0.3* on the DVD in the sheet "10-y-synthesis", as described in appendix V. Note that gaps in the base data have been closed using the methodology in chapter 4. Each line stands for a year. Each column does represent one of the 12 indicators. All values are given as the respective amounts of the money equivalents which are equivalent to 100 NCU (Nominal currency units) in the respective year. In an extra column the assigned NCU for each year is listed next to the "NCU factor" that shows hypothetical nominal relationship of 1 NCU to 1 Gulden (fl.) if this currency would have been still in use in this time.

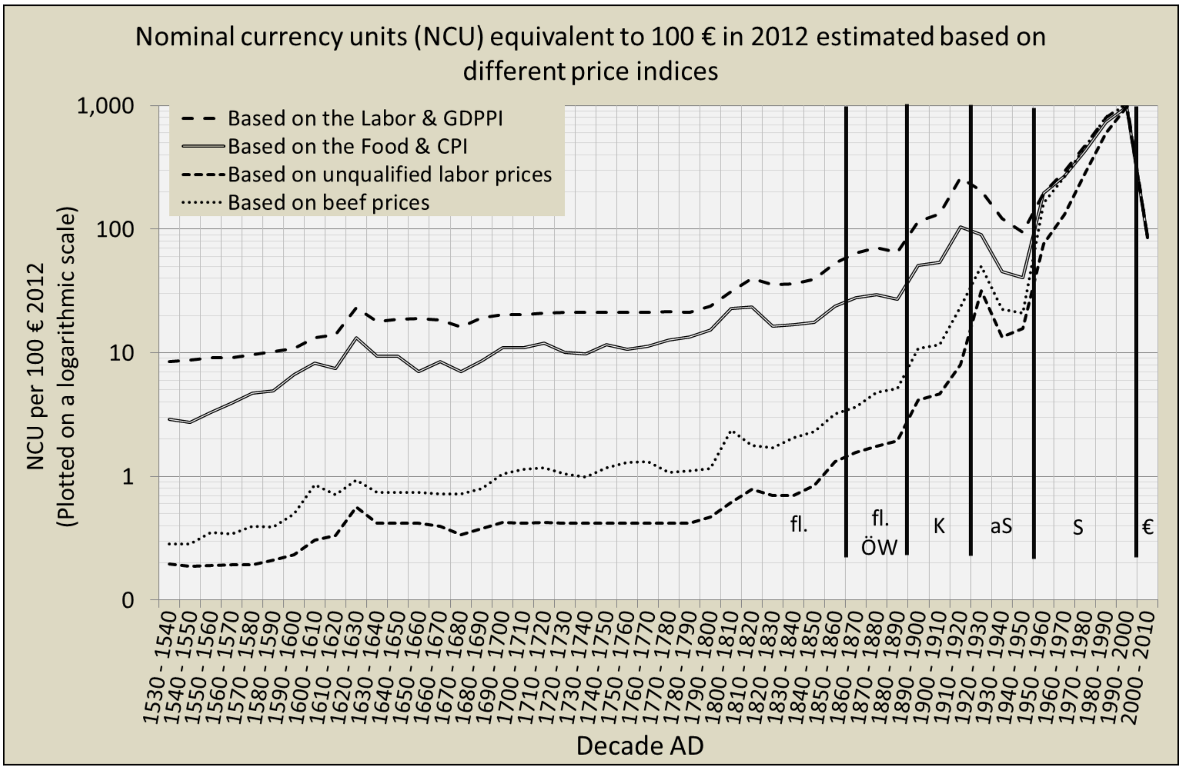

Figure II-1: Calculated equivalents to 100 € in nominal currency units (NCU) over time plotted on a logarithmic scale; based on a standardization with different price indices using a decadal average from 1530 to 2010 AD.

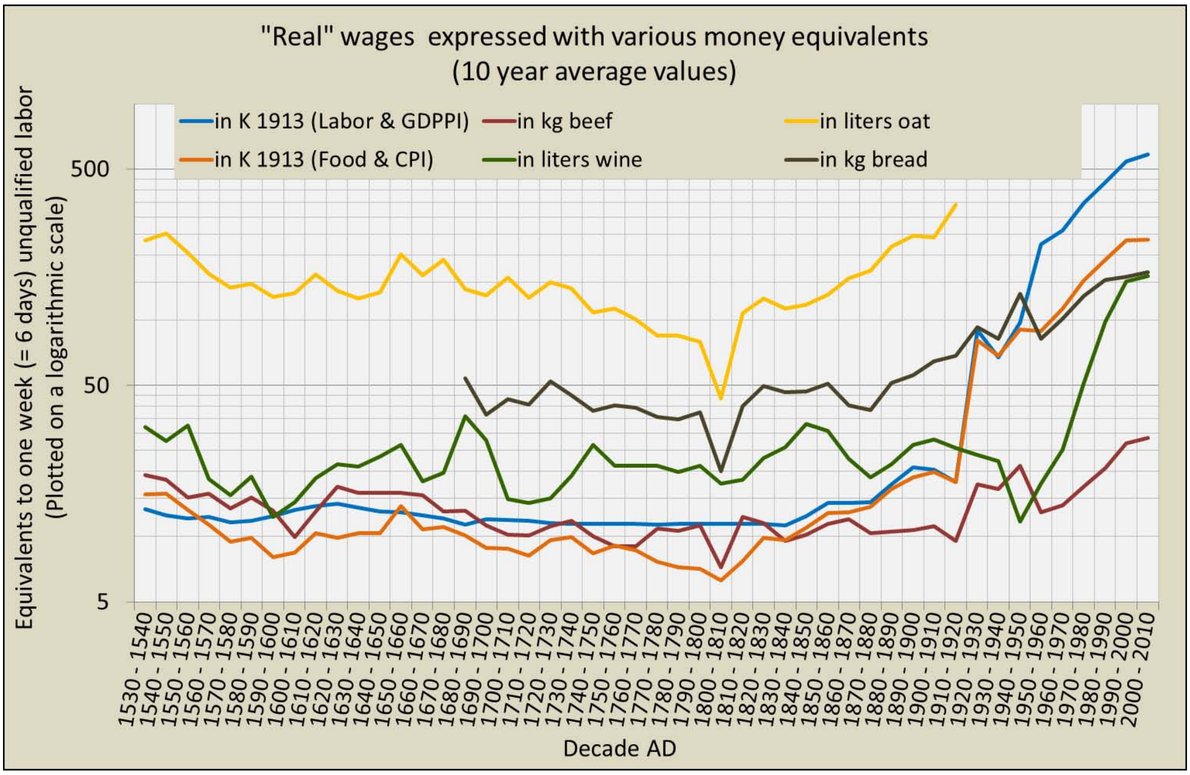

Figure II-2: Real wages of an unqualified mason / construction worker in Vienna expressed with various money equivalents plotted on a logarithmic scale; based on a decadal average from 1530 to 2010 AD.

APPENDIX III. PART B: TEMPORAL AND SPATIAL PATTERN OF APPLIED COST INDICES

The figures III-1 and III-3 show the temporal price distribution in Kronen 1913 (deflated by the *Labor & GDPPI*). The methodology can well be identified, where price categories (cost indices) for specific hydraulic construction types where usually applied on several entries in the database: The price categories assign distinct deflated prices to the measures. That means, measures from two different years assigned to the same cost index (e.g. 96 - 176 K 1913 for a dike based on data from 1830-1850) show exactly the same price level in K 1913, fl. 1721-1745 or € 2012, based on the *Labor & GDPPI*. According to the exchange rates for the Labor & GDPPI which were derived in chapter 4.3, the illustrated prices in K 1913, can be transferred into the values for other reference periods: 1 K 1913 = 0.1304 fl. 1721-1745 = 0.6134 € 2012. As described in chapter 5.2 and 5.3 all cost indices were derived based on references in historical sources and literature stating a nominal price for this construction type. The deflated price categories can be used as prediction tools for the developments of prices of a construction type over time. For example, two dikes from the price category "dikes 1830-1850" would correspond to a likely nominal price for in 1840 of 21 - 40 fl. / m and a higher nominal price of 30 - 64 fl. / m, but is based on the same deflated price level. The figures III-5 and III-6 show distribution maps with resulting price estimates in Kronen 1913 (deflated by the *Labor & GDPPI*) per meter for linear measures and per hectare for areal measures in the original DB. The *Labor & GDPPI* can furthermore be seen as one method of interpretation of the prices and would then represent the development of prices in the entire economy after 1830 and the overall development of wages before 1830 (chapter 4.3). Following chapter 4.4, historical money amounts can be interpreted with 12 available methods. In order to demonstrate how a different method changes the interpretation of prices per meter or hectare, the temporal pattern has been illustrated (figure III-2 and III-4) in *days of unqualified labor (duql)* equivalent to the prices. The used methodology leads to the consequence that the amount of labor, equivalent to the prices for "dikes 1830-1850" and within other categories from the 19th century are slightly decreasing over time. This can be explained by the increasing productivity of labor after industrialization, leading to increasing real wages compared to overall price trends in the economy. The prices in *duql* are the base data for the analyses of the price distribution over time in chapter 5.5.

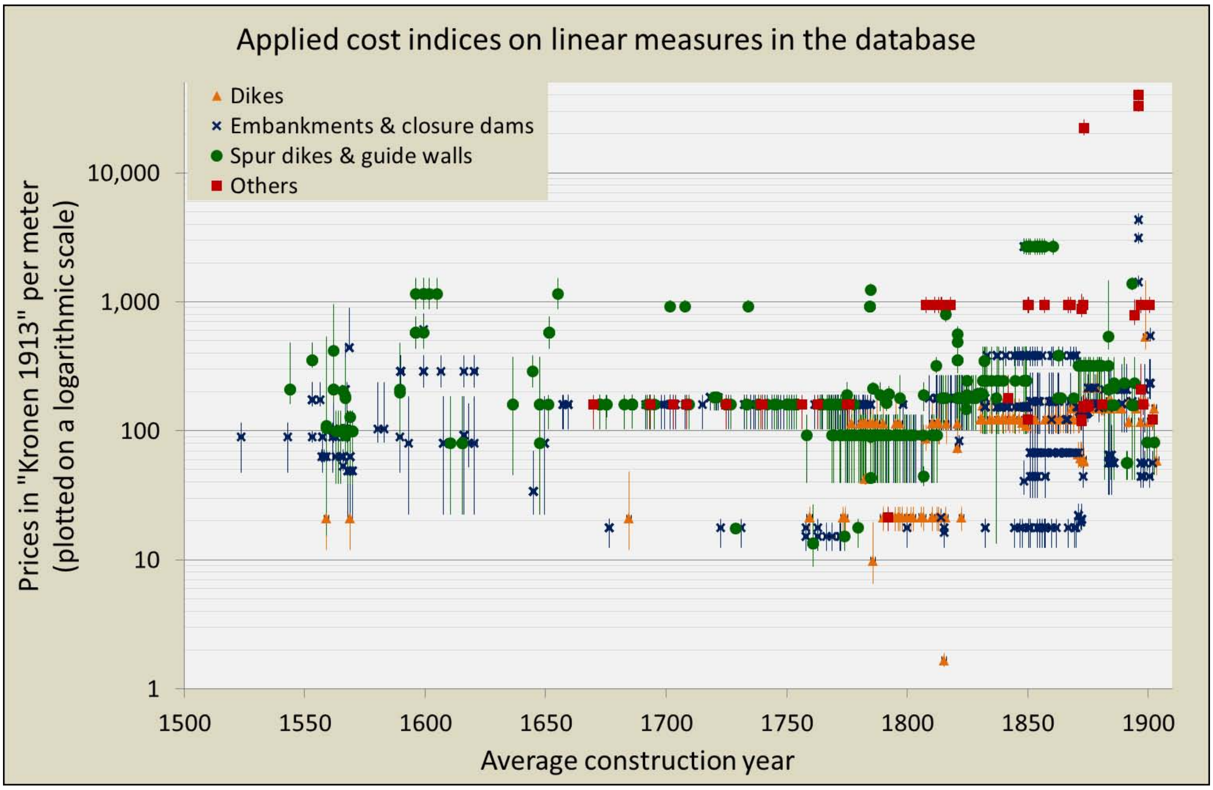

Figure III-1: Temporal pattern of estimated price ranges in Kronen 1913 per meter for linear river engineering measures in Vienna.

