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Historical River Training Works on the Lower Elbe

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Abstract. The paper deals with river training works built on the reach of the Elbe River between the city of Ústí nad Labem (CZ) and the Czech/German border. Downstream of the Ústí nad Labem, the Elbe in the Czech Republic and in Germany has only been made navigable through river training measures without building weirs. The goal of river training for watercourse navigability is to attain the required waterway parameters through fairway adjustments. This is primarily achieved through channel dredging and the construction of training dams to concentrate the water flow into a narrower but deeper main channel. The paper describes the historical development of river training works during the period from the Middle Ages to the present day. Initially, such works were not meant as part of a unified conceptually designed system of measures. Instead, they were local initiatives aimed to remove natural obstacles from the river bed and to build facilities and structures to aid navigation. Systematic regulation works along the Czech and German sections of the Elbe only started in the early 19th century. The research was focused on studying the original project documents and documentation of the actual design of the training dams since 1894. This historical design documentation was digitised and projected into the maps in the Czech JTSK local coordinate system through the use of advanced geographic information system (GIS) methods. The final atlas of river training works on the Elbe-Vltava Waterway (EVW) along the lower Elbe in the Czech Republic is the first of its kind, utilising geographic information systems to document the locations of technical structures built since the early 19th century in the Elbe River bed in order to make the river navigable and maintain its navigability. The collection of maps also documents the development of the river training works in time based on map data obtained from digitised design documentation from the 19th and 20th centuries, historical aerial photographs dated 1930–1946 and 1950–1964, and present-day maps and orthophotomaps of the Elbe section in question. The atlas of the Elbe-Vltava Waterway river training works is publicly available via a web-based application. The maps are a result of original research and offer a synthesis of interactions between the existing technical structures, the sediment regime of the Elbe and sites that are subject to environmental protection. The research was conducted as part of project no. DG18P02OVV004 entitled “Documentation and presentation of technical cultural heritage along the Elbe-Vltava Waterway” within a support programme for applied research and experimental development of national and cultural identity, funded by the Ministry of Culture of the Czech Republic.

1. Introduction

The Elbe-Vltava Waterway (EVW) is the primary waterway used for water transport in the Czech Republic. The beginnings of the use and development of this waterway date back to the 14th century. Initially, local measures were made in order to eliminate major obstacles to navigation lying on the riverbed. The efforts eventually turned into systematic river training works, starting in the early 19th



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century. Since the early 20th century, the majority of the EVW has step by step been made navigable by the channelisation method, by building over 30 weir pools [1, 2]. Figure 1 shows the Elbe River under Sřřekov Castle in Űstř nad Labem: the left-hand picture is a photo made in 1874, when the Elbe was only made navigable due to river training works, the right-hand photo shows the current status, with the most recent barrage (Masaryk barrage, 1936). The lower EVW segment downstream of Űstř nad Labem, however, was never channelised, navigation conditions were only ensured by river training measures, and their reliability is thereby limited. The research project was focused on systematic documentation and registration of training works on the lower Elbe downstream of Űstř nad Labem as far as the Czech/German national border. The project was based on research in the archives of the Elbe River Board, which enabled the initial design documents and documents of the as-is status of the concentrating constructions after 1894 to be analysed. The final atlas of training works on the Elbe Waterway along the lower Elbe is the first of its kind, utilising geographic information systems to document the locations of the technical structures built since the early 19th century in the Labe riverbed channel in order to make the river navigable and maintain its navigability. The collection of maps also documents the development of the training works in time based on map data obtained from digitised design documentation from the 19th century, historical aerial photographs dated 1930–1946 and 1950–1964, and present-day maps and orthophotomaps of the Elbe reach in question. The maps are an outcome of original research and offer a synthesis of the interactions between the technical structures on the one hand and sites that are subject to environmental protection on the other hand, including new findings.

