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Historical Structures and Technical Heritage on the Elbe-Vltava Waterway

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Abstract. The paper describes the past development of the Elbe-Vltava waterway (EVW) and focuses on the documentation and presentation of the historical structures which were built for the rivers' continuous navigability. Modern modifications of the waterway started at the beginning of the 19th century and focused mainly on regulatory work aimed at widening, straightening and deepening the fairway and removing the narrow fairway sections. In 1896, the Commission for Channelling the Vltava and the Elbe Rivers in Bohemia was established. The commission began implementing a plan to canalise the Elbe-Vltava waterway. On the EVW, a cascade of 34 barrages have been built, which are connected by their backwaters and ensure year-round navigability of the Vltava River from the Slapy Dam to the town of Mělník (92 km) and the Elbe River from the town of Chvaletice to the city of Ústí nad Labem (172 km). The last section of the Elbe River between Ústí nad Labem and the border with the Federal Republic of Germany (41 km) has so far been made navigable only by historical regulation works. Barrages on the EVW are typically composed of a weir structure, a navigation lock, a hydroelectric power plant producing renewable energy and a fish pass or sport whitewater canal. Most of these structures were built in the first half of the 20th century and represent a huge and unique technical heritage that still serves its purpose. The development of the EVW objects was documented in detail. The result is a software designed as a computer application with a web interface, which also serves for the presentation of technical heritage using original and modern technologies. Database operations enable the sharing of more information resources by competent organizations in the area of management, operation and maintenance of objects on the EVW. The system contains detailed descriptions of individual objects including their main technical parameters. For all the barrages were also systematically documented archival historical documents, maps, drawing documentation, photo gallery and for the most important barrages a description of the architectural design. The research also focused on mapping the development of regulatory adjustments of the Elbe River based on preserved historical documentation from the 19th and 20th centuries and the first aerial photographs since 1938. The presentation for the general public is complemented by an index of prominent personalities who contributed to the development of the EVW. There is also an explanatory dictionary of technical elements and objects on the EVW, including functional diagrams. Tourist attractions around the waterway are also included in the software.

1. Introduction

Nearly all waters in the Czech lands flow into the Elbe River and one of its left tributaries – the Vltava River. The two rivers flow through a cultural landscape which has been settled rather densely since the



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Middle Ages, and the rivers have been subject to numerous technical modifications. Such modifications of the Elbe and Vltava rivers were motivated by human efforts to use the water sources for satisfying their needs, to attain good navigation conditions for the transport of goods and people and to protect their property from floods. The early adjustments the watercourses served many diverse purposes, such as the use of the water power for driving flour mills, sawmills and iron mills: for this, fixed weirs were built, starting as early as the 13th century. Making the rivers navigable was the next goal: efforts to this end started during the time of the reign of Charles IV in the 14th century.

A systematic approach to river training works, with emphasis on the multi-purpose uses of the rivers, has been seen only since 1896 when the Commission for Channelling the Vltava and the Elbe Rivers in Bohemia was established [1]. A waterway modification programme was then set up within the Waterway Act of 1901. The lower Vltava as far as the town of Mělník was made navigable through the construction of a cascade of barrages during the years 1899–1905. Canalization projects made the Vltava navigable in Prague during the 1907–1913 period. The Elbe segment between the towns of Mělník and Lovosice was made navigable through canalization work during 1907–1919 and the Střekov barrage was completed in 1936. The barrages of the cascade on the middle Elbe were made operable one by one in the order of importance for the protection of the flood areas. The majority of the structures had been completed by the mid-20th century. The adjustments of the navigable waterways and the barrages on them have been serving many important purposes, such as maintaining the rivers adequately deep for navigation, protection of the flood areas from floods, generation of pure electric power by hydroelectric power plants built at the weirs, surface water withdrawal to satisfy the needs of the population, industry and agriculture, and recreational uses. The construction of the Elbe-Vltava waterway (EVW) was certainly an important step in the development of industry and trade in Bohemia (the western part of today's Czech Republic) in the 19th and 20th centuries, like in other European countries. In England, for instance, the construction of waterways contributed appreciably to the success of the initial phase of the Industrial Revolution in the late 17th and early 18th centuries, according to Newman [2].