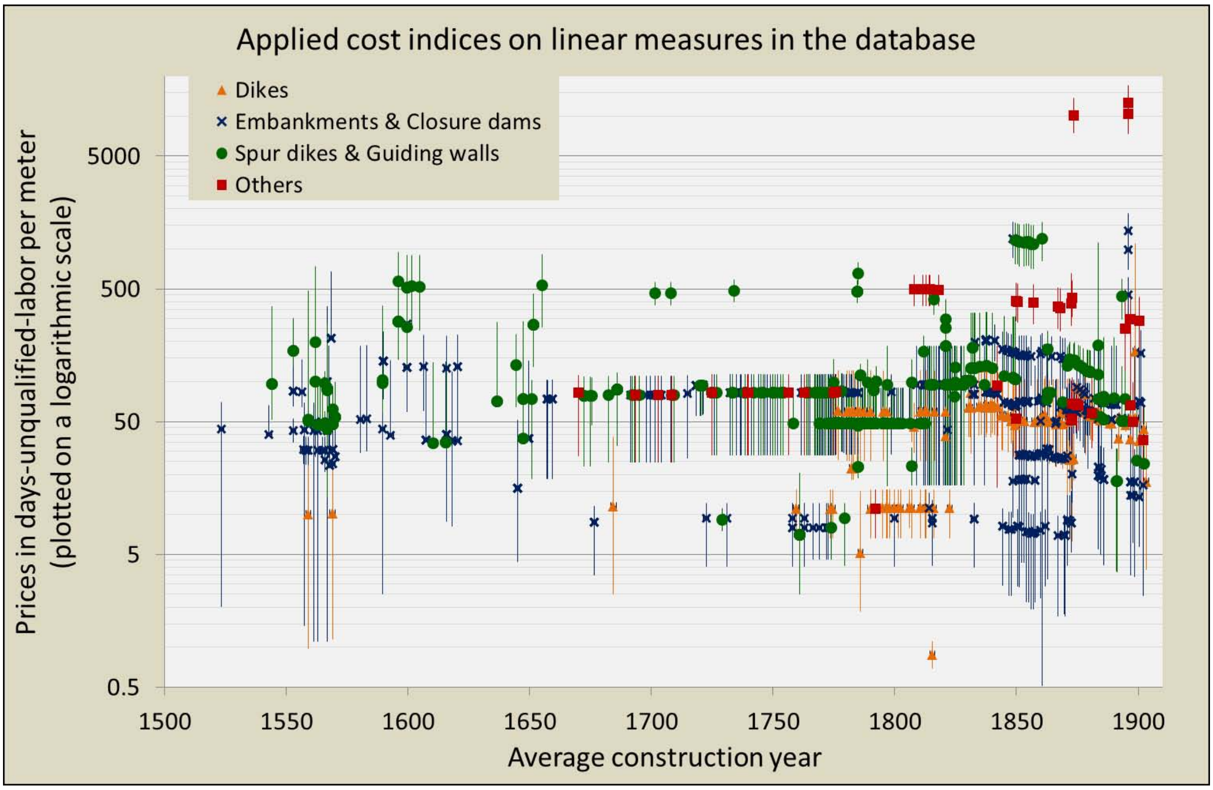

Figure III-2: Temporal pattern of estimated price ranges in days unqualified labor equivalents (duql) per meter for linear river engineering measures in Vienna.

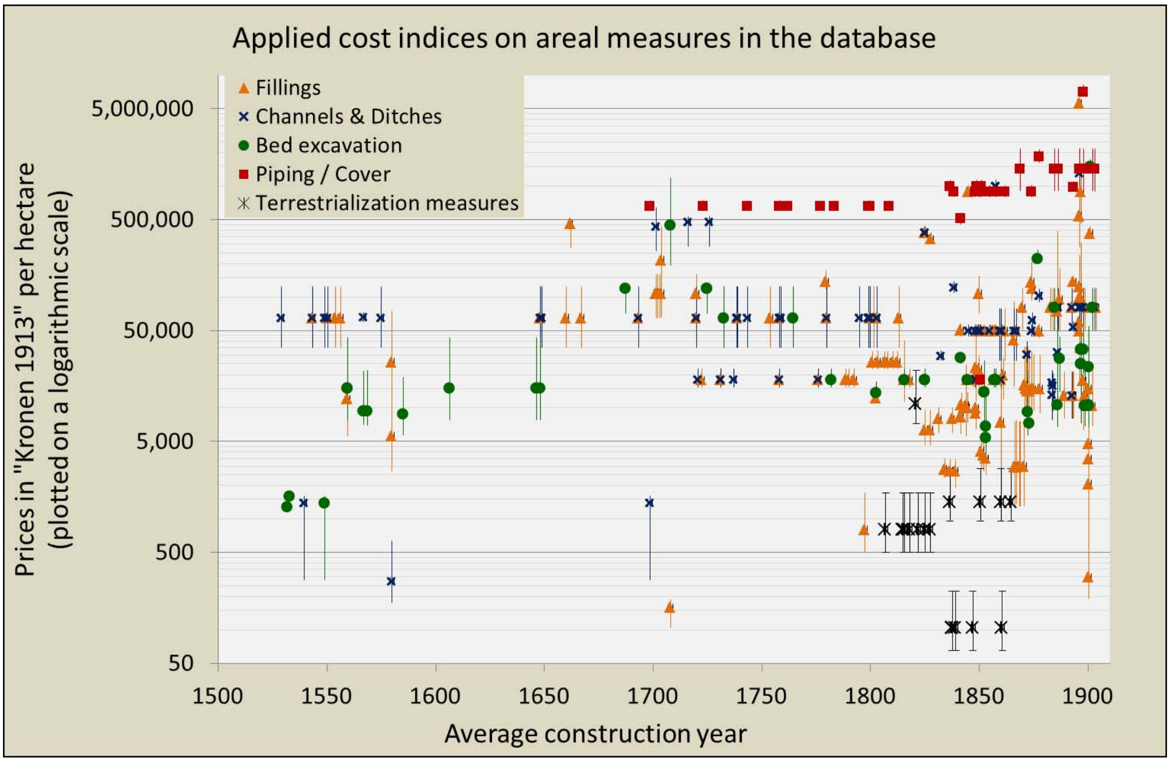

Figure III-3: Temporal pattern of estimated price ranges in Kronen 1913 per hectare for areal river engineering measures in Vienna.

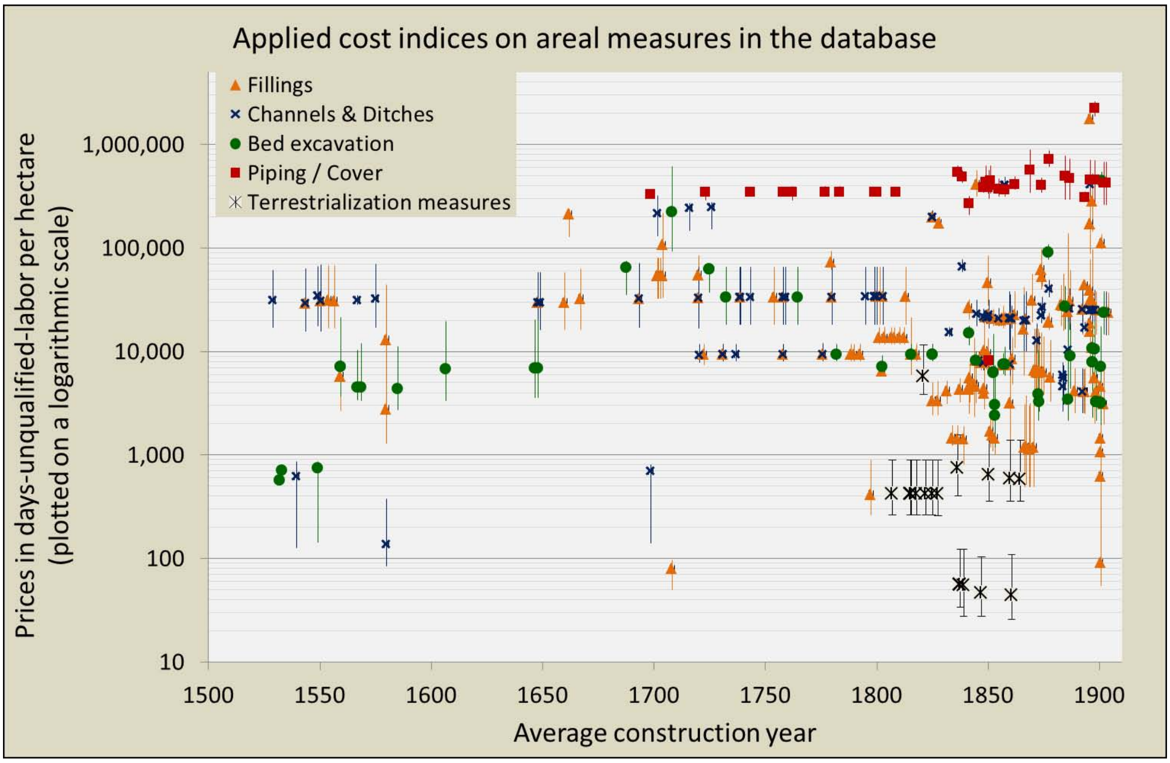

Figure III-4: Temporal pattern of estimated price ranges in days unqualified labor equivalents (duql) per hectare for areal river engineering measures in Vienna