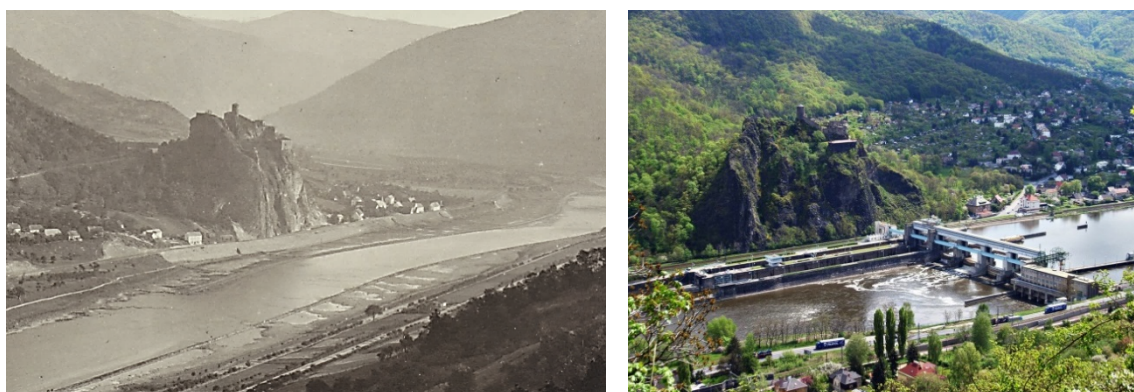


Figure 1. The Elbe under Sřřekov Castle in Űstř nad Labem: a) river training works by means of training dams (1874); b) Masaryk barrage built in 1936.

The aim of the Elbe training works is to attain the required waterway parameters through fairway modifications, particularly by channel dredging and by building structures concentrating the flow into narrower and deeper river channel segments. Focus is on permanent improvement of the flow route, slope and shape of the riverbed and shape and size of the longitudinal profile. Efforts when ensuring river navigability must concentrate on attaining a unified navigation depth along the whole treated segment, creating a suitable longitudinal profile, slope and route of the waterway so that the navigation conditions are uniform to the greatest possible extent [3]. Furthermore, free passage must be ensured for extreme flow rates through the trained riverbed so the waterway should not be distorted. Measures must be made for the deposits and ice to be freely transported through the whole navigable waterway reach, so the water stream should not have too much energy to cause riverbed erosion and deepening while depositing the material at other places. Historically, making rivers navigable through training works can be divided into (a) medium flow rates and (b) low flow rates. In addition to building modifications, effective operational management tools using modern optimization and artificial intelligence methods have been used successfully in recent years to improve navigation conditions [4].

Characteristic of the lower Elbe segment between Ústí nad Labem and the Czech/German national border is the existence of many sites requiring environmental protection. This includes two sites of the Natura 2000 system, requiring preservation of adequate conditions for the existence of objects of protection of site No. 3270 (Rivers with muddy banks with *Chenopodium rubri* p.p. and *Bidenton* p.p. vegetation) according to Council Directive 92/43/EEC and conditions suitable for fish population. A close correlation exists between the habitats of such populations and the hydrodynamic and morphological properties of the river. The existence of historical concentrating dams in the Elbe channel significantly affects the grain-size characteristics of the riverbed and banks, including gravel beaches, providing favourable conditions for local flora and fauna. Therefore, the interactions between the protected environmental compartments, the locations and design of the historical concentrating structures, and sediment management by the river basin management body must be thoroughly studied.

Research into the various types of training dams was the focus of Henning and Hentschel [5], who compared the transverse and longitudinal dams with respect to the natural habitats on the river banks. From their analysis it follows that transverse dams are more suitable, creating diverse bank lines with a potential for making up for the past technical measures on the Elbe. On the contrary, Collas et al. [6] consider longitudinal training dams more favourable with respect to fish communities, which find a shelter between the dam and the bank, separated from the waterway with its sometimes very vigorous boat traffic. Vermeulen et al. [7] recommended replacing transverse groynes with longitudinal dams in the context of flood protection measures. Concentrating groynes and protection of the habitat on the lower Elbe were the focus of Kašpar et al. [8]. They used a physical model with riverbed position change monitoring by 3D scanning technology [9]. Optimizing the riverbed embankment using physical modelling was also successfully used by Pavůček et al. [10].

2. Study area

Training works were made on the lower Elbe since the early 19th century with the aim to improve and maintain the waterway parameters by channel dredging, and by building structures to concentrate the stream into a narrower profile, where the same amount of water flows through a deeper channel. The river reach studied, between Ústí nad Labem and the national border, has only been made navigable by river training measures. This also holds true for most of the German Elbe. The Czech river trained segment is about 40 km long and follows up the canalised EVW (see Figure 2). The training works only resulted in a limited navigability, with a mere 54 % navigation reliability.

2.1. Training for medium flow rates

Any river training in this segment must respect the initial nature of the stream as governed by the natural and local conditions, i.e., the magnitude, course and duration of the flow, slope of the area, site of the grains entrained, composition and anti-erosion resistance of the bed-forming material, etc. Among the main technical principles of river training for medium flow rates are elimination of too sharp river bends and, as appropriate, digging large-radius meanders. The waterway is modified so as to create favourable conditions for safe and smooth navigation.

