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Metabolism and Waterscape in an Industrializing City: A Quantitative Assessment of Resource Use and its Relation to the Transformation of the Urban Waterscape in Nineteenth-Century Vienna

Metabolismo y paisaje acuático en una ciudad en la industrialización: Una evaluación cuantitativa del uso de los recursos y su relación con la transformación del paisaje acuático urbano en Viena del siglo XIX

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Resumen — En este trabajo tomamos la perspectiva del metabolismo urbano para investigar la transformación del paisaje acuático de Viena. Mostramos cómo el metabolismo de la ciudad se entrelaza profundamente con el paisaje acuático y cómo esta relación cambió durante la industrialización. El eje metodológico de esta investigación parte de una evaluación cuantitativa del uso de los recursos urbanos utilizando métodos de contabilidad de flujos metabólicos. Se presentan los datos sobre la entrada de energía (1800 a 1914), materiales (1830-1874) y agua (1860 a 1910), así como los flujos de las aguas residuales de los hogares (1800 y 1910). Se añade además una discusión crítica sobre las fuentes más importantes de esta investigación. Nuestros hallazgos sugieren que en la transformación de una economía agraria a una sociedad industrial se afectó profundamente el paisaje acuático dentro de la ciudad y en sus alrededores. Funciones tradicionalmente desempeñadas por los ríos y arroyos, que van desde el transporte, el suministro de energía, el suministro de agua dulce o la descarga y limpieza de las aguas residuales fueron sustituidas por la oferta de nuevas tecnologías basadas en combustibles fósiles y en la separación de los materiales de los cuerpos de agua. Se detectaron cambios y presiones ecológicas en la calidad del agua, originando complejas intervenciones hidrológicas que alteraron profundamente el paisaje acuático y su papel en el funcionamiento urbano. Algunos legados de estas transformaciones todavía influyen hoy en día en el metabolismo de la ciudad.

Abstract — *In this paper we adopt an urban metabolism perspective to investigate the transformation of Vienna's waterscape. We show how deeply the city's metabolism is intertwined with the urban waterscape and how this relationship changed during industrialization. The central focus of this study is a quantitative assessment of urban resource use using material and energy flow accounting methods. We present data on input flows of energy (1800 to 1914), material (1830 to 1874) and water (1860 to 1910) and household wastewater (1800 and 1910), as well as a critical discussion of the important sources for this research. Our findings suggest that the transformation from an agrarian economy to an industrial society profoundly affected the waterscape within the city and its surroundings. Functions traditionally filled by rivers and creeks ranging from transport, electric power, fresh water supply and wastewater treatment became increasingly provided by new fossil fuel based technologies and separated from the bodies of water. Ecological changes and pressures on water quality generated complex hydrological interventions that deeply altered the urban waterscape and its role in urban operations. Legacies of this transformation still influence the functioning and the metabolism of the city today.*

Palabras clave: metabolismo, paisaje hídrico, Viena, transición socio-metabólica, suministro de agua, descarga de aguas residuales, recursos urbanos
Keywords: urban metabolism, waterscape, Vienna, socio-metabolic transition, water supply, wastewater discharge, urban resources

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Introduction[1]

In summer 2010 heavy rain poured down for hours in Vienna. All of a sudden water from the gutters of homes and other buildings began to spill out along *Lerchenfelder* Street in Vienna's central seventh district and flooded streets and cellars. What had happened? *Ottakringerbach*, a former creek, now vaulted and put underground, burst its banks. The creek was channelled and integrated into the sewage system as part of urban sanitation in the nineteenth century. On that summer day in 2010 the sewer system was not able to handle the unusually large amount of water that rushed down the underground creek, reminding us of the legacies of a historic transformation of the urban waterscape.

At the beginning of the nineteenth century numerous creeks crossing the city were still part of the cityscape. Their water was used in manifold ways as a material resource that provided drinking and processing water and as an energy source that powered mills and other waterworks. Rivers functioned as a means of transportation, as a cleansing agent in domestic and commercial contexts or as a habitat for fish and other aquatic creatures. At a larger scale, including the banks and floodplains, other elements of the urban waterscape like water meadows and riparian forests came into focus. They were used to graze livestock and produce forage, for timbering or served as hunting grounds for the nobility. The waterfront was a prime space for urban development and infrastructural projects and water had symbolic applications in the form of fountains and other waterworks. During the process of industrialization Vienna's urban waterscape underwent a fundamental transformation. Most of the smaller creeks were tunnelled and disappeared from the cityscape, medium size rivers like Wien River and *Donaukanal* (a branch of the Danube) were stabilized in a concrete bed and the large Danube was channelized. In this paper we take an urban metabolism perspective to investigate the transformation of this urban waterscape. We show how urban metabolism has been (and still is) closely intertwined with the urban waterscape and how both changed in the course of industrialization. In this context we understand industrialization as the transition from an agrarian to an industrial socio-metabolic regime, which triggered a shift in the energy needs from biomass to a fossil fuel driven energy system[2].

The idea that cities have a metabolism was put forward by Abel Wolman in 1965. Urban systems require a vast amount of materials, water and energy for their functioning. All resource inputs into the city sooner or later turn to output flows of wastes and emissions. Understanding these flows is important to comprehending urban functioning and sustainability. Concepts and methods for investigating the metabolism of urban agglomerations have greatly advanced[3] and a significant number of empirical studies exploring patterns and trends of urban resource flows have been conducted[4] following Wolman's introduction of the notion of metabolism. More recently the approach has also been applied in historical studies investigating the evolution of resource supply and emission. For example, reconstructions of historical patterns and trends of urban metabolism are available for Paris, Barcelona and Vienna[5]. The concept of urban metabolism fosters the understanding of the complex interrelationship between the city and its natural environment. Water itself is a key urban metabolic resource, but it is not just a physical asset. It is part of a network of socio-natural relationships[6]- the urban waterscape. In this paper we understand the urban waterscape as a socio-natural hybrid[7] encompassing both ecological and socio-economic dimensions. Apart from the city's water related ecosystems such as rivers, banks, floodplains, creeks and groundwater the waterscape also comprises technical (infra)structures that regulate and use water such as sewers, pipes or mills. In this study we focus on the biophysical and technological aspects of the socio-natural relationships and only occasionally touch on the social and institutional issues.

During the last years, an interdisciplinary working group at the Institute of Social Ecology has undertaken a series of research projects focusing on different aspects of urban metabolism and the environmental history of the Danube in Vienna from a long-term socio-ecological perspective[8]. The paper builds on data and findings from this body of research and provides new insights and an in-depth discussion of the changing interrelations of the city's metabolism and its waterscape. The main innovative contribution of this paper is to explicitly link changing material and hydrological flows in the city of Vienna during the process of industrialization and to demonstrate how the metabolic transition that took place over the nineteenth century interacted with an evolving regime of increasing human control over water flows and the dynamic urban waterscape. Infrastructural changes appear to be an important link between urban metabolism and the transformation of the waterscape; the grand infrastructural projects built during the late nineteenth century are the basis for water supply and discharge until the present day. By exploring these relations we aim to contribute to a better understanding of urban dynamics and operations and their relation to water.

Vienna, the former capital of the Habsburg Empire (Map 1), is an interesting case for such examining these changes. Like most other central European metropolises it underwent major transformations in the nineteenth and early twentieth centuries, which were driven by urbanisation, industrialization and sanitation, among other factors. Population rose from around 230,000 inhabitants in 1800 to slightly over 2 million before World War I (WWI), a peak that has not been reached since then (Graphic 1). This rapid population growth during the industrial transformation posed new challenges regarding resource supply, sanitation and disposal

1 We acknowledge funding from the Austrian Science Fund (projects P25796-G18 "URBWATER Vienna's Urban Waterscape 1683-1918. An environmental history" and P21012-G11 "GLOMETRA Global Metabolic Transition") and the Social Sciences and Humanities Research Council of Canada (project sustainable farm systems).

2 Sieferle, 2001. Krausmann and Fischer-Kowalski, 2013.

3 Barles, 2010. Zhang, 2013. Niza, Rosado and Ferrão, 2009.

4 For example Adger et al., 2011; Barles, 2009. Kennedy, Pincetl and Bunje, 2011. Rosado, Niza and Ferrão, 2014. Warren-Rhodes and Koenig, 2001.

5 Barles, 2007. Hoffmann, 2007. Kim and Barles, 2012. Krausmann, 2013. Schmid Neset, Bader, Scheidegger and Lohm, 2008. Tello and Ostos, 2012.

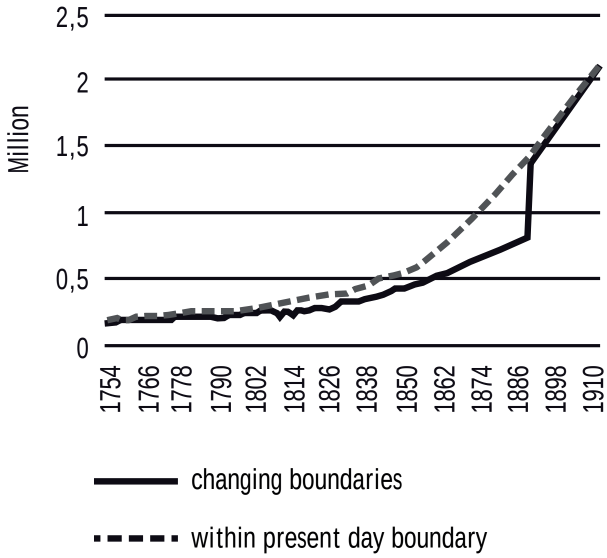
6 Swyngedouw, 1999.