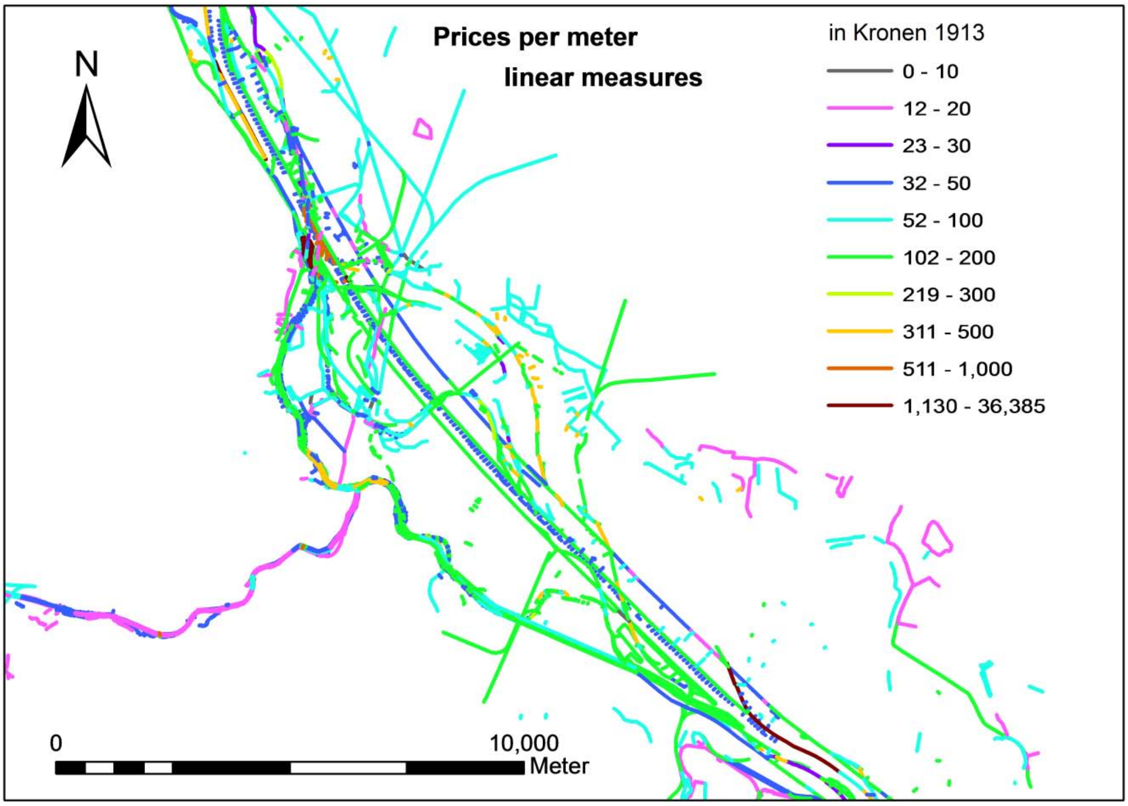

Figure III-5: Spatial distribution of estimated prices per meter of linear river engineering measures in Vienna.

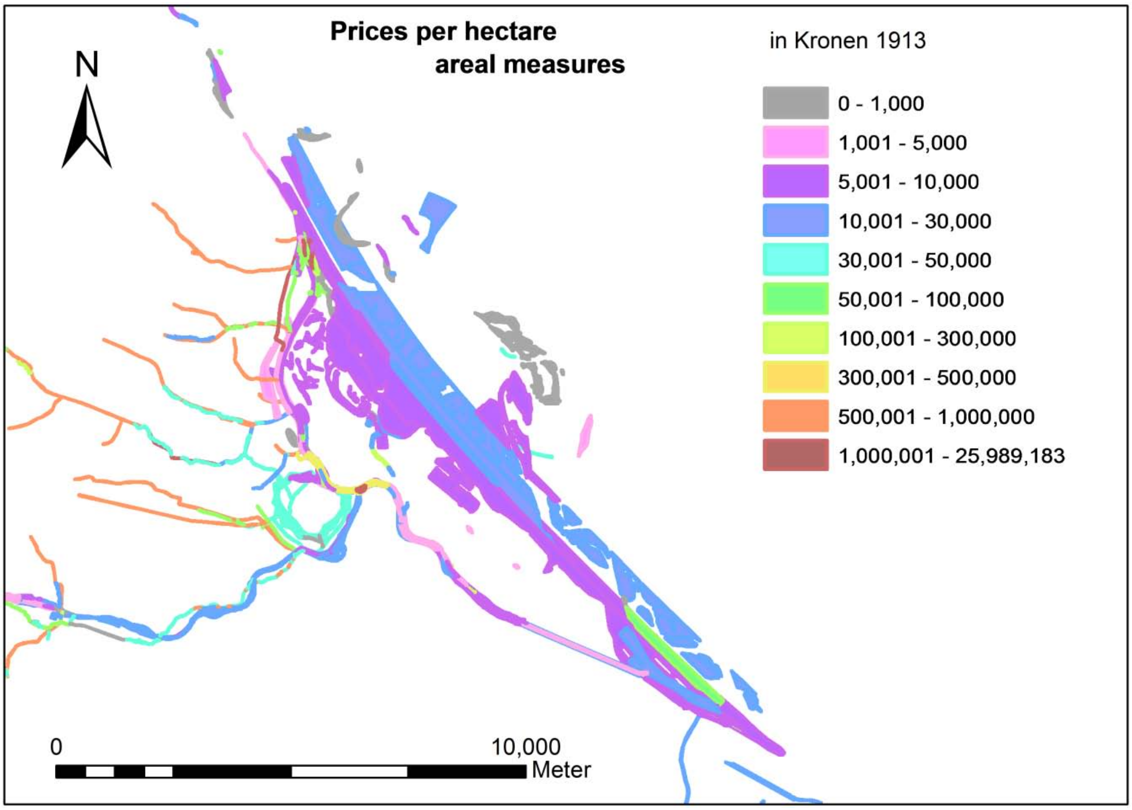

Figure III-6: Spatial distribution of estimated prices per hectare for areal river engineering measures in Vienna.

APPENDIX IV. PART C: COST STRUCTURE – ADDITIONAL ILLUSTRATIONS

Apdx. IV.1 Alternative methods to illustrate expenses on river engineering in Vienna per time interval

In chapter 6.1 the cost volumes per time interval spent on hydraulic engineering in Vienna were expressed in standardized money equivalents (*Kronen (K) 1913, Gulden (fl.) 1721-1745 and Euro (€) 2012*) and in days unqualified labor equivalents. A minor attention has been on the interpretation based on food product amounts equivalent to the expenses: In chapter 6.1 there are representations of the amounts of beef (in tons) and oat (in m^3) equivalent to the expenses in the time of implementation of the measures. Beyond, the money equivalents derived in chapter 4.5 allow for illustrations of the expenses as equivalent amount of wine (in m^3) and bread (in tons):

> Figure IV-1 illustrates the results in wine equivalents: Based on the minimum, maximum and medium reconstructions the following yearly average values can be expected for three major periods. From 1540 till 1700 the estimated average amount of wine equivalent to the expense lies between 37 and 291 (mean: 97) m^3 per year. From 1700 till 1830 the expenses were estimated on a higher level 215 and 725 (mean: 405) m^3 wine per year, respectively. And from 1830 till 1910 2,800 - 6,000 m^3-wine equivalents were spent on average per year. The mean estimate is 3,700 m^3.

> The illustrations of expenses in "tons bread" (figure IV-2) were limited to the period from 1700 to 2010 as there was no data for bread prices prior to 1690. From 1700 to 1830, on average, expenses of 400 - 1,700 tons-bread equivalents (mean 860 tons) and from 1830 to 1910 expenses of 5,300 - 11,000 tons-bread equivalents (mean 7,500 tons) can be assumed per year.

If the period 1700-1830 is considered as 100 % and mean cost estimates are used the following ratios can be observed: The average expenses 1540-1700 would equal 24 % and those from 1830 to 1910, 910 % following the *m^3-wine equivalent*. For the years 1830-1910, using the *tons-bread equivalent*, the yearly average expenses would equal 870 % of those from the period 1700-1830.

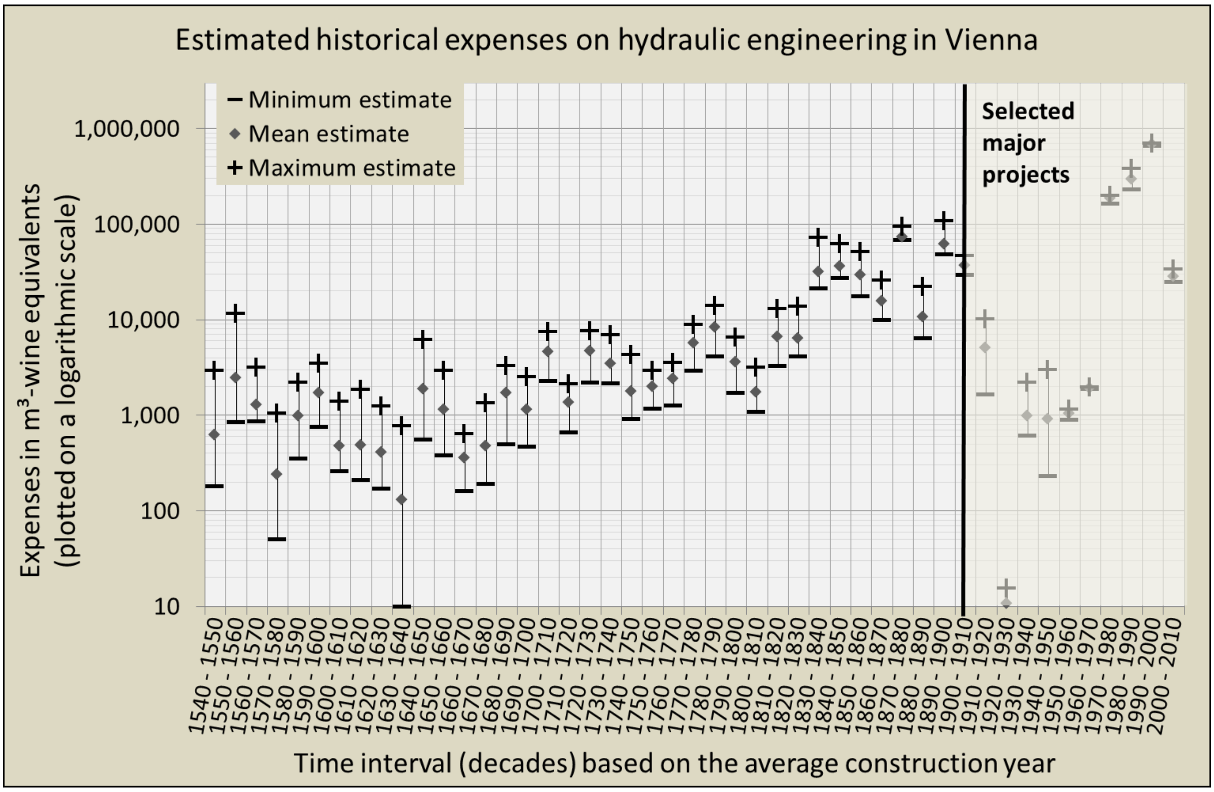

Figure IV-1: The amount of wine per decade (in cubic meters) equivalent to the expenses on historical river engineering measures in Vienna at contemporary price levels.