2.2. Training for low flow rates

Riverbed modifications to medium flow rates do not ensure an adequate navigation depth at low flow rates, so vessels cannot be used to full draught and water traffic is less effective or must even be stopped altogether during low water periods. This situation is typical of the autumn months on large streams of lowland nature with a wide channel and a rather high slope. This is currently encountered very frequently on the lower Elbe downstream of Ústí nad Labem during long dry periods. Therefore, for channelised segments that are of water traffic importance it is proposed that a narrower navigation channel (cunette) be dug in the unified bed and the low flows be concentrated in it through transverse training dams in order to attain a larger depth for navigation. However, a water stream concentrated in

a narrow fairway with a marked gradient can erode the bed. To prevent this effect, the concentrating groynes are extended across the whole channel as submerged sills that stabilise both the channel and the shape of the stream line. Such sills were also built in the past on the trained Elbe, which is one of the reasons why the Elbe channel is stable in the long-term there. Flowing water runs over such groynes during medium and higher flow rates. Therefore, the fairway must be marked with navigation marks on the groyne crest so the navigation should be safe at medium flow rates.



Figure 2. EVW layout showing the river training segment between Ústí nad Labem and the Czech/German border (red color) follows up the canalised EVW (blue color).

2.3. Historical development of river training works on the lower Elbe

Important river training works were made on the river as early as the start of the 19th century. Banks were reinforced with quarry stone pavement 30 cm thick, laid in a gravel-sand bed 15 cm thick. Paving stones were used, separated with wedges, and turfs were laid between them. The paved slope was secured with quarry stone riprap. The bank lining height reached the level of the current water surface, which roughly corresponds to 220 cm on the water gauge in Ústí nad Labem. The channel crest was 140 cm wide and horse team paths were constructed on them on the left bank after 1820. Start of steam navigation on the Elbe and the navigation acts signed in 1844 obligated the Austrian empire to dig the international segment of the Elbe to the prescribed depth and to maintain this depth constantly. Any river islands had to be removed, old weirs dismantled and the river channel straightened.

Stage 1 of modern training of the Elbe-Vltava Waterway (EVW) was based on Imperial Water Act No. 93/1869, followed by land water acts issued by individual land assemblies since 1870. The Bohemian Assembly established a task force, which supported the plans for extensive training works on the lower Vltava and on the Elbe during 1875–1887, substantially promoting additional development of navigation. The lower Elbe channel was additionally deepened and the banks reinforced. These training works included reinforcement of the left bank with widening of the initial horse team path. The lining was designed for a flow rate of approximately Q_1 . The lining on the right bank was designed for a flow rate of approximately Q_{180d} and, at the sites of towns and villages, also for Q_1 .

Stage 2 of the modern training started in 1896, with the establishment of the Committee for Canalisation of the Vltava and Elbe rivers in Bohemia. Additional training for medium and low water on the lower Elbe downstream of Střekov was a continuation of Stage 1. Training dams were built, combined with dredging. The small dams, as well as the bank reinforcement, were paved using quarry stone and secured with a foundation of quarry-stone riprap. The area between the training dams and the bank was then used to dump the material excavated from the riverbed during bed cleaning work. Floods covered this area with sediment at some places. The Svádov site in Ústí nad Labem is an example (Figure 3). The Elbe training works 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 a navigation depth increase by tens of centimetres at low and medium flow rates. The flow velocity also increased by approximately 30 %, whereby the nature of the riverbed material changed to the current gravel or stone in this river segment.



Figure 3. Svádov after the construction of concentrating dams in the late 19th century (left) and today (right).

3. Materials and methods

3.1. Spatial database creation

The research into the documentation of the technological heritage on the EVW is based on extensive archival sources and depositories of a number of museums and archives. A big volume of historical documents, maps and drawings has been digitised within the research project. The obtained materials have been systematically sorted and are now presented to the wider public as a web application on the project portal at www.lvvc.cz. Of prime importance was the research in the archives of the Elbe waterway management body, which enabled us to study the initial design documents and documents of the as-is status of the concentrating structures built after 1894. This historical design documentation was digitised, analysed and projected into the maps by employing advanced geographic information system (GIS) methods.

