Methodology for Classification and Evaluation of the Industrial Heritage from the Perspective of Heritage Management

WATER MANAGEMENT

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Prague-Bubeneč, old wastewater treatment plant. Photograph Viktor Mácha, 2019.

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INTRODUCTION/PREFACE

This publication, presenting methodology for the classification and protection of industrial heritage in the field of water management, is the first of a series of industry-specific methodological publications which set out to provide a basic grounding in a range of industrial and technical fields that are encountered on a daily basis by heritage management specialists. The series will focus on fields that have been of key significance for historical economic development, industries that have been of particular importance in the territory now covered by the Czech Republic (such as coal mining, the iron industry, rail transport, power engineering, textiles, sugar refining and brewing), and fields of activity that have been essential to the development of these industries and the evolution of municipal infrastructure.

The present publication is a successor to the more generally conceived guide entitled *Methodology for the Evaluation and Protection of Industrial Heritage from the Perspective of Heritage Management*, which was published in 2018 by the National Heritage Institute's Methodological Centre for Industrial Heritage with contributions from a range of experts in various fields as well as heritage management specialists. That initial guide outlined key concepts of relevance to industrial heritage, criteria for evaluation, methods of research and documentation, and some key trends in managing industrial heritage.

The present publication applies these general principles to a specific field of activity – water management – and takes into consideration its specific features:

- it outlines the history and development of water management,
- it presents a basic typology of sites and buildings associated with water management; these often overlap into other industries and fields of activity such as power engineering and transportation,
- it sets out evaluative criteria for assessing the heritage values of these sites,
- it presents the current situation regarding heritage sites whose origins and functions are connected with water management,
- it gives practical examples of how these sites are managed,
- it offers general recommendations with regard to the renovation and protection of these heritage sites.

The purpose of this publication is to serve as a guide and a tool for heritage management experts, museum staff, administrative authorities, investors, architects, designers and owners of water management sites – whether these sites are legally protected or not.

This guide was produced as a collaborative project by the T. G. Masaryk Water Research Institute, the National Heritage Institute, the Faculty of Science at Palacký University in Olomouc, the Institute of History at the Czech Academy of Sciences, and a number of experts and consultants from outside these institutions.

1. INTRODUCTION TO THE FIELD OF WATER MANAGEMENT

1.1 DEFINITION OF THE TOPIC AND SCOPE OF THIS PUBLICATION

This methodological publication focuses on water management sites/buildings, which it assesses from the perspective of heritage management. It offers a basic grounding in the field, a typological overview, and tools for evaluating water management sites. These sites are defined (see chapter 3) as buildings or technical equipment with functional structures which perform one or more water management functions. A water management building may stand separately, or it may form an integrated part of a larger functional entity.

This publication is divided into nine chapters:

- **1. Introduction to the field of water management.** This opening chapter defines the topic and scope of the publication and then presents a brief historical overview of the development of water management, focusing particularly on the early phases and the specific features of water management in the territory now covered by the Czech Republic.
- **2. Current state of heritage protection at water management sites in the Czech Republic.** This chapter presents the water management sites and structures that are currently subject to legal heritage protection in the Czech Republic (around 700 items), both separately standing structures and those that form part of a larger entity.
- **3. Evaluation of water management sites from the perspective of heritage management.** This chapter focuses on several specific aspects: typological value, value deriving from the technological flow (process), value deriving from systemic interconnections and functional authenticity.
- **4. Description and evaluation of selected water management groups and structures.** This is the longest chapter in the book, presenting a classification of water management sites (buildings, structures). It is intended to provide a grounding in the typology of the field, and is divided into six sub-chapters:

  4.1. Dams,

  4.2. Small water reservoirs,

  4.3. Waterways,

  4.4. Buildings/structures exploiting hydropower (water wheels, water turbines, hydroelectric power plants),

  4.5. Water works (water supply structures),

  4.6. Sewerage and water treatment.

  Where possible, this chapter gives information on the number of existing examples of the basic types as well as their oldest surviving representatives in the Czech Republic. It provides illustrative examples of typical (common) uses of the individual types, and also of exceptional (typologically unique) uses. The chapter also includes examples of functional complexes and presents comprehensive evaluations of selected sites applying the set of evaluative criteria presented in chapter 3. Each of the sub-chapters concludes with an overview of the representatives of the particular segment of water management that are currently legally protected heritage sites. Water wheels are an exception; the large majority of them are not legally protected in their own right, but rather as part of larger industrial buildings and sites that fall outside the purview of water management (e.g. water mills, hammer mills, sawmills, fulling mills, etc.).

- **5. Examples of the preservation, renovation and new use of water management structures.** This chapter presents examples of how legally protected heritage sites or complexes have been dealt with; some of them continue to serve their original purpose, while others have been transformed and now have new functions. Selected examples of various types of buildings and sites also draw attention to the possible problems that heritage specialists may encounter when protecting industrial heritage sites (e.g. conflicts between the interests of conservation and functionality). This chapter also summarizes general principles and recommendations regarding the heritage protection of water management sites.
- **6. Conclusions.**
- **7. The Bibliography** contains a list of the published and unpublished sources used in the work, as well as pointing out sources of relevance to those wishing to gain a deeper insight into the field.
- **8. List of abbreviations.**
- **9. Subject index.**

It should be noted that this publication is very brief, considering the breadth of the field it addresses. It does not address a complete range of topics that are relevant to water management; particularly, it omits spa technology, alterations to watercourses and amelioration-related structures. Some of the topics frequently encountered by heritage specialists could also usefully be addressed in greater detail in separate methodological publications (such as water wheels and the hydraulic structures associated with them).

1.2 A BRIEF HISTORICAL ACCOUNT OF THE DEVELOPMENT OF WATER MANAGEMENT

The emergence and development of human civilizations was accompanied by the development of systematic activities involving the widely varying exploitation of water sources by society, as well as providing protection against the potentially destructive effects of water. Humans have pursued a wide range of water exploitation- and management-related activities since ancient times. Annual floods were a key aspect in the development of sophisticated civilizations in Mesopotamia and Egypt. The same floods became symbols of the ambiguous relationship between humans and water. On the one hand, they manifested the life-giving function of water, yet on the other hand they demonstrated the destructive force of water as an untamed element. It is a natural human desire to intrude on the natural order of the world, to shape the world in line with humanity's own needs and ambitions – and it is likewise natural that people focused this desire on water as the development of civilization increasingly offered means of doing so. The ideal was to strike a balance – to achieve a state in which the utility of water was maximized while its threat to civilization was minimized.

The first man-made hydraulic structures were created in the early phase of the ancient civilizations that lived in the basins of the Euphrates, Tigris and Nile. They comprised systems of irrigation canals, which channelled water away from the immediate vicinity of the rivers into previously barren areas, enabling agriculture to develop in these areas. As these civilizations developed, a more effective form of water management evolved, as isolated projects were replaced by a more systematic approach. The first historically documented water management plan was commissioned by King Samsu-iluna (who reigned approximately from 1750–1712 BCE), the son of the most famous Babylonian king Hammurabi. The plan incorporated irrigation canals, water supply channels with distribution networks, the regulation of the Euphrates, the creation of a lake near Babylon, water supply systems for 27 gardens in the city, a royal bath-house, and the construction of numerous water wheels for tradespeople. The planned structures were built over a period of 16 years. The early codification of water management reached such levels of detail that ancient

Mesopotamian kings issued laws stipulating how much water individual farmers could take from the irrigation channels, and when they were allowed to access the water (Beran, 2006).

Comparable processes also took place in ancient India and China. Dating back to around 2600 BCE are the remnants of the urban settlement of Mohenjo-daro in the Indus Valley (now Pakistan). The sophisticated terracotta sewage network, which connected houses with bathrooms and flushing toilets, could certainly not have been built without water management plans. In China, we know of the plans for the regulation of the Yellow River and the Yangtze River. These rivers flooded on an almost annual basis, affecting huge areas and drowning thousands of people. The first emperor of the unified China, Qin Shi Huang (260–210 BCE), launched a number of massive building projects to create irrigation canals and systems that supplied water to many thousands of square kilometres of agricultural land. The first reservoirs in China date back to around 2000 BCE. At approximately the same time, fish were introduced to similar reservoirs, creating proto-modern fish farming systems (Beran, 2006). The first dams are sometimes said to date back to around 3000 BCE in ancient Egypt, though dams were also being built around the same time in Mesopotamia and the Middle East. One example is ancient Palestine, where the local Canaanite tribes addressed water shortages by building small reservoirs to capture rain water (Lemche, 1998).

It was the Romans who perfected the system of water supply in ancient cities. They built huge aqueducts spanning entire valleys. The use of water in Roman cities combined utility with aesthetic appeal in the form of ornamental fountains. The first known aqueduct, the Aqua Appia, was 16.5 kilometres long. It was built in 312 BCE by Appius Claudius. During the imperial era, Rome had 12 aqueducts supplying a population of around 900,000; they were managed and maintained by 700 employees. Augustus Octavianus Caesar built around 700 public wells, 130 fountains and 150 aqueducts. He uttered a well-known statement: *"The Roman Empire is built on roads and aqueducts. It is only an aqueduct that can turn a village into a city."* In 97 CE the emperor Nerva appointed the first Roman water commissioner, the engineer Sextus Julius Frontinus. This "curator aquarum" drew up a plan detailing all the Roman aqueducts, which had a total length of 404 kilometres, and he also issued the first treatise on water management, De aquatictus urbae Romae. In order to prevent wastewater from polluting cities, many ancient civilizations elaborated and implemented sophisticated plans for sewer systems to remove wastewater. The most famous sewer system in the Roman Empire was the Cloaca Maxima in Rome. It was originally an open channel, but during the imperial era it was covered over. The Cloaca Maxima was up to three metres wide and four metres deep (Hopkins, 2007).

The subsequent centuries brought turbulent changes in Europe, and the decline of ancient civilization into the "Dark Ages" also affected the relationship between humans and water. The Roman aqueducts and baths were destroyed by the Goths, Langobards and Vandals. In the absence of aqueducts, the local population had to make do with wells (often with tainted water) or supplies taken from: rivers and streams. Instead of sewer systems, there were ditches in the streets. This situation (which is characterized here in general terms, and is thus necessarily not entirely precise) lasted in Europe for more than a thousand years – a period during which the Church's dogma encouraged people to view care of their own bodies (and the related health benefits) as a potentially sinful form of activity, associated with secular "vanity" – which was contrasted with the eternal virtues that existed beyond the physical world. The consequences of these attitudes included plagues, which killed up to a third of the population (Bergdolt, 2002). For example, the Bohemian chronicler Kosmas wrote that in 1083 a third of Bohemia's population had perished in a plague.

Of course, the "Dark Ages" in Europe did not involve a complete leap into darkness; knowledge of many of the achievements of ancient civilizations was preserved by Christian (and also Muslim) scholars and their libraries, and this knowledge became the basis for future progress. In the territory that is now the Czech Republic, medieval towns and cities possessed good water supply systems; underground channels brought water (of varying quality) to private or public fountains. However, towns and cities found it difficult to remove wastewater. This was highly detrimental to hygiene, and (along with the presence of municipal waste) it was the most significant cause of infectious diseases. Municipal water supply systems are documented e.g. in the Bohemian town of Žatec (Saaz); the first mention of such a system, taking water from the Ohře River, dates from 1386, and a document from 1489 describes the production of wooden pipes connected together with wrought iron rings. The city of Brno (Brünn) had three water supply sources. One took water from the Svratka River below the Puhlík hill (now Denisovy sady), the other channelled water from the Cimpl hill to the municipal fountain at the vegetable market (Zelný trh) and the city's lower square, and the third (known as the Carthusian conduit) supplied water from the large Geisper pond, which was located near the Carthusian monastery in what is now the city's Královo Pole district (Gottwald et al., 1972).

Hydropower was used to drive water mills – first in the Near East, and later also in Europe. In the second half of the 3rd century CE there was a large mill in the French city of Arles (Nechleba, 1962). In Bohemia, the first water mills had been built by the beginning of the 12th century (and according to legends, as early as the 8th century). The first documented water mill existed by 1100; it is no coincidence that the mill was located near the monastery in Hradiště nad Jizerou, evidently established by the Benedictine Order. However, water wheels were not only used for milling grain. Hydropower was also used at sawmills, crushing mills, oil mills, grinding mills and hammer mills. Milling (and the use of water wheels) grew substantially during the era of Charles IV, who issued a law that provided support for millers. It was thus during the 16th century that milling (like fish farming in ponds) experienced its greatest boom in Bohemia (Frajer, 2008).

Many authors consider fish farming in ponds to be the most typically Bohemian phenomenon in the history of water management. To be more precise, the pre-phase in the development of water management in Bohemia, Moravia and Habsburg Silesia (the Bohemian Crown Lands, covering the territory of the present-day Czech Republic) is closely linked with the creation of fishponds, primarily from the 15th–17th centuries. Fishponds were already a widespread feature during the Middle Ages, and the systematic construction of ponds on the estates of secular landowners and the Church became common during the reign of the Luxembourgs (1310–1437). Prominent examples included the construction of ponds in the Pardubice region under the reign of Charles IV – a project which could not have been implemented without water management plans. Nevertheless, the creation of a more comprehensive water management system only began in the 16th century, a period associated with several important designers and builders of large hydraulic structures (including Štěpánek Netolický, Kunát Jr. of Dobřenice or Jakub Krčín of Jelčany). This system comprised the watercourses (rivers, streams) which supplied water via complex systems of river weirs, conduits and drainage channels, thus enabling people to control the supply of water into reservoirs where it was stored. A key difference compared with the situation in the Middle Ages was the removal of the obstacles caused by the fragmented ownership of land. In the medieval era, a single village was often divided among two or more owners. This made it unviable to build larger-scale hydraulic structures on the estates of the minor nobility, as changes in the water regime would affect land held by several owners, and this naturally caused difficulties when attempting to reach agreement on a shared approach. Moreover, watercourses often marked the traditional boundaries between estates. A further obstacle was created by the legal reality of the era; during the Middle Ages, property was viewed as essentially a temporary asset, as many "owners" in fact only possessed their estates in the form of a fief or an object of lien, and they had no assurance that the property would be inherited by their children. In such a situation, investing in earthworks was not viewed as a worthwhile activity.

By the beginning of the Early Modern Era, the situation had changed. The wealthiest aristocratic families now had a relatively secure hold over extensive assets, and the monarchy had ceded many of its medieval-era land rights to the aristocracy. It is therefore unsurprising that in the Bohemian Crown Lands during the 16th century, fish farming in ponds was almost exclusively a form of economic activity pursued by the aristocracy. The specific legal situation that existed at the end of the 15th century facilitated the rapid creation of large, territorially cohesive estates, whose owners had adequate assurances that any investments would be sustainable in the longer term. This was an important precondition for the creation of large hydraulic structures. Investors had no need to fear becoming embroiled in disputes if areas of land were submerged or water conduits were built, and their investments were unlikely to lose their value. The creation of a pond system began with the construction of a weir on a river that served as the system's main water source. The weir raised the water level in the river to the required height, and diverted it from the main watercourse into a channel which fed it into the ponds. For smaller man-made reservoirs, small streams were adequate as water sources. Systems of fish farming and distribution became established in the first half of the 16th century and lasted until the outbreak of the Thirty Years' War (1618), because this use of the ponds continued to be a useful form of economic activity. Nevertheless, by the beginning of the 17th century it had become evident that the golden age of Bohemian fish farming was over, and major new investments were instead directed into other fields of activity. It became more economically viable to drain the ponds for good and plant grain on the land. Weirs, sluice-gates, dykes and supply conduits thus gradually succumbed to dereliction. By the late 18th century only a fraction of the original ponds remained to be drained as part of the Josephine reforms (Vorel, 2007). The only substantial pond system to survive on a regional basis was in South Bohemia, where the ponds became an important component of the local identity (Rozkošný et al., 2015).

PrThe first elements of the water management system in the Bohemian Crown Lands became separated from each other with the onset of the industrial revolution, as people needed increasing quantities of water for use in industrial activities. There was an emphasis on the effective exploitation of water, drawing on findings from the expanding fields of science and medicine. As such, the construction of sewer systems was a characteristic feature of water management during the 19th century. The development of Prague's sewer system is associated with the name of Count Karl Chotek, who during the first half of the 19th century drew on plans produced by his father Johann Rudolf and created a sewer system in the Bohemian capital. The construction of the system began in the Hradčany (Prague Castle) district and gradually expanded to cover parts of the Malá Strana area and the Old Town, as well as the district of Na Františku. The overall solution of the city sewer system became a topic until the end of the 19. Century. Even later, the water network was finished. The water supply situation in Prague was partially addressed shortly before the outbreak of the First World War (1914 was the first year in the city's history that its people were able to use water that was genuinely safe to drink), and the system was finally completed during the second half of the 20th century.

The technical achievements of the industrial revolution, and the related attempts to intensify agricultural production and increase yields, affected (and sometimes disrupted) the water regime. This led to technically sophisticated interventions, which were carried out for the purpose of removing surplus water during periods of flooding and also to irrigate land during dry periods. In this connection we can speak of the first amelioration-related structures. For example, there are records of drainage ditches created in the 19th century by the municipal authorities in the South Bohemian town of Podivín on municipally owned meadowlands, or drainage ditches maintained by residents of Mikulčice and Moravská Nová Ves (South Moravia) to improve drainage conditions and channel water away from the Stupava River (today the Kyjovka River) in periods of flooding. These ditches are marked on indicative sketches dating from 1827. One project worth mentioning was designed by the Viennese engineer J. Hobohm, who proposed the creation of a network of ditches in the vicinity of springs in order to slow the flow of water away from the spring, reduce the force of the current and retain the water within the landscape (Bínová, 1992). However, in practice the opposite trend gained the upper hand; this trend – which was promoted in agricultural textbooks from the beginning of the 19th century – involved the cultivation of so-called "barren land". Considerable attention was thus devoted to draining marshes and carrying out amelioration work. These artificial interventions disrupted the natural water regime by accelerating the removal of water from the landscape and then returning the water to the land (a complex and demanding process) for purposes of irrigation during dry periods. In Moravia, it was the Liechtenstein estates that undertook the first major and systematic amelioration projects after the middle of the 19th century. The Schwarzenbergs undertook similar projects at their large South Bohemian estates, as did the Pálffy family in Upper Hungary, today the Záhorie region of Western Slovakia (Veselý, 2017).

The Schwarzenbergs also built a canal for transporting timber, which crosses the watershed between the drainage basins of the North Sea and the Black Sea (constructed 1789–1833). By the second half of the 19th century, technological progress enabled the construction of artificial waterways all over the world (the Suez Canal, the Panama Canal). In Central Europe, plans were drawn up for a canal linking the Danube and the Oder (Odra), or for the Danube-Oder-Elbe (Labe) canal; neither of these were built.

The intensification of industrialization in the Bohemian Crown Lands around the turn of the 20th century corresponded with the construction of modern dams. Four centuries after Bohemia's first man-made reservoir was built (Jordán, 1492), plans were drawn up to create reservoirs that would supply a number of rapidly expanding towns and cities. The oldest dam with a brick dam is the Marianske Lazne water reservoir, built between 1894 and 1896. However, the construction proposal has been discussed since 1883. The main reason for building dams was the occurrence of serious floods during the 1890s. Local groups known as "water associations" were established to commission experts to produce conceptual solutions. A destructive flood in the valley of the Lužická Nisa (Lausitzer Neiβe) in 1897 forced leading political and community figures in the Liberec and Jablonec region of North Bohemia (Reichenberg and Gablonz – both cities with large majorities of German speakers, which at a time of increasing national tensions cultivated close links with nearby Germany itself) to employ Otto Intze (1843–1904), a professor from the technical university in Aachen, to produce a solution (Sauer, 2008). Intze supervised the creation of five dams, whose design became known as the "Intze type" (Harcov, Bedřichov, Fojtka, Mlýnice, Mšeno).

Besides provincial, district and municipal governments and the socio-economic elites, a key role in the construction of dams was also played by the above-mentioned "water associations". The establishment of these groups became possible after the approval of provincial water management legislation in 1870 (for the provinces of Bohemia, Moravia and Habsburg Silesia) which was based on 1869 legislation applicable throughout the Austro-Hungarian Monarchy. In general terms, the aim of the water associations (some of them local, others transcending regional boundaries) was to improve water management within the landscape. They focused particularly on constructing drainage and irrigation systems in order to increase agricultural yields and stabilize production or to protect land from flooding; projects implemented for these purposes included the regulation of watercourses and the construction of dams for flood protection, power generation and water supply. The associations had various names depending on the main focus of their activities: water associations, amelioration associations, associations for regulation, dams, water supply systems, etc. The first water association was established in the Čáslav region in 1882. Associations sometimes merged with neighbouring associations if necessary in order to coordinate larger-scale projects. Statistical data shows that between 1890 and 1939 water associations played a key role in improving water management systems and facilities. The institutions (and their controlling bodies) not only initiated and organized water management projects; they also played a role in educating the public and as investors (or as procurers of public funding). By the mid-1950s, when the water associations formally ceased to operate, there were almost 4,500 of them in the Czech-speaking part of Czechoslovakia (Pelíšek, 2021). Later these activities were brought within the purview of the State Bureau for Amelioration (Státní meliorační správa) and then the Bureau for Agriculture and Water Management (Zemědělská vodohospodářská správa).

Czechoslovakia's independence in 1918 had an impact on the construction of dams, as the state took control over new water management projects via its provincial authorities. Policy shifted to prioritize power generation at hydroelectric plants – a form of generation that began to establish itself internationally around the turn of the 20th century. Concrete was increasingly preferred as a building material; for many years earthwork dams were eschewed in Czechoslovakia as a result of the collapse of a dam in the Jizerské Hory mountains. In the second half of the 20th century, despite the ideological divide that split the world in two, construction technologies in Czechoslovakia (and indeed structural design in its entirety) were substantially influenced by international projects in Europe and beyond. The disaster at the Vajont dam in Italy (1963) had a major impact on the perception of dams as a whole. The dam structure withstood the force of a tsunami caused by a huge landslide into the reservoir; the water overtopped the dam and destroyed several villages in the valley below, claiming over 2000 lives. In 1997, when Moravia was hit by catastrophic floods, the events at Vajont influenced the decision to alter the water level at the Šance dam above Ostravice, where the right bank of the reservoir is under constant monitoring due to the instability of the slope above it. The largest number of dams were built in the second half of the 20th century, though these were often constructed at locations that had already been identified and recommended around the turn of the century. With a certain degree of exaggeration, we can speak of a golden age of dam-building during the massive economic boom that followed the end of the Second World War. From 1950 onwards, the newly installed communist regime in Czechoslovakia used propaganda to promote dams as "great socialist structures", and "work brigades" (ostensibly "voluntary" groups of workers and students) were used in the state's dam-building programme.

Until the mid-20th century, water management structures and infrastructure were built on a "bottom-up" basis, in response to the needs of municipalities, local agriculture, industry, or flood protection. In most cases, the local populations were supportive of these projects. The situation changed after the communists seized power in Czechoslovakia in 1948. Water management was treated as a separate industry, and like all other industries, it was subject to centralized state control. In 1949 a nationwide water management survey was conducted. Its aim was to create a comprehensive register of watercourses, hydraulic structures built on them, and the quantities of water consumed by individual industrial companies. The conclusions of this survey were incorporated into the State Water Management Plan, which was drawn up in 1954 with support from the Central Bureau for Water Management. The survey was a major undertaking, and some parts of it are still used today, as well as being reflected in legislative instruments (e.g. the register and protection of locations that are suitable for surface water accumulation, protected areas of natural water accumulation, etc.). Other parts of the Plan became subject to ongoing annual updates, creating a body of documents which helped improve efficiency in water management (water management maps, audits of water volumes and quality, water management systems control, etc.). Negative aspects of this period included a rapid increase in water consumption and the drastic neglect of anti-pollution measures – in other words, the perception of water as an inexhaustible natural resource. However, obstacles to new construction projects – such as private ownership, local community networks, public opinion, and so on – were easy for the communist-era authorities to circumvent. This planned construction of water management facilities, imposed on a "top-down" basis and sometimes with the use of force, caused dissatisfaction among certain sections of the population, and it also led to a number of problems that have still not been adequately addressed to this day. One example is the catchment area around the Švihov reservoir, where there are official restrictions on agricultural and other activities, despite the fact that the advantages of these restrictions are not felt by local residents, but rather by the inhabitants of Prague, who benefit from better-quality water.

During the 1970s, water management in Czechoslovakia moved into a new phase of development associated with a general process of economic and societal stagnation. The previously dynamic growth of public water supply and sewage systems slowed almost to a complete halt, and new developments were essentially stalled at the planning stage. Due to the inherent issues with the centrally planned economic system, there was a lack of motivation either to improve the efficiency of production or to reduce levels of water pollution. Theoretically Czechoslovakia's water management system was among the world's best; its legislation (Government Directive no. 25/75) stipulated that surface water should be of sufficient quality to enable "normal life by fish of the trout type in watercourses, and by fish of the carp type in other bodies of water"; the legislation also stipulated that surface water should possess "undisrupted self-purifying capability". In practice, however, the construction of wastewater treatment plants lagged behind, and the state dealt with this situation by granting thousands of exemptions to the ban on releasing wastewater into watercourses. In the 1980s the economic situation deteriorated to such a level that some construction projects already underway were halted, and work on them did not resume until the 1990s (e.g. the Dlouhé Stráně PSHPP).

The years following the collapse of Czechoslovakia's communist regime in 1989 brought many changes in the field of water management. Currently, water management falls within the purview of several ministries of the Czech Republic, chief among them the Ministry of the Environment and the Ministry of Agriculture. The Czech Republic's accession to the European Union meant that it adopted the relevant EU legislation, which is rooted in the 2000 Water Framework Directive. This legislative instrument emphasizes the role of water as an element in the environment. The principles underlying the directive are not alien to the Czech Republic, and their official adoption is in line with the previous aspirations of numerous water management experts and hydrobiologists, as set out already in the 1954 State Water Management Plan: retaining water in its natural state, coordination of water management on the basis of hydrological entities (drainage basins), long-term planning, the use of the best available technologies in industry, and so on.

With regard to water management infrastructure, this is now substantially more fragmented than was formerly the case, as facilities have been acquired by municipalities or private owners (including large foreign-owned corporations). The problems associated with this situation have become increasingly evident during recent periods of drought, when water has become a resource that is a subject of disputes. On a small scale, these disputes may arise if a householder sinks a deeper well, thus taking water from neighbours. On a large scale, disputes may spill into international relations, as in the conflict between the Czech Republic and Poland over the expansion of the open-cast coal mine near the Polish town of Bogatynia.

The current water management situation in the Czech Republic does not enable the construction of strikingly individual buildings with interesting architecture. However, measures implemented to ensure that water resources are used more sustainably have brought improvements to the landscape (reducing the area of land given over to monocultures, revitalizing watercourses and networks, accompanying vegetation) as well as aesthetic improvements in urban areas (green roofs and façades, greenery plantings, park maintenance, the installation of small water features).

2. THE CURRENT STATE OF HERITAGE PROTECTION AT WATER MANAGEMENT SITES IN THE CZECH REPUBLIC

The legal protection of industrial heritage (as part of the Czech Republic's cultural heritage) is currently defined by Act no. 20/1987 Sb. on state heritage management, which replaced Czechoslovakia's first heritage protection law (Act no. 22/1958 Sb. on cultural monuments).

Note: The 1958 Act on cultural monuments introduced the practice of listing in the Central Register of Cultural Monuments (formerly known as the State Register of Cultural Monuments); this process was delegated to regional authorities, which collaborated with district authorities and heritage management workers to conduct initial surveys. The 1987 Act on state heritage management transferred responsibility for maintaining the Central Register of Cultural Monuments to the predecessors of today's National Heritage Institute. Now, a site or item does not become a cultural monument by being listed in the register; instead it is declared (or not declared) a cultural monument on the basis of a decision made by the Ministry of Culture.

The Czech Republic currently has approximately 2,500 cultural monuments, both movable and immovable, which can be characterized as technical monuments or industrial heritage sites. These monuments include movable and immovable heritage sites/items associated with industrialization, as well as bridges, structures from the pre-industrial period associated with the storage and processing of agricultural products, water-powered technical structures, or elements of water supply and management systems.

Of these 2,500 monuments, around 700 are related to water management. These include structures using water power – i.e. water mills (235), hammer mills (10), mangles (2), fulling mills (2), and hydro power plants (17). The large number of water mills is a consequence of extensive ethnographic research conducted during the 1960s and 70s, which encompassed production sites that sit on the boundary between ethnographic and technical monuments.

This set of 700 water management-related monuments also includes 382 fountains, which thus make up over half of the total water management structures listed in the Central Register. This disproportion is due to the art-historical, architectural and urbanistic values embodied in these fountains; as artistically executed structures situated in prominently visible locations, they represent important elements of the urban fabric in numerous historic cities and towns.

Classifying these water management-related monuments into the six categories used in this publication, their representation (both as individual monuments and as component parts of larger complexes) is as follows:

- dams (13);
- small reservoir-type structures: around 40 ponds, either as individual monuments or as component parts of larger complexes, e.g., the Rožmberk pond system (others also form part of castle/chateau complexes and their parks, etc.);
- watercourses (or structures for transporting water or goods): around 80 monuments, including aqueducts, weirs, docks/quays, locks, mill-races, retention facilities, canals, etc.;
- structures forming part of water management systems: approximately 175 monuments, of which the most commonly represented types are water treatment plants (35, including railway water towers), water towers/tanks (58), wells (around 60), plus other structures/complexes, all represented by less than 10 monuments (water supply conduits, water supply networks, cisterns, sources, pumps, small wells, deacidification stations at water treatment plants);
- structures related to sewerage and water treatment: a wastewater treatment plant (1), a sewer network (1, Slavonice).

Besides the above-listed monuments, the following structures are also related to water management (each represented by less than 10 monuments): fish reservoirs, water sources/springs (in connection with spa facilities), pumping stations, water cranes. A larger group consists of ditches, channels, swimming pools, reservoirs, fountains, ornamental fountains and cascades that are protected as part of the grounds of castles/chateaux and monasteries.

The UNESCO World Heritage List includes the following complexes in the Czech Republic which also incorporate water management-related structures:

- Erzgebirge / Krušnohoří Mining Region (joint nomination – Germany / Czech Republic), including hydraulic structures for ore mining and processing (e.g., the Horní Blatná Water Ditch);
- Landscape for Breeding and Training of Ceremonial Carriage Horses at Kladruby nad Labem, including a water tower and engine-house (2019);
- Lednice-Valtice Cultural Landscape, including structures at the Lednice chateau – a water works, an aqueduct, a small hydro power plant, a quay, a fountain, and two ponds – the Chateau Pond and the Rose Pond (1996);
- Gardens and Castle at Kroměříž (1998) with three ponds in the castle garden (Long Pond, Wild Pond, Chotek Pond) and the Trout Ponds in the Pleasure Garden; Historic Centre of Prague (including Průhonice Castle, 1992); Holašovice Historic Village (1998); Historic Centre of Telč (1992) including the pond system.

Czech sites currently on the indicative list for inscription on the World Heritage List are an old wastewater treatment plant in Bubeneč (Prague) and the Třeboň fish-pond heritage complex. Water management-related sites also form part of heritage-protected areas. Examples include the above-mentioned water ditches in the protected landscape zones of the Krušnohoří region (which were associated with ore mining and processing), as well as the Ostrava-Vítkovice urban heritage zone (covering an area shaped by heavy industry, housing schemes and social infrastructure, and also including elevated water tanks that were built to serve industrial facilities and the newly constructed town). Many heritage reservations and urban heritage zones in the historic centres of towns and cities include fragments of the earliest water management systems (water towers, fountains) as well as more recently built structures related to water management or watercourse regulation (e.g., for purposes of navigation or power generation). Village and landscape heritage zones include structures such as wells, mill-races, reservoirs, ponds, pre-industrial production facilities using hydro power, etc.

The protection of water management-related sites and structures in the Czech Republic faces an obstacle in the form of the current, somewhat one-sided approach taken by heritage management professionals; generally, the prioritized values are artistic, architectural or ethnographic. For this reason, the Central Register of Cultural Monuments contains numerous examples of fountains (due to their artistic value), water towers (for their architectural and urbanistic value, and in some cases due to their having been designed by prominent architects such as Jan Kotěra or Josef Gočár), or water mills (for their ethnographic value). Other types of water management-related sites and structures tend to feature in the Register only in small numbers, and in isolation (i.e., without acknowledging the connection with the water system of which they form a part, and without which they would cease to be significant).

The main problem facing legally protected water management-related sites and structures is the fact that taken in their entirety, they do not represent an overview of the various types of water management sites/structures that exist or of the key phases in the historical development of these sites/structures. This publication devotes a substantial amount of space to a typology of water management sites/structures and their historical development; it will thus help to rectify the imbalance in the protection granted to the individual types.

A further aspect of heritage values that is analyzed and discussed in detail within this publication – though it has not yet been adequately reflected in the legal protection granted to relevant sites and structures – is the understanding of water management sites/structures as integral parts of a larger entity (system), whether on the local, regional, national or international level (especially with reference to canal systems).

3. EVALUATION OF WATER MANAGEMENT SITES FROM THE PERSPECTIVE OF HERITAGE MANAGEMENT

3.1 THE APPROACH TO THE EVALUATION OF INDUSTRIAL HERITAGE IN OTHER COUNTRIES

Industrial heritage comprises an extensive set of physical remains encompassing practically all forms of human activity in the fields of production (and resource extraction), transportation (including communications) and storage, spanning a lengthy historical period. The purpose of heritage management is to record, document and evaluate these remains, and when they are adjudged to be of exceptional value, to protect them.

The principles applied to the evaluation of industrial heritage from the perspective of heritage management have evolved over the course of time into an international consensus of opinion, which is presented in the specialist literature and in internationally accepted documents (see Matěj and Ryšková, 2018).

The differences in how individual countries deal with their industrial heritage are rooted in the degree of knowledge that has been attained (not all typological categories have been systematically documented and evaluated in all countries), as well as in each society's approach to the values identified. Exceptional sites, structures and technical equipment do not enjoy the same level and type of legal protection in all countries, and there are also differences in the degree to which the protected values are respected. In practice, we can witness a wide spectrum of approaches, ranging from full respect for identified values (including the unique atmosphere of the location, the genius loci) to the partial or complete suppression of these values as a consequence of a failure to understand the original functions and typological values represented by a particular site/structure, or due to inappropriate creative ambitions which lead to the deliberate (subjectively perceived) alteration of original architectural forms.

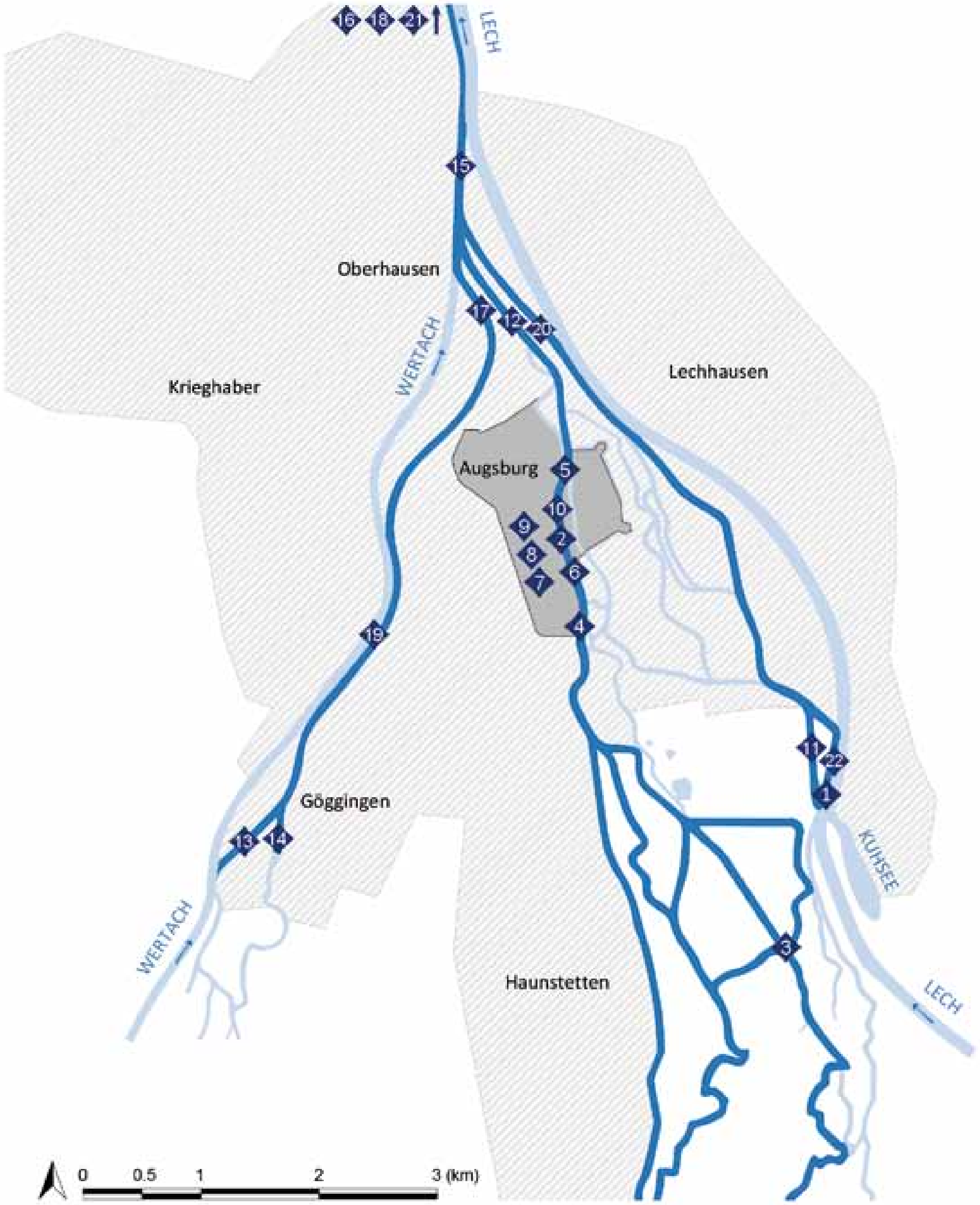

Fig. 3.1: Augsburg (Germany), water management system: 1 – the Hochablass (high drain) weir is a retention facility for most of the city's canals, the weir as it is now dates from 1911–1912 with the exception of some elements that have been replaced; 2 – the canals of the River Lech were first mentioned in 1276, they supplied water to craft production sites, powered water wheels and later water turbines; 3 – Galgenblass (culvert) – the most important intersection of watercourses, enabling drinking water and non-drinking water to be kept separate from each other; 4 – the Red Gate water works – a set of three water towers with a pumping station, which supplied the city with water from 1416 and is considered Central Europe's oldest known water supply system, its pumping engines remained in operation until 1880; 5 – the lower waterworks, operational from around 1500; 6 – the Vogeltor waterworks, dating from 1538, in 1774 the wall tower was converted into a water tower; 7–9 – a set of three monumental fountains topped with bronze statues and sculptural groups: the August Fountain (1594, no. 7), the Mercury Fountain (1599, no. 8) and the Hercules Fountain (1602, no. 9); 10 – the municipal slaughterhouse (1609) featuring the innovative use of water drawn from a canal that passes through the building in order to cool meat and dispose of waste material; 11 – waterworks at the Hochablass weir, marking the beginning of the city's modern water supply system (1879–1880); 12 – power plant on the municipal stream – built in 1873 originally as a cotton spinning mill (the largest spinning mill in Germany at the time); 13 – power plant on the factory mill-race, opened in 1885 originally as a power source for a yarn spinning mill, still in operation today; 14 – Singold power plant, opened in 1887 as a power source for a yarn spinning mill; 15 – Wolfzahnau power plant (1901), built for a cotton spinning mill, with a huge flywheel that was displayed at the Paris World Expo; 16 – Gersthofen power plant on the Lech canal, opened in 1901; 17 – power plant dating from 1904, originally to supply power to an engineering works, machinery (no longer functioning) from 1923 has been preserved, the plant is still in operation with modern machinery; 18 – Landweid power plant on the Lech canal, opened in 1907, originally to supply power to a factory and later also for the public power network, today it houses a museum devoted to the River Lech; 19 – power plant (1920) on the Wertach canal, which in addition to producing electricity was also designed to reduce the risk of flooding, it was originally built to supply power to the public transport system; 20 – power plant (1922) built to supply a cotton spinning mill, the turbine and generator dating from 1922 are still in operation; 21 – Meitingen power plant (1922), the city's only hydro power plant still in operation using its complete original machinery; 22 – the "ice canal" built for the 1972 Olympic Games, the first man-made whitewater canoe course, still in use. Diagram by Radek Míšanec, 2021 (modified according to: Das Augsburger Wassermanagement-System. Available at: https://wassersystem-augsburg.de/de/interaktive-karte).

Fig. 3.2: Augsburg (Germany), water management system: (A, C) water towers at the Red Gate, (B) Gersthofen power plant on the Lech canal; (D, E) Hochablass weir. Photograph (A, C, D, E) by Michaela Ryšková, 2019 and (B) by Radek Bachan, 2022.

We can witness a general shift away from the protection of individual sites or structures (detached from the overall context of technological flows and functional complexes) and towards the protection of entire systems. This trend is reflected in (and also influences) the selection of successful candidates for inscription on the UNESCO World Heritage List. A model example from the field of water management is the successful nomination of the water management system of the city of Augsburg (2019). This system evolved in successive phases over the course of eight centuries (beginning in the 14th century). It comprises a network of canals, water towers from the 15th–17th centuries (including pumping stations), a water-cooled slaughterhouse, a set of three monumental fountains, and functioning hydro power plants. The technological innovations associated with the operation of this system meant that Augsburg ranked among the pioneers in the development of hydraulic engineering. The system's value lies in the combination of elements from the earlier phases of development (which are no longer functional but have been preserved) with fully functional hydraulic structures and hydroelectric power plants dating from the late 19th century and the first half of the 20th century. The system thus offers a comprehensive insight into the importance of water for the development of cities, incorporating not only issues connected with the (drinking) water supply, but also the importance of water for economic development, embodied in the use of water to power production facilities in the pre-industrial and industrial eras.

A similar concept is found in proposals for the protection of systems incorporating hydraulic structures and buildings supplying hydroelectric power to industrial customers and municipalities; this is typical of the industrial heritage of Norway, which is closely associated with hydroelectric power and water transportation. The Vemork and Saheim hydroelectric power plants (and the protection granted to them) are presented in Chapter 5.

Central European water management systems are represented by the Erzgebirge / Krušnohoří Mining Region, which includes structures and landscape remnants connected with ore mining and processing, as well as hydraulic structures which were used in these processes (inscribed on the UNESCO World Heritage List in 2019; see also Chapters 2 and 5).

Although attention partially remains focused on specific types of structures (particularly those that represent the most "visible" components of water management systems, such as elevated water tanks), internationally there is a clear tendency towards incorporating these structures into wider-ranging systems and evaluating them as part of these systems.

3.2 THE APPROACH TO THE EVALUATION OF INDUSTRIAL HERITAGE IN THE CZECH REPUBLIC

In 2018, the National Heritage Institute's Methodological Centre for Industrial Heritage published the *Methodology for the Evaluation and Protection of Industrial Heritage from the Perspective of Heritage Management* in order to define a unified concept and approach to the field. The publication set out to define the key terms and evaluative criteria as well as presenting the ways in which industrial heritage can be managed (Matěj and Ryšková, 2018).

In order to determine heritage value, it is essential to assess the individual values of each assessed item – both from the perspective of traditional evaluative categories applied to monuments and also considering the specific nature and features of industrial heritage.

Traditional heritage values are the following (these may acquire new dimensions in connection with industrial heritage):

- art-historical value,
- architectural value,
- urbanistic value,
- value deriving from age.

Among the most important types of values that are specific to industrial heritage are the following:

- historical value (in the sense of positive or negative information);
- typological value – deriving from the site's or structure's role in the typological development of the industry/field; a key task is to identify typical representatives, unique representatives, and the first and last representatives of a particular course of development; typological value also includes the value of emblems and symbols from a particular industry/field, the value of a model solution, or a repeatedly used module;
- value deriving from the technological flow (process), i.e. the process beginning with the raw materials and ending with the final product (including the role of individual steps within this flow as part of the complete production cycle and related technological flows); an item (structure, building) that is unimportant when viewed in isolation may be valuable due to having played a key role in a technological flow that has survived in its entirety;
- value deriving from systemic and technological interconnections – the item is thus viewed within its broader context, comprising mutually interlinked and interacting flows of raw materials, products and related transportation systems that transcend the boundaries of the site, region, or even country;
- the technical value of individual pieces of equipment and technological complexes;
- value deriving from authenticity in relation to industrial heritage, in relation to individual categories – the authenticity of the volume, form, function or production process, including the definition of "last working day" authenticity, i.e. the preservation of a structure/site in the same condition as when it was last used for its intended purpose, thus bringing its process of development to a close;
- value deriving from the atmosphere of the location (genius loci), in this case from the industrial environment (Matěj and Ryšková, 2018).

By taking into consideration the above-listed values, it is possible to achieve a comprehensive assessment of the value of an item (building, structure, machine, technical equipment) and a complex (industrial complex, agglomeration, linear structure, etc.). This in turn facilitates the objective selection of the most important representatives of individual industries or fields. A qualified assessment of values should lead to the selection of genuinely representative examples that are worthy of heritage protection, as well as helping to prevent their values from being suppressed or obliterated. The higher the value, the less potentially damaging interference should occur. The lower the value, the greater the scope for modernization or modifications connected with conversion for new uses.

From this perspective, it is possible to formulate four ways of dealing with industrial heritage:

- preservation of the original function (the ideal solution, even at the cost of necessary compromises arising from changing requirements for performance or safety);
- preservation of an authentic operation in the form of a museum exhibit, for the most important physical remains; the extreme form of this is the preservation of "conserved information" from the last working day;
- the physical relocation (transfer) of a structure or part of it, if it is not possible to preserve it at its original location (most commonly in connection with the musealization of machinery and technical equipment);
- conversion – possibilities for new use if the original function has been lost.

3.3. APPROACHING THE EVALUATION OF WATER MANAGEMENT SITES

The methodology for the identification of potential heritage values of water management sites (structures) and the evaluation of their importance for heritage management, preservation and protection is drawn from the general methodology presented by Matěj and Ryšková (2018), which is outlined above in Chapter 3.1.

When selecting a set of evaluative criteria with relevance to water management sites (structures), the authors have taken into consideration the specific features of the various types of water management sites dealt with in this publication. The importance of each of the various values may differ depending on the type of site or functional entity being evaluated. A typical feature of water management sites in general (as a consequence of their nature and expected functions) is the fact that they only rarely operate (perform their function) independently, without any interconnections to other water management sites. For this reason, it is very important to identify these interconnections, describe them, and assess their importance within the framework of a larger or smaller functional entity (complex). A separate building or structure may not be particularly exceptional in its own right, but when viewed as part of a wider functional entity, it may contribute to a unique concept or solution. For example, the individual components of water supply or water treatment systems may be standardized designs (produced in series), but a system such as this may represent a unique entity (this uniqueness may consist in the adaptation of a solution to the specific conditions of a particular location). The opposite is also true, of course: it may happen that an otherwise standardized functional entity incorporates a particular building or structure that is in some way unique.

Water management buildings/structures

Buildings or technical equipment with functional structures performing one or more water management functions (water supply, anti-flood protection, water accumulation, water transportation, etc.). A water management building/structure may stand separately, or it may form part of a larger functional entity (e.g. a weir with/without a hydroelectric power plant, a small reservoir, a retention facility, a cistern, a dam, etc.).

Functional entities

Complexes of water management buildings/structures with one or more functions, which are functionally interconnected on the local, regional, national or international level. Individual buildings/structures may have their own functions or a set of functions, which they perform by means of the equipment inside them, or they may exist in close conjunction with other buildings/structures, enabling the function to be performed at a higher level (in terms of area or volume) or enabling other functions to be performed by other types of buildings/structures within the framework of the functional entity (complex). Examples include a dam with a hydroelectric power plant or a water supply draw-off, a weir with a head-race and a hydroelectric power plant, a complete water supply system (a reservoir, a draw-off facility, a water treatment plant, conduits, water retention facilities, etc.), the Vltava River Cascade (a series of nine hydraulic structures and related structures), a canal with locks (gates and chambers), boat elevators, and hydroelectric power plants.

Evaluative criteria

The expert perspectives applied to the evaluation of a particular water management building/structure or functional entity in connection with the identification of its potential importance as a heritage site. Each evaluative criterion is defined via a description of the values that are considered when evaluating the site, i.e., evaluating whether and to what extent the site embodies those values. This can be expressed via a categorization of the criterion in question. Each criterion may also assume a different degree of importance (weighting) in the overall evaluation of a particular water management building/structure.

The text below presents a set of evaluative criteria that are decisive for identifying potential heritage values in water management-related buildings/structures and functional entities. The criteria are listed here in descending order of their importance within the process of evaluation.

In accordance with the general methodology presented by Matěj and Ryšková (2018), the most important task is to identify the unique nature, or on the other hand the typical nature (i.e. the extent to which it is a representative example of its type), of the evaluated site within the overall typological development of the particular type under consideration – in both the national and international context, if possible (see also Föhl, n.d.). The value of uniqueness is already mentioned in work by Radová (1987). The degree of uniqueness grows in direct proportion to the decreasing number of similar representatives of the same type. Likewise, Douet (2018) states that when evaluating water management sites as representatives of cultural heritage (on both the national and international levels), it is essential to identify major historical milestones in order to be able to recognize outstanding and representative sites with potential heritage value. Douet ranks this as the most important criterion for water management-type heritage sites – and indeed its importance is also paramount when evaluating representatives of other industries. Particular emphasis is placed on evaluating the parameters of the structural and technological aspects of the site, i.e., the structural and technological solutions that are applied. Other criteria of key importance for water management sites are the values deriving from the technological flow (process) and systemic interconnections, which are of particular relevance in the case of functional entities. As these play a crucial role in water management infrastructure, it is essential to describe and explain the links between individual buildings/structures on all levels of functionality. A functional entity frequently represents either a unique solution (e.g., a series of dams) or a standardized solution (e.g., in the case of wastewater treatment plants).

With regard to authenticity, the heritage value of water management sites derives not only from the traditional concept of authentic volumes, materials or forms; a further crucial consideration is the degree to which the original functions of buildings/structures and technical equipment have been preserved.

3.3.1 TYPOLOGICAL VALUE

When applying this criterion, it is essential to be aware of the overall course of typological development of the evaluated type, including key milestones, typical representatives and unique sites (Fig. 3.3). Additionally, it is advantageous to be aware of the number of existing structures of the given type, if such information is accessible – e.g., if an acceptable number of examples exists to enable assessment. For each type of water management structure, it is necessary to correctly identify and describe the characteristics which define it from the perspective of its typological development and which are essential for evaluating its importance. The typological development of the types of water management structures dealt with in this publication forms the subject of Chapter 4.

A structure can be deemed to have an **exceptional character** if it embodies one of the parameters listed below; it is necessary to assess both structural characteristics (e.g., a dam wall structure, the structural part of a weir) and technological characteristics (e.g., the closure mechanisms of the bottom outlets, dam wall segments), as well as the methods used. The uniqueness of a structure can be assessed within various contexts, ranging from the local to the international:

- the first structure of its type,
- the oldest surviving structure of its type,
- the only surviving structure of its type,
- exceptional parameters (both structural and technological),
- exceptional structural solutions/use of a particular technology,
- exceptional occurrence within the Czech Republic/internationally.

Fig. 3.3: Březová aqueduct no. 1: (A) aqueduct supply valve; (B) gate valve chamber; (C) entrance to the Holé hory 2 water tank; cast iron long-distance aqueduct for drinking water (57 km), preserved in its original form with the exception of the addition of a remote control system to operate the machinery. Photograph (A, B) by Miriam Dzuráková, 2018 and (C) by David Honek, 2019.

A **typical representative** of a particular type of structure will display the characteristic features of its type, and (in an ideal case) its current condition will be good or adequate – i.e., the structure and its technologies will be completely preserved and functional (preserving the authenticity of both function and form). A typical representative can be identified e.g., by evaluating similarities – i.e., comparing a set of structures on the basis of selected features. This will identify a group of similar structures, from which it is then possible to select a representative of the group. In order to apply this method, it is necessary to have access to data on the characteristics of structures of the given type; this has been the case e.g., in the evaluation of dams in the Czech Republic for purposes of heritage protection conducted by Špana et al. (2021).

3.3.2 VALUE DERIVING FROM THE TECHNOLOGICAL FLOW (PROCESS)

The notion of technological flow is connected with the existence of functional entities (complexes). A structure may form part of a larger or smaller functional entity with one or more defined functions. An evaluated structure may be responsible for a complete phase in the technological flow (a dam; a water treatment plant; a weir), or it may represent the technological flow in its entirety (a dam with a hydroelectric power plant; a retention facility with an aqueduct and a water treatment plant; a weir with a lock), or it may form part of a wider-ranging complex representing a technological flow (e.g. the series of dams making up the Vltava River Cascade; a drinking water supply system as shown in (Fig. 3.4; a canal system). According to UNESCO (2016), the technological flow (i.e., the functional interconnection of individual structures) is a fundamental and characteristic attribute of the heritage of water management, which made a major contribution to the development of modern "network cities" (drinking water supplies, drainage/sewer systems, wastewater treatment, canal systems). It should also be taken into consideration that a structure may in the past have formed part of a technological flow (e.g., a water tower or similar retention facility), but nowadays it no longer performs its original function or has been converted for new use – yet nevertheless it may embody numerous other heritage values.

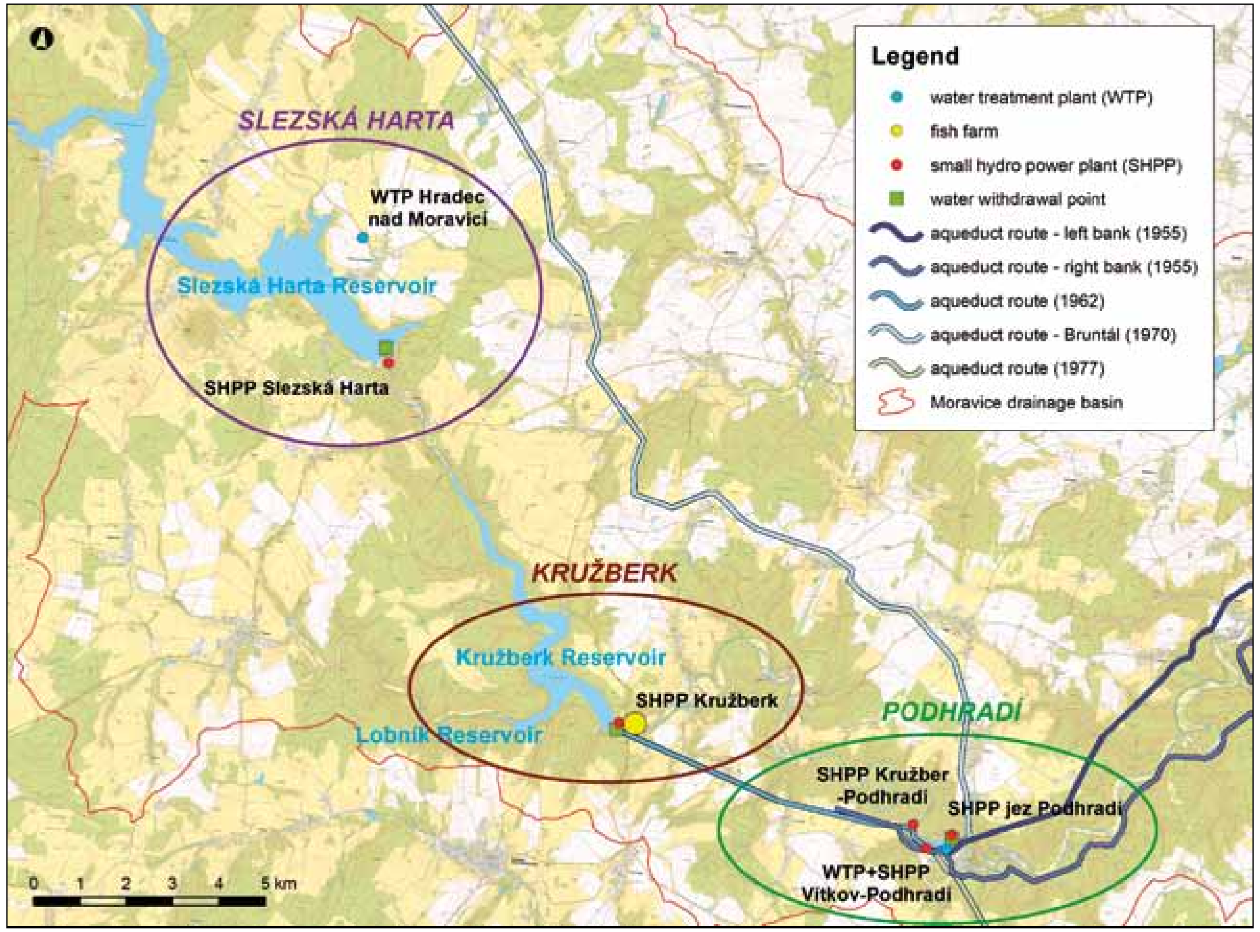

Fig. 3.4: Ostrava area aqueduct (Opava branch) – an example of a wider-ranging technological flow system; this complete system can be subdivided into three main functional entities which are mutually interconnected; the individual functional entities comprise structures which in their own right represent complete phases in the technological flow or the technological flow in its entirety (a dam with a small hydroelectric power plant, a water treatment plant, a long-distance aqueduct, a weir with a hydroelectric power plant). Diagram by David Honek, 2021.

3.3.3 VALUE DERIVING FROM SYSTEMIC INTERCONNECTIONS

When considering this value, a water management site is viewed as a technological entity in the wider context, i.e. in terms of its interconnections with other industries, transportation or power engineering systems. It is not defined (or delineated) in spatial terms; a water management site may have systemic interconnections at various levels, from the local up to the international level. Examples of systemic interconnections include mills, sawmills, water-powered hammer mills (Fig. 3.5; transportation canals, Fig. 3.6, 4.113–4.119), etc.

3.3.4 VALUE DERIVING FROM AUTHENTICITY

The value of authenticity expresses the degree to which a site has been preserved in its original state, viewed from a number of perspectives. The original state may be defined as the state at the time of building or when the site first became operational. However, it may also be decided that a certain phase in a site's represents a more valuable state – e.g., a remodelling or modernization which undisputedly enhanced the quality of a structure compared to its state when originally built. A deeper analysis of water management sites should particularly take into consideration the following:

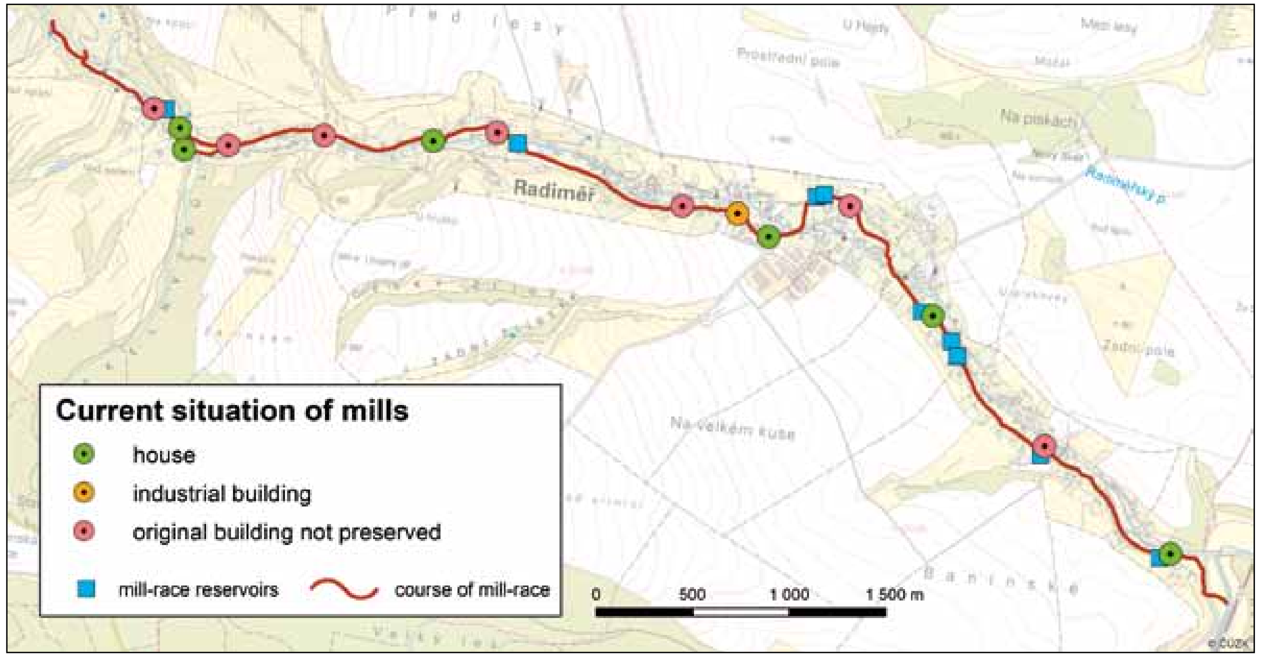

Fig. 3.5: System of the Radiměř mill-race, with 14 mills and 9 small hydroelectric power plants – current situation (the course of the mill-race has partially survived as a landscape remnant); an example of a wider-ranging technological flow system consisting of the mill-race and control devices (sluice-gates, channels for water wheels), small reservoirs to aid water accumulation in the mill-race, water wheels (not preserved) with systemic connections to the technologies used in water mills, which themselves represent a complete phase in the technological flow. Diagram by David Honek, 2020.

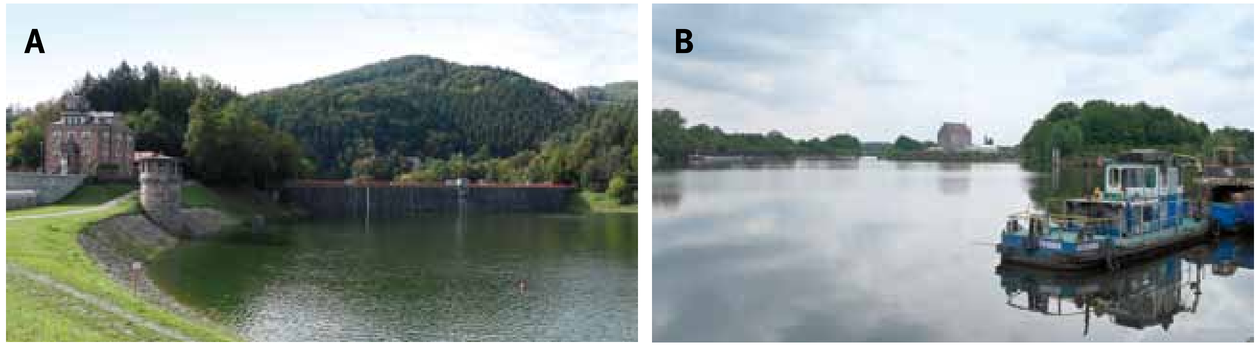

Fig. 3.6: Danube–Odra (Oder)–Labe (Elbe) canal (planned but not built). In 1908–1912 the Bystřička dam was built as a source of water for the planned canal. Another existing element of the planned system is the Polish port of Koźle on the Odra River. Photograph by Michaela Ryšková, 2018.

- authenticity of function,
    - value of the new use (if the original function has not been retained),
- authenticity of technical equipment,
- authenticity of technological solutions,
- authenticity of form,
- authenticity of material (the degree to which the original structure has been preserved).