The present contribution describes the development of the EVW with focus on documentation and presentation of the historical objects built to make the waterways fully navigable. This research was made within the project “Documentation and Presentation of Technical Cultural Heritage on the Elbe-Vltava Waterway”, which is part of the National and Cultural Identity Programme administered by the Czech Ministry of Culture. The research of the documentation of the technological heritage on the EVW is based on extensive archival sources and depositories of several museums and archives. A considerable number of historical documents, maps and drawings has been digitised within the research project. The materials obtained have been systematically sorted and now are presented to the wide public as a web application. Digitisation of cultural artefacts is gaining in importance now that various options to process the data based on artificial intelligence are increasingly available [3]. Local population's awareness of the potential of the cultural heritage near the navigable rivers is generally low, as documented by the examples of the Loire River [4]. However, technological heritage on waterways constitutes a territorial capital which can be expressed financially and can be directly used to the benefit of the affected regions [5].

2. Regulation improvements on the EVW

The first regulation changes on the Vltava and lower Elbe were made starting the early 19th century. The banks were reinforced with quarry stone laid on a gravel-sand bed. Paving stones were used, tightened with wedges, and turfs were laid between them. The paved slope was secured with a top body made of quarry stone, with a crest at the level of the today's water surface corresponding to a flow rate which has the probability of its being exceeded for 180 days in a year. A path for horses towing boats upstream was frequently built along with the embankment (Figure 1). Now the paths are used as service paths by employees of the watercourse management bodies and as cycleways. The paths were built at the water level corresponding at one-year peak flow discharge.

Additional regulation work was done during the next stage, 1880–1920. Longitudinal training dams interconnected by dykes (transverse dams) with the initial bank reinforcement were built at wide riverbed sites. The training dams, like the bank reinforcement, are paved using quarry stone and secured with a toe of quarry-stone riprap. The area between the training dams and the embankment was used to dump material excavated from the river bed during the sediment removal. Floods covered this area with sediments at some places. The Svádov site in Ústí nad Labem is an example (Figure 2).



Figure 1. Tow-path on the Vltava.

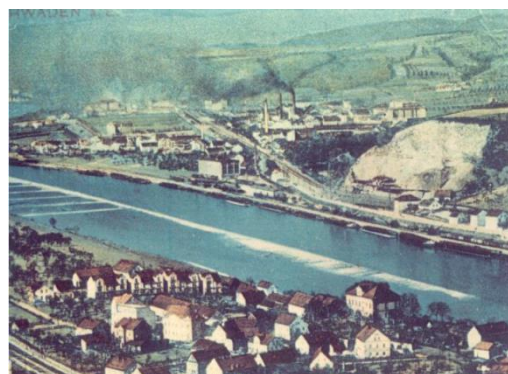


Figure 2. Training dams on the Labe at Svádov.

The waterway regulation work on the lower Elbe between the Střekov barrage and the Czech-German state border could be documented in great detail within the research project based on the study of archival materials, design documents and historical aerial photographs taken during the years 1938 to 1964. The training dams within this 40 km river segment have been serving their purpose and partly improve the navigation conditions. The development of the longitudinal training dams and groynes, from the design phase to the present can be illustratively seen in Figure 3 for the Nebočady village area.

Longitudinal training dams after Collas [6] make up good shelters for fish. The Elbe river adjustments in the 19th century were associated with fairway narrowing by up to 60% at certain profiles – from the initial 200 m to the present 80–100 m. This resulted in navigation depth increase by dozens of centimetres at low and medium flow rates. The flow velocity also increased by approximately 30%, whereby the nature of the river bed material changed to gravel or stone in this river section. The effect of changes in the velocity conditions on navigation safety on fairways was studied by Možiesík et al. [7]. Morphological changes in the waterway bed caused by the training dams were studied by Yossef and Rupprecht [8]. Currently, navigation through the regulated section of the Elbe river below Ústí nad Labem must be stopped from time to time because of inadequate navigation depths. The issue of minimum flow rates in the Czech Republic has been analysed by Balvín et al. [9].

3. Canalization works on the EVW

As mentioned above, the Commission for Channelling the Vltava and the Elbe Rivers in Bohemia was set up in 1896. The activities of the Commission were supported by the issue of the Waterway Act in 1901, providing a legal framework for waterway adjustments to make them navigable. The Commission started implementing the EVW canalization plan by building a cascade of 34 weirs, interrelated by their backwaters and ensuring all-year navigability. The works were commenced on the lower Vltava, and the following barrages were built downstream of Prague rather fast: Klecany (1899), Libčice (1900), Trója (1902), Měřejovice (1905) and Vraňany–Hořín (1905), see Figure 4. This largely included the realisations of barrages usually involved the construction of a weir structure and a navigation device in the form of one or two locks.