The map sheets were also augmented with historical aerial photographs made during 1930–1946 and 1950–1964 and the current orthophotomap of the relevant segment of the Elbe. Such documents enable us to graphically depict the time development of the training works from 1894 till now. This approach to the presentation of the development of technical structures and the landscape in time was also used, e.g., by Tobias and Cajthaml [11].

3.2. Sediment regime in the Elbe

The sediment regime in the Elbe is substantially affected by the construction of a number of reservoirs, dams and weirs in the river basin, whereby the amount of sediment brought to the channel are reduced markedly. An interesting analysis of the development of the Elbe bed between the

Czech/German national border and the German Geesthacht barrage has been presented in the study [12]. The changes in the riverbed positions, levels and sediment grain composition in the trained segment of the German Elbe over the 1898–2004 period were examined. Important river training works in Germany date back to 1844. The works included the construction of protective dams to prevent land flooding during floods and the construction of transverse groynes. Such measures increased the capacity of the river to wash away deposits and debris. At the same time, the inflow of sediment from the Elbe tributaries in Germany and in Bohemia was appreciably limited by the construction of transverse structures [13]. When using the initial German kilometre spacing of the Elbe channel, which begins on the left-hand border with the Czech Republic, with the kilometre spacing along the water stream, the bed of the Elbe in the 0.0 to 120.0 segment is similar to that in Bohemia. On the contrary, the km 120.0 to 290.0 segment, between the towns of Mühlberg and Wittenberg, is referred to as an ‘erosion segment’. Here the Elbe channel is spontaneously deepened at a rate of about 2 cm/year, and so the Elbe is approximately 2.0 m deeper there now than it was 100 years ago. This German Elbe deepening problem is so serious that various counteracting measures have been attempted, such as artificial addition of sediment. This project was started in 1996 and was determined partly successful after 5 years of operation [14].

The study [12] attributes the Elbe riverbed stability within the German segment of km 0.0 to about 120.0 (like in the trained Bohemian segment) to the bottom pavement, the formation of which was enabled by the coarser grain composition of the riverbed. Based on the above facts, the International Commission for the Protection of the Elbe River formulated a sediment management concept [15]. The following recommendations were presented in order to maintain inland navigation operable: maintain, optimise and adapt the training measures in the trained segments of the Elbe, stabilise the river’s longitudinal profile and the dams in the canalised segment. Similar strategic recommendations form the core of the Overall Strategy for the Elbe [16], according to which the river engineering measures are acceptable provided that they simultaneously serve environmental, water-management and traffic purposes, combining them reasonably.

3.3. Natural habitat mapping

An important requirement put on gravel management in the Elbe Valley and Porta Bohemica sites of community importance (SCIs) is that appropriate environmental conditions are preserved at the protected sites, specifically Site 3270 (Muddy river banks with *Chenopodium rubri* pp and *Bidention* pp vegetation) according to Council Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora. The Site 3270 muddy river banks location was processed within the mapping of biotopes (visit, e.g., the Nature Conservation Agency of the Czech Republic map server).

4. Results and discussion

4.1. Technical and distribution analysis of historical training dams

In addition to the global map, a relation database on the MS Access platform was also set up for the documentation needs of the river training works. The database is based on 4 tables. The first table serves for presentation of the river training projects and contains all the relevant attributes, such as the project name, kilometre spacing data with location, technical description, date of creation, names of the designer and the construction company and current status of the works. The next table contains geographical information with the locations of all training elements, providing documentation of each training dam in a unified format and as a basis for the GIS module on the www.lvvc.cz portal. The remaining tables are to store photographic documentation and documents associated with the training works (technical dossier, books, papers, reports, etc.). The database is also a smart tool for information sharing between government bodies, users and waterway administrators.

The new set of map sheets and the associated database constitute the only integral documentation of historical river training structures on the lower Elbe in the segment between Ústí nad Labem and the national border. Analysis of historical design documents, cadastral maps and historical aerial photographs enabled a new vector layer of training dams and collect the various technical structures to a set of 40 sites in total (Figure 4).