7 Winiwarter, Schmid and Dressl, 2013.

8 Enviedan (P 22265-G18), Urbwater (P 25796-G18) and Glometra (P 21012) - funded by the Austrian Science Fund.

Map 1. The city of Vienna in the nineteenth century: Geographic location in the Habsburg Empire Austria-Hungary, 1899*

Graphic 1. Development of urban population Vienna, 1754-1913**



* The blue line marks the river Danube, the red circle locates Vienna, source: based on Lange D. H. 1899, edited by Friedrich Hauer.
** Data derived from MSW 1883-1913.

of waste for the city's authorities. The urban waterscape was strongly affected by a growing and changing metabolism and the transformation of supply and disposal systems. The existence of a multitude of small tributaries flowing through the city on the one hand and a massive alpine river, the Danube, on the other hand makes Vienna a particularly interesting case for exploring changes in the role of the urban waterscape for supply and discharge.

We begin this contribution with a brief outline of the hydro-morphological characteristics of Vienna's waterscape. We then introduce the urban metabolism approach and a critical assessment of the main sources used to study urban resource flows, in particular the records of urban consumption taxes. In the main part of the text we first present key findings concerning the metabolic transition in Vienna. Here we focus on changes in the energy system, the supply of construction materials, water and the discharge of human excrements (household wastewater) into the waterscape and elaborate about how the resource flows are interlinked with the urban waterscape. This is followed by a discussion of the transformation of the waterscape in relation to the metabolic transition. We point to the various interactions that existed between energy use, supply and discharge, physical growth, the expansion of the scale of metabolism and the transformation of the Danube and its tributaries. We conclude the section by identifying four key processes characterizing this transformation and highlighting the implications of this development for the functioning of the city until present day.

Hydro-Morphological Characteristics of Vienna's Waterscape

The organization of Vienna's water metabolism and the transformation of its waterscape over time can only be understood when we take the geomorphological and hydrological characteristics of the region into account. The map of Vienna in 1825 (Map 2) shows that the Danube flows through the city from the north-west to the south-east and delaminates and shapes the city in particular to the East. In the north and west, Vienna is surrounded by hilly woodlands (*Wienerwald*). The city is located downstream of a gorge (*Wiener Pforte*) in a basin (*Wiener Becken*). In the flat alluvial stretch east of the city center, the floodplain of the Danube spreads over about 6 kilometers in width. The Viennese Danube is a small stretch of the upper part of the Danube River Basin[9] of alpine character. It has a steep slope[10] characterized by low water temperature, high velocity and coarse bed sediments[11]. Today, the velocity of the Viennese Danube varies between 1 and 3.5 m/s, the annual mean discharge from 910 m^3/s at low tide, 1915 m^3/s at mean tide and 5700 m^3/s at high tide[12]. However, the medieval and early modern waterscape looked very different[13]. Until the Great Regulation in the 1870s the Viennese Danube was divided into multiple side arm and meanders stretching over the ample floodplain and forming numerous islands (Map 2). This highly dynamic fluvial landscape changed repeatedly due to extreme events like floods and ice jams but also due to geomorphological processes like sedimentation and erosion. In early modern times Vienna was not located at the main arm of the river. Instead the city was situated next to a smaller branch at the southernmost arm of the river now called *Donaukanal* (Map 2). The *Donaukanal* used to be the main shipping and supply route but also functioned

9 The entire catchment is 817,000 km^2 in size.

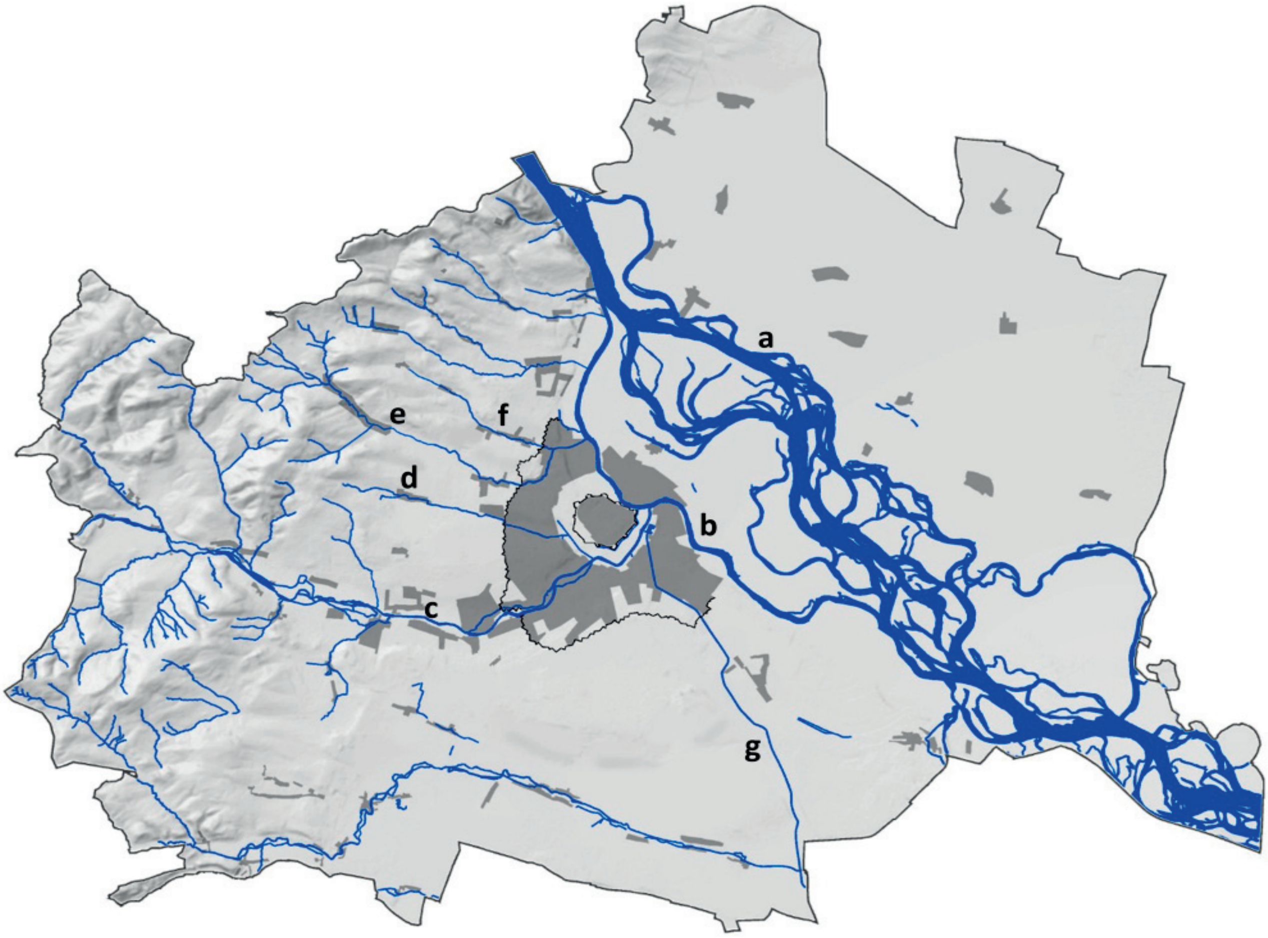
10 40 cm/km (1.3 feet/km), ten times the slope of the lower Danube, see Winiwarter, Schmid and Dressl, 2013.

11 Hohensinner, Lager, Sonnlechner, Haidvogl, Gierlinger, Schmid, Krausmann and Winiwarter, 2013.

12 Schratt-Ehrendorfer, 2011, 333.

13 Hohensinner, Lager, Sonnlechner, Haidvogl, Gierlinger, Schmid, Krausmann and Winiwarter, 2013.

Map 2. Vienna's urban waterscape in 1825



Note: Map boundaries are present day city limits. a) Danube b) *Donaukanal* c) Wien River with mill creeks d) *Ottakringerbach* e) *Alserbach* f) *Währingerbach* g) *Wiener Neustadt* shipping canal. Source: Drawing by Friedrich Hauer based on Franciscan Cadastre (original digitalisation by Stadtarchäologie Wien), shaded relief based on SRTM data.

as the main watercourse that discharged Vienna's waste and wastewater. Efforts to stabilize the riverbed have a long history and for centuries moderately successful attempts have been made to influence the course of the river[14]. It was important to keep the river close to the city so that the ships can enter and deliver raw materials and goods for everyday life. At the same time the prevention of floods became an issue. Although most pre-industrial channelization projects concentrated on the *Donaukanal*, it was only in the nineteenth century that attention shifted to the main arm of the Danube until the comprehensive regulation was finally realized in the 1870s[15]. Since the so-called Great Regulation of the Viennese Danube in the 1870s the river runs straight through the city from the north-west to the south-east. In the 1970s a second parallel bed has been built as a retention basin to cope with floods. Nowadays, almost one fifth of the urbanized space of the city lies in the former floodplain[16].