In the case of **authenticity of function**, we assess a structure's functional continuity and its degree of authenticity – i.e., whether the evaluated structure serves its original purpose (or whether this original purpose has since been expanded or altered), whether it is still operational (or in a condition making it potentially operational), or whether the structure now performs an entirely new function (i.e. the original function is absent). One of the ways in which water management structures differ from other types of industrial heritage structures is that many of them still serve their original purpose, or will have to continue serving this original purpose even if they are identified as having heritage value. This is typically the case with structures used to collect and treat wastewater; it is rare for this function to be moved to a different location if the original structures are no longer adequate to serve their original purpose. Regular ongoing maintenance, renovation and modernization are an integral part of these structures' character (Douet, 2018); this is also acknowledged by Hughes (1996) in his study of canals as world heritage sites, as well as by the Nara Document on Authenticity (ICOMOS, 1994). Such cases are examples of "continuity through change" (Coulls, 1999); the cited text focuses on the cultural heritage of railways, but the same principle can also be applied to water management structures.

Even if a structure's function changes, the new use may nevertheless bring substantial (or even exceptional) added value from the perspective of heritage protection.

Evaluating the **authenticity of technical equipment** involves assessing the extent to which the original equipment has been preserved and documenting which changes (replacements) have been made due to repairs. This is connected with the **authenticity of technological solutions** – i.e., whether repairs and reconstructions of individual parts of the structure or equipment have been conducted using original technological solutions (tools, methods, technological processes).

In water management structures, it is usually the case that technological equipment has to be replaced and modernized if the structure is to retain its functionality and enable safe operation. All functional components are thus subject to regular maintenance, which usually applies new technologies and materials to ensure that the goals outlined above are achieved. Technologies and equipment that no longer serve their original purpose can be decommissioned but retained on site (in situ) as examples of older technological phases in the development of the structure or site. In the case of hydroelectric power plants, when necessary modernization is carried out in order to increase output, an ideal solution is to retain at least one element of the original machinery in situ.

When assessing **authenticity of form**, the current situation is compared with the original architectural or technical design (plans) and the situation immediately after the structure was built. Deviations from the original form may have been a consequence of subsequent modifications made in order to enhance safety (e.g., the addition of earth to the masonry-built Mariánské Lázně dam after the structure's height was raised) or the expansion of a structure's functionality (e.g. the subsequent addition of a hydroelectric power plant at an existing hydraulic structure, as when a power plant was later incorporated into the main structure of the Kružberk HS).

Authenticity of material involves the preservation of the original materials that were used when the structure was built. As in the case of technical equipment, material has to be regularly renovated and/or replaced if parts subjected to loading incur heavy wear and tear.

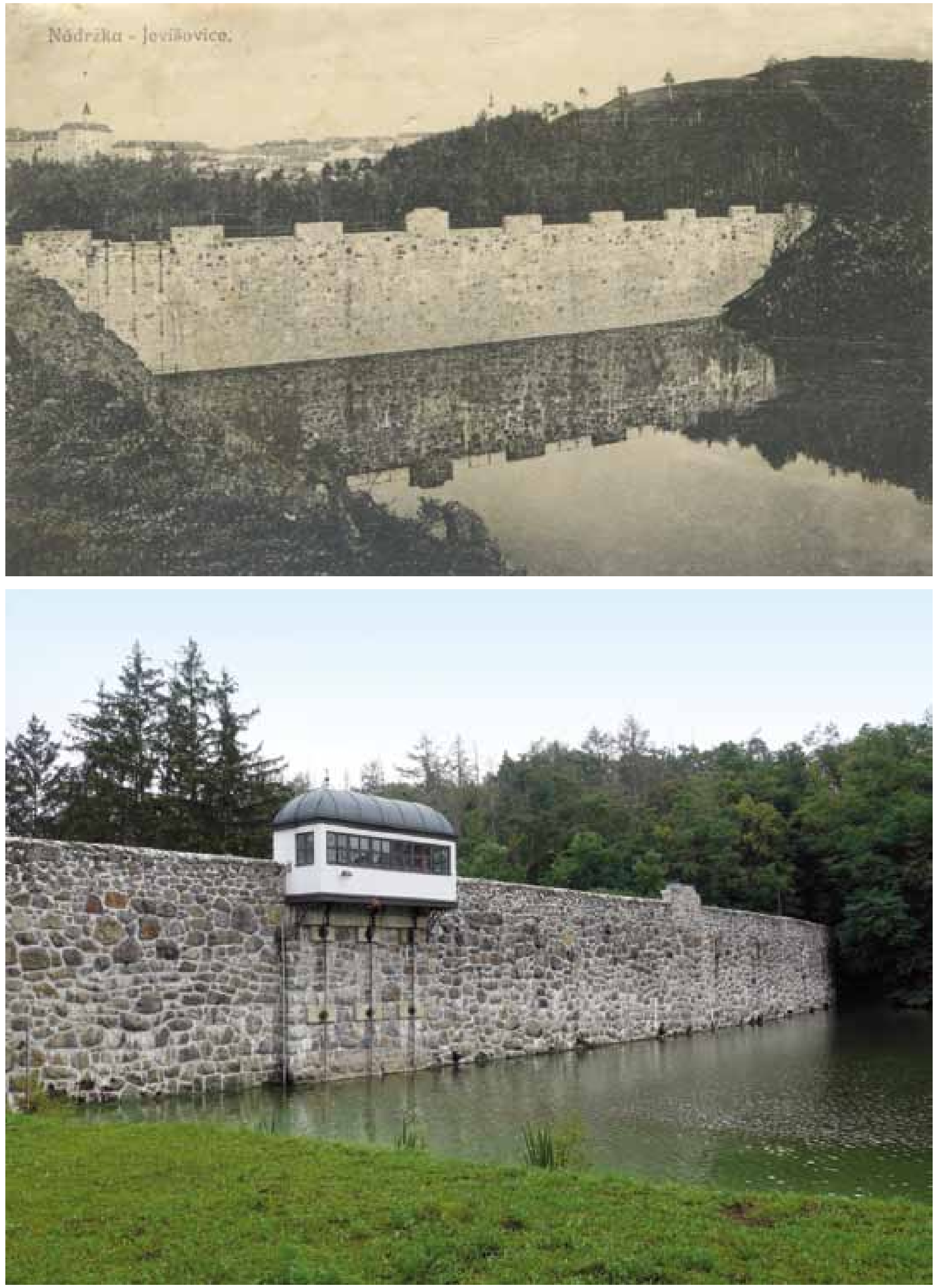

Fig. 3.7: The Jevišovice dam (1884–1896) is one of the two oldest masonry-built dams in the Czech Republic. The authenticity of form has been disrupted by modifications to the crest of the dam and the addition of an engine room containing the control mechanisms for the bottom outlets. Historical postcard, collection of Michaela Ryšková. Photograph by Michaela Ryšková, 2020.

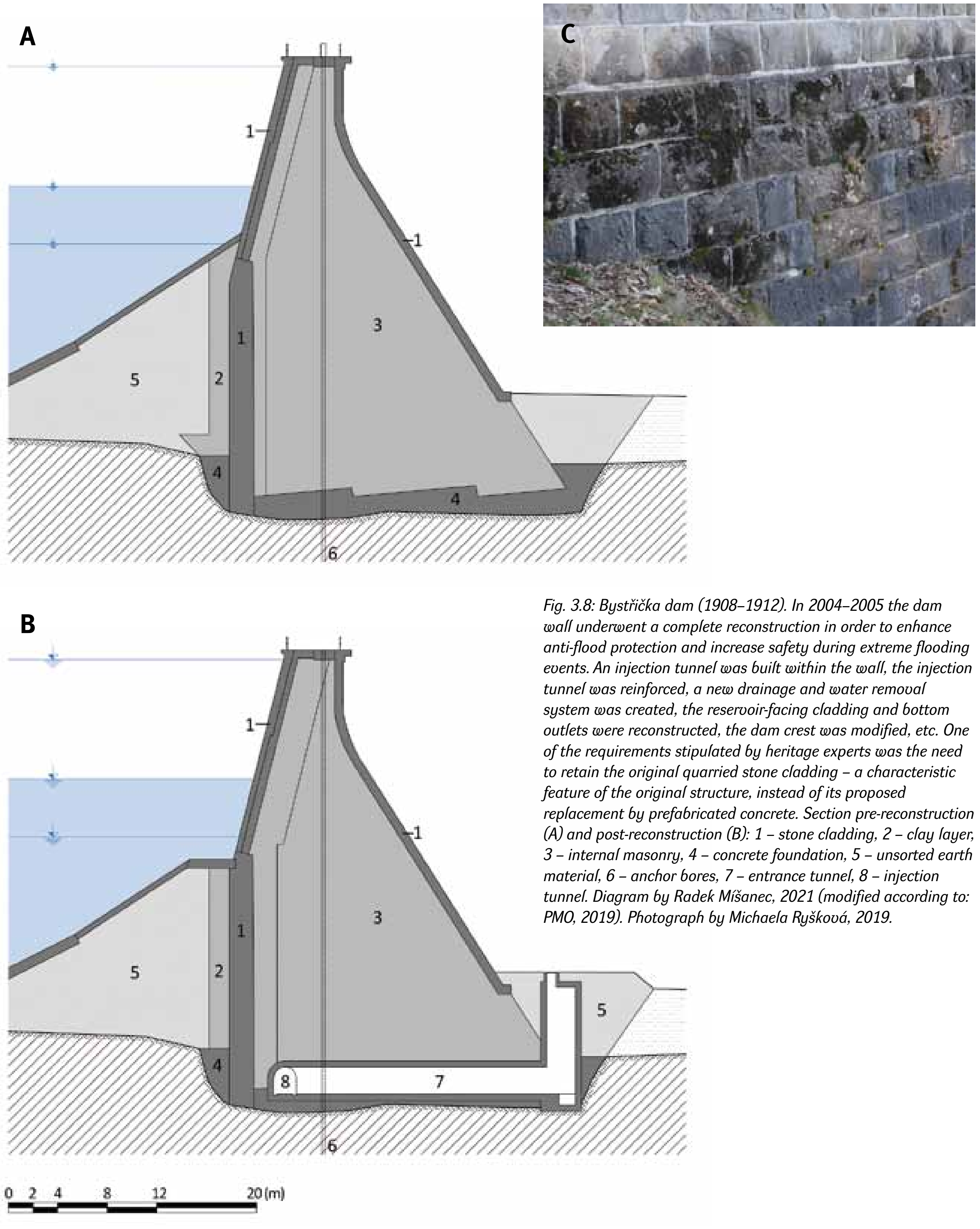

Fig. 3.8: Bystřička dam (1908–1912). In 2004–2005 the dam wall underwent a complete reconstruction in order to enhance anti-flood protection and increase safety during extreme flooding events. An injection tunnel was built within the wall, the injection tunnel was reinforced, a new drainage and water removal system was created, the reservoir-facing cladding and bottom outlets were reconstructed, the dam crest was modified, etc. One of the requirements stipulated by heritage experts was the need to retain the original quarried stone cladding – a characteristic feature of the original structure, instead of its proposed replacement by prefabricated concrete. Section pre-reconstruction (A) and post-reconstruction (B): 1 – stone cladding, 2 – clay layer, 3 – internal masonry, 4 – concrete foundation, 5 – unsorted earth material, 6 – anchor bores, 7 – entrance tunnel, 8 – injection tunnel. Diagram by Radek Míšanec, 2021 (modified according to: PMO, 2019). Photograph by Michaela Ryšková, 2019.

Fig. 3.9: Water towers: (A) Plzeň, late Gothic water masonry water tower, first documented in 1532. The Classicist pumping station (right) was built using stone from the city's demolished Prague Gate. The Gothic-inspired shape of the roof evidently dates from 1845, when the tower was raised as part of a reconstruction project carried out by the contractor Kristian Lexa. In 1843 the upper level of the tower contained a copper tank with a volume of 2.7 m^3. The pumping station was equipped with a metal-plated water wheel and a three-cylinder pump; it drew water from the river. The entrance portal, added during the 19th century, was originally from a house in the city (Hlušičková 2003). (B) Tábor, the Renaissance tower, with its sgraffito inscriptions and arched gables, was built after a fire in 1559. The town was supplied with water from the Jordán valley reservoir (1492); below the dam there was a pumping station with a wooden pump driven by a water wheel, which pumped water into a tower that supplied the municipal fountains (Vávra 1913). Today the building houses a gallery. Photograph (A) by Alena Borovcová, 2020 and (B) by Eva Dvořáková.

3.3.5 ARCHITECTURAL VALUE

Architectural quality is a traditional criterion for assessment when evaluating heritage value. It involves the assessment of whether a structure is a typical representative of a particular style, movement or period or whether it goes beyond these parameters, whether the structure consists of an agglomeration of multiple phases of high-quality structural development or whether it comprises an original core accompanied by later additions. Value is added if the design or construction involved important architects, designers or building contractors of the era.

In the case of water management structures, the situation is highly variable; many types are technical structures without architectural form (ponds, small reservoirs, modern water supply and treatment facilities). By contrast, there are also structures which were considered important and prominent at the time of construction, and in such cases their architectural quality often reflects this societal perception. In many cases, structures of high architectural quality were designed by prominent contemporary architects: the Háj hydro power plant in Třeština was designed by the architect Bohuslav Fuchs and Josef Štěpánek, the hydro power plant in Spálov was designed by Emil Králíček, the Zelená Liška water works with water tower in Prague by Jan Kotěra, a water tower in Lázně Bohdaneč by Josef Gočár, the Podolí water works in Prague and the Poděbrady power plant by Antonín Engel, and so on.

Besides the architectural design of water management structures, a further important aspect is the civil engineer and the contractor that built the structure. An example of this is the Lanna company, which during the 19th century and the first half of the 20th century built many important water management structures, among them the locks on the Labe River at Mělník and Nymburk, the weirs on the Labe at Miřejovice and Kostelec (including a hydro power plant) and on the Vltava River at Hluboká, the lock chambers on the lateral canal at Hořín and the Vltava at Štvanice in Prague, etc. The company also worked on the construction of the oldest concrete dams in the Czech Republic, at Vranov and Březová (Žákavec, 1936). She also participated in the construction of the oldest concrete dams Vranov and Březová (Žákavec, 1936).

Fig. 3.10: Former pumping stations: (A) Opava, (B) Brno. The appearance of this former steam-powered pumping station is characteristic of this type of building. It was a single-floor structure with a gable roof and windows incorporating semicircular upper sections. Photograph (A) by Alena Borovcová and (B) by Michaela Ryšková, 2021.

Fig. 3.11: Hořín, lock chambers, bridge and power plant on the Vraňany–Hořín lateral canal. Historical postcard, collection of Michaela Ryšková.

Fig. 3.12: Vienna-Nussdorf (Austria), bridge above a lock. The architecture of the lock, including the bridge and technical buildings (1894–1899), was designed by architect Otto Wagner (taken from: Wagner, 1910).

Fig. 3.13: Nymburk, a Secession water tower dating from 1904, designed by the architect Osvald Polívka and the engineer Jan Vladimír Hráský. Photograph by Michaela Ryšková, 2018.

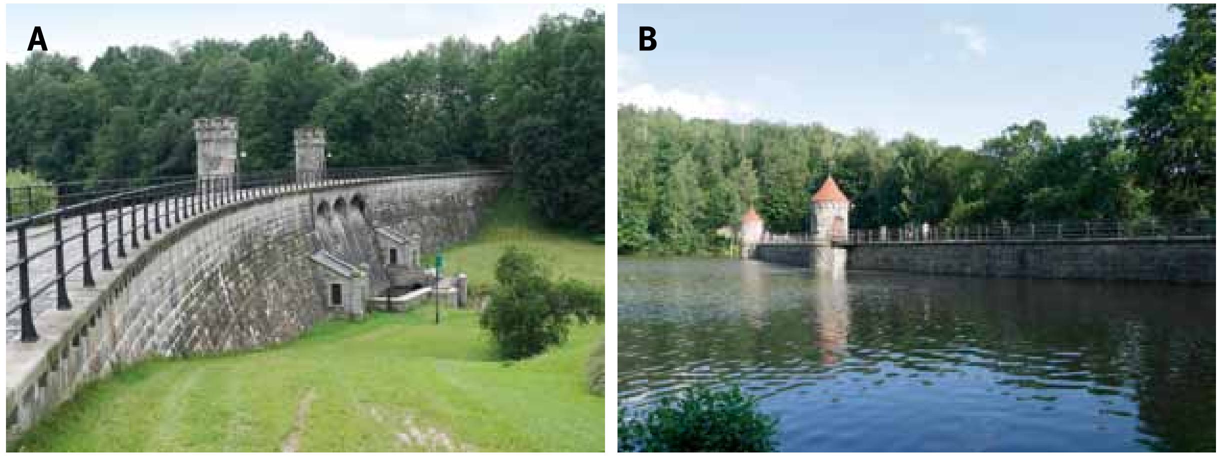

Fig. 3.14: Fojtka (1904–1906, A) and Harcov (1902–1904, B) dams, featuring a Historicist (pastiche) architectural style, were built as part of a flood protection project on the Lužická Nisa. Photograph by Michaela Ryšková, 2021.

Fig. 3.15: Třeština, Háj hydroelectric power plant (1922–1923) designed by architects Bohuslav Fuchs and Josef Štěpánek. Its function is expressed in its architectural language: the architectural elements depict the energy contained in the water and its transformation and concentration. Photograph by Viktor Mácha, 2019.

Fig. 3.16: The Vrchlice dam (1966–1970), punctuated by the control blocks at the dam crest, contrasting with the monumental outward-facing surface of the dam. Photograph by Viktor Mácha, 2020.

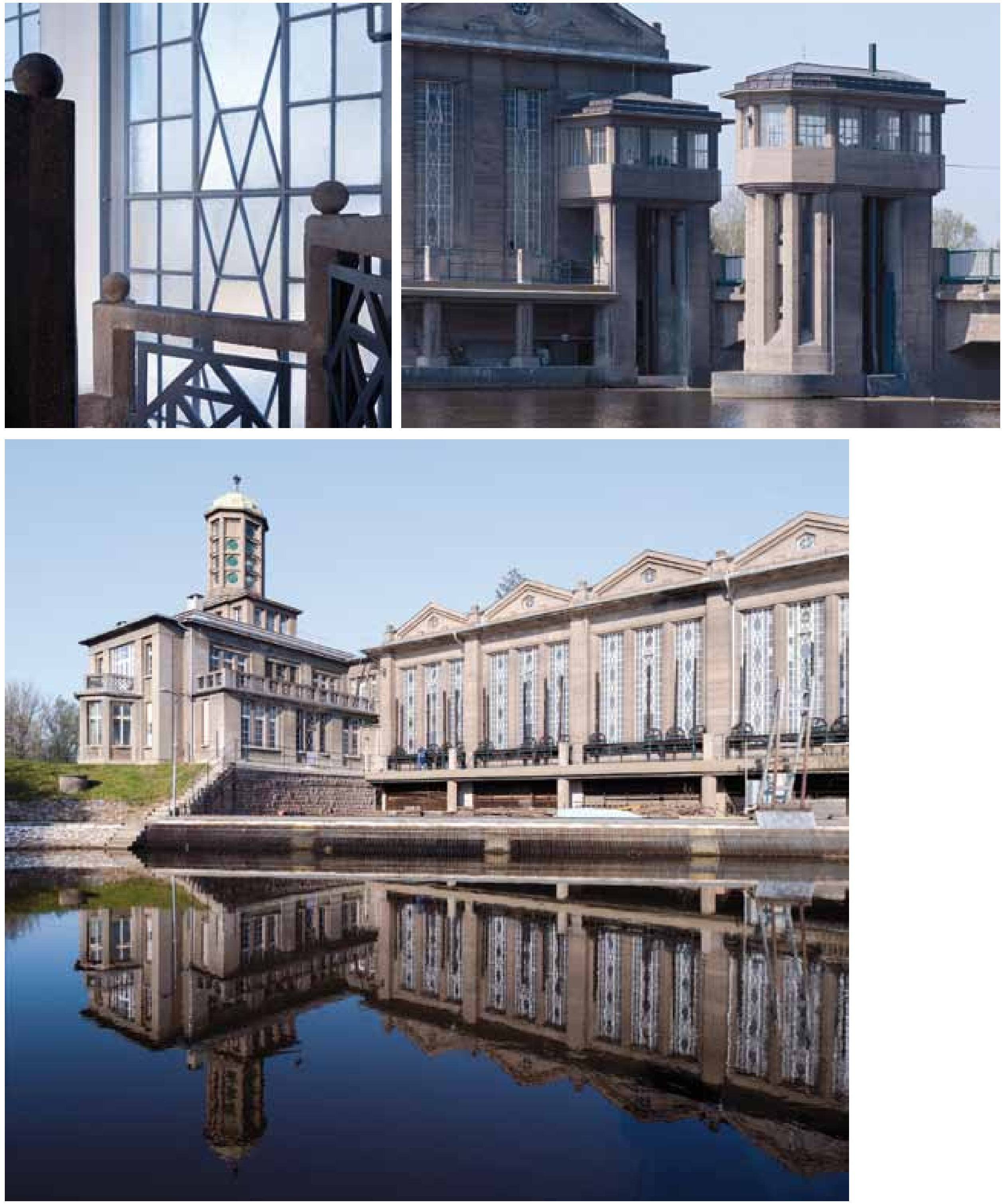

Fig. 3.17: Poděbrady, weir and hydroelectric power plant, the complex features a unified architectural style and was designed by the architect Antonín Engel. Photograph by Viktor Mácha, 2019.

Fig. 3.18: Vítkov-Podhradí, water treatment plant, cycle of reliefs 'Water in our Life' by the sculptor Vincenc Makovský. Photograph by Roman Polášek, 2019.

3.3.6 ARTISTIC-HISTORICAL VALUE

The artistic-historical value of a structure is evaluated on the basis of its decorative artistic elements (glasswork, ironwork, ornamental railings, glass bricks, ceramic elements, light metal features – water spouts, weathervanes etc.) and artistic detailing (masonry details, wall cladding, stucco, sgraffito, special plasterwork, glass mosaics, ceramic wall and floor tiles) or art works.

The incorporation of art works into water management structures was a typical feature of large-scale projects in the second half of the 20th century. Initially these works were in a realistic style, but during the 1960s a preference emerged for freer depictions, often including landscape elements and poetic allusions. The works in this new style expressed the importance of water to life. The works in this new style expressed the importance of water to life. Among the first works of this type were reliefs by Vincenc Makovský on the façade of the water treatment plant in Vítkov-Podhradí (Borovcová, 2011). Others included works at the Dalešice power plant, the Přísečnice dam, or the power plant at the Nové Mlýny reservoir (Lacina and Halas, 2017).

All works of art that have survived at water management structures should be respected as manifestations of the era when they were created, as well as forming an integral part of the structure and its wider vicinity. The art-historical evaluation of these works is a subject for separate research as well as a topic of ongoing discussion among experts (Skřebská, 2020).

Fig. 3.19: Znojmo, water retention facility with two reinforced concrete circular tanks, built in 1949–1950 to a design by Vilém Lorenz. The window on the street-facing side features glasswork entitled 'Allegory of the River Dyje', made from glass of various types and textures and created to a 1950 design by Vojtěch Kubašta (Stará, 2007). Photograph by Michaela Ryšková, 2020.

Fig. 3.20: Orlík hydroelectric power plant, the sculptural group 'The Creation of Electrical Energy' by L. Novák and J. Svojanovský, 1958–1963 (Sochy a města, 2021) and a mosaic in the entrance hall. Photograph by Viktor Mácha, 2021.

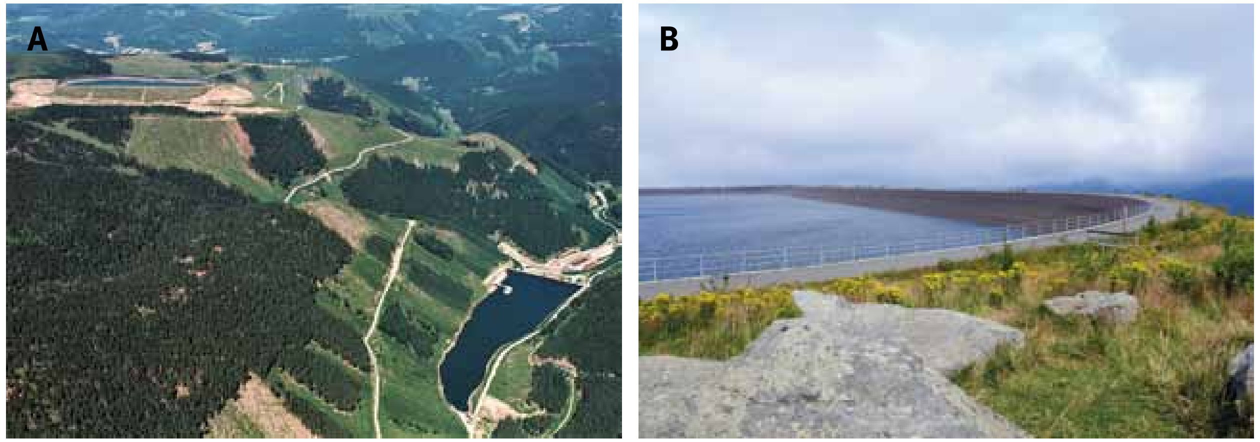

Fig. 3.21: Dlouhé Stráně PSHPP: (A) aerial photograph; (B) upper reservoir; an example of upper and lower reservoirs with controversial landscape/urbanistic value and a substantial impact on the appearance of the location. The upper reservoir has had a major impact on the panorama of the High Jeseníky mountains due to the removal of the hill's original summit, which has been levelled. Photograph by (A) Jan Höll, 1994, (B) by Michaela Ryšková, 2019.

3.3.7 LANDCAPE/URBANISTIC VALUE

This criterion involves the way in which a structure or building fits into the surrounding landscape – including its impact on the landscape and the transformation of the landscape due to subsequent construction (e.g. the concentration of industrial sites along a mill-race). The evaluation focuses on how the structure fits into the landscape, and how it affects the landscape:

- as a dominant landmark,
- as part of a panorama,
- creating identity for a city or place,
- as a landscape-forming element (the degree to which it is incorporated into its wider environment).

In a methodological publication focusing on the identification of urbanistic values, Kuča (2015) notes that *"the concept of a dominant structural landmark has a neutral value. Besides positive landmarks, there are also negative landmarks – disruptive structures which detract from the historic panorama of a settlement or from important, stabilized visual relations."* Kuča also emphasizes that it is only possible to speak of a structure's urbanistic value if this value is positive. In a revised definition of the concept of urbanistic value, the Institute for Territorial Development (2018) states that *"[t]he subject of evaluation is primarily the urbanistic configuration of a territory, vistas, sight-lines and visually related areas (e.g. green horizons), […] the presence of greenery and the quality of the environment as a place where time can comfortably be spent. In wider contexts, it involves not only the value of the urban structure of individual settlements that has developed over a lengthy period, but also the relations with the values of the surrounding landscape, as well as the value of the landscape itself, as it has been created and cultivated by long-term human activity."*

Douet (2018), in a comparative study for TICCIH focusing on water management structures as part of the world cultural heritage, states that it is particularly challenging to assess the importance of (for example) dams – not only because they are numerous, technically diverse and multifunctional, but also because their impact on the landscape (both above and below the dam) is perceived in varying ways. Opinions on the impact of these structures on the landscape differ substantially, especially in the case of larger structures or functional entities. A typical example is the Dlouhé Stráně PSHPP (Fig. 3.21), which is a major landscape-forming feature and a part of the panorama.

Fig. 3.22: Mělník, confluence of the Labe, Vltava and the Vraňany–Hořín lateral canal, view from the Mělník chateau. Historical postcard, collection of Michaela Ryšková.

3.3.8 HISTORICAL VALUE

This criterion encompasses a broad spectrum of parameters depending on the context – local history, the history of the industry or field, the history of technology, cultural history etc., including direct connections with historical figures and events of relevance to the structure. Historical value may be positive or negative.

Considering water management on an international level, Douet (2018) notes that a fundamental/universal topic is the way in which towns and cities dealt with the urban sanitary crisis that accompanied the process of industrialization. The concentration of residents and industrial facilities in growing industrial towns and cities overwhelmed the traditional systems of water supply and waste disposal. Urban settlements, especially their poorer districts, suffered from diseases transmitted by tainted water (cholera, typhus). The growing mortality rate and the collapse of existing systems were overcome thanks to a range of technical, scientific and administrative changes introduced during the 19th century and in the early 20th century.

3.3.9 VALUE DERIVING FROM AGE

The traces of external influences and human activities are manifested in a certain degree of wear and tear. In the case of water management structures, this includes wear and tear caused by the action of flowing water. In view of the regular maintenance and repairs undertaken at water management infrastructure sites, these traces of the passage of time can only be found sporadically or in parts of the structure that are not essential for their functionality.

Fig. 3.23: Bethlehem (USA), pumping station. America adopted European Early Modern-era systems of water supply (16th–17th centuries) based on the principle of remote gravitational supply, using pumps driven by water wheels. The oldest water pumping station in the USA was built in 1754 for the town of Bethlehem, established by immigrants from the Moravian community. The water was pumped from a source to a water tower, from where it flowed gravitationally into five cisterns and tanks. The building in the photograph functioned as a pumping station until 1832. (Douet, 2018). Photograph by Michaela Ryšková, 2018.

3.3.10 RECOMMENDATIONS FOR EVALUATION

The evaluation of water management structures and their functional entities must be conducted from various perspectives, applying the evaluative criteria described above. As has already been stated, the key tasks are to situate the particular structure within the context of the overall typological development of the particular type, to identify the architectural/structural and technological values and functional interconnections, and to assess the value derived from authenticity (within the highly diverse scope of these structures) while taking into consideration traditional heritage values (criteria). In order to arrive at an objective evaluation, it is therefore necessary to be aware of the historical context and typological development of a particular type of structure, both in the national and international context.

When selecting typical representatives for potential heritage protection with regard to the typological development of a particular type of water management structure, it is desirable to conduct an evaluation of the largest possible number of buildings of the particular type within a defined hydrological or territorial scope (drainage basin, region, country). Besides evaluating the above-listed criteria, the assessment must also focus on the structural condition of the site, including a description of all reconstructions and modifications undertaken since it was first built.

In order to achieve a higher degree of objectivity in the evaluation and subsequent comparison, the evaluating expert may decide to categorize the individual evaluative criteria. The appendices to this publication include a draft evaluation form, which has been tested at selected water management structures in the drainage basins of the Svitava, Moravice, Upper Morava, Ploučnice, and in the Čáslav region (Dzuráková et al., 2020, 2021; Pavelková et al., 2021). Collections of annotated maps accompanied by the result of the evaluations of the selected water management sites are available at: https://heis.vuv.cz/data/webmap/datovesady/projekty/vhobjekty/).

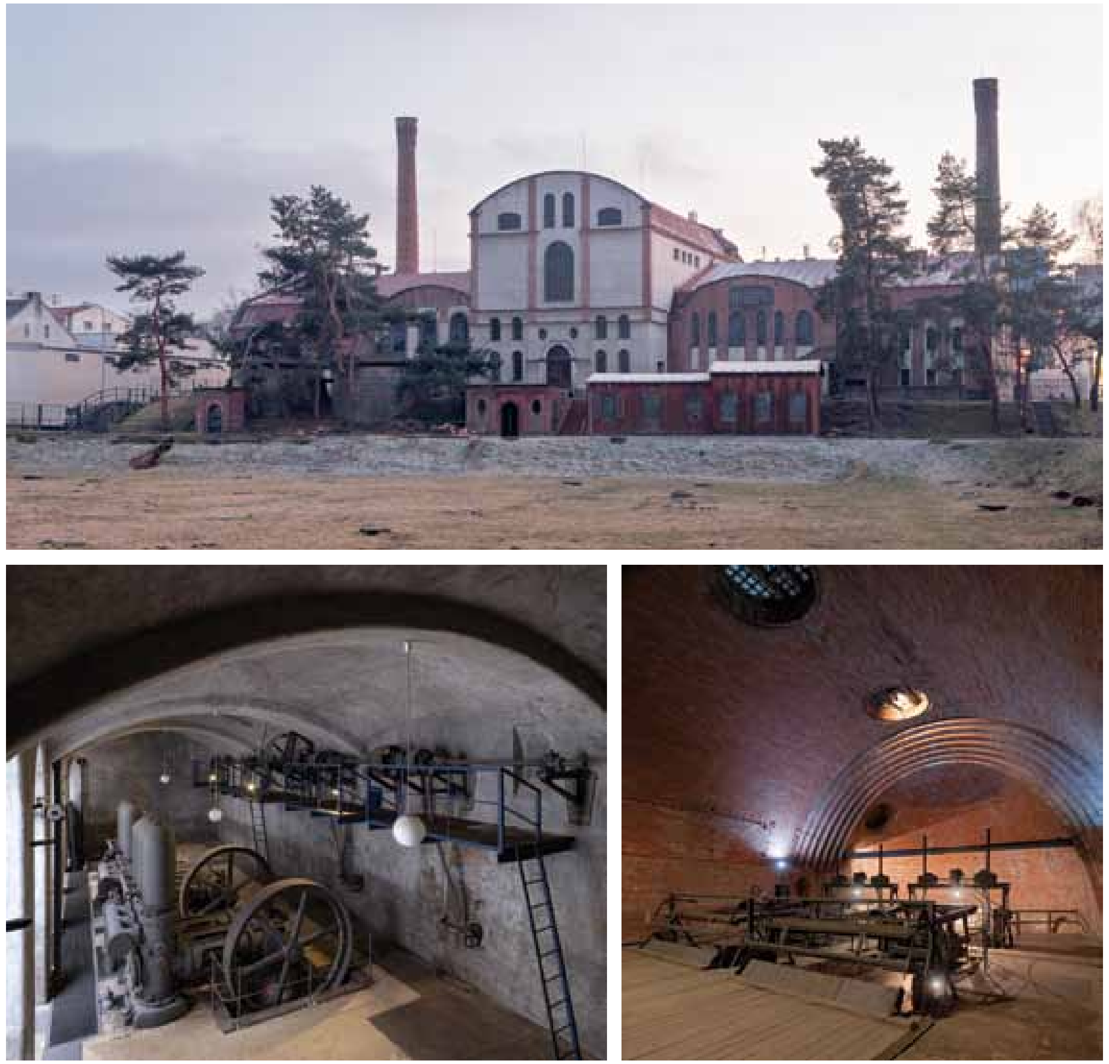

Fig. 3.24: Prague-Bubeneč, old wastewater treatment plant. This treatment plant, designed by William H. Lindley in 1894, is one of the most important European examples of a solution to the problem of wastewater – an issue faced by rapidly growing industrial cities towards the end of the 19th century. For more information see Chapter 4.6. Drainage/sewerage and water treatment. Photograph by Viktor Mácha, 2020.

4. DESCRIPTION AND EVALUATION OF SELECTED WATER MANAGEMENT GROUPS AND STRUCTURES

4.1 DAMS

"A dam is an impoundment structure damming a watercourse and its valley and creating a reservoir. A dam is formed by a wall barrier and functional facilities (outlets, spillways, intakes, etc.) that can be located directly in the dam or in separate structures. In a narrower sense, the term dam can also refer to the impoundment structure itself (the wall)" (Říha, 2006). In 1928, the International Commission on Large Dams (ICOLD), which provides a forum for the exchange of knowledge and experience in the field of dam engineering, was established. The ICOLD has introduced criteria according to which a large dam is any dam above 15 m in height measured from the foundation to the crest or any dam between 5 to 15 m in height which has the storage capacity of the reservoir over 3 million m^3 (ICOLD, 2021).

"The purpose of any dam is always to create a reservoir. The rise of water by a dam is sometimes used to obtain hydraulic head for the energy use of water or for the gravitational transportation of water through pipelines. A reservoir may serve any water management purpose or multiple purposes simultaneously. The purpose of a reservoir has a decisive influence on the design of dam facilities (functional, flow control structures). The selected design and dimensions of spillway, outlet and intake structures correspond to the required function of the dam (increase in flow rate, flood discharge, minimal outflow discharge, etc.) and of the reservoir at each possible water level. The water level varies significantly over time according to the reservoir function and depending on the hydrological conditions" (Broža et al., 1987).

Note: *"Another type of an impoundment structure is a weir. Unlike a dam, its purpose is not to create a reservoir but only to increase the depth of water in the watercourse, for example, for sailing, facilitating water intake from the river, obtaining hydraulic head, etc. A weir basin is usually not used to regulate the outflow, therefore it has a constant or only slightly variable water level height during normal operation. The height of a weir is usually small compared to a dam"* (Broža et al., 1987).

Definitions of basic terms (Fig. 4.1, Fig. 4.2):

- dam body (wall) – impoundment structure made of natural or artificial materials,
  - downstream face,
  - upstream face,
  - crest – the highest part of a dam body;
- functional structures – the required function of every dam is ensured by *functional structures* which are sometimes also called dam facilities. Dam functional structures include:
  - outlets,
  - safety spillway,
  - intake structures;
- reservoir (submerged area) – area that is inundated by water with the maximum water level in the reservoir.

Fig. 4.1. Definitions of basic terms – the Kružberk dam (1948–1955). Photograph by Radek Bachan, 2021.

Fig. 4.2: Definitions of basic terms – the Kružberk dam (1948–1955). Photograph by Radek Bachan, 2021.

4.1.1 HISTORY OF DAMS

The construction of dams has accompanied the entire history of mankind since the appearance of the oldest civilizations in Mesopotamia and the Middle East, which dates back to 3000 BC. Among important dam builders were the Romans, who built dams of various construction types using various materials (Charles et al., 2011).

The construction of large dams in the Czech Republic was preceded by the construction of dams and reservoirs associated mainly with the construction of ponds in the 15th and 16th centuries, these were mainly built in the South Bohemian and Pardubice regions and had already begun to be constructed in the 11th and 12th centuries. One of the oldest retention basins in the Czech lands is Mácha Lake which was built in 1366 (Kolka, 2003) and, in 1367, the dam of Dvořiště Pond was built. The first waterworks reservoir in the Czech territory was the Jordán reservoir which consists of an 18 m high dam built in 1492 and which was used to supply the town of Tábor with drinking water. Alongside fish farming, reservoirs were also built for mining and, later on, for the metallurgical industry (Broža et al., 2005).

The construction of dams and modern dam engineering dates back to the end of the 19th century when the primary impulse for the construction of dams was the extensive flooding in the 1890s. At that time, in the area of Europe and the Czech Republic, mainly masonry dams (e.g. Jevišovice, 1897; Mariánské Lázně, 1896; Kamenička, 1904; Harcov, 1904; Pařížov, 1913; Les Království, 1919; Pastviny, 1938; Husinec, 1939, etc., and the last masonry dams in our country, Pastviny, 1938 and Husinec, 1939) were built. At the beginning of the 20th century, when our country belonged to the Austro-Hungarian Empire, hydraulic structures were built as part of comprehensive measures to reduce the destructive effects of floods. Apart from the provincial, district and municipal authorities and socio-economic elites, an important initiating, organisational and investor role in the construction of dams was played by the so-called water cooperatives. Their foundation was enabled by provincial water laws of 1870. Water cooperatives approached leading experts for their projects, such as Professor Otto Intze or A.R. Harlacher. In the first third of the 20th century, dams based on the Intze principle, designed by Professor Otto Intze from Aachen, were being built in the Czech Republic as part of flood mitigation measures in the North Bohemian mountain areas. The water cooperatives formally ceased their activities only in the mid-1950s when they already had no influence on the construction of dams (Broža et al., 2005), (Pelíšek, 2021).

Later on, mainly concrete dams were built (e.g., Březová, 1934; Vranov, 1936; Brno, 1940). The massive construction of concrete dams dates back mainly to the 1950s. The largest concrete dams were built on the Vltava River: Slapy, 1957; Lipno I, 1960; or Orlík 1963. With the development of the society and economy, the need to provide sufficient water for the population and industry was also increasing. Therefore, the biggest expansion of dam construction took place between the 1960s to 1980s (Fig. 4.3). The preparation of these constructions was transferred from individuals to state-owned enterprises (e.g., Hydroprojekt) responsible for preparing, projecting and constructing dams. Thus, the process involves the role of an investor, designer, supplier and supervisor. Important personalities and experts in the field could be found at all levels of preparation but the role of individuals and the role of significant builders ceased to exist. New construction designs, new materials and procedures were being applied in order to achieve economic solutions and to meet the needs of the growing industry, agriculture and population. Efforts to save cement and the depletion of profiles suitable for the construction of concrete dams led, from the late 1960s, to the re-construction of earthfill dams – dams made of local materials, e.g., Nechranice (1961–1968), Želivka (1965–1975), Dalešice (1970–1979), Stanovice (1972–1978), Římov (1974–1978), Dlouhé Stráně (1978–1996), Slezská Harta (1987–1997), etc. (Broža et al., 2005).

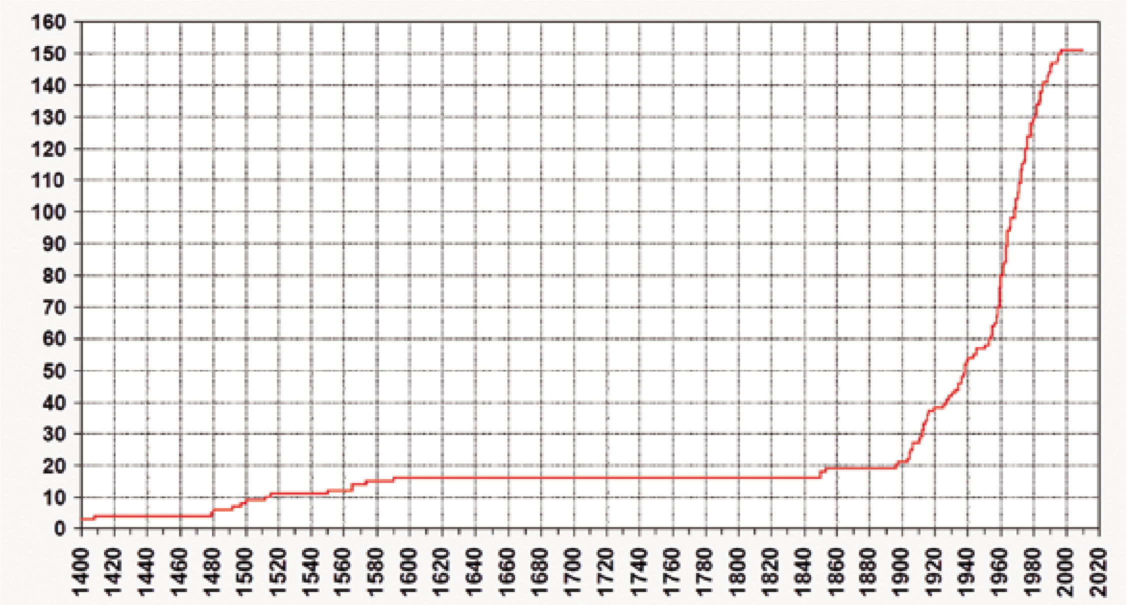

Fig. 4.3: Development of dam construction in the Czech lands (taken from: Horský, 2015).

4.1.2 CLASSIFICATION OF DAMS ACCORDING TO THEIR MAIN BUILDING MATERIAL

The building material determines by its mechanical properties the most significant construction layout and static effect of dams. Therefore, it becomes the basic distinguishing aspect in their classification:

- dams made of local materials:
  - earthfill,
  - rockfill,
  - zoned rockfill;
- rubble masonry dams,
- concrete dams,
- composite dams.

4.1.2.1 Dams from local materials

"Dams made of local materials are dams with a dam body made mainly from local earth, stone or other similar materials that can be found in the immediate proximity of the dam site (hence the designation, "dams from local materials"). Dams usually consist of stabilising, sealing and protective parts; sometimes one part can perform two functions, such as stabilising and sealing or stabilising and protective. Depending on the type of material used, they can be further divided into earthfill, rockfill or zoned rockfill dams. In addition, dams with a sealing element can be divided according to the location and material of the seal" (Broža et al., 1987). The sealing element can be located inside the dam body or in parallel with the upstream slope (inclined upstream impervious zone) – the choice of the seal depends on specific conditions. Sealing materials used for dams made of local materials are, for example, clay and soil sand or gravel, concrete, asphalt concrete, plastic foils and others (Broža et al., 2000). More detailed

information and general principles of embankment dams are summarised in the ČSN 75 2310 standard. For large dams made of local materials, the most common type of a spillway used in the Czech Republic is an uncontrolled side safety spillway. Nevertheless, shaft and crown spillways are also very common. Duckbill and channel spillways are rather exceptional.

4.1.2.1.1 Earthfill dams

"Earthfill dams (Fig. 4.4)*, their basic material for the stabilising part is earth. According to the construction technology, we distinguish between embankment and hydraulic fill dams, and according to the body composition in a cross-section, between homogeneous dams and dams with a sealing element (heterogeneous)"* (Broža et al., 1987). Homogeneous dams are mainly used for lower dams (Broža et al., 2000).

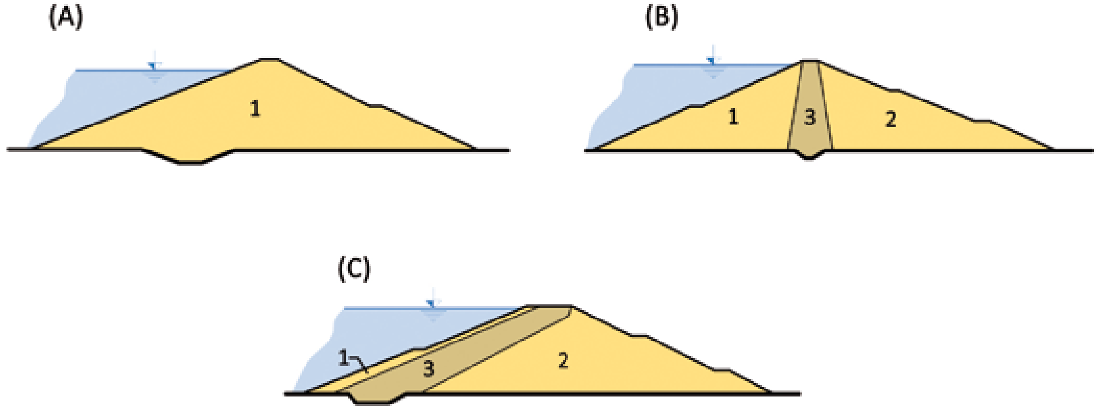

Fig. 4.4: Basic types of earthfill dams: (A) earthfill homogeneous: 1 – stabilising part (shoulder); (B) earthfill with hearting zone: 1 – upstream shoulder, 2 – downstream shoulder, 3 – earth seal (core); (C) earthfill with inclined upstream impervious zone: 1 – revetment, 2 – downstream shoulder, 3 – earth upstream impervious zone. Diagram by Radka Račoch, 2021 (modified according to: Broža et al., 2005).

Number of occurrences in the Czech Republic: Large earthfill dams are most commonly represented in the Czech Republic, there are about 60 large earthfill dams.
The oldest surviving structures in the Czech Republic: Mácha Lake, 1366 (Kolka, 2003)
The most recent use in the Czech Republic: Výrovice (1979–1983) (Broža et al., 2005)
Examples: Láz (1818–1822), Souš (1911–1915), Chřibská (1912–1924), Plumlov (1922–1933), Fryšták (1935–1938), Nechranice (1961–1968), Rozkoš (1965–1972), Želivka (1965–1975), Letovice (1972–1976), Josefův Důl (1976–1982) (Broža et al., 2005)

4.1.2.1.2 Rockfill dams

"The main building material is stone without a binder, obtained from disconnected rocks. According to their construction method, we divide them further into flattened and embankment dams. They always have a special sealing element" (Říha, 2006), (Fig. 4.5).

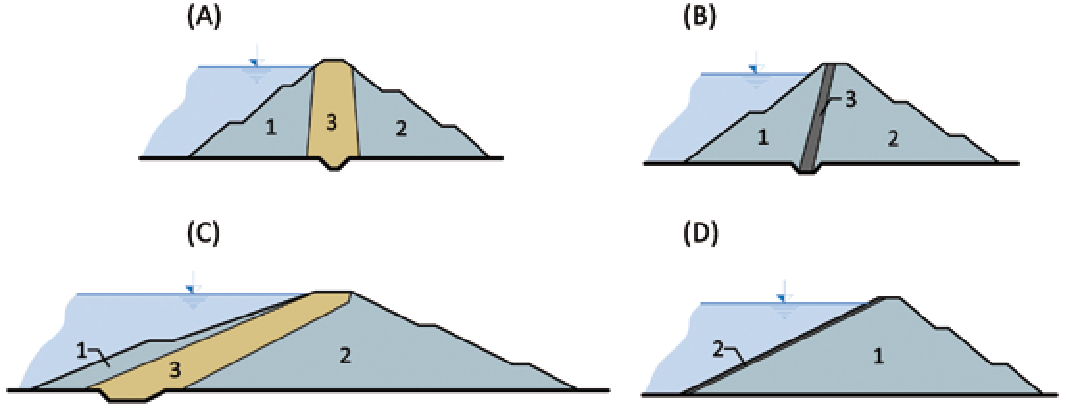

Fig. 4.5: Basic types of rockfill dams: (A) rockfill with earth hearting zone: 1 – upstream shoulder, 2 – downstream shoulder, 3 – earth impervious zone; (B) rockfill with asphalt concrete hearting zone: 1 – upstream shoulder, 2 – downstream shoulder, 3 – asphalt concrete impervious zone; (C) rockfill with earth upstream impervious zone: 1 – upstream shoulder, 2 – downstream shoulder, 3 – earthfill seal; (D) rockfill with inclined upstream asphalt concrete impervious zone: 1 – shoulder, 2 – asphalt concrete upstream impervious zone. Diagram by Radka Račoch, 2021 (modified according to: Broža et al., 2005).

Number of occurrences in the Czech Republic: 18 large rockfill dams
The oldest surviving structures in the Czech Republic: Mostiště (1957–1961) (Broža et al., 2005)
The most recent use in the Czech Republic: Slezská Harta (1987–1997) (Broža et al., 2005)
Examples: Skalka (1962–1964), Šance (1964–1970), Boskovice (1985–1990), Dalešice (1970–1979), Dlouhé Stráně (1978–1996), Slezská Harta (1987–1997) (Broža et al., 2005)

4.1.2.1.3 Zoned earthfill dams (combined)

"Zoned earthfill dams shoulder (Fig. 4.6) *is partially rockfill and partially earthfill. The earthfill part usually serves in this case also a sealing function"* (Říha, 2006). They are also sometimes called rockclayfill dams, but in the Czech Republic they are not very common.

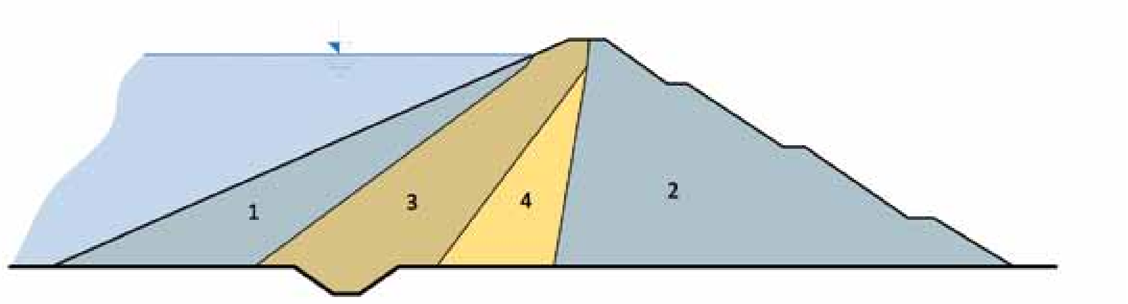

Fig. 4.6: Zoned earthfill dam: 1 – upstream shoulder from rubble, 2 – downstream shoulder from rubble, 3 – earth impervious zone, 4 – downstream shoulder from earth. Diagram by Radka Račoch, 2021 (modified according to: Broža et al., 2005).

4.1.2.1.4 Typical representative – the Hracholusky dam

The construction of the Hracholusky dam was carried out in 1959–1964. The original high weir on the Mže River about 10 km above the profile of the current dam was unable to provide increasing water consumption at the end of the 1950s. For this reason, the Regional National Committee issued a decision on the construction of a hydraulic structure in 1959. The main purpose of the work was the accumulation of water for industry (Škoda), irrigation and a heating plant. Other purposes were the reduction of the effects of floods, recreation, small hydroelectric power plant, fishing, sailing and the provision of a minimum residual flow (Broža et al., 2005).

The Hracholusky reservoir has an earthfill dam with a clay hearting, the crest length is 270 m and the crest width is 5 m. The downstream slope is grassed and the upstream slope is fortified by six-sided concrete blocks. At the time of the construction of the Hracholusky HS, there was not enough experience with shaft safety spillways, and therefore, two spillways were designed. This makes the Hracholusky dam distinct from other dams made of local materials because it is the only one that has two safety spillways – a shaft and a crown side spillway. The crown side spillway is located by the right bank and has a long reinforced concrete chute with a stilling basin. The shaft spillway crest is 50 cm higher than the crest of the second spillway. The shaft spillway has six concrete wing walls in the upper expanding area which deflect the water overflow to the inside side of the spillway shank. Two lower outlets and a small hydroelectric power plant with a vertical Kaplan turbine are part of the multipurpose structure with a shaft spillway. Bottom outlets with 1.4 m in diameter are controlled by a sluice gate on the upstream side and by a hollow jet valve on the downstream side (Broža et al., 2005). Dams from local materials represent the largest group of dams in the Czech Republic. The Hracholusky HS is a good example of two typical safety spillways for an earthfill dam and multipurpose structure with water intakes and a small hydroelectric power plant.

Fig. 4.7: The Hracholusky reservoir (1959–1964). Photograph by Shutterstock, 2018.

4.1.2.2 Rubble masonry dams

"Their body is built from mortar, usually cement walls. They are mostly gravity type" (Broža et al., 1987).

When rubble stone is used, the dam material is characterised by great cohesion, flexible deformation strain, relatively high resistance to loading or other effects. Thanks to these properties, it is possible to design a dam body with significantly less volume compared to dams made of local materials. On the other hand, there is a need for the use of industrially produced materials – high-quality assorted stone. Due to the increased loading of foundations because of smaller dimensions of the foundation joint compared to dams made of local materials, masonry dams place higher demands on mechanical properties of the foundations (Broža et al., 1987). In the Czech Republic, an uncontrolled crown safety spillway, and often also a side spillway, is usually used for masonry dams (Fig. 4.8). Nevertheless, we can also encounter a shaft safety spillway, or a combination of two types. A more detailed classification of rubble masonry dams based on their construction types is described in Chapter 4.1.3.

Otto Intze (1843–1904) was the founder of modern water management in Germany, his work was significantly influenced by neighbouring countries, including the Czech lands. He was a pioneer, whether it was the construction of dams, water tanks, bridges, quay walls or locks. As one of the first, he recognized the advantages of steel for the construction of water management structures. In 1882, he presented a program of "rational use of German energy of water" in Magdeburg. He recommended the construction of dams, the first one of which was the Eschbach gravity dam from rubble with a triangular cut (1889–1891), which then became a model of the second Intze principle (the first Intze principle concerned water towers) for a huge number of other dams. (Sauer, 2008). Intze type dams in the Czech Republic: Harcov (1902–1904), Bedřichov (1902–1906), Fojtka (1904–1906), Mlýnice (1904–1906), Mšeno (1906–1909), Labská (1910–1916) (Broža et al., 2005).

Number of occurrences in the Czech Republic: 18 large masonry dams
The oldest surviving structures in the Czech Republic: Jevišovice (1884–1896), Mariánské Lázně (1896) (Broža et al., 2005)
The most recent use in the Czech Republic: Husinec (1934-1939) (Broža et al., 2005)

Fig. 4.8: The Janov dam (1911–1914) – an example of a masonry dam. Photograph by Viktor Mácha, 2020.

Examples (full list): Jevišovice (1884–1896), Mariánské Lázně (1896), Kamenička (1899–1904), Jezeří (1902–1904), Harcov (1902–1904), Bedřichov – Rudolfov (1902–1906), Fojtka (1904–1906), Mlýnice (1904–1906), Mšeno (1906–1909), Bystřička (1908–1912), Pařížov (1909-1913), Les Království (1910–1919), Labská (1910–1916), Janov/Hamerská (1911–1914), Sedlice (1921–1927), Seč (1924–1934), Pastviny (1933–1938), Husinec (1934–1939) (Broža et al., 2005)

4.1.2.2.1 Typical representative – the Pařížov dam

The Pařížov reservoir was one of the first protective reservoirs in the Czech Republic. The construction of its dam was carried out from 1909 to 1913. It is a horizontally curved rubble (gneiss) gravity dam. The Pařížov dam represents many characteristics typical for masonry dams. The Pařížov dam is the only masonry dam in the Czech Republic which has both a crown and a side spillway. At the same time, it is one of five dams in the Czech Republic with a bottom outlet. The Pařížov dam has been a cultural monument since 1958 (Broža et al., 2005).

As it is mentioned in Chapter 4.1.4.1, every dam must have at least two bottom outlets which can be used separately and are functionally independent. The Pařížov dam is exceptional because of the fact that it even has four bottom outlets. There are two bottom outlets 800 mm in diameter placed in the dam body shaft. Outlets in the dam body are operated by means of a service valve on the downstream shoulder. These valves are located in operation buildings under the dam together with a small hydroelectric power plant. Both outlets also have inspection slide gate valves which are operated by means of two control towers on the upstream shoulder (Fig. 4.9). The other two outlets 1,200 mm in diameter are located in the side by-pass tunnel. There were originally three pipes with 800 mm in diameter but due to their insufficient capacity, they were replaced in 2005. New outlets in the by-pass tunnel use slide gate valves and a radial gate valves, their operation mechanisms are located in the operation and access shafts

Fig. 4.9: The Pařížov dam (1909–1913) – control towers on the upstream side of the dam for the handling of inspection slide gate valves. Photograph by Viktor Mácha, 2020.

Fig. 4.10: The Pařížov dam (1909–1913) – handling of operational radial gates of bottom outlets (DN1200) located in the by-pass tunnel. Photograph by Viktor Mácha, 2020.

Fig. 4.11: The Pařížov dam (1909–1913) – overflow edge of the side safety spillway and drop structure which behind the bridge follows the cascade. Photograph by Viktor Mácha, 2020.

and in the adjacent underground engine room (Fig. 4.10). The original slide gate valve is displayed by the road leading to the dam (Broža et al., 2005).

There is a side spillway with a 97.4 m long overflow edge located on the left bank of the Pařížov reservoir to facilitate flood discharges (Fig. 4.11). As for masonry dams, water from the safety spillway is often diverted through a cascade, the same method is used in case of the Pařížov dam where water cascades down over ten stone levels. The second safety spillway is located on the right side of the dam and this is a crown spillway (Fig. 4.12 (A)) with seven 5 m wide sluices. Water from the spillway is diverted over the downstream side of the dam to the adjacent cascade (Fig. 4.12 (B)) with eight irregular levels and flows into a stilling basin under the dam. In masonry dams, the most common type of a safety spillway is a side spillway or an uncontrolled crown spillway. The Pařížov dam is a nice example of these both safety spillways (Broža et al., 2005).

Fig. 4.12: The Pařížov dam (1909–1913): A) the view on the crown safety spillway from the upstream side; (B) the view from the downstream side on the crown spillway cascade. Photograph by Viktor Mácha, 2020.

4.1.2.2.2 Unique structure – the Mariánské Lázně dam

The Mariánské Lázně dam was built in 1896. At that time, it was a masonry dam with a radius of curvature of 300 m, 150-m long crest and total height of 16.9 m. The width at the crest was 3.3 m and the width at the heel was 7.9 m. The body had a concrete base up to the level of the original terrain. On the upstream side there was an embankment in order to increase the stability of the dam. The total volume of the reservoir was 93,000 m^3. On the grounds of insufficient capacity of water withdrawal for the expanding spa industry, the idea of raising the dam was adopted. The masonry part of the dam was elevated by 3 m and widened at the crest to a 3.5 m width. The elevated and widened masonry dam was filled up to the crest from both sides in order to increase the stability. The dam rise was completed in 1912 (Broža et al., 2005).

The Mariánské Lázně dam is 116 m long and 19.9 m high above the foundations. The crest with the earthfill part is 19.5 m wide and the heel is now 117 m wide. By raising the dam the whole area of the reservoir has tripled to 278,000 m^3. The dam has got an uncontrolled side safety spillway with three brakes in the overflow edge and it is situated on the right bank of the reservoir. The bottom outlet pipeline 1.5 m in diameter is placed in the shaft. The Mariánské Lázně dam is unique in the Czech Republic for its layout, and for more than 100 years it has been reliably serving its purpose (Broža et al., 2005).

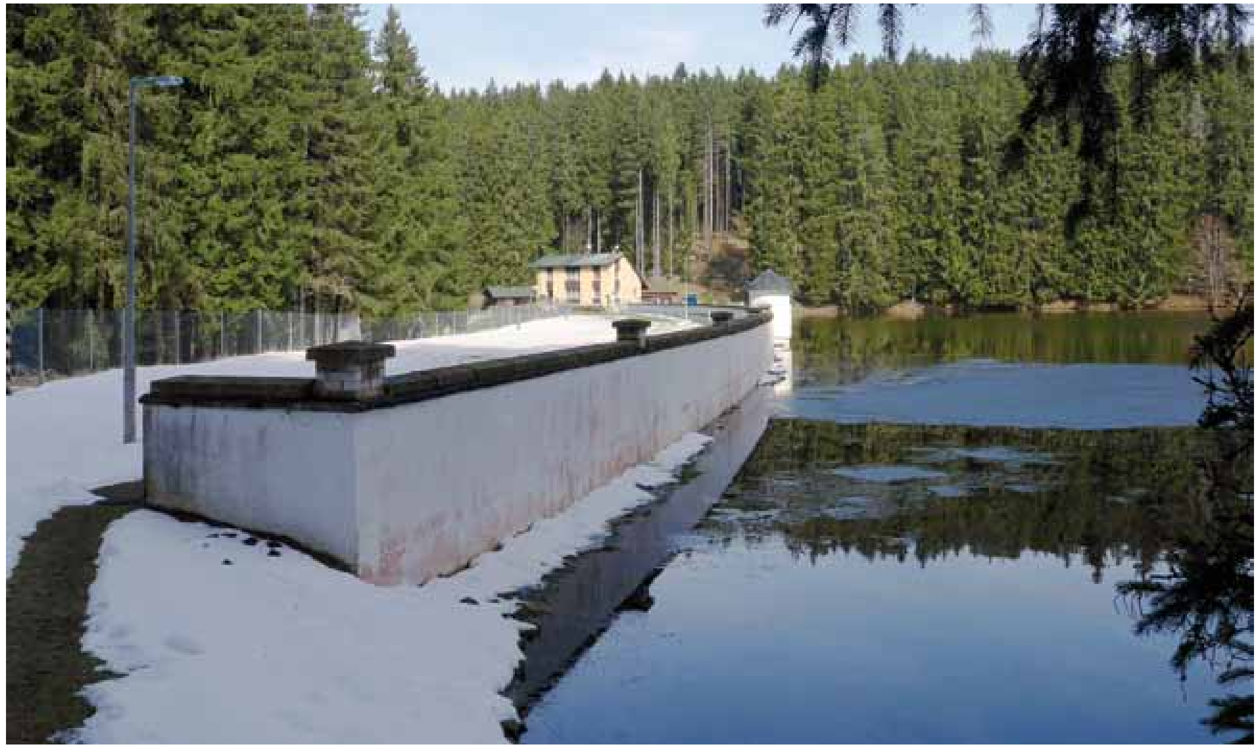

Fig. 4.13: The Mariánské Lázně dam (1896). Photograph by Michalea Ryšková, 2022.

4.1.2.3 Concrete dams

“Their body is from cement concrete (plain, reinforced or prestressed) or from concrete components. Concrete provides constructors with great possibilities when designing a dam” (Broža et al., 1987).