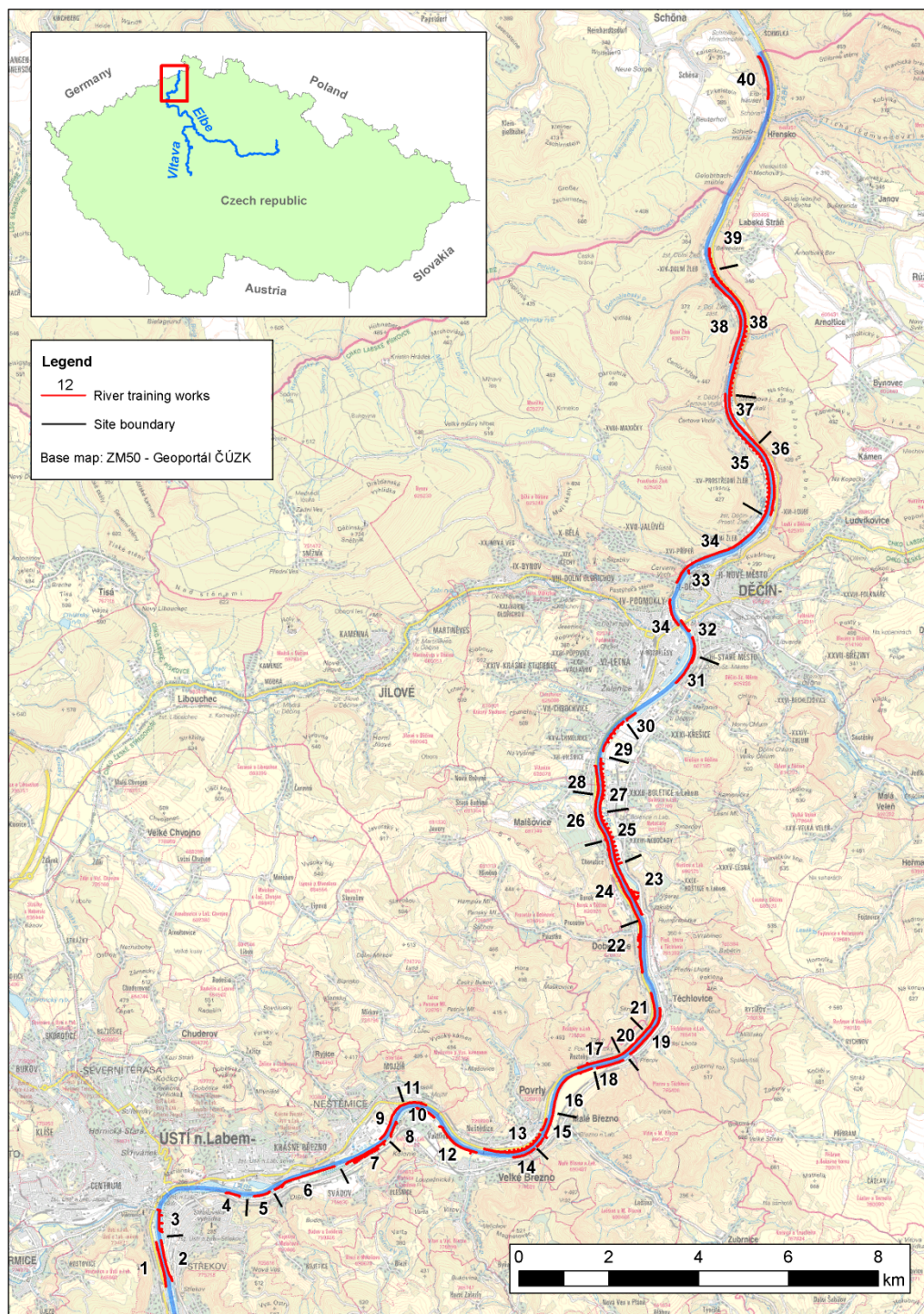


Figure 4. Locations of 40 sites with historical training dams between Ústí nad Labem and the national border.

The documents attest to the technical skills of our ancestors when making systematic efforts to make the Vltava-Elbe waterway navigable to the greatest possible extent. They also constitute an important basis for the activities of the fairway and river management authority.

The assets of the database can be illustrated on the longitudinal and transverse training dams in the Elbe at the Loubí III site, roughly 4 km downstream of Děčín (Figure 5). The database includes an attribute table containing detailed data of each of the training construction sites.