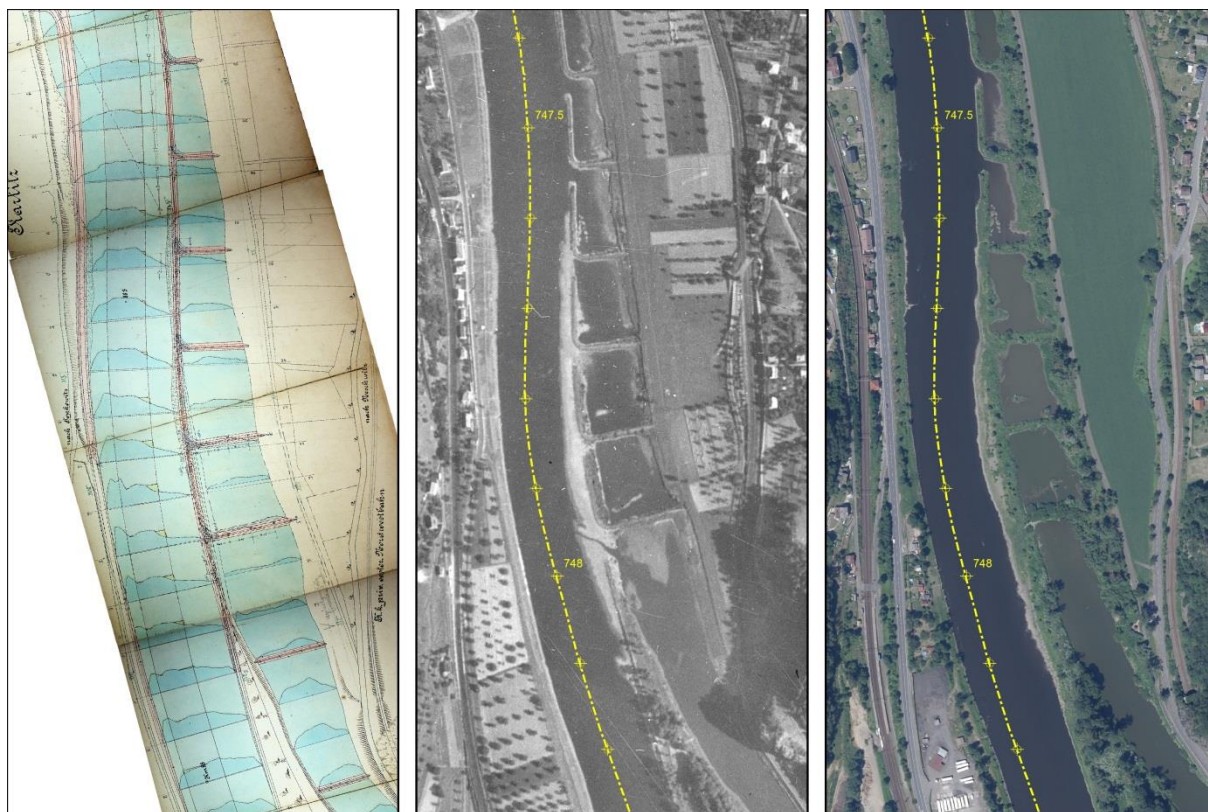


Figure 3. Development of training dams in the Nebočady village area: a) design document 1906, b) aerial photograph 1938, c) aerial photograph 2018.