Thanks to the great cohesion of concrete, its flexible deformation and high resistance to loading and other effects, concrete dams (Fig. 4.14), as well as rubble masonry dams, can be designed with significantly smaller volumes than dams from local materials. Due to the increased loading of foundations because of smaller dimensions of the foundation joint, similarly as for masonry dams, there are higher demands on the mechanical properties of the foundations compared to dams from local materials (Broža et al., 1987). Controlled and uncontrolled crown spillways are the most common types of safety spillways used for concrete dams in the Czech Republic (Fig. 4.14). A more detailed classification of concrete dams based on their construction types is described in Chapter 4.1.3. Concrete dams allow their designers a wide range of options when creating the overall layout. Concrete dams are often associated with the construction of hydroelectric power plants (see Chapter 4.4), pumped storage power plants or navigation facilities (see Chapter 4.3), e.g., lock chambers or water lifting devices. They are much more likely to have controlled safety spillways compared to other types of dams.

Number of occurrences in the Czech Republic: 17 large concrete dams
The oldest surviving structures in the Czech Republic: Vranov (1930–1934), Březová (1931–1934) (Broža et al., 2005)
The most recent use in the Czech Republic: Hněvkovice (1986–1991) (Broža et al., 2005)
Examples: Vranov (1930–1934), Březová (1931–1934), Brno/Kníničky (1936–1940), Štěchovice (1937–1945), Křižanovice (1947–1953), Slapy (1949–1957), Fláje (1951–1963), Orlík (1954–1963), Vrchlice (1966–1970), Mohelno (1970–1979) (Broža et al., 2005)

Fig. 4.14: The Vranov dam (1930–1934) – example of a concrete dam and uncontrolled crown spillway (on the right). Photograph by Michaela Ryšková, 2020.

4.1.2.3.1 Typical representative – the Orlík dam

It represents a concrete gravity dam. The Orlík dam (Fig. 4.15) is the largest concrete dam in the Czech Republic and, at the same time, the longest concrete dam in the Vltava basin. Orlík is also known as the most significant part of the Vltava River Cascade. The construction of the Orlík dam was carried out in 1954–1963. Its reservoir capacity of 716.5 million m^3 is the biggest in the Czech Republic. Crown-type safety spillways are very often used in concrete dams. And also controlled safety spillways are quite often used in concrete dams. In the Orlík dam there is a crown spillway with three 15 m wide bays controlled by 8 m high radial gate valves used for flood discharge. The spillways end with concrete baffle blocks, and water then falls over into a 95 m long and 5.25 m wide stilling basin. Orlík has two bottom outlets with 4,000 mm in diameter situated in the dam body. The outlets are operated by Johnson valves on the downstream shoulder of the dam and by slide gate valves. By the left bank, there is a power plant with four Kaplan turbines. On the other bank, there is navigation equipment for small sport vessels. Transportation is carried out by a platform carriage here. For ships, there is navigation equipment up to a displacement of 300 tons, which is designed as a slanting water lifting device made only in the construction part. Broža et al., 2005).

Fig. 4.15: The Orlík dam (1954–1963) – concrete gravity dam. Photograph by Viktor Mácha, 2021.

4.1.2.3.2 Unique structures – the Fláje, Vrchlice and Dlouhé Stráně dams

The Fláje dam – see Chapter 4.1.3.1.1, Vrchlice dam – see Chapter 4.1.3.2.1, Dlouhé Stráně dam – see Chapter 4.4.8.3.

4.1.2.4 Composite dams

“Composite dams (Fig. 4.16) *belong among special types of dams. In the longitudinal direction (across the valley) they are composed of several dam types, often made from different materials”* (Broža et al., 1987).

Examples: Lipno I (1952–1960), Skalka (1962–1964), Znojmo (1962–1965), Nechranice (1961–1968), Nové Mlýny (lower reservoir) (1974–1988) (Broža et al., 2005)

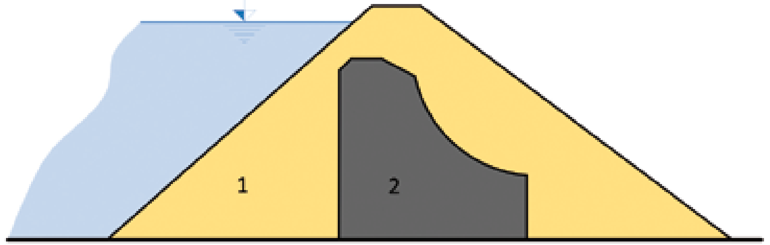

Fig. 4.16: Composite dam: 1 – earthfill part, 2 – gravity part from concrete. Diagram by Radka Račoch and Radek Bachan, 2021 (modified according to: Broža et al., 1987).

4.1.2.4.1 Typical representative – the Znojmo dam

Combined dams are less common in the Czech Republic than other types of dams. The Znojmo HS is a great example of a combined dam. The construction of the work was carried out in 1962–1965. The Znojmo HS supplies water to the Znojmo group water supply system and to the Krhovice-Hevlín irrigation system, regulates flow fluctuation caused by the operation of a hydroelectric power plant in Vranov, ensures a minimum flow and also serves for power generation (Broža et al., 2005).

The Znojmo dam (Fig. 4.17) is an embankment rockfill with a width of 4.5 m at the crest. The upstream slope of the dam is fortified by stone paving and the downstream slope is grassed. The loess impervious core is a concrete block adjacent to the granite rock foundation. The safety spillway is crown-type and is controlled by two flaps. Each bay is 8.7 m wide. The Znojmo HS has two bottom outlets 1 m in diameter and their service valve is cone-type. The hydroelectric power plant is located directly in the body of the concrete part of the dam under the safety spillway. The power plant has two tubular Kaplan turbines (Broža et al., 2005).

Fig. 4.17: The Znojmo dam (1962–1965) – composite dam. Photograph by Michaela Ryšková, 2020.

4.1.3 CONSTRUCTION TYPES OF CONCRETE AND MASONRY DAMS

Concrete and masonry dams can be further divided according to their construction and to the static action on them into:

- gravity,
- arch,
- multiple,
- special.

4.1.3.1 Gravity dams

*“**Gravity dams*** (Fig. 4.18 (A)) *are those dams whose each block bounded by two vertical cross sections perpendicular in plan to the axis of the dam is capable of resisting independently by its own weight to the load acting on it and transferring it to the foundation. They can be straight, polygonal or curved in plan”* (Broža et al., 1987).

Examples of gravity dams: Orlík (1954–1963), Vír (1949–1957), Slapy (1949–1957), Vranov (1930–1934) (Broža et al., 2005).

*“**Hollow gravity dams** have a dam body from plain concrete in which large hollows are created in order to save concrete compared to massive gravity dams. They can be further divided into:*

- ***Dams with wide joints** – the hollows in the dam body have the form of widened expansion joints (approx. to 3 m), rare type.*
- ***Dams with longitudinal joints** – the longitudinal joint extends through the dam blocks (rare type).*
- ***Buttress dams** – provide a greater lightening effect than the first two types. The dam body consists of thick buttresses whose heads widen on the upstream shoulder to touch each other to form a continuous damming wall. Each buttress is independently capable of transferring the load acting on it to the foundations by using its own weight”* (Říha, 2006), (Fig. 4.18 (B)).

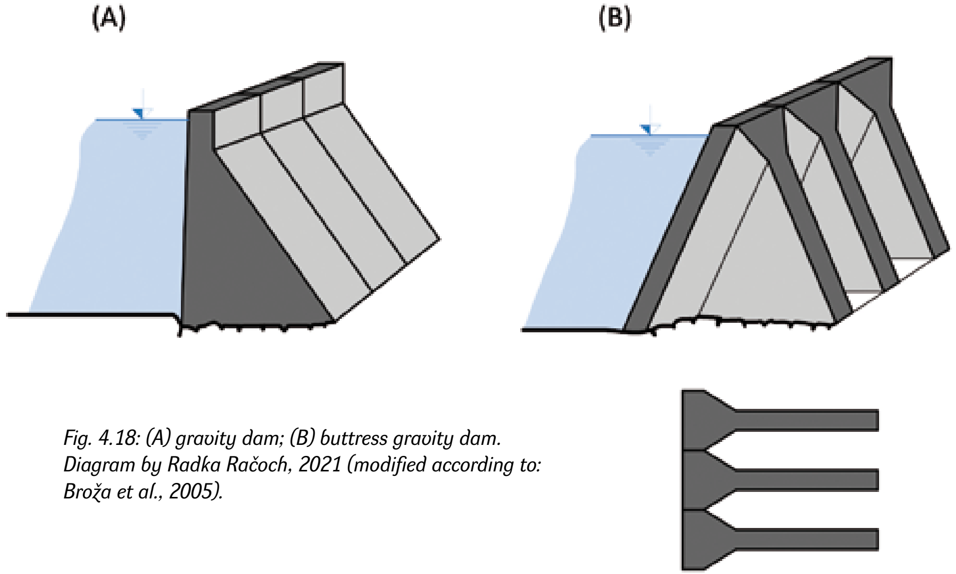

Fig. 4.18: (A) gravity dam; (B) buttress gravity dam. Diagram by Radka Račoch, 2021 (modified according to: Broža et al., 2005).

4.1.3.1.1 Unique example – the Fláje dam

The Fláje dam (1951–1963) is the only buttress dam in the Czech Republic so far (Fig. 4.19). Its design is based on the Swiss buttress dam called Lucendro built in 1947. The Fláje dam consists of 19 Noetzli-type buttresses and 15 gravity blocks. The distance between the axes of individual buttresses is 13 m. The buttresses heads touch each other on the upstream shoulder and on the downstream shoulder the gap between the buttresses is additionally covered by 1 m thick boards. In this way, large cavities, similar to church naves, are created between the buttresses. Its straight dam is curved on the right side by an arch with a radius of 200 m. The Fláje dam has four bottom outlets 2 × DN 1200 mm and 2 × DN 250 mm. The dam has an uncontrolled crown safety spillway consisting of three bays (3 × 11.5 m), which is bridged (Broža et al., 2005).

Fig. 4.19: The Fláje dam (1951–1963) – buttress dam. Photograph by Viktor Mácha, 2020.

4.1.3.2 Arch dam

“Arch dams (Fig. 4.20) *use the arch effect to transfer the major part of the load to the valley sides directly or by means of gravity abutments. The arch axis can be vertical, inclined or curved in vertical cross section”* (Broža et al., 1987*)*. Arch dams can be further divided into:

- ***“Dome dams*** *are arch dams with a high curvature of the structure not only in horizontal but also in vertical directions.*
- ***Arch gravity dams*** (Fig. 4.20 (B)) *represent a transitional type between gravity and arch dams. They are concrete or masonry dams with a curved plan which combine the main arch effect (transfer of load to valley sides) with a significant gravity effect*” (Říha, 2006).

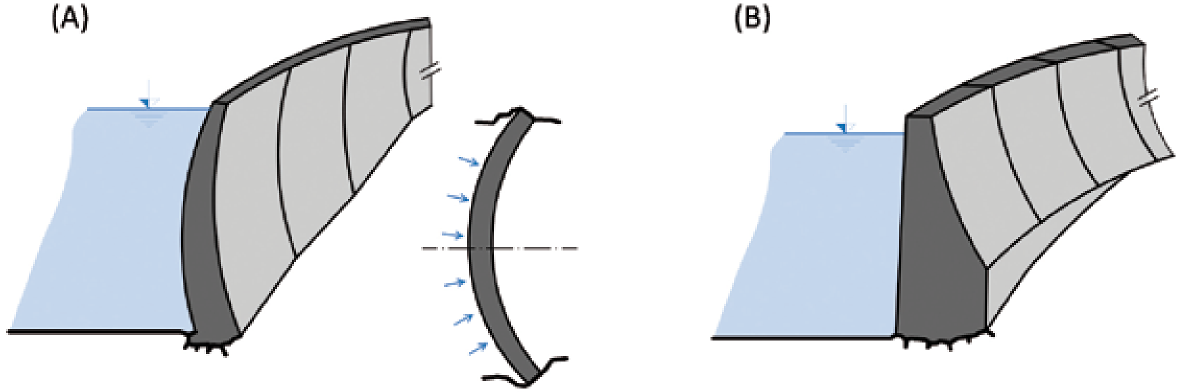

Fig. 4.20: (A) arch dam; (B) arch gravity dam. Diagram by Radka Račoch, 2021 (modified according to: Broža et al., 2005).

4.1.3.2.1 Unique example – the Vrchlice dam

The Vrchlice dam (1966–1970) is the only arch dam in the Czech Republic so far (Fig. 4.21). The dam body is shaped into a cylindrical surface with a radius of curvature of 66.5 m. The dam shape enables the transfer of part of the load to the foundations and part of the load by the arch effect to the valley sides. The Vrchlice dam has two bottom outlets 700 mm in diameter. Its safety spillway is an uncontrolled crown spillway with five bays of 6 m in diameter nominal which are arched with a bridge deck.

Fig. 4.21: The Vrchlice dam (1966–1970) – arch dam. Photograph by Viktor Mácha, 2020.

Fig. 4.21: The Vrchlice dam (1966–1970) – arch dam. Photograph by Viktor Mácha, 2020.

4.1.3.3 Multiple dams

"Multiple dams (Fig. 4.22) *are dams whose structure is segmented into several elements with various functions and different statical action and weight. Damming elements (flat slabs, archs) form the damming wall and transfer the load to a system of buttresses by means of whose gravity effect the load is transferred into the foundations"* (Broža et al., 1987).

- ***"Flat-slab multiple dams*** (Fig. 4.22 (A)) *are multiple dams whose damming wall is formed by slabs (usually from reinforced concrete) leaning against buttresses or inserted into them on the upstream side"* (Broža et al., 1987). An example of a flat-slab multiple dam in the Czech Republic is Vír II which, given its parameters, does not fall into the definition of large dams, according to ICOLD.
- ***"Multiple arch dams*** (Fig. 4.22 (B)) *are multiple dams whose damming wall is formed by a system of arches that transfer the load to the upstream shoulder of buttresses"* (Broža et al., 1987). In the Czech Republic, the first multiple arch dam was supposed to be the Křímov dam, originally intended with five vertical 46 m high arches with a 60 m span of the middle arch. It would have been our only multiple arch dam with an extremely interesting architectural concept. However, the design was changed during the construction to a gravity variant due to poor geological conditions (Říha, 2006).
- ***"Dome multiple dams*** *– multiple dams with a significant curvature of arches even in a vertical direction"* (Broža et al., 1987).

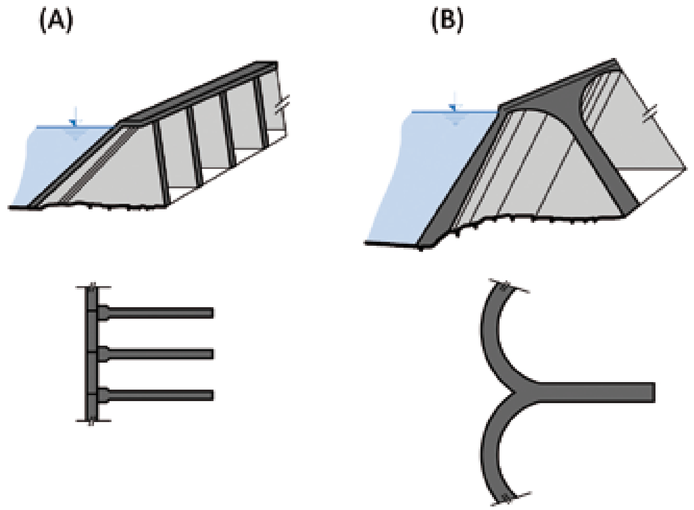

Fig. 4.22: (A) flat-slab multiple dam; (B) dome multiple dam. Diagram by Radka Račoch, 2021 (modified according to: Broža et al., 2005).

4.1.3.4 Special types of dam

Special types of dam include the following (Broža et al., 1987):

- ***"Anchored dams*** *– the structure is coupled with the foundation by a system of prestressed cables or anchors fixed both to the rock at a certain depth under the foundation and in the structure of the dam (buttress). Anchoring usually replaces a part of the weight of the dam body itself".*
- ***"Prestressed dams*** *– dams built from monolithic prestressed concrete".*
- ***"Dams from components*** *– dams whose substantial part is assembled from components (from plain, reinforced or prestressed concrete)".*
- ***"Dams with wide outlets*** *– similar to gravity or multiple dams. The load is transferred to the foundation usually by means of thick buttresses into which reinforced concrete damming spatial structures are inserted".*
- ***"Composite dams*** *– can be classified as special dam types".* For more information see Chapter 4.1.2.4.

4.1.4 DAM FUNCTIONAL STRUCTURES

Functional structures, also known as dam facilities, provide the necessary functions of given dams. To prepare a conceptual and layout design of functional structures is a complex individual task for each dam and depends primarily on the required functions of the hydraulic structure, type of dam and also on the morphology and geology of the dam site. If a functional structure contains at least two facilities with different functions (or if, for example, combined with a hydroelectric power plant), it is known as a *"multipurpose structure"*.

Based on their function, we distinguish these functional facilities:

- outlets,
- safety spillways,
- intake equipment.

Structures which are constructionally related to a dam but which do not contain functional facilities, e.g. hydroelectric power plant, lock chamber, boat lift, fish pass or equipment for passing wood, do not belong among functional structures of the dam. They are structures with their own purpose (hydroelectric power plant) or structures stemming from the dam construction (fish pass).

4.1.4.1 Outlets

Outlets serve (or can serve) these functions (Říha, 2006):

- reservoir emptying in accordance with handling regulations and in extraordinary situations,
- diverting a part of flood flow,
- improving flows under the dam (hygienic minimum),
- diverting flows during repairs and reconstructions of works,
- diverting flows during constructions of works.

Outlets can be located in the dam body as concreted pressure pipes or as free-standing pipes in a tunnel or they can be situated outside the dam body usually in a by-pass tunnel. In terms of their layout, outlets can be divided according to their height position into the following (Říha, 2006; Fig. 4.23):

- *“**Bottom outlets** are situated by the bottom of a reservoir. They basically enable full reservoir drawdown and can also provide intake function. Every dam must be equipped with at least two separately usable, functionally independent bottom outlets. Exceptionally, a dam can be equipped with one bottom outlet only”.*

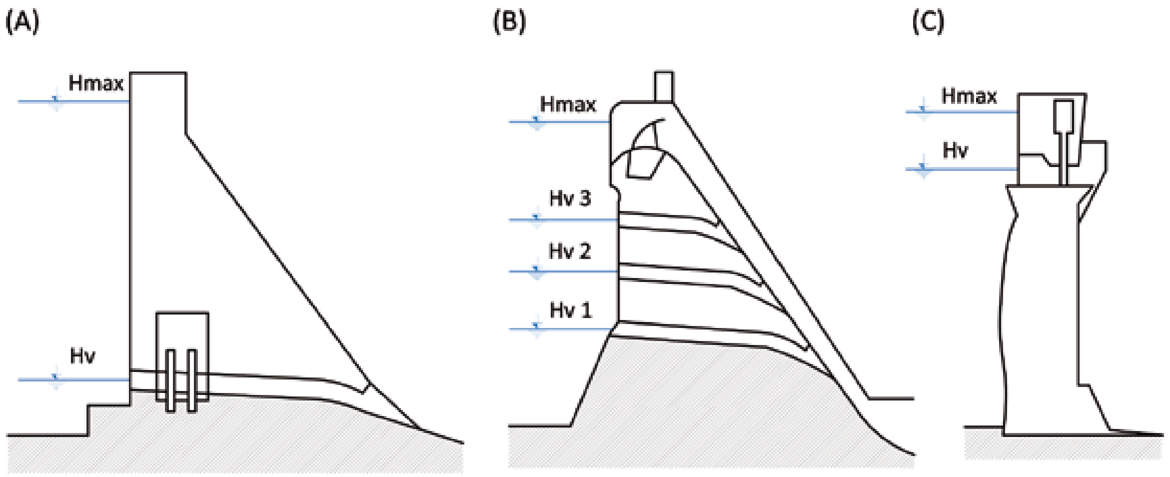

Fig. 4.23: Height position of outlets: (A) bottom outlets; (B) middle outlets; (C) upper outlets. Diagram by Radka Račoch and Radek Bachan, 2021 (modified according to: Broža et al., 1987).

- *“**Middle outlets** are situated at a certain height above the bottom of a reservoir and can perform the aforementioned functions only to a limited extent. The reason for the construction of a middle outlet can be, for example, clogging of part of the area in front of the dam and decommissioning of the bottom outlet”.*
- *“**Upper outlets** are situated in the upper part of the water supply storage and are similar, in terms of their location, to a controlled safety spillway”.*

With only some exceptions, outlets must be equipped with three valves – an inspection one and two operational ones (Fig. 4.24, Fig. 4.25). The choice of the valve type depends on the flow control requirements, operating conditions, permissible degree of leakage, hydraulic parameters and design of inlet and outlet structures. The method of driving the valve can be mechanical, hydraulic, motor or manual (Říha, 2006).

Fig. 4.24: The Vrchlice dam (1966–1970) – arch dam: (A) operational Howell Bunger valve of bottom outlets; (B) control equipment of Howell Bunger valves. Photograph by Viktor Mácha, 2020.

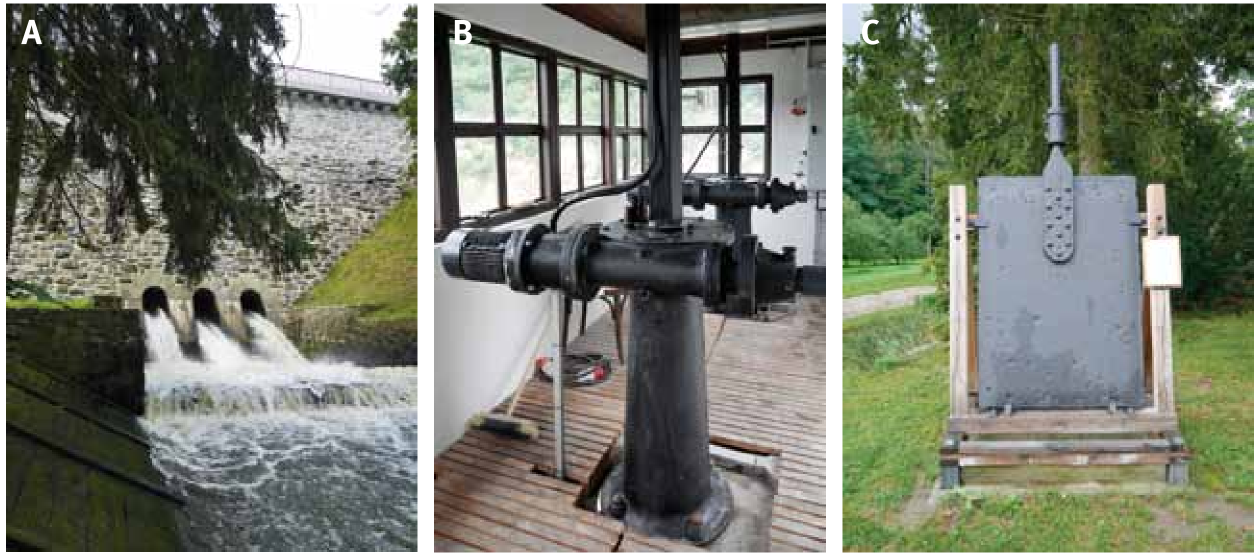

Fig. 4.25: The Jevišovice dam (1884–1896) – masonry gravity dam. (A) bottom outlets of the dam which constitute three tunnels; (B) control of operational valves of bottom outlets located at the crest of the dam which was originally outdoor, only later there was a structure built above it; (C) one of the original outlet valves, nowadays located under the dam. Photograph by Michaela Ryšková, 2020.

4.1.4.2 Safety spillways

“Every artificial reservoir into which water from a certain river basin flows (either directly or through a headrace from another river or reservoir), must be equipped with a spillway. A spillway serves as an emergency outlet structure that protects the dam body from an overflow during floods and secures a harmless flood discharge into a channel under the dam” (Říha, 2006). Safety spillways consist of:

- spillway crest, overflow edge,
- overflow surface (in drop structures, or on downstream face of gravity dams),
- drop structure and chute or cascade-type chute in case of side, lateral, fountain and channel spillway,
- shafts and tailrace tunnel in case of shaft or tunnel spillway,
- stilling basin in the area under the dam (Říha, 2006).

“Spillways can be parts of dams or they can form a separate structure situated outside the dam body” (Říha, 2006). They can be divided into two basic groups:

- ***“Controlled spillways*** *– their flow rate can be operated by means of valves. Valves can be controlled in upwards or downwards directions, sometimes in both directions”* (Broža et al., 1987).
- ***“Uncontrolled spillways*** *– their flow rate depends only on the water level in the reservoir, it cannot be regulated in any way”* (Broža et al., 1987).

According to their location and construction layout, spillways can be classified as crown, lateral, side, shaft, fountain, channel and tunnel.

Fig. 4.26: The Pastviny dam (1933–1938) – masonry gravity dam. The last masonry-built dam in the Czech Republic to this day. In the pictures, there is an uncontrolled crown spillway with six bays having different overflow edge levels. Water is diverted through a chute into a stilling basin which is shut by a stepped sill. Photograph by Viktor Mácha, 2020.

- ***“Crown*** *– they are part of the dam crest and water is diverted via them directly over the dam body”* (Broža et al., 1987; Fig. 4.26).
- ***“Lateral*** *– built in the extension of the dam crest in the side of the valley over which water falls parallel to the direction of the water flow”* (Broža et al., 1987; Fig. 4.27).

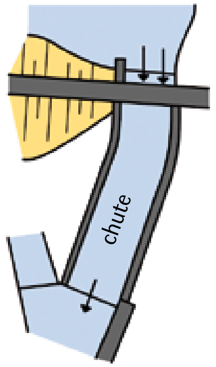

Fig. 4.27: Lateral safety spillway. Diagram by Radka Račoch and Radek Bachan, 2021 (modified according to: Broža et al., 1987).

Fig. 4.28: The Jevišovice dam (1884–1896) – masonry gravity dam. Top left, overflow edge of an uncontrolled side safety spillway. Top right, overflow edge and drop structure. Bottom left, view into the drop structure from under the bridge. Bottom right, the chute. Photograph by Michaela Ryšková, 2020.

- ***"Side*** *– built outside the dam body in the side of the reservoir over which water falls mostly transversally to the direction of the water flow"* (Broža et al., 1987; Fig. 4.28).
- ***"Shaft*** *– water from the reservoir overfalls into a vertical shaft carved out of a rock or created as a tower structure in the reservoir"* (Broža et al., 1987; Fig. 4.29, Fig. 4.30).
- ***"Fountain*** *– water from the reservoir overfalls into a drop structure the depth of which is usually such that the spillway capacity is not affected"* (Broža et al., 1987; Fig. 4.31).
- ***"Channel*** *– water from the reservoir overfalls into an elongated drop structure which turns directly into a chute which diverts water into the stilling basin. These spillways can be single-sided, double-sided or duckbill-shaped"* (Broža et al., 1987; Fig. 4.32).
- ***"Tunnel*** *– built in the side of the valley over which the water from the reservoir falls into a tunnel by means of which it is diverted into the stilling basin under the dam"* (Broža et al., 1987; Fig. 4.33).

Fig. 4.29: The Labská dam (1910–1916) – masonry gravity dam, shaft safety spillway which was being reconstructed in 2017–2019. Photograph by Radka Račoch, 2021.

Fig. 4.30: The Josefův Důl dam (1976–1982) – earthfill dam, shaft safety spillway. Photograph by Michaela Ryšková, 2020.

Fig.4.31: Mácha Lake (1366) – straight earthfill dam from local materials, detail of fountain safety spillway. Photograph by Miroslav Kolka, 2016.

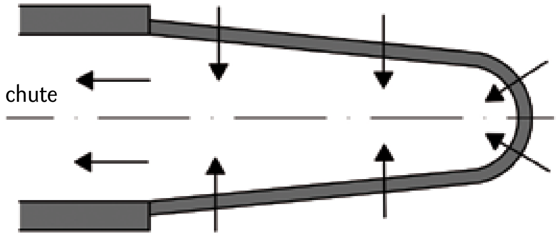

Fig. 4.32: Channel safety spillway. Diagram by Radka Račoch and Radek Bachan, 2021 (modified according to: Broža et al., 1987)

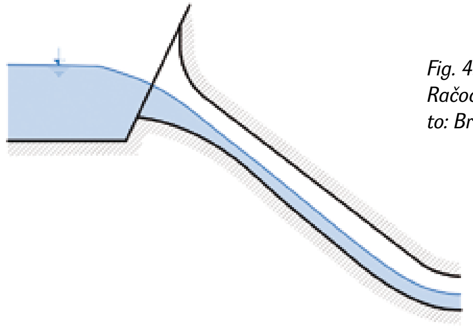

Fig. 4.33: Tunnel safety spillway. Diagram by Radka Račoch and Radek Bachan, 2021 (modified according to: Broža et al., 1987).

4.1.4.3 Intake structures

Water withdrawals from a reservoir usually fulfil the main purpose of the work. They can include withdrawals for water supply, industry, hydroelectric power plant, agriculture, etc. The design and layout of intake structures are adapted to their purposes. When designing an intake structure, its connection to other functional structures and the overall layout of the hydraulic structure is taken into account (Říha, 2006).

Intake structures can be located (Fig. 4.34):

- in the dam body,
- outside the dam body in an intake structure:
    - in a side intake structure if it is situated in the side of the reservoir,
    - in a tower intake structure if it is in the form of a tower in the reservoir outside the dam body.

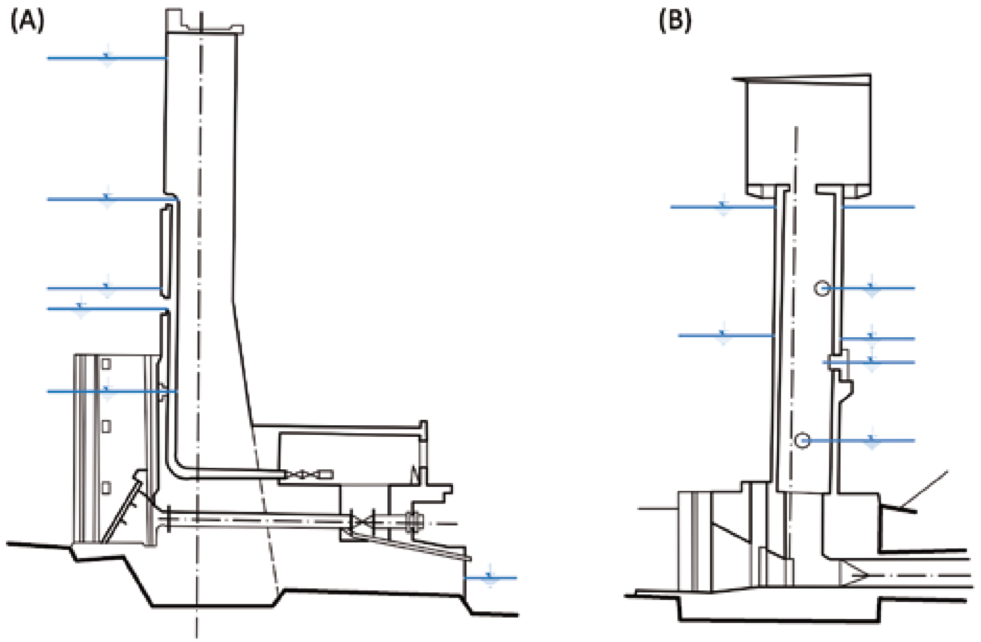

Fig. 4.34: Intake structures: (A) multi-level intake structure in the dam body; (B) multi-level tower intake structure. Diagram by Radka Račoch and Radek Bachan, 2021 (modified according to: Broža et al., 1987).

In the case of drinking water withdrawal, there are usually multi-level intake structures established but not necessarily for water supply use only. Multi-level intake structures allow water to be withdrawn from different height levels depending on its quality and are therefore suitable for water supply purposes.

Note: The term *"intake structure"* is often confused with the term *"flow-control structure"*. Flow-control structure is used only to operate bottom outlets valves and not to withdraw water. In Fig. 4.9, there is an example of the Pařížov dam control towers.

4.1.4.4 Multipurpose structures

As it has already been mentioned in the introduction, (see Chapter 4.1.4), it is possible to combine several functional structures into one *multipurpose structure*. The reasons for this include offering a more economical solution, savings in foundation works and constructions and also in building materials and some operational advantages (Broža et al., 1987).

A multipurpose structure can contain the following combinations of functional equipment:

- bottom outlets and safety spillway,
- bottom outlets and intakes,
- bottom outlets, intakes and safety spillway.

In some cases, apart from the functional structures of the dam, a hydroelectric power plant or other facilities may also be part of a multipurpose structure (Říha, 2006).

4.1.5 FUNCTIONAL COMPLEXES

From the point of view of safety and functionality of a hydraulic structure, a dam must be equipped with functional facilities (bottom outlets, safety spillway, Intake structures). These dam facilities are not considered parts of the functional complex. Nevertheless, facilities which might be structurally related to a dam and which fulfil the target purpose or facilities stemming from the dam construction are part of the functional complex. These can include a hydroelectric power plant, lock chamber, boat lift, reservoir system, fish pass, etc. A dam might also be part of a water supply unit in terms of drinking water supply for the population and thus part of a broader waterworks system, or irrigation system and industry. The most common example of a functional complex is a dam with a hydroelectric power plant (Křižanovice, Josefův Důl, Hněvkovice, Sedlice, Mohelno, Vranov), system of interconnected reservoirs (Bedřichov + Rudolfov, Pastviny + Nekoř, Seč + Padrty + Křižanovice + Práčov, Vltava River Cascade) or part of a water supply unit (Želivka, Staviště, Láz, Křižanovice, Kružberk + Slezská Harta, Mostiště).

4.1.5.1 The Štěchovice HS

The Štěchovice dam (1937–1945) (Fig. 4.36) is a concrete gravity dam with a crown safety spillway which has five bays controlled by sluice gates. There is an outlet tunnel with dimensions of 7 × 7 m located in the dam body under the middle bay used for full reservoir drawdown. The outlet tunnel is controlled by a sluice gate. During the construction, the tunnel was used for the lockage of boats and rafts (Broža et al., 2005).

The parts of the functional complex (Fig. 4.35) of the Štěchovice HS are navigation equipment, a medium head and high head pumped storage hydropower plant with associated storage and a high-pressure headrace (Broža et al., 2005):

- The navigation equipment, consisting of two lock chambers, is situated on the right bank. The lock mitre gates are, in terms of their height, considered as unique within European water management;
- The medium head power plant is situated diagonally from the dam axis outside the dam body. Intake structures are, however, in a straight line with the body. The power plant is equipped with two Kaplan turbines with an absorption capacity of 2 × 80 m^3/s and an installed capacity of 2 × 11.25 MW at maximum head;
- At the time of the completion, the pumped storage hydropower plant was, in terms of its parameters, unique in Europe. The PSH power plant is positioned underground in such a way that the impeller wheel axis is 30 m under the tailwater level. Water is pumped into an artificially made concrete reservoir on the Homole hill. The

storage reservoir Homole has a safety spillway and an inlet into high-pressure headraces. The headraces are connected just before the hydroelectric power plant by a *"bifurcation piece"* into one inverted Francis-type unit which replaced the original two Francis turbines;

- The Štěchovice HS is also used to regulate peak discharges from Slapy and Orlík HPPs and their subsequent energetic use. In addition, the Štěchovice HS is used to ensure conditions for navigation in the given part of the watercourse;
- The Štěchovice dam is part of the Vltava River Cascade.

Fig. 4.35: The Štěchovice HS (1937–1945) – concrete gravity dam. Example of a functional complex – dam + lock chamber + hydroelectric power plant. Photograph by Michaela Ryšková, 2020.

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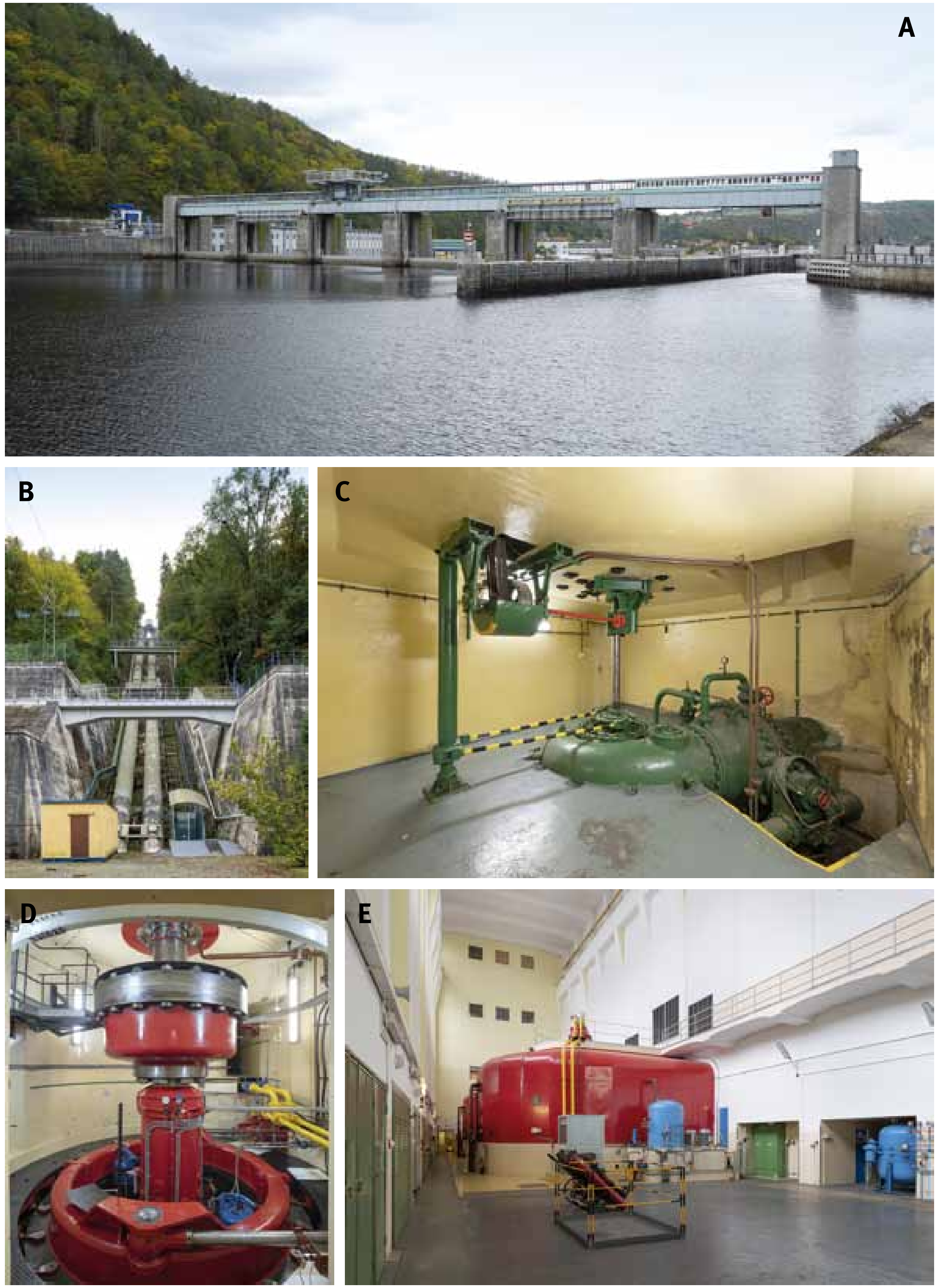
Fig. 4.36: The Štěchovice HS (1937–1945) – concrete gravity dam: (A) view of the upstream face, (B) to (E) pumped storage hydropower plant. Photograph (A) by Michaela Ryšková, 2020, (B) to (E) by Viktor Mácha, 2021.



4.1.5.2 The Vltava River Cascade

The origins of the Vltava River Cascade date back to the time of Charles IV, who considered connecting the Vltava with the Danube. At that time, the Vltava was mainly used for rafting and navigation, especially for the purpose of soil, stone and timber transportation. In 1894, the first comprehensive project for making the Vltava River navigable was prepared by Lanna-Vering. The project involved 33 low step weirs with a height of 2–4 m with lock chambers. There was a significant turnaround after the First World War, when a new energy interest intruded into the main navigation interest and started to be dynamically applied in all new studies. After the Second World War, the storage function and improvement of the discharge of Vltava and Lower Elbe were preferred. Current main purposes of the Vltava River Cascade are mainly energy, navigation, protection against floods, water supply and recreational ones (Broža et al., 2005; PVL, 2021).

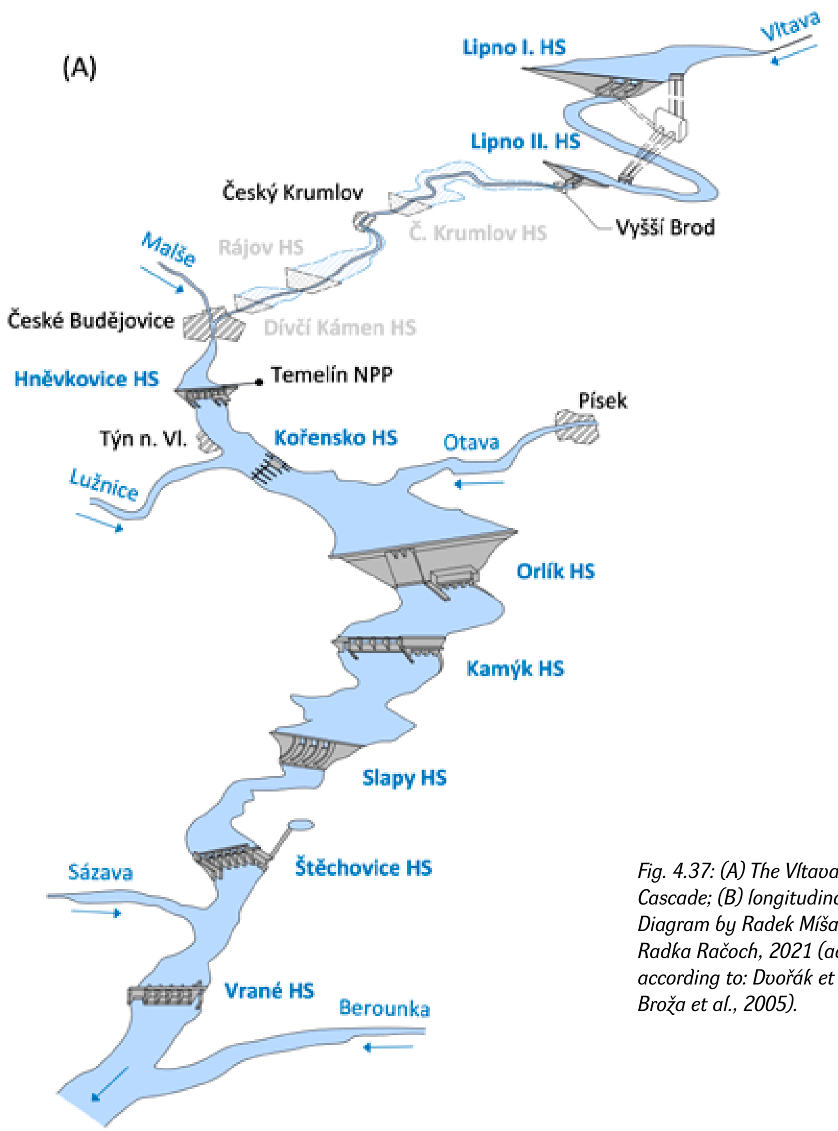
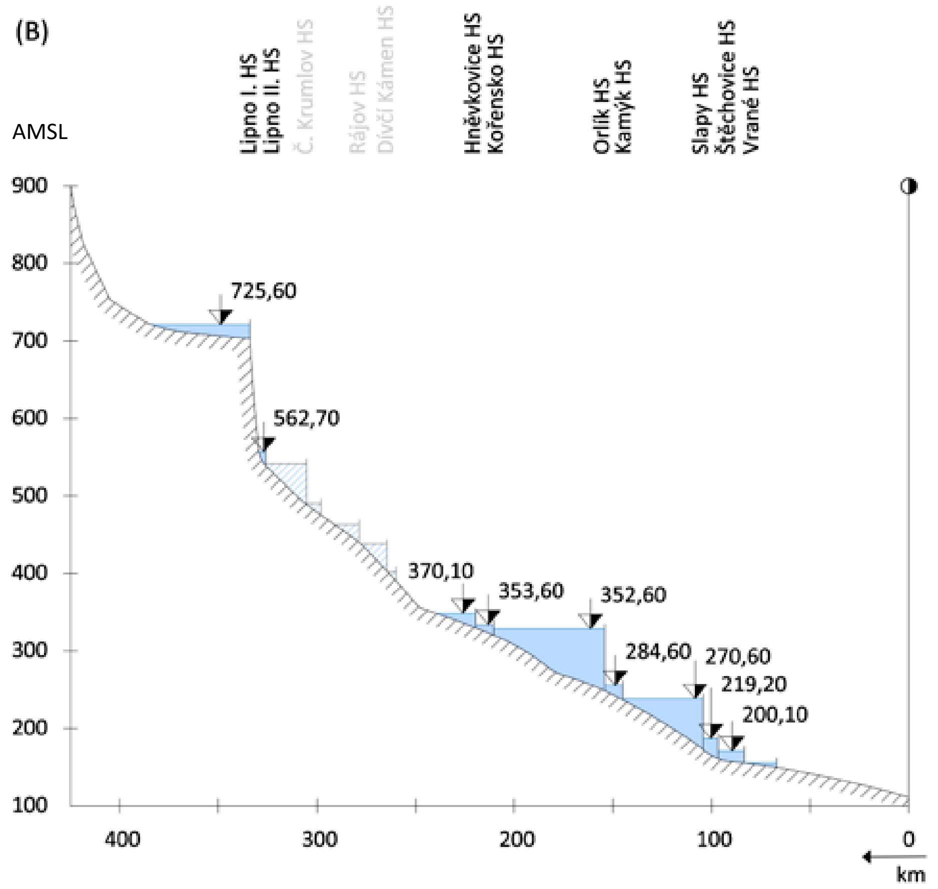


Fig. 4.37: (A) The Vltava River Cascade; (B) longitudinal section. Diagram by Radek Míšanec and Radka Račoch, 2021 (adapted according to: Dvořák et al., 1969, Broža et al., 2005).

The Vltava River Cascade is a unique functional complex of a large scale. It is a system comprising nine hydraulic structures in the Vltava River which are interconnected in terms of the regulation of peak discharges from hydraulic power plants and their subsequent energetic use and also in terms of navigation and safe diversion of flood flows. The hydraulic structures are appreciated for the technical solution they offer and their architectural rendering. In a broader international context, they are also important because of their parameters. On the other hand, the construction resulted in many natural and historically valuable places being destroyed (Broža et al., 2005; PVL, 2021).

The parts of the Vltava River Cascade functional complex are the following hydraulic structures:

- Lipno I (1952–1960), composite dam,
- Lipno II (1952–1960), earthfill dam,
- Hněvkovice (1986–1991), concrete gravity dam,
- Kořensko (1986–1991), gated weir,
- Orlík (1954–1963), concrete gravity dam,
- Kamýk (1957–1963), concrete gravity dam,
- Slapy (1949–1957), concrete gravity dam,
- Štěchovice (1937–1945), concrete gravity dam,
- Vrané (1930–1935), gated weir.



4.1.6 EVALUATION FROM THE POINT OF VIEW OF HERITAGE PRESERVATION BASED ON SPECIFIC EXAMPLES

In general, dam structures are important landscape-forming elements which create new images of landscape units that are sometimes even more impressive than the original landscape framework. Dam bodies themselves also form new dominant landmarks of the valley below them. Although their monumentality emerges mainly from a bird's eye view, even the actual structures of (especially) masonry and concrete dams and functional structures have become dominant landmarks of the valley below them and significantly shaped the identity of the location.

The degree of impact of the dam and the water body itself in the landscape image is conditioned by the landscape nature, landscape cover character – and therefore the potential for viewpoints – and the (in)accessibility of some places in the vicinity of the dam or the dam as a whole.

The construction of dams is almost always associated with the destruction of settlements and individual buildings, especially in the case of the largest reservoirs (Nechranice, Orlík, Lipno). At the same time, their construction often initiates urban developments on the reservoir banks unless it is not intended solely for water supply and technological purposes. These may be replacements for flooded built-up areas which, however, sometimes took place in closer or more distant towns but other times on the edges of non-flooded parts of villages or in new locations. Sometimes these were urbanistically remarkable design units (Bítov, Kníničky, Nové Zvírotice). On the banks of recreationally used reservoirs, recreational complexes for accommodation and catering were often built – sometimes with interesting urban and architectural design, or associated with landscaping on the banks – as well as cottage areas, which, on the contrary, lack any building culture. The specific landscape context is linked to waterworks reservoirs, the area and surroundings of which are inaccessible to the public and for protective reasons a wide ring of forest greenery is deliberately planted along their banks.

Dams are logically located in open countryside, far from towns or villages. Contrary cases are rather exceptional. This is the case, for example, of the Znojmo reservoir where the contact with the town veduta is relatively immediate and the dam is also prominent in views from many parts of the old town. Probably the most significant case is the Mšeno reservoir, built near the small town of Mšeno nad Nisou and the town of Jablonec nad Nisou, whose new housing development has surrounded the water area on almost all sides, and the architecturally distinctive dam is also an integral part of the intravilan. In the case of such reservoirs and their dams, we can even talk about not only landscape values but also urban ones.

Masonry dams from the turn of the 19th and 20th centuries adopted the romanticising language of medieval architecture (Mšeno; Labská; Bedřichov – Rudolfov; Harcov; Fojtka a Mlýnice; Pařížov; Jezeří; Kamenička; Les Království). Neo-Renaissance influences can be seen on the dam of the Janov reservoir or at the dam keeper‘s house of the Bystřička reservoir. A form influenced by architectural modernism and functionalism prevailed in late masonry dams. Concrete dams took advantage of the variety of building materials (Vranov, Brno, etc.) and their forms were gradually directed towards expressing the monumentality of an impeccable technical work (Kružberk; Klíčava; Vír I, Vír II; Křímov, Slapy, Orlík; Fláje; Vrchlice, etc.). In the case of earthfill dams, the implementation of architectural intentions is limited by the nature of the dam.

In the latest typology of historical cultural landscapes, the reservoir landscape is defined as a separate type which in some cases may show significant cultural values.

4.1.6.1 The Les Království HS

The Les Království dam, also known as "Nad Dvorem Králové", "Bílá Třemešná" or "Tešnov", was built on the basis of an initiative to build dams on the Upper Elbe after the catastrophic flood in July 1897, after which in 1903 the legal basis for the start of the systemic regulation of the Elbe from Špindlerův Mlýn to Jaroměř was given. The main purpose of the hydraulic structure is mitigation of flooding, as well as production of electricity in the hydroelectric power plant below the dam and improvement of flows in the Elbe. The dam body is gravity-type, made of sandstone on cement mortar with trass with the ratio of curvature of 200 m (Broža et al., 2005).

Temporal determination/date of origin: 1910–1919
Authorship: Ing. arch. Jaroslav Valečka
Heritage preservation: cultural monument (1958), national cultural monument (2010)
Reconstruction:
1922 – The first sealing of cracks on the left slope by cement grouting from boreholes in front of the upstream face of the dam (leakage reduction of 50%). After the hydroelectric power plant was put into operation and the water level rose, the leaks again increased.
1929 – Re-sealing of the left side of the valley with cement grouting of the rock around the by-pass tunnel and subsequently construction of 24 m high left-side sealing wall led against water to the distance of 182 m from the upstream face of the dam in order to prevent water from entering from the reservoir into the rock slope.
1937–1938 – Extension of the sealing concrete wall by an underground wall running perpendicular to the slope (width 2 m, length 95 m) due to further leakage.
1952–1959 – Overhaul and reconstruction of the dam bottom outlet with pipeline replacement. Construction of a new stilling basin under the outlet. Reconstruction of a water headrace to the hydroelectric power station by replacing two pipes - by one with 2.6 m in diameter. Cancellation of the bottom outlet in the right by-pass tunnel with its upstream part concreted.
1992–1993 – Reconstruction of outlets in the left discharge tunnel. New steel tubes with a diameter of 1 m were inserted into three cast-iron tubes with a diameter of 1.1 m and all six slide gate valves were replaced.
1996–1997 – Final sealing of sandstone bedrock on the right side of the valley. A sealing curtain of cement and chemical grouting with polyurethane was implemented in two rows of boreholes up to 30 m deep from the inspection gallery and in a newly established grouting gallery to reduce leaks.
1998–1999 – The depth of the stilling basin of the dam bottom outlet was increased by 2.5 m and the resistance was increased by inserting a new reinforced concrete tank.
2005–2006 – Renovation of bottom outlets in the right by-pass tunnel.
2018–2019 – Reconstruction of the dam keeper's house, both passage gates and the left valve tower. With regard to heritage preservation, materials and building elements used in the reconstruction of the buildings corresponded to the historic originals, as well as traditional building procedures (Broža et al., 2005).

Evaluation:

Typological value:

- **Exceptional parameters of structural and technological parts:** The Les Království dam is exceptional for its number of bottom outlets and number of safety spillways. The hydraulic structure has a total of 5 bottom outlets. The dam bottom outlet 2,000 mm in diameter, situated on the left slope, is controlled by a steel board and at the outlet by a radial gate valve. There are three bottom outlets 1,000 mm in diameter in the shaft leading into the left by-pass tunnel, each of which is controlled by a pair of slide gate valves. In the shaft leading into the right tunnel, which is under the dam keeper's house, there is one outlet 1,800 mm in diameter with a knife gate valve, flap valve and radial gate valve. The dam has two uncontrolled shaft safety spillways bays and one uncontrolled spillway in the body dam (Broža et al., 2005).
- **Exceptional occurrence within the Czech Republic:** It is the only dam in the Czech Republic which has 5 bottom outlets and 3 safety spillways. Large dams usually have two bottom outlets and one or two safety spillways (Broža et al., 2005).

Value deriving from the technological flow: A dam with a hydroelectric power plant forms a functional complex. Part of the flood protection system on the Upper Elbe.

Value deriving from authenticity:

- **Authenticity of function:** The construction serves its original purpose and its purpose has not been extended in any way during its operation.
- **Authenticity of form:** Two concrete extensions from the 1950s on the upstream side are evaluated negatively.
- **Authenticity of mass/material:** The Les Království HS has undergone a considerable amount of reconstruction in more than 100 years of its operation. The reconstruction concerning buildings was carried out with due regard to heritage protection. In the reconstruction of the buildings, such materials and building elements were used which corresponded to the historic originals, as well as traditional building procedures. Some reconstruction (e.g., reconstruction of the dam bottom outlet stilling basin) completely changed its original design parameters. Many reconstructions are not apparent at first sight and served to ensure the reliable functionality of the hydraulic structure. Nevertheless, some non-original material was used.
- **Authenticity of technical equipment:** The technical facilities of the Les Království dam underwent a lot of reconstruction and replacement. Some devices are still original, others with extensive repairs, or replaced with new ones.
- **Authenticity of technological solutions** – Modern technical solutions were partially used. Broža et al., 2005).

Architectural value: With the arrival of masonry dams at the end of the 19th century, an aesthetic aspect began to be applied in dam designing. The masonry dams took over the historicising architectural morphology applied in industrial architecture and in technical buildings. The Romanticising morphology of the Middle Ages, inspired by castles with dominant towers and massive castle walls crowned with battlements, was apparent in the case of dams situated in picturesque natural scenery (Mšeno, Fojtka, Mlýnice, Harcov, Pařížov, etc.). In the Les Království dam these aesthetic and architectural forms are used in abundance. The dominant elements of the complex are two gates on the dam crest, framing the crown spillway, cylindrical valve towers with battlements and the dam keeper's house. The stone masonry of the structures and dam cladding, combining Cyclopean masonry with worked blocks, complement the crafted architectural details. The power plant in the spirit of architectural modernity is a younger layer, sensitively complementing the original complex.

Landscape/urban value: Thanks to its historicising concept, the dam structure (with the power plant and accompanying structures) has become a very distinctive landscape-forming element which is applied both when viewed over the water surface, and especially from the valley below the dam and from the place of the dam itself and road leading to it. The creation of the dam wall enabled the origin of a new road connection between Bílá Třemešná and the left-bank area. The role of the dam wall in a wider landscape is limited because it is hemmed in by a wooded valley. This also applies to the whole water area which is quite long but except for the section close to the dam it is very narrow. Apart from the mill in the area of the dam, no other settlements or buildings have been flooded.

Fig. 4.38: The Les Království dam (1910–1919) – masonry gravity dam. Photograph by Viktor Mácha, 2020.

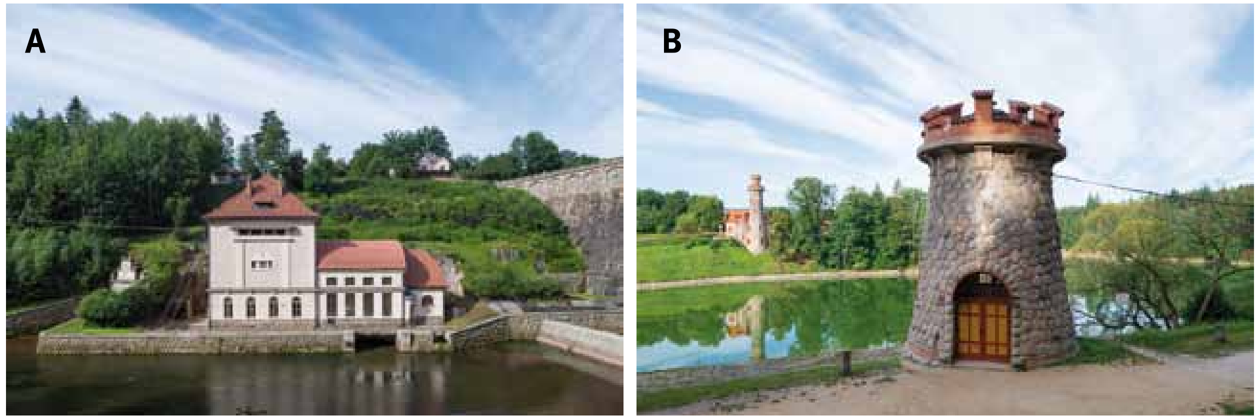


Fig. 4.39: The Les Království dam (1910–1919): (A) hydroelectric power plant building; (B) valve tower to control bottom outlets in the left by-pass tunnel; in the background, the dam keeper's house. Photograph by Viktor Mácha, 2020.

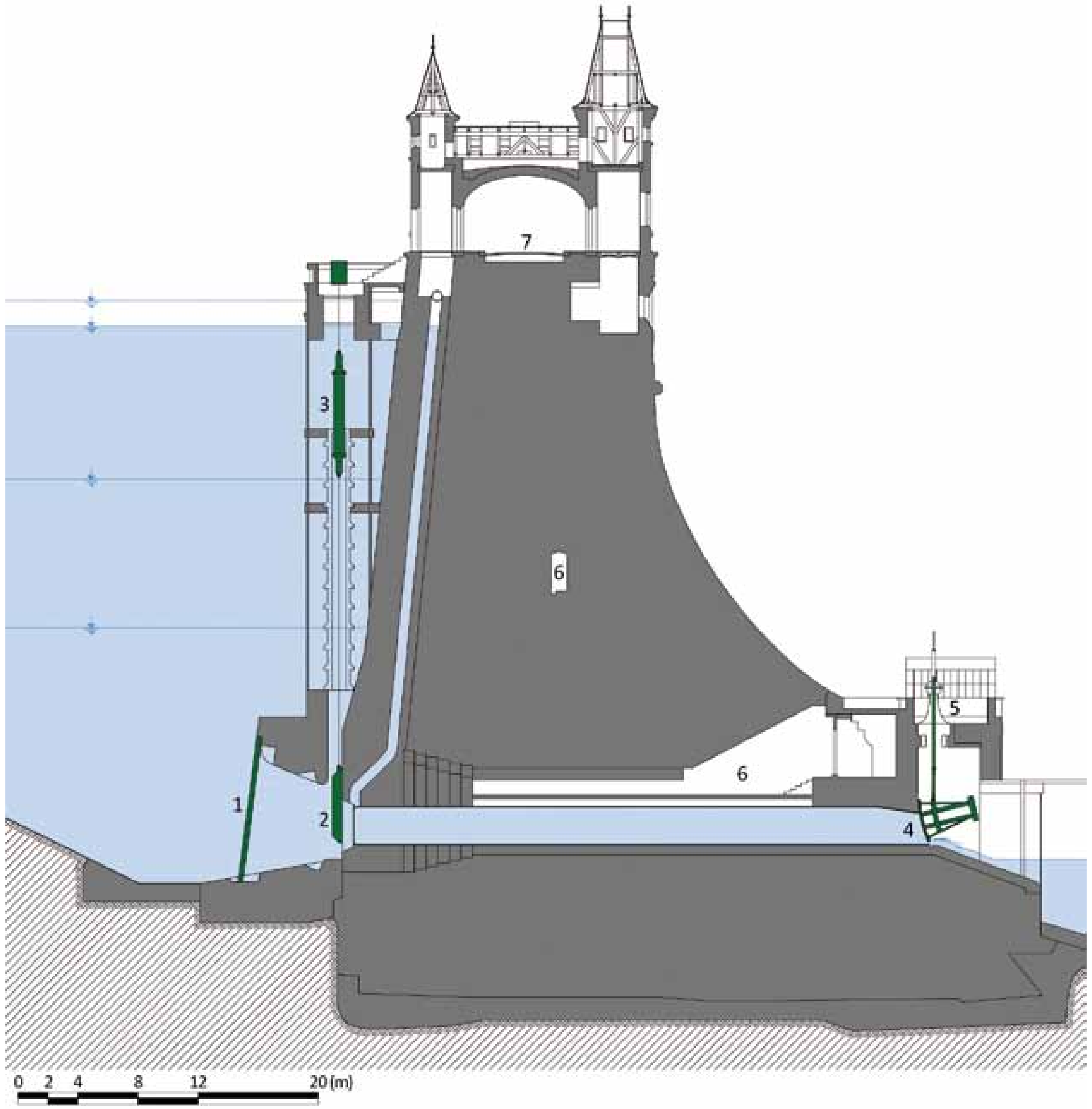


Fig. 4.40: The Les Království dam (1910–1919) – cross-section of the dam at the bottom outlet: 1 – thrashracks, 2 – gate valve, 3 – control of the gate valve, 4 – radial gate valve, 5 – control of the radial gate valve, 6 – inspection gallery, 7 – crest of the dam. Diagram by Radek Míšanec, 2021 (adapted according to: the Elbe River basin archive).

4.1.6.2 The Slapy HS

The construction of the Slapy dam was carried out in 1949–1957. The Slapy dam is a masonry gravity dam 67.5 m high above the foundation 260 m long at the dam crest. The crown safety spillway of four bays is controlled by lifting gates. At the end of the spillway there are reinforced concrete baffle blocks. The dam has two bottom outlets 4,000 mm in diameter. In the dam body there are six inspection galleries at four different levels. From the lowest grouting gallery, 15–30 m deep grout curtains were made. From the aforementioned grouting gallery, it is possible to see the dam junction with the rock slope. The hydraulic structure is particularly interesting for the unconventional solution of the hydroelectric power plant that is overtopped. The main purpose of the work is the use of flow and hydraulic head to generate peak energy. Furthermore, the improvement of the flow rates on the Lower Vltava–Elbe navigation route. Other purposes are drinking and industrial water withdrawal, flood flow control, sport and recreation (Broža et al., 2005).