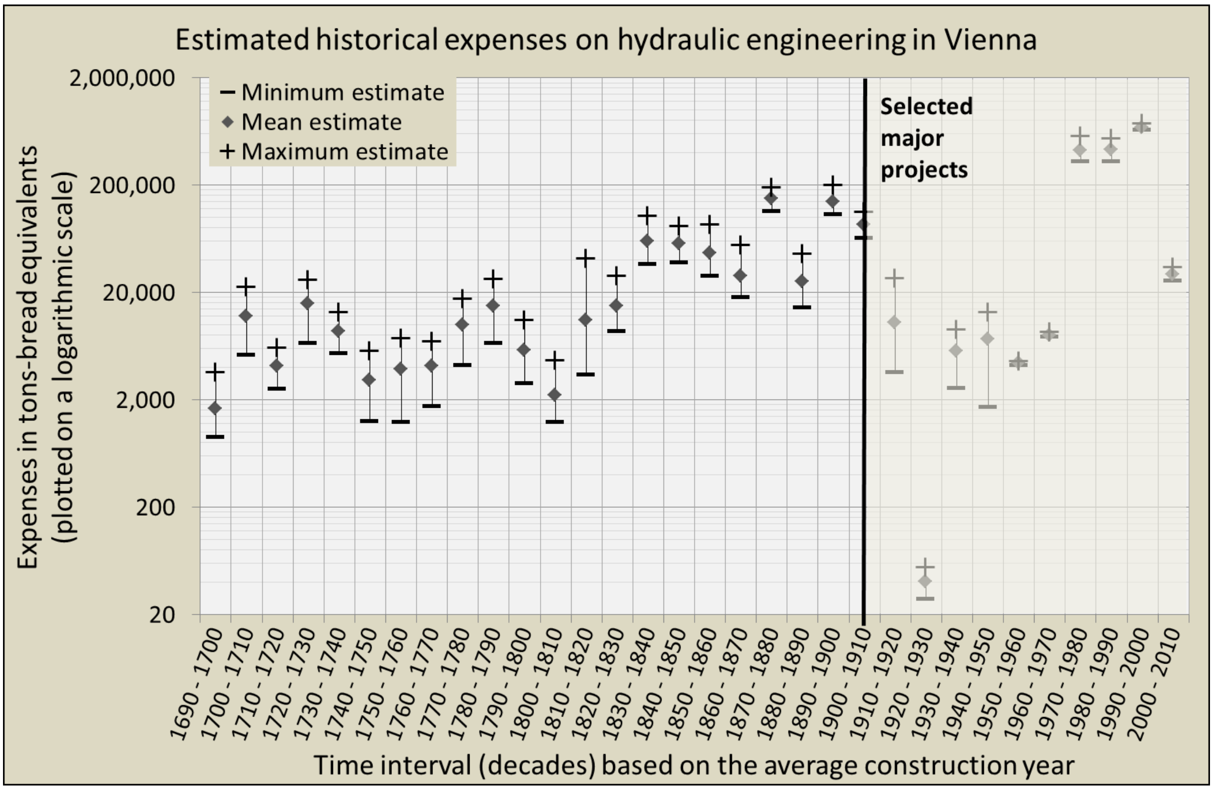

Figure IV-2: The amount of bread per decade (in tons) equivalent to the expenses on historical river engineering measures per decade in Vienna at contemporary price levels.

Apdx. IV.2 Expenses by project category and century

The following tables use the 31 "project categories" defined in chapter 3.2 and the century assigned to the measures in the original database. The sums for each category are based on the database entries listed as "projects". Total expenses estimated for each project category are listed in table IV-1: the medium, minimum and maximum cost estimate, in *1,000 days unqualified labor* and in *1,000 Kronen 1913* (based on the *Labor & GDPPI*) and the minimum and maximum estimate in *tons beef equivalents* were used for this overview. The numbers represent the present state of documentation, in particular for tributaries and the 20th century!

Table IV-1: Estimated expenses on defined project categories in the database; medium, minimum and maximum estimate of total expenses in various money equivalents (in 1,000 days unqualified labor / tons beef / 1,000 K 1913).

Project category	in 1,000 days unqualified labor			in tons beef		in 1,000 K 1913 (Labor&GDPPI)		
	MED	MIN	MAX	MIN	MAX	MED	MIN	MAX
Creeks & Ditches, before 1830	1,169	525	2,704	1,079	8,749	2,350	1,087	5,222
Mill weirs & streams	1,260	858	1,969	1,476	5,209	2,706	1,901	4,085
Tributaries, before 1830	914	606	1,296	997	2,669	1,746	1,160	2,467
Excavations & Fillings, before 1830	3,357	1,754	5,106	3,260	10,683	6,600	3,527	10,004
Other early flood dikes before 1787	290	179	515	307	1,149	557	346	977
Infrastructure before 1868	2,768	1,853	4,584	2,864	8,329	5,362	3,665	8,667
Regulation works near Nussdorf before 1650	3,143	1,873	5,932	4,108	14,241	6,662	4,109	12,047
Other Regulation works before 1650	81	38	133	106	408	168	82	265
Regulation works, 1650 - 1700	507	263	774	520	1,793	994	528	1,424
Regulation works, 1700-1787	5,249	3,468	6,809	5,779	13,105	10,093	6,684	13,067
Regulation works, Hubert	1,224	707	1,770	1,226	3,625	2,337	1,352	3,342
Flood dikes, Hubert	782	496	1,344	802	2,800	1,494	949	2,536
Regulation works, 1787-1830	3,784	2,284	5,683	3,527	13,123	7,217	4,380	10,804
Flood dikes,1787 - 1830	960	667	1,458	597	3,920	1,831	1,272	2,780
Creeks & Ditches, 1830 - 1903	11,192	8,654	14,413	15,359	26,038	31,767	26,078	40,427
Tributaries, 1830 - 1890	1,279	736	2,314	1,324	4,640	3,046	1,861	5,101
Flood dikes, 1830 - 1870	3,894	2,684	6,455	4,482	11,329	8,243	6,000	12,787
Regulation works, 1830 - 1870	12,167	9,162	16,125	15,933	30,042	27,116	21,341	34,694
Excavations & Fillings, 1830 - 1870	1,070	798	1,429	1,299	2,575	2,238	1,693	2,874
Infrastructure, GDR / Railworks 1868 - 1870	2,416	1,964	3,077	3,378	5,560	5,995	5,151	7,094
Regulation works, GDR	8,208	6,866	10,409	11,944	18,330	19,297	15,695	25,364
Flood dikes, GDR	1,986	1,376	2,863	2,360	5,111	5,134	3,720	6,921
Excavations & Fillings, GDR	12,372	11,783	13,340	20,570	23,738	28,844	26,093	34,430
Danube Regulation in Lower Austria since 1881	2,547	1,819	4,106	3,082	7,296	7,801	5,666	12,116
Infrastructure, Post GDR	159	136	188	243	346	502	437	575
GDR Supplementary Projects	13,908	11,753	17,680	25,786	35,126	222,247	190,753	256,458
Flood dikes, Post GDR	1,980	1,485	2,843	2,700	5,263	7,463	5,808	10,115
Tributaries, Wien River Regulation	2,791	1,535	4,723	1,952	8,737	9,239	3,956	15,338
Creeks & Ditches, 20th century	728	563	946	859	1,811	2,527	1,832	3,186
Tributaries, Liesing & Schwechat Regulation	286	268	296	611	667	11,560	11,195	12,665
Correction of the GDR	6,810	4,960	8,412	22,000	27,767	520,944	445,725	602,729
Hydropower	25,425	24,016	31,292	118,076	126,225	2,357,267	2,328,906	2,614,101
Improved flood protection since 1972	29,486	22,335	43,706	79,318	122,118	1,951,752	1,638,309	2,568,073
SUM all projects	164,192	128,462	224,692	357,924	552,521	5,273,100	4,771,262	6,342,737

Based on the medium cost estimates in *1,000 days unqualified labor (1,000 duql)*, the distribution of *expenses per project category & century* were calculated separately: Estimates across the turn of the centuries were listed separately and then assigned as a sum to the previous century. Table IV-2 shows the estimates from the 12th till the turn from the 17th to 18th century and table IV-3 those from the 18th century till today. Many details become more visible in the tables. E.g., around 80 % of the known expenses from 16th century applied obviously to the early regulation works near Nussdorf.

Table IV-2: Expenses by century on defined project categories (12th till 17th century); medium estimate in 1,000 days of unqualified labor (1,000 duql).

Project category	12th - 15th C	16.	16./17.	16th C	17.	17./18.	17th C
	SUM	MED	MED	SUM	MED	MED	SUM
Creeks & Ditches, before 1830	195	295	0	295	140	0	140
Mill weirs & streams	210	1	0	1	43	174	217
Tributaries, before 1830	0	0	0	0	5	30	35
Excavations & Fillings, before 1830	12	73	47	119	357	1,200	1,557
Other early flood dikes before 1787	20	0	0	0	16	0	16
Infrastructure before 1868	45	11	0	11	0	0	0
Regulation works near Nussdorf before 1650	0	1,664	471	2,134	1,008	0	1,008
Other Regulation works before 1650	6	65	10	74	0	0	0
Regulation works, 1650 - 1700	0	0	0	0	445	62	507
Regulation works, 1700-1787	0	0	0	0	0	880	880
Regulation works, Hubert	0	0	0	0	0	0	0
Flood dikes, Hubert	0	0	0	0	0	0	0
Regulation works, 1787-1830	0	0	0	0	0	0	0
Flood dikes,1787 - 1830	0	0	0	0	0	0	0
Creeks & Ditches, 1830 - 1903	0	0	0	0	0	0	0
Tributaries, 1830 - 1890	0	0	0	0	0	0	0
Flood dikes, 1830 - 1870	0	0	0	0	0	0	0
Regulation works, 1830 - 1870	0	0	0	0	0	0	0
Excavations & Fillings, 1830 - 1870	0	0	0	0	0	0	0
Infrastructure, GDR / Railworks 1868 - 1870	0	0	0	0	0	0	0
Regulation works, GDR	0	0	0	0	0	0	0
Flood dikes, GDR	0	0	0	0	0	0	0
Excavations & Fillings, GDR	0	0	0	0	0	0	0
Danube Regulation in Lower Austria since 1881	0	0	0	0	0	0	0
Infrastructure, Post GDR	0	0	0	0	0	0	0
GDR Supplementary Projects	0	0	0	0	0	0	0
Flood dikes, Post GDR	0	0	0	0	0	0	0
Tributaries, Wien River Regulation	0	0	0	0	0	0	0
Creeks & Ditches, 20th century	0	0	0	0	0	0	0
Tributaries, Liesing & Schwechat Regulation	0	0	0	0	0	0	0
Correction of the GDR	0	0	0	0	0	0	0
Hydropower	0	0	0	0	0	0	0
Improved flood protection since 1972	0	0	0	0	0	0	0
SUM (century / turn of the century)	**488**	2,108	527	**2,635**	2,014	2,346	**4,360**

In the 18th century regulation works and flood dikes implemented by *Hubert* between 1770 and 1790 contribute with together c. 20 % to the expenses (7 % for flood dikes). In the 19th century with a total volume of expenses equivalent to around 80 million days unqualified labor, approximately 32 % were spent on the Great Danube Regulation (GDR) between 1868 and 1884 (16 % of the century's expenses only for the excavations, 10 % only for the regulation works during the GDR). The expenses in these twelve years exceed those from the Danube floodplain in the years 1830 till 1870 (21 % of the documented expenses from Vienna).