Map 2 also shows that various small streams, originating in the *Wienerwald* in the West, pass through settlements and the city center. They drop almost 400 meters after crossing the (current) city limits until they rise into the *Donaukanal*. In the beginning of the nineteenth century these creeks were used for the discharge of all sorts of waste and wastewater. With urban growth, they were all gradually integrated into the sewage system of the city. Even though most of these creeks had been covered and transformed into sewers towards century's end, they have formed characteristic topographic patterns still visible in the city's layout today. From a topographical perspective, the hydrological characteristics of Vienna with many tributaries of steep slopes and the fast flowing *Donaukanal* provide almost ideal preconditions for a waterborne sewage system. The drawback is that these tributaries are highly dynamic water courses where short but heavy floods alternate with periods of very low water. This is mainly due to the composition of the soils in the catchment area, mainly marl lime, marl clay and sandstone, which trigger impermeability and therefore lead to fast precipitation run-off.

The hydro-morphological conditions in Vienna are in some parts favorable to the extraction of groundwater. Three types of

14 Idem. Haidvogl, Guthyne-Horvath, Gierlinger, Hohensinner and Sonnlechner, 2013.

15 Haidvogl, Guthyne-Horvath, Gierlinger, Hohensinner and Sonnlechner, 2013. Gierlinger, Gingrich, Haidvogl and Krausmann, 2013.

16 Winiwarter, Schmid and Dressl, 2013.

groundwater can be distinguished. Groundwater in the Danube floodplain area, that is under the influence of the river; groundwater that is in the soil underneath layers of impermeable sandstone, which can be accessed via artesian wells; and water found in layers of permeable soil on top of the impermeable sandstone layer. All three types of groundwater were used as sources for drinking and processing water and in the mid-nineteenth century thousands of wells sprung up all over the city. Most of these were abandoned in the second half of the century with the establishment of the alpine water pipeline.

Reconstructing Vienna's Urban Metabolism

After this brief introduction to the hydro-morphological characteristics of Vienna's waterscape we now turn to Vienna's urban metabolism, including the quantification of material, water and energy flows for historic time periods. Detailed descriptions of urban metabolism methods as well as sources and estimation procedures used to investigate the evolution of the metabolism of the city of Vienna are available from previous publications[17]; therefore what follows is a brief outline of the basics of historical assessments of urban metabolism and a critical discussion of the most important sources. The metabolism approach is based on the assumption that any socioeconomic system, such as a city or a national economy, requires a permanent inflow of materials and energy to produce and reproduce its physical structures[18]. The resource inputs are processed, used and consumed, sometimes stored for long periods of time but ultimately they will leave the system either as exports to other socioeconomic systems or as waste, wastewater and emissions to the environment. Methods like material and energy flow accounting have been developed to quantify these urban resource flows[19]. They allow investigating interactions of urban systems with their local environment and their distant hinterland[20]. These interrelations are of key importance to the functioning of urban systems and the sustainable development of cities[21].

Accounting for input and output flows requires clearly defined system boundaries. This is a challenge for urban systems, where different types of system boundaries can be applied and whose physical locations or shapes can be highly dynamic over time. Typically (among others, for reasons of data availability) administrative city boundaries are chosen as system boundaries, although these are not necessarily equivalent to the functional urban system and do not correspond well with ecological systems such as water sheds. In the case of Vienna, the main source that is available for quantifying resource inputs in the nineteenth century (i.e., the urban consumption tax records) also determines the boundary of the observed system (Map 3). This implies a major statistical break when the tax boundary was expanded in 1891/92. As population data corresponding to the different systems are available it is possible to produce per capita values of material flows which are comparable over time.

The urban consumption tax is the main source to quantify the annual flow of food, energy carriers and other materials into Vienna and it provides a broad and reliable primary data source. Similar sources are also available for other European cities such as Budapest, Prag, Triest, Paris and Berlin[22]. In combination with other sources such as railroad statistics, statistical records of ship transport or industry surveys and administrative reports on urban supply, the consumption tax allows for a comprehensive reconstruction of the amount of the inflows and use of key resources ranging from wood and coal to food and feed and even construction minerals such as bricks, sand or gravel. In some cases, it is further possible to assess the spatial footprint of urban consumption if information on the origin of the imported goods is provided[23]. A critical perspective on the sources that takes into account who recorded the information, in which way, for whom and for which purpose is, of course, essential for any meaningful assessment of urban resource flows. We therefore provide a brief overview of this source which provided the backbone of quantitative assessments of resource use in Vienna: The so called "*allgemeine Verzehrungssteuer*" levied in the city of Vienna between 1829 and 1921 was recently a subject of extensive study[24]. Its registers provide basic data for further calculations of material flows into the expanding city[25].

"*Verzehrungssteuer*" was a state-wide consumption tax implemented in November 1829. Big towns were much more heavily taxed than smaller ones and rural regions. Convenience goods of everyday needs, such as food, animal feed, fuel and construction materials, were taxed as they were delivered into the city's fiscal district. Excise registers provide information about the quantities of these commodities imported to the city. In Vienna this comprised up to around 200 different items. The revenues of Vienna's excise were of high importance for state and city budgets which made any changes in the system a matter of tough and long negotiations. The Austrian "*Verzehrungssteuer*" was abolished after WWI. Turnover and value added tax systems that succeeded are still in place today.

A series of tax offices at all road entrances to Vienna's fiscal district registered the influx of goods to the city and levied the excise. Initially, most of them were situated at the "*Linienwall*", a fortified wall built in early eighteenth century that had proven futile for military purposes but was soon very useful for fiscal purposes. As water transport was of high importance for the supply of the city, excise offices were also situated at the entrance to Danube harbours and landings and at the *Wiener Neustadt* shipping canal. With the rise of railway transport from 1838 onwards, virtually all important stations within the tax district would be

17 Krausmann, 2013. Gingrich, Haidvogl and Krausmann, 2012. Gierlinger, Gingrich, Haidvogl and Krausmann, 2013. Gierlinger, 2015. Hauer, 2010. Sandgruber, 1982.

18 Niza, Rosado and Ferrão, 2009.

19 Barles, 2010. Zhang, 2013. Niza, Rosado and Ferrão, 2009.

20 Billen, Barles, Garnier, Rouillard and Benoit, 2009. Krausmann, 2013.

21 Niza, Rosado and Ferrão, 2009.

22 Hauer, 2010. Barles, 2007.

23 Billen, Barles, Garnier, Rouillard and Benoit, 2009. Krausmann, 2013.

24 Hauer, 2010, 2014. Hauer, Gierlinger, Nagele, Albrecht, Uschmann and Martsch, 2012.

25 Sandgruber, 1982. Krausmann, 2013. Albrecht and Martsch, 2014. Nagele and Uschmann, 2014.

equipped with tax offices monitoring the transport of goods by private persons, corporations and even public authorities.

For the period from 1829 to 1913[26] Vienna consumption tax registers provide product quantities and monetary data; hence, they may be used to compile charts of the total import of convenience goods into the city in one year. They cover over 80 categories of products. Some of the registers cover periods of more than eighty years; others list shorter intervals because taxation of several items was abolished earlier. The taxed goods comprise of alcoholic beverages, meat and fish (dataset 1830-1913), butter, lard, cheese, eggs, cereals, flour, legumes, vegetables and fruits, animal feed, candles, soap, firewood and coal (dataset 1830-1891) but also construction materials (dataset 1830-1874) and some petroleum products (dataset 1870-1891). As the tax was levied by a large state-run agency, excise data is relatively reliable, consistent and well documented. The study period covers the phase of largest urban growth in the history of Vienna, which makes "*Verzehrungssteuer*" a potentially broad source basis for urban history, economic and social history and, not least, for environmental history.

In order to rearrange, process and interpret the data it seems crucial to critically address its qualities and several factors which may possibly limit its value as a primary source of information. Moreover, for some data threads of secondary assumptions for the calculation of actual quantities need to be made. In the case of meat consumption for instance, tax registers provide us mainly with the number of animals brought within the city limits. Thus, in order to get useful data it is necessary to estimate the respective carcass weights of different animal species and age groups, which in turn requires finding and examining further source material.

The consistency and composition of the record, the practice of tax-raising and its legal framework requires a critical view of these sources so as to assess the data's significance. Even though the analysis of the tax registers yields seemingly precise data, the resulting figures are open to question. Factors like smuggling, tax free military consumption, regulations for goods transit, tax exemptions or agricultural production within the fiscal district need to be taken into account. Overall, it can be assumed that calculations based on consumption tax records will underestimate the amount of resources consumed in the city. But for aggregate material flows underestimation is of minor significance and probably does not account for more than a few percent of total inflows. On the other hand, underestimations due to smuggling, tax exemptions and tax evasion are difficult to quantify, but in particular for bulk flows such as cereals, wood or construction minerals the undercount may be generally considered to be low. More is known about urban agriculture. While agricultural production within the city limits was considerable for specific products such as vegetables and milk, the contribution to total urban food supply was rather low. An estimate for 1830 based on information available from the Franciscan cadastre indicated that production of food and processed wood within the city limits was less than 2% of total urban supply and declined in relevance over time[27].