Temporal determination/date of origin: 1949–1957
Authorship: Ing. Libor Záruba-Pfeffermann
Heritage preservation: –
Reconstruction:
2011 – Modernisation and complete reconstruction of the TG3 turbo generator (NAŠE VODA, 2021).
2018–2020 – Modernization and complete reconstruction of the TG1 turbo generators which also included the replacement of the impeller wheel chamber and TG1 draught tube mouthpiece. In addition, the reparation of the generator stator, rotor poles and cooling circuit of the block transformer. Modernisation of the control hydraulics (HN, 2019) was also carried out.
2021–present – Modernization and complete reconstruction of the TG2 turbine generators which includes the replacement of the impeller wheel chamber, complete replacement of the turbine and its regulation. In addition, the repair of the generator stator, rotor poles and cooling circuit of the block transformer. Restoring the internal protective coating of the headrace pressure tunnel to a turbine, the former being over 50 m long and having the diameter of 5 m. Modernisation of the control hydraulics (VODA, 2021) will also be carried out.

Evaluation:

Typological value:

- **The first of its kind:** During the construction of the Slapy hydraulic structure, an unconventional solution of the hydroelectric power plant was implemented. The first overtopped hydroelectric power plant was built in the Czech Republic, located in direct contact with the dam body below the spillways. There were also the first reinforced concrete baffle blocks at the end of the spillway, closing the roof of the hydroelectric power plant. At that time, it was a unique work even within Europe. Crown spillways of the Slapy HS are also called “ski jumping hills” (Broža et al., 2005; PVL , 2021).
- **Exceptional structural solutions/use of a particular technology:** An unconventional solution with overtopped hydroelectric power plant and reinforced concrete buffle clocks at the end of the spillway. At that time, it was a unique work even within Europe (Broža et al., 2005).

  Interesting facts: According to the proposed project, the Slapy navigation equipment would use the unconventional solution of a rotary boat lift when, where the boat trough would move along a single helix-shaped supporting rail. Another unusual solution proposed was a load-lifting device with compacted chains, which is protected by a patent. However, for financial reasons and time constraints, the proposed navigation equipment has not been implemented. Now small vessels up to 3.5 tons are transported in front of the Slapy HS on special tows pulled by a tractor (Broža et al., 2005), (PVL, 2021).

Value deriving from the technological flow: This dam with a hydroelectric power plant is a functional complex. The dam is also part of the Vltava River Cascade and interacts with other reservoirs, thus it is part of another functional complex.

Value deriving from authenticity:

- **Authenticity of function:** The construction serves its original purpose and its purpose has not been extended in any way during its operation.
- **Authenticity of form:** Preserved.
- **Authenticity of mass/material:** Preserved; the dam is without major renovations.
- **Authenticity of technical equipment:** The technical equipment underwent significant reconstruction and modernization and was replaced by a new or more modern one. The reconstruction was mainly used to extend the lifetime and increase the efficiency of the hydroelectric power plant.
- **Authenticity of technological solutions:** Modern technical solutions were partially used.

Architectural value: The Slapy dam, which forms with a hydroelectric power plant one building unit, is one of the most architecturally and artistically impressive concrete gravity dams. The post-war trend accentuating the monumental form of technical works was supported by the architectonic representation of forms, punctuated by the crown spillways and chutes on the downstream face topped with water buffle blocks above the roof of the power plant. The complex is embellished by architectural details, e.g., in the form of original public lighting columns installed on the railing pillars.

Project author, Ing. Libor Záruba-Pfeffermann, who was the Hydroproject chief engineer and holder of patents in the field of water construction and machinery.

Art-historical value: A statue of St. Jan Nepomucký was transported from the flooded area to the vicinity of the power plant.

Landscape/urban value: The construction of the Slapy HS meant a radical landscape intervention of the Central Vltava River basin, especially in the deep Vltava canyon itself, which represented an extraordinary landscape value at least within Central Europe. A number of smaller villages, hamlets, mills and other secluded places were also flooded, especially Přívozec, Buzice, Byčice, Bučily, Záběhlice, Zvírotice (part), Županovice (part), Oboz, Sejce, Ústí, Živohošť (the church remained above the water level), Královská and Ždáň. In return, a new image of the landscape was created with the water surface the dominant effect which is very much prominent in viewpoints.

Thanks to the primary recreational purposes of the reservoir, a number of new recreational areas and facilities (Ždáň, Nová Rabyně, Nová Živohošť) and new residential construction were built on its banks. The most remarkable design achievement is New Zvírotice, a uniformly established village in the early 1950s, replacing the old village, largely flooded by the reservoir of the Slapy dam. It is the only village in our country whose architecture is designed according to the concept of so-called socialist historicism. The village was founded with an effort to follow the principles of the traditional village. Simple, gable-oriented houses have mostly been preserved with the original simple stuccoed decoration, inspired by the South Bohemian rustic Baroque, but also with completely contemporary motifs (tractor). The large sloping rectangular village square remotely resembles the South Bohemian Holašovice. This is a unique and preserved almost intact example of a modern village residence which has followed older traditions in an interesting way (Kuča, 2020).

The dam itself is a very distinctive landscape element which forms a dominant landscape image and can be viewed very well thanks to the road connecting both sides of the Vltava valley and also because the port of river steamers from Prague lies not far from the dam. The landscape of the Slapy reservoir can also be extensively enjoyed when taking the regular passenger shipping holiday line from the dam to Nová Živohošť.

Fig. 4.41: The Slapy dam (1949–1957) – concrete gravity dam, crown safety spillway with four sections controlled by a lifting gate. Photograph by Viktor Mácha, 2021.

Fig. 4.42: The Slapy dam (1949–1957) – a concrete gravity dam, view of the upstream face. Photograph by Viktor Mácha, 2021 and Michaela Ryšková, 2020.

4.1.6.3 General summary of the principles of dam evaluation

When evaluating dams from the point of view of heritage preservation, it is important to focus primarily on the typological criteria, which highlight the values of the building from the perspective of construction and technological design, the degree of authenticity and quality of architectural processing, to which was paid full attention especially in the case of rock and concrete dams. When assessing the historical importance of dams, it is important to consider their influence downstream and upstream of the watercourse from different points of views, which usually have different impacts, whether positive or negative. (Douet, 2018)

Some **general evaluation criteria** are irrelevant in the evaluation of dam structures (*construction state, state in relation to technology*, *existing functionality*) or less significant (*authenticity of function* and *value of new use*). Since all dams (except for Bílá Desná) are functional and in operation (*authenticity of the function* is therefore maintained), for which they also need complete technological equipment, it makes no sense to evaluate them in this respect. In the event of decommissioning, the dam must be adjusted in such a way that it cannot be a source of potential damage to the river basin which usually involves dismantling of a substantial part of the dam (impoundment structure).

When assessing heritage preservation and its extent, the safety and functionality of the dam must be primarily taken into account. Heritage protection may involve either the structure as a whole or only its constituent parts. The protection of a hydraulic structure should not restrict the functionality of the structure (for example, some types of valves are no longer produced). Long-standing experience has shown that it is beneficial to have two independent bottom outlets available although many older hydraulic structures are equipped only with one. Where possible, bottom outlets are added. An attempt is quite often made to increase the diameter of the bottom outlet in order to improve the conditions for handling the water level in the reservoir (e.g., faster emptying of the reservoir during flooding). During the reconstruction of dams, it is usually necessary to propose such a solution which respects current regulations (e.g., requirement for a specific width of the road on the dam crest may lead to an extension of the dam crest) (Špano et al., 2021).

4.1.7 REGISTER OF LOCATIONS

Name	Period of construction	Type of dam	Type of protection	Protected from	USKP registry number	Item name according to the Monument catalogue	District
Bílá Desná HS	(1911–1915)	earthfill	CM	08/04/1998	11290/5-5756	reservoir	Jablonec nad Nisou
Bystřička HS	(1908–1912)	masonry gravity	CM	23/09/2003	100560	Bystřička reservoir	Vsetín
Fláje HS	(1951–1963)	concrete buttress	CM	09/06/1987	43165/5-5080	reservoir	Most
Fryšták HS	(1935–1938)	earthfill	CM	04/07/1997	11849/7-8782	Fryšták reservoir	Zlín
Harcov HS	(1902–1904)	masonry gravity	CM	30/12/1987	43960/5-5244	reservoir	Liberec
Hracholusky HS	(1959–1946)	earthfilled	-	-	-	-	Plzeň-North
Janov HS (Hamerská reservoir)	(1911–1914)	masonry gravity	CM	09/06/1987	42697/5-5079	reservoir	Most
Jezeří HS	(1902–1904)	masonry gravity	CM	18/06/1963	42932/5-302	reservoir	Chomutov
Les Království HS	(1910–1919)	masonry gravity	CM NCM	18/04/1964 01/07/2010	24486/6-3435 349	reservoir and hydroelectric power plant Tešnov hydroelectric power plant – Les Království reservoir in Bílá Třemešná	Trutnov
Mariánské Lázně HS	1896	masonry gravity	-	-	-	-	Cheb
Mšeno HS	(1906–1909)	masonry gravity	CM	23/11/1987	43939/5-5219	reservoir	Jablonec nad Nisou
Orlík HS	(1954–1963)	concrete masonry	-	-	-	-	Příbram
Pařížov HS	(1909–1913)	masonry gravity	CM	12/06/1986	28234/6-4750	reservoir – dam including overflow system	Chrudim
Sedlice HS	(1921–1927)	masonry gravity	CM	23/11/2012	104938	Sedlice reservoir dam	Pelhřimov
Slapy HS	(1949–1957)	concrete masonry	-	-	-	-	Prague-West
Štěchovice HS	(1937–1945)	concrete masonry	-	-	-	-	Prague-West
Vrchlice HS	(1966–1970)	concrete arched	-	-	-	-	Kutná Hora
Znojmo HS	(1962–1965)	composite	-	-	-	-	Znojmo

4.2 SMALL WATER RESERVOIRS

Small water reservoirs are hydraulic structures in accordance with the provisions of Section 55 (1) of the Water Act No. 254/2001 Sb. According to the standard ČSN 752410 (ČSN, 2011), small water reservoirs are structures with an earthfill dam with a capacity of up to 2 million m^3 (active storage) and a maximum depth of 9 m (dam wall approx. 10 m). The term "**pond**" (in Czech "rybník") became established in Czech in the past as a designation for most of the small water reservoirs, whether they were used for fish (in Czech "ryba") farming or not. Nowadays, this designation is used primarily in connection with the production function in accordance with the Act on Fisheries No. 99/2004 Sb., Section 2 (c) as a designation for a hydraulic structure *"which is a water reservoir intended primarily for fish farming, in which the water level can be regulated, including the possibility of draining and fish harvesting; the pond is made up of a dam, reservoir and other technical equipment".*

Every small water reservoir (SWR) currently has handling rules – a set of regulations, principles and guidelines on how to handle water in a hydraulic structure and how to manage it efficiently. It also contains information on the construction (diagrams, drawings, graphs), flow rates, operators and users, filling and emptying time, water volume, reservoir area, water area and cadastral area. Furthermore, for operation there are also operating rules – a set of regulations, guidelines and instructions for the operation of all equipment of the hydraulic structure. Each small water reservoir is classified, after being assessed, in the category I to IV and based on this classification it is necessary to secure technical safety supervision of the hydraulic structure (in accordance with Sections 61 and 62 of the Water Act No. 254/2001 Sb.).

With respect to its parameters, reservoir storage is divided into several parts that are separated by levels from each other. We distinguish them thus: Permanent storage (dead) which extends to the invert level of the lowest discharge outlet – in the case of fish tanks, this space is usually missing; supply storage which extends from the bottom to the normal level – it is designed for various uses of water supply depending on the reservoir functions; flood storage which is used for retention of floods and flattening of flood waves. The active storage delimits the flood storage which can be regulated in the reservoir by means of outlet structures. As soon as the level reaches the edge of the safety spillway, the amount of water in the reservoir can no longer be safely controlled (Fig. 4.43).

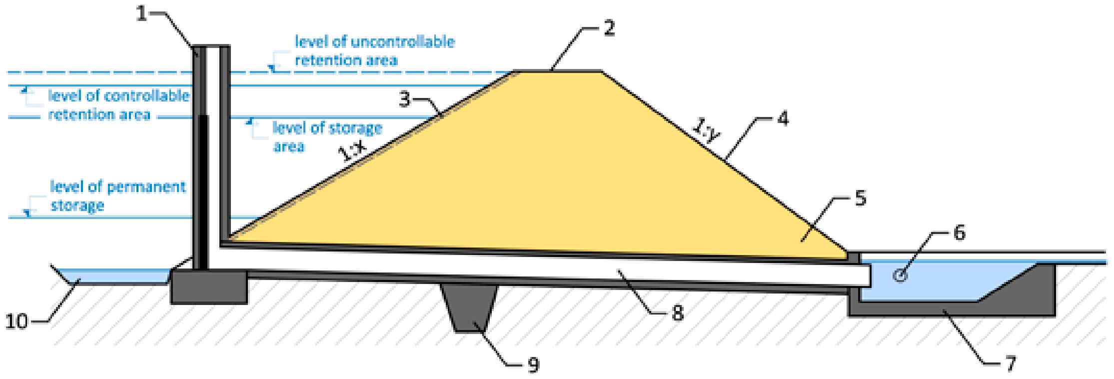


Fig. 4.43: General reservoir scheme: (1) – outlet structure (monk outlet), (2) – dam crest, (3) – upstream face, (4) – downstream face, (5) – toe drain, (6) – pipeline pit, (7) – stilling basin, (8) – outlet pipeline, (9) – cutoff, (10) – dead storage. Diagram by Radka Račoch and Radek Bachan, 2021 (modified according to: Ministry of Agriculture, 2015).

4.2.1 HISTORY OF PONDS

The first references to the establishment of ponds in Central Europe come from the Early and High Middle Ages, the oldest mention of ponds in the territory of today's Czech Republic being mentioned in the Appendices to Chronica Boemorum from 1034. The foundation charter of the Kladruby Monastery (from 1115), in which the monarch Vladislav I donated to the monastery land for the establishment of ponds, is also widely mentioned. This charter, however, was a forgery from the 13th century. As these written references show, the origin of the first ponds in our territory is attributed to the activity of monastic orders (Benedictines and Cistercians). Nevertheless, archaeological research shows that the first small reservoirs could have been a common part of rural settlement already in the 10th century. Initially, ponds were created on smaller streams or rivers, and technically they were in no way complicated, these were actually earthfill dams on smaller watercourses. They were widely used mainly for the needs of water mills. Since their origin, small water reservoirs have been multi-purpose hydraulic structures. Apart from fish farming, they also served as a retention basin, the aforementioned energy source for the drive of water mills, saw mills, hammer mills and mines or as a source of potable and non-potable water with fire-fighting function. In the course of time, fish farming became a profitable economic sector, nobility and towns took charge of construction and ponds began to be stocked with carp, which was in demand in neighbouring Germany. Thanks to this economic profit, fish farming became a symbol of the Czech lands in the 15th and 16th centuries, and the total area covered by ponds in the Czech Republic is estimated to be as big as 180,000 ha. A well-known treatise written by Bishop Jan Dubravius ("De pisces") in 1559 contributed to the spread of fish farming farther abroad. In this period, ponds were also successfully built on the territory of Germany, Poland and Austria. In the golden era of pond building, these reservoirs had a considerable social and cultural overlap. They became a certain symbol of power, and their ownership was often associated with famous noble families. At the expense of ponds, not only agricultural land but sometimes even parts of villages were inundated. Subjects had to participate in the repair and maintenance of ponds within their corvée. The boom of pond building was slowly beginning to come to an end as early as at the beginning of the 17th century. The interest in fish gradually declined, and after the Thirty Years' War, there were no monetary resources available for the restoration of neglected ponds, therefore some of them naturally filled in or fell victims to flood events. Most of them, however, started to be intentionally dried out, especially for the purpose of making arable land or meadows profitable within the intensification of agricultural production. The cancellation of ponds culminated in the 18th and 19th centuries. Their decline is clearly visible when comparing military maps I, II and III. About two thirds of the original extent of ponds disappeared. In the second half of the 20th century, the total area of ponds is estimated at 51,800 ha, and this figure has not changed much until now, despite the fact that in recent years some ponds have been restored within subsidy schemes (Pavelková et al., 2014). The current number of ponds in the Czech Republic is only estimated at 22,000–24,000 (according to some sources up to 30,000).

The largest pond in the Czech Republic was Blato Pond, in the past also called Blatské Lake, (1,733 morgens – 996 ha, originally even more), which was part of the complex pond system in the Poděbrady and Nymburk regions. Built around the second half of the 15th century, Blato Pond ceased to exist in the second half of the 18th century. Due to the flat terrain, the pond was shallow, in some places it basically had the character of marshy areas (hence probably the name Blato – "mud" in English). The other three ponds (Úslovický, Vyhlíd and Vepřík) were separated from Blato only by dam walls. The pond was fed by the so far partially preserved Sánský Channel (also called Lánská Gulley) built to feed the ponds of the Poděbrady manor in the 15th century. The channel bypassed the area of the pond along its southwest bank and also by several natural streams (Blatnice). The pond had several dam walls and outlets – the main one was a short dam at the place of the Blatnice outlet, on the road between Kouty and Netřebice, allegedly equipped with a stone bridge (now no longer there) at the weir. Others were to the south of Kouty and Pátek. Now the area is used as a field and the dam wall is only apparent in some sections. Its shape is noticeable near Senice, to the left of the road Poděbrady – Jičín. The name of the pond is preserved in the local names of fields and meadows existing in this place (Elleder et al., 2020).

4.2.2 CLASSIFICATION OF SMALL WATER RESERVOIRS

4.2.2.1 Classification of SWRs by function

- **Storage reservoirs** – retain in their storage area a sufficient amount of water usable when there is a shortage of it (e.g., water supply, industrial, irrigation, energetic, regulating, spare reservoirs, etc.).
- **Flood-control (retention) reservoirs** – protect against negative effects of floods by catching flood flows in their flood-control storage, and thus they partially transform flood waves (e.g., dry or semi-dry, erosion-control, storm-water, detention basins*, etc.).
- **Reservoirs altering water characteristics** – chemical, biological or physical water characteristics are deliberately altered in them (e.g., cooling, sedimentation, aeration biological reservoirs, etc.).
- **Fish farming reservoirs** – ponds, reservoirs aimed at fish farming (e.g., hatchery, spawning, for fry, rearing, hibernating, stock, store and guarantive isolation pond).
- **Local reservoirs** – reservoirs aimed at providing specific economical functions (e.g., fire, poultry farming, feed and floatage reservoirs, flooding basin, liman basins, revitalising reservoirs).
- **Operational reservoirs** – reservoirs of various types for operating needs (e.g., pumped storage, recirculating, equalising irrigation basins).
- **Sanitation reservoirs** – reservoirs designed for the sanitation of anthropogenic disturbances to the land, or for storage of substances negatively affecting the environment (e.g., catch, storage and sludge settling, lagoons, open sludge-digestion).
- **Landscape-forming and urbanistic reservoirs** – reservoirs built with the purpose of increasing the aesthetic value of the landscape – in urbanised environments their function is usually enhanced by fountains and works of art, e.g., ornamental ponds in parks (Fig. 4.44), village square little ponds, hydromelioration water areas, artificial wetlands.
- **Recreational reservoirs** – reservoirs intended for water sport activities, complemented by special equipment and specific entry into water.

**The term "detention basin" is often mixed up with "dry or semi-dry basin" – it has no natural inflow and water is supplied into it from a side of the dam directly from the watercourse during higher levels of water.*

Fig. 4.44: Mimoň, Chateau Pond – an example of a reservoir that is part of the chateau park and is fed only by springs. Photograph by Miroslav Kolka, 2018.

4.2.2.2 Classification of SWRs according to the authors Tlapák and Herynek (2002)

- **Stream/river** – reservoirs that are situated directly on the watercourse (with natural inflow) or that are built outside the watercourse and water is supplied by a system of gulleys and head races (without natural inflow).
- **Spring** – reservoirs situated in the spring area of the watercourse, fed directly by a spring. The spring is located in the bottom or bank of the reservoir. They are the most watery in spring. A special case is exhausted quarries and gravel pits that are filled with groundwater and can be adapted to a small water reservoir.
- **Celestial** – reservoirs that are primarily fed by rainfall or melted snow, potentially containing a drainage system (Fig. 4.45 and Fig. 4.46). Most of them must be deeper, with only a lightly permeable bottom and banks in order to prevent water losses (e.g., Vlkovický Pond near Třeboň, with 85 ha being the largest one in our country).

Fig. 4.45: Bezděz – reservoir in the middle of the village fed by rainfall and springs in the slope below the castle hill. Photograph by Miroslav Kolka, 2011

Fig. 4.46: Dražejov – reservoir in the middle of the village square, fed by rainfall and overflow from the local historical water supply. Photograph by Miroslav Kolka, 2014

4.2.2.3 Classification of SWRs according to water supply method*, according to the authors Šálek (1996) and Just, Moravec (2017)

- **With natural inflow** – situated directly on the watercourse so that the watercourse is dammed and the water supply into the reservoir cannot be much regulated.
- **Without natural inflow** – several types; water supply can be partially regulated (Fig. 4.47):
  - **By-pass** – for water supply there is a channel coming from the main watercourse which then flows around the reservoir. The amount of water flowing into the reservoir can be regulated;
  - **Bank** – the reservoir dam is on the river bank from where the reservoir is fed;
  - **Side** – the reservoir dam runs along the watercourse and at the same time the dam is above its level. They are connected with the watercourse by a feeder (race), or a tunnel, where the amount of water flowing in is regulated;
  - **Impound** – the whole area of the reservoir is diked;
  - **Dug (excavated)** – the reservoir is excavated underground.

** These are mainly stream (river) reservoirs.*

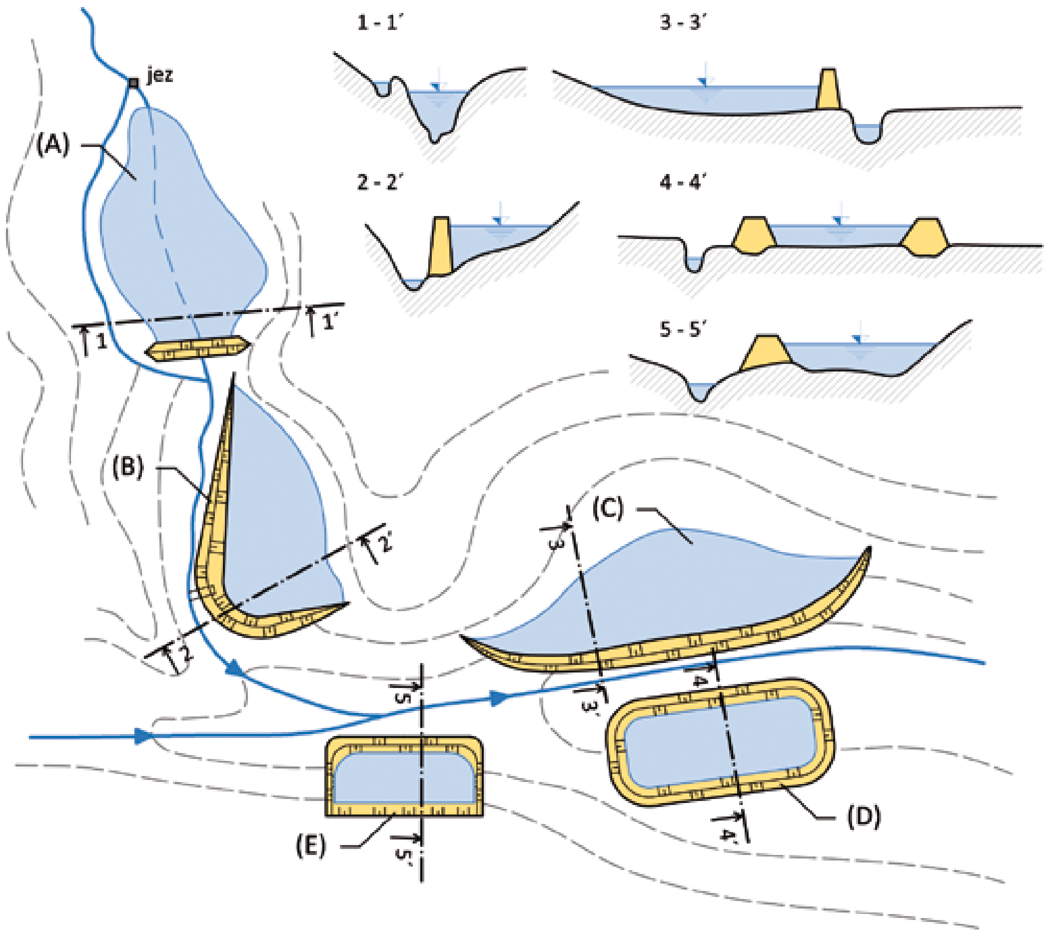


Fig. 4.47: Types of reservoirs without natural inflow and their cross-section: (A) – valley by-pass, (B) – bank, (C) – side, (D) – impound, (E) – dug. Diagram by Radka Račoch and Radek Bachan, 2021 (modified according to: Šálek,1996).

4.2.3 BASIC FUNCTIONAL STRUCTURES OF SMALL WATER RESERVOIRS

4.2.3.1 Dam

A dam is a basic building element of a small water reservoir. Dams are created mostly from the local soil by filling or sluicing, also with the use of concrete and masonry elements. Dams of our oldest ponds were originally built directly on a grassed footing but they were not very stable. For this reason, the dam foundations were embedded into the ground with a minimum depth of 20–30 cm, but in coarse-grained (sandy) soils even around 170 cm, as recommended by Jan Dubravius in his treatise from the 16th century. The material for the construction of the dam was mostly taken from: local sources. The soil was gradually filled on the dam foundations and compacted by means of pile drivers.

Classification of historical ponds according to the dam construction (Fig. 4.48):

- **Dubravius's ponds:** Mostly material-homogeneous dams, in the base 3 times wider than in the crest of the dam and the upstream and downstream slopes of the dam were very steep, in a ratio of 1:1 with the base. The oldest ponds had only a short, straight dam;
- **Krčín's ponds:** From the second half of the 16th century, they had more gradual dam slopes and the base was by 4.5 times wider than the crest. Such dams were able to transfer possible water leaks to the dam and not to the downstream slope in front of the dam where there often was a risk of disruption of its stability (Dubravius's ponds). The width of the dam was increased at the heel of the downstream side by layers of soil.
- **Modern SWRs:** According to the standard ČSN 752410, they need to have a minimum slope of 1:2 on the downstream side and 1:3 on the upstream side of the dam. The ratio between the height and the base is therefore at least 1:5, with the fact that the dam crest must not be smaller than 3 m. In modern ponds, there are also non-homogeneous dams used, composed of several materials and soils of different types (ČSN, 2011).

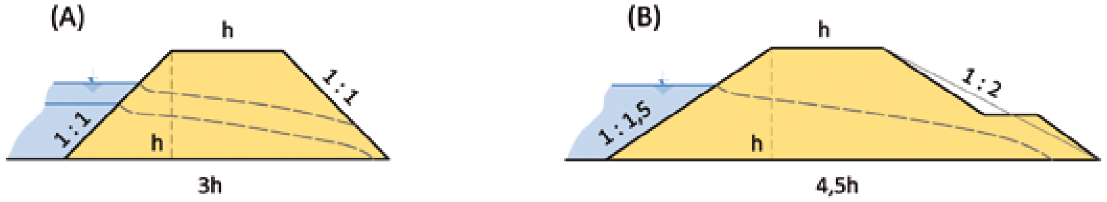


Fig. 4.48: Dam types according to the dam construction: (A) Dubravius's ponds; (B) Krčín's ponds, where h – dam crest width. Diagram by Radka Račoch and Radek Bachan, 2021 (modified according to: Pavelková et al., 2014).

Classification of dams according to their position and shape:

- **Frontal** – sometimes also the main dam that obstructs the watercourse (Fig. 4.49):
  - direct (Fig. 4.50, Fig. 4.52),
  - convex,
  - concave (Fig. 4.51),
  - polygonal,
  - irregular.
- **Side** – secondary dam that limits the submerged area.
- **Dividing** – a common dam that separates two small water reservoirs from each other.

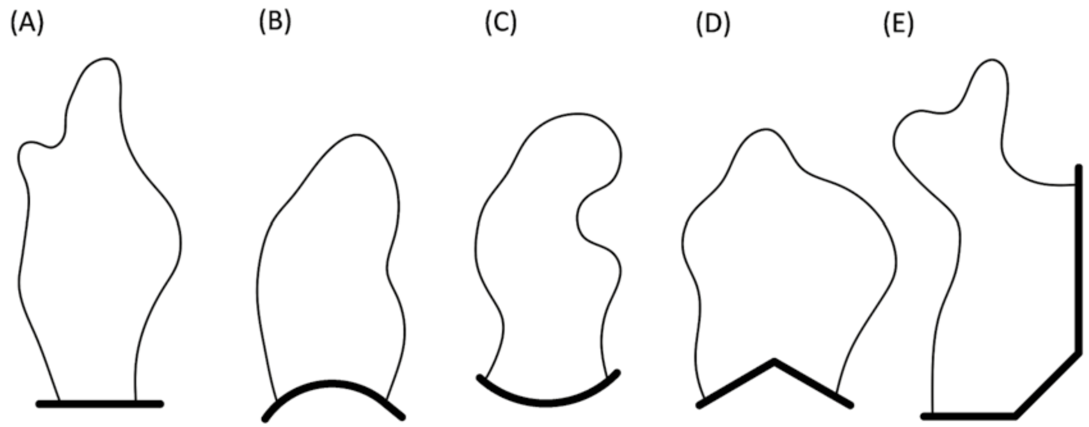


Fig. 4.49: Dam front shapes: (A) straight; (B) convex; (C) concave; (D) polygonal; (E) irregular. Diagram by Radka Račoch and Radek Bachan, 2021 (modified according to: Šálek, 1996).

Fig. 4.50: Doksy – Staré Splavy, Mácha Lake – In the left part of the picture, a straight dam of a pond which consists of an outcrop of a sandstone bedrock with a basalt vein, in the middle part there is an outlet gully; state during the reconstruction of the outlet structure and the pond drawdown. Photograph by A. Kopecký, 2014.

Fig. 4.51: Holany, Holanský Pond – a concave shape of a dam with a restored upstream wall from sandstone blocks. Photograph by Miroslav Kolka, 2018.

Fig. 4.52: Hradčany, Hradčanský Pond – a straight dam with a main outlet (on the right) and a discharge to the race to the extinct mill (on the left); state after the pond drawdown. Photograph by Miroslav Kolka, 2017.

Dam revetment

The upstream sides of the dam were protected against the adverse effects of water (waves and subsequent erosion) by ripraps. These were originally wooden, formed either by braided twigs among stakes or loosely stacked in the form of a series of stakes hammered into the dam. Nevertheless, stakes could eventually wobble and cause damage to the dam itself. The technique of stone riprapping (revetment) is used till today (Fig. 4.53). The downstream side of the dam was reinforced by simple turfing.

Fig 4.53: Zbýšov, stone riprap of the upstream dam side of Zbýšovský Pond. Photograph by Jindřich Frajer, 2018.

Fig. 4.54: Holany, Holanský Pond – construction of the dam with the revetment of the upstream face, the sandstone masonry is founded on the beam grid from the beginning of the 16th century. Photograph by Miroslav Kolka, 2018.

For the construction of some of the dams in different regions, bedrock outcrops were used. Typical examples are the pond systems in the sandstone regions of northern Bohemia – the system around Doksy and Hradčany (e.g. Mácha Lake, Břehyňský Pond), the system around Zahrádky, Holany and Stvolínky (Novozámecký Pond, Holanský Pond – Fig. 4.54, Fig. 4.56; Mlýnský/Hrázský Pond, Dolanský Pond and others), ponds in the Bohemian Paradise (e.g. Nebákov). A typical solution here is the use of sandstone bedrock for the placement of dam bodies, outlet structures, safety spillways, races, discharge channels, siting of sluice gates, etc.

Fig. 4.55: Holany, Jílovka Pond – construction of the dam with the revetment of the upstream face from sandstone masonry, a part of the revetment in connection with the main outlet and the fishing ground. Photograph by Miroslav Kolka, 2018.

Fig. 4.56: Holany, Holanský Pond – the main outlet with a discharge to the sandstone rock gulley. Photograph by J. Vidman, 2018.

4.2.3.2 SWR outlet structures

The most common type of outlet structure was a bottom outlet valve and a tailrace. The outlets were usually located at the lowest part of the dam. **The bottom outlet valve** was usually in the form of a pin, a shovel or a bucket (monk) or was formed by more complex mechanisms of wedges. Before the outlets we can often find a **rack** which served as a protection of the outlets from being clogged by suspended sediments and, at the same time, prevented fish from passing through.

Bottom outlets types:

- **With an open tailrace**:
  - **Sluice gate** – consisting of boards made of oak plants placed in water grooves which are handled by a rod. It allows partial regulation of the water level and discharge the water from the pond; it is suitable for lower dams (4.57).

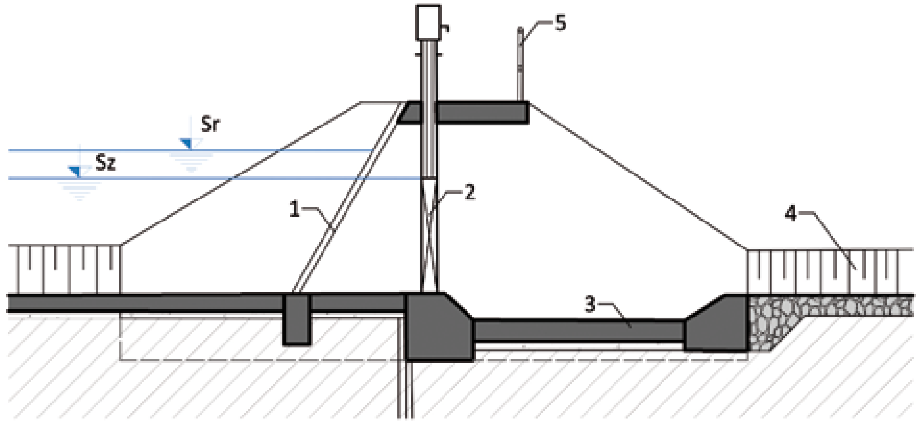


Fig. 4.57: Diagram of a sluice gate: 1 – rack, 2 – sluice gate, 3 – stilling basin, 4 – tailrace, 5 – operation bridge, Sz – level of storage area, Sr – level of controllable retention area. Diagram by Radka Računoch and Michaela Mrvová, 2021 (modified according to Tlapák, Herynek, 2002).

- **With a closed tailrace**:
  - **Pin** – common in older types of ponds where the pin was formed by a trunk made round, it had the lower part conically hewed (basically wooden bung) which reached the outlet hole and was sealed with a straw binder from sedge. The upper part of the pin had a helix thread to facilitate the lifting of the valve. The pin – open and closed – allowed only limited regulation (Fig. 4.58).
  - **Shovel** – common in older types of ponds, it was a wooden board of oval shape, which was inserted into the grooves on the upstream end of a pipeline. It was handled by a wooden or iron rod (Fig. 4.59). It allowed greater regulation of the water discharged from the pond than a pin.
  - **Gate valve** – a board located in the water grooves handled by means of a lifting mechanism (with toothed wheels and a gearbox with a steel rod) or a bolt rod.
  - **Monk outlet** – the most common type of bottom outlet valve in SWRs which allows effective regulation of the water level in the reservoir. It is an open or closed shaft in a concrete or masonry structure of a cuboidal shape which is connected to the bottom outlet. The amount of water entering the monk outlet is regulated by means of wooden planks (sluice boards). Some monk outlets allow water intake from the bottom (Fig. 4.60, Fig. 4.61).

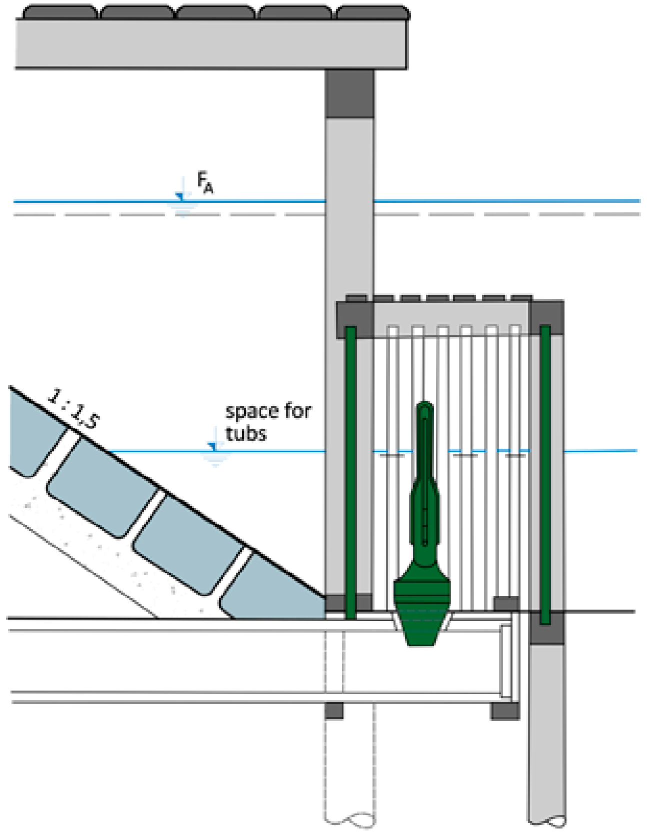
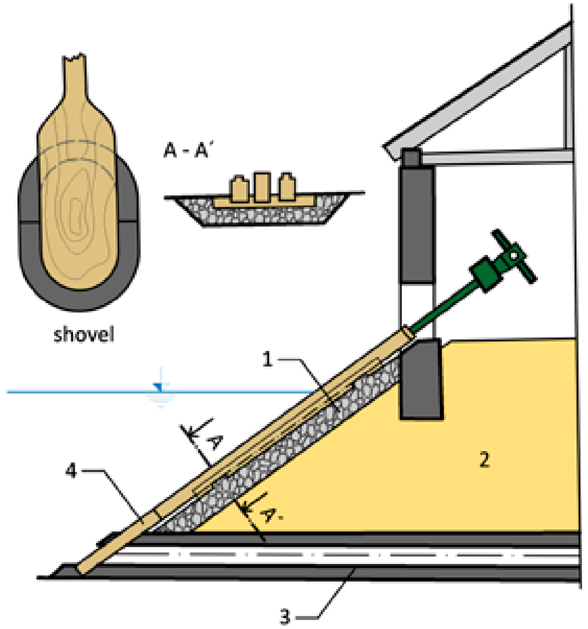


Fig. 4.58: Pin valve: F_A - maximum water level. Diagram by Radka Računoch and Michaela Mrvová, 2021 (modified according to Pavelková et al., 2014).

Fig. 4.59: Shovel valve: 1 – stone riprap, 2 – dam body, 3 – bottom outlet, 4 – bottom part of the blade. Diagram by Radka Računoch and Michaela Mrvová, 2021 (modified according to Vrána, Beran, 2008).



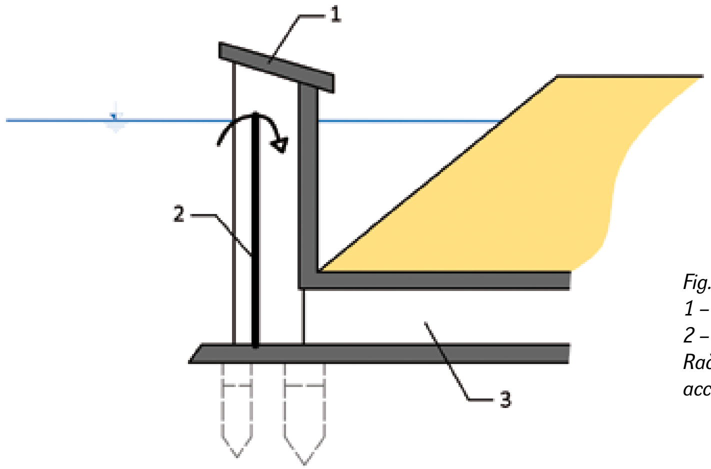


Fig. 4.60: General diagram – open monk outlet: 1 – crown of monk outlet with lockable lid, 2 – sluice wall, 3 – pipeline. Diagram by Radka Račoch and Radek Bachan, 2021 (modified according to: Slavík, Neruda, 2007).

Fig. 4.61. Ostrov u Stříbra – village square SWR with concrete open double monk outlet. Photograph by Renata Pavelková, 2021.

Fig. 4.62: Zbýšov – the original bottom outlet of the extinct Nový Pond with preserved relics of a pipeline pit and stilling basin. Photograph by Jindřich Frajer, 2020.

The tailrace was mostly in the form **of wooden pipes** (oak or fir) which were inserted into the dam already during its construction (Fig. 4.62 – Fig. 4.65). The pipes led into a **sump** (**today a stilling basin**) so that the outlet pipes were under the water level and were not subject to weather conditions which could cause their disruption or leakage. At present, steel, reinforced concrete or concrete outlet pipes are used.

Fig. 4.63: Zahrádky, Novozámecký Pond – outlet with an open tailrace and massive sluice gate beam structure with a foot bridge, roof and racks; all structures are installed into grooves in sandstone walls. Photograph by Miroslav Kolka, 2015.

Fig. 4.64: Markvartice near Jablonné v Podještědí, Markvartický Pond – the bottom outlet of the idle discharge with a monk outlet, upstream face with typical revetment from sandstone blocks; state after the pond drawdown. Photograph by Miroslav Kolka, 2014.

Fig. 4.65: Hamr na Jezeře, Hamerský Pond – downstream face of the dam with the bottom outlet, dated 1821; state after the modern modifications of walls. Photograph by Miroslav Kolka, 2017.

4.2.3.3 Safety elements of ponds

The pond was protected against floods by either an **idle by-pass channel** which transferred water from a weir structure safely out of the pond. Alternatively, **idle overflows**, today **safety spillways**, were built, i.e. structures in the form of a weir directly in the side of the dam by means of which it was possible to increase the amount of water running off the pond (Fig. 4.66 – Fig. 4.68).

Fig. 4.66: Svolínky, Mlýnský/Hrázský Pond – the main outlet of the pond with a bridge; to the left of it, a safety spillway. Photograph by Miroslav Kolka, 2013.

Fig. 4.67: Svolínky, Dolanský Pond – a rock gulley of the safety spillway; in the background a bridge in the dam route. Photograph by Miroslav Kolka, 2016.

Fig. 4.68: Ralsko, Vavroušek Pond – safety spillway. Photograph by Miroslav Kolka, 2012.

4.2.3.4 Special elements of fishponds

When discharging a pond, the water remains in the **fishing ground** (Fig. 4.70) which is the lowest part of the pond by the dam from where fish are caught during the fish harvest. A system of drainage sewers and gutters is used for thorough draining of ponds during their dropdown. Fishponds also contain a **space for tubs** accessible by road. The diagram of a fishpond is clearly shown in Fig. 4.69.

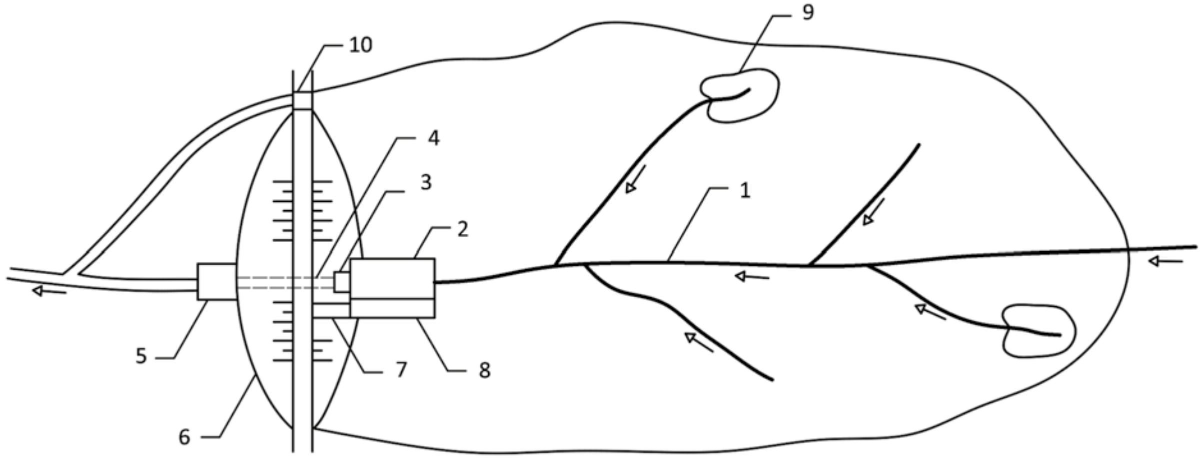


Fig. 4.69: Diagram of a fishpond with structures and specially prepared bottom: 1 – main drainage sewer, 2 – fishing ground, 3 – monk outlet, 4 – pipeline, 5 – stilling basin, 6 – dam, 7 – access stairs, 8 – space for tubs, 9 – drainage of gutters, 10 – safety spillway. Diagram by Radka Račoch and Radek Bachan, 2021 (modified according to: Pokorný, 2009).

Fig. 4.70: Zahrádky, Novozámecký Pond – fishing ground with a reconstructed fishing house in front of the pond sluice gate outlet, walled by sandstone blocks. Photograph by Miroslav Kolka, 2006.

4.2.4 FUNCTIONAL COMPLEXES

4.2.4.1 Rožmberk pond system

The Rožmberk pond system represents a unique water management structure of interconnected ponds and artificial watercourses (a symbol of the landscape of South Bohemia). Technically talented and experienced builders – Štěpánek Netolický and Jakub Krčín of Jelčany – have contributed to the transformation of the originally marshy, barren and infertile landscape into a functional system of water reservoirs for land drainage and fish breeding. These projects were the culmination of activities of several generations of fishermen who, in the period of the Late Middle Ages and in the early modern period, created in the landscape an important water management structure that is still worthy of admiration today. Water reservoirs have become the basis for the systematic use of the landscape and have contributed to the economic prosperity of the area. The large complex is dominated by the generously established Rožmberk Pond with the Zlatá stoka and Nová řeka canals and other ponds. The largest pond in Bohemia, Rožmberk, which also documents the power of the Rosenberg family, was created by damming the Lužnice River. The 14 km long Nová řeka canal was established at the same time as Rožmberk Pond, and till now it has been used for the distribution of water from the Lužnice River out of the pond to the Nežárka River. The spatial and visual connection of Rožmberk Pond to the historical centre of the town of Třeboň and farther to the Svět and Opatovický Ponds creates, together with a number of small technical monuments, fish hatchery and related linear elements, a unique landscape complex. Until now, in addition to fish farming, its retention function in flood situations is irreplaceable. The Rožmberk pond system represents a unique territory of extraordinary value, which has been nominated for the World Heritage List under the name, "Pond heritage of the Třeboň region".

The system involves artificial watercourses and dozens of ponds used for fish farming. The following elements are protected: 1. Opatovický Pond, 2. Dvořiště Pond, 3. Kaňov Pond, 4. Koclířov Pond, 5. Velký Tisý Pond, 6. Svět Pond, 7. Rožmberk Pond (NCM), 8. Zlatá stoka (NCM), 9. Nová řeka (NCM), 10. Stará řeka (NCM) (Třeboň Pond Heritage, 2003).

4.2.4.2 The Jordán reservoir

The Jordán reservoir cultural monument is an important technical work with an area of 50 hectares dating from the end of the 15th century. It is one of the oldest artificial reservoirs for supplying the town's inhabitants with water in Central Europe. At the same time, it is an important urban-ecological element in the landscape.

In 1492, Tismenický Brook was obstructed by a 280-m long, up to 20-m high, and at the heel almost 60-m wide clay dam in which there were upper outlets established for the needs of the inhabitants of the town and bottom outlets to drain water to the valley of Tismenický Brook. All the outlets worked on the pin principle. From 1508, water was led through a system of pipes to water mills with a water wheel and from there it was pumped by means of discharge mechanism into water towers for water distribution into fountains, located in the historical centre of the town of Tábor. The whole system was so significant for the town that it was kept operational for several centuries. In 1830, Jordán Pond was discharged for the purpose of the dam repairing and fish hunting for the last time (Krajíc, 2019).

Nowadays, Jordán Pond is fed by Košínský Brook which flows into it via its narrow north overhang and is part of the Košínský pond system. The pond dam is located in the south-western part and serves transportation and infrastructure management of the city. The safety spillway channel is complemented by a trash rack and sluice gates. The last archaeological research was carried out between 2012 and 2015.

Technical parameters: dam crest length 283 m, dam height 20 m, reservoir area 49.5 ha.

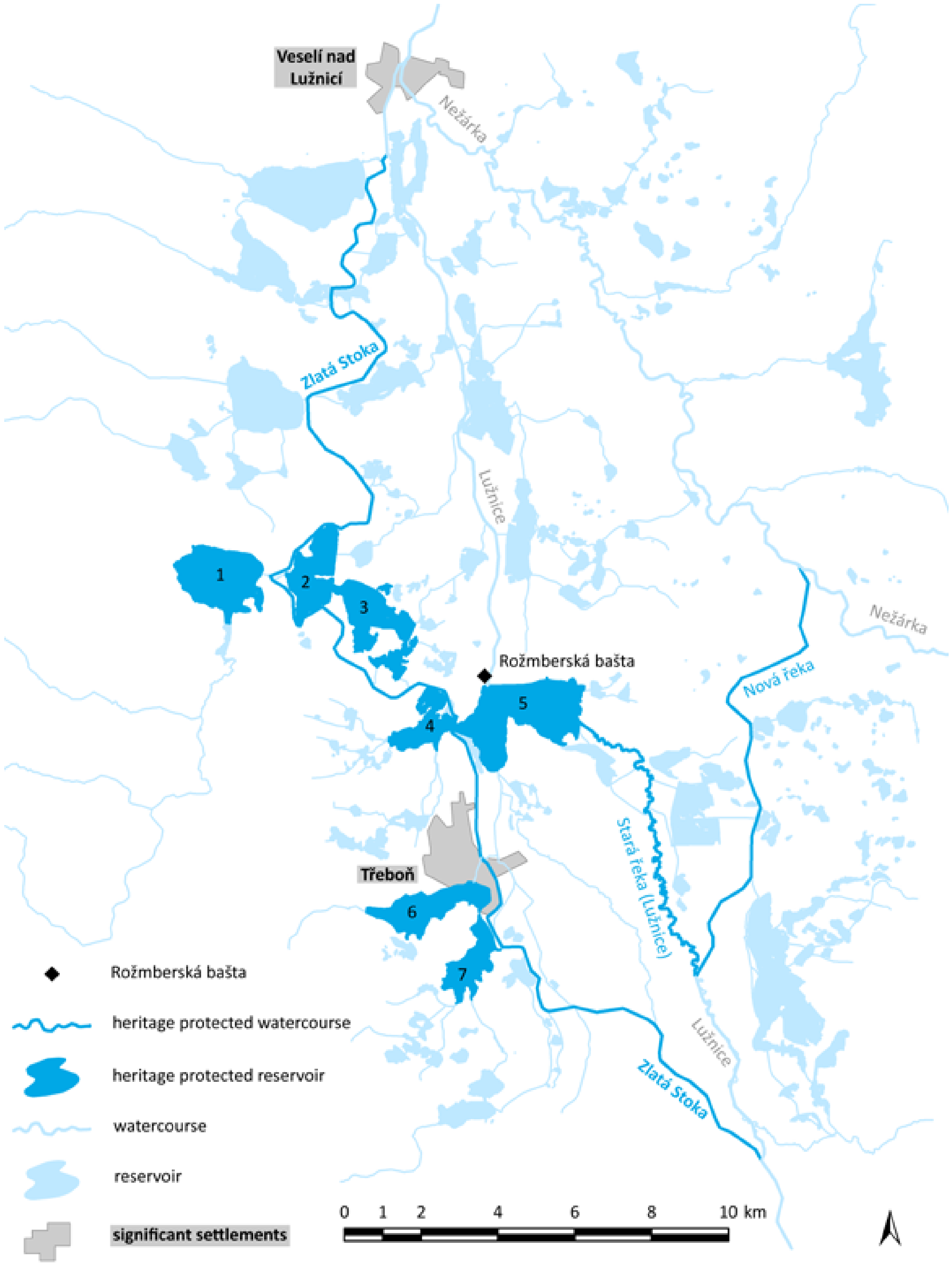


Fig. 4.71: Diagram of the Rožmberk pond system cultural monument: 1 – Dvořiště, 2 – Koclířov, 3 – Velký Tisý, 4 – Káňov, 5 – Rožmberk, 6 – Svět, 7 – Opatovický Pond. Diagram by Radek Bachan, 2021.

4.2.4.3 Novozámecký Pond

The system of ponds between Zahrádky, Holany, Provodín and Stvolínek is part of the landscape protected heritage region of Zahrádky in Bobří Brook basin. The system was built between the 14th and 17th centuries. Interconnected ponds on two basic branches of the watercourse ingeniously take advantage of the sandstone bedrock for the placement of dam walls, outlet structures, safety spillways, races, siting of gates, etc.

Novozámecký Pond (cultural monument) is an extensive hydraulic structure, probably created at the turn of the 15th and 16th centuries (it is certainly documented in 1617, probably listed in 1545 under the name “Karaský Pond”). Until now, a number of unique **historic pond facilities** and structures have been preserved, including an impressive **discharge channel**, partially carved in the gulley of the sandstone bedrock. The pond is located on the eastern edge of the village of Zahrádky. The pond area occupied the originally marshy plain extending from Zahrádky to the neighbouring village of Jestřebí. The pond is fed from the southeast from Doksy by Mlýnský pond and from the southwest by Bobří Brook which drains water from the system in the area between Holany, Provodín and Stvolínek. Water to Novozámecký Pond inundation area is led from Bobří Brook through Mnichovská průrva (gorge), which was part of the dam of the extinct Velký Mnichovský Pond (founded in 1480, it probably ceased to exist at the end of the 18th century). Mnichovská průrva consists of two rock gorges over which single arch bridges of the Reichstrasse (an imperial road) from the beginning of the 19th century (the route of today’s road I/9 Mladá Boleslav – Česká Lípa) are constructed. Barrel vaults of bridges from sandstone blocks have two older construction phases and modern extensions by reinforced concrete bridge decks. The gorges have maintained vertical grooves and pockets after massive wooden sluice gates frames, structure lagging and siting of trash racks. The first gorge, by which Bobří Brook is diverted, served as the main outlet, the second one served as a safety spillway. On both sides of the gorge, there is the lower dam body visible on whose crest a road runs. The heel of the western part towards St. Barbara’s church is revetted with a wall from sandstone blocks.

On the western side of Novozámecký Pond there is a high lower dam formed by a sandstone outcrop, probably reinforced with an igneous basalt vein and supplemented with an earth body. The upstream and downstream dam faces are revetted with walls from sandstone blocks. The aforementioned imperial road runs on the dam crest. At the south-west edge of the pond there is a renovated **water bailiff’s log house, a historic boat quay** and a **fishing ground** demarcated by walls from sandstone blocks. In the corner of the fishing ground, there are outlet facilities with a massive wooden structure which diverts the water into the deep rock gorge of the discharge channel. The gorge is led through an arc few hundred metres long so that the dam body is not weakened. The gorge walls contain high grooves and pockets for wooden structure of sluices and foot bridges. There is a single arch bridge of the imperial road with barrel vault from sandstone blocks in about half of the length over the gorge. The bridge has two older construction phases and is extended with a new reinforced concrete bridge deck. At the end of the gorge there is a torso of the weir preserved and a diversion of a race for mill No. 34.

4.2.5 EVALUATION FROM THE POINT OF VIEW OF HERITAGE PRESERVATION BASED ON SPECIFIC EXAMPLES

4.2.5.1 Rožmberk Pond

Rožmberk Pond is a work of the builder Jakub Krčín of Jelčany and Sedlčany. It was built between 1584 and 1590, concurrently with the regulation of the Lužnice River which, at that time, flowed through the inundation area of the future pond. The regulation resulted in the creation of Nová řeka which drained water by a 13.4 km long channel from the Lužnice to Nežárka Rivers. Rožmberk Pond is currently the largest pond in the Czech Republic. It has an area of 489 ha and a cadastral area of 677 ha which is usually flooded during elevated flows. It impounds 6.2 million m^3 of water. In terms of the classification, it is a pond with natural inflow. Rožmberk Pond is part of the Rožmberk pond system national cultural monument (Fig. 4.71).

The main original outlets were three – Hluboká, Samice and Stezka. Each of them had three pipes, while Hluboká might have had even six. The outlet wooden pipes were made of fir wood from Šumava (prismatic trunks – over 1 m in diameter) and consisted of two parts (hollowed wooden trough of rectangular profile). The wooden pipes were fitted with pins and here at Rožmberk they were huge, reaching a depth of up to 6 m and were handled by a chain lever. Later, they were replaced with easier to operate wooden shovels. The original riprap was on the upstream side of the dam wooden (at the heel of the dam, it was propped on driven piles; higher, there were smaller piles placed). Stone riprap was established only in 1662 (Kubíková, 1980). An important part of the outlets was a wooden fish protection screen – a grating preventing fish from escaping during hunting. The structure had two weirs (safety spillways) – a western weir in Kaňkovský Brook and another one, called Smitka, on the opposite side of the dam (eastern weir). This one originally had twenty-four sluice gates, one of them having a width of 1.2 m, a height of 2.4 m, with an overflow edge length of 28.8 m (Hule, 2004).

Temporal determination/date of origin: 1584–1590
Authorship: Jakub Krčín of Jelčany and Sedlčany
Heritage preservation: National cultural monument (2002), part of the nomination of the Třeboň Pond Heritage for the World Heritage Sites list.
Reconstruction of the Rožmberk Pond dam (Hule, 2004)**:**
1590 – After the first filling to the total capacity of 1,100 ha, there was a gap created in the dam which has to be fixed and the pond was revetted by another layer.
1662 –After the flood in 1656 and after the Thirty Years’ War, Prince Schwarzenberg had a wooden riprap replaced by a 1,770 m long stone one.
1787 – The wooden safety spillway (so-called eastern weir), which was often destroyed after the floods, was replaced by a stone structure.
1804 – The eastern weir was destroyed and replaced again by a wooden structure.
1830 – The overflow edge was supplemented with random rubble.
1879–1880 – Vítek Pond was singled out and built in the inundation area of the Rožmberk pond system.
1890 – The dam proved successful during the flood when the pond retained up to 50 million m^3 and the dam resisted.
1916–1918 – The construction of a modern outlet with metal installations, the capacity was increased to 27 m^3/s with two channels with a width of 1.6 m and a height of 2.2 m and 2.65 m at the tailrace. The outlet gate is formed by cast steel boards handled by screw rods, the inlet is protected against fish escape by steel screens.
1922 – At the outlet, there was a small hydroelectric power plant with two Francis turbines with installed power of 240 kW put into operation.
1935 – The wooden fish protection screen on the safety spillway was replaced by a stone and steel structure with a steel footbridge with a total length of 157 m.
2004 – After the flood in 2002, when the pond retained up to 70 miles m^3 of water, the safety spillway and the screen were reconstructed.

Evaluation:

Typological value:

- Rožmberk Pond is a symbol of Czech fish farming. It is the largest preserved work of Jakub Krčín whose pond dams represent one of the two types used in the Czech lands. Other Krčín’s projects include: the initiation of the construction of Nevděk Pond (later called Svět) in 1570; the construction of Spolský Pond in 1571; the extension of Opatovický Pond in 1574; the construction of Potěšil Pond and the extension of the Naděje and Skutek Ponds in 1577, the extension of the Dvořiště and Záblatský Ponds in 1580.

Fig. 4.72: Rožmberk Pond and outlet structures, small hydroelectric power plant built at Rožmberk Pond in 1922 and historical wooden pipeline from the pond dam. Photograph by Eva Dvořáková, 2006.

- **Exceptional parameters of structural and technological parts:** The cubage of the dam body is estimated at 750,000 m^3 of earth. At the heel, it is up to 55 m wide and is mounted on the foundation cut-off with the cross-section of 1.8 × 1.8 m with an additional layer of soil on the downstream side. The dam is earthfilled, compacted layer by layer – the material was taken from: the immediate vicinity and clay was used only around outlet pipes. The height of the dam was up to 11 m and the width at the crest was 9 m, its length is 2,430 m. On the dam wall there are 150–300 years old oaks in two rows on each side of the dam crest.
- **Exceptional occurrence within the Czech Republic**: The largest pond with the Krčín-type dam in the Czech Republic preserved to this day. Probably the only fishpond associated with power generation in the Czech Republic (the hydroelectric power plant was built in 1922). The only pond within the system which was created directly by damming the Lužnice River (Stará řeka) and is not fed by a system of artificial watercourses.

Value deriving from the technological flow: The dam structure with all technical elements serves the two main original purposes – fish farming and anti-flood. At the same time, it is part of the Rožmberk pond system, i.e. a complex of interconnected ponds fed with water from a system of artificial watercourses, which represents a wider system within the technological flow.

Value deriving from symbol: Rožmberk Pond is a symbol of Czech fish farming. It is the largest preserved work of Jakub Krčín whose pond dam walls represent one of the two types used in the Czech lands (see above). Other Krčín's projects include: the initiation of the construction of Nevděk Pond (later called Svět) in 1570; the construction of Spolský Pond in 1571; the extension of Opatovický Pond in 1574; the construction of Potěšil Pond and the extension of the Naděje and Skutek Ponds in 1577, the extension of the Dvořiště and Záblatský Ponds in 1580.

Value deriving from authenticity:

- **Authenticity of function:** Preserved and expanded – in 1922, a small hydroelectric power plant, equipped with two Francis turbines which are still in operation, was built (Fig. 4.72).
- **Authenticity of form and mass/material**: Rožmberk Pond, especially its dam wall and technical facilities, have undergone several reconstructions in more than 400 years of operation. Some reconstructions, e.g. a new outlet, have completely changed its original design parameters. Partial use of non-authentic material for repairs after floods in 1656, 1670, 1698, 1730, 1829, 1876, 1890 and 2002.

- **Authenticity of technical equipment:** Technical facilities of the pond dam wall underwent a lot of reconstruction and replacement. Some of the facilities (the pipes) in the dam body are still original but no longer fulfil their purpose. Other parts are still functional but with extensive repairs (the safety spillway on the east side). Some elements (e.g. sluice gates) have been replaced with new ones (the original sluice gates have been replaced by cast steel boards).

Architectural value: Rožmberk Pond is a technical work. Its integral part is a fishing bastion which is the only Renaissance building of this type in the Czech Republic. The hydroelectric power plant additionally built bears the architectural features of its time, i.e. the 1920s.

Landscape/urban value: The almost 2.5-km long body of the dam wall, which was exceptionally impressive for its time, and the large water area have remained for centuries constant dominant features defining the landscape character of the Třeboň region. While in many fish farming areas the influence of fish farming on the landscape formation was suppressed after the disappearance of ponds and their systems, in the case of South Bohemia, it remains the essence of the local landscape image and quality.

4.2.5.2 General summary of the principles for the evaluation of small water reservoirs

When assessing whether to protect and preserve the water management heritage of small water reservoirs, many general and specific criteria must always be comprehensively taken into account. These can be: historical values (e.g. identification of the physical remains of structures in a dam, existence of historical sources and literature related to the structure); typological value (unique or typical representative, specific structure, configuration, e.g. model solutions of dams by Dubravius × Krčín); value of functional continuity at small water reservoirs or ponds in the landscape (their use and importance in the landscape cannot be taken out of the geographical and social context of their period); technical value (the technical equipment itself in the dam body). Heritage protection may cover either the structure as a whole or only its constituent parts.

The dominant landscape impact is linked to the water area itself because dam walls are usually relatively low and short and, unlike reservoirs, do not function in the landscape as dominant features. The technical and material solutions of the dam on which the degree of its natural integration into the landscape image depends, is naturally important. This also involves tree avenues on the dam wall which are typical for ponds but at modern small water reservoirs mostly do not occur.

Small water reservoirs within intravilans, both urban and rural, are also urbanistically important and always have a positive impact within the urban structure of the seat. A separate group is represented by desludging or final sedimentation reservoirs which form part of the technological flow, especially with regard to coal mining. In this case, a landscape value can hardly be mentioned because they represent an environmental burden on the industrial landscape.