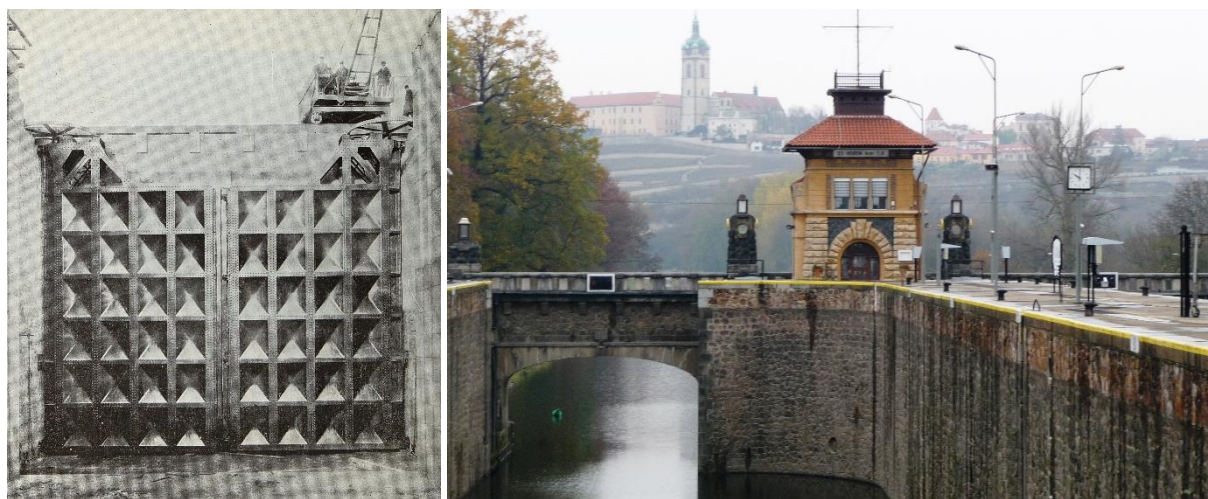


Figure 4. Hořín lock – lower mitre gate during the construction work 1901 (left) [10], view of the lock with the Mělník castle in the background (right) (source: Povodí Vltavy, state ent.).

The weirs were largely needle weirs, which enabled the water level in the weir pool to be controlled by a technique that was quite modern then. Needle weirs (Figure 5) consist of dismountable segmented gates of the weir sluices with manual control. They consist of 3 basic elements: needles making up a segmented slab wall, horizontal beams and needle supports. The needles are wood or steel beams which are placed next to one another, slightly inclined in the water flow direction. The needles lean by their lower ends on a sill in the substructure and by their upper ends on a transverse horizontal beam.

This beam (rod) is typically a short steel tube which is connected to the needle supports. The needle supports are planar steel trussed structures that transmit the load from the horizontal beams to the substructure, to which they are connected through articulated joints. The installation and adjustment of the needles were very time-consuming because of their high number, and also tedious and dangerous if the weather was bad. Therefore, the original needle weirs were replaced one by one with modern automated-control flap gates and radial gates along the entire EVW during the 1970s.

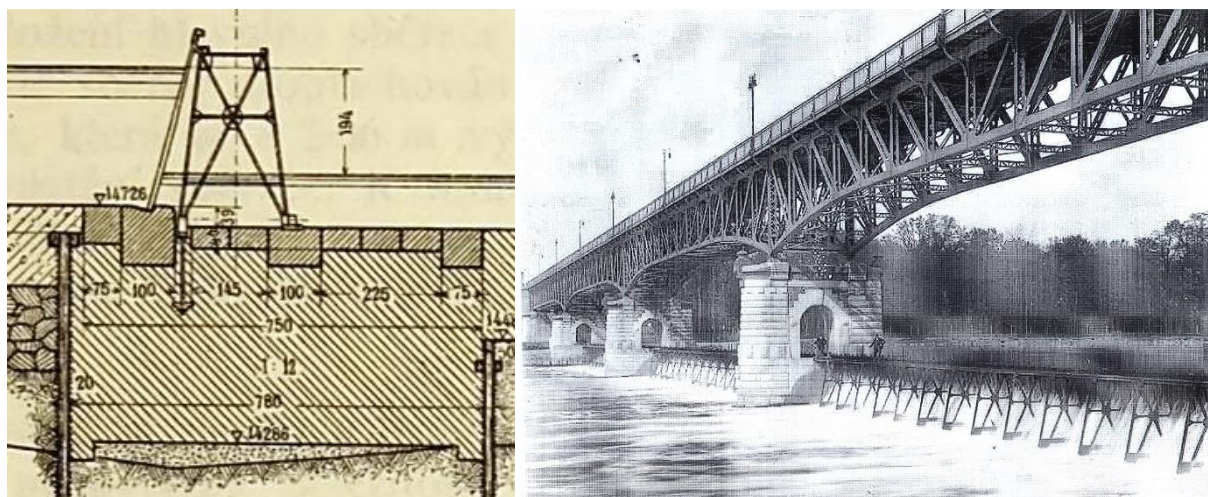


Figure 5. Roudnice nad Labem needle weir - layout (left) and photo, 1914 (right) [11].