Furthermore, differentiations according to product and period are necessary, because the spatial, administrative and demographic context of the excise underwent changes during the industrial transformation of the nineteenth century. In the beginning of Vienna's excise system around 1830 the city had 320,000 inhabitants (Graphic 1) and the vast majority of the urbanised area was part of the tax district. This started to change in the 1850s with industrialization gaining momentum and the rapid growth of the legal boundaries of the city's suburbs. By the beginning of the 1890s the situation had changed dramatically with excise taxation covering only slightly more than 50 percent of the city's population —which had already quadrupled to more than 1.3 million. As a (rather late) response, Vienna's administrative limits shifted outwards, incorporating the suburbs in 1891/92. The tax district's boundaries moved apace, leaving out only the periphery east of the Danube River and covering more than 95% of the urbanized area and its population until the end of Habsburg Empire (Map 3). This caesura in the city's administrative development went along with a reduction of taxed items but brought a sharp increase in the number of urbanites affected by "*Verzehrungssteuer*". Hence, when it comes to deriving gross and per capita urban consumption figures from the tax registers, significance of the data is increasingly limited in the period from 1860 to 1891 by the developments described above. Nonetheless the tax registers provide us with what is probably one of the most comprehensive and versatile datasets for a European metropolis of the nineteenth century.

One of the few resource flows not covered by the consumption tax is water. As far as the quantification of water supply in urban households and industries consistent data available from the statistical yearbooks of the city of Vienna was consulted. But they only cover the period since the establishment of the first alpine water pipeline (*Hochquellwasserleitung)* beginning in 1876. For earlier time periods, when water supply was based on thousands of wells supplying individual households and urban quarters we only have sporadic estimates from the public construction authority[28], drawn from a publication by civil servant Barth Bartenheim (1829) and from a memorandum on the occasion of the opening of the *Hochquellenwasserleitung* published by civil servant Rudolf Stadler (1873).

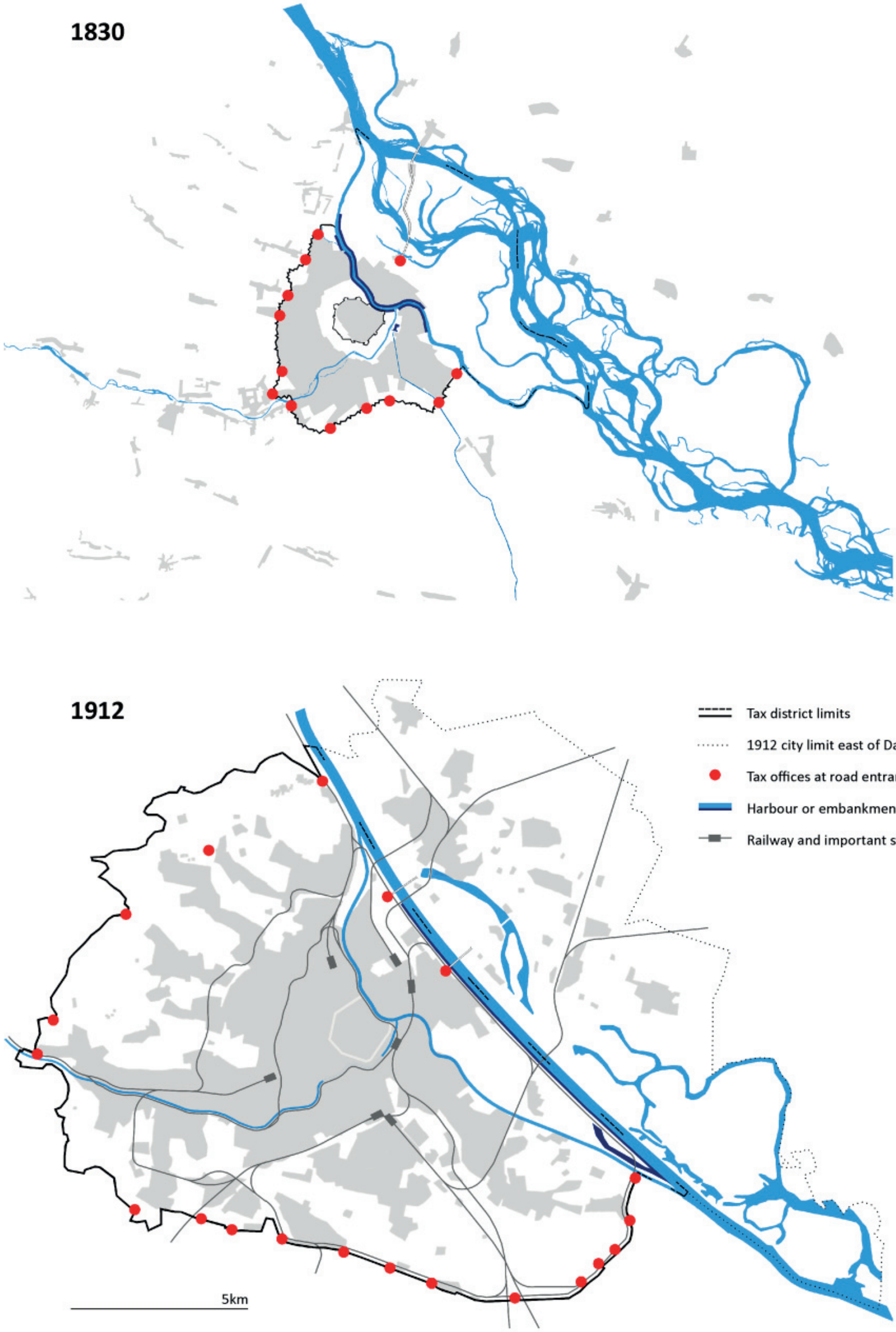
A different issue is the quantification of outflow of wastes and emissions. None of these flows has been recorded in historical statistical sources, but estimation procedures based on input data and biophysical relations (e.g. excretion rates of humans and livestock) can be applied to arrive at rough numbers. For the case of Vienna, this has been done for the outflow of organic wastes from human and animal consumption in terms of tons of human and animal excreta and its content of nitrogen. Next to airborne emissions from the combustion of wood and coal these were the most significant urban outflows in the nineteenth century and particularly important for the urban waterscape as their

26 WW1 and post-war years (1914-1921) may not be taken into account for reasons of scarce and incoherent source material.

27 Gierlinger, 2014.

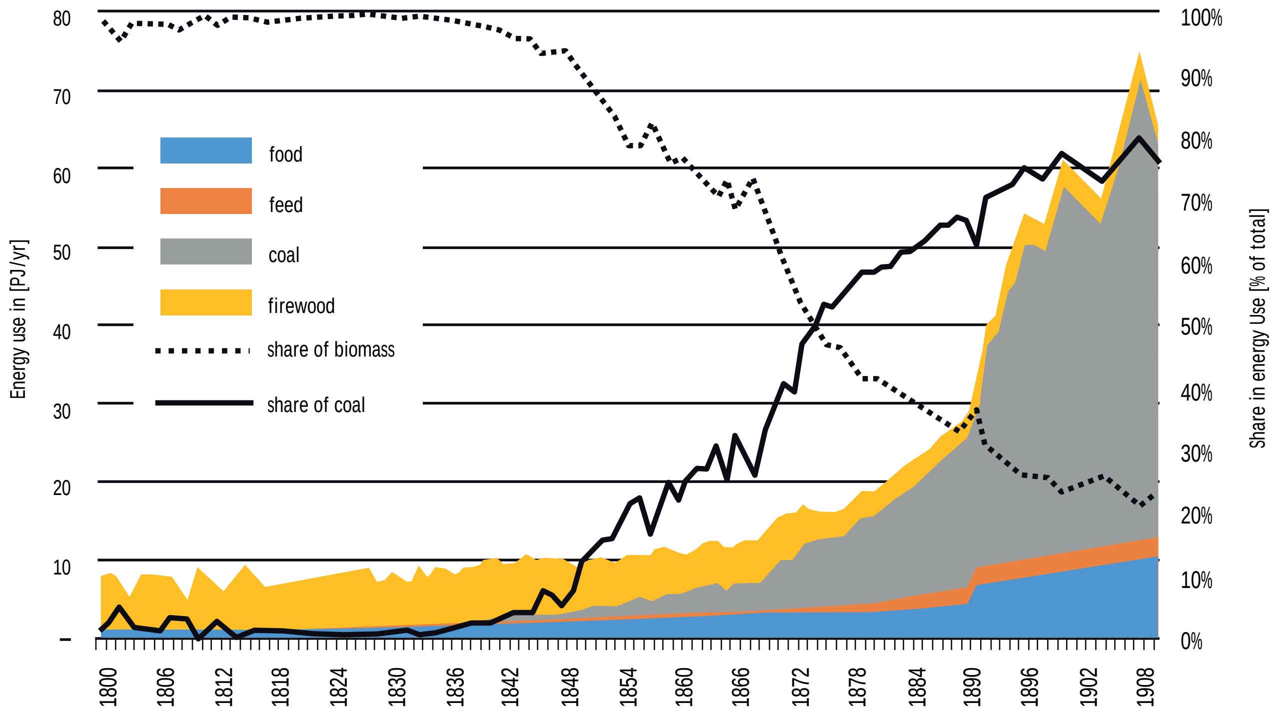
28 Stadtbauamt, 1861.