The protection of a hydraulic structure should find a compromise between the preservation of historical values and the requirements for the operation of a hydraulic structure, specifically for ponds or small water reservoirs, as well as the safety of the structure (e.g., some types of monk outlets are no longer produced). In addition, during the reconstruction it seems to be convenient to relocate some parts of the equipment to other protected places (e.g., museum collections or deposits) but there might be a problem with the value of authenticity and credibility. The question of meaningful preservation of the heritage for the future can also be, in the case of small water reservoirs or ponds, whether or not to remove vegetation on historic banks, which can significantly change the overall atmosphere of the place (e.g., the dam wall of Rožmberk Pond with a two-row alley of oak trees).

4.2.6 REGISTER OF LOCATIONS

Name	Protected from	Type of protection	USKP registry number	Item name according to the Monument catalogue	District	Municipality	Cadastral territory
Rožmberk pond system	31/12/1963 1/8/2002	CM NCM	33857/3-2381 293	Rožmberk pond system	Jindřichův Hradec	-	-
Nekysel and Kyselov Ponds	3/2/1998	CM	49613/3-6146	Kyselov Pond, a village square pond, seven wells, four wooden pumps	České Budějovice	Jankov	Holašovice
Královský Pond	31/12/1963	CM	37654/3-407	pond dam with a statue of St. John of Nepomuk	České Budějovice	Rudolfov	Rudolfov near České Budějovice
Mrhal Pond	31/12/1963	CM	16860/3-101	Mrhal Pond	České Budějovice	Hlincová Hora	Hlincová Hora
Vlhlavský Pond	31/12/1963	CM	34489/3-546	dam of Vlhlavský Pond with an outlet and alley of oak trees	České Budějovice	Sedlec	Vlhlavy
Kladský Pond and Nový Pond	21/11/2003 1/10/2014	CM NCM	100490 383	Dlouhá stoka hydraulic structure with Kladský and Nový Ponds Dlouhá stoka with the Kladský and Nový Ponds	Cheb	Mariánské Lázně	Mariánské Lázně
Novozámecký Pond	20/1/1965	CM	28674/5-3407	Novozámecký Pond	Česká Lípa	Jestřebí	Jestřebí near Česká Lípa
Jordán reservoir	30/6/1992	CM	11059/3-6104	Jordán reservoir	Tábor	Tábor	Tábor
mill race with a dam of Břehyňský Pond	20/1/1965	CM	23655/5-2884	mill race with a dam	Česká Lípa	Doksy	Doksy near Mácha Lake

4.3 WATERWAYS

The chapter Waterways is devoted to all the cases where a natural or artificial watercourse is used for water or cargo transport. Waterways are by definition always functional complexes. If one of the main structures is not functional, the entire waterway becomes non-functional. Nevertheless, in terms of the heritage preservation of technical works, even a single structure or a set of structures which are already only torsos of the original waterway, can be valuable.

A functional waterway consists of basic components which are schematically shown in Fig. 4.73.

Individual concepts in the general diagram of a waterway represent a variety of different elements which can be used, the most important of which are:

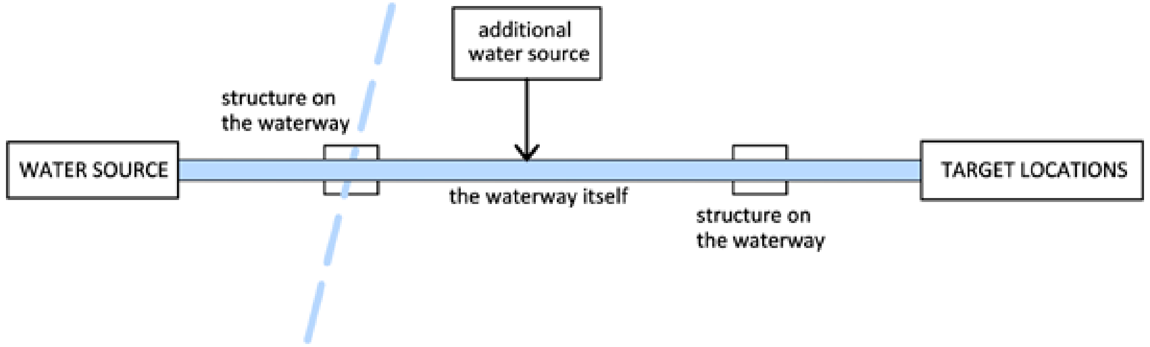


Fig. 4.73: General diagram of a waterway. Photograph by Radka Račoch, 2021.

Water source:

- natural watercourse,
- lake – natural, man-made (dam),
- pond,
- weir basin.

The **waterway itself:**

- natural watercourse,
- adapted, canalised watercourse,
- artificial channel.

Structures on the waterway:

- overcoming height differences,
- crossing other roads and natural obstacles.

Additional water source:

- natural water tributary,
- water supply from artificial basin.

Target locations:

- waterfront area,
- port,
- inlet for energy use,
- withdrawal of technological water.

A waterway's design was always based on the objectives to be achieved. Nevertheless, it had to respect the natural conditions, morphology and hydrology of the territory. All routes and structures are therefore unique works, although they are sometimes based on type solutions and previous best practices. It always depended on the builder, or later a designer, how effectively they were able to use local conditions and technical resources at the time. The architectural morphology corresponded to the time of creation. Nevertheless, technical heritage protection should be primarily focused on the original and functional application of the technical solution.

With regard to the approach chosen and the definition of the waterway, it covers activities of the first civilizations settled in river valleys, such as the construction of irrigation systems and the use of rivers as main roads. In our territory, deliberately built waterways from the Middle Ages to the present date fall into the defined area.

The chapter is divided into two main specialisations of waterways, i.e., waterways for cargo transport and waterways for the transfer of water to the required location. A separate chapter is devoted to the main structures of these waterways – weirs.

4.3.1 WORKS FOR MAKING RIVERS NAVIGABLE

4.3.1.1 History of the use of rivers for transport

The history of using watercourses as transport routes is described in detail in the book Svět vodních cest (Kubec, 1988). We have documents from archaeological finds in our countries from different historical periods, especially on the lower lowland stretches of rivers. The boom in the use of watercourses with higher heads occurred at the time of timber floating for both the construction industry and as energy raw materials. For these purposes, requisite structures were built either on their own navigated watercourse or various approach channels and chutes for approaching wood to the river and also storage reservoirs for one-time water delivery to the navigation channel.

One important example of the artificial waterway system, built for cargo transport, is the Schwarzenberg Navigation Canal. The author of this works is the prince's engineer Josef Rosenauer, who also designed another Schwarzenberg Vchynice-Tetov Navigation Canal built for the connection of the Vydra and Křemelná Rivers in 1799–1801. The origin of the Schwarzenberg Navigation Canal was based on the effort to use timber supplies of the Šumava forests on the Czech–Austrian and Czech–Bavarian borders. The route was set in 1775, with the construction taking place in two phases in 1789–1793 and 1821–1823. The canal is fed by 27 watercourses, three artificial reservoirs and Plešný Lake, which was adapted for the needs of navigation. The canal starts at an altitude of 925 m and is led by a gradient of 2–75 per mile. The depth of the canal is 0.96 m, the width at the bottom is 1.9 m and the width at the crest is 3.8 m. It is faced with hewn beams, granite slabs and its bed is partly rock-cut. During the construction it was necessary to overcome a number of technical problems, such as overcoming the Elbe and Danube watershed, crossing the canal with streams and paths, leading part of the route through tunnels or feeding the canal with water. The work was gradually modified and expanded. Regular navigation was stopped in 1891, while in the territory of Austria the last extraordinary navigation took place in 1916, and in the Czech territory navigation continued with breaks till 1961. Heritage-protected: cultural monument (1963, heritage protection was extended in 2012 and 2013), national cultural heritage (2014) (Dvořák, 2000; Monument catalogue, 2021).

Since the early Middle Ages, in connection with timber floating, there were floaters' settlements founded along rivers. The first mention of duty collection from floated timber dates from 1130. The first documented report on rafting on the Vltava River was the privilege of John of Luxembourg from 1316, which specified the rules of the trade with timber. Charles IV reduced and equalised the navigation duties by his decree in 1347, ordered the construction of weirs and set a minimum width of sluices. In 1590, Petr Vok issued the first navigation rules for rafting (Čáka, 2002; Vondrášek and Blüml, 2012).

Already at the beginning of the modern age, in the 16th century, there were disputes about the right to trade with timber. The first record on freedom of navigation is known from 1567. At the end of the 18th century, free rafting was generally introduced. In 1801, Joseph Schwarzenberg received a privilege to float timber to Prague, which expired in 1861 and was not renewed. The biggest boom in rafting came in the 19th century. From the middle of the 19th century, the railway gradually became a major competitor for rafts. Wood as a fuel was pushed out by cheaper coal. The local navigation on the Otava River continued, especially during the period of the great bark beetle calamity in the 1870s. The extensive regulation of watercourses and construction of dams, especially of the Vltava River Cascade, ended the period of rafting. The last raft navigated through the Orlík dam, which was under construction at that time, on 12 September 1960. The last navigation on the Otava River took place in 1958 (Čáka, 2002; Vondrášek and Blüml, 2012).

A new chapter of the navigation was the effort to transport goods and raw materials even upstream of a river. In the period before the use of engines, it was possible to use tractive force along banks. However, this required the modification of the channel and the construction of a waterside trail. Horse power was used as the source of tractive force, but sometimes also human power, e.g. the well-known burlaks in Russia. Later, these trails were reinforced and rebuilt to make it possible to use a tractor or a locomotive, an example is the preserved waterside trail in the surroundings of Veselí nad Moravou (Fig. 4.74 (A)) and the underpass of the service trail under the railway near Sudoměřice (Fig. 4.74 (B)). The preserved sections of these waterside trails are now used, for example, as cycle paths.

The transition to high-output diesel engines allowed more volumes to be transported simultaneously, in the form of a group of vessels towed by a tugboat. Nevertheless, the efficient use of this transport requires modernisation and especially sufficient capacity of the waterway itself and of important structures belonging to it (e.g.: Wiki, 2021).

Fig. 4.74: A waterside trail by the Baťa Canal: (A) in the section below Veselí nad Moravou; (B) an underpass of the trail under the railway near Sudoměřice. Photograph by Miriam Dzuráková, 2021.

4.3.1.2 Classification of waterways into classes

During the development of waterborne transport, it was necessary to standardise the navigation route. A waterway can be classified according to the width and length of lock chambers, guaranteed depth of the navigation route and underpass height of bridges. Navigation currently in operation in the Czech Republic corresponds to the following classes and determinative parameters (Wiki, 2021):

- **Class 0** – this regional class covers, under Decree No. 222/1995 Sb., the Morava River from the confluence with the Bečva River to the Dyje River, it is intended only for small vessels up to 20 × 5 m with the draught of 1.2 m;
- **Class I** — the Central Vltava — vessel dimensions up to 41 × 4.7 m and draught of 1.6 m;
- **Class IV** – the Elbe River from Přelouč to Mělník, the Vltava River from Třebenice to Mělník – dimensions of 80 × 9.5 m and draught of 2.5 m;
- **Class Va** – the Elbe River from Mělník to Wittenberge – dimensions of the group of vessels is 110 × 11.4 m, suitable draught 2.5 up to 4.5 m;
- **Class Vb** – waterways currently built and designed in Europe, including considerations of the Oder–Danube Canal – dimensions of a set of a tugboat and two boats in a row are 185 × 11.4 m.

A minimum underpass height of 5.25 m, or better 7 m, is required for higher classes.

Cargo transport has always been crucial in history for its energy efficiency. Nowadays, time demands are considered to be its disadvantage. Nevertheless, in the case of higher pressure on emissions reduction, countries with a developed network of waterways will be at an advantage.

Passenger river transport was not of great importance in our country. It often involved, both in the past and at present, a local transportation solution, such as traditional river ferries, for example on the Vltava River or later on dam lakes, where they replaced former flooded roads (Lipno, Slezská Harta). Public waterborne transport on rivers and dam lakes has always had a mostly recreational character in our country.

Individual recreational cruise. Waterways, which were previously used for cargo transport, often ceased to serve their original purpose, especially for capacity reasons. In countries where waterborne transport was part of the industrial revolution, these original channels are already part of the landscape and towns. They are used for both individual and organised recreation. See Fig. 4.75.

In our country's conditions, something similar happened with the Baťa Canal. A specific phenomenon in the Czech lands is the popularity of paddle sports, which follows the previous rafting and often uses structures that were built for timber transport. Sluices on weirs are often rebuilt during their reconstruction in such a way to enable the attractive floating of small vessels, or sometimes these structures are also adapted as a fish pass (see Fig. 4.75 (C)).

The phenomenon of paddle sports has developed especially on rivers in the Elbe River basin, which had served for long-distance timber transport by water from border forests for the needs of Prague, but also farther to Germany, even up to Hamburg. Apart from the Vltava River, other rivers used for rafting to supply Prague were Berounka, Lužnice, Sázava, Malše and Otava, which are popular among paddlers to the present day. In the vicinity of Prague, some of the weirs from the end of the 20th century are equipped with a canal intended for training and competitions in wildwater canoeing (e.g. Troja weir) (Čáka, 2002; Vondrášek and Blüml, 2012).

In the eastern part of the Czech Republic in the Morava and Oder River basins, timber transport and rafting was not used to such an extent, it served only for local needs for short periods of time. This was associated with both hydrological conditions, when for a significant part of the year there were insufficient flows, and with places of higher timber consumption. Towards large towns on the Danube River below Vienna, timber was transported from Slovak mountains, for example, through the Váh River, and towards Poland, for example, through the Dunajec River. Today's recreational and sports cruise, even in the Danube River basin, imitates historical rafting (Čáka, 2002; Vondrášek and Blüml, 2012).

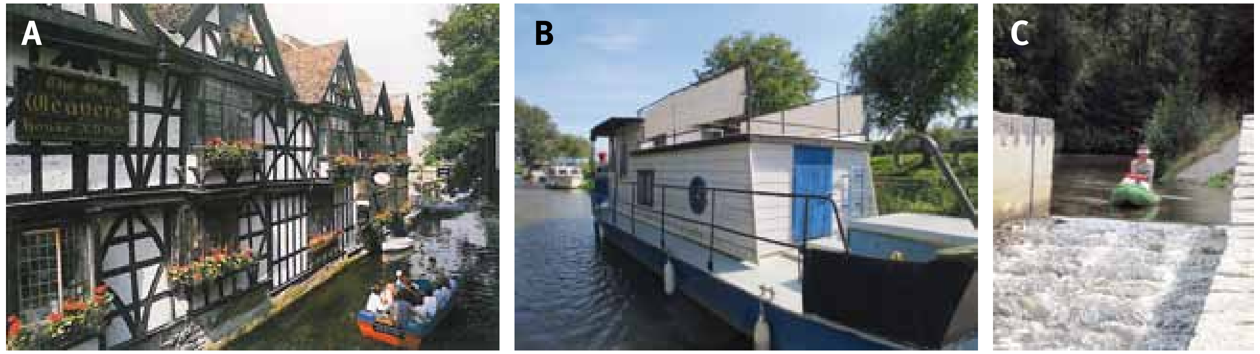


Fig. 4.75: Use of waterways as tourist attractions: (A) England, originally a navigation channel for industrial needs; (B) the Baťa Canal in 2012; (C) the Ohře River, Tuhnice weir, sluice adapted for the pass of small vessels. Photograph (A) and (C) by Milena Forejtníková, 1993, 2012; (B) by the TGM Water Research Institute archive, 2012.

4.3.1.3 Characteristics, types and diagrams of structures for landlocked navigation

Landlocked navigation uses natural watercourses in their original form as waterways if they have sufficient navigational depth for the required waterway class. However, in most cases it was necessary to adjust the water course longitudinally to ensure the navigation route, or new navigational channels were built in sections of a meandering or wild watercourse. These modifications are not, apart from some exceptions, addressed by the methodology. Similarly, attention is not paid to locations and structures which are rather temporary in nature in our conditions and often form a set of technological devices for a specific purpose. After the disappearance of their main purpose, they quickly fall into disrepair (see Fig. 4.76 (A) the port of Chvaletice). Exceptions can be individual structures with a targeted effort to preserve them, e.g., a coal tippler on the Baťa Canal, Fig. 4.76 (B).

The following text is mainly devoted to structures intended for overcoming differences in levels and crossing with other roads, without which waterways would not be conceivable.

Fig. 4.76: (A) the port of Chvaletice after coal stopped being transported by water; (B) a coal tippler on the Baťa Canal near Sudoměřice. Photograph (A) by Miriam Dzuráková, 2021; (B) by Michaela Ryšková, 2022.

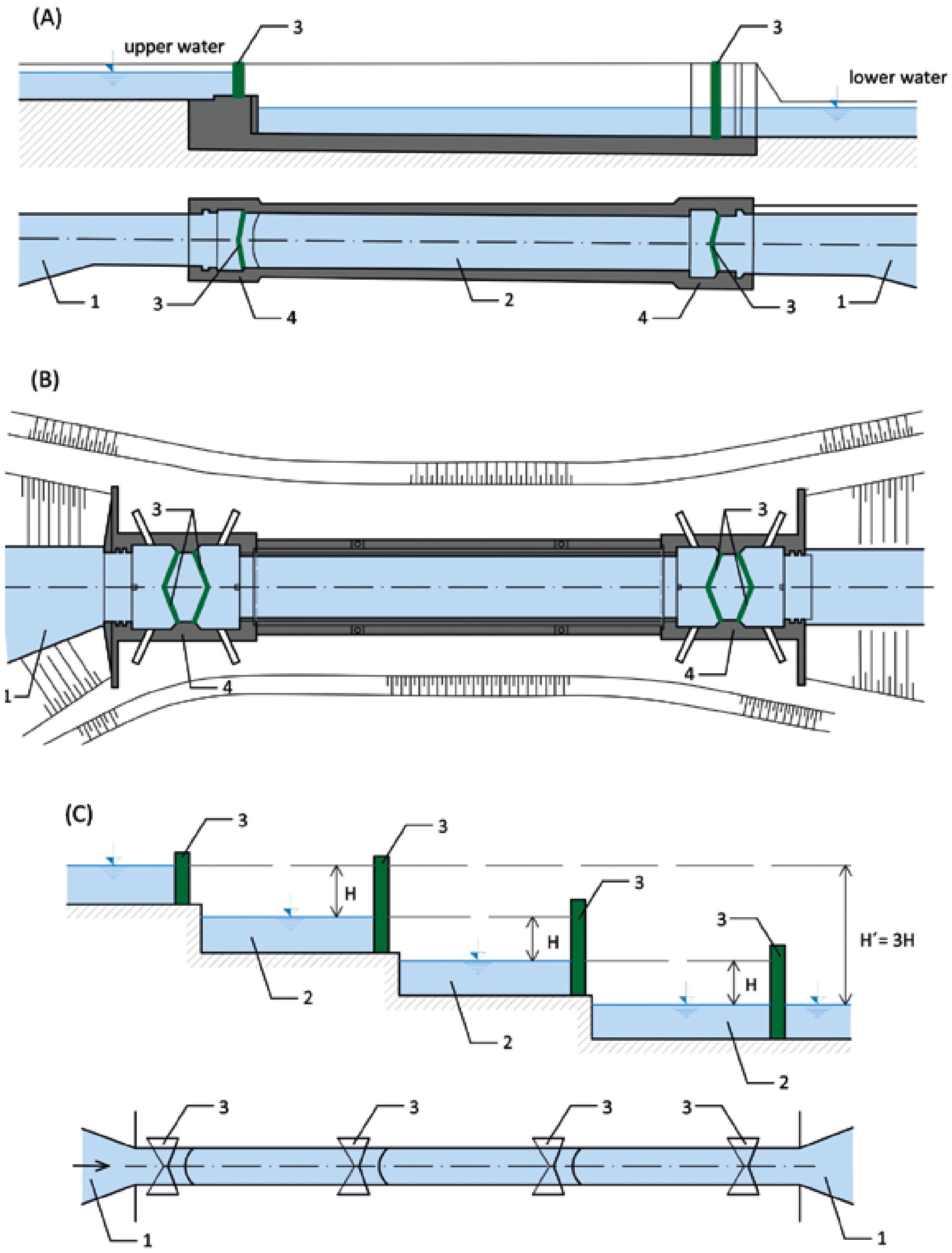


Fig. 4.77: (A) diagram of a simple lock chamber; (B) lock with double gates; (C) diagram of a multi-level lock chamber; 1 – lock cut, 2 – the lock chamber itself, 3 – lock chamber gates, 4 – head. Diagram by Radka Račoch and Michaela Mrvová, 2021 (modified according to: VSB – Technical University of Ostrava, 2013).

4.3.1.3.1 Types of lock chambers

Lock chambers ensure vertical movement of vessels by means of filling and emptying of given spaces. It is an oblong basin, usually rectangular in shape, equipped with gates in the lower and upper head of the lock chamber. These are massive concrete structures, capable of transmitting loads acting on them and on the gates.

Former locks, with regard to the building material and technology available, exceeded at height of only a few metres at one navigation level. Today‘s technology on newly built navigation waterways enables to heights of up to about 25 m to be overcome (e.g., on the Mohan – Rhine waterway)

The lock chamber is connected to the navigation route by means of lock cuts, sufficiently spacious and adapted for the safe manoeuvring of vessels when entering and exiting the lock chamber.

Basic types and components of lock chambers can be seen in Fig. 4.77.

The lock chamber is filled and emptied by a system of openings in the gates or culverts (basic systems can be seen in Fig. 4.78).

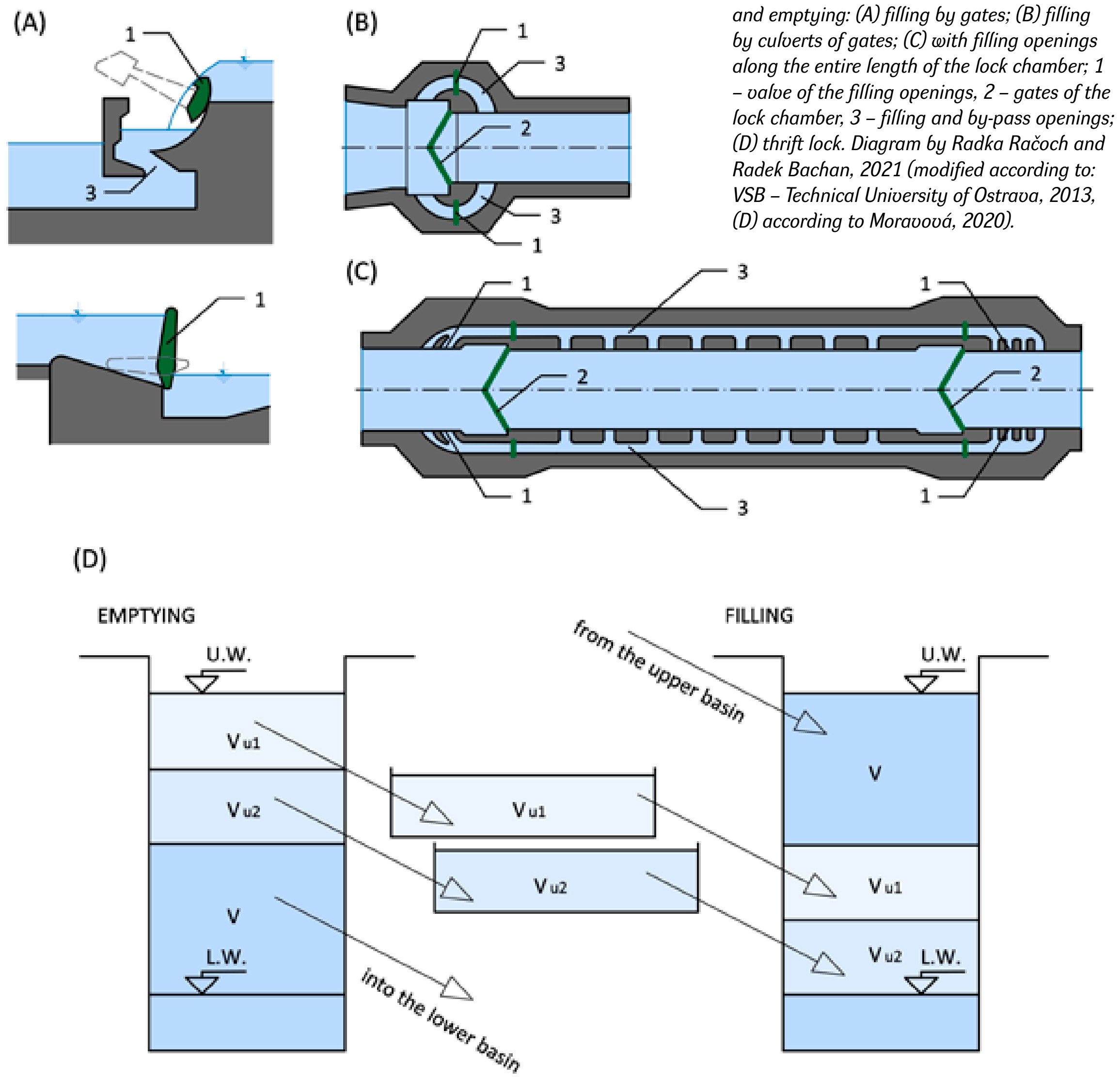


Fig. 4.78: Diagram of a lock chamber filling and emptying: (A) filling by gates; (B) filling by culverts of gates; (C) with filling openings along the entire length of the lock chamber; 1 – valve of the filling openings, 2 – gates of the lock chamber, 3 – filling and by-pass openings; (D) thrift lock. Diagram by Radka Račoch and Radek Bachan, 2021 (modified according to: VSB – Technical University of Ostrava, 2013, (D) according to Moravová, 2020).

Advantages, disadvantages and problems of various types of lock chambers

Navigation locks are energy-efficient due to the use of the gravitational force of water. When a vessel is going upstream after the closure of lower gates, the lock chamber is filled with water from the upper section which lifts the vessel to the necessary level without energy requirements.

The large amount of water necessary for vessels to pass through the lock chambers is often pointed out by any member of the public nearby, which can be decisive in the case of sections with a shortage of water. The basic austerity measures are the adequate size of the lock chamber and the vessel passing thought it (water is necessary only for filling the space between the walls of the lock chamber and the vessel). Therefore, to overcome the height difference, a system of two or more chambers of different size is built at each navigation level. Modern buildings use side thrift basins, which can save up to 2/3 of water volume necessary for the lockage, without the need for water pumping (Fig. 4.78 (D)).

In Fig. 4.78 (B) there is a diagram of the filling of a lock chamber with a simple by-pass at the door. This method was used on smaller waterways in the past, but it can present a danger of rough water for vessels, so filling must be slow (see Fig. 4.79 (A)). Newer lock chamber filling systems use longitudinal even-filling by-pass channels with openings at different heights, allowing faster water inflow without putting the vessel in danger. Construction is often preceded by verification of the system on a hydraulic model.

Fig. 4.79: Examples of lock chambers: (A) Netherlands, filling of a lock chamber by a gate by-pass; (B) Poděbrady, a lock chamber with steel gates filling by-pass channels openings; (C) a lock on the Baťa Canal on the lower water, Cyclopean masonry; (D) Poland, a lock with wooden gates on the Augustów Canal. Photograph (A) by V. Forejtník, 2007; (B) by Miriam Dzuráková, 2021; (C) by the TGM WRI archive, 2012; (D) Milena Forejtníková's personal archive.

Material for the construction of lock chambers

The majority of lock chambers are built from solid materials with regard to the alternation of water pressures and flow effects during filling and emptying of the locks. At the beginning of the construction of waterways, lock chambers were sometimes constructed in the same transverse profile as the canal itself with sloping earth banks, revetted only with a wooden palisade or other wooden elements. This method, however, required frequent repairs and was mostly after some time rebuilt into masonry, or later concrete, locks with perpendicular walls. These durable structures are already built as one body, including both heads.

Types of lock chamber gates

All of the above diagrams and photographs show two-wing mitre lock chamber gates operating against the water pressure. In Fig. 4.79 (D) there are wooden gates with a service bridge for manual control of filling sluice gates in each wing. Each of the gate wings has a long beam in the upper part, which serves as a lever for handling the gates. After equalising the water levels in the lock chamber and the canal, it is possible to handle the gate with this lever by one person. The type of gate displayed above was common on all channels in the 18th and early 19th centuries from England, through Western to Eastern Europe.

Later on, wooden structures were covered with sheet metal for greater strength and tightness. With the increasing dimensions of locks, there was mostly steel equipment of controllable elements introduced and manual handling of gates was replaced by hydraulic. This allowed the eventual switch to automated control of the entire lock chamber.

In some cases, other door structures are also used, such as folding or sinking into the bottom. Gates rotating around a horizontal axis may be designed in such a way to allow the lock chamber to be filled or emptied directly over its upper edge.

4.3.1.3.2 Other types of equipment for overcoming height differences in water levels

In some cases, there are mechanical boat lifts built, which can be used for overcoming very high heads up to the limit of around 100 m. Examples of vertical lifts can be seen in Fig. 4.80. Inclined plane lifts, examples of transport by railway, are shown in Fig. 4.81.

Comparison of boat lifts and lock chambers

Advantages: possibility of overcoming high heads; minimum water consumption; high transport productivity of the equipment and thus of the waterway; high speed of overcoming the head; no fluctuations of water levels in adjacent basins.

Disadvantages: higher construction costs; technical and structural complexity of the equipment; increased requirements for the construction founding; smaller size of the trough, and thus the possibility for only individual boats to pass through; the need to balance the trough when it is moving.

As for the boat lifts, effort is also made to minimise the energy consumption during the operation. This is ensured, for example, by the use of counterweights, various hydraulic systems, coupling of two troughs acting against each other, etc. There are also special boat lifts created, which then become “technical monuments” already at the time of their creation. An example is the Falkirk Wheel rotating boat lift in Scotland completed in 2002 (see Fig. 4.82). In the promotional materials for this technical work, admirable parameters are given: The length of each of the two arms is 25 m, the weight is approximately 300 t, one rotation cycle including preparation process takes 15 minutes and consumes 1.5 kWh. This operational energy efficiency is due to the balancing of the entire system where the arms with water, and also boats, act as counterweights.

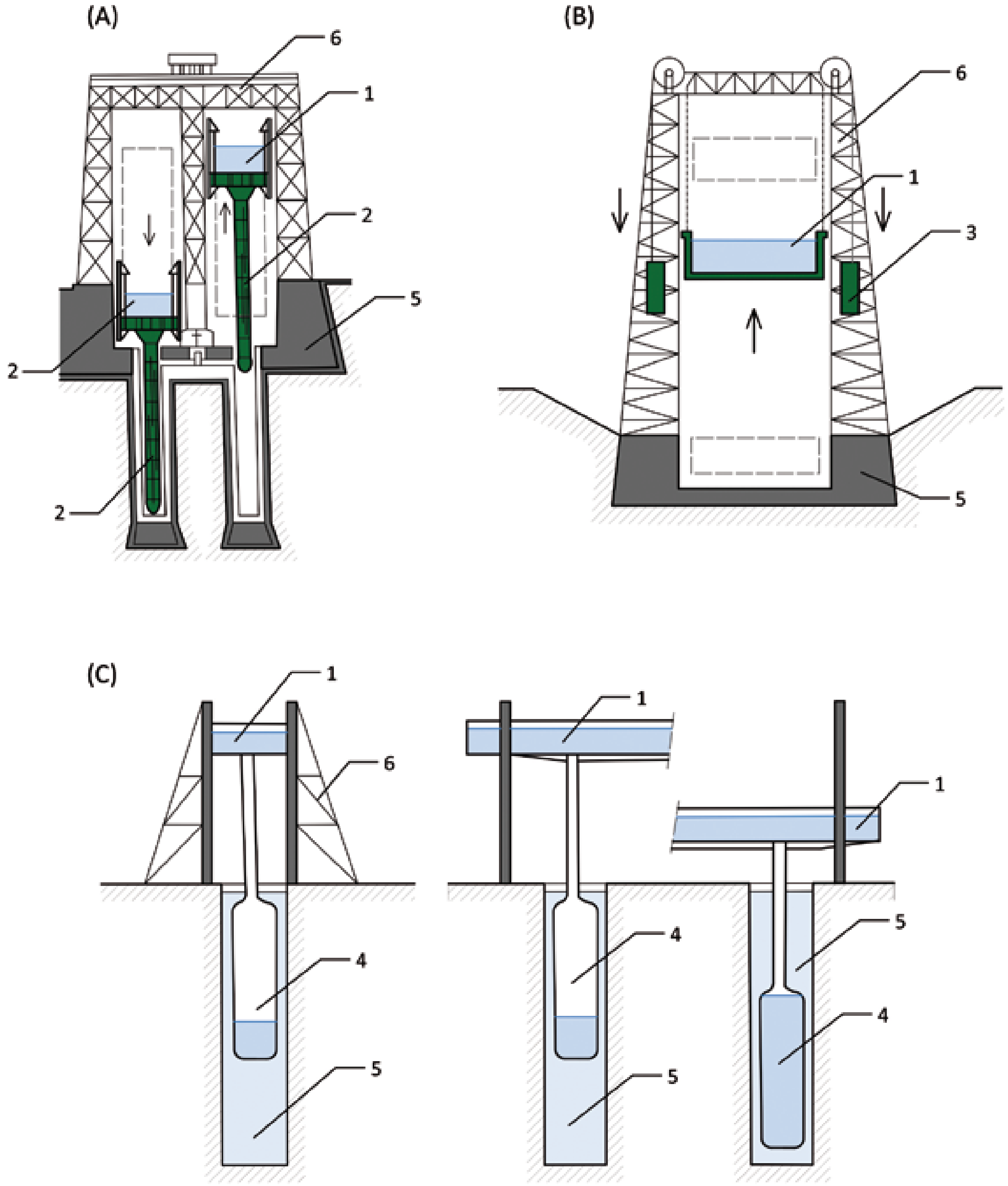


Fig. 4.80: Vertical boat lifts: (A) piston boat lift; (B) diagram of a boat lift with counterweights; (C) diagram of a boat lift with floats; 1 – basin for boat transport; 2 – hydraulic-controlled piston; 3 – counterweight; 4 – float, 5 – solid technological elements, 6 – overground supporting structure. Diagram by Radka Račoch and Michaela Mrovová, 2021 (modified according to: VSB – Technical University of Ostrava, 2013).

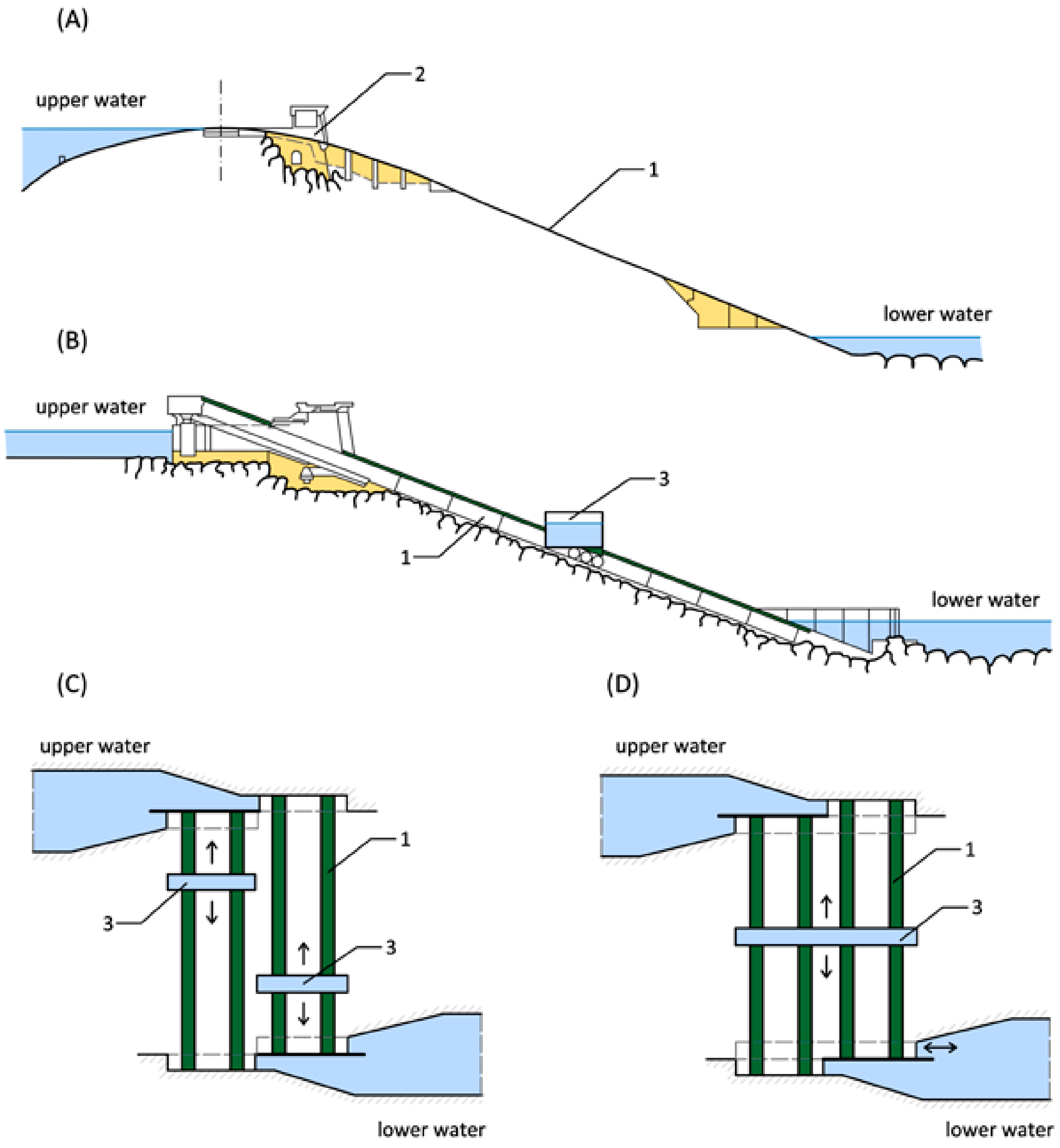


Fig. 4.81: Inclined plane lifts: (A) rail transport of smaller boats on a cart; (B) rail transport of larger vessels in a straight movable trough; (C) transverse movable trough, dual rail track; (D) possibility of connecting two troughs for the transport of long boats; 1 – rail track, 2 – cart for transporting small boats, 3 – movable trough for transporting larger vessels. Diagram by Radka Račoch and Michaela Mrovová, 2021 (modified according to: Březinský, 2020 and VSB – TUO, 2013)

Fig. 4.82: Falkirk (Great Britain, Scotland), a rotating boat lift. Photograph by Shutterstock, 2015.

4.3.1.3.3 Crossing of a navigation way with other roads

The operation of waterborne transport is dependent on the longest possible routes conducted in one grade line. Therefore, when they cross with other roads, overpasses or underpasses are used due to the change in the elevation of these roads, tracks or railways. When a navigation way is bridged, the underpass height of the bridge above the water level is decisive. If the conditions for sufficiently high bridging are not adequate, moveable bridges of various structures are used. In Fig. 4.83 (A) and (B) there are bridge structures with horizontal road lifting using a counterweight. In (C) and (D) there is an older and a modern version of a bascule structure: on the latter, in Amsterdam, there is even tram transport operated on the bridge structure. The last example (E) is a hydraulic bridge in the raised position on a recently repaired lock in Hořín.

Further photographs in Fig. 4.84 show an example of a navigable canal on a bridge structure over a motorway. In our country's conditions, this way of crossing is not used but in other countries there can even be seen several hundred-long navigable canals used as aqueducts spanning whole valleys.

An example of a navigable canal through an aqueduct is the UNESCO World Heritage site – **Pontcysyllte Aqueduct** on the Llangollen Canal in northern Wales (see Fig. 4.85; Pontcysyllte, 2009): "*The Aqueduct was built at the turn of the 18th and 19th centuries and it is the highest and longest aqueduct in Great Britain. The cast iron and brick bridge crosses the valley with eighteen arches, each with a span of 13.7 metres. Only four buttresses stand in the river itself. The length of the bridge is 307 metres, the height from the water level to the bottom of the trough with water is 38.4 metres. The navigable canal carried by the bridge is 3.4 metres wide and has a depth of 1.6 metres. The entire building was opened just ten years after the foundation stone had been laid, on 26 November 1805.*"

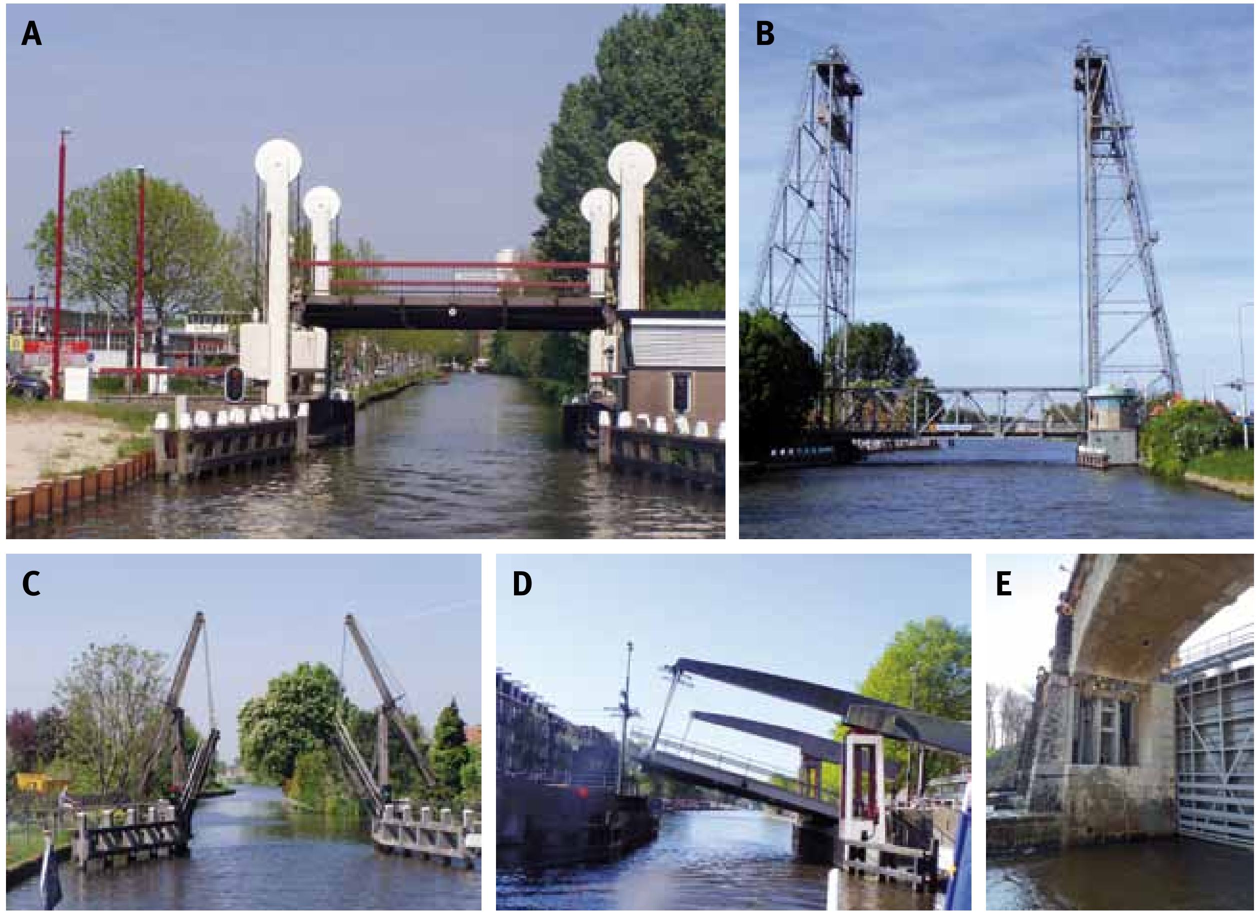


Fig. 4.83: Moveable bridges of various structures: (A) and (B) with counterweight, raised with a road in the horizontal position; (C), (D) bascule bridges; (E) hydraulic bridge on the reconstructed lock Hořín. Photograph (A)–(D) by Vít Forejtník, 2007 (Netherlands); (E) by Otakar Hrdlička, 2021.

Fig. 4.84: The Netherlands, crossing of a navigable canal of higher class and a service road with a motorway. Photograph by Milena Forejtníková, 2007.

Fig. 4.85: Aqueduct Pontcysyllte (Great Britain, Wales). Photograph by Shutterstock, 2021.

On waterways in the Czech Republic, however, there can be found a level crossing at navigable canal with a natural watercourse. Both of the following examples are located in South Moravia on the Baťa Canal (PMO, 2018). In Fig. 4.86 there is a diagram of crossing with the Velička River, which consists of lock chambers with double mitre gates because both situations can occur – a boat passing through it can rise or descend on the Velička level. The continuity of water flow and level height in the canal is ensured by an inverted siphon below the Velička River and the navigable depth is ensured by a weir just below the crossing.

Another method was used at the crossing of the canal with the Morava River near Vnorovy. When there are different water levels in the canal and in the river, restored lock chambers between the canal and the river (Vnorovy I) and between the river and the canal (Vnorovy II) are used in the transition areas until the present day. Part of this crossing solution is also the Vnorovy weir which allows manipulation not only with the Morava River water level but also controls the outflow and inflow of water into both parts of the Baťa Canal. During the original use of the canal for cargo transport, boats were dragged between the locks on a rope by means of a funicular lift which used the Morava River flow for the movement, similarly as ferries. Until today, this unique technical solution is commemorated by the funicular steel torso (see Fig. 4.87).

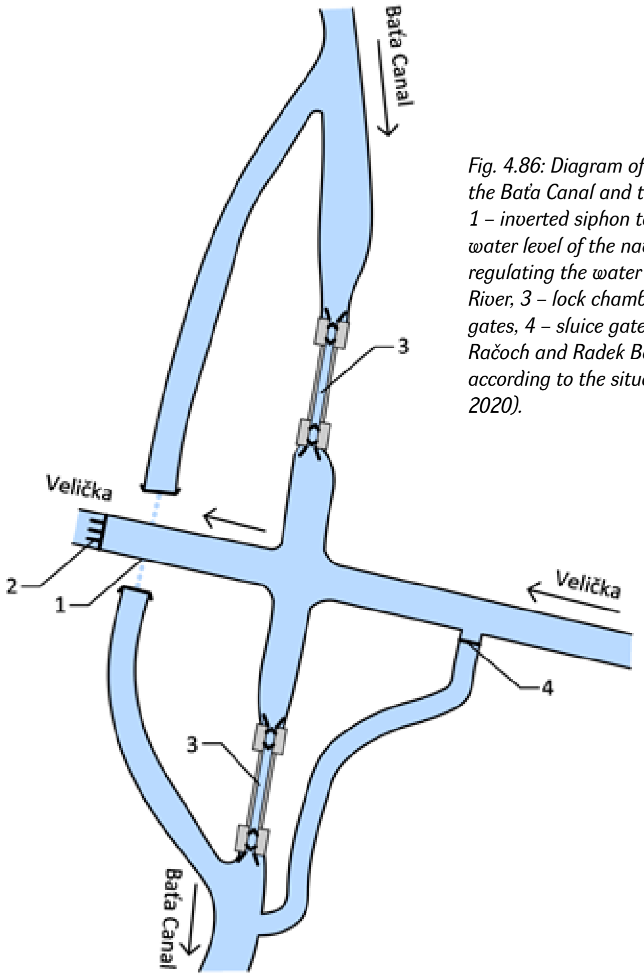


Fig. 4.86: Diagram of the crossing of the Baťa Canal and the Velička River: 1 – inverted siphon to maintain the same water level of the navigable canal, 2 – weir regulating the water level of the Velička River, 3 – lock chambers with double gates, 4 – sluice gate. Diagram by Radka Račoch and Radek Bachan, 2021 (modified according to the situation in the terrain in 2020).

Fig. 4.87: Remnants of a boat funicular lift for crossing of the Baťa Canal with the Morava River near Vnorovy. Photograph from the TGM WRI archive, 2012.

4.3.2 RACES AND OTHER WORKS FOR WATER TRANSPORT

4.3.2.1 Construction of hydraulic structures for water transport

Many examples of terrain unevenness can be found in the Czech and Moravian landscape, which, after closer examination, show that these are remains of human activity. In the case of linear elements, they might be races or water channels that no longer exist. On the contrary, in maps from various periods, including old cadastral maps, we can find watercourses that are no longer visible in the terrain. As it was mentioned in Chapter 1.2, the history of watercourse modifications in our landscape is long and the use of energy of water has accompanied it from its very beginning. The construction of races to conduct water to the place of its use has, therefore, a long tradition.

The simplest race-type hydraulic structures were built on the local level for the water and hammer mills needed within one valley. The inflow from a watercourse into their route was originally regulated only by free-laid stones or gravel banks, similarly as the natural branching of a watercourse occurred. The height difference for achieving the necessary head of water was obtained by leading the race route along contour lines of a hillside. The subsequent construction of weirs as impoundment and water distribution structures enabled to further increase the height difference and regulate the amount of water supplied into a race.

In the Czech Republic, there are races and canals preserved of varying quality which exceed the watershed between streams and basins of big rivers. In these cases, it was not often a matter of energy use only but it was also necessary to conduct water from a place with a sufficient amount of it to a place where it was needed. The development of mining and glass-making also contributed to the construction of such hydraulic structures.

Over time, the original purpose of a structure sometimes changed. An example is the Blatná Water Ditch built between 1540–1544 which supplied water from peat bogs near Boží Dar into tin mines in the surroundings of Horní Blatná. The ditch was still renovated in 1929 although it was not used for further mining despite until 1945 serving as a potential source of firewater. It underwent further renovation between 1995 and 2001 when the main purpose was to separate peat water from sources of water of the Myslivny water-supply reservoir.

With the development of manufacturing and, later, industrial production, there was a growing need for water for other sectors, such as textile production or cellulose processing. This resulted in growing volumes of transported water and dimensions of race troughs.

Multi-purpose use of races and canals was often planned since their origin. With the supply of the necessary volume of water for technology, its energy potential was used, and, at the same time, the race of the canal was also used to bring timber to the place of its processing. An example of this multi-functionality is the Weisshuhn Canal in the Moravice River basin, or a canal supplying water and timber from the Mílnice River to Huťský Pond and farther to the glassworks in Harrachov.

In the 20th century, when technology and mechanisation advanced, hydraulic structures of many times larger volumes for the transport of water were also created. The most important is the Podkrušnohorský headrace, which diverts water from streams in the Krušné Mountains outside opencast coal mines to the Bílina River, or the transfer of water from the Morávka River to the Žermanice reservoir built between 1951 and 1956.

4.3.2.2 Characteristics of races and types of structures

4.3.2.2.1 Types of races and canals

According to the purpose:

- increase in head at the place of energy use (e.g., mills, small hydroelectric power plant),
- increase in flow speed and cross-section (e.g., for timber floating),
- transfer of water from a place of its surplus to places of its need (feeding fishpond systems, supplying technological water to industrial premises).

According to the alignment method:

- on a slope along a contour line,
- via a watershed line (e.g., Blatná Canal),
- in the fill of an alluvial plain (e.g., some races of the Svitava River plain),
- by gallery and tunnel driving (part of the race for the Spálov small hydroelectric power plant – see Chapter 4.4),
- aqueducts, tunnels, inverted siphons - crossing with another watercourse or road (e.g., see Fig. 4.93),
- river meander artificial cutoff (e.g., “Myší díra” (Mouse hole) in Litice nad Orlicí – see Fig. 4.88).

In the case of more important hydraulic structures, a combination of several methods of alignment is used.

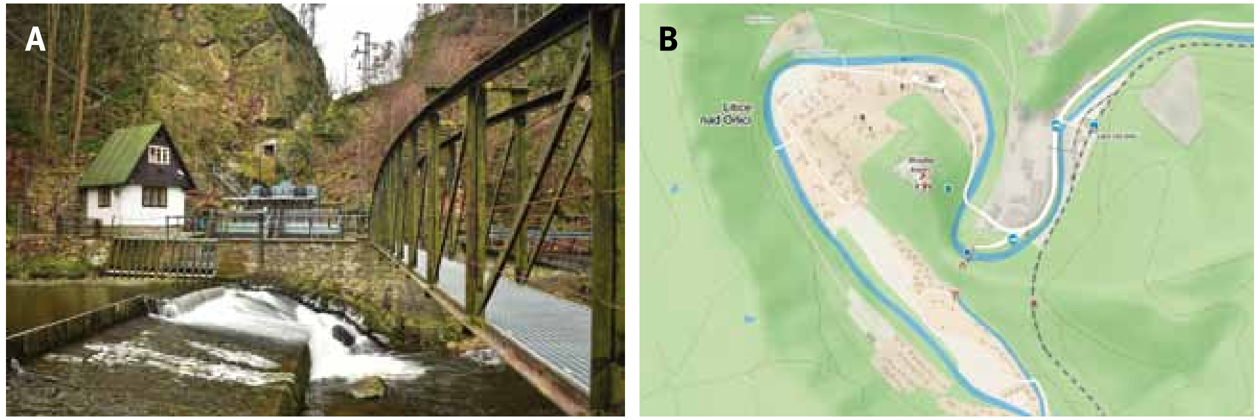


Fig. 4.88: Litice nad Orlicí: (A) a weir with the inflow to the cutoff; (B) situation of the location on the map. Photograph (A) by Milena Forejtníková, 2020; (B) taken from: mapy.cz.

According to building material:

In the past, local materials were clearly used according to local building practices and experience. A typical example is the use of unjointed stone in Jeseníky, which was laid in such a way to resist the increased pressures of flood water during spring melting (see Fig. 4.91). On the other hand, in the Česká Lípa region, there were advantageously used sandstone structures, into which it was possible to dig and shape the necessary profile of the trough without any extensive use of machinery (see 4.90). In lowland areas, the newly formed race troughs were dug in local soil; the advantage was the well-sealing clay soil. The revetment of banks in the places where arches are located was made of stone or wood.

Some sections and detailed solutions were carried out in wood. However, these sections were not preserved in their original form and were eventually renewed based on the period drawings. In Fig. 4.89 there is a newly made adjustment of wooden elements at the end of the mill race at the Babiččino údolí (Granny’s valley). Even at the time of their creation and operation, these parts were often repaired and, in the case of mills, rebuilt according to the needs of the subsequent technology (for the most effective inflow to the water wheel).

At the time of industry development, the demands on the amount of water supplied by races increased and standardised solutions and more durable materials, such as concrete, stone masonry into cement mortar, or concrete prefabricated elements, were used.

Fig. 4.89: Ratibořice, wooden elements of the mill race at Granny's valley. Photograph by Milena Forejtníková, 2010.

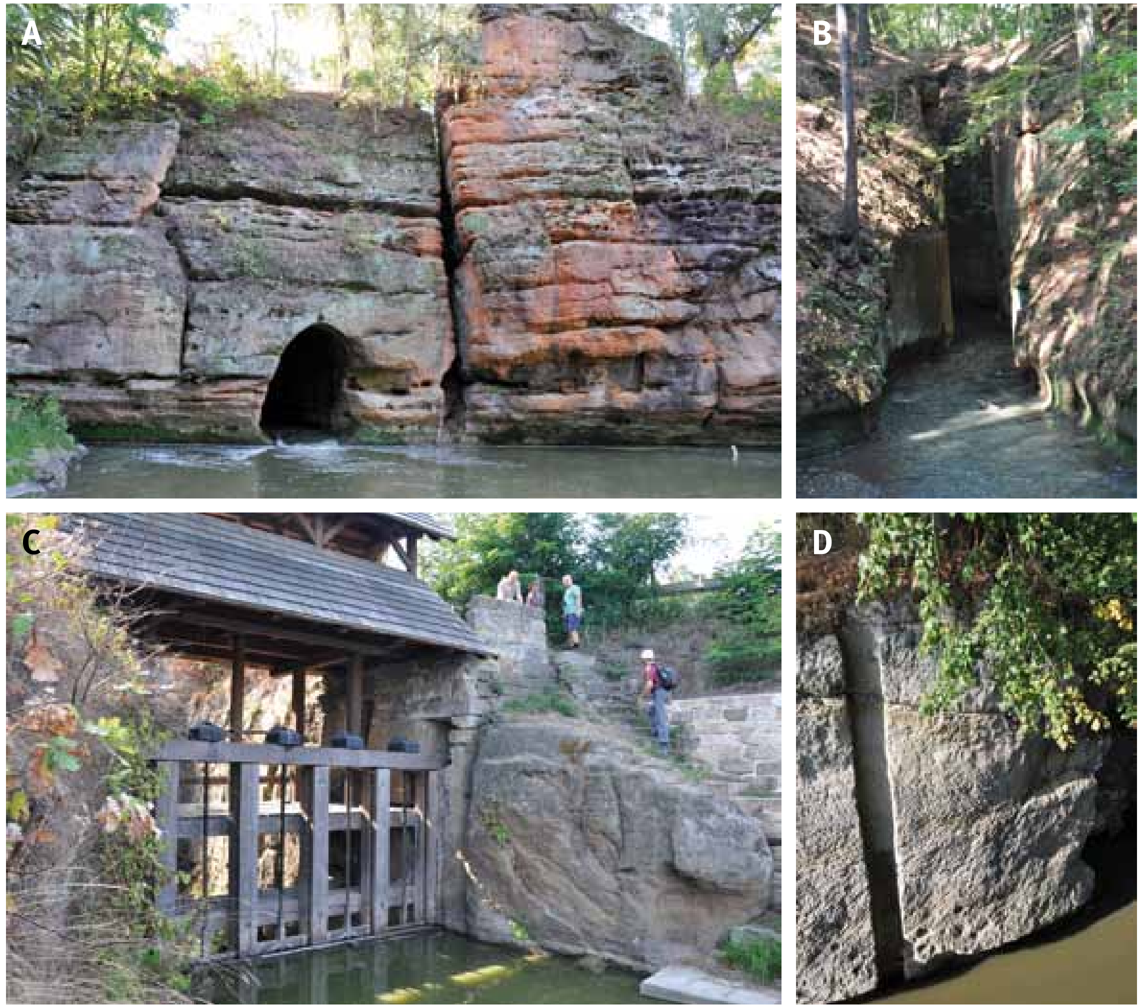


Fig. 4.90: Building material of water canals – sandstone: (A) and (B) Ploučnice gulley, artificial shortening of the watercourse by a tunnel and an open trough; (C) the siting of the structure with sluice gates directly into the sandstone block; (D) the detail of the groove for temporary flashboard cut in sandstone. Photograph by David Honek, 2019.

Fig. 4.91: Building material – stone – Jeseníky (Karlov, Malá Morávka): (A) assembled stone, durability verified over time; (B) newer variant of assembled stone; (C) Chrudim, stone race which is no longer there; (D) stone walls of a water canal in an intravilan. Photograph by David Honek, 2020.

4.3.2.2.2 Structures on water canals and races

Watercourses in our landscape have been influenced by people's activities for centuries. It is surprising how many and what kind of structures can be found on a seemingly natural watercourse. In the case of water channels and races we often find still functional aqueducts or inverted siphons for the crossing of artificial channels with natural watercourses or a road.

Examples of water bridges – aqueducts are shown in the following pictures. In Fig. 4.92 there is the renovated Semínský aqueduct on the Opatovice Canal. The reconstruction from 2003 was carried out only with regard to maintaining the functionality of this structure using reinforced concrete and steel Larssen profiles (a relief sluice formwork), as can be seen in (A). In picture (B) there is a detail of the transition between the trough and the bridge part of the canal with the remains of wooden revetment elements. In Fiig. 4.93 there is a crossing of the Dyje mill race with the Pulkava River, the original material of the aqueduct is preserved, as the title of this structure also suggests – Železná postel (Iron bed). Other aqueducts are found, for example, on the Schwarzenberg Canal (national cultural monument) on a crossing with Koňský Brook, in Chřibská near Česká Kamenice (cultural monument), or aqueducts on the Weisshuhn Canal (without protection).

Inverted siphons use the principle of communicating vessels where water is conducted into a pipeline or into another sealed trough lower under the level of the crossing line and subsequently returns to its level line. In the lower section there is a pressure flow, so for the correct function of the inverted siphon, its route must be water-resistant. The inverted siphon cannot be used on the navigation route and adequate maintenance is required to prevent the blockage of the inflow part. The entrance is therefore fitted with grating or racks.

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Fig. 4.92: The Semínský aqueduct on the Opatovice Canal: (A) state after reconstruction; (B) remains of old wooden elements. Photograph by David Honek, 2020.

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Fig. 4.93: Laa an der Thaya (Austria) – an iron aqueduct on a race from the Dyje River. Photograph by Milena Forejtníková, 2019.

Sluice gates and residual overflows for the flow control in races

On races and water channels, various water distribution structures and flow control facilities can be found. These structures are needed not only at the inflow and at the end of the channel but also along the whole route to adjust the appropriate flow in individual sections of the channel, when crossing or collecting water from tributaries, relieving surplus water through residual overflows with fixed edge or handling sluice gates. Most of these facilities are described in other chapters, especially in the section on the use of energy of water. The following photographs illustrate some typical or unique solutions. In general, it can be observed that the original hand-operated sluice gates were gradually equipped with electric motors for their easier control, while mostly maintaining the original elements.

Subsequently, it turned out to be convenient to control the sluice gates remotely using an electrical network. A special case of remote control is the residual outflow before the entry of the race into the plant premises on the Weisshuhn Canal where a hydraulic remote control was selected to operate sluice gates.

Fig. 4.94: Control structures details: (A) Chrudim, wood, hand-operated sluice gates; (B) the Weisshuhn Canal, an originally hand-operated sluice gate converted into electrically-powered; (C) the same place, right-bank residual outflow operated hydraulically; (D) mechanism for manual control of sluice gates from the side. Photograph by Radka Račoch, 2021.

4.3.2.2.3 The destiny of old races on the example of a mill race in Jakubčovice

The race was built for the Wesselsky mill, whose name comes from the owners who were operating here from 1762 for 200 years. The 3-kilometre long race was built for the Wesselsky mill which was mentioned for the first time in 1571. There is preserved mill technology with quartzite millstones, oak water wheel and transmission to the barn. (Water mills, 2021). The mill has undergone gradual reconstruction and the owners have tried to maintain the functional race and wastewater channel behind the mill, which are, however, located on other grounds.