Table IV-3: Expenses by century on defined project categories (18th till 21st century); medium estimate in 1,000 days of unqualified labor (1,000 duql).

Project category	18.	18./19.	18th C	19.	19./20.	19th C	20.	20./21.	20th C	21st C
	MED	MED	SUM	MED	MED	SUM	MED	MED	SUM	SUM
Creeks & Ditches, before 1830	190	66	256	282	0	282	0	0	0	0
Mill weirs & streams	31	95	126	645	62	707	0	0	0	0
Tributaries, before 1830	458	22	480	399	0	399	0	0	0	0
Excavations & Fillings, before 1830	1,541	19	1,559	109	0	109	0	0	0	0
Other early flood dikes before 1787	239	14	253	0	0	0	0	0	0	0
Infrastructure before 1868	0	0	0	2,712	0	2,712	0	0	0	0
Regulation works near Nussdorf before 1650	0	0	0	0	0	0	0	0	0	0
Other Regulation works before 1650	0	0	0	0	0	0	0	0	0	0
Regulation works, 1650 - 1700	0	0	0	0	0	0	0	0	0	0
Regulation works, 1700-1787	4,360	9	4,369	0	0	0	0	0	0	0
Regulation works, Hubert	1,224	0	1,224	0	0	0	0	0	0	0
Flood dikes, Hubert	756	0	756	26	0	26	0	0	0	0
Regulation works, 1787-1830	650	285	935	2,845	0	2,845	0	0	0	0
Flood dikes,1787 - 1830	206	149	355	600	0	600	0	0	0	0
Creeks & Ditches, 1830 - 1903	0	0	0	5,517	5,635	11,153	39	0	39	0
Tributaries, 1830 - 1890	0	0	0	1,279	0	1,279	0	0	0	0
Flood dikes, 1830 - 1870	0	0	0	3,894	0	3,894	0	0	0	0
Regulation works, 1830 - 1870	0	0	0	12,167	0	12,167	0	0	0	0
Excavations & Fillings, 1830 - 1870	0	0	0	1,070	0	1,070	0	0	0	0
Infrastructure, GDR / Railworks 1868 - 1870	0	0	0	2,416	0	2,416	0	0	0	0
Regulation works, GDR	0	0	0	8,143	65	8,208	0	0	0	0
Flood dikes, GDR	0	0	0	1,986	0	1,986	0	0	0	0
Excavations & Fillings, GDR	0	0	0	12,372	0	12,372	0	0	0	0
Danube Regulation in Lower Austria since 1881	0	0	0	2,491	56	2,547	0	0	0	0
Infrastructure, Post GDR	0	0	0	123	0	123	36	0	36	0
GDR Supplementary Projects	0	0	0	3,694	5,018	8,711	4,084	0	4,084	1,113
Flood dikes, Post GDR	0	0	0	1,444	351	1,795	185	0	185	0
Tributaries, Wien River Regulation	0	0	0	1,544	165	1,709	1,082	0	1,082	0
Creeks & Ditches, 20th century	0	0	0	0	0	0	728	0	728	0
Tributaries, Liesing & Schwechat Regulation	0	0	0	0	0	0	286	0	286	0
Correction of the GDR	0	0	0	0	0	0	6,810	0	6,810	0
Hydropower	0	0	0	0	0	0	25,134	0	25,134	290
Improved flood protection since 1972	0	0	0	0	0	0	27,937	0	27,937	1,549
SUM (century / turn of the century)	9,654	660	**10,314**	65,759	11,352	**77,111**	66,322	0	**66,322**	**2,952**

The overall data quality of the expenses based on medium cost estimates in duql in each project category is shown in table IV-4. In the bottom line it shows the overall data quality according to this method with 61 % safe, 11 % good, 19 % moderate, 9 % poor or arbitrary estimates. This quite high quality of estimates originates from the fact, that expenses for the most significant regulation projects along the Viennese Danube (e.g. the GDR between 1870 and 1875) were often safely documented, while uncertain information exist for periods with minor efforts.

Table IV-4: Data quality of the estimated financial means spent for each project category.

Project Category	Arbitrary	Poor	Moderate	Good	Safe	SUM
Correction of the GDR	0%	0%	0%	0%	100%	100%
Creeks & Ditches, 1830 - 1903	0%	4%	44%	11%	41%	100%
Creeks & Ditches, 20th century	0%	0%	67%	33%	0%	100%
Creeks & Ditches, before 1830	0%	90%	10%	0%	0%	100%
Danube Regulation in Lower Austria since 1881	0%	3%	3%	94%	0%	100%
Excavations & Fillings, 1830 - 1870	0%	8%	20%	35%	36%	100%
Excavations & Fillings, before 1830	7%	53%	3%	36%	1%	100%
Excavations & Fillings, GDR	0%	0%	4%	10%	86%	100%
Flood dikes, 1830 - 1870	0%	1%	27%	64%	8%	100%
Flood dikes, GDR	0%	0%	98%	2%	0%	100%
Flood dikes, Hubert	0%	0%	100%	0%	0%	100%
Flood dikes, Post GDR	0%	13%	55%	22%	11%	100%
Flood dikes,1787 - 1830	0%	0%	82%	0%	18%	100%
GDR supplementary projects	0%	11%	1%	11%	77%	100%
Hydropower	0%	0%	1%	0%	99%	100%
Improved flood protection since 1972	0%	0%	0%	0%	100%	100%
Infrastructure before 1868	2%	3%	7%	83%	5%	100%
Infrastructure, GDR / Railworks 1868 - 1870	0%	2%	98%	0%	0%	100%
Infrastructure, Post GDR	0%	84%	16%	0%	0%	100%
Mill weirs & streams	25%	63%	5%	0%	7%	100%
Other early flood dikes before 1787	0%	12%	86%	0%	1%	100%
Other Regulation works before 1650	7%	64%	29%	0%	0%	100%
Regulation works near Nussdorf before 1650	0%	27%	37%	11%	25%	100%
Regulation works, 1650 - 1700	0%	26%	33%	33%	7%	100%
Regulation works, 1700-1787	0%	67%	7%	0%	26%	100%
Regulation works, 1787-1830	1%	1%	68%	8%	22%	100%
Regulation works, 1830 - 1870	0%	0%	77%	22%	1%	100%
Regulation works, GDR	0%	7%	4%	22%	66%	100%
Regulation works, Hubert	11%	0%	70%	0%	19%	100%
Tributaries, 1830 - 1890	8%	53%	39%	0%	0%	100%
Tributaries, before 1830	6%	16%	43%	26%	11%	100%
Tributaries, Liesing & Schwechat Regulation	0%	0%	0%	0%	100%	100%
Tributaries, Wien River Regulation	2%	44%	14%	39%	0%	100%
All expenses	**1%**	**8%**	**19%**	**12%**	**60%**	**100%**

Apdx. IV.3 Data selection: The Donaukanal and its precursors

The following figures show in an exemplary way how the list of "individual measures" in the DB (see chapter 3.2) can be used for the analysis of any data selection. In this case, only the data for individual measures on the *Donaukanal and its precursors* has been selected – including the *Donaukanal* itself and before 1700, the *Wiener Arm*, *Tabor Arm*, *Nussdorfer Arm* and *Waschenkittel.* The upper part of the present Donaukanal – the Tabor Arm has actually been a main branch till the late 16th century, while the Wiener Arm had always been the supply line between the main branch of the Danube and Vienna. This regulation history of this river section is a particularly interesting case and has its very individual characteristics while the rest of the *Viennese Danube* – at least since 1830 – is more embedded in the large-scale regulation history of the entire Danube section upstream and downstream of Vienna.

Figure IV-3 shows the estimated total expenses in *days unqualified labor equivalents* (duql) on hydraulic engineering in this section from 1540 to 1830. Figure IV-4 on a different scale adds the expenses for the years 1830 to 1910. The data quality is illustrated in figure IV-7, showing at least a moderate quality for most of the 19th century and partly moderate quality in the early 18th and late 16th century. The estimated range before 1700 never exceeds a maximum of 410,000 duql per decade. In a majority of decades from 1700 till 1910 the minimum estimate was exceeding this value, and in the decade 1700-1710 already more than one million duql were spent at least. The mean estimates of 1700-1710 and 1720-1730 reach up to almost 2 million duql. In this time the systematic creation of the Donaukanal had started with massive efforts for a straightening and stabilization of its entry at the branch-off from the Danube main branch near Nussdorf. 1890-1900 even up to 7.5 million duql were spent which can be explained by major projects such as the *Nussdorf weir and lock* and new quay walls and a turning basin for steam ships.

The figures IV-5 (in total numbers) and IV-6 (as percentage) qualitatively approach the importance of the river functions which were addressed by the expenses for the regulation of the Donaukanal and its precursors. The increasing importance of flood risk for the city of Vienna and the suburbs becomes particularly obvious.