Map 3. Built up area and tax district limits in 1830 and 1912



Note: Road access points to the tax district and main harbours / landings are highlighted. Besides the establishment of an extensive railway network the most significant change was the alteration of the city's waterscape, which had a lasting effect on urban geography. While the *Wiener Neustädter* canal was abandoned in 1879 the great Danube Regulation 1870-75 brought with it extensive new embankments, relocating the harbour zones to the newly rectified main arm. As the two new bridges crossing the river were much easier to control and suburbs east of the river were still quite small it was prohibitive to enlarge the fiscal area, for the monitoring of transport apparently would have become much more complex and expensive.

Graphic 2. Energy use (DEC) in Vienna, 1800-1910



Source: Krausmann, 2013.

discharge was closely tied to urban streams and rivers. We can further draw on reconstructions of the urban water network and in particular the Danube River based on an evaluation of historical maps published in Hohensinner et al. 2013.

The Metabolic Transition: Resource Flows in Vienna in the Nineteenth Century

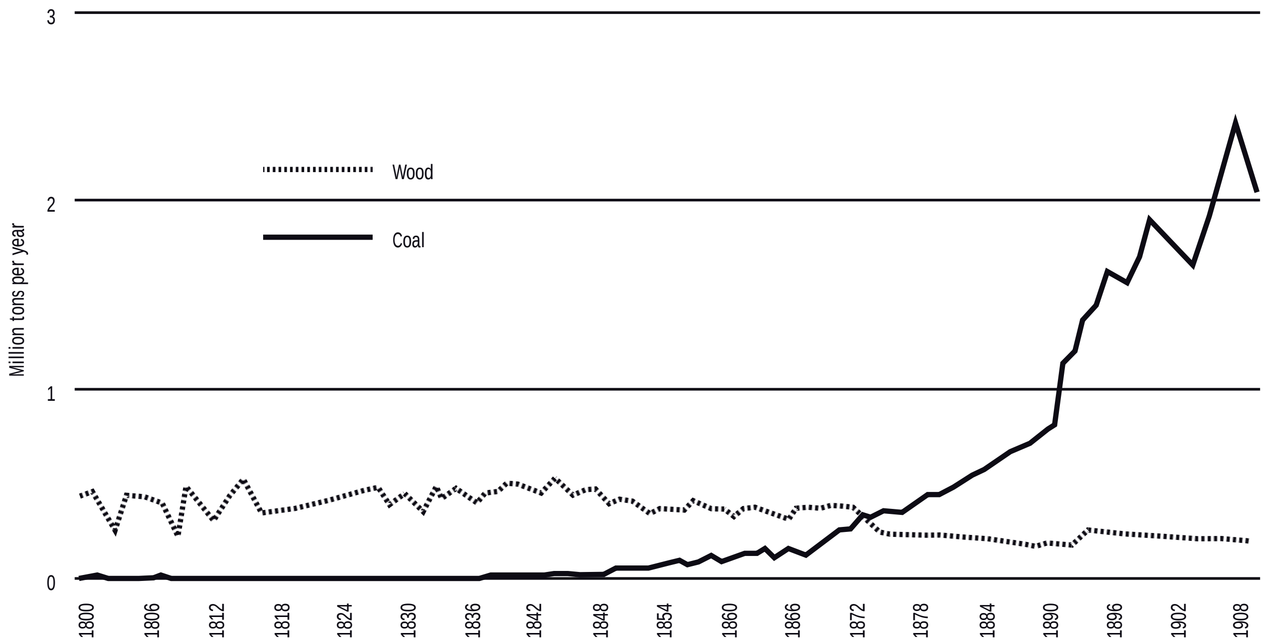
The biophysical backbone of the Industrial Revolution in the nineteenth century is the transition in society's metabolism[29]. The environmental historian Rolf Peter Sieferle[30] has described this process as a transition from a *controlled solar energy system* based on area and labour intensive biomass as the main energy and material resource towards a coal based energy system with a high share of mineral and fossil materials in resource supply. The new energy system provided society with large and concentrated amounts of energy. The corresponding conversion technologies facilitate the extraction, transport and processing of materials in a new order of magnitude and provide unprecedented means to transform hydrological systems. It is the physical precondition for rapid growth of population and economy and large-scale urbanisation[31]. The basic pattern of the metabolic transition can be observed for all industrial economies and is still ongoing at the global scale[32]. During this process the share of biomass in energy supply declined from 85 to only 20-30%, the use of fossil and mineral resources surges and the physical size of the economies (measured as material or energy use) reaches new heights. This has not only been shown for national economies but it can also be observed at the urban scale[33]. Until the mid-nineteenth century the energy system of Vienna rested almost exclusively on firewood and human and animal power, only in the 1840s the use of coal began to take off (Graphic 2): Between 1846 and 1910 the percentage share biomass in energy supply declined from 95 to 20 and total energy supply surged from 10 to 75 PJ/yr. The data also indicate that throughout the first half of the nineteenth century the biomass-based energy system could not expand with the already growing urban population and per capita energy use declined from 35 GJ/cap/yr to around 20 GJ/cap/yr[34]. Only after 1865 did energy use begin to rise again and multiplied 1.6 fold until 1910, a transition quite similar to that observed in Paris[35]. The transition of the energy system affected all features of urban metabolism. In this section we discuss the development of the supply of Vienna with energy, construction materials and water and the disposal of wastewater.

Energy Carriers

The nineteenth century was a period of rapid urban growth. The city of Vienna grew in terms of population, territory and metabolic flows, driven by positive feedback mechanisms between the new abundance of primary energy, the steam powered tech-

29 Barca, 2011. Krausmann and Fischer-Kowalski, 2013.
30 Sieferle, 2001.
31 Fischer-Kowalski, Krausmann and Pallua, 2014.
32 Krausmann, Fischer-Kowalski, Schandl and Eisenmenger, 2008. Krausmann, Schandl, Sieferle, 2008.
33 Kim and Barles, 2012. Krausmann, 2013.
34 Krausmann, 2013.
35 Kim and Barles, 2012.

Graphic 3. Supply of wood and coal in Vienna between 1800 and 1910



Source: Krausmann, 2013.

nologies providing useful work and the novel possibilities to transport and process resources. This changed the relation between the city's metabolism and the waterscape: The biomass-based energy system was largely relying on river transport. Between 1800 and 1850 between 400 and 500 ktons of wood were transported each year into the city (see Graphic 3), 60 percent of which came via the Danube on floats and rowing boats each carrying 10 to 100 tons[36]. A branch of the Danube which later became the Danube channel brought the wood and other resources close to the consumers and the wood was stacked up and sold at regulated prices on certain locations near the river. The wood came from distant regions up to several 100 km upstream of the Danube. The river provided a natural and inexpensive means of long distance transport but it was also unreliable and risky. Transport was severely constrained by low and high water levels; in particular, during winter months from December to March transport was restricted. Efforts to stabilize the course of the river in the Vienna region to contain flooding and improve navigability continued for centuries, but it was largely impossible to control the kinetic energy of the Danube by reliance on sunpower alone. This would only become feasible with the technologies and the power available in the fossil energy system in the late nineteenth century (see below). Losses were also considerable during the process of extracting the wood and bring it to market. This involved several transport steps where up to 20 percent of the product was lost. And finally, river transport was spatially inflexible since the Danube and its tributaries connected the city only to the western hinterlands while other regions rich in wood and other resources were only accessible via costly land shipment. With urban growth and increasing demand already in the late eighteenth century attempts were made to improve the connection of the city to the southern hinterlands that lacked appropriate waterways. A supply channel (*Wiener Neustädter Kanal*) was constructed and opened in 1803, which allowed to ship wood from the southern forests to the city.

Coal, although in use in Austria since the early nineteenth century became an urban resource only with the establishment of the railroad network which connected the city with the coal mining regions in the north and south in the 1860s. From then on coal supply increased rapidly from a few ktons in 1800 to 2200 ktons around 1910 (Graphic 3)[37]. The shift in the energy supply and the means of transport changed the urban-hinterland relations drastically and made urban supply more flexible. This happened just at a time when energy availability also allowed for large scale transformations of the river, facilitating significant improvements of its use for transportation through the adoption of regulations and steamships as will be discussed below.