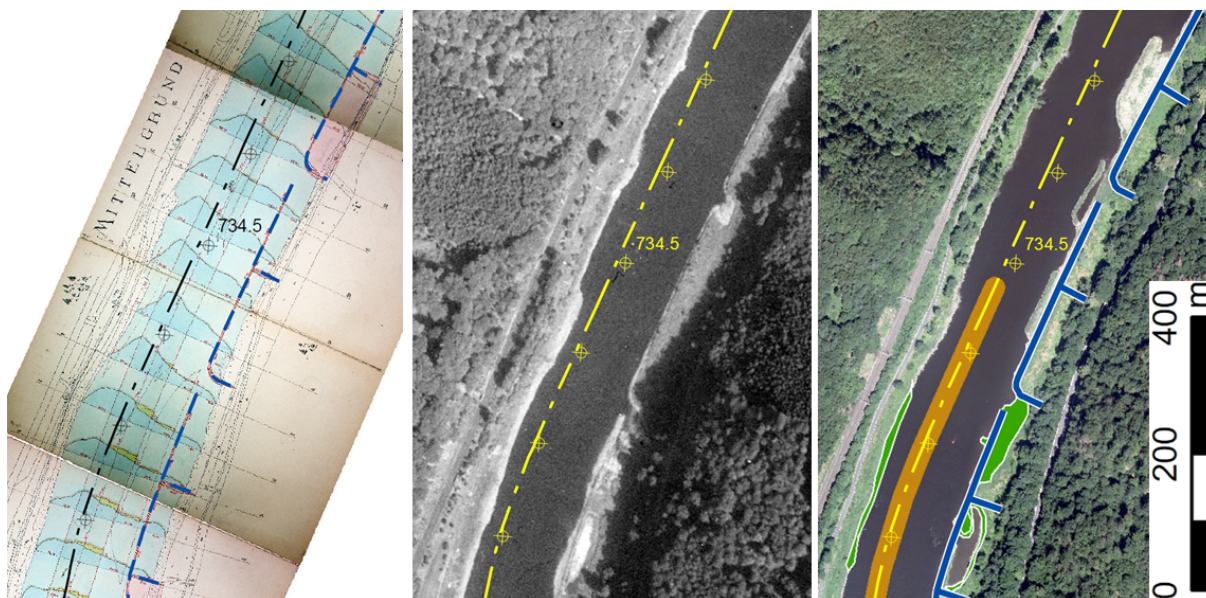


Figure 5. Detailed illustration of the time development of concentrating dams at Loubí III, original documentation from 1917 (left), historical orthophoto from 1953 (middle) and current orthophoto showing the locations of Habitat 3270 (green color) and sediment management (right).

4.2. Spatial interaction between historical training dams and natural habitats

The sites of the ‘Muddy river banks with *Chenopodium rubri* pp and *Bidention* pp vegetation’ habitat according to the Natural Habitats Directive (Habitat No. 3270) and sites of sediment management established by the river management body (The Elbe River Basin Authority, a state-owned enterprise). This synthesis gave rise to a set of maps documenting the training of the lower Elbe between Ústí nad Labem and the national border, which revealed new facts regarding the interactions of technical constructions, sediment management and environmental protection sites. This well-arranged documentation of the training works demonstrates that the river channel in the relevant segment has been trained along the majority of the stream. From the current condition of the river channel and banks it is clear that anthropogenic changes, i.e., the concentrating structures, have given rise to new habitats, now considered very valuable from the environmental protection aspect. From this viewpoint, this is an excellent case of concert between technical measures made in order to create a fairway and the interests of the environment.

Local investigation near the historical training structures also revealed strong interaction between the occurrence of objects of protection of Habitat 3270 and management of sediment from dredging made by the river basin management authority. This finding strongly supports the conclusion that sediment management can be suitably steered to improve the environmental conditions. An example of this can be found at the Heger site in Děčín, where 600 specimens of strapwort (*Corrigiola litoralis*) were recorded in 2018 after rebuilding the transverse training dam following the 2013 flood and creation of an artificial beach. Such findings constitute highly valuable and practically demonstrable

information on the feasibility of creating artificial conditions in the trained Elbe segment that are comparable to the natural gravel beaches for the formation of Habitat 3270.

5. Conclusions

The aim of this research was to document historical training works on the Bohemian lower Elbe made in the late 19th century and early 20th century in order to improve the navigation conditions. The conclusions of the project are as follows: (1) A database of training dams containing the main technical parameters of the structures has been set up. Furthermore, the documented training dams have been digitised in the GIS. (2) The database is the first of its kind and is intended for use by the fairway management body and the navigation authority when planning fairway maintenance and modernisation projects. (3) The systematic documentation of the training structures is a major contribution to the presentation of those elements of technical cultural heritage to the wider public. (4) The research demonstrated that the entire studied segment of the Bohemian lower Elbe was subject to important favourable anthropogenic changes. The surroundings of the concentrating structures frequently constitute environmentally highly valuable habitats of the Natura 2000 system.

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