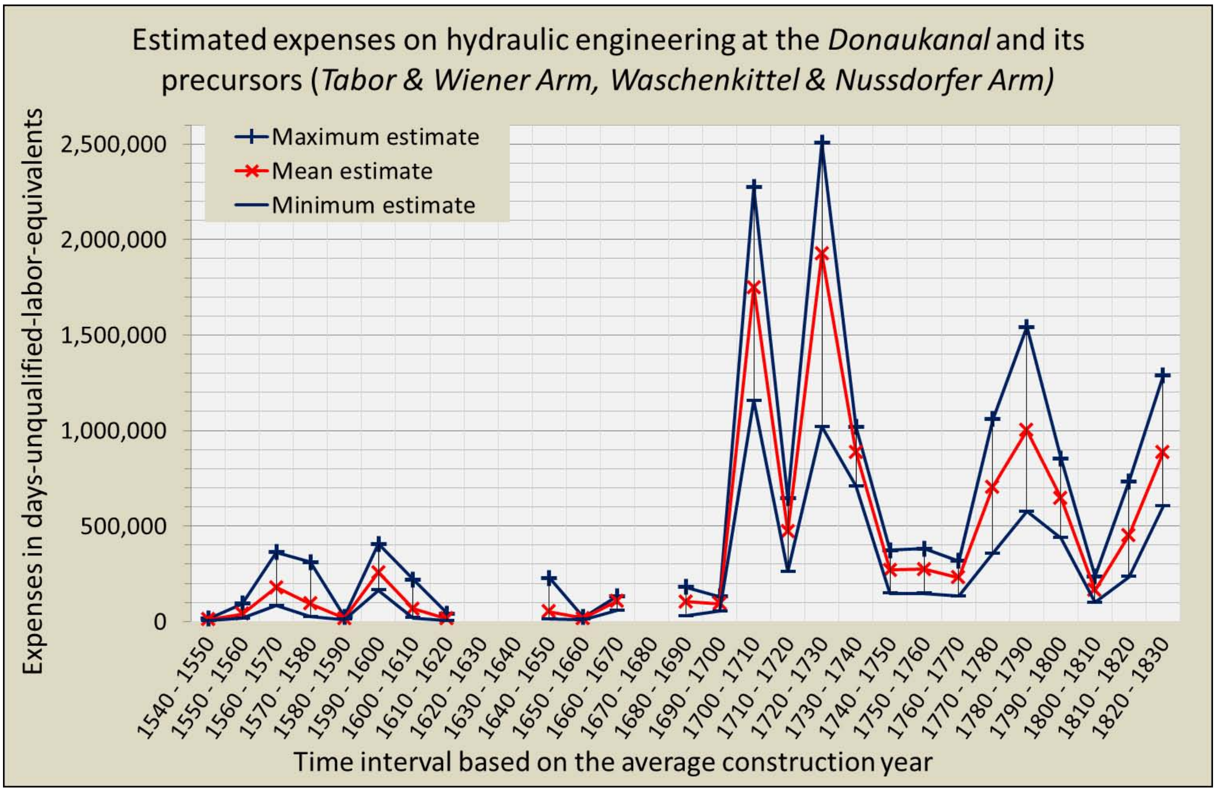

Figure IV-3: Expenses on hydraulic engineering at the Donaukanal and its precursors per decade from 1540 to 1830; based on cost estimates for individual measures in the DB.

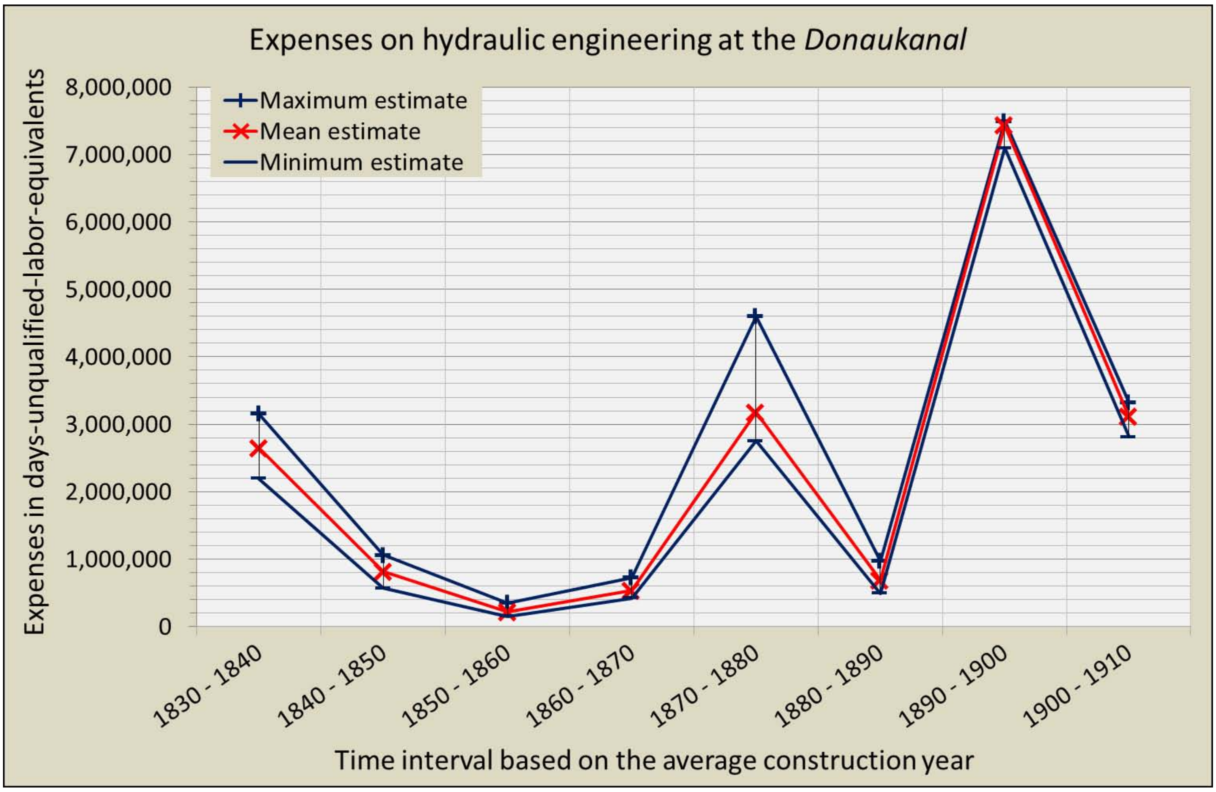

Figure IV-4: Expenses on hydraulic engineering at the Donaukanal per decade from 1830 to 1910; based on cost estimates for individual measures in the DB.

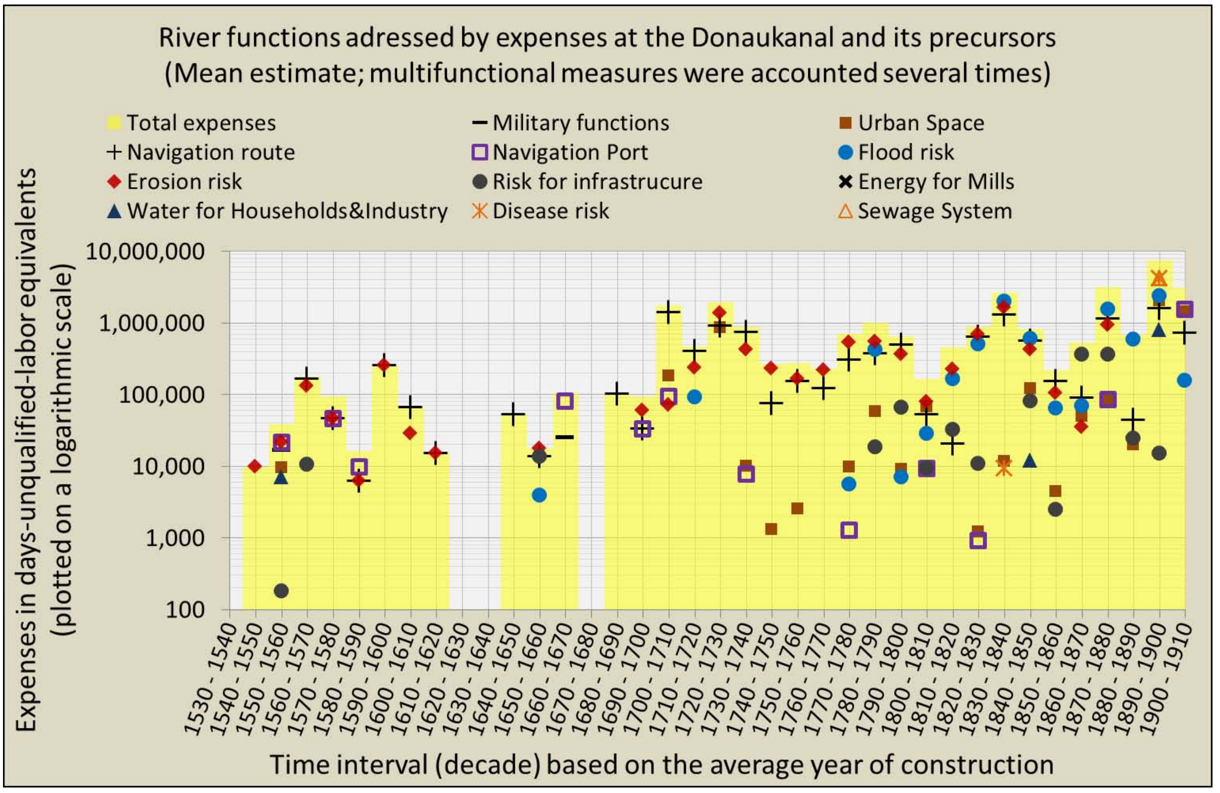

Figure IV-5: River functions addressed by the expenses at the Donaukanal and its precursors (in total numbers).

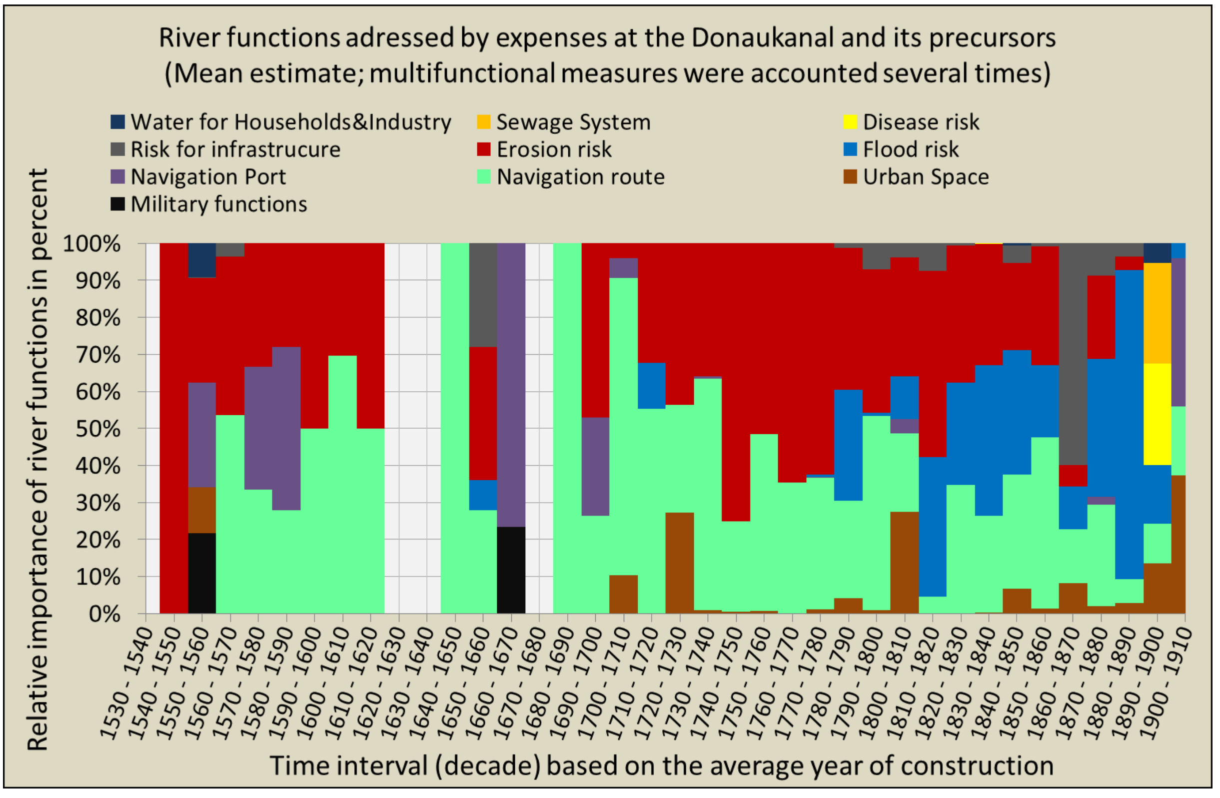

Figure IV-6: The relative importance of river functions in each time interval addressed by the expenses at the Donaukanal and its precursors.