Canalization in Prague followed during the 1907 to 1913 period. A new Helmovský weir and two navigation locks at the Štvanice island were built first. The structures that followed included the Smíchov lock and the Mánes lock to overcome the Staroměstský and Šitkovský weirs. On the Elbe, barrages were subsequently built in Štětí (1906), Dolní Bečkovice (1907), Roudnice nad Labem (1910), České Kopisty (1913) and Lovosice (1919). The Střekov barrage in Ústí nad Labem was built in 1936. The construction of the barrages on the EVW is documented in detail in Figure 6.

The development of the works on the middle Elbe has been described by Trejtnar [12]. The works between Hradec Králové and Mělník were divided into 5 stages and the majority of the work had been done before the end of World War II. Stage No. I encompassed 60 km of work, either completed or underway. As for barrages, weirs with navigation locks were built in Mělník and Obříství. The Hadík weir in Mělník was removed in 1974 and the weir in Obříství was modernized. Construction of weirs was commenced in Nymburk, Poděbrady, Kolín and Předměřice. The construction of the single structures within stage No. I was begun after finishing the design activities in about 1906 after the governmental financial contribution had been approved. The construction works were limited considerably and almost stopped during World War I.

During the second stage of modifications on the middle Elbe in 1919 to 1930, a tendency existed to combine the initially planned weir pools into a smaller number with larger backwater heights. This idea of association of weir pools was mainly objected to by farmers, who were concerned about the adverse impacts of the high weirs on the groundwater levels and flooding of large areas of agricultural land along the Elbe. The idea of association of weir pools was rejected only in 1928. The construction work had been deliberately limited until then to prevent any appreciable conceptual changes in the complete barrages. Focus of stage No. II was on the building of hydroelectric power plants within the barrages under design. Stage No. II included, in particular, completion of the barrages at Poděbrady (1923), Nymburk (1924) and Kolín (1925). Also, a barrage was built at Přelouč (1927). Attention was mainly paid to new changes on the Elbe within the segment between the towns of Mělník and Kolín,

where a 65 km segment of the fairway was improved. Hydroelectric power plants were made operable at Poděbrady, Nymburk and Přelouč, and the power plant at Kolín was nearly completed. The construction work on the Elbe was intensified appreciably during stage No. III, starting in 1931. Most of the work was done during the 1931 to 1938 period, when the barrages were completed at Lobkovice (1932), Kostelec nad Labem (1932), Lysá nad Labem (1935), Brandýs nad Labem (1936), and also at Čelákovice (1937), Kostomlátky (1937) and Srnojedy (1937). The barrage at Klavary was made operable in 1939. Also, river training works were started and nearly completed along a 35 km length. Only the most urgent work needed for starting navigation between Mělník and Kolín was done after 1943.

Stage No. IV of middle Elbe river modifications encompassed the years 1945 to 1963. This was a stage of a certain attenuation due to economy restoration after World War II. Work on the Elbe river bed was resumed in 1946 at Čelákovice and in the Drahelice–Nymburk, Osek–Klavary and Smiřice–Černožice sections. The barrages at Velký Osek (1952) and at Hradištko (1954) were completed.