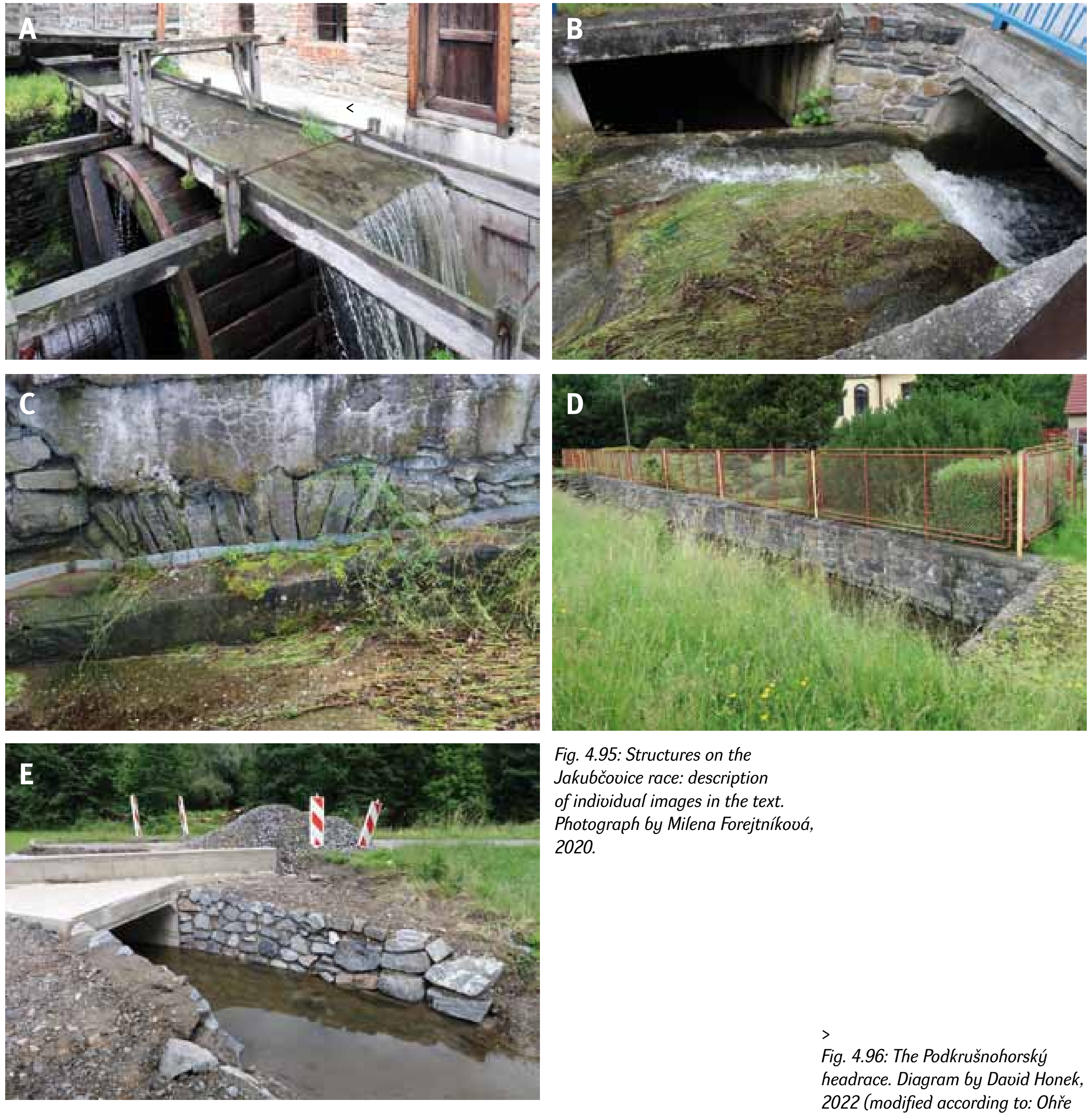

Fig. 4.95: Structures on the Jakubčovice race: description of individual images in the text. Photograph by Milena Forejtníková, 2020.

The mill race takes water from the Oder River on the Jakubčovice weir 88.3 kilometre along the river. Most of the route passes through the built-up area of the villages of Jakubčovice and Loučky. In some parts it is piped, a small water reservoir (originally with accumulation function) is preserved on it and it also passes under storage and production structures. Originally, it carried pure water of the Oder River, including fish and other aquatic animals. Rainwater from adjacent properties was also diverted into it and during the 20th century it gradually became rather a sewer, as living standards and household amenities progressed. In fact, the sewage system network or wastewater treatment of the aforementioned villages have not been finalised. The mill owners are concerned about the race completely disappearing by being piped and converted into the main waste collection sewer.

Some interesting details are in Fig. 4.95. In part (A) there is the newly built wooden equipment of the race – flumes before the inflow to the water wheel; wooden levers allow adjustment of the length of the inflow bottom and thus influence the fall of water jets on the water wheel. In part (B) the bridging of the race for the transfer of Dobešovský Brook directly to the Oder River is captured; in the case of increased flows in the stream, part of the water would be automatically released into the race. (C) shows the detail of materials used at the place of this crossing from various periods and repairs. (D) and (E) allow the comparison of the craftsmanship of the stone revetment and bridge earlier and now (both of these photographs are from the initial stretch of the race above the continuous built-up area of Jakubčovice.

4.3.2.2.4 Large transfers of water from the 20th century

With the development of industry, and especially the power industry, in the 20th century, water management construction works were further developed. In the case of water channels and races, these new works are mentioned in other chapters of the Methodology, where water inlet and outlet form an integral part of a functional complex (typically small hydroelectric power plant).

Nevertheless, water transfers and water volume management had to be addressed in larger territorial units too, so, within the scope of water management planning, a separate discipline – Water management systems control – was created. A practical output of these considerations and calculations is a system of dam reservoirs in the Oder River basin where the aim was to ensure sufficient water for the developing industrial area of the Ostrava region in all respects. In order to use all the possibilities of water accumulation in dam reservoirs, an open water channel from the Morávka River to the Žermanice reservoir was built.

Another example is the Podkušnohorský headrace in the Ohře River basin (Fig. 4.96). Opencast coal mining has disturbed the entire landscape, including the natural network of watercourses. The channel, as well as the final sections of some streams – its tributaries, is led partly in covered profiles and in a pipeline. In open-trough sections there is a concrete trapezoidal cross-section. This water channel transfers the water, originally pertaining to the Ohře River, to Bílina. Although the whole works have probably no architectural quality and even the technology of its construction does not bring new solutions, it is unique in terms of idea design. Nowadays, negotiations about the future of the water management solution of the entire mined district are held. Individual mining pits are converted into water areas and their energy use in the form of pumped storage power plants is also being considered.

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Fig. 4.96: The Podkrušnohorský headrace. Diagram by David Honek, 2022 (modified according to: Ohře River Basin, state enterprise).

4.3.3 WEIRS

4.3.3.1 Historical development

The construction of weir structures was related to the settlement of territories which was most intensively carried out in the valleys of important watercourses. The oldest historically documented pond structures were built 3000 years BC. They come from Egypt, China and India, where their construction was related to the need for irrigation of agricultural crops and later to the development of production facilities (e.g., mills). The Romans brought basic knowledge regarding the construction of weirs to Europe. In the Czech lands, the construction of weirs was associated with watercourses modifications whose aim was to ensure protection from floods, navigability, stabilisation of a watercourse through flow but also the use of energy of water and water supply. The oldest weir in our territory was probably built near Žatec in 778. The construction of weirs in Prague was documented from 993. The development of fixed weir construction falls into the 13th century when they were constructed from wood, stone and earth. In this way, permanent fixed weirs were created which were relatively systematically maintained. Many of them have been preserved to this day. Timber weirs with filling are especially characterised by their considerable resistance. They are historically valuable buildings. For example, there were many weirs on the Vltava River in Prague in the 14th century, from which the Šítkovský and Staroměstský weirs have been preserved. Their aesthetic effect is still part of the overall panorama of Hradčany (Průcha, 1980).

The construction of fixed weirs created obstacles for navigation. Disputes over water were resolved by Charles IV who established the “Sworn millers’ guild” in 1340. They were responsible for judging disputes over water and weir height. The guild can therefore be considered the first water management institution in the history of the Czech state (Průcha 1980). With the development of industry in the 19th century and the availability of metallurgical materials, especially steel, the first gated weirs started to be created. First, there were rather smaller structures where damming elements were usually formed by wooden planks and beams and only the main supporting part was made of steel. The possibility of keeping the level in the weir basin constant up to a certain flow ensures better use of the watercourse, and thus there was a rapid development of weir systems in this period. At the same time, a large number of new technical solutions of gated weirs were created in this period, some of which are still used (Gabriel et al., 1989).

4.3.3.2 Classification and structural types

The function of a weir is the impoundment of water in the watercourse, which can be used for several water management purposes. It is necessary to distinguish between weir-type and dam-type structures. A weir differs from a reservoir due to the weir basin function. There is a relatively small fluctuation of levels in a weir basin (in the case of fixed weirs it is more pronounced), the overflow is primarily carried out over its own structure, and flows are transferred through the weir basin without being influenced (i.e., the inflow is equal to the outflow). From the point of view of the construction design and ground plan layout, we distinguish between *straight* weirs (these are perpendicular, oblique, polygonal and side) and *curved* weirs (e.g., arched, S-shaped, etc.) (see Fig. 4.97).

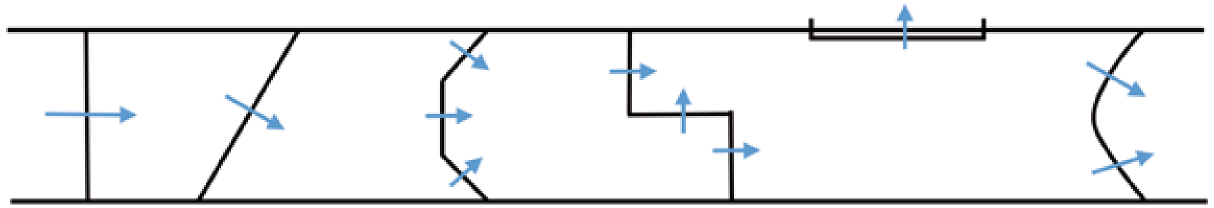


Fig. 4.97: Examples of ground plan layout of weir structures. Diagram by Tomáš Julínek, 2019.

According to the function, weirs can be divided, with regard to their construction layout, into two main types, more specifically fixed and gated weirs. A fixed weir impounds water in the watercourse by means of a body with a fixed level of the overflow edge. The backwater level in the area upstream of the weir varies depending on the change in the flow rate. On the other hand, in the case of gated weirs, the water in the watercourse is raised by damming elements (weir gates), which allow the position of the overflow edge to be changed. This allows the upper water level to be kept at a constant level by the gradual opening of the gates up to a certain flow rate, e.g., up to the weir capacity. Weir structures can be divided into groups according to the construction layout of the damming elements as follows (Gabriel et al., 1989):

- **Fixed weirs** – timber, stone, masonry, concrete, multiple buttress, siphon;
- **Gated weirs** – needle, stop-log, shutter, sluice gate, radial gate, roller drum gate, hydrostatic.

4.3.3.2.1 Fixed weirs

Fixed weirs are built mainly in watercourse stretches where upper water level fluctuation is acceptable. It can be mainly used during the stabilisation of the bottom and banks of the watercourse trough, or during the adaptation of smaller watercourses. Fixed weirs can be divided into several categories according to various aspects. For example, according to the height, structure shape in the cross-section, building material used or method of diverting flows. Fixed weirs form an uncontrolled solid body stabilised into the structure foundations. The overflow edge is not fitted with movable gates.

4.3.3.2.1.1 Timber weirs

Timber weirs (see Fig. 4.98) represent the first type of weir structures that were built. Their structure is simple and later they were often used as temporary ones. The damming structure is usually made of a timber pile wall, supplemented by a stabilising stone material (see Fig. 4.98 (A)) or stabilised by timber struts (see Fig. 4.98 (B)). Pine, larch or oak wood was used in the construction. Another solution is a more massive frame structure with filling, which represents the most durable type of timber weirs. The wooden frame is formed of wooden sheet pile walls, piles, horizontal beams and stabilising waling. The frame is filled with stone, rammed earth, etc. The overflow surface is protected by formworks or stones. In the case of a rocky or boulder bottom, which is not suitable for pile-driving, crib weir structures were built (see 4.98 (C)).

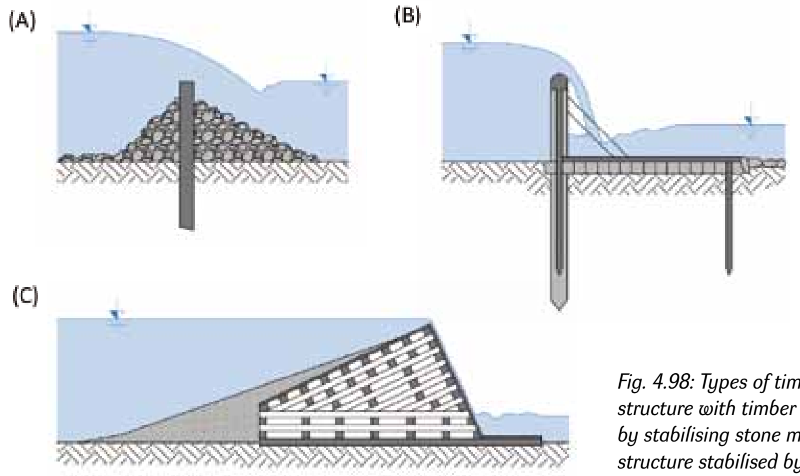


Fig. 4.98: Types of timber weirs: (A) a damming structure with timber pile wall complemented by stabilising stone material; (B) a damming structure stabilised by timber struts; (C) a crib weir structure. Diagram by Radek Mišanec, 2021 (modified according to: Průcha, 1980).

Fig. 4.99: Praha – the Šítkovský weir. Photograph by Miriam Dzuráková, 2022.

Timber weirs have been preserved at some locations to this day. Timber weir structures were often used in the Vltava River in Prague in the 13th century. These weir types are still referred to as Prague or Old Prague weirs. Examples are the Old Town Weir above Charles Bridge with a diagonal longitudinal axis or Šítkovský weir with polygonal axis (see Fig. 4.99). In the Central Elbe River stretch there were several weirs of this type, some of them have been renovated over time (Průcha, 1980).

4.3.3.2.1.2 Stone weirs

Stone weirs represent another historic type of weirs. These weirs were usually constructed as a stone dam with filling from finer material (see Fig. 4.100). The material used for stone weir construction was random rubble which was resistant against abrasion and frost. The slope of the upstream part was approximately 1:1 – 1:2 and was revetted by stone pavement. The downstream part of the weir was adapted within a slope of 1:2 or more. The overflow surface was revetted by stone pavement filled with wedges. The bottom downstream of the weir was usually protected against scour by a stone riprap. The weir body was usually relatively permeable and thus its stability was endangered from a long-term perspective. This type was used for damming lower heights during short-term use or during the shutdown of secondary watercourse branches (Gabriel et al., 1989).

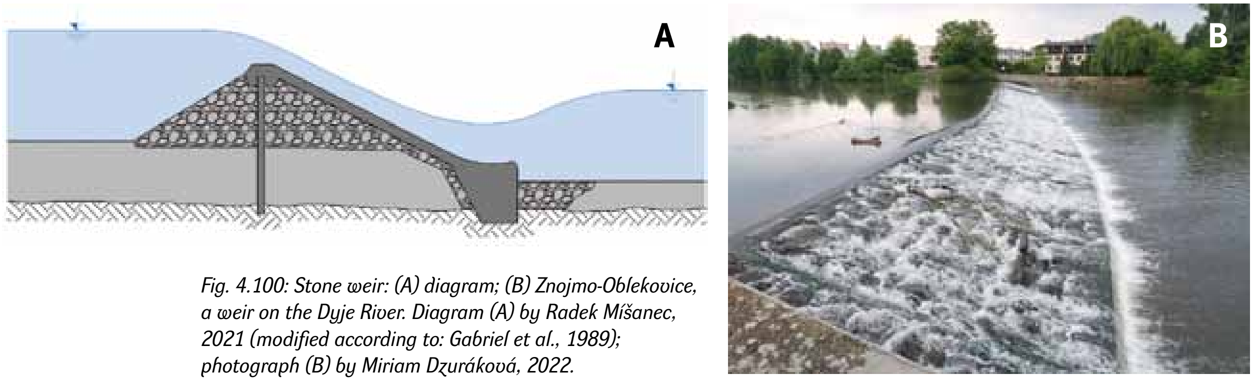


Fig. 4.100: Stone weir: (A) diagram; (B) Znojmo-Oblekovice, a weir on the Dyje River. Diagram (A) by Radek Míšanec, 2021 (modified according to: Gabriel et al., 1989); photograph (B) by Miriam Dzuráková, 2022.

4.3.3.2.1.3 Masonry weir

For permanent damming of higher flows, the stone structure was replaced by a more durable masonry structure. Masonry weirs are formed by a solid body which is stabilised by its own weight. The masonry is most often made of rubble and worked stone blocks. The first masonry structures were based on timber and stone weirs and had a rectangular, trapezoidal and triangular cross-section. On the basis of the hydraulic development of higher fixed weirs, the trapezoidal body was supplemented with a deepened stilling basin and revetment behind the basin. The term "stilling basin" refers to a deepened area of the bottom below the weir which helps to dampen the kinetic energy of the overflowing water jet. This type of weir is represented, for example, by the Helmovský weir on the Vltava River in Prague (see Fig. 4.101).

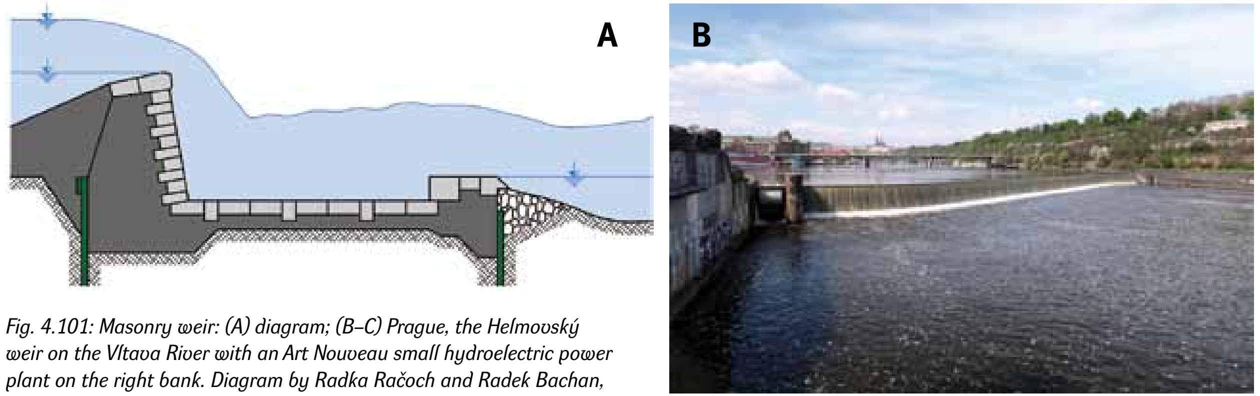


Fig. 4.101: Masonry weir: (A) diagram; (B–C) Prague, the Helmovský weir on the Vltava River with an Art Nouveau small hydroelectric power plant on the right bank. Diagram by Radka Račoch and Radek Bachan, 2021 (modified according to: Průcha, 1980); photograph (B) by Miriam Dzuráková, 2022; (C) by Michaela Ryšková, 2022.

4.3.3.2.1.4 Concrete weirs

Since a lot of hard manual work is necessary for constructing masonry structures, they were gradually replaced by concrete ones. The advantage of fixed concrete weirs is mainly their impermeability and speed of construction. From the point of view of a transverse shape, the first concrete weirs were constructed in a similar manner to the previous types. Gradually, rounded shapes of the overflow edge were constructed and connected to the horizontal bottom by means of a cylindrical surface. Based on the experience of the Helmovský weir, where frequent damage (erosion, ice action) occurred, an ogee-shaped weir with streamline spillway was designed (see Fig. 4.102). Due to the reduction of water leaks through the subsoil, the structure was supplemented with steel sheet pile walls (Gabriel et al., 1989).

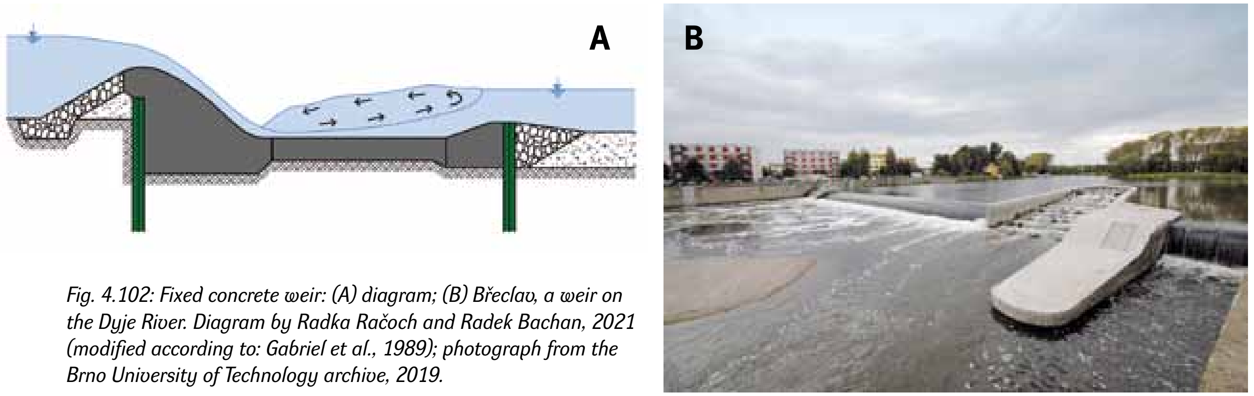


Fig. 4.102: Fixed concrete weir: (A) diagram; (B) Břeclav, a weir on the Dyje River. Diagram by Radka Račoch and Radek Bachan, 2021 (modified according to: Gabriel et al., 1989); photograph from the Brno University of Technology archive, 2019.

4.3.3.2.1.5 Buttress weirs

Buttress weirs are thin reinforced concrete structures. A multiple buttress weir has a triangular shape in the cross-section, with an inclined upstream side formed by waterproof reinforced concrete slabs leaning against buttresses (see Fig. 4.103). This is a lightweight structure that is quite difficult to build. Its hollow body can be open or closed on the downstream side. Somewhere, the damming panel is replaced by a wall made of arches or thin reinforced concrete shells supported by buttresses. They differ in the distance between buttresses.

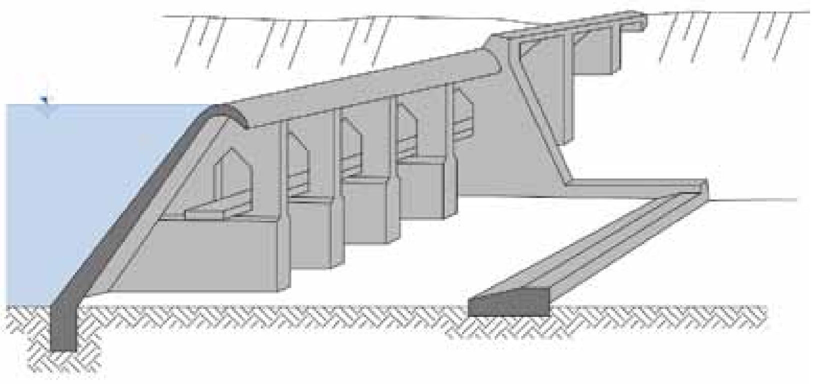


Fig. 4.103: Multiple buttress weir. Diagram by Radek Míšanec, 2021 (modified according to: Gabriel et al., 1989).

4.3.3.2.1.6 Siphon weirs

Siphon weirs are usually used when there is a limited overflow head or overflow edge width. This type of weirs allows the level in the upper reservoir to be kept at approximately constant level. The flow is transferred by means of siphons that are located on the weir body. A siphon weir is formed by an overflow surface and a top cover. The upper part is connected below the minimum operating backwater level and the lower part usually ends below the lower water level (see Fig. 4.104). The siphon starts acting when the upper water level exceeds the overflow edge level. A relatively high speed is produced in the siphon, so it is often armoured.

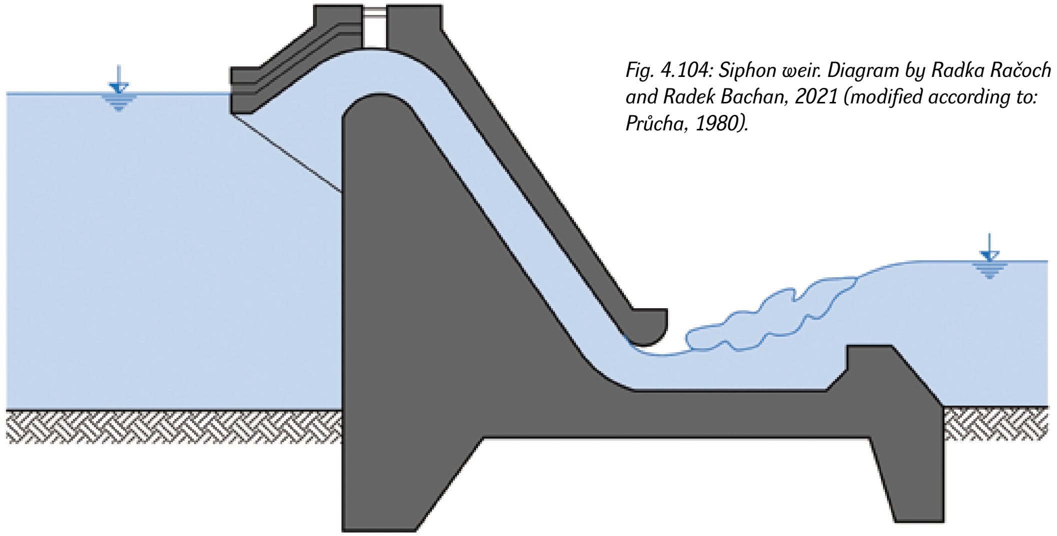


Fig. 4.104: Siphon weir. Diagram by Radka Račoch and Radek Bachan, 2021 (modified according to: Průcha, 1980).

4.3.3.2.2 Gated weirs

Gated weirs are usually located on middle and lower watercourses. A gated weir is often part of a set of buildings used for water management purposes. The weir usually involves a small hydroelectric power plant, water intake or high flow relief facilities, fish pass and lock chamber (in the case of navigable watercourses). Contrary to fixed lakes, it is possible to keep the water level in the upper basin at a constant level even at higher flows. This can reduce the waterstream overflow during flooding and, where appropriate, enable management of the relieved quantities into inundation areas. The gate control allows a safe transfer of ice and sediments.

A weir is always composed of a solid substructure, a trapezium-shape solid concrete spillway sill, or the so-called Jambor sill, and movable gates. The movable gates, most often steel, are mounted between buttresses. The gated weirs can be divided into categories according to various aspects:

- according to the damming elements control – manually, mechanically, by a change in pressure;
- according to the function/operation – automatic, semi-automatic, with continuous operation;
- according to their segmentation – compact, multiple;
- according to the load transfer from the damming mechanisms – to the lower part of structure, to buttresses;
- according to the type of damming mechanism – needle/stop-log, shutter, sluice/slide gate, roller drum, hydrostatic.

4.3.3.2.2.1 Needle and stop-log weirs

Needle weirs were mostly built from the middle of the 19th century to the first decade of the 20th century. They were mainly used for canalisation. Their weir consists of a needle, frame and short steel bars (Klír 1908, Kratochvíl 1947). The needles are wooden or metal beams stacked vertically side by side at a slope of about 10°. The frames are truss structures located at a distance of 1–6 m and connected by short steel bars. The frames transfer the pressure to the weir substructure (see Fig. 4.105).

Stop-log weirs are formed by horizontal beams placed on each other leaning against vertical grooves in the buttresses. The beams are wooden or steel with a rectangular or circular cross-section.

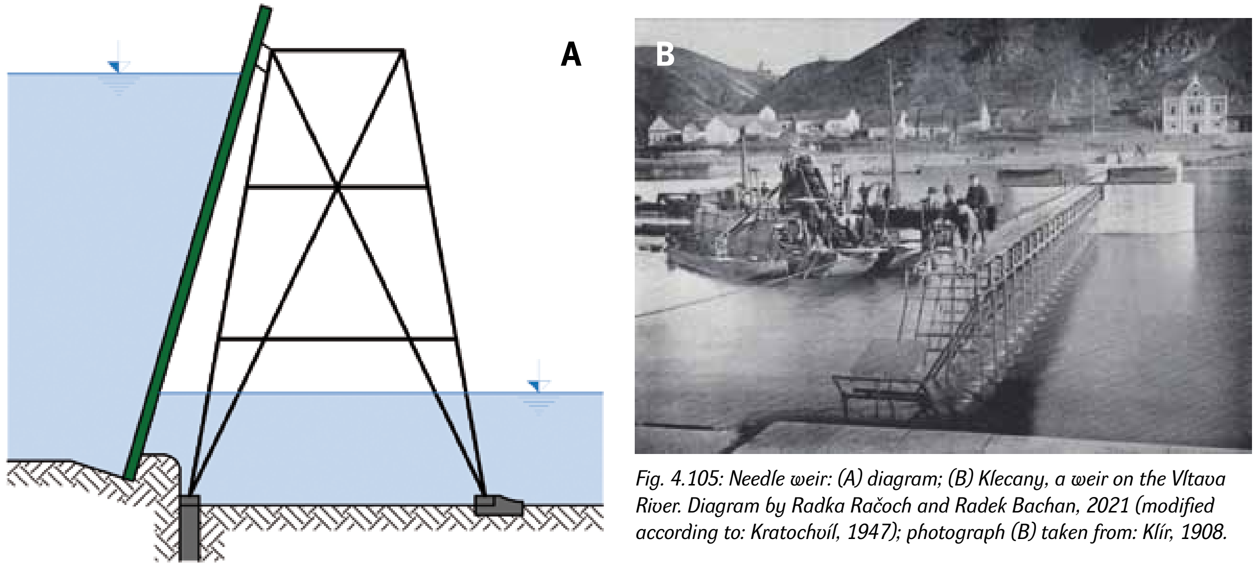


Fig. 4.105: Needle weir: (A) diagram; (B) Klecany, a weir on the Vltava River. Diagram by Radka Račoch and Radek Bachan, 2021 (modified according to: Kratochvíl, 1947); photograph (B) taken from: Klír, 1908.

4.3.3.2.2.2 Shutter weirs

Shutter weirs use a panel as a damming element. Originally flat panels were appropriately rounded for hydraulic reasons and spatially reinforced for static reasons. When handled, the body rotates around the horizontal axis. According to the location of the shutter rotation axis, shutter weirs can be divided into three categories:

- shutter with the rotation axis on the substructure,
- shutter with the rotation axis between the substructure and the minimum operating backwater level,
- shutters with the rotation axis above the minimum operating backwater level.

The handling of water in the upstream area of the weir is carried out by overflow, outflow or a combination of both. Originally, straight panels were used, which formed a wooden formwork, and struts, which held the weir in the upright position, were hinge-attached to them. Gradually, the construction started to be made from steel profiles clad with steel sheets. The most widespread type of the shutter weir gate is a flap gate. The flaps can be divided into panel (see Fig. 4.106 (A)), pipe (see Fig. 4.106 (B)) and hollow (Fig. 4.106 (C)). The flap consists of a gate panel reinforced by cross bars connected to the main girder. If this is located at an overflow edge, it is an angular flap. The pipe flap has a supporting pipe located usually behind the solid sill of the substructure. The flap movement is ensured by the rotation of the supporting pipe by means of a servomotor. The most commonly used one is a hollow flap with the rotation axis on the substructure. The flap has a lenticular shape formed by two cylindrically rounded sheets. The rigidity of the compact flap is ensured by reinforcing ribs, the so-called diaphragms. The good rigidity makes it possible to control the flap both bilaterally and unilaterally.

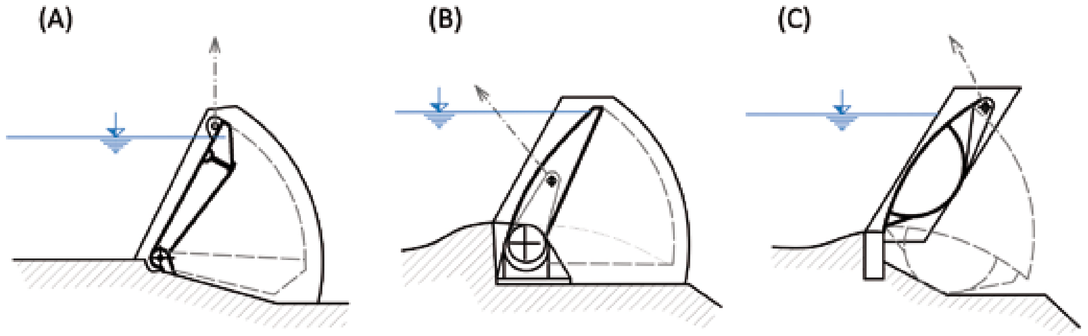


Fig. 4.106: Types of flap gates: (A) panel; (B) pipe; (C) hollow. Diagram by Radka Račoch and Michaela Mrvová, 2021 (modified according to Průcha, 1980).

Shutter gates with the rotation axis between the substructure and the minimum operating backwater level were more common abroad (the USA, France). In the Czech Republic, they were more often considered in proposals for potential technical solutions.

A shutter gate with the rotation axis above the minimum operating backwater level was used only at some localities in our country. The most famous Záhorského shutter weir with overhead bridge was built on the Chrudimka River in Pardubice. The shutters are hung on a bridge deck and when necessary, they are raised to the plane of the bridge deck lower edge. There is currently only one functional shutter weir with overhead bridge – on the Mže River in Křimice (see Fig. 4.107).

Fig. 4.107: Křimice, a shutter weir with overhead bridge on the Mže River. Photograph from the Brno University of Technology archive, 2018.

4.3.3.2.2.3 Slide gate weirs

Slide gates are considered to be the oldest type of a movable damming structure. The gate is formed by a vertical spatial element. Slide gate weirs have either several smaller sections dammed by individual sluice gates (see Fig. 4.108 (B)) or the damming element is formed by a compact body moving in the grooves of the weir buttresses. The weirs on which compact sluice gates are used are also known as slide gate weirs (Gabriel et al., 1989, and Čábelka, 1965).

The first sluice gates were made of wood but gradually they were replaced by steel ones. Water is transferred over the weir either by the outflow below the sluice gate or it falls over its upper edge. The movement of a sluice gate is ensured by Gall's chains or by a spindle bar. Sluice gates can be divided into **lifting** (Fig. 4.108 (A)) resting on the spillway sill edge, **lowering** with the possibility of sinking behind the substructure (sill), **with a flap in place** for a more accurate control and setting of upper water level under lower flow rates and **two-piece** sluice gates.

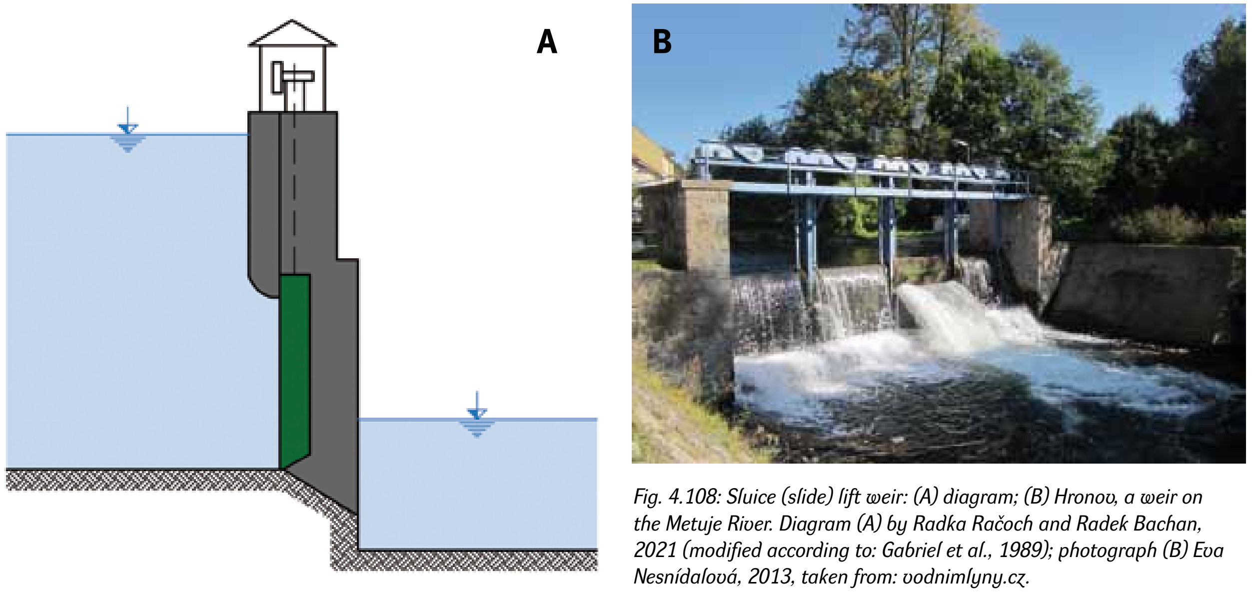


Fig. 4.108: Sluice (slide) lift weir: (A) diagram; (B) Hronov, a weir on the Metuje River. Diagram (A) by Radka Račoch and Radek Bachan, 2021 (modified according to: Gabriel et al., 1989); photograph (B) Eva Nesnídalová, 2013, taken from: vodnimlyny.cz.

4.3.3.2.2.4 Radial gate weirs

The basic characteristics of radial gate weirs is the rotary movement around the horizontal axis of pins which are situated considerably outside the damming element. The damming element is usually formed by part of the cylindrical surface. Water pressure is transferred from the damming area to the segment shoulders which are anchored in buttresses by means of pivot pins. Depending on the position of pin bearings, we distinguish between segments with bearings on the upstream side (shoulders are under tension) and on the downstream side (shoulders are under pressure). The radius of the cylindrical dam wall and the length of the shoulders depend mainly on the gate height. The radial gates can be divided, similarly to sluice gates, into lifting (see Fig. 4.109) lowering, with a flap in place and two-piece.

The lifting radial gates rest on the spillway sill edge and at the highest position they are raised above the water level. They are not suitable for a subtler control of water level in the weir basin but they are suitable for the transfer of sediments in gravel-carrying watercourses. The lowering radial gates allow a subtler control of the upper water level. The space required for putting them into operation is significantly smaller than in the case of sluice gate weirs. A flap or two-piece radial gate is used for a more precise control of the upper water level (Výbora and Podsedník, 1989).

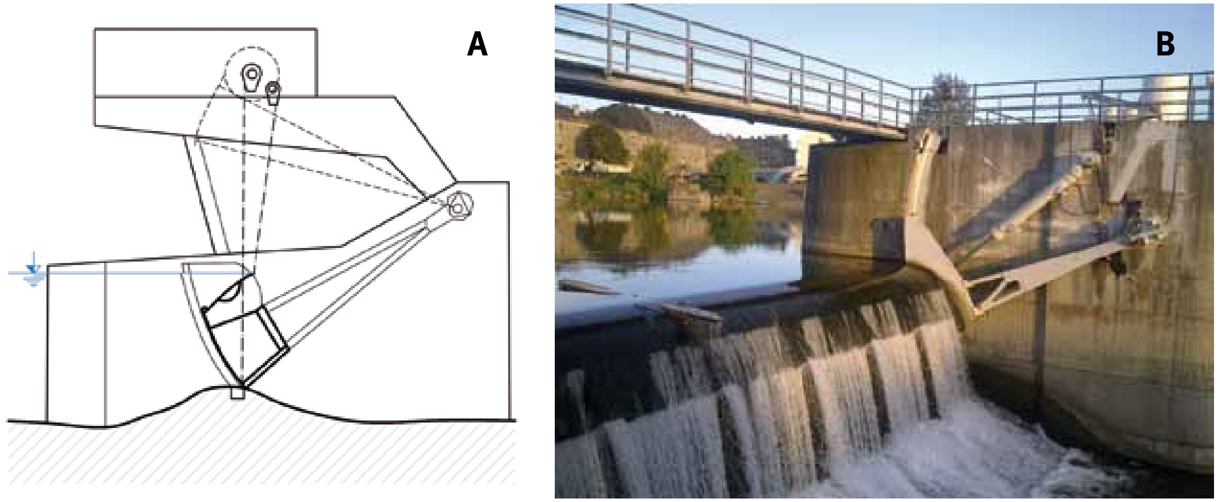


Fig 4.109: Radial gate weir: (A) diagram; (B) Přerov, a weir on the Bečva River. Diagram (A) by Radka Račoch and Michaela Mrvová, 2021 (modified according to Gabriel et al., 1989); photograph (B) from the Brno University of Technology archive, 2019.

4.3.3.2.2.5 Roller drum weirs

Roller drum weirs are characterised by their rolling movement of the damming element – a cylinder. The cylinder moves along a usually slanting route. The steel cylinder has toothed weirs at the ends which move in grooves. The movement of the damming body was first secured by means of steel ropes, later on, Gall's chains were used.

Roller drum weirs began to be built relatively late. The first roller drum weir was built only in 1901. Roller drum weirs can be divided into (Průcha, 1980):

- lifting, whose cylinders are of smaller dimensions than the required damming height, and a lower damming shield is attached to the cylinder (see Fig. 4.110);
- lowering, which are dropped below the overflow edge, and water is transferred primarily by the overflow which enables better control of the upper water level;
- with a flap in place, also for a better control of the upper weir basin water level.

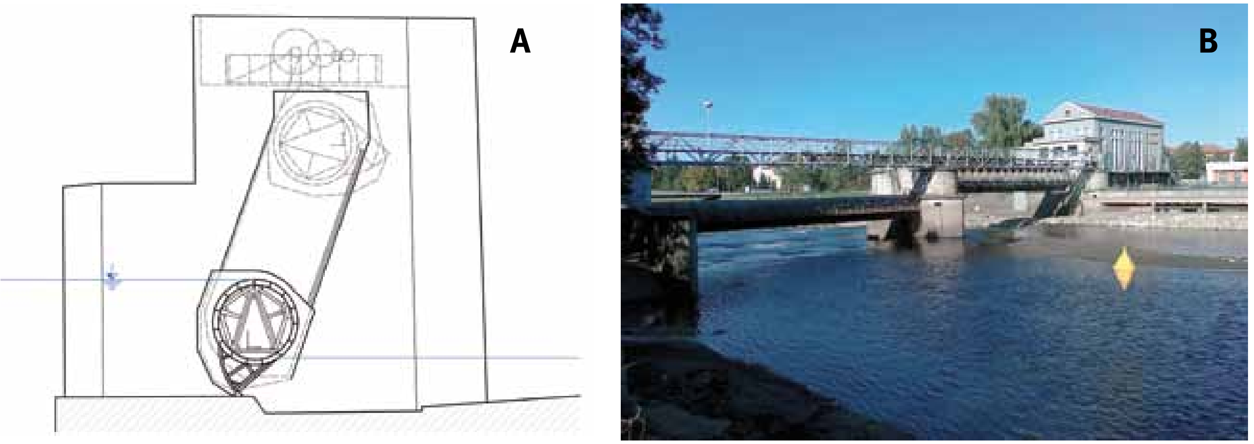


Fig. 4.110: Roller drum weir: (A) diagram; (B) České Budějovice, the Jirásek's weir on the Vltava River. Diagram (A) by Radka Račoch and Michaela Mrvová, 2021 (modified according to Průcha, 1980); photograph (B) from the Brno University of Technology archive, 2017.

4.3.3.2.2.6 Hydrostatic weirs

Hydrostatic weirs differ from other moveable weirs due to the fact that their movement (opening and closing) is based on the pressure change which influences the water level in the weir basin. The structure does not require any additional motion mechanisms. The hydrostatic weirs are characterised by a push chamber in the substructure. The push chamber is connected to both the upper and the lower basins by a pipeline. The control is done either automatically or manually by opening and closing check gates on the connecting pipes. The hydrostatic weirs can be divided according to their function and basic characteristics into (Jermář, 1956):

- shutter (double shutter, triple shutter or lifting),
- tilting,
- radial gate,
- sector,
- slide gate.

Double shutter hydrostatic weirs consist of a front cover shutter and a rear moving shutter. When tilting, the free end of the rear shutter moves along the lower surface of the front shutter. The push chamber is located under the shutters. **Triple shutter** systems divide the rear shutter into two joint parts. In Europe, however, this structural solution has been used very rarely.

Tilting weirs are made up of two shutters which form a compact body with the rotation axis on the overflow edge. The damming shutter is usually tilted slightly downstream. The lower moving shutter is located in the push chamber on the substructure. The space in the chamber in front of the moving shutter is connected to the upper basin, and the space behind the shutter to the lower basin.

The hydrostatic **radial gate** weirs are formed by a cylindrical damming surface, moving lower wall and upper overflow wall. Together they form a hollow body that rotates around the joint connection in the weir substructure at the level of the overflow edge. There is a push chamber in the substructure into which the radial gate tilts. Handling is ensured by adjusting the pressure in the push chamber.

A similar solution is used for **sector** weirs (see Fig. 4.111). In the case of the sector weir, the damming body does not have a lower moving wall. The water pressure acts on the overflow edge from its lower side. The structure is formed by a damming cylindrical surface and an overflow wall which also works as a moving wall. The sector weirs are the most common hydrostatic weirs. In our country, they are used, for example, on the Elbe waterway.

Sluice gate hydrostatic weirs are usually formed by a hollow panel which is inserted into the push chamber in the substructure. Water pressure loading is transmitted in the upright position to the vertical grooves in the buttresses in which the panel moves. They can be used as gates for spillways of higher weirs or dams.

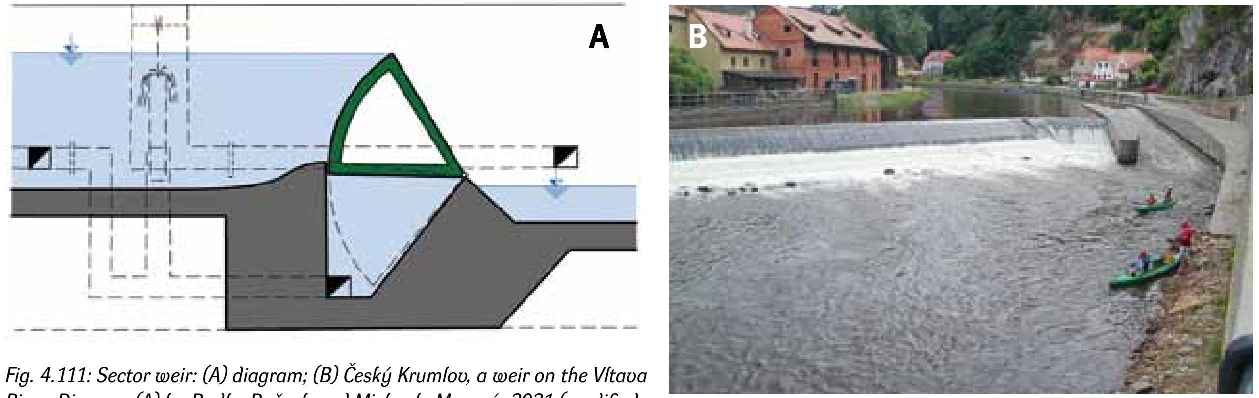


Fig. 4.111: Sector weir: (A) diagram; (B) Český Krumlov, a weir on the Vltava River. Diagram (A) by Radka Račoch and Michaela Mrvová, 2021 (modified according to: Jermář, 1956); photograph (B) from the Brno University of Technology archive, 2019.

4.3.3.2.2.7 Inflatable weirs

Inflatable weirs work on the principle of pneumatic structures which found their use in the building industry. The damming structure is formed by a bag made of rubber fabric filled with water (see Fig. 4.112). The bag is attached by means of stainless steel profiles with anchor bolts to the concrete substructure and buttresses. The gate body is handled by filling or emptying the bag. Filling can be carried out mechanically by means of pumps, but also automatically by means of e.g., a hydraulic ram. The advantage of this structure is low purchasing costs and the possibility of automating the operation of the weir (Průcha, 1980). The inflatable weirs have been built in the Czech Republic since the 1960. Their use spread rapidly and there are currently dozens of such types of weirs.

Fig. 4.112: Jihlava, an inflatable weir on the Jihlava River. Photograph from the Brno University of Technology archive, 2013.

4.3.4 FUNCTIONAL COMPLEXES

Within waterways, functional complexes can be observed based on several perspectives. Structures intended for navigation can fulfil their purpose only in conjunction with other structures and technical facilities. A functional complex can be observed in the longitudinal or transverse profile of the waterway. In the longitudinal direction, we are talking about, on a larger scale, the entire waterway – see diagrams Fig. 4.113, Fig. 4.114, Fig. 4.117, Fig. 4.118, in detail then one navigation level, which is equipped, however, not only with its own lock but also with other necessary structures in the upper and lower water (watercourse canalisation, port, lock cut before entering the chamber, etc.).

In the transverse direction, we refer to a grouping of structures in locations where height difference of levels is to be overcome. The basis is the weir itself, often with control devices to regulate the water level above it. The resulting difference in levels allows the energy use of water, whether directly on the weir body or via the inflow of impounded water into the race and its transfer to a place with higher hydraulic head.

At the same time, this functional complex may include other elements such as a watercourse overbridge or navigation facilities. Such multifunctional use can be illustrated on the example of a navigation lock in Poděbrady on the Elbe River. A similar solution is applied on most of the Elbe navigation locks as well as on the Vltava River in the section from Prague to Mělník. However, a similar functional complex arrangement derives from an earlier period. Weirs equipped with a basic wooden structure, inflow into the race that brings water to energy use in the mill and a sluice in the weir body for raft navigation are, in terms of functionality, identical to modern river navigation locks.

The mill races themselves are always part of functional complexes, and at the same time they can be multifunctional works, if they not only transfer water to the place where it is needed but are also used, for example, for timber floating.

4.3.4.1 Functional complexes of waterways in the longitudinal profile of watercourses

The evolution of possibilities considered concerning the navigability of our watercourses and their connection into the functional network, even in the transition over watersheds, can be traced back to the Middle Ages. In projects and studies focused on the navigability of certain sections of watercourses, the idea of completing this network in the future was also in the background, which influenced the parameters of the planned navigation route (Master Water Management Plan [SVP], 1971). This way of thinking can later be demonstrated, for example, on the lower Morava River, where the adjustments of the river were adapted from the 1920s to the idea of building a waterway connecting the Danube and the Oder Rivers.

The route demarcation was also influenced by the then political situation. In the times of the Austro–Hungarian empire, the idea of building a north-south connection between the Danube and the Oder Rivers was so tempting that on the Danube below Vienna we can see a several-hundred-metre-long diversion built in the north direction towards the Marchfeld (Morava Field) and the Morava near Lanžhot. After the establishment of independent Czechoslovakia, the Danube–Oder connection was considered from Bratislava. Independent Poland also lost interest in this connection and concentrated on inland waterways in the west–east direction (Polenka, 2019). Only now, as an EU member state, it shows interest in extending the navigable section of the Oder River at least to the Ostrava region so that the waterway could obtain the status of an international waterway and thus also receive support from EU funds. In the past, the prevailing idea was to connect the Czech lands to the Danube River with the route from the Vltava River through Šumava.

At present, only those sections and structures that allow continuous navigation can be considered as functional complexes in the longitudinal direction.

4.3.4.1.1 The waterway on the Elbe River

Currently, the section of the Elbe River from Střekov to Přelouč can be considered as a functional complex. The completion of two weirs with facilities that would improve navigation conditions in low water periods downstream below Střekov has been negotiated for a long time. Further building adjustments have also been prepared above

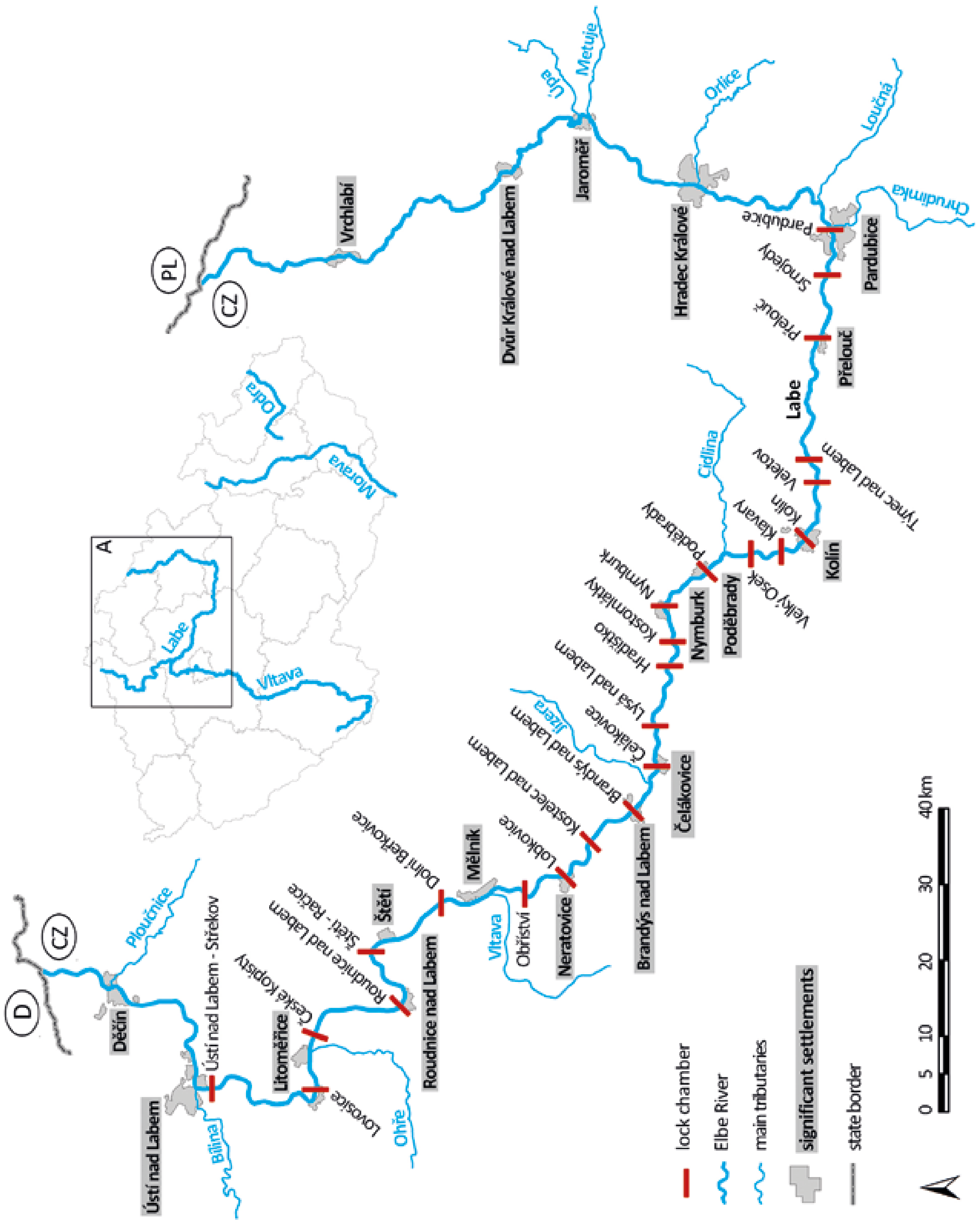


Fig. 4.113: The Elbe waterway. Diagram by Radek Bachan, 2021.

Přelouč so that a seamless waterway could be extended to Pardubice and beyond. See a schematic map in Fig. 4.113.

The current image and parameters of this waterway stem from 1896 when the Commission for Channelling the Vltava and the Elbe Rivers in Bohemia was established (Fošumpaur et al., 2020). The fairway is led mainly directly through the Elbe watercourse. During the building adjustments, the aspects that were taken into account included the protection of adjacent areas against floods, power generation in run-of-river hydroelectric power plants, provision of water abstraction for supplying the population, industry and agriculture. Therefore, all lock chambers and weirs, often with the possibility of regulating the water level upstream of the weir, should be included in waterway functional complex necessary structures.

The actual construction had already started at the turn of the 19th and 20th centuries, and although it lagged a little bit behind the turbulent development of waterways and navigation in England, France and Germany, as in these countries, it contributed significantly to the economic development of the Czech Republic.

4.3.4.1.2 The waterway on the Vltava River Cascade

The Vltava waterway has been navigated and maintained for rafting since the time of Charles IV. However, its modern form is associated with the construction of the Elbe waterway, and to this day, it has a similar character from the confluence with the Elbe to the dam of the Slapy reservoir. A unique part of this functional complex is the Vraňany–Hořín Navigation Canal, which is, together with its lock structures, heritage protected (see Fig. 4.116). Its construction was required due to the natural conditions of the Lower Vltava River and confluence with the Elbe. Fig. 4.114 shows the current state of the location. When comparing the aerial picture of this location from the period just after the construction of the canal (see postcards in Fig. 3.22) with today's state, we can see that the landscape conditions have not changed much.

Fig. 4.114: Mělník – the confluence of the Elbe, Vltava and lateral canal, view from the chateau. Photograph by Michaela Ryšková, 2021.

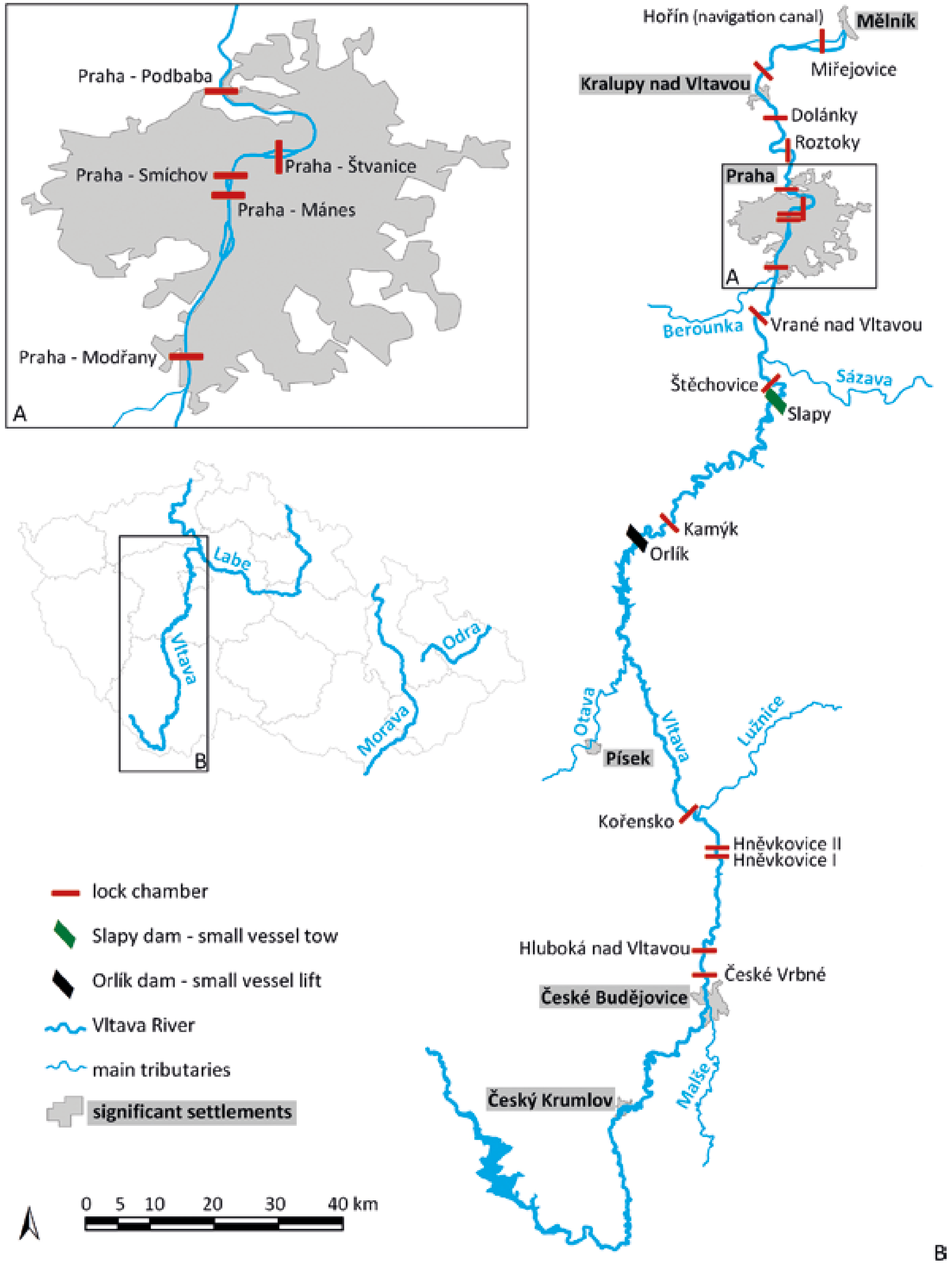


Fig. 4.115: The Vltava waterway. Diagram by Radek Bachan, 2021.

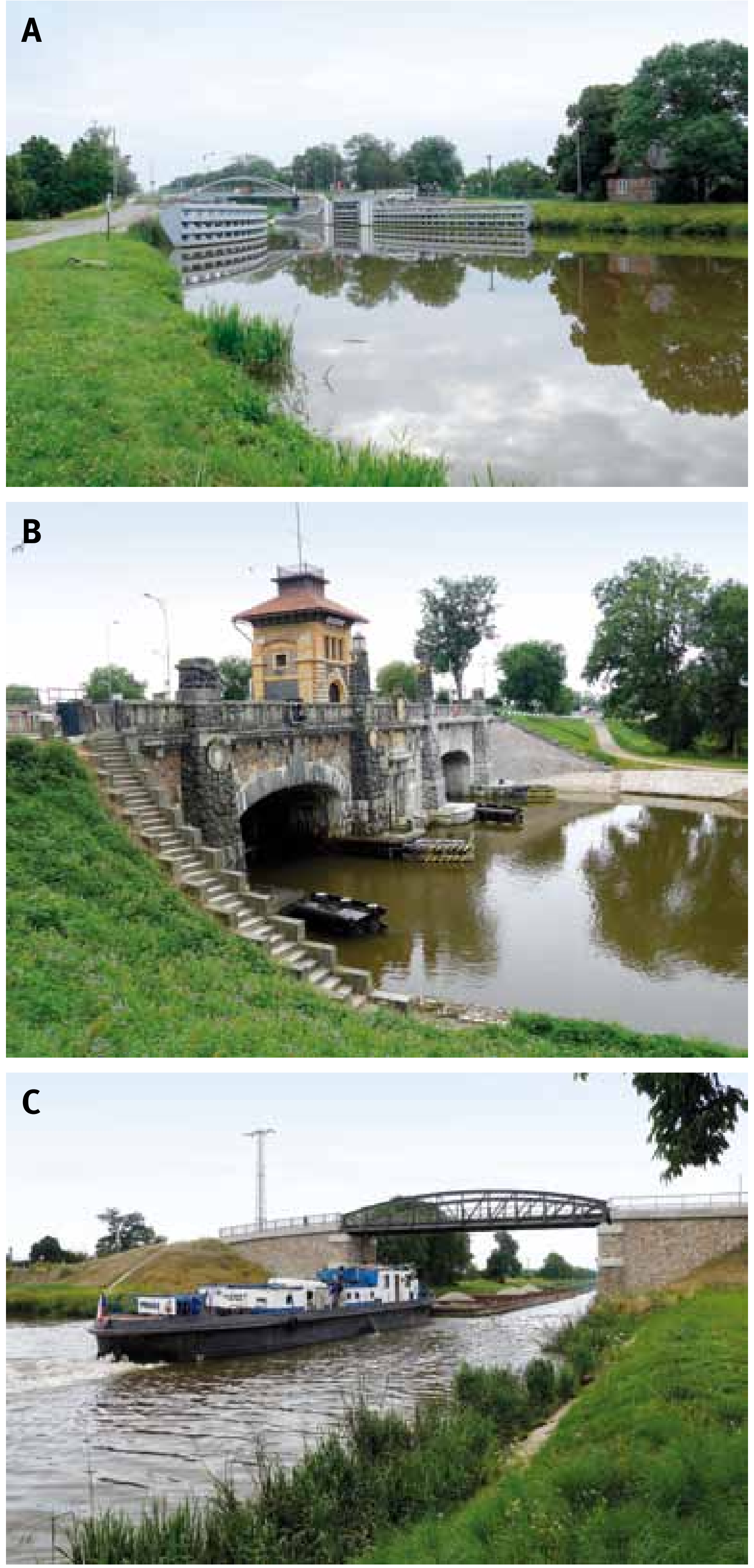


Fig. 4.116: The Vraňany–Hořín lateral canal: (A) Vraňany; (B) Hořín; (C) Chramostek, the canal overbridge. Photograph by Michaela Ryšková, 2021.