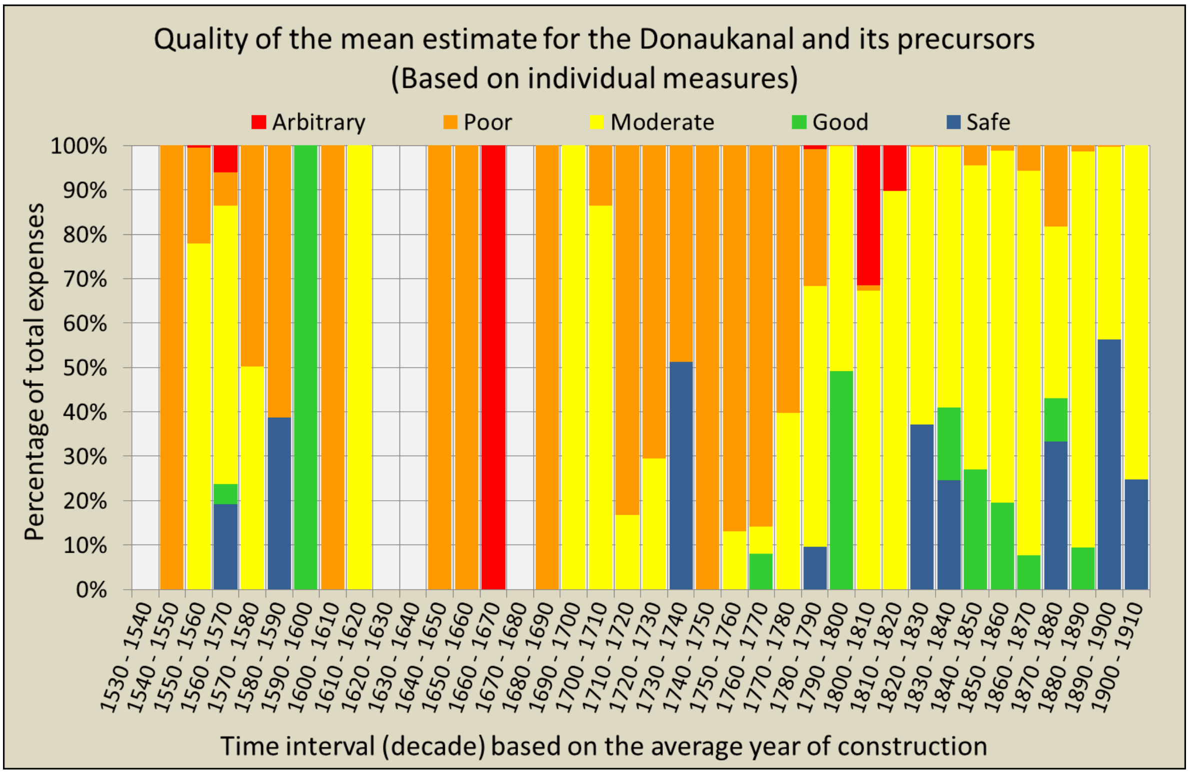

Figure IV-7: Data quality of the cost estimates for individual hydraulic engineering measures at the Donaukanal and its precursors.

APPENDIX V. FILES ON THE ATTACHED DVD

A DVD is attached to the hard copy of the thesis in the library of the *University of Life Sciences and Natural Resources* in Vienna. This DVD-version contains two folders:

1. The text of the master thesis as PDF-file (“Text (PDF)”)
2. Selected data tables as XLSX-files (“Tables (XLSX)”)

The “Text (PDF)”-folder contains the entire text version of the thesis including the appendix. For opening the data tables on the DVD the program *Microsoft Excel* is required. The files in the folder “Tables (XLSX)” have been subdivided into four folders according to the structure of this research:

> Part 0: the database of historical river engineering measures from HOHENSINNER et al. (2012) which was extended and restructured for this thesis.

> Part A: the collection of historical values of money based on existing collections in secondary literature, in particular: PŘIBRAM et al. (1938), MÜHLPECK et al. (1979a, 1979b); KAUSEL et al. (1979); SANDGRUBER (1994); STATISTIK AUSTRIA (2014)

> Part B: the protocol of prices and cost of river engineering measures in historical documents after e.g.: THIEL (1904, 1906); DRC (1868, 1886, 1898), PASETTI et al. (1850); PASETTI (1862); BAUMGARTNER (1862); WEX (1876a); SCHREY (1899); SLEZAK (1977, 1978, 1980); BUCHMANN et al. (1984); KORTZ (1905) etc.

> Part C: the synthesis of parts 0, A and B, leading to the cost structure of historical river engineering measures in Vienna.

Each of the four parts consists of three files. In each case the first file contains the base data or the basic arrangement, the second file transforms the base data to a usable format and the third file is the application, outcome or analysis of the transformed dataset in the previous file. On the following pages the files will be presented shortly. They only contain the selected data which is most central to the structure of the research. Numbers were copied to these data tables, while calculations, illustrations and additional material are only available in a complete data version which will be preserved at the *Institute of Hydrobiology and Aquatic Ecosystem Management (BOKU)* and the *Centre for Environmental History* of the *Alpen-Adria-University Klagenfurt*.

The subfolder “0_Database(DB)” in the “Tables (XLSX)”-folder on the DVD is the foundation for chapter 3 and appendix I of the thesis. *File 0.1_Orig_GIS-DB_GER* is a copy of the initial dataset from the geodatabase *Historical river engineering measures in Vienna* (Original title: *Historische Wasserbauten Wien*) from HOHENSINNER et al. (2012). The file contains two sheets. The sheet “linear” is the database of linear river engineering measures (1403 measures) and the sheet “areal” is the database of areal river engineering measures (450 measures) as described in chapter 3.1. Each line stands for an individual river engineering measure. The columns are attributes (= characteristics) of each measure. The first line contains the name of the “attributes”. The specifications under those headlines for each measure are referred to as “attribute values”. The original DB is entirely in German, the names of the “attributes” and a short description are attached in table V.1 on the next page.

The *file 0.2_New_Excel-DB_ENG* contains a new synthesis of the database according to the principles described in chapter 3.2. This synthesis is the starting point for many further steps in this research. There are three types of entries:

1. The existing database with 1453 linear river engineering measures in Vienna
2. The existing database with 450 areal river engineering measures in Vienna
3. 142 additional entries mainly originating from cost information in literature which is not clearly associated with individual linear or areal measures in the database

Compared to *file 0.1* the following columns are new in this file (marked by a red shaded headline). Many of the new categories are shown in the tables 5-1 to 5-5.

> Under the headline “# of the time interval” the following four columns were added: The columns “Individual” and “Project” label the number of the time interval between “1” and “52” based on the average construction year of the database entry. For the column “MIN” the interval was defined based on the earliest (minimum) year of the construction period, for “MAX” based on the latest (maximum) year of the construction period. If the entry needs to be excluded from the calculations which are either based on individual measures or projects, the time interval is set in brackets in the respective column (“individual” or “project”).

> Under the headline “CATEGORIZATION” four new categories were introduced: the “water body type”, the “chronology”, the “construction material” and the “project category”; the colors of the lines in the database were assigned to the project categories, providing each category with a distinct color.

> Under the headline “EXTENT” the following additions were made: The given length (for linear measures) and the given width (for areal measures) were interpreted. Above the tables in line 1 of the sheet an uncertainty was specified: +/- 50 % for measures for which “location uncertain” was specified by HOHENSINNER et al. (2012), +/- 10 % on the extent of all other measures. The assumed minima and maxima were calculated based on those uncertainties (see chapter 3). Additionally,

columns for the "volume" (in m³), the "cross section" (in m²), and "height" and "width" (in m) were added, enabling an integration of this information, either.

> Under the headline "DURABILITY" the "duration of existence" and the "duration of functionality" including the remarks given in the original DB were processed in such a way, that both the durations in years (medium, minimum, maximum) and the dates, the structures were likely existing till or functioning till, were listed.

Table V-1: Attributes in the original DB (HOHENSINNER et al., 2012)

German / Deutsch		English / Englisch	
GIS-Attribut/Feldname	**Attributwerte**	**GIS-Attribute/Field name**	**Attribute values**
Baujahr (n.Chr.)	Jahreszahl(-Jahreszahl)	**Construction year**	Year date
Anmerkung zum Baujahr	Zusatzinformationen zum Baujahr	**Remarks construction year**	Additional information concerning the construction year
Jahrhundert	z.B. 16.	**Century**	e.g. 16. (=16th)
Gewässer	Bezeichnung des Gewässers	**Water body name**	Name of the water body
Bezeichnung Wasserbau	allfälliger Name des Wasserbaus	**Project name**	if available common name of the measure
Bautyp (linear)	Sporn (MW-Buhne), Leitwerk, Uferschutz, Abdämmung (Nebenarm), HW-Damm, Infrastruktur-Damm, Querbauwerk, NW-Regulierung, Demolierung (von alten Wasserbauten)	**Construction type (linear)**	Spur dike (Mean water-Spur), Guiding wall, (Embankment), Closure dam, Flood dike, Infrastructure dike, Transverse structure, Low water regulation, Demolition (of old river engineering measures)
Bautyp (flächig)	Durchstich, Sohlbaggerung, Geländeabtrag, Verfüllung (Aufschüttung), Verlandungswerk, Bachumleitung, Einwölbung	**Construction type (areal)**	Channel, (River) Bed excavation, Excavation of Land, Filling (Elevation), Aggradation works, Ditch (Redirection of a Creek or Ditch), Piping / Cover (vaulted stream)
Länge (m)	Länge in Meter	**Length (m)**	Length in meter
Fläche (qm)	Fläche in Quadratmeter	**Area (sqm)**	Area in square meter
Ziel der Maßnahme generell (primäres Ziel)	Regulierung, HW-Schutz, Schutz Infrastruktur, Flächengewinnung, militärisch, Wasserversorgung, Abwasserentsorgung, Energiegewinnung	**General objective of the measure (primary objective)**	Regulation, Flood protection, Protection of infrastructure, Gain of Space, Military, Water supply, Wastewater disposal, Energy supply
Maßnahmen-beschreibung	Beschreibung der Maßnahme	**Description of the measure**	Description of the measure