Construction Material

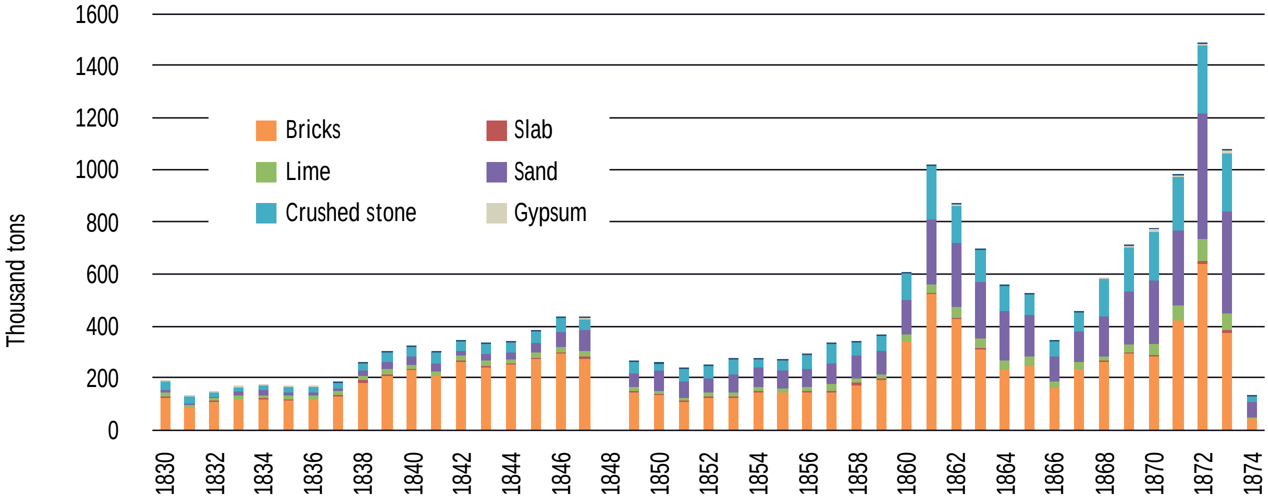
The energy transition was the basis for urban growth and affected the flow of all other materials. Urban development, expansion of the city and large scale infrastructure projects drove the increased use of construction materials, such as bricks, lime, sand and crushed stone or timber. Data recorded in the *Verzehungssteuer* indicate that the use of construction materials increased from 185 kt/yr in the 1830s to a peak of over 1500 kt/yr in 1873. This eightfold increase in material consumption compared with only a doubling of the population reflects a stark rise in the amount of construction minerals used per capita.

This increase was not steady but figure 6 shows several waves of growth which relate to periods of rapid urban development or

36 Gingrich, Haidvogl and Krausmann, 2012.

37 Krausmann, 2013.

Graphic 4. Supply of construction material in the city of Vienna between 1830 and 1874



Source: Hauer, 2010. Hauer et al., 2013.

specific-large scale infrastructural projects in the nascent metropolis of Vienna. Increased construction activity is apparent in the "*Vormärz*"[38] period from about 1838 onwards, a pattern mostly related to early industrialization. The stagnation following the revolution of 1848 was followed by another boom in the 1860 related to the demolition of the city walls (starting in 1858) and the start of an inner-city expansion phase. After a sharp decline in construction activity in 1866 Vienna experienced the brief but intense building boom of the so-called "*Gründerzeit*"[39]. This was the time of the strongest increase of newly established corporations, expansion of the financial sector and speculative investments, all of which triggered a spike in prices and wages[40]. In the climax of this period Vienna hosted the 4th World Exhibition, where countries from all over the world exhibited products and shared knowledge about their industrial and agricultural output. Ironically only 9 days after the opening of the World Fair the stock market crashed and this was the beginning of the economic crisis that lasted for years. With the stock-market crash in 1873 and the economic crisis that followed the construction industry slumped, as is clearly visible in the drastic decline of construction mineral use seen in 1874. The abolition of the consumption tax on building materials was a consequence of this crisis. Urban authorities wanted to stimulate the construction market by implementing this regulatory change[41].

The surge in the use of construction minerals, in particular in the period 1866 to 1873, among others, reflects the transformation of the urban waterscape. The largest infrastructural projects of that time directly concerned the waterscape: The Great Danube Regulation, the installation of a pipe-bound water supply system, the construction of a waterborne sewage system and other projects all took place during this period and boosted the consumption of construction materials. These construction projects indicate a new quality of human control and transformation of urban waterways and they resulted in the disappearance of many bodies of water from the cityscape. The extraction of construction minerals also impacted the waterscape. Resources like sand and gravel in particular abound in floodplains. The growing demand for these resources was at least partly met by extracting in these regions, which would have adversely affected floodplain ecosystems and groundwater[42]. The impacts of brick production on the waterscape are still visible today. The excavation sites for clay in the south of Vienna, where the large brick industries were located, have turned into ponds and lakes and nowadays serve as recreation areas that are partly protected as nature reserves[43].

Water

Reliable data for water consumption in Vienna is only available for a comparatively short interval from 1876 to 1910, a period during which water use multiplied as shown in graphic 5 and per capita consumption increased from 50 to 60 l/cap/yr. But not only the amount of water consumed changed; the supply system and the origin of the water were equally transformed. In the beginning of the nineteenth century most of the drinking water came from the many wells dotting the city. Several smaller water pipelines existed, but they mostly provided water for the imperial court and the nobility[44]. Many artisanal shops such as tanneries, dye works, millers and so on used water directly from the many creeks or millstreams, as well as from wells, for their respective industries. Before the introduction of a citywide water pipeline in 1873 around 10,000 wells existed in Vienna. An 1817 fire regu-

38 Vormärz is the term to describe the time period between the Congress of Vienna in 1814/15 and the Revolution in 1848. This time period is marked by an absolutistic regime in political terms and changes in the economic system from a system of manufacturing to early industrialization.

39 Gründerzeit is the term to describe the time period after the Revolution until the stock-market crash in 1873. This period is marked by classical liberalism and high fluctuations in economic activities.

40 Chaloupek et al. 1991, 358-367.

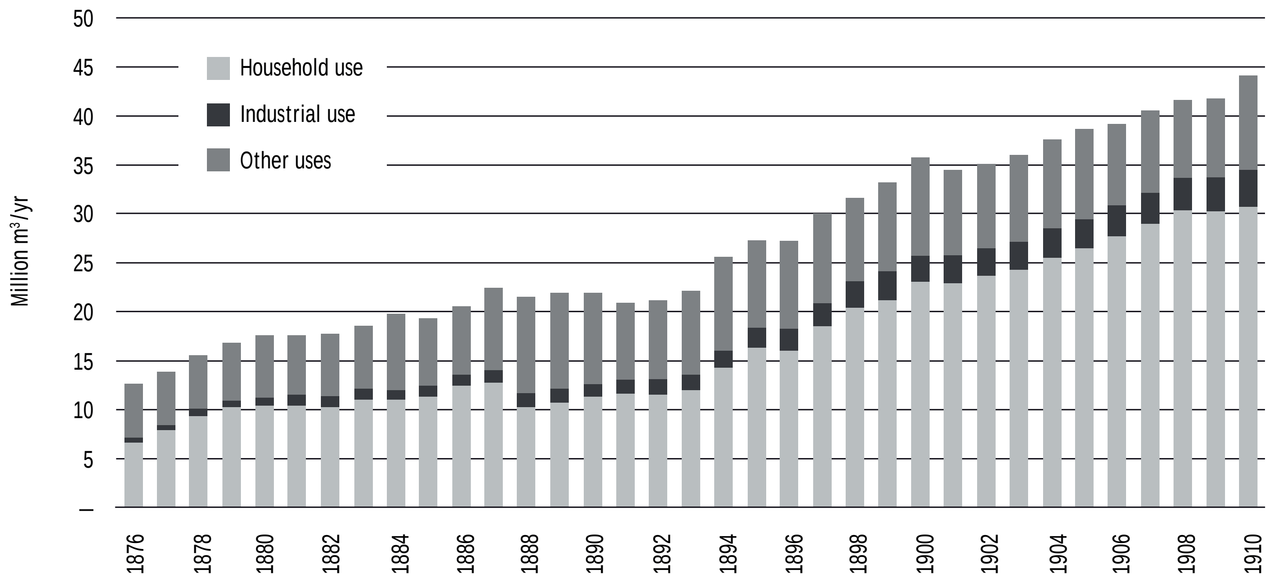
41 Hauer, 2010.

42 Pollack, 2013.

43 http://www.wien.gv.at/recht/landesrecht-wien/landesgesetzblatt/jahrgang/1995/pdf/lg1995035.pdf (accessed on October 28, 2014).

44 Barth Bartenheim, 1829.

Graphic 5. Water consumption in Vienna between 1876 and 1910



* Only water provided by the alpine water pipeline is recorded.
Source: Magistrat der Stadt Wien (MSW) 1876-1910.

lation law (valid until 1859) required every house in the city to be equipped with a well[45]. The urban Construction Department assumed that from the public wells and the *Kaiser-Ferdinands* water pipeline around 5,6 million m^3 of groundwater were extracted per year, corresponding to roughly 31 litres per person and day[46]. This number includes the use of water for sprinkling the many kitchen gardens. In the aftermath of the first cholera epidemics preventive measures were taken to improve the sanitary situation. The *Kaiser-Ferdinands* water pipeline which was built between 1836 and 1846, using filtrated groundwater near the *Donaukanal*, can be seen as a direct reaction to the first outbreak of the disease[47]. The pipeline only stretched across the western part of the city and its water yield was not always sufficient. The water quality soon began to decline as the filter system wore out[48]. City authorities tried to find a new solution to the problem. The city council established a water supply commission made up of local politicians, architects, engineers and geologists with the mission to find the optimal water supply system[49]. After years of debate the first alpine water pipeline (*Hochquellenleitung*), which brought water from two springs around 80 km located to the southwest of the city, was constructed and opened in 1873. Within 6 years more than 70 percent of private homes were connected to this water pipeline that soon stretched across the whole city. In 1890 when the suburbs were incorporated into the city the new parts of the city also became gradually connected to the alpine water pipeline. Water consumption rose from 12.6 million m^3 in total or 50 liter per person per day in 1876 to more than 43.8 million m^3 in total in 1910 or 60 liter per person per day (Graphic 5). Compared to other European cities, this appears to be a rather low level of water use. In Barcelona, for example, around 136 liters of waters per person per day were available in 1910[50]. The numbers for Vienna only include water delivered by the alpine water pipeline. There was a smaller water pipeline for industrial use only (*Wientalwasserleitung*) not accounted here and one can assume that groundwater extraction still took place. Another question is that of water quality and distribution. Even though Vienna consumed less water per person the resource was of a high quality and access was given for the vast majority of inhabitants. This was different from other cities such as Barcelona, where water was distributed unequally and quality and associated health issues were still a topic of some discussion[51].