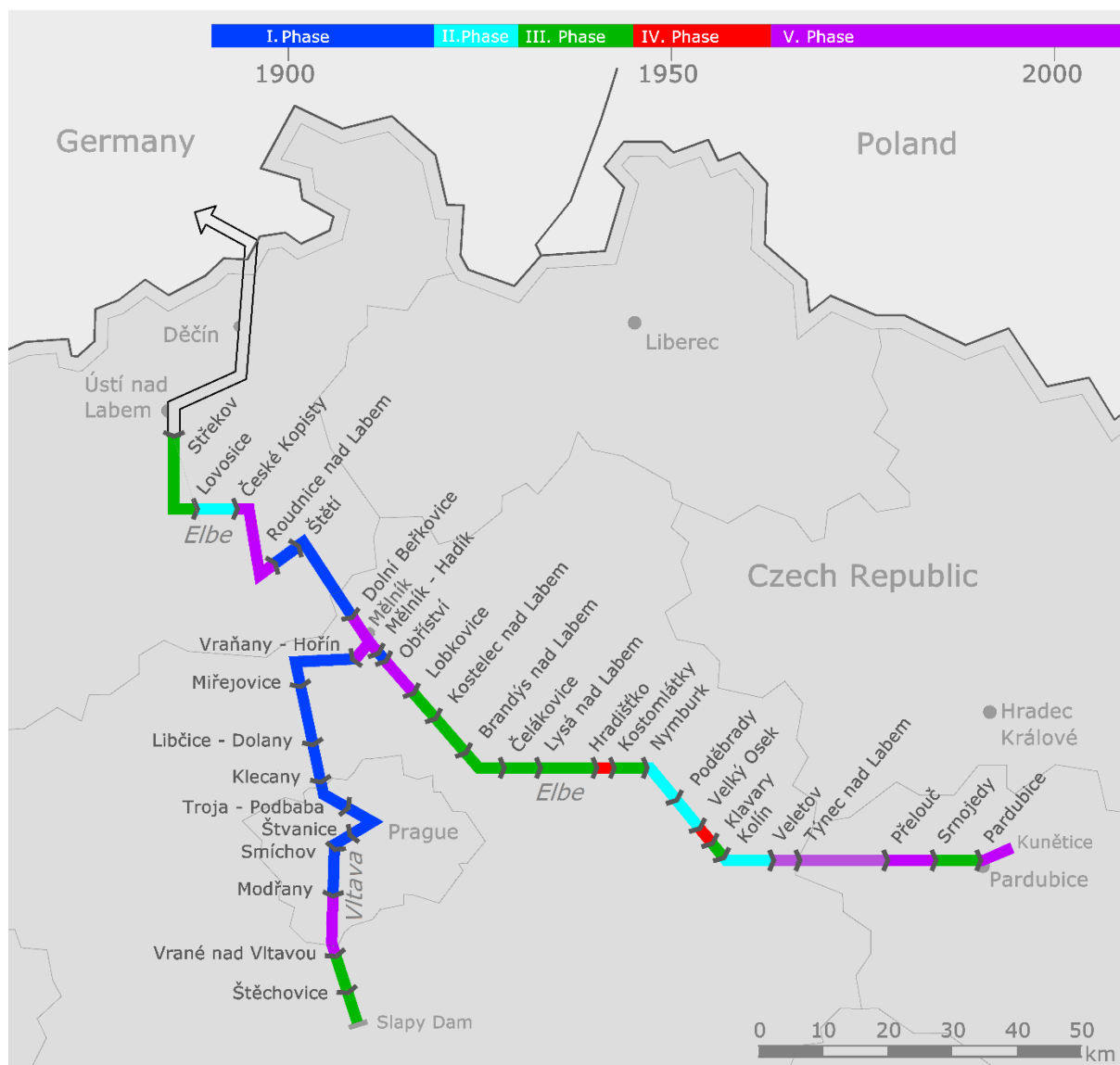


Figure 6. Time/space scheme of canalization works on the EVW.

The last stage of middle Elbe river bed modifications, stage No. V, was started in 1963. A new barrage was built at Obříství (1974) to replace the old Hadík barrage at Mělník and the obsolete barrage at Obříství. Newly built structures included a barrage at Pardubice (1972), a navigation lock at the weir at Veletov (1975) and a barrage at Týnec nad Labem (1977). At the same time, Elbe river adjustments were made within the Veletov–Přelouč and Brozany–Opatovice sections. Planned changes were completed in the weir backwater areas at Čelákovice, Hradištko, Veletov and Týnec nad Labem. This stage No. V was affected appreciably by the construction of the coal-fired power plant at Chvaletice, for which coal was transported on the Elbe. Modřany barrage in Prague was built on the Vltava River (1987).

Many of the historical monuments on the EVW are important parts of cultural heritage. A hydroelectric power plant Art Nouveau style stands out on the Vltava in Prague at the Štvanice barrage, built during 1913–1914 based on the design by the architect Alois Dlabáč in the style of French castle architecture. Another cultural monument can be viewed upstream of the Vltava-Elbe confluence, viz. the Vraňany–Hořín navigation canal, which was technically unique already when opened. An architecturally interesting and unique construction on the middle Elbe is the Masaryk bridge in Kolín, designed by the architect František Roith. The area between the bridge pillars accommodates a weir, a hydroelectric power plant and a navigation lock. The hydroelectric power plant and weir at Poděbrady, designed in the spirit of modern classicism by the architect Antonín Engel, are national cultural monuments. The most important historical monument on the lower Elbe river is undoubtedly the architecturally as well as technologically interesting barrage at Střekov, which is so far the last navigation step on the Bohemian segment of the Elbe. The barrage at Střekov was designed by the architect František Vahala and is one of the largest barrages on the EVW. When built up, it was among the most modern constructions of this type in Europe. This fact of technological heritage and patriotic feeling is expressed by two huge blocks with a sculpted Czech lion.