Bauleiter	Name des/der Bauleiter(s)	**Engineer**	Name of the engineer(s)
Ort der Maßnahme	Beschreibung der Lage	**Location**	Description of the position
Lagegenau-igkeit (m)	potenzieller Lagefehler in Meter	**Positional Accuracy**	Potential positional error in meter
Zweck der Maßnahme	Beschreibung des Maßnahmenzwecks	**Purpose of the measure**	Description of the purpose of the measure
Lebensdauer (Jahre)	Anzahl der Jahre des physischen Bestandes	**Duration of existence**	Time period in which the measure had/has physically existed (Number of years)
Anmerkung zur Lebensdauer	Zusatzinformationen zur Lebensdauer	**Remarks Duration of existence**	Additional information concerning the duration of existence
Funktions-dauer (Jahre)	Zeitraum in der die Maßnahme ihre Funktion erfüllt	**Duration of functionality**	Time period in which the measure had/has fulfilled its purpose (Number of years)
Anmerkung zur Funktions-dauer	Zusatzinformationen zur Funktionsdauer	**Remarks Duration of functionality**	Additional information concerning the duration of functionality
Quelle Literatur	Zitat aus schriftlichen Quellen (Name Jahr, Seite)	**Source Literature**	Quote from written sources (Name Year, page)
Quelle Karte	Zitat aus kartografischen Quellen (Name Jahr, Archiv-Signatur)	**Source Map**	Quote from cartographical Sources (Name Year, Archive-Signature)
Vertrauens-würdigkeit	Wenn relevant: Lage unsicher, Zeitpunkt unsicher, fraglich ob gebaut, Ausdehnung unsicher, Bautyp unsicher	**Reliability**	If relevant: Situation uncertain, Construction time uncertain, questionable if built, Extent uncertain, Construction type uncertain
Anmer-kungen	zusätzliche Informationen	**Remarks**	additional remarks
Breite (nur bei linearen Bauten)	5 = schmaler Wasserbau, 10 = breiter Wasserbau, 15 = schmaler Damm, 20.25 = breiter Damm	**Width**	5 = narrow regulation work, 10 = wide regulation work,15 = narrow dike, 20/25 = wide dike

Furthermore, the *file 0.2* contains the initial literature work. Costs in literature were directly assigned to database entries under the headlines: “cost”, “currency”, “remarks”, “carrier of cost” and “sources for costs”.

In *file 0.3_DB_Analysis* the temporal pattern of selected database properties is shown. Each line stands for a time interval (“1” to “52”). The following properties were selected:

1. The number of measures implemented in each time interval and the length of linear measures and the area of areal measures in each time interval.
2. The absolute number of occurrences of the different a) “construction types”, b) “primary objectives” of measures in each time interval (as shown in figure 3-3 & figure 3-4 as percentages for each time interval)

3. The absolute length of linear measures and area of areal measures, which belong to certain attribute values, based on a) "construction types", b) "construction material", c) "chronology" of measures in the DB (as shown in figures I.8 - I.13 in appendix I.3)

The subfolder "A_Values_of_Money" in the "Tables (XLSX)" folder on the DVD is the foundation for chapter 4 and appendix II of the thesis. In *file A.1* primarily each line represents a certain year and the columns characterize this year in terms of documented prices of different goods and services or price levels according to certain price indices. The sheet "References&Currencies" lists various preliminary specifications such as definitions of the size of one "Metzen" in liters, nominal currencies and their exchange rates, wages from 1790 till 1990 as documented by SANDGRUBER (1994) etc.

The other four sheets in *file A.1* represent groups of price information which have been used during this research (see chapter 4.2): The sheet "CPI" stands for the *consumer price index* of Austria, and combines data from different sources between 1800 and 2012 and chain links trends referring to different base years. The sheet "GDP" stands for the *gross domestic product* (*GDP*) and the *GDP price index* (= *GDP deflator or GDPPI*) of Austria and combines data from different sources between 1830 and 2012. Indices were calculated, where values in the reference periods 1830-1838, 1913 or 2012 were equalized with a value of 100 both for the CPI and the GDPPI. The sheet "food" lists documented food prices in Vienna since the 14th century combined from different sources. The sheet "wages" stands for labor prices in Vienna since the 15th century obtained from various sources, either. Generally for different price (or wage) lists there is always the same structure: First base data are collected, second, the base data is transferred to homogeneous and comparable numbers such as *nominal currency units* (*NCU*) per liter, kilogram or week labor etc., and third, indices are defined referring to selected base years, usually the periods 1721-1745 for wages and food prices. Exchange rates between the NCUs were eliminated, which allows showing explicitly the price trends over the entire period, based on different indices. An average *labor price index* and average indices for different groups of food products were derived related to the same reference period (1721-1745).

File A.2 extracts central information from *file A.1.* The sheet "indices" lists the derived indices showing trends related to all above reference periods (1721-1745, 1830-1838, 1913 and 2012). An average *food price index* before 1800 was calculated and chain-linked based on the reference period 1830-1838 with the *CPI* from 1800 to 2012. Besides, in the same fashion the *labor price index* before 1830 was chain-linked with the *GDP price index* (1830-2012). As a result the two indicators for overall price developments, the *Labor & GDPPI* and *the Food & CPI* are obtained. This step has been described in chapter 4.3. The sheet “1-year synthesis” is the scheme of historical values of money expressed by the twelve derived money equivalents to 100 NCU and 100 fl. defined in chapter 4.4 (*food equivalents*: liter oat, liter wine, kg beef, kg bread; *labor equivalents*: days unqualified labor, days qualified labor; *standardized money equivalents*: fl. 1721-1745, K 1913 and € 2012, each interpreted both with the *Labor & GDPPI* and the *Food & CPI*). As described in the chapters 4.1 and 4.4 the transfer of money equivalents per 100 NCU into money equivalents per 100 fl. can easily be done by a simple transfer factor for each nominal currency (e.g. 1 fl. equals 1.05 fl. ÖW and 2.1 K, nominally). The sheet “10-year synthesis” calculates an average of yearly data for each of the 52 time intervals.

In *file A.3* the scheme of historical values of money has been applied to the database of historical river engineering measures in Vienna. Each entry in the database is provided with a set of money equivalents (median; minimum and maximum) from the construction period of the measure for each of the twelve value-of-money indicators – as described in chapter 4.4 and shown in the tables 4-4 and 4-5.

The subfolder “B_Costs_Prices” in the “Tables (XLSX)” folder on the DVD is the foundation for chapter 5 and appendix III of the thesis. *File B.1* should be read as a protocol of the literature work for the thesis and makes no claim to be complete. Different types of information from literature on prices, extents, total expenses etc. have been collected in 11 groups of entries which are represented by 11 sheets in the file. Each entry has a name (1st column). The entries follow the structure presented in table 5-2 in chapter 5.1. A detailed description of selected and relevant entries is given in chapter 5.2.

File B.2 – as outlined in chapter 5.3 – extracts valuable information from *file B.1* in two sheets: The sheet “project_DB” filters out information on total expenses on implemented river engineering measures and projects which have actually been realized in Vienna. In the sheet “price_DB” useful price information from Vienna and the close surrounding was filtered out as price ranges per hectare, meter or cubic meter (“price range” means, a minimum, a maximum and a most likely or directly documented mean value has been obtained). The respective entry in the protocol can be identified by the entry number transferred from *file B.1*. The values of money from the respective years were used to calculate standardized prices for the measure using a selection of tools developed in the part “A” (see chapter 5.3). The primary tool is the standardization based on the *Labor & GDPPI*. The “price list” is the foundation for the further analysis and contains the individual data points which were further processed in the following sheets: the data points (deflated prices) are grouped by their construction types separately for “dikes”, “regulation measures” and “excavation measures”. Measures at a similar price level with comparable construction types from the same time period were interpreted as price categories (= cost indices, see chapter 5.3). The so-defined price categories were again extracted from those overviews, grouped by the time period and collected in the sheet “cost indices” (deflated by the *Labor & GDPPI*, and expressed in fl. 1721-1745, K 1913 and € 2012; compare table 5-5 in chapter 5.3)

In *file B.3* these deflated cost indices have been applied to the database of historical river engineering measures in Vienna: Except for those measures with direct cost information from literature, each measure was assigned to one price category and the quality of this match was stated (see chapter 5.4). In this file the all columns concerning the application of cost indices on individual measures including information on data quality, the reference year, category and period and further remarks were added to the DB. Beyond initial cost estimates in NCU and DCU and price estimates in duql and K 1913 were calculated (see chapter 5.4). Hence, nominal (in NCU) and deflated prices were calculated, and medium, minimum and maximum cost estimates could be assigned to each entry in the database.

The subfolder “C. Cost structure” in the “Tables (XLSX)” folder on the DVD is the data related to chapter 6 and appendix IV of the thesis. The *file C.1_CostEstimates* features preparations for the final analysis: The assumed expenses on river engineering measures in Vienna in NCU or DCU were transformed to medium, minimum, maximum estimates using the 12 money equivalents for each DB entry. For this transformation, assigned “values of money” to each construction period and in *file A.3* were used. In the sheet “addressed river functions” the interpretation of primary objectives and purpose of measures as “river functions” is shown for all DB entries, following the illustration in chapter 3.2 (→ table 3.4). And, in the sheet “cost-efficiency”, the prices of areal and liner DB measures, in K 1913 and duql, were divided by the assigned efficiency in order to calculate a (reciprocal) cost-efficiency.

The *file C.2_Synthesis* shows a synthesis of the entire database in one sheet (a synthesis of the *files 0.2, B2 and C.1*). It is particularly useful to use the “auto filter” function in *Excel* to show only parts of the database, e.g. all embankments, or all measures conducted in the *Donaukanal*, etc.

The *file C.3_Results* is an overview of central results of the cost structure which have been summed up or calculated from *file C.2*. As in *file 0.3*, which is featuring basic database properties, the lines stand for the 52 time intervals. Basically, the explanations for the different specifications can be found in chapter 6 of the thesis. The following sheets are in *file C.3*:

> "Cost volumes": expenses on hydraulic engineering in Vienna per time interval, based on different money equivalents
> "Data quality": amounts of expenses per time interval with certain data qualities
> "Per Capita": number of inhabitants of Vienna and expenses in days unqualified labor (duql) per inhabitant in each time interval; nominal Austrian GDP, nominal expenses and share of the GDP spent on hydraulic engineering in Vienna since 1830.
> "Average Price": average prices per kilometer and hectare in each time interval
> "Distribution" of the estimated expenses, based on "projects" in "1000 duql" for the Danube floodplain (DF) – entirely and for main branches and side branches only – and for Danube tributaries (DT)
> "RF" (= river functions): the amount of expenses in duql for each time interval addressing different river functions (based on "individual measures in the DB
> "Overview": the calculation of the values in table 6.1 based on the sheets, "Cost volumes", "per capita", "distribution" and "RF".