Even after opening the *Hochquellenleitung* a constant water supply could not be secured as the amount of it coming from the springs fluctuated. Efforts to ensure a sufficient supply of drinking water resulted in the construction of the second alpine water pipeline that was opened in 1910. With this pipeline another 8 sources in the alpine hinterland were taped to supply Vienna with water. In order to ensure a steady supply of high quality water city authorities decided to directly control and protect the headwaters[52]. The city began to acquire forests, grasslands, alpine pastures and rocky regions around the sources; it reduced agricultural activities and placed areas under strict protection. With the pipelines in place the urban waterscape expanded geographically into catchment areas far away from Vienna and services provided by distant ecosystems became increasingly controlled and managed by the city of Vienna. Nowadays the spring protection area encompasses 320 km^2, administered and managed by the forestry department of the city of Vienna[53].

45 Idem.
46 Stadtbauamt, 1861.
47 Meissl, 2001, 161. Birkner, 2002, 104.
48 Koblizek and Süssenbek, 2003.
49 On the genesis of the first alpine water pipeline: Peretti, 2014.
50 Tello, Ostos, 2012.
51 Idem.
52 Johann, 2005.
53 See https://www.wien.gv.at/umwelt/wald/quellenschutzwaelder/

Wastewater

The discussion of the flows of key urban resources (energy, construction materials and water) has shown how an expanding urban population and industrialization multiplied urban resource use. The growing input (and use) of materials brought about a surge of outflows, as the quantity of wastes and emissions increased. In particular, the rising amounts of wastewater from households and industries posed a logistical challenge for the city and had a far-reaching impact on the waterscape. While sources on industrial wastewater are scarce and still remain to be evaluated, more information on wastewater from households and their discharge is available. Already in the year 1830 more than 80 percent of the houses were connected to sewers, open ditches or directly to receiving creeks and rivers[54]. Unlike in many other cities at that time it was a common practice to discharge human excreta into sewers that carried them into the creeks. We estimate that the Viennese produced around 420 tons of excreta (fresh weight solid and fluid) per day in 1830[55]. Most of it was disposed in one of the city's bodies of water, which became a major sink for valuable plant nutrients. Gierlinger et al. 2013 found that an amount of 900 tons of nitrogen, contained in human and animal excreta was disposed into the urban waterscape in 1830. With population growth, outflows from human excrements rose to 2600 tons per day in 1910, containing a nitrogen content totally more than 6500 tons/yr. Agricultural chemists and economists pleaded for the reuse of urban excreta as fertilizer. Cities like Paris or Berlin installed sewage farms by the end of the nineteenth century. Such proposals were not realized in Vienna; instead city authorities decided for the construction of a waterborne sewage system. After the opening of the alpine water pipeline the concerns of urban health authorities who doubted the potential usefulness of a system that constantly required certain amounts of water faded away. This is an example where an innovation on the input side of urban metabolism (water supply) made the favored disposal system possible. The construction began and by 1910 the wastewater of almost the entire urban population got discharged untreated into a single spot at *Donaukanal* shortly before reuniting with the main arm of the Danube. Unlike many other cities organic loading of the river was not an issue in Vienna at that time. The Viennese Danube is quite a large river (around 1900 m^3/sec mean discharge compared to for example 250 m^3/sec mean discharge of the Seine in Paris). It can cope with a much higher amount of organic material and it took until 1980 for a central water purification plant to be installed[56].

The Transformation of the Waterscape

In the previous section we have shown how urban growth in the nineteenth century was related to a metabolic transition which changed the composition of urban resource flows and dramatically increased the size of urban material, water and energy consumption and the production of urban outflows. From that discussion it becomes clear that urban supply and discharge conditions of nineteenth-century Vienna were deeply intertwined with the urban waterscape in many different ways, from transport to the construction of water-related infrastructure. The transformation from agrarian to industrial societal metabolism deeply affected the waterscape of the city and its surrounding area. The metabolic transition provided the energetic and material basis for the (infrastructural) projects driving this transformation. In this section, we discuss the three most important infrastructural projects affecting the waterscape in Vienna and the public discourse behind them: the establishment of an effective discharge system for urban waste water; the closely related construction of the alpine water supply pipeline; and the great Danube regulation.

Sanitation was a prime motive of urban stakeholders for the transformation of a great part of the urban waterscape. The use of creeks and rivers for discharging domestic and industrial waste turned them into openly flowing sewers causing sanitary nuisances. As shown in the section on wastewater, pressure on bodies of water increased with a rapidly growing population and industrial development since the beginning of the nineteenth century. Innovations in production processes led to the release of new and often toxic substances such as heavy metals or polycyclic aromatic hydrocarbons (PAH). Another problem was the proximity between wells and sewers or cesspools because they could leach and thus, pollute drinking water. Such circumstances provided ideal conditions for the growth and proliferation of such pathogens as *vibrio cholerae*, the bacteria causing cholera. At that time, the common understanding was that airborne pathogens ("miasmas") originate from putrefactive processes in the soil, spread in the air and cause infections. Accordingly, the idea was to get away from bad smell. In reaction, intercepting sewers were erected between 1831 and 1839 on both sides along the Wien River (the major urban tributary to the *Donaukanal* – see map 3). Subsequently, many of the smaller creeks and ditches like *Ottakringerbach*, *Alserbach* and *Währingerbach*, were transformed into covered (vaulted) canals and integrated into the sewer system. But the measures taken to solve hygienic problems were soon outgrown by the steadily rising amounts of wastes from the growing population, industrial development and the further expansion of the city.

In the second half of the nineteenth century urban hygienists and physicians together with city planners, engineers and communal authorities discussed different options for a new disposal system, spanning from the collection of excreta in bins to be used as fertilizer to improving existing infrastructures to a city-wide centralized sewage system. The *Stadtphysikat* (public health authorities) favored the latter solution for hygienic reasons. Excreta should be removed as fast and as decomposed as possible to avoid infiltration of soil and air[57]. However, this system needed large amounts of freshwater as a prerequisite, which was only available with the construction of the first alpine water pipeline in 1873 (see section *water*). Soon cases of infections with diseases like typhoid fever went down[58].

54 Pollack, 2013.

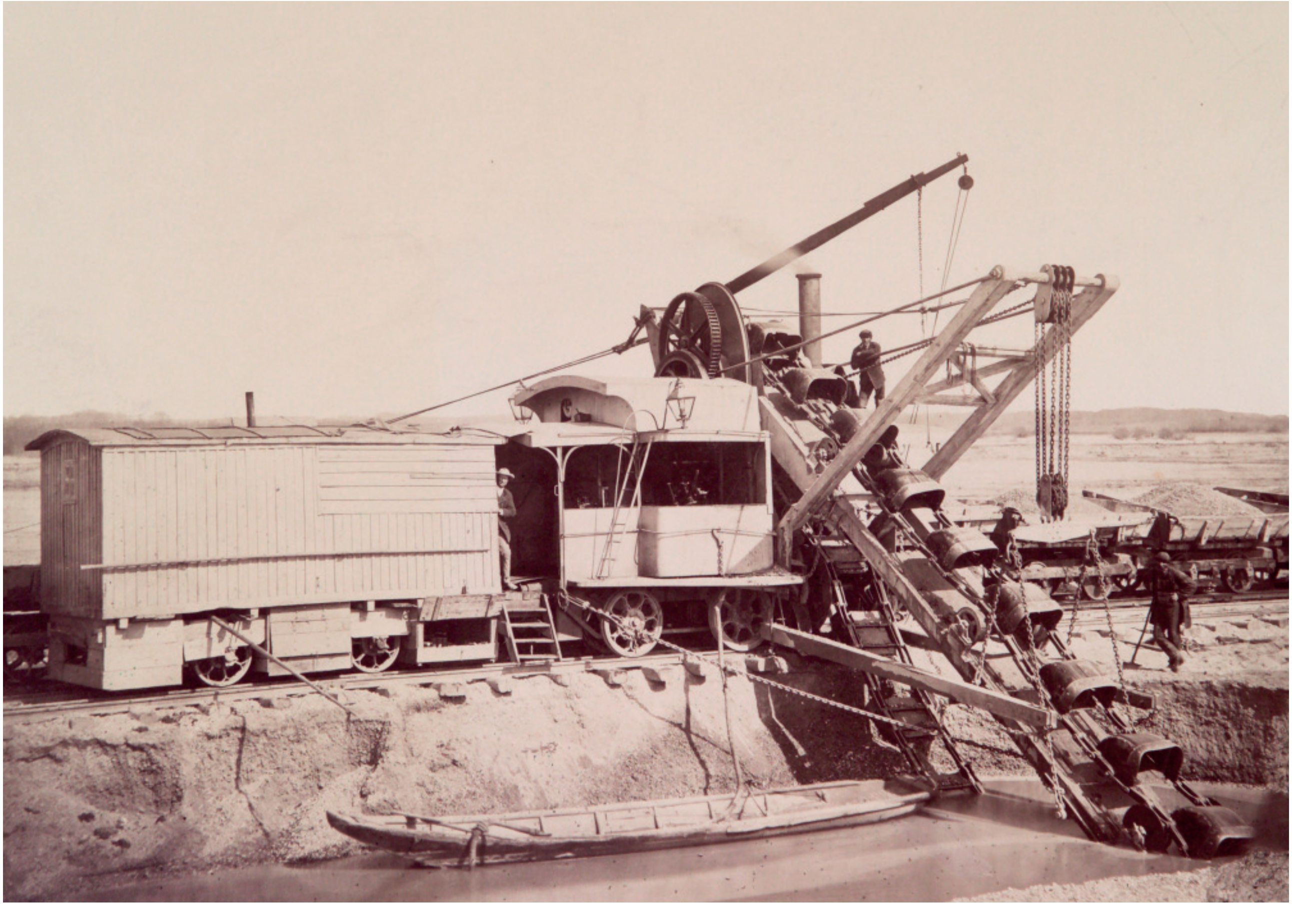
55 Gierlinger, Gingrich, Haidvogl and Krausmann, 2013.