4. Current purposes of the EVW

All modifications of the Elbe and Vltava fairways were always aimed at ensuring good conditions for navigation and protection of the adjacent land areas against floods. Additional purposes emerged during the 20th century: water energy use and surface water withdrawal for the industries and agriculture. The recreational potential of the navigable segments also plays a role. Since the start of the settlement of land along the Elbe, life was concentrated on the development of the important royal towns near the river. Floods started to trouble the Czech basin during the second half of the 19th century. The banks lay too low and the water gradient was too small, and so floods occurred every year and lasted long because water remained in numerous pools and abandoned backwaters in the neighbouring landscape. This brought about the danger of infection in the towns and villages and precluded the use of agricultural areas. So, regulation of the Elbe to prevent the annual floods was a matter of great importance to the population in the Elbe valley. The completed river bed modifications really contributed to the protection of the adjacent land against floods. At the same time, the outflow was slowed down within the canalized section of the lower and middle Elbe and in the Vltava from Prague to Mělník owing to the construction of the system of weirs. The favourable health aspect of the minimum flow rates during hydrologically dry seasons plays also an important role.

Waterway freight transport contributes relatively little (less than 1 per cent) to overall freight transport in the Czech Republic although its potential is much higher. The major reason for this is the inadequate reliability of the navigation conditions on the regulated section of the Elbe downstream of Ústí nad Labem, which is as low as 54%. Freight water transport plays a role primarily in international trade because it is well suited particularly for large-distance transport. EVW serves the supply of goods to important regions of the Czech Republic as well as to other European countries. It is specifically important in areas where processing/production industries are located, and also in agriculture.

As mentioned above, the generation of electricity is also an important purpose of the barrages on the EVW. Hydroelectric power plants, generating renewable energy, have been built at nearly all of the barrages. The total capacity of the hydroelectric power plants on the Vltava between the Slapy Dam and Mělník is 115.1 MW; the total installed capacity on the middle Elbe between Pardubice and Mělník is 30.2 MW and on the lower Elbe between Mělník and Ústí nad Labem, 43.6 MW.

Water supply is also an important purpose of the water management infrastructure on the EVW. It follows from an analysis of the major facilities withdrawing water from the rivers that the largest consumer is the power sector, with a 65.7% share, followed by the industry, with a 17.1% share. The share of withdrawal for supplying public water mains is about 14.3%. The shares of agriculture and the food industry in total river water withdrawal are mere 1.7% and about 1.2%, respectively.

Recreation and tourism near the EVW have been increasing dynamically during the past years, thereby appreciably improving the economic status of the towns and villages nearby. This trend is associated with the need to provide appropriate facilities and a wide range of leisure activities for the holiday-makers. The EVW offers activities including cruises, cultural events, tourism and beauties of nature in the surroundings.

5. Web application

The results of research of the historical development of civil engineering structures on the EVW were made available to the public on <https://www.lvvc.cz> as a web application. Its English version is under construction. This is an original application which is available online via a web interface: it is easily accessible, is independent of the computer platform and can be readily updated. The application has three user levels. The basic public level is a graphic presentation of available information about the constructions of all the 34 barrages on the EVW. The option of multi-criteria search in a related database is also available. Level 2 is intended for the professional community mainly of organisations involved in the management and administration of the EVW and institutions for the protection of historical monuments. This level makes available the complete contents of the database including the viewing and inspection of historical documents, extended multi-criteria search and data on the bridges and ports. Level 3 is the system administrator level. From the functional aspect, the application is divided into 2 main parts: the server part (back end) and the client part (front end), see Figure 7. The server part, set up in the PHP scripting language, is responsible for the performance of the entire application, communicates with the clients, makes available the database and performs all operations over it in SQL and, also, provides the connection to external databases. The client part is designed as a conventional HTML website, functionally extended with scripts in JavaScript providing data exchange with the server and imaging the geographic data.

Among the important parts of the application is a database, created on the MS Access platform and interfaced to the application through the SQL language enabling multi-user sharing. This is a relational database, enabling also the time/space aspects of the development of the entire Elbe-Vltava waterway to be stored.

A glossary of basic technical terms used in the explanation of the objects on the EVW is a component of the application which is of user importance. This glossary of terms is arranged in the alphabetical order. Efforts were made to formulate the explanations of the technical terms to be easily understood by the general public. Currently, the glossary contains over 150 terms with detailed explanatory notes plus performance layouts and photographs of the objects occurring on the EVW.