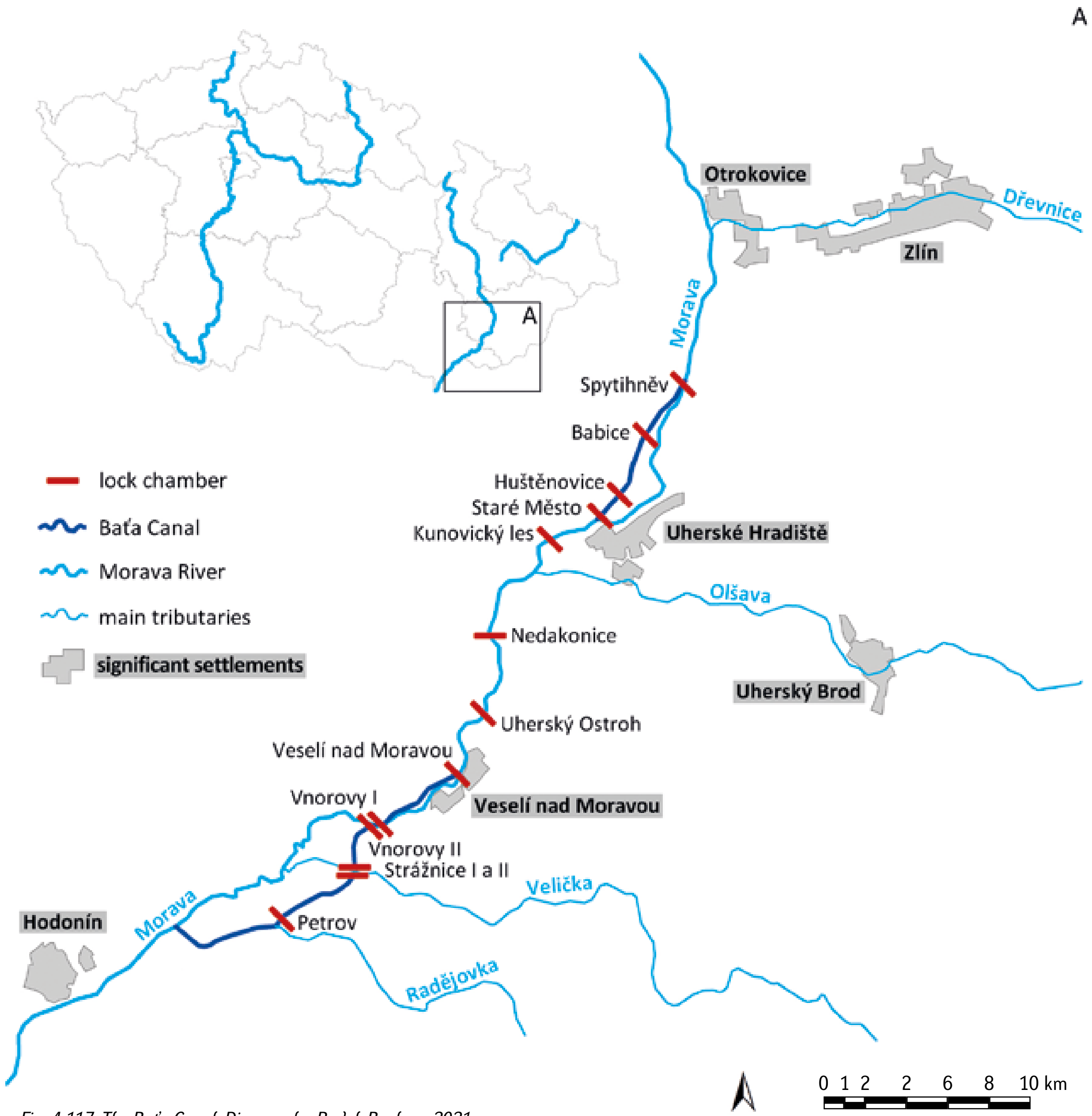


Fig. 4.117: The Baťa Canal. Diagram by Radek Bachan, 2021.

However, farther upstream, the Vltava section can no longer be included in the same functional complex due to the construction of dams collectively called the Vltava River Cascade. The navigational conditions of the individual dam reservoirs have, of course, improved significantly. However, as some structures have not been completed, a continuous navigation from České Budějovice to Mělník is not possible and therefore we cannot talk about a functional complex. Barriers in the navigation of larger vessels are the Orlík and the Slapy dams. At present, this waterway serves mainly for recreational purposes although there are still building works of some structures going on, which were already planned during the construction of dams. See a schematic map in Fig. 4.115.

4.3.4.1.3 The Baťa Canal

This waterway was built for a specific purpose – the transport of lignite from Ratiškovice to Otrokovice. In this respect, it can be considered a functional complex; the waterway was reconstructed in this section after 1990. The functional complex should also contain other associated structures and facilities which were built to fulfil the original purpose, such as the connection to the railway from Ratiškovice, preserved coal tipper structure and the entire solution of the port in Sudoměřice. At the other end of Otrokovice, the route continued along the artificial canal to the Baťa factories, where, apart from the Baťa port itself, there were also boatyards where boats were manufactured to be used for transportation on the canal. In contrast to Sudoměřice, the structures in Otrokovice are in complete dispair.

The purpose of the Baťa Canal is currently only recreational and tourist. From this point of view, it will be possible to consider another functional complex when the other planned locks are completed: at the Rohatec weir (on the Slovak side there is the port of Skalica) it will extend the waterway to Hodonín, and at the Bělov weir above Otrokovice it will extend the route up to Kroměříž.

4.3.4.1.4 The Váh waterway

For the sake of comparison, the waterway on the Váh River in Slovakia is also included here which was built almost simultaneously with the Vltava waterway and, given the two countries were at that time united, its concept was based on similar considerations to those in Bohemia. In spite of that, the character of this functional complex is different from the one on the Vltava River due to other natural morphological conditions. In both cases, the main purpose of the construction was energy use. While on the Vltava, the river cut into the massif made it possible to build valley reservoirs with relatively high dams, the gravel-carrying wild Váh in its wide alluvial plain required a different approach. Derivation channels were built from one river power plant to another, which shortened the watercourse and thus increased the energy potential of the river (Kučerý et al., 1969). At the same time, these canals were conceived as navigable, although they do not form one functional complex. Navigation locks are currently designed and reconstructed in several stages to make the waterway usable from the Danube to Žilina. The lower Váh is considered one of the options of the Danube-Oder Canal linking the Danube and the Morava Rivers.

Fig. 4.118: The lock chamber of Selice on the Váh River. Generated as 3D on Mapy.cz.

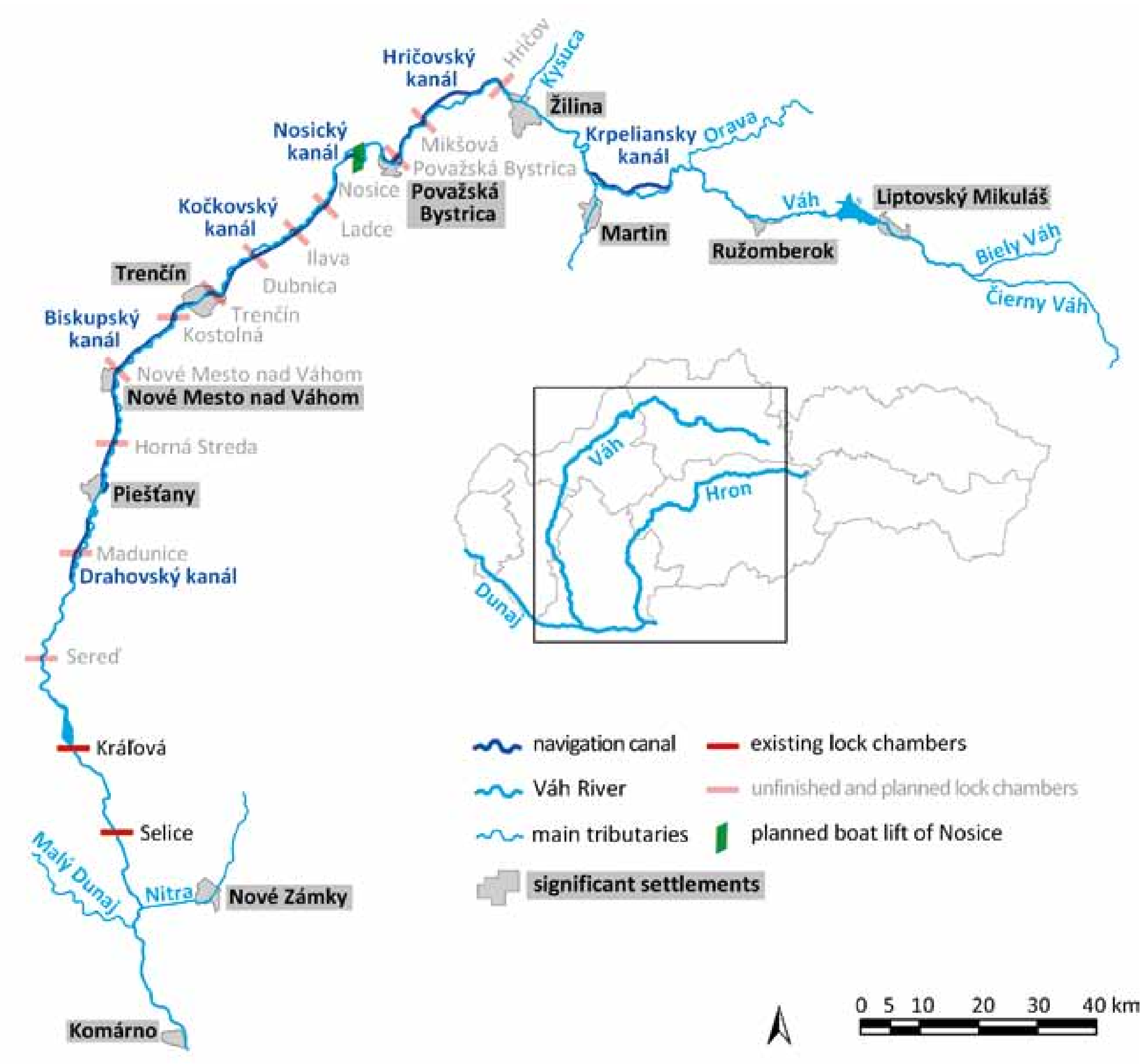


Fig. 4.119: The Váh waterway. Diagram by Radek Bachan, 2021.

4.3.4.2 Functional complexes of waterways in the watercourse transverse profile

4.3.4.2.1 The Poděbrady navigation lock

A typical example of a transverse functional complex on the Elbe waterway is the Poděbrady navigation lock. Individual elements of this functional complex are shown in Fig. 4.120. All the other navigation locks on the Elbe waterway also have similar functional arrangements, just some of them have a mirror reversed power plant on the right bank and a lock chamber on the left bank. In the section below Mělník, there are mostly two lock chambers next to each other.

Individual elements of the functional complex are interconnected: The first one was the canalisation of the river for a freeway which accelerated the river flow and brought about the need for calming it down. For this purpose, there was a weir designed and it was convenient to use the difference created in levels for power generation. The basic requirement – the river navigability – was made possible thanks to the construction of a lock chamber with facilities.

The next picture Fig. 4.121 shows the development of this locality over time. On the military mapping map (see Fig. 4.121 (B)), from the time before the construction of the navigation lock, the Elbe River near Poděbrady is a wide, meandering river with ford sections, side branches and earth banks in the trough. The situation after the construction is documented on a postcard from that period (see Fig. 4.121 (A)). By using part of the river branch as the lock chamber, an island, separating the weir with a power plant from the fairway, was created in the river.

The accessibility of transportation infrastructure is necessary for the control of the entire works. By comparing the current and previous states, it is clear that a wheelchair accessible footbridge has been built, which has a sufficient underpass height at the crossing with the fairway. Originally, the connection was provided at the lock chamber only by a service walkway on the gates but when the upper gate was open, accessibility was interrupted.

4.3.5 EVALUATION FROM THE POINT OF VIEW OF HERITAGE PRESERVATION BASED ON SPECIFIC EXAMPLES

4.3.5.1 Evaluation based on a specific example of a functional complex – the Poděbrady navigation lock

A uniquely preserved hydroelectric power plant with an authentic, yet functional technology and a very valuable architectural solution. It is one of the oldest locks in the Central Elbe River basin and also a valuable example of a technological and operational solution of this type of water construction. The hydroelectric power station is located in the south part of the town, on the left bank of the main channel opposite the chateau. The power plant building is partly situated on the bank and partly on the buttresses in the river bed, where it is followed in the north by a weir body with four control buildings (Monument catalogue, 2021).

EVALUATION OF THE PODĚBRADY WEIR

Temporal determination/date of origin: 1914–1915

Authorship: Eduard Schwarzer, architect Antonín Engel; construction company: Zdenko Kruliš, Adalbert Lanna, Jaroslav Hanauer, Vladimír Vlček, Karel Herzán (Industriální topografie)

Heritage preservation: cultural monument (2012), national cultural monument (2017)

Reconstruction: The reconstruction of construction and machinery equipment corresponds to the structure time of use and the gradual modernisation of some control devices. However, the reconstruction has not much influenced the original appearance of the structure and machinery.

Evaluation: The uniqueness lies in the combination of technical (types of gates) and architectural (buttresses, ma-

Fig. 4.120: The Poděbrady navigation lock – functional complex elements. Photograph by Radek Bachan, 2021.

chine rooms of gates, overbridge) solutions.

Typological value: Probably one of the oldest weirs with regard to the gate types and the weir structure architectural solution (there is no comprehensive database). The technology of damming by means of a Stoney-type sluice (slide) gates was used here for the first time in the area of the Central Elbe. The weir structure has been preserved and no major reconstruction has been required.

Value deriving from the technological flow: The construction is, together with a lock chamber and a small hydroelectric power plant, part of a technological complex.

Value deriving from systemic interconnections: The structure is an essential part of the Elbe navigation waterway.

Value deriving from authenticity: There are no records about major reconstructions of a weir body. Minor construction repairs can be expected, such as the masonry jointing and repairs/replacement of the damming element components.

Architectural value: Part of the architecturally uniform complex of a power plant and hydraulic structure. See summary evaluation.

Landscape/urban value: The structure strongly shapes the identity of the location and has an influence on the wider surroundings (watercourse adjustment and its surroundings, related transport structures – footbridge, cycle paths, recreation locality).

EVALUATION OF THE PODĚBRADY HYDROELECTRIC POWER PLANT

The hydroelectric power plant was built on the left bank of the Elbe trough, partially located on buttresses in the river bed with a connection to the weir body. The hydroelectric power plant is formed by a machine room and a control building. The four original Francis turbines supplied by the company Prokop a synové have been preserved.

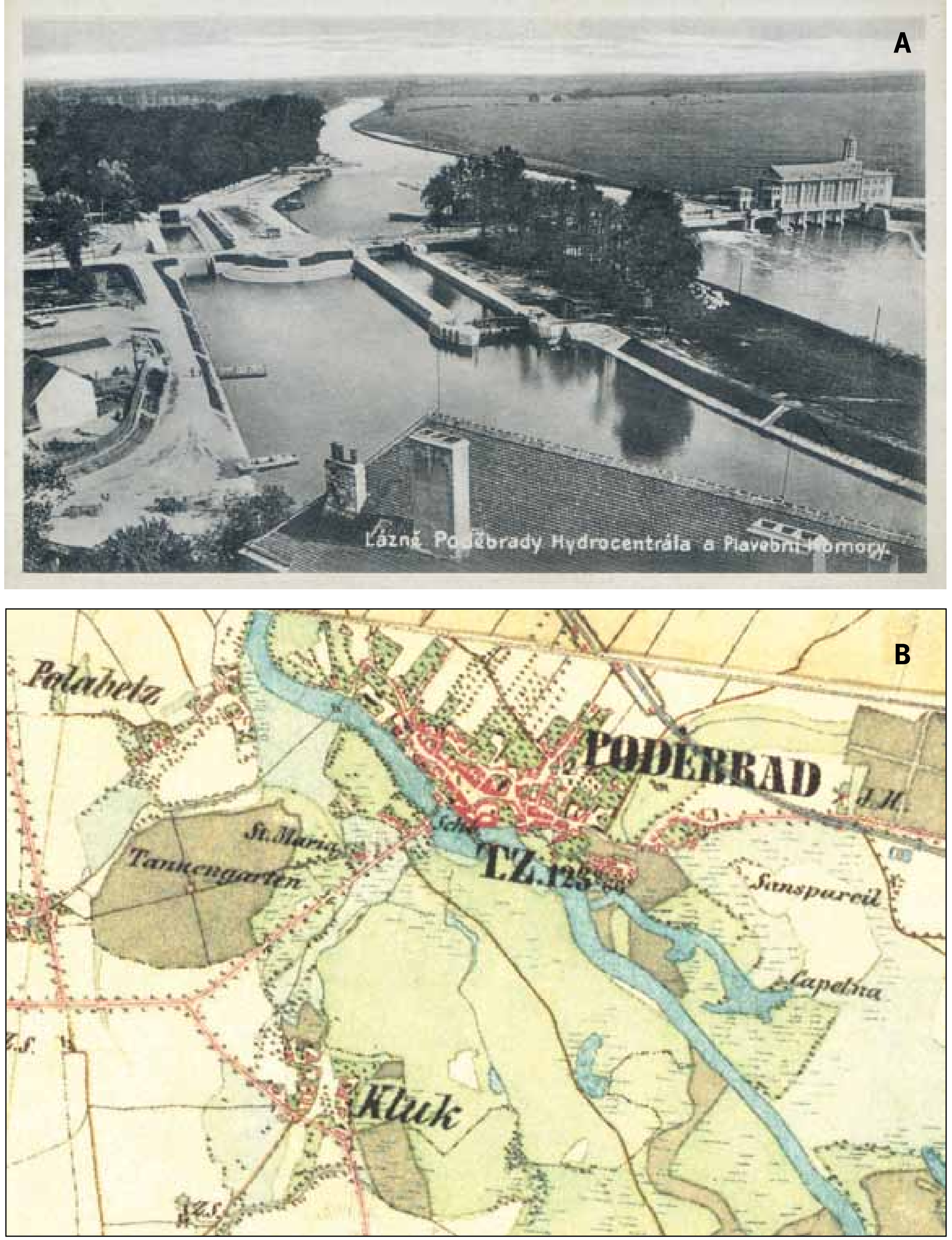


Fig. 4.121: Situation in the locality of the functional complex of the Poděbrady navigation lock: (A) state after the navigation lock construction, a postcard from that period; (B) natural state before the construction. Photograph (A) from Michaela Ryšková's collection; (B) the military mapping II, taken from: mapy.cz.

Fig. 4.121: Situation in the locality of the functional complex of the Poděbrady navigation lock: (C) weir and power plant. Photograph by Viktor Mácha, 2019.

Temporal determination/date of origin: 1914–1923
Authorship: Eduard Schwarzer, architect Antonín Engel; construction company: Zdenko Kruliš, A. Lanna, Jaroslav Hanauer, Vladimír Vlček, Karel Herzán; technology: electrical equipment – the company Křižík, machine parts – Českomoravská továrna na stroje Praha (First Czech-Moravian Machinery Factory in Prague), Bratři Prášilové Praha-Libeň (Prášil brothers in Prague-Libeň), Prokop a synové Pardubice (Prokop and sons in Pardubice), etc. (Industriální topografie, Zdymadlo a hydroelektrárna Poděbrady)
Heritage preservation: cultural monument (2012), national cultural monument (2017)

Evaluation:

Typological value:

- It is a typical representative of weir hydroelectric power plants implemented at the beginning of the 20th century.
- At the time of the construction, there was the first Kaplan turbine on the territory of the Czech Republic temporarily installed and tested in the hydroelectric power plant.

Value deriving from the technological flow: The hydroelectric power plant is part of the functional complex of the weir with a bridge and a lock chamber. The power plant supplies electricity to the public network.

Value deriving from authenticity:

- **Authenticity of function:** Preserved, the hydroelectric power plant serves its original purpose.
- **Authenticity of technical equipment:** Partially preserved. Original machine sets with Francis turbines are installed in the hydroelectric power plant; historic gears and generators were replaced. A new control workplace was established in the switch house; the original one has been preserved.
- **Authenticity of technological solutions:** Modern technological processes and materials were used during the repairs of technological equipment in order to ensure adequate operational reliability and durability. Some parts of the machine set were completely replaced (gears, generators, parts of regulation).

Architectural value: A complex consisting of a hydroelectric power plant and the associated hydraulic structure, which can be observed in the architectural morphology and monumental forms. The author of the architectural design was Antonín Engel, the author of the water treatment plant in Prague-Podolí (Švácha, 1995).

EVALUATION OF THE PODĚBRADY LOCK CHAMBER

The lock chamber is situated near the left bank, its usable dimensions are 85 × 12 × 3 m. In both the heads there are mitre gates located, controlled by hydraulic servo cylinders. Filling and emptying of the lock chamber is enabled by long side arch-profile culverts, which are controlled by hydraulic drive radial gates (PLA, 2021)

Time of creation: 1915–1924 (Industrial topography)
Authorship: type solution
Heritage protection: -
Reconstruction:
1976–1977 – 90 cm increase of the lock chamber; extension including new grooves of gates and grooves for replacement gates; wiring; installation of hydraulic drives for the control of mitre gates and radial gates; construction of a new control house; partial grouting of walls and masonry jointing.
1998–1999 – Re-jointing of the masonry of both walls and grouting of the left wall.
2005–2007 – Stone cladding of the lock chamber replaced by concrete panels; entries for outlet openings were left; space between panels is filled with fitting and cast concrete; reconstruction of electrical wiring; modernisation of the main switchboard and auxiliary switchboards on the heads; modernisation of the lock chamber control.

Evaluation:

Typological value: It is a typical representative of lock chambers on the Elbe–Vltava waterway.

Value deriving from the technological flow: The lock chamber is part of the functional complex of the weir with a bridge and a hydroelectric power plant. At the same time, it is an essential part of the functional complex of the Elbe waterway.

Value deriving from authenticity:

- **Authenticity of function:** Preserved, it serves its original purpose.
- **Authenticity of technical equipment:** The basic technical solution has been preserved since the works' creation; necessary maintenance and continuous modernisation of individual elements have been carried out.

Architectural value: Part of the architecturally uniform complex of a power plant and hydraulic structure. See summary evaluation.

SUMMARY EVALUATION OF THE FUNCTIONAL COMPLEX OF THE PODĚBRADY NAVIGATION LEVEL

Time of creation: 1914–1923 (1924) (Industrial topography), new footbridge 2002
Authorship: see above; footbridge: PONTEX s.r.o. and JHP spol. s.r.o.
Heritage preservation: small hydroelectric power plant and weir – cultural monument (2012) and national cultural monument (2017), lock chamber without heritage protection

Evaluation:

Typological value: It is a typical representative of structures of the functional complex on the Elbe–Vltava waterway.

Value deriving from authenticity:

- **Authenticity of function:** The functional complex serves its original purpose.
- **Authenticity of technical equipment:** The basic technical solution has been preserved since the time of construction.

Architectural value: A complex consisting of a hydroelectric power plant and the associated hydraulic structure, which can be observed in a uniform architectural morphology and monumental forms, characteristic of the author's works – architect Antonín Engel, student of Otto Wagner, the author of the water treatment plant in Prague-Podolí (Švácha 1995).

The footbridge built in 2002 bears the award of an excellent concrete structure – Mostní dílo (Bridge Work) 2002. It has 13 sections with a total length of 122 m and the main section from prestressed concrete over the navigation canal has a span of 31 m. This section is supported by a steel strut frame and thus forms a coupled steel-concrete cross-section.

Landscape/urban value: The evaluated functional complex strongly shapes the identity of the location and has an influence on the wider surroundings (watercourse adjustment and its surroundings, related transport structures, , protection against floods, recreation use). The value of the functional complex was also increased by a new footbridge for pedestrians and cyclists, which made the functional complex and the island of Elbe available to the public. The functional complex is in immediate vicinity to the urban conservation zone declared in 1992 and, for example, from the road bridge it creates a panorama with the Poděbrady chateau.

4.3.5.2 General summary of the principles for the evaluation of waterways

The term "waterway" can be used when speaking about rafting for timber transport on the Elbe River from the Giant Mountains to Kutná hora and on the Vltava River from Šumava to Prague from the 16th century. This activity did not require major modifications of the trough (except for local interventions such as the blast of dangerous rocks in St John's Rapids on the Vltava River) or any special water management buildings (except for log chutes). From the point of view of this methodology, this historic period is of negligible importance, as technical interventions related to it have not been preserved in most cases.

This does not apply to lock chambers for timber transport in Šumava (Schwarzenberg Navigation Canal, Vchynice-Tetov Navigation Canal and Kaplický Brook Navigation Canal near Lenora). Mountain rivers full of boulders could not be used for the timber transport, therefore these remarkable technical works, preserved to this day, were built, which are, thanks to the sensitive integration, of excellent landscape value.

In addition, we cannot forget long linear works, whose transport significance lay in the fact that the "commodity transported" was the water itself. In the case of the Blatná Canal in the Ore Mountains and Dlouhé stoky in the Slavkov Forest, they served technological needs and as the drive equipment of ore mines, while the Zlatá stoka (Golden Canal) in the Třeboň region and the Opatovice Canal in Pardubice supplied a large-scale pond system with water. At first glance, these water works hardly differ from natural watercourses, and their landscape value is high, albeit often discreet. Many of them are part of town urban structures, such as the Golden Canal in Třeboň, which flows along the town walls and its urban importance is not negligible.

A real waterway was built between 1894 and 1936 on the Lower Vltava and the Elbe between Prague, Mělník and Střekov (where it is followed by a naturally navigable river) and on the Central Elbe. The work consisted mainly in water impoundment by a system of needle gates and in partial regulation of the trough, the course of which was stable for a long time. The intervention in the existing image of the river landscape consisted mainly in river canalisation, when the rise of water between locks enabled easy navigation in both directions. Between 1902 and 1905, the waterborne transport on the Lower Vltava River was transferred to the newly built lateral canal Vraňany–Hořín.

The most important water management structures on this waterway are locks, some of which are of very high architectural quality (Hořín, Poděbrady, Miřejovice, Střekov, etc.), and some of them included hydroelectric power plants from their creation (others only later). They are located mostly in the open countryside or on the outskirts of settlements and their landscape value is high. The section from Lovosice to Mělník is less significant; there were the original locks replaced between 1966 and 1973 by new ones without any major construction necessary (except for Štětí).

The Central Elbe between Mělník and Pardubice was navigated gradually from 1908. The system of locks (mostly with power plants) between Mělník and Přelouč from the first third of the 20th century represents mostly excellent architectural works from modernism to functionalism, designed by leading architects. Those located in the open countryside (Kostelec nad Labem) have a significant landscape value, one reason for this is because they represent an obvious civilisation quality on an otherwise featureless plain. On the entire Central Elbe up to Jaroměř, it was necessary to divert the river in almost its whole course into a new straightened trough, whose landscape value is problematic.

Many of the locks are located directly in towns (Brandýs nad Labem, Nymburk, Poděbrady, Kolín), often in visual contact with the main town landmarks, which gives them an extraordinary urban value. The afore-mentioned cases are iconic buildings from the point of view of these towns and co-create their identity.

The regulation on the Lower Morava River began in 1905, progressed very quickly, and was practically completed between Kroměříž and Hodonín already in the 1930s. Here, the result was also a featureless canalised river, whose landscape value is incomparably lower to the original meandering watercourse. The shortening of the watercourse and the acceleration of the outflow fundamentally influenced the water regime due to the decline in groundwater level and the Lower Morava Valley began to suffer from drought. From 1927, the construction of an irrigation system with races was therefore prepared, which was used by Jan Antonín Baťa in 1934 to build a system that would also allow the transport of lignite from the mine in Ratíškovice to the power plant in Otrokovice. The water management structures on the Lower Morava and the Baťa Canal are often of very high architectural quality and their landscape value is indisputable.

4.3.6 REGISTER OF LOCATIONS

Name	Protected from	Type of protection	USKP registry number	Item name according to the Monument catalogue	District	Municipality	Cadastral territory
weir – Vltava km 208.9 water mill – Královcův mill	05/03/2015	CM	105633	water mill and weir	České Budějovice	Týn nad Vltavou	Hněvkovice near Týn nad Vltavou
Dyje weir km 128.5 – Na hrázi weir	03/05/1958	CM	48858/7-8257	weirs	Znojmo	Znojmo	Oblekovice
Dyje weir km 130.7 Loucký weir	03/05/1958	CM	48994/7-8397	weirs	Znojmo	Znojmo	Znojmo-Louka
Dyje weir km 173	03/05/1958	CM	48950/7-8350	weirs	Znojmo	Vranov nad Dyjí	Vranov nad Dyjí
weir – Moravská Dyje water mill – Loucký mill	03/05/1958	CM	25225/3-2208	Loucký mill with a weir and a race	Jindřichův Hradec	Staré Hobzí	Staré Hobzí
Poděbrady weir	27/09/2012 01/07/2017	CM NCM	104923 415	hydroelectric power plant hydroelectric power plant in Poděbrady	Nymburk	Poděbrady	Poděbrady
Vltava weir km 317.9	02/02/1998	CM	49617/3-6145	weir with a log chute	Český Krumlov	Vyšší Brod	Vyšší Brod
Vltava weir km 325.4 Spirův weir	06/11/2012	CM	104928	Huber Lutz weir	Český Krumlov	Loučovice	Loučovice
Horní Slavkov drainage gallery	28/05/1990	CM	44327/4-4523	other mining structures – drainage G. Pflug's hereditary gallery	Sokolov	Horní Slavkov	Horní Slavkov
drainage tunnel of Lukavice pyrite mines	03/05/1958	CM	38435/6-4624	other mining structures – pyrite mines drainage gallery	Chrudim	Lukavice	Lukavice
Staré Sedlo drainage gallery	08/12/2000	CM	50715/4-5221	John the Baptist hereditary gallery – mouth with supporting wall and drainage gallery in the length of 950 m	Sokolov	Staré Sedlo	Staré Sedlo near Sokolov
navigation canal – Rajnochovice timber rafting dam	03/05/1958	CM	27448/7-6118	timber rafting dam	Kroměříž	Rajnochovice	Rajnochovice
Český Jiřetín navigation canal	03/05/1958	CM	42649/5-5081	navigation canal	Most	Czech Jiřetín	Czech Jiřetín

Name	Protected from	Type of protection	USKP registry number	Item name according to the Monument catalogue	District	Municipality	Cadastral territory
Dlouhá stoka navigation canal	21/11/2003	CM	100490	Dlouhá stoka navigation canal	Cheb	Mariánské Lázně	Mariánské Lázně
Horní Vltavice navigation canal	26/04/2013	CM	105084	navigation canal of Kaplický Brook	Prachatice	Horní Vltavice	Horní Vltavice
Vchynice–Tetov navigation canal	03/05/1958	CM	26816/4-3299	Vchynice–Tetov navigation canal	Klatovy	Srní	Vchynice-Tetov I
Vraňany–Hořín navigation canal	03/05/1958	CM	33582/2-3683	Vraňany–Hořín navigation canal	Mělník	Vraňany	Vraňany
Schwarzenberg navigation canal	03/05/1958 01/10/2014	CM NCM	14743/3-3714 380	Schwarzenberg navigation canal	Prachatice	Nová Pec	Nová Pec
Blatná water ditch, water canal	03/05/1958 01/07/2017	CM NCM	21605/4-4149 417	Blatná water ditch	Karlovy Vary	Horní Blatná	Horní Blatná
Imperial millrace in Pardubice, water canal	05/03/1964	CM	45666/6-2010	feeder – Imperial millrace, with bridge	Pardubice	Pardubice	Pardubice
Dlouhá strouha in Kvasiny, water canal	03/05/1958 01/10/2014	CM NCM	25190/6-2320 383	feeder – Dlouhá strouha	Rychnov nad Kněžnou	Kvasiny	Kvasiny
Millrace in Doksy, water canal	03/05/1958	CM	23655/5-2884	mill race with a dam	Česká Lípa	Doksy	Doksy near Mácha Lake
Mouse hole in Litice nad Orlicí, water canal	03/05/1958	CM	22296/6-4026	feeder, a tunnel called Mouse hole	Ústí nad Orlicí	Záchlumí	Litice nad Orlicí
Opatovice water canal	03/05/1958	CM	25076/6-4411	Opatovice water canal	Pardubice	Opatovice nad Labem	Opatovice nad Labem
Plchovice water canal	31/05/2005	CM	101535	irrigation water canal	Ústí nad Orlicí	Plchovice	Plchovice
Počaply water canal	03/05/1958	CM	17351/6-2033	Počaply water canal	Pardubice	Sezemice	Počaply nad Loučnou
River race in Chrudim, water canal	01/11/1990	CM	44991/6-4751	feeder – river race	Chrudim	Chrudim	Chrudim
Strouha (Alba) in Častolovice, water canal	03/05/1958	CM	41404/6-2239	water canal called Struha or Alba	Rychnov nad Kněžnou	Častolovice	Častolovice

4.4 STRUCTURES FOR THE USE OF HYDROPOWER

4.4.1 THE HISTORY OF HYDROPOWER

Our ancestors were dealing with the necessity of transporting water to requisite places and ensuring the necessary supply of energy for the operation of technical and agricultural equipment as early as prehistoric times. From the outset, manpower or animal power was needed for the operation of wheels or subsequently screw conveyors for pumping water. Later on wind power was used and much more stable hydropower was harnessed via water wheels. The use of wheels powered by water to pump water was described in the 1st century BC by the Roman architect Vitruvius, and according to unverified sources the paddle wheel was invented by the ancient Greek mathematician and physicist, Ctesibius, in 135 BC (Bednář, 2013). At the outset of Christianity waterwheels started to be used for powering mills, firstly in the Middle East and subsequently in Europe. In the period 260–300 AD there was, for example, a water wheel complex near the town of Arles in France (Nechleba, 1962). The first written record concerning the use of a water wheel in our lands, specifically concerning the watermill in Únětice near Prague, comes from 1125 (Bednář, 2013). According to Pažout (1990), however, a water-driven mill existed on the Ohře River near Žatec, the first one of its kind in Central Europe. In addition to water mills, water wheels were also used for the operation of sawmills, the oldest of which was known to operate in Asia Minor in the 3rd century. In the Czech lands, the first saw mill appeared at the earliest in the second half of the 13th century, or more likely in the 14th century. This period also saw the spread of hammer mills, both for ironware and tools production. Generally during the Middle Ages small but not insignificant developments occurred as well as the spread of use of hydropower. In the 14th century, the much more efficient bucket wheel was added to the paddle wheel, into which water flowed from above.

From the early modern age, crucial development of water motors occurred with regard to not only the improvement of existing types but the invention of new ones. The use of waterwheels enhanced by the dynamic impact of water jets started in the 17th century. In the 18th century, the enhancement of theoretical and empirical based development in the use of hydropower took place. After 1750 Leornard Euler and Daniel Bernoulli laid the theoretical foundations for the construction of water turbines and pumps.

Turbines were brought into use at the start of the 19th century and gradually greater efficiency, operational parameters, regulation, improvement of technology and design occurred. In 1835 Frenchmen Bourdin and Fourney designed and brought into operation the first centrifugal turbine. One of the oldest types was the Jonval turbine invented in 1837 in France (ASME, 1999), which was used from the 1840s to the start of the 20th century (Malá voda, 2021). From later developed machines, the most significant turbines were designed by Francis, Girard, Pelton, Bank and Kaplan. The Francis turbine, nowadays the most widespread type (ASME, 1975), was designed by an Anglo-American engineer James B. Francis at the end of the 1840s based on the previous types of water turbines. Its development, based on the modifications of the turbine runner blades, took place until the end of the 1920s (Lewis et al., 2014) when this turbine replaced the Girard turbine. This turbine was developed in 1863 and was most widely used in the period from the 1890s (Malá voda, 2021). Another type of turbine was developed in the 1870s by an American engineer and inventor Lester A. Pelton, who had it patented but sold the rights at the end of the 1880s. Production of the Pelton turbine at the end of the 19th century skyrocketed. Products from the production plants in San Francisco and New York were exported all over the world (SFPD, 2012). In 1913 an Austrian professor at a German university in Brno, Viktor Kaplan, made a proposal for a turbine with tilting turbine runner blades (Bednář, 2013). The first piece was produced by a Brno company, Ignác Storek, in 1919. Another prototype was shortly afterwards installed and made operational at a hydroelectric power plant in Poděbrady and the Kaplan turbine started, because of its efficiency and reliability, to be used in our country and abroad. Among other types we can mention the Bánki-Michell turbine, which was theoretically invented by an Australian engineer Anthony Michell in 1903 and for practical use was upgraded by a Hungarian professor Donát Bánki (Popescu et al., 2017).

4.4.2 BASIC SCHEMES OF HYDROPOWER WORKS

Description of the main parts and patterns of the arrangement of hydropower works stems primarily from the core literature from the field of the use of hydropower and applicable standards (especially Broža et al., 1990; Hynková, 1985, 1984; Kratochvíl, 1956; Štoll et al., 1977; Čábelka, 1958, 1959).

In general, every hydraulic structure intended for the use of hydropower has the following main parts (Broža et al., 1990; Čábelka 1958):

- **impoundment structure,** formed by a dam or a weir;
- **inlet structure** with facilities (gates, racks, scumboard, etc.), to which a settling tank is attached to collect sediments if necessary;
- **headrace** (with corresponding gates and structures, such as an inverted siphon or an aqueduct) which can be free-surface (race, canal, free water level shaft) or pressure (shaft, gallery, pipeline);
- **production structures of hydroelectric power plants** (machine room, operation buildings, switch house) with facilities;
- **tailrace** (open channel, free water level or pressurised shaft);
- **operational and safety equipment** (gates, synchronous valves, surge chamber, regulating chamber, rack cleaning machine, ice pass, etc.);
- **special equipment when a hydraulic structure is a complex works** (lock chamber, boat lift, fish pass, intake structure, etc.).

Based on the local conditions, not all of the above parts are necessarily required to be included in the specific scheme of each hydropower works. According to the constructional-technical solution of the hydropower use in a certain watercourse section, the schemes of hydropower works can be divided into four basic groups:

A. **Impoundment** schemes (see Fig. 4.122), where the hydraulic head, and also the flow, is concentrated through an impoundment structure, i.e. by a weir or a dam. These schemes are common mainly in the case of rivers with a small longitudinal slope of river bed and high flows;

B. **Diversion** schemes (see Fig. 4.123) where the hydraulic head is concentrated through free-surface or pressure derivation. The term derivation is used to mean such a water conduct which enables, due to its directional and slope conditions, to reach minimum hydraulic losses and thus the maximum concentration of the usable hydraulic head. The slope of the derivation is usually much smaller than the slope of the river bed. These schemes are common mainly in the case of rivers with a greater slope of the river bed;

C. **Dam-derivation** schemes (see Fig. 4.124) where the hydraulic head is obtained by both the impoundment structure (dam) and derivation (by means of a headrace or tailrace). Such schemes are common in the case of watercourses with a greater longitudinal slope and smaller flows;

D. **Pump** schemes (see Fig. 4.124), where the concentration of the hydraulic head and the degree of accumulated flow does not depend on the watercourse wateriness. The hydraulic head and flow values are determined by the need for peak power in the electrical system and by the volume of excess basic energy in daily and weekly cycles, and at the same time they are conditioned by the morphology of the territory.

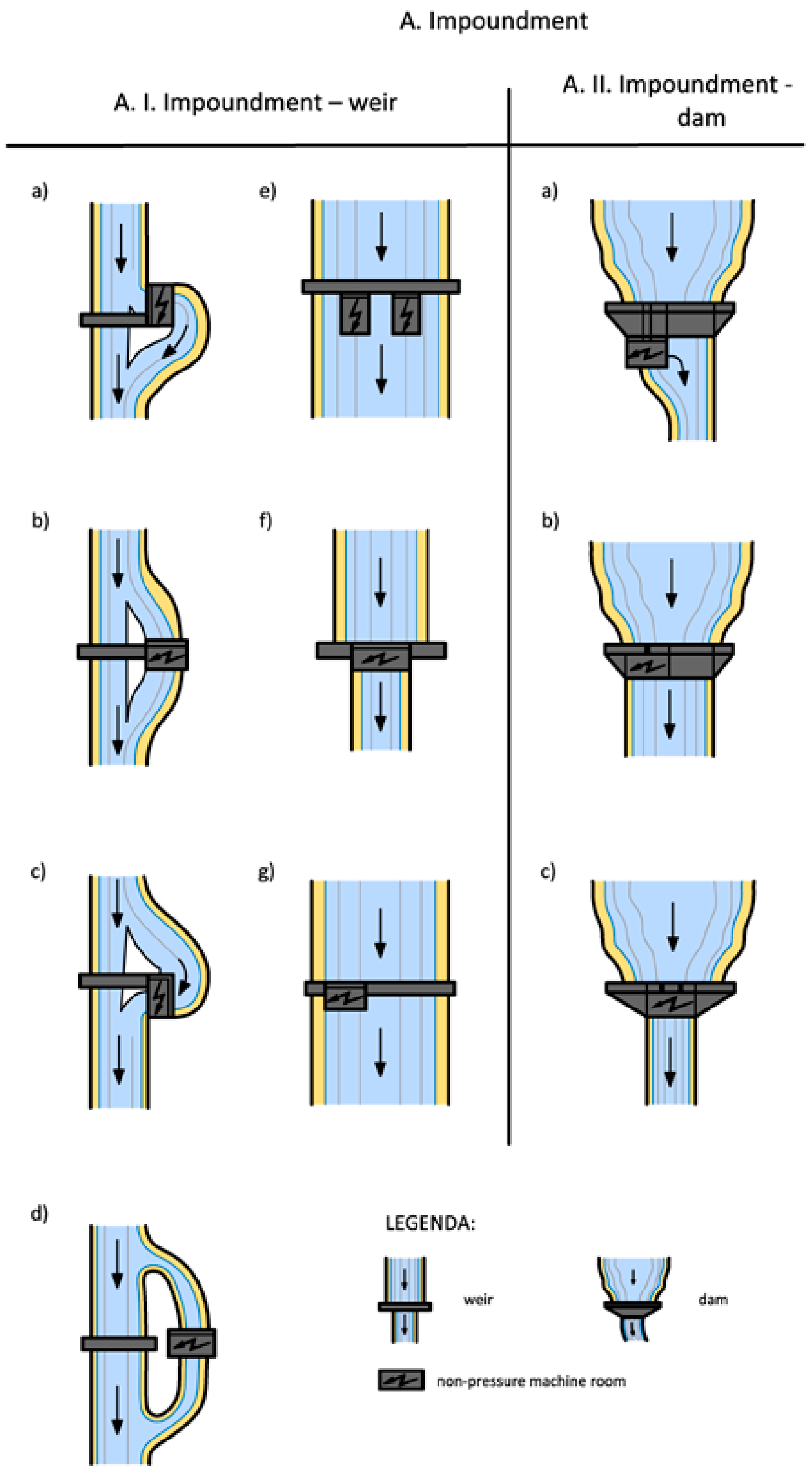


Fig. 4.122: Impoundment scheme of hydropower works. Diagram by Radka Račoch and Radek Bachan, 2021 (modified according to: Broža et al., 1990; Čábelka, 1958).

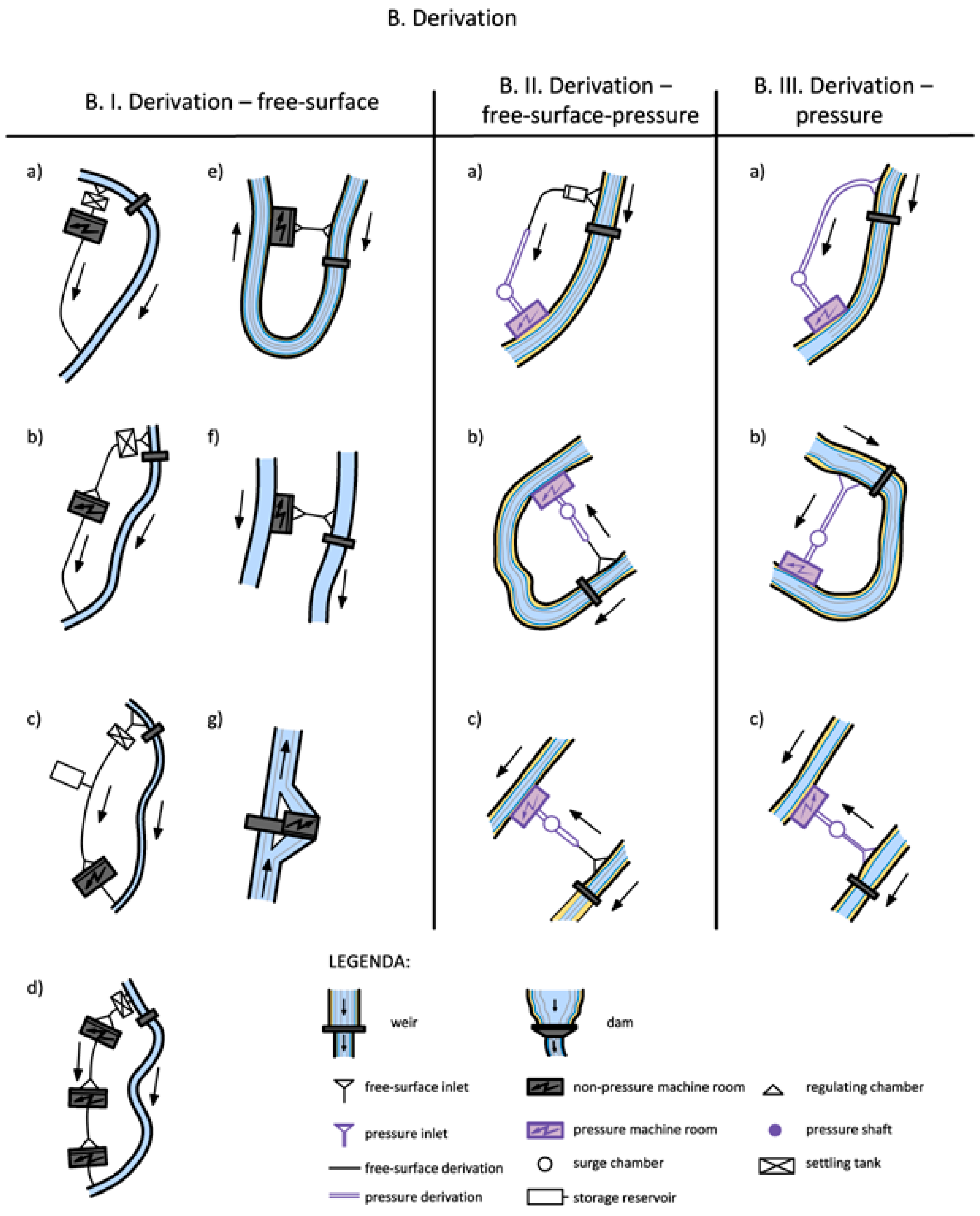


Fig. 4.123: Derivation schemes of hydropower works. Diagram by Radka Račoch and Radek Bachan, 2021 (modified according to: Broža et al., 1990; Čábelka, 1958).

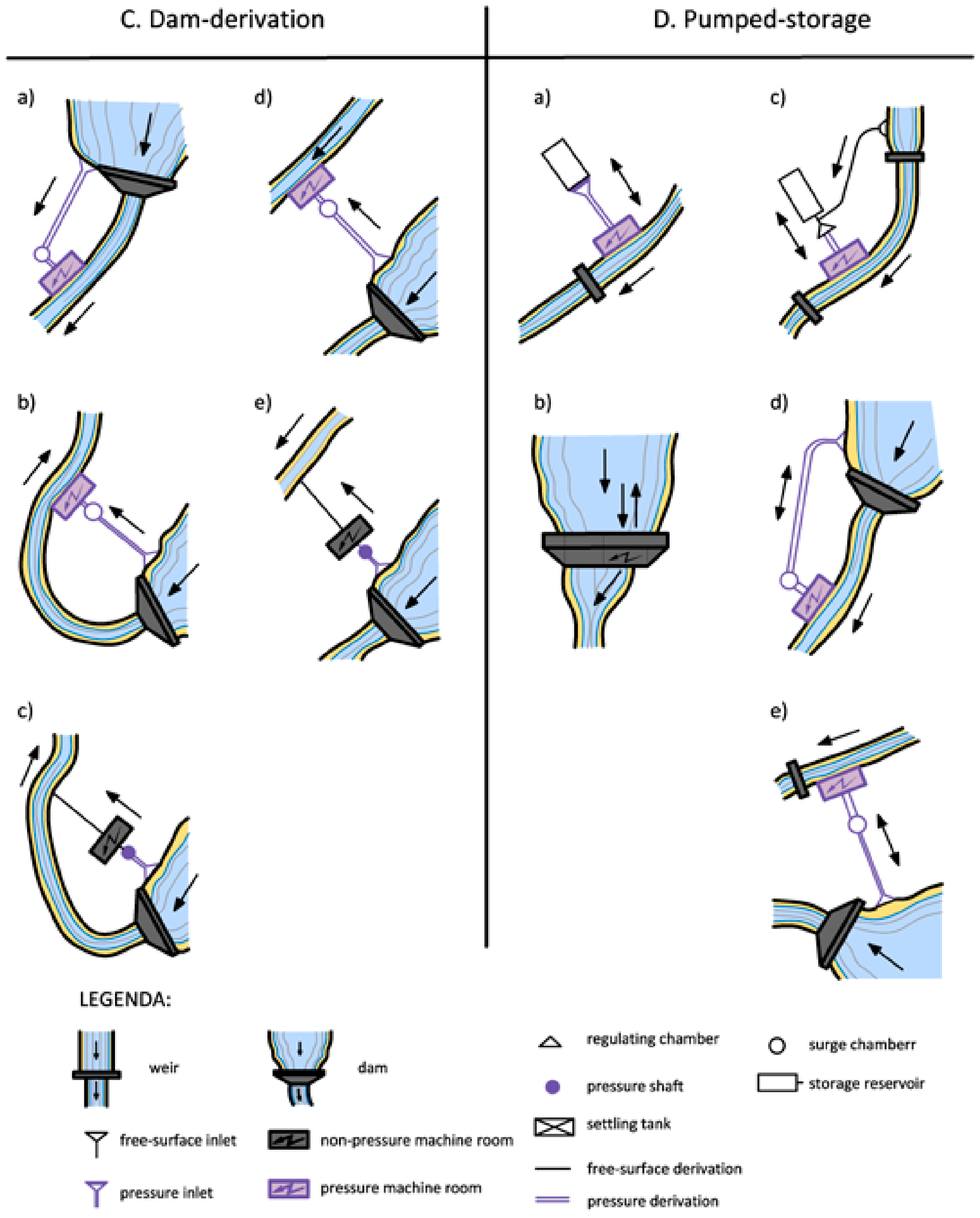


Fig. 4.124: Dam-derivation and pump schemes of hydropower works. Diagram by Radka Račoch and Michaela Mroová, 2021 (modified according to Broža et al., 1990; Čábelka, 1958).

4.4.2.1 Impoundment schemes

Impoundment schemes (see Fig. 4.122) can be further divided into weir and dam ones. A weir hydroelectric power plant (see A.I in Fig. 4.122) is usually located in close proximity to an impoundment structure, or directly in its body. A headrace and tailrace are short or completely missing. The power plant machine room may be located:

- on a short headrace (see the small hydroelectric power plant in Miřejovice in Fig. 4.125);
- just next to a weir as a river-side hydroelectric power plant while the building of the power plant can be turned upstream or downstream, or it is directly adjacent to the weir (see e.g. small hydroelectric power plant in Hradec Králové – Hučák, in Nymburk, in Poděbrady in Fig. 4.128 and Fig. 4.129);
- directly in the weir body, either in its buttresses as a buttress hydroelectric power plant, or under the overflow as an overflow power plant, or combined as a block hydroelectric power plant.

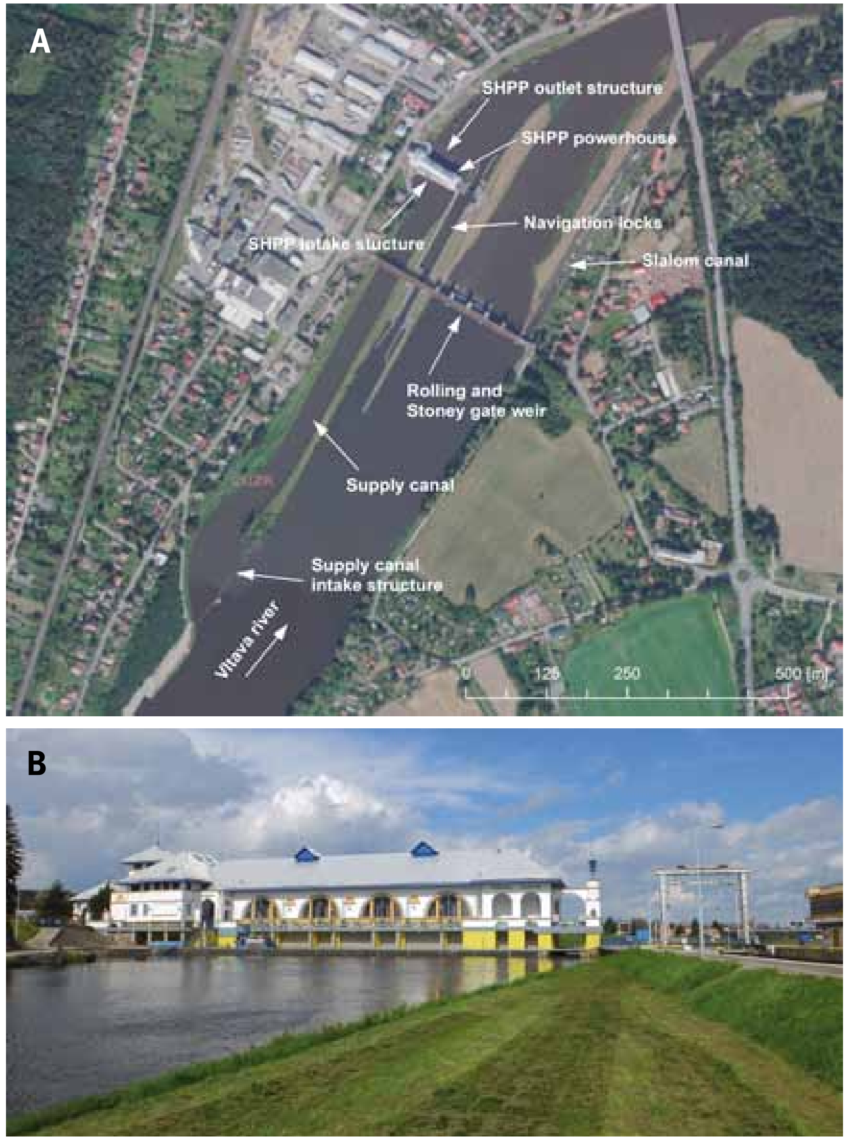


Fig. 4.125: Miřejovice SHPP on a short headrace: (A) diagram; (B) a view of the inlet part. Diagram (A) created on the basis of the ČÚZK data, 2021; photograph by Brno University of Technology, Faculty of Civil Engineering, 2014.

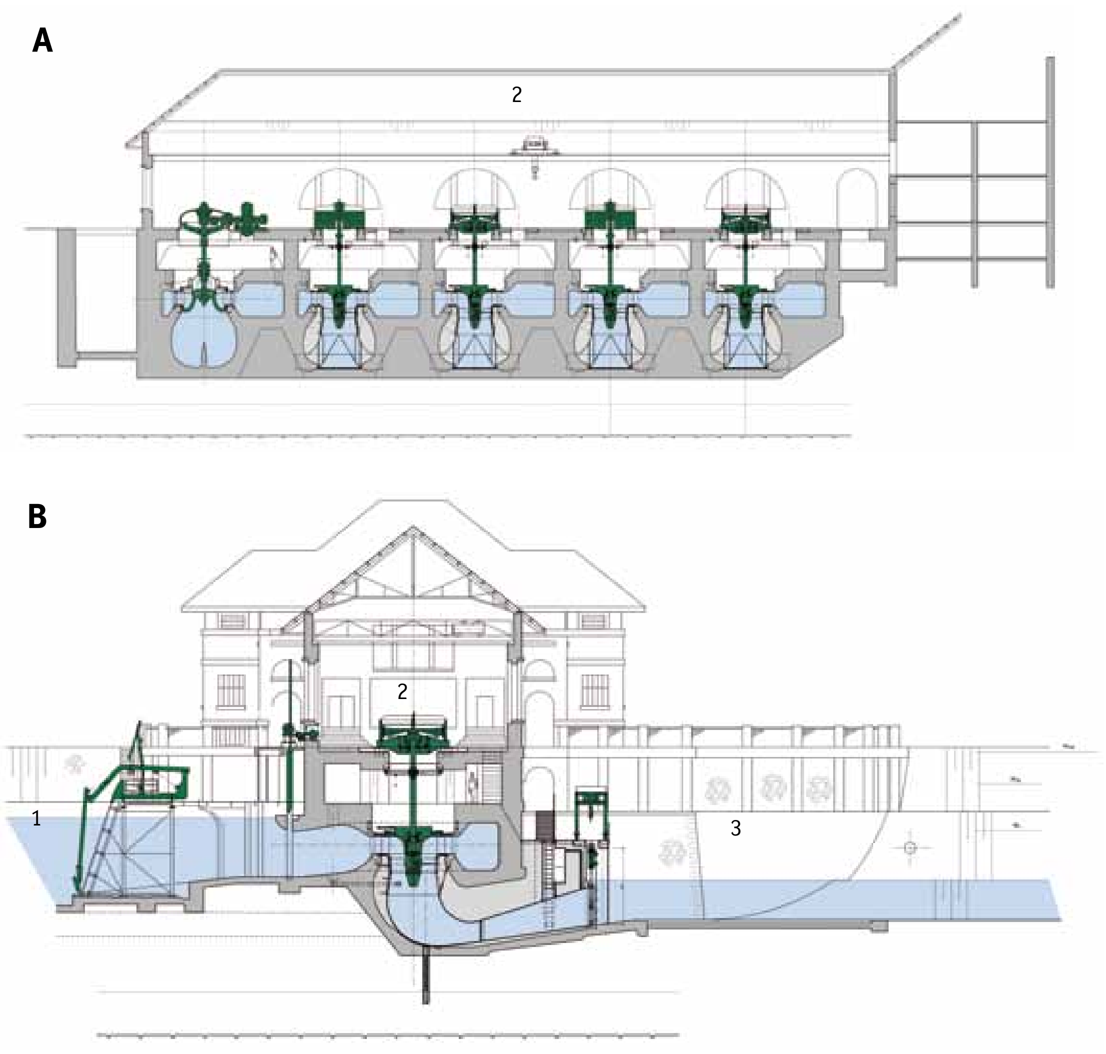


Fig. 4.126: Mířejovice SHPP on a short headrace – sections: 1 – inlet structure, 2 – machine room, 3 – outlet structure (taken from: Aquatis, a. s.).

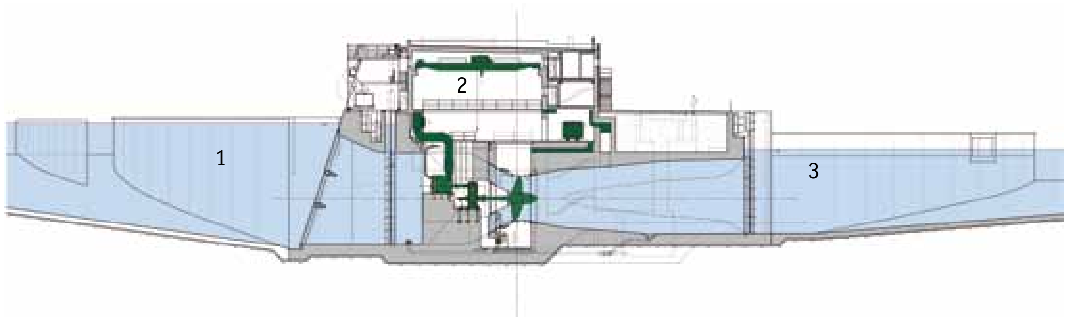


Fig. 4.127: Litoměřice SHPP – longitudinal section: 1 – inlet structure, 2 – machine room, 3 – outlet structure (taken from: Aquatis, a. s.).

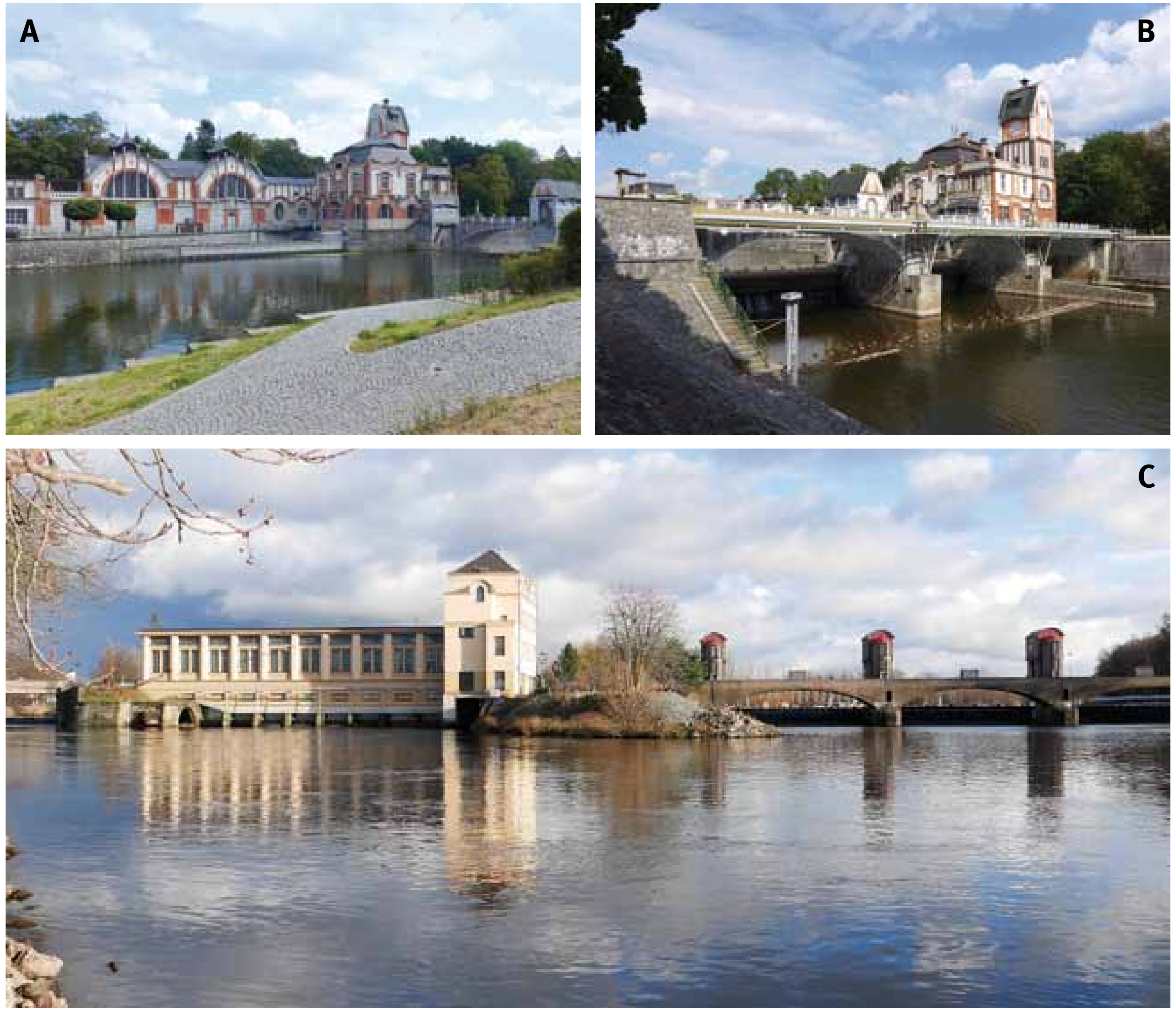


Fig. 4.128: (A) and (B) Hradec Králové – Hučák SHPP; (C) Nymburk SHPP. Photograph by Michaela Ryšková, 2018.

Fig. 4.129: Poděbrady SHPP – an inlet structure. Photograph by Brno University of Technology, Faculty of Civil Engineering, 2014.

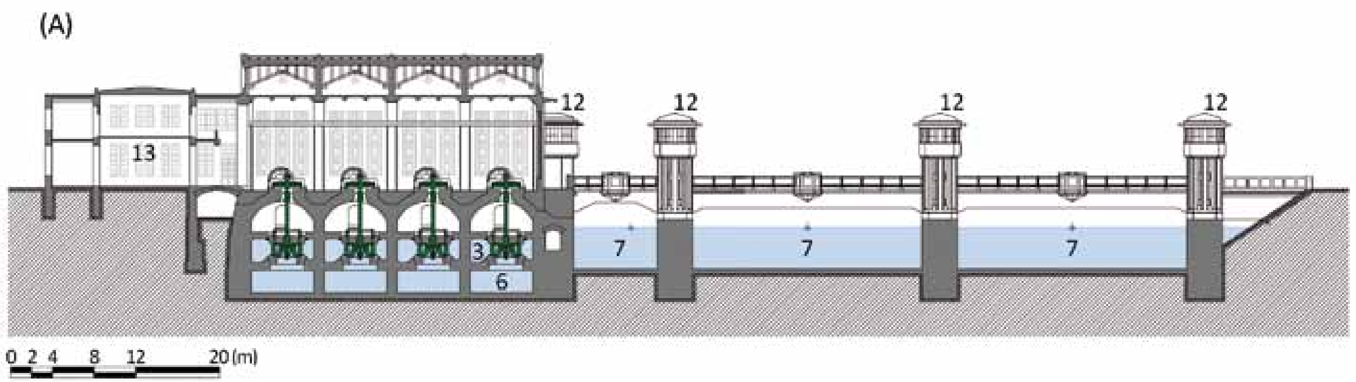


Fig. 4.130: Poděbrady SHPP – sections: A – longitudinal section of the hydroelectric power plant turbine hall and longitudinal elevation of weir bays; B – cross-section of a lock chamber; C – cross-section of a weir bay; D – cross-section of the hydroelectric power plant turbine hall; 1 – headwater (headrace), 2 – rack and turbine inlet gate, 3 – spiral (supply pipeline), 4 – Francis turbine (four in total, produced by the J. Prokopa synové company), 5 – AC electric generators with the power of 250 kW (four generators in total with the installed power of 1 MW, produced by the Fr. Křižík company), 6 – stilling basin, turbine water outlet, 7 – weir bays, 8 – Stoney-type one-piece lifting sluice gate, 9 – connecting flumes between a lock chamber and by-pass channel, 10 – by-pass channels for filling and emptying of lock chambers, 11 – lock chamber, 12 – lock chamber control room, 13 – tailwater (tailrace). Diagram by Radek Míšanec, 2018 (modified according to: the company archive of 1. elektrárenská s. r. o., České Budějovice).

Fig. 4.131: Kolín SHPP – a view from the area downstream of the weir of the machine room and the outlet part of the small hydroelectric power plant (on the left) and three sections of the roller drum weir (on the right). Photograph by Brno University of Technology, Faculty of Civil Engineering, 2014.

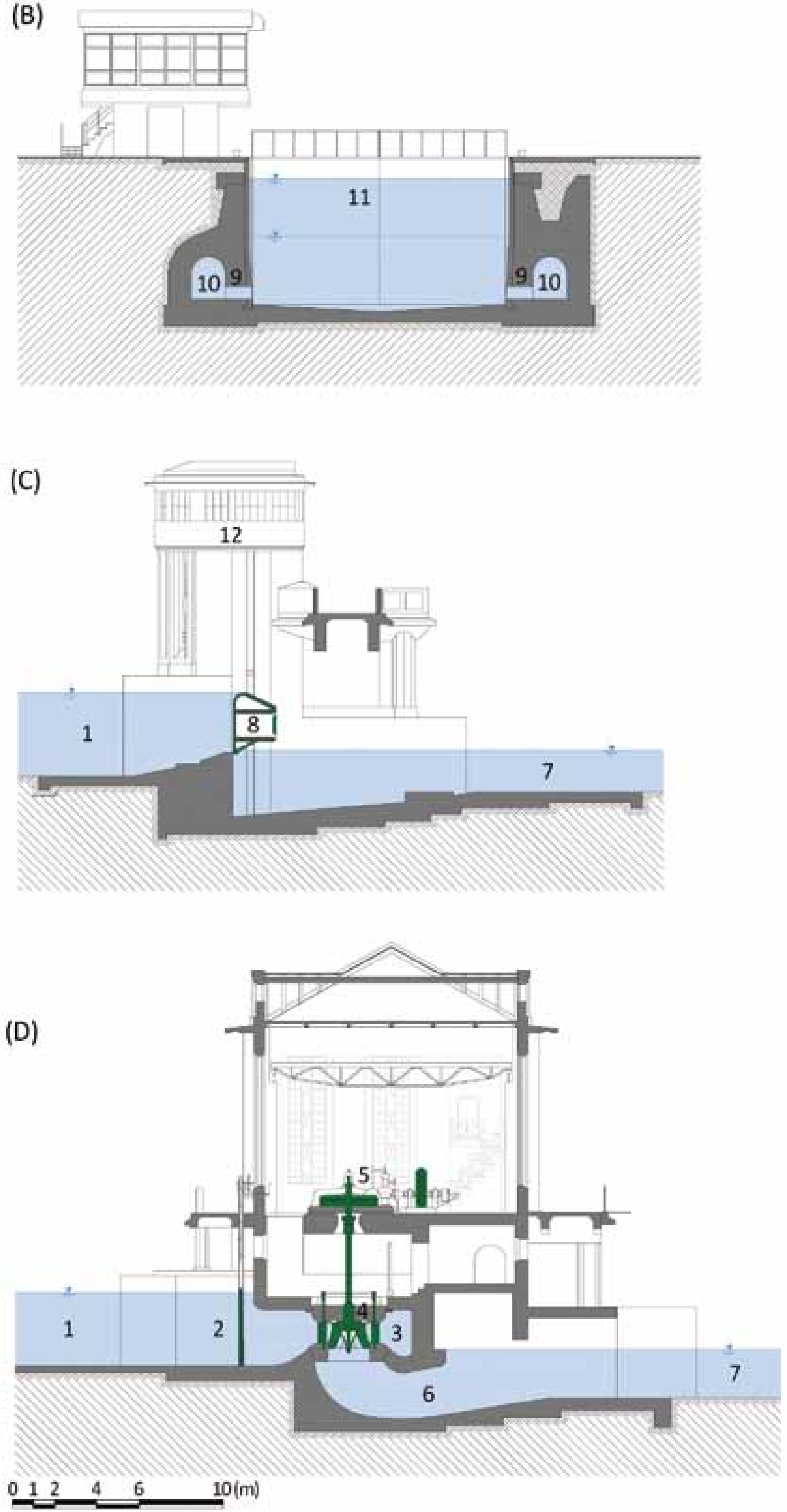


Fig. 4.132: Rudolfov II SHPP: (A) upstream slope of the dam with an inlet structure; (B) SHPP machine room. Photograph by Michaela Ryšková, 2021.

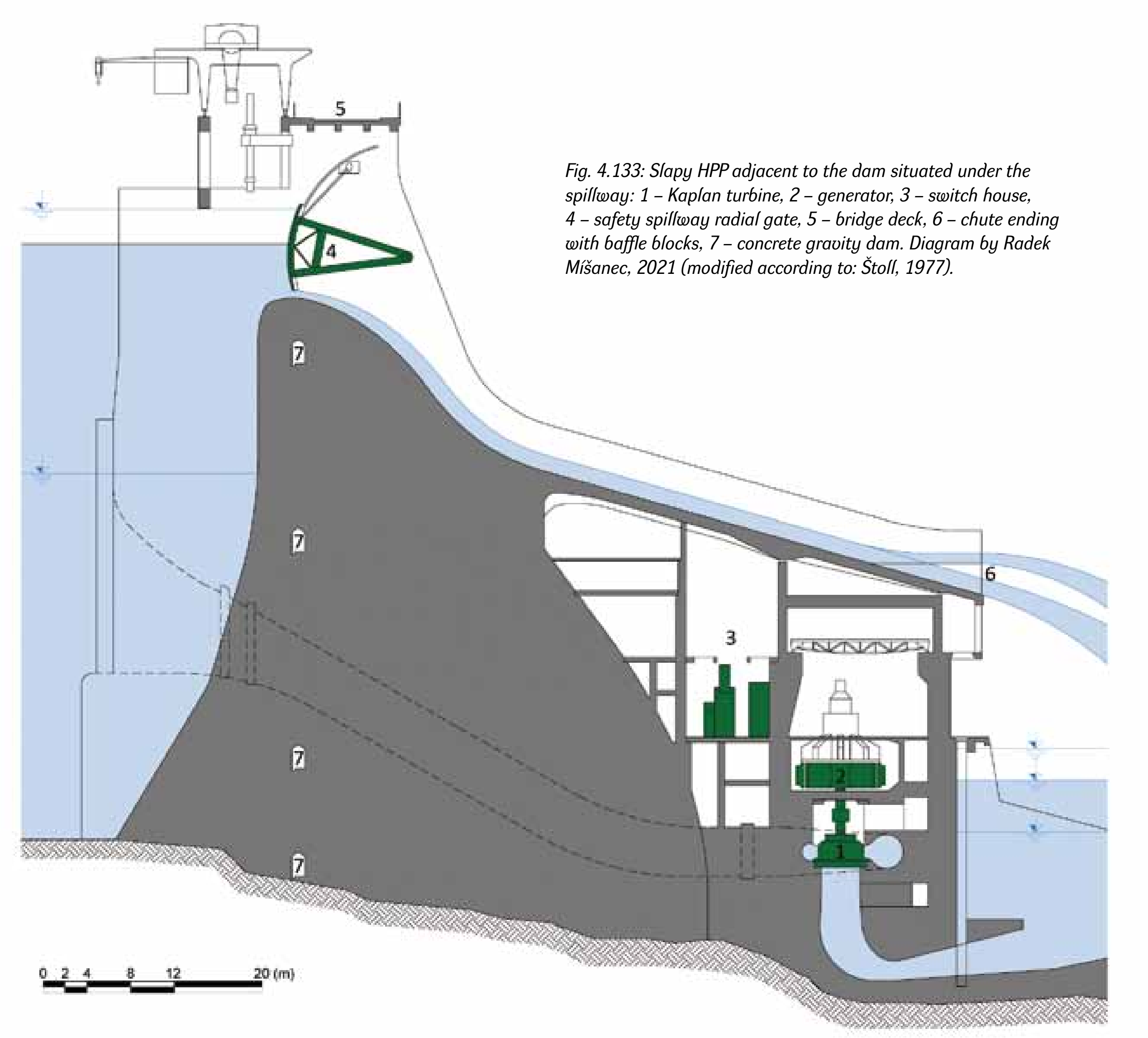


Fig. 4.133: Slapy HPP adjacent to the dam situated under the spillway: 1 – Kaplan turbine, 2 – generator, 3 – switch house, 4 – safety spillway radial gate, 5 – bridge deck, 6 – chute ending with baffle blocks, 7 – concrete gravity dam. Diagram by Radek Míšanec, 2021 (modified according to: Štoll, 1977).

Hydroelectric power plants adjacent to a dam (see B.II in Fig. 4.122) are characterised by the fact that the dam impounds and accumulates water and at the same time concentrates the necessary hydraulic head and flow. Based on the location of the power plant machine room, we recognise four main types. They are:

- hydroelectric power plant situated below a dam with a machine room situated by the downstream toe of the dam (see the Rudolfov II SHPP in Fig. 4.132 and the Štěchovice HS in Fig. 4.138);
- hydroelectric power plant with a machine room situated partly or completely in a dam body outside spillway blocks;
- hydroelectric power plant with a machine room situated under a spillway by the downstream toe of a dam (see the Slapy HPP in Fig. 4.133);
- tower hydroelectric power plant with a machine room situated before the upstream toe of a dam (in the reservoir).

4.4.2.2 Derivation and dam-derivation schemes

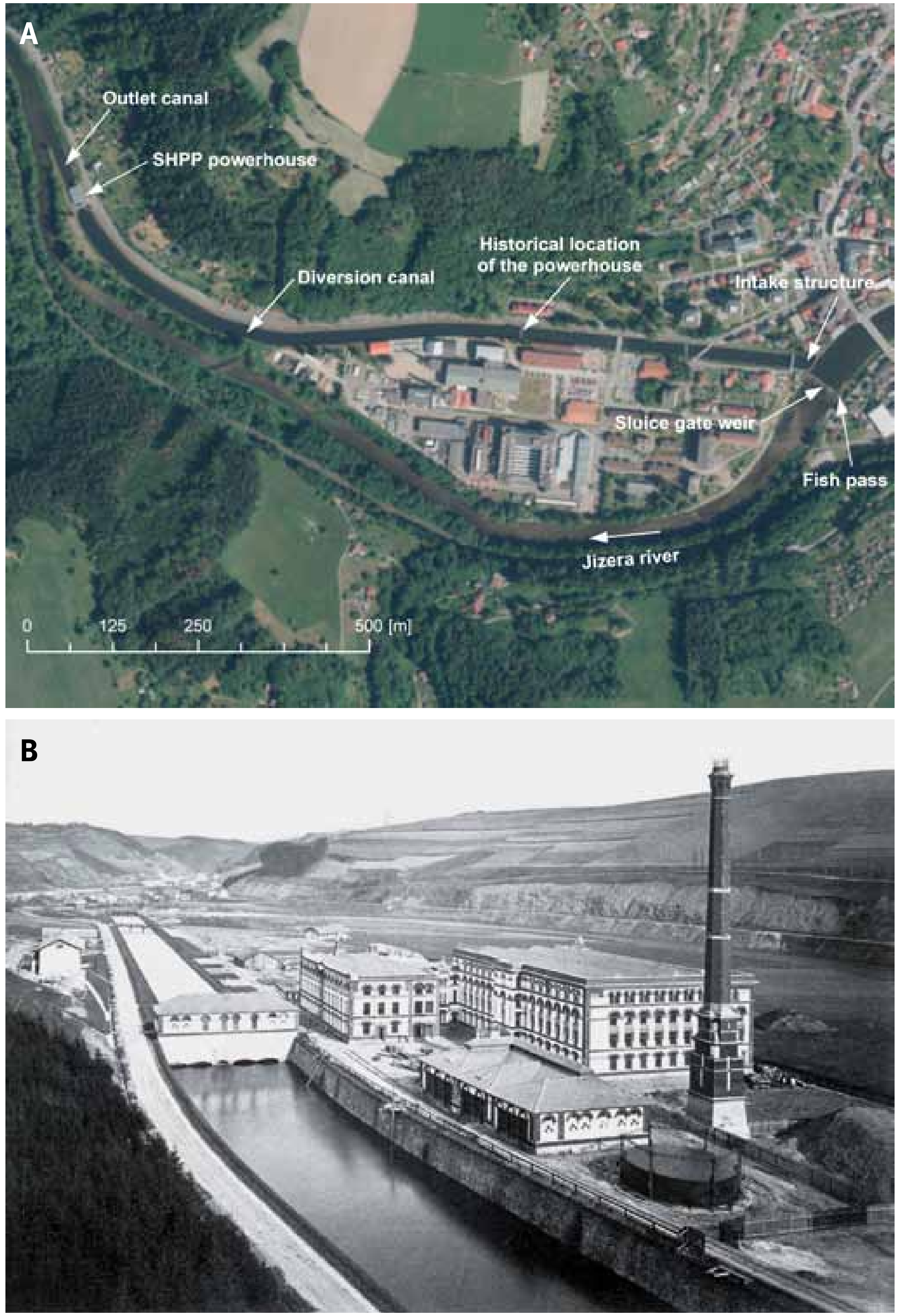
Derivation schemes (see Fig. 4.123) use an artificial conduct of water from the watercourse to the hydroelectric power plant by means of a headrace and back into it by means of a tailrace. The impoundment structure is usually a weir whose main task is not to concentrate the hydraulic head but to ensure the water supply to the derivation. The concentration of the hydraulic head is obtained by derivation and is achieved by the difference of longitudinal slopes of the river level and of the derivation, by shortening the length of the derivation compared with the length of the used section of the river or also by using the natural height differences of two rivers.

Derivation schemes can be:

- free-surface (see B.I in Fig. 4.123),
- free-surface-pressure (see B.II in Fig. 4.123),
- pressure (see B.III in Fig. 4.123).

The water supply to the hydroelectric power station usually consists of a free-surface or pressure headrace and pressure pipeline between which there is usually a surge chamber. Each of the aforementioned schemes can be divided into three types, according to the method of the hydraulic head concentration:

- The derivation is conducted along the watercourse. If this derivation is free-surface, created as a channel, we get a channel type of hydroelectric power plant. The machine room of the channel hydroelectric power station can be located at the beginning of the derivation, at its centre or at its end (see the Železný Brod SHPP in Fig. 4.134 – Fig. 4.136). There might be even more hydroelectric power plants situated on one derivation channel.
- The derivation shortens a meander or a river turn.
- The derivation transfers the flow from a river at a higher level to another one at a lower level.



4.134: Železný Brod – current situation of the derivation channel-type small hydroelectric power plant: (A) current layout after the demolition of the original machine room and subsequent complete reconstruction with a new machine room at the end of the derivation channel; (B) historic layout with the original location of the machine room from 1897. The diagram (A) was created on the basis of the ČÚZK data, 2021; photograph (B) from the archive of the company Vodní elektrárna Železný Brod, a. s.

4.4.2.2.1 Typical representative

Type of hydropower works scheme: derivation channel small hydroelectric power plant
Structure name: The Železný Brod small hydroelectric power plant
Location: Železný Brod, the Liberec region
Watercourse: Jizera, 97.480th km along the river
Turbine types: 3 × tubular bulb-type Kaplan turbine in an “S” arrangement
Maximum absorption capacity: 2 × 6.8 m^3/s + 1 × 10.8 m^3/s
Installed capacity: 2,245 kW + 1 × 496 kW
Operated by: Vodní elektrárna Železný Brod, a. s.

The existing Železný Brod SHPP uses the hydropower potential of the Jizera River 97.480 kilometre along the river. From the point of view of the use of hydropower potential in a given area, it is possible to classify the power plant as a so-called derivative channel-type hydroelectric power plant. The hydraulic head is concentrated here by free-surface derivation (i.e. via supply and wastewater channels with free surface).

The small hydroelectric power plant underwent extensive reconstruction aimed at preserving the original design and, to the maximum extent possible, restoring the historic buildings constructed in this area in the second half of the 19th century. The historic small hydroelectric power plant was put out of operation in the 1960s, including the dismantling of all technological equipment of the power plant and the gradual filling of the entire length of the headrace. The historic buildings of the hydroelectric power plant included a sluice weir, inlet structure, headrace, machine room of the small hydroelectric power plant and outlet channel (tailrace). The historic machine room of the small hydroelectric power plant, which has not been preserved (see Fig 4.135), was located at the end of the original headrace, i.e. at a distance of about 480 m from the inlet structure. Its design corresponded to the overground derivation channel small hydroelectric power plant with an upper structure. The other small hydroelectric power plant structures have been, in many cases, restored and are part of the Železný Brod SHPP.

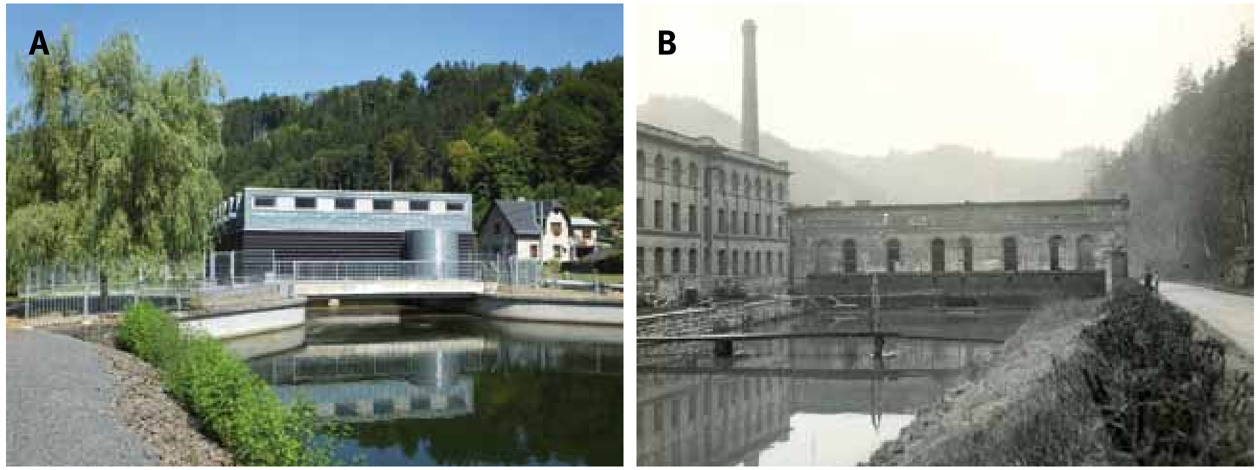


Fig. 4.135: Železný Brod SHPP: (A) current machine room in a new location; (B) the original machine room in 1965. Photograph (A) by Brno University of Technology, Faculty of Civil Engineering, 2020; (B) from the archive of the company Vodní elektrárna Železný Brod, a. s.

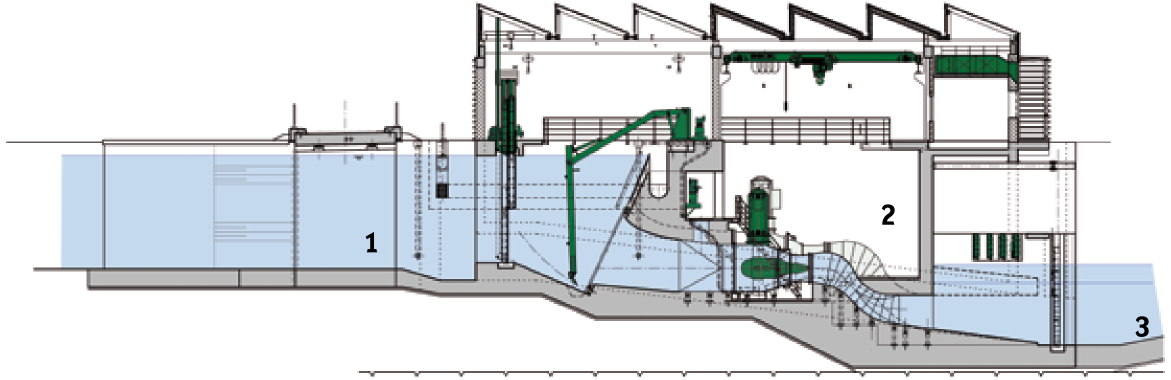


Fig. 4.136: Železný Brod SHPP – longitudinal section of the SHPP machine room in the turbine axis: 1 – inlet structure, 2 – machine room, 3 – outlet structure (taken from: Aquatis, a. s.).

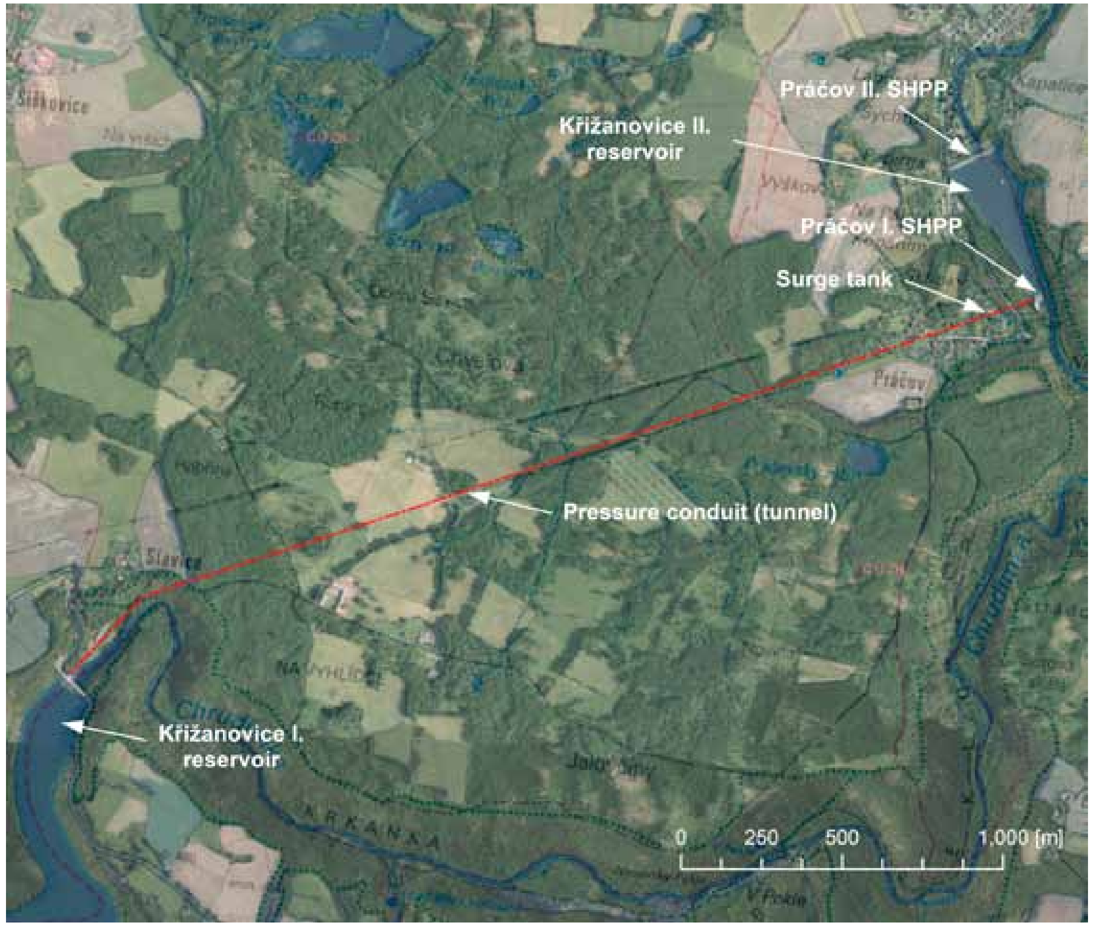


Fig. 4.137: Dam-derivation situation of the Práčov I SHPP and the Práčov II SHPP situated below the dam. Diagram created on the basis of the ČÚZK data, 2021.

Dam-derivation schemes are most often used in mountain regions. The impoundment structure is a dam, the purpose of which is to concentrate the hydraulic head and flow and to divert water into a pressure headrace. Dam-derivation schemes are, similarly to derivation schemes, of three types:

- derivation is conducted along the watercourse;
- derivation shortens a meander or a river turn;
- derivation transfers water from a river at a higher level to another one at a lower level.

4.4.2.3 Pumped-storage

Pumped-storage schemes are used during the secondary generation of peak power. According to the combination of the upper and lower reservoirs and inflow into them we distinguish:

- purely pumped-storage schemes where natural inflow is not supplied to the upper reservoir;
- mixed storage schemes where, besides pumping, natural inflow is supplied to the upper reservoir.

Hydroelectric power plants can be classified according to a number of other aspects. Here is an example of classification in accordance with the standard ČSN 750128 based on the size of installed power (ČSN, 1989):

- small hydroelectric power plants (SHPPs) with installed power to 10 MW;
- medium hydroelectric power plants with installed power from 10 MW to 200 MW;
- large hydroelectric power plants with installed power over 200 MW.

According to the water management possibilities, we distinguish two main types of hydropower works:

- run-of-river works (without storage), which use the natural flow of water in the watercourse up to a certain height that corresponds to the total amount of the absorption capacity of individual installed turbines;
- storage works (regulatory), which take water from the storage capacity of reservoirs in which it is possible to retain and regulate flows according to the needs of the power industry and other consumers; these hydropower works operate mainly during times of peak demand for a several amount of hours per day and cover both medium-peak and peak parts of the load diagram (Hynková, 1985).

Fig. 4.138: Situation of the Štěchovice HS with a PSHPP and a HPP situated below the dam. Diagram created on the basis of the ČÚZK data, 2021.

4.4.3 IMPOUNDMENT STRUCTURES

Issues related to impoundment structures are discussed in more detail in the Chapters 4.1 Dams, 4.2 Small water reservoirs, 4.3.3 Weirs.

4.4.4 INLET STRUCTURES

The purpose of inlet structures is to supply and, if necessary, regulate the water flow from a river or a reservoir into a hydroelectric power plant headrace. At the same time, it is necessary to achieve as little hydraulic losses as possible, and also to prevent the penetration of sliding sediments, ice blocks or other objects into the power plant headrace. Inlet structures can be divided according to a wide range of aspects. According to their height position in relation to the upper water surface, we distinguish the following inlet structures (Broža et al., 1990; Hynková, 1985, 1984; Kratochvíl, 1956; Štoll et al., 1977; Čábelka, 1958, 1959):

- free-surface, which are projected in the event of minor fluctuations of water level in the upper basin (e.g. weir basin);
- pressure, which are usually used in cases of major fluctuations of water level during water abstractions from reservoirs or weir basins.

According to the type of hydroelectric power plants for which the inlet structures are designed, we recognize:

- inlet structures of weir hydroelectric power plants,
- inlet structures of channel hydroelectric power plants,
- inlet structures of derivation hydroelectric power plants with settling tank built on sediment-carrying watercourses,
- inlet structures of dam and dam-derivation hydroelectric power plants,
- inlet structures of pumped storage hydropower plants.

4.4.4.1 Inlet structures of weir hydroelectric power plants

A complete inlet structure of a weir hydroelectric power plant consists of the following parts (Broža et al., 1990; Hynková, 1985, 1984; Kratochvíl, 1956; Štoll et al., 1977; Čábelka, 1958, 1959):

- intake sill,
- scumboard,
- coarse rack,
- concentrating buttresses,
- turbine intake structures,
- fine rack,
- cleaning machine,
- upstream gate,
- temporary flashboard.

Depending on the local conditions, some of the aforementioned parts of the inlet structure can be omitted.

The intake sill serves to catch coarse sediments sliding over the river bottom. For this reason, it is designed to be raised above the river bed. The disposal of sediments settled in front of the sill can be carried out, for example, by a gravel sluice (in the case of fixed weirs) or by opening the outer bay of a gated weir.

The scumboard immersed below the minimum operating level is situated under the intake sill and its function is to protect it from the penetration of floating objects into the inlet. In addition, it can also serve as a support for the course rack and operation bridge.

Concentrating buttresses used on the inlet are designed from a hydraulic point of view with the aim of achieving a uniform velocity field in front of the turbine inlets, preferably under normal operating conditions of the hydroelectric power plant. The buttresses are placed in the area of the intake sill and can simultaneously serve as a support for the scumboard.

Coarse racks are positioned above the intake sill. They are usually designed from steel pipes which are attached to the intake sill with the lower end and leaned against and attached to the scumboard with the upper end.

Turbine inlets should have a continuous shape in both the vertical and longitudinal sections. Inlets can contain a transition from the inlet rectangular cross profile to the circular profile, which is especially used when tubular Kaplan turbines are installed. In the case of vertical machine sets with a concrete spiral casing, the profile remains rectangular in its entire length up to the spiral casing entrance. Before the turbine inlets there can be a second intake sill designed at the bottom with the aim of catching the sediments sliding over the bottom and entering into the inlet structure. A side flushing channel is usually used to remove the sediments captured here.

Fine racks are positioned before the turbine inlets and they rest with the lower edge either directly on the inlet bottom or on the second intake sill. The racks usually consist of steel bars (rack bars) of rectangular cross-section.

The cleaning machine serves to remove the dirt captured on the fine racks. At present, manual cleaning is used only exceptionally, specifically in the case of small hydroelectric power plants of small capacities. The cleaning machines can be divided into stationary and mobile ones, depending on whether the machine is fixed above the turbine inlets or whether it is moving along the inlet width. According to the structural solution of the dirt raking, the machines can be divided into the following basic types:

- rope machines,
- chain machines,
- hydraulic machines (see Fig. 4.139 (A), (B)),
- others.

Upstream gates are parts of the turbine inlet. The most commonly used type is a hydraulic or electro-mechanical slide gate (see Fig. 4.139).

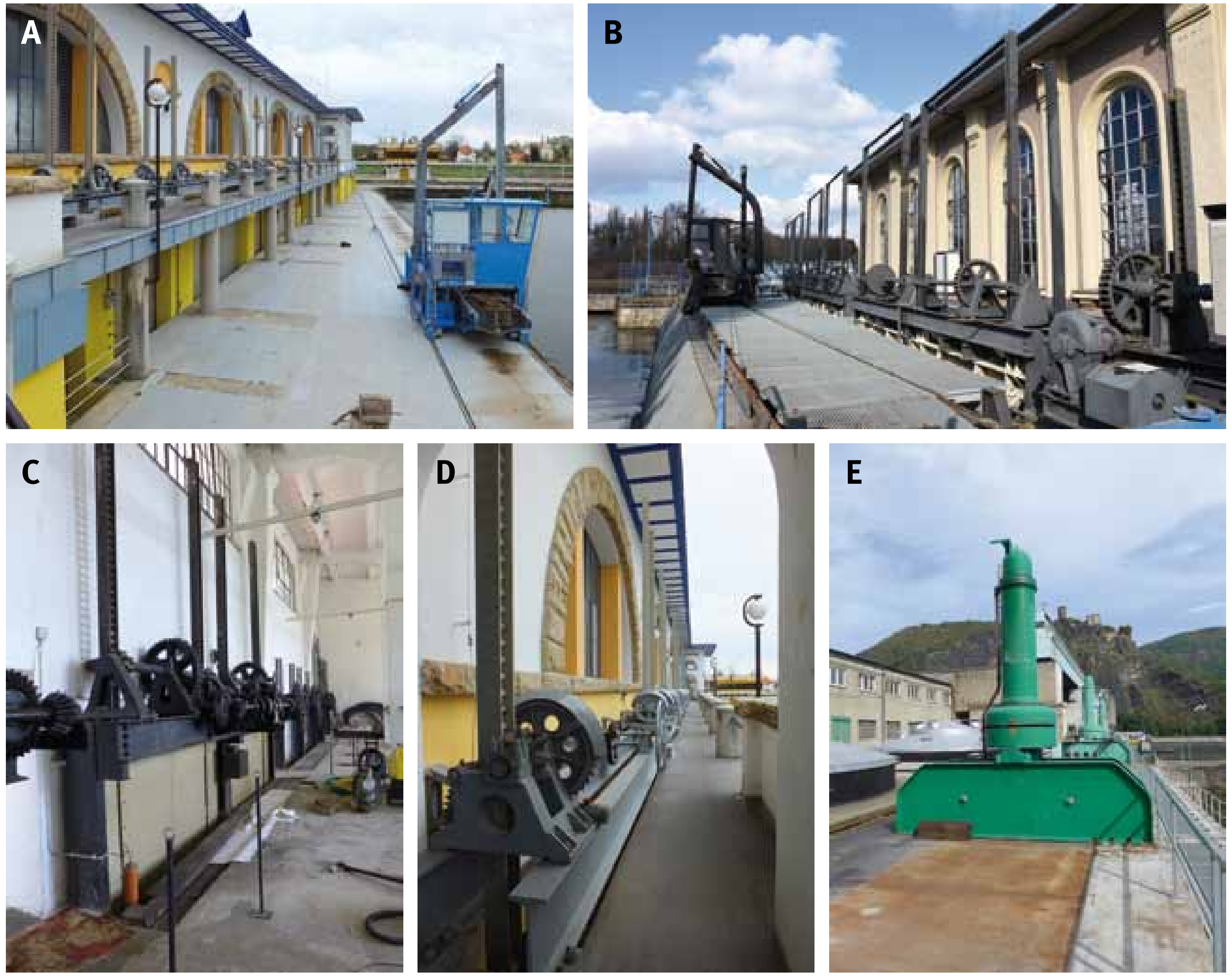


Fig. 4.139: Slide gates and cleaning machines on weir inlets of a small hydroelectric power plant: (A) and (D) Miřejovice SHPP; (B) Kroměříž SHPP; (C) Háj SHPP near Třeština; (E) Střekov HPP. Photograph (A) and (D) by Brno University of Technology, Faculty of Civil Engineering, 2014; (B) by Miloš Matěj, 2016; (C) and (E) by Michaela Ryšková, 2018, 2015.

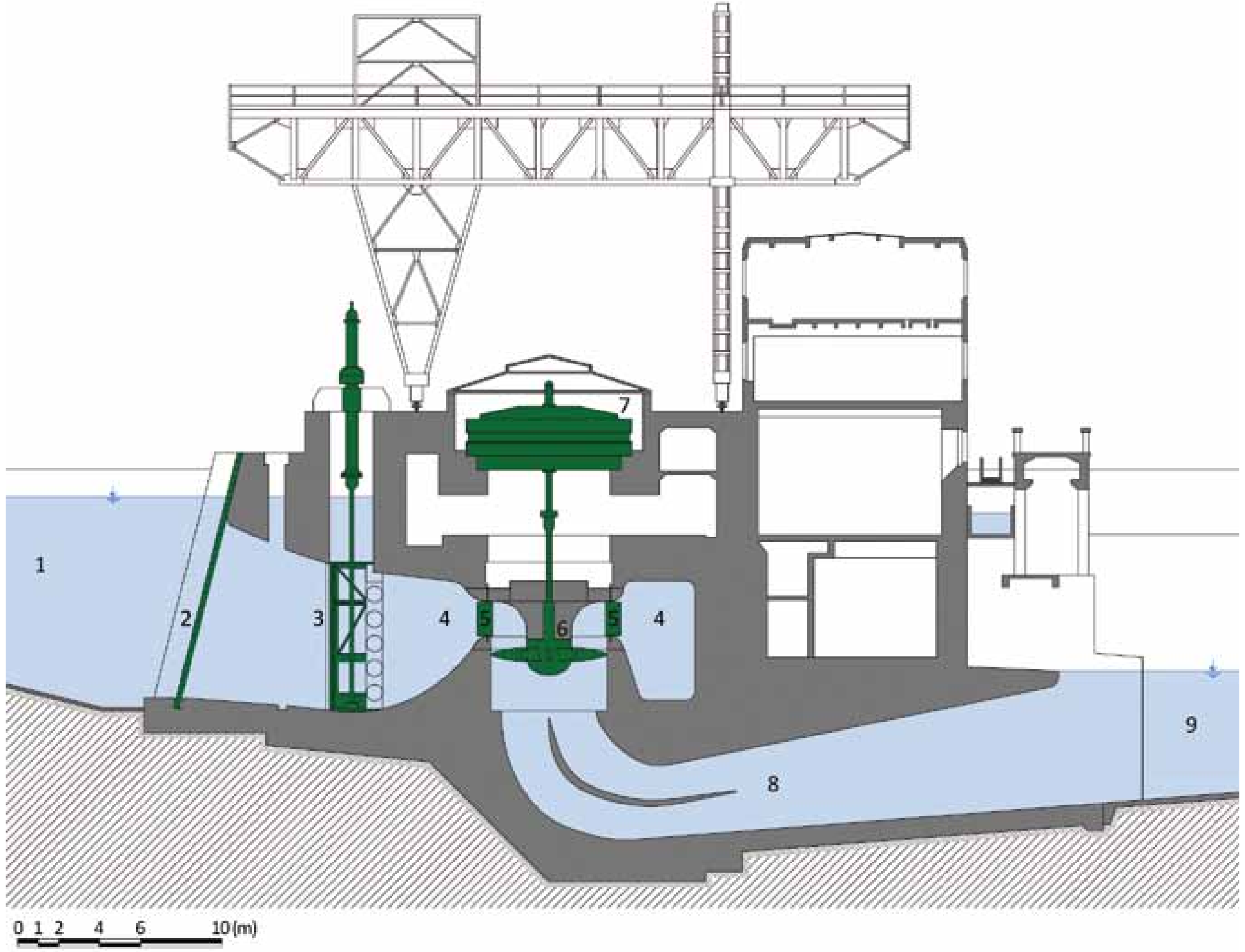


Fig. 4.140: Střekov SHPP – cross-section of the hydroelectric power plant turbine hall: 1 – headwater (headrace), 2 – rack, 3 – steel scumboard with a cleaning machine for closing turbine inlets, 4 – spiral (supply pipeline), 5 – guide (regulating) blades, 6 – Kaplan turbine (three turbines in total, produced by the Českomoravská-Kolben-Daněk company), 7 – AC electric generator with the power of 6.5 MW (three generator in total with the total maximum installed power of 19.5 MW), 8 – stilling basin, turbine water outlet, 9 – downstream water (tailrace). Diagram by Radek Míšanec, 2021 (modified according to: plan documentation).

Fig. 4.141: Kolín SHPP: (A) inlet structure; (B) outlet structure. Photograph by Brno University of Technology, Faculty of Civil Engineering, 2015.

The temporary flashboard is used at the turbine inlets and at the turbine draught tube outlets for the purpose of performing revisions or repairs of individual parts of the hydraulic system, including turbines (see Fig. 4.141). The most commonly used type is steel gates, inserted into the grooves using a crane installed at the hydroelectric power plant, a mobile crane or a crane can be designed as part of a cleaning machine.

The solution of inlet structures of a weir hydroelectric power plant can be designed in a number of modifications depending on the layout solution of the hydroelectric power plant, the used type of a machine set and other factors.

4.4.4.2 Inlet structures of derivation hydroelectric power plants

Inlet structures into derivation hydroelectric power plant headraces work on similar principles as in the case of weir hydroelectric power plants. An example of the ground plan of an inlet structure can be seen in Fig. 4.142 and Fig. 4.143. It includes these basic parts (Broža et al., 1990; Hynková, 1985, 1984; Kratochvíl, 1956; Štoll et al., 1977; Čábelka, 1958, 1959):

- intake sill,
- scumboard with coarse racks,
- settling zone,
- regulating valve.

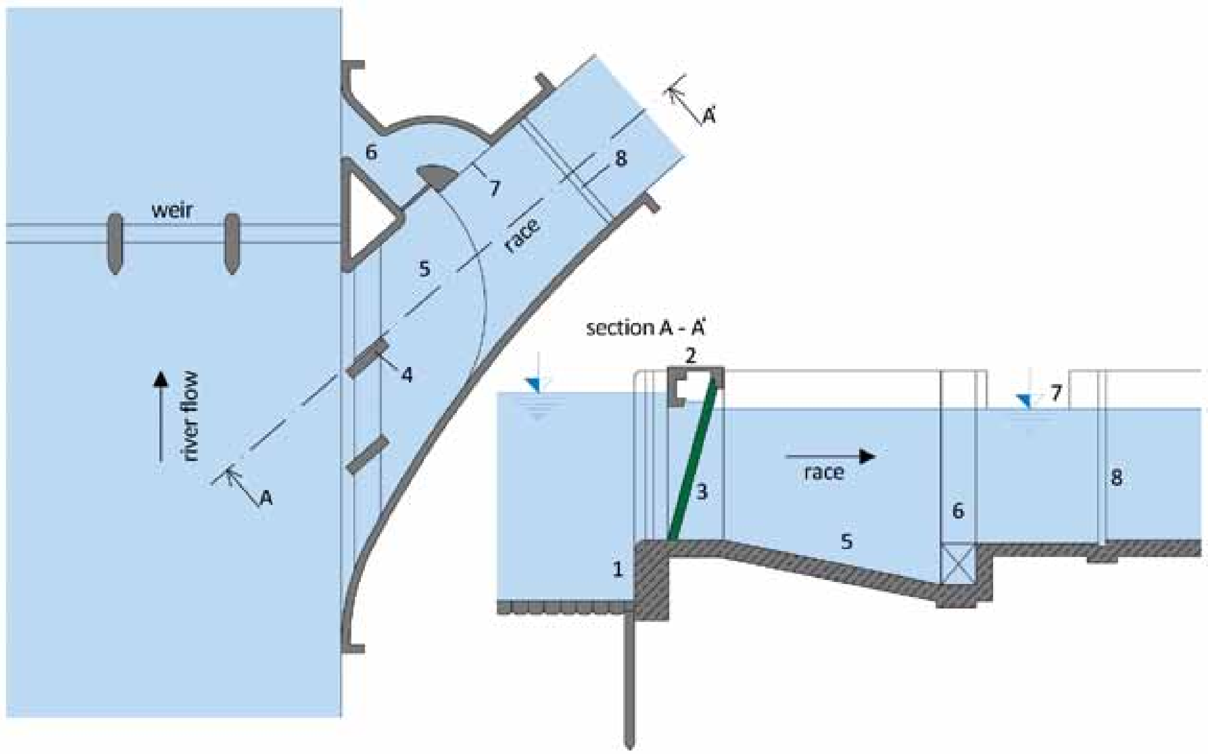


Fig. 4.142: Diagram of a derivation hydroelectric power plant inlet structure: 1 – intake sill, 2 – scumboard, 3 – coarse rack, 4 – dividing pier, 5 – settling tank, 6 – flushing channel, 7 – side (residual) overflow, 8 – regulating valve. Diagram by Radek Míšanec, 2021 (modified according to: Kratochvíl, 1956).

Fig. 4.143: Spálov derivation SHPP – inlet structure, state without water at the time of repair in 1998. Photograph by Brno University of Technology, Faculty of Civil Engineering, 1998.

Fig. 4.144: Orlík HS – under construction, detail of blocks with inlets to the HPP. Photograph by Brno University of Technology, Faculty of Civil Engineering.

The intake sill is designed based on similar principles as in the case of weir hydroelectric power plants. Intake structures of the given type are usually situated in upper stretches of a watercourse, where significant movements of sediments occur. For this reason, effective flushing of the area in front of the intake sill is usually proposed e.g. by a gravel sluice.

The settling zone is created by deepening the bottom behind the intake sill. At the end of the settling zone there is a second intake sill whose ground plan is adapted toward the flushing channel. The regulating valve is located behind the second intake sill. The gate, usually a sluice one, regulates the water flow into the headrace and the water level in it. It is also used to close the headrace during its repairs and revisions.

A specific type of derivation hydroelectric power plant inlets are structures designed on gravel-carrying watercourses. In mountainous sections of gravel-carrying watercourses with large longitudinal gradients and small flow rates, high-pressure derivation hydroelectric power plants usually work continuously with the natural flow. Typical examples of these inlet structures are so-called bottom-type (also called “Tyrolean type”) rack intakes. These types of inlet structures are mentioned in more detail, for example, in publications (Holata 2002). A characteristic structural element of the bottom-type rack water intake is the intake channel in a concrete, or masonry impoundment sill which is covered by densely mounted fine racks with a relatively large slope downstream. The abstracted water thus gets rid of coarse dirt on the racks, falls into the collecting trough, or is further conducted into the settling tank and through the tank is led to the pressure inlet which leads into the tube conduit.

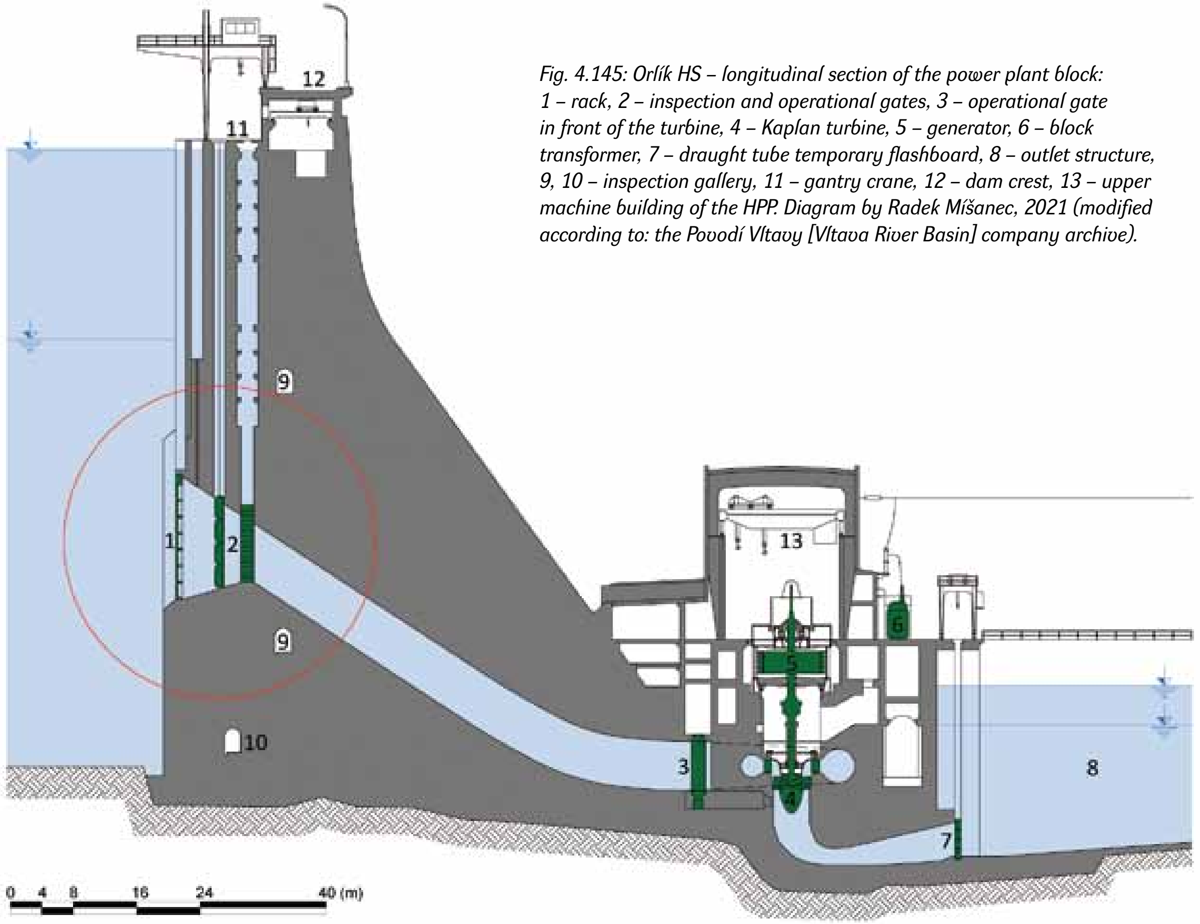


Fig. 4.145: Orlík HS – longitudinal section of the power plant block: 1 – rack, 2 – inspection and operational gates, 3 – operational gate in front of the turbine, 4 – Kaplan turbine, 5 – generator, 6 – block transformer, 7 – draught tube temporary flashboard, 8 – outlet structure, 9, 10 – inspection gallery, 11 – gantry crane, 12 – dam crest, 13 – upper machine building of the HPP. Diagram by Radek Míšanec, 2021 (modified according to: the Povodí Vltavy [Vltava River Basin] company archive).

4.4.4.3 Inlet structures of dam and dam-derivation hydroelectric power plants

Inlet structures of dam, dam-derivation hydroelectric power plants and pumped storage hydropower plants are basically similar constructions and are usually designed as pressure.

According to their position, they can be divided into the following inlet structures (Broža et al., 1990; Hynková, 1985, 1984; Kratochvíl, 1956; Štoll et al., 1977; Čábelka, 1958, 1959):

- in the dam function block, on its upstream side,
- in a special structure (intake tower, gallery or immersed inlet structure),
- in the side slope of a storage reservoir.

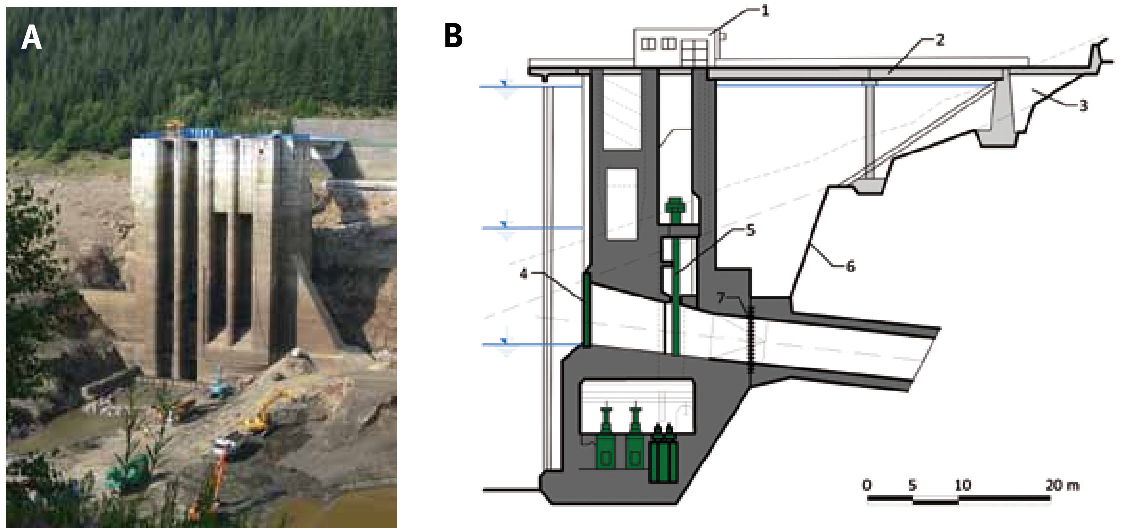


Fig. 4.146: Dlouhé Stráně PSHPP, lower reservoir – tower inlet structure (multipurpose – it also contains bottom outlets and safety spillways): (A) state during the reservoir drawdown; (B) section: 1 – machine room of safety spillways radial gates, 2 – bridge, 3 – backfill, 4 – rack or temporary flashboards (stop logs), 5 – slide gate valve, 6 – gunite, 7 – sealing element of expansion joints. Photograph (A) by Brno University of Technology, Faculty of Civil Engineering; diagram (B) by Radka Račoch and Michaela Mrvová, 2021 (modified according to Hynková, 1984).

Fig. 4.147: Dlouhé Stráně PSHPP – lower reservoir. Photograph by Michaela Ryšková, 2019.

The entrance profile of inlets is usually right-angled for structural reasons and its distorted zone turns into the headrace circular profile. Every watercourse includes a rack and a temporary flashboard which enables repairs and revisions of inlets and turbine intake pipeline. An operational gate is also usually designed in most cases.

Intake towers are usually built in the upper basin outside the dam body, either at the upstream toe of the dam or at the heel of the bank slope.

An inlet structure in the side of the reservoir is most often used in the case of dam-derivation and pumped storage hydropower plants. It is usually positioned in the rock slope of a storage reservoir. It contains common equipment of pressure inlets: racks, temporary flashboards and operational gate. A specific characteristic of inlet structures of pumped storage hydropower plants is the fact that they enable an inverted operation, i.e. both pump and turbine operation.

4.4.5 HEADRACES, TAILRACES AND SURGE CHAMBERS

Headraces and tailraces are made at a hydroelectric power plant when it is necessary to ensure the concentration of head and flow by so-called derivation. Derivation refers to the equipment to conduct water from a watercourse, weir basin or storage reservoir to a hydroelectric power plant (headrace) and farther from the power plant back to the river (tailrace). Headraces and tailraces can be divided according to various aspects. We recognise these headraces and tailraces according to the basic hydraulic point of view: (Broža et al., 1990; Hynková, 1985, 1984; Kratochvíl, 1956; Štoll et al., 1977; Čábelka, 1958, 1959):

- free-surface (e.g. channel, gallery),
- pressure with water conducted under pressure (e.g., gallery, pipeline),
- mixed when a part is pressure and a part is free-surface.

Free-surface headraces and tailraces can be either open (channels, troughs) or covered (covered channel – see Fig. 4.148 and Fig. 4.149 or trough), gallery and pipeline with free surface.

Derivation channels and races were the most commonly used type of headraces and tailraces. A hydroelectric power plant with a free-surface derivation via open channels are built especially on central and lower stretches of larger watercourses.

For operational reasons, the headrace must be closable at the beginning and at the end so that revisions and repairs can be carried out. There are relief spillways installed at appropriate locations of the headrace (e.g. at the crossing with a brook) and in front of a hydroelectric power plant because they divert flows that are larger than the capacity of the headrace. In long headraces, water shocks could occur when turbines or gates are suddenly shut down and opened. That is why there is a re-regulating reservoir established at the end of a free-surface headrace before a hydroelectric power plant inlet where shock waves are suppressed.

Other structures can be found at the crossing of a channel with brooks and roads, such as inverted siphons, aqueducts, bridges, etc.

The cross section of a channel is usually trapezoidal but in the case of small canals (races), if they are made of building materials (concrete, reinforced concrete, wood), the section can also be rectangular or semicircular.

The sealing of supply channels is made of clay and earth types of soil, concrete, reinforced concrete, or pre-stressed concrete, asphalt concrete and plastic sheeting.

The revetment of supply and wastewater channels should increase the stability of slopes, protect the slope against weather conditions and mechanical effects of waves. It is carried out as stone riprap, stone riprap poured through by mastic asphalt, stone pavement and pavement made of concrete slabs – prefabricated or covered with concrete in situ.

A power hydraulic gallery is an underground structure excavated by mining in solid rock and is used to conduct water (see Fig. 4.150). These galleries are horizontal or have a very small longitudinal inclination. Vertical galleries or galleries with a large inclination are called shafts.

According to their function, we distinguish energy galleries and inlet shafts through which water from a watercourse or a reservoir is led to a hydroelectric power plant, and outlet shafts through which the used water is conducted back to the watercourse.

From a hydraulic point of view, galleries can be divided into free-surface and pressure ones.

Pressure galleries usually serve as headraces of derivation, dam-derivation, underground and pumped storage hydropower plants and as pressure tailraces of pumped storage hydropower plants and underground hydroelectric power plants with a greater fluctuation of lower water surface.

Running water fills up the whole flow cross-section which is usually circular.

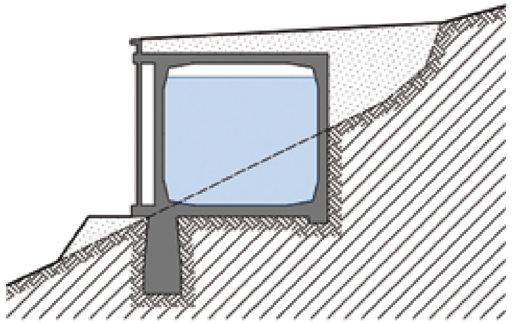


Fig. 4.148: Spálov SHPP – section of a reinforced concrete supply channel. Diagram by Radek Míšanec, 2021 (modified according to: ZSV, 1924).

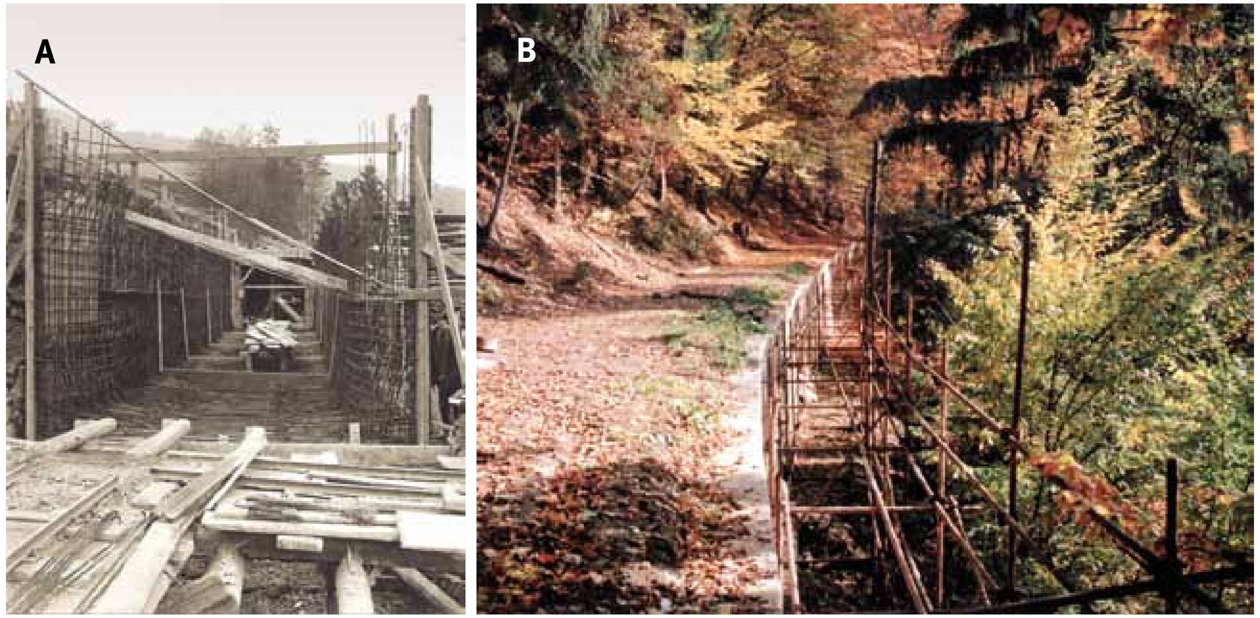


Fig. 4.149: Spálov SHPP – reinforced concrete supply channel: (A) reinforcement procedure in 1925; (B) view from the channel ceiling in 1998 during reconstruction. Photograph (A) taken from: VČE, 2000; (B) by Brno University of Technology, Faculty of Civil Engineering, 1998.

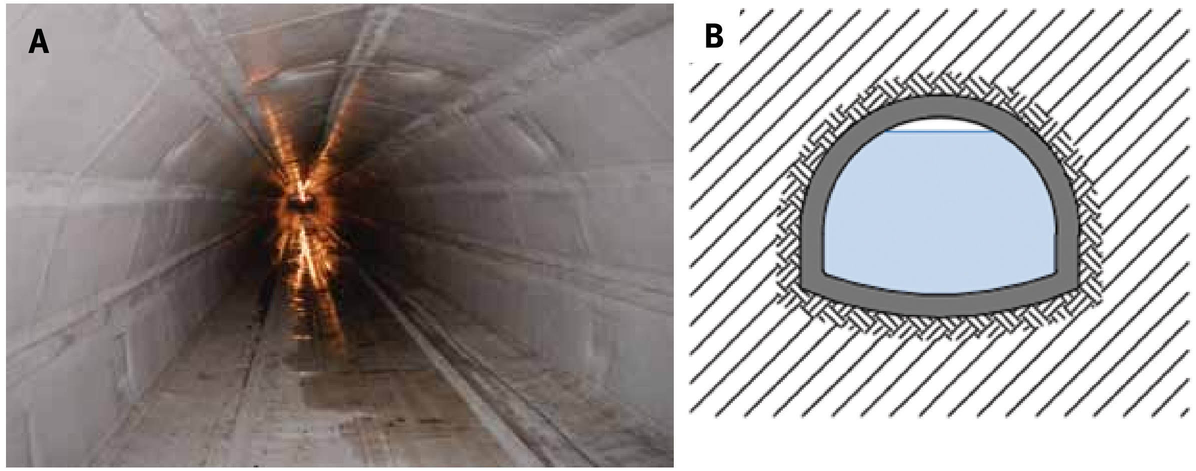


Fig. 4.150: Spálov SHPP – free-surface gallery: (A) view of the gallery after reconstruction with the use of geomembrane; (B) diagram. Photograph (A) taken from: ZČE, 2000; diagram (B) by Radek Míšanec, 2021 (modified according to: ZČE, 2000).

Commonly used cross-sectional shapes of free-surface galleries are rectangular with an arch, horseshoe-shaped, and mouth-shaped.

The shape of the cross-sections of pressure shafts is almost always circular because it is suitable for both hydraulic and static reasons.

Pressure pipeline fulfil two basic functions:

- Derivation pressure pipelines are used as hillside headraces in complex terrain in which it is not possible to establish an open or covered derivation channel, or it is not more convenient to establish a pressure or free-surface gallery. Derivation pressure supply pipelines on hillside slopes are usually made of steel, reinforced steel and sometimes wood. Laminate and plastic-based materials are also used.
- A turbine pressure pipeline is used to conduct water from the inlet structure to power plant turbines.

Fig. 4.151: Dlouhé Stráně PSHPP – positioning of