56 Idem.

57 Wiener Stadtphysikat (WSTP), 1872.

58 Weigl, 2000, 187.

Image 1. One of the six land based moveable excavators used for work at the Great Danube Regulation in the year 1873



Source: Technisches Museum Wien, Signature: BPA-000437-07, Photographer: Herman Voigtländer 1873.

After the construction of the *Hochquellenleitung*, the implementation of a citywide, waterborne sewage system followed. The old system was enhanced (e.g. bricks replaced by concrete) and extended to the former suburbs which had been incorporated into the city in 1890. The vaulting of small watercourses, which was already complete in densely populated areas, was continued further upstream. All main sewers still discharged directly into the *Donaukanal* and heavily polluted this river. Therefore, intercepting sewers were built along *Donaukanal*. The new solution functioned as combined system that discharged processed water from industry, manufacture and household as well as precipitation runoff. In analogy to the water supply system, the aim was to connect all buildings in the city to the sewage system.

While the smaller creeks were integrated into the sewer system and gradually disappeared from the cityscape, the river Danube was brought under control only in the 1870s in one large effort. The availability of new forms of energy and the technology to convert this energy into useful work were the metabolic precondition of what became the greatest transformation of the Viennese stretch of the Danube: the Great Danube Regulation between 1870 and 1875. Prior to the implementation of the comprehensive regulation project the river had several arms meandering through a vast floodplain area (Map 3). The highly dynamic riverine landscape changed its formation with every flood and especially during ice jams[59]. Flooding was a severe threat to the urban population. Fluctuating water levels and changing water courses were also problematic for shipping and thus obstructed the regular supply of raw materials and energy for the industrialising city[60]. Attempts to gain better control over the river can be traced back for centuries[61]. From the beginning of the nineteenth century comprehensive river regulation projects were discussed[62]. These aimed to overcome shipping obstacles, protect the city from flooding and to build a stable bridge across the Danube. Until then bridges were often destroyed after big floods or ice jams. In the 1850s a further goal was formulated in the debates about the Danube regulation: gaining urban land suitable for permanent residential houses, as well as commerce and trade for the industrialising city. Settlement area was an urgently needed resource in the growing city[63]. A first Danube regulation commission was created in 1850. Finally in 1869/1870 the Emperor Franz Joseph I approved the programme of the second Danube Regulation Commission and construction work began. From

59 Hohensinner, Lager, Sonnlechner, Haidvogl, Gierlinger, Schmid, Krausmann and Winiwarter, 2013.

60 Gierlinger, Gingrich, Haidvogl and Krausmann, 2013.

61 Hohensinner, Lager, Sonnlechner, Haidvogl, Gierlinger, Schmid, Krausmann and Winiwarter, 2013.

62 Thiel, 1904. DRK, 1868.

63 Haidvogl, Guthyne-Horvath, Gierlinger, Hohensinner and Sonnlechner, 2013.

1870 until 1875 a French company accomplished the Great Danube Regulation with thousands of low-paid workers mostly coming from the eastern provinces of the Habsburg Empire[64]. Huge amounts of material had to be moved. The construction company used 400 lorries made of iron as well as 11 locomotives and two freighters which were formerly used by the same company for construction work at the Suez Canal. Furthermore eight floating dredges, six moveable and two stable excavators built in Vienna, were also employed (Image 1).

Most of the side arms of the Danube were cut off and a straight river bed was dredged. These efforts stabilized the course of the massive river and had a far reaching impact on the whole waterscape from the floodplains to the groundwater. This endeavour was based on the concentrated input of human labour and machine power which was made possible in this way with the adoption of new forms of energy and technology. Transport facilities such as harbours, landing places, or warehouses were moved from *Donaukanal* to the main arm of the Danube[65]. Ironically, after the Great Regulation the river rapidly lost importance for transporting resources from distant the hinterlands to Vienna. Except for grain, the carriage of goods almost completely handled by railways[66].

Before the comprehensive channelization of the Viennese Danube the floodplain area was inundated on a yearly basis. Settlements were restricted to some locations close to the city center. With the channelization and the prevention of flooding via dykes new land was generated for urban expansion. In the following decades most of the new buildings subsequently built were erected in *Brigittenau* and *Leopoldstadt*, two districts in this area[67].

Conclusions

The interlinkages between the metabolic transition and the transformation of the urban waterscape in the nineteenth century are multifaceted. In pre-industrial cities, rivers and the waterscape fulfilled crucial functions for maintaining urban metabolism: transport, energy provision, fresh water supply, discharge and cleaning of wastewater. In the course of industrialization, the interrelations between metabolism and waterscape changed. The services previously provided by rivers and creeks were increasingly conducted by new, fossil fuel based technologies and separated from the bodies of water. We distinguish four different processes, which are important for the changing relationship between urban metabolism and urban waterscape that may be observed in nineteenth-century Vienna:

1) Functions which were formerly carried out by a river as such were separated from the actual body of water and dislocated by means of material arrangements. An example is the abstraction of some of the Wien River water to the main sewers alongside the river, which took over the discharge function.
2) Fossil fuel based technologies (coal, steel and steam engine) substituted the supply function of the Danube. They were the basis for new transport systems, which made the key function that waterways played for urban supply with resources for centuries obsolete within only a few decades. Similarly, due to the rise of steam engines urban rivers lost their significance for providing mechanical energy (e.g. in mills) – although they gained significance again in providing electricity at the turn of the twentieth century.
3) Only the new fossil fuel-based technologies enabled large infrastructural projects such as the Danube regulation or the construction of a citywide network of water supply and wastewater disposal. On the one hand, this set large material flows in motion, which were required to build and maintain these structures. On the other hand, the new structures meant a shift in environmental pressures from water quality to ecosystem control. Human control of watercourses drastically increased (from vaulted creeks to the regulated Danube) while in parallel pollution of urban waterways from industrial and household wastewater was drastically reduced. The pressures of pollution were at first shifted further downstream through the installation of a citywide waterborne sewer system. The establishment of centralized purification plants in the second half of the twentieth century further reduced altogether.
4) Instead of tapping local fresh and groundwater, the new infrastructures shifted water supply to the distant alpine hinterland. This increased the amount of water available, improved the quality of the drinking water and was the basis for the waterborne sewage system. This expanded the direct water footprint of the city to areas about 80 km away and required the city to manage ecosystems and maintain their services in distant regions.

The metabolic transition brings a new quality and quantity of human influence on and control over the waterscape and an expansion of the spatial imprint of urban influence on the waterscape. This shifts pressures away from water quality towards interventions in hydro-morphology of the waterscape. Overall, the waterscape appears to be highly dynamic and changes with urban development. The legacies of the transformation in the nineteenth century are considerable. Not only are they still visible in the modern city, they also still have significant influence on the functioning and the metabolism of the city.

Most of the creeks vanished from the image of the city. Though they are not visible anymore, the creeks are still there. The flow of water (through the sewers) now has to be managed by society at large. The physical disposal infrastructure has to be maintained as well as the water supply system and installations

64 Idem.

65 Idem.

66 Gingrich, Haidvogl and Krausmann, 2012. Gierlinger, Gingrich, Haidvogl and Krausmann, 2013.

67 A more detailed analysis is provided by Haidvogl, Guthyne-Horvath, Gierlinger, Hohensinner and Sonnlechner, 2013.

for flood protection. A constant effort in terms of material, energy, labour and money has to be invested into managing city water flows and maintaining the respective material arrangements. With the transformation from an agrarian to an industrial sociometabolic regime the dynamic/complexity of the waterscape has come more and more under the control of society. But the dynamic of the natural world cannot be fully controlled as the case of the flooding of *Ottakringer* creek summer 2010 illustrates.

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