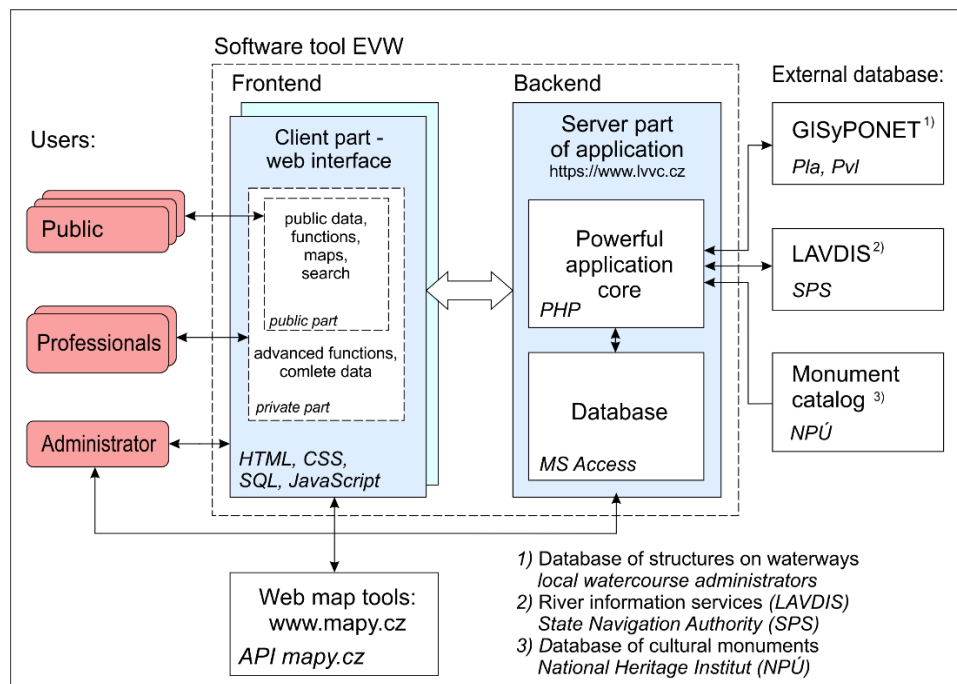


Figure 7. Functional layout of the EVW web application.

The preparatory work, as well as the construction activities, were contributed to by several foremost architects, builders and designers in diverse technical branches. The web application includes an index of the prominent personalities as well as their short biographies and lists of works. Among them are, for example, the industrialist and boat and shipbuilder Vojtěch Lanna, the inventor František Křížík, the architects František Sander and Kamil Roškot and professor Jaroslav Čábelka. The presentation of historical monuments on the EVW also contains references to various objects of tourist interest, such as castles, châteaux, churches, monasteries, birthplaces of important personalities of the Czech history as well as other tourist points of interest and tourist paths.

The software also incorporates a database of historical and current documents, plans, maps, drawings and layouts of the dams, barrages, weirs and other civil engineering structures on the EVW. The historical documents provide evidence of the then existing visions and intents for economic and social progress by using contemporary technologies. The historical maps illustrate the wider context of the waterworks and the towns and villages associated with them. Historical drawings illustrate the design precision of the visionaries of that time, which led to a successful construction and many years of operation of the waterworks and waterways. The EVW has been fully functional for long decades now and, also, is more efficient and safer, as documented by current technical documents. Navigation maps making it possible for the boat masters to orientate themselves safely on the fairway constitute an integral component of the database system. The system includes graphic sections and situations of the waterworks intended both for the general public and the professional community. Considering the goal of the project – make the wide public familiar with technological cultural heritage, professional maps, specialised maps and maps specifically targeted to interest groups are included.

6. Conclusion

This paper was a presentation of the historical development of the Elbe-Vltava waterway, where extensive regulation changes, improvements and construction works were done starting in the early 19th century to ensure in navigation conditions meeting the existing water transport needs. Starting in the early 20th century both the Vltava and the Elbe were made navigable owing to the construction of 34 barrages ensuring all-year navigability in their backwaters. All the structures were built to enable

their versatile usability. In other words, in addition to their transport functions, the civil engineering structures serve many other purposes, such as protection of the adjacent land areas against floods, renewable water energy generation, water withdrawal for agriculture and industries, and tourism near the waterway. Their historical potential and architectural significance constitute a specific feature of such structures. Implementation of the research project encompassed the collection of a wealth of historical documents, maps and drawings, their sorting and presentation to the wide public in the form of a graphic web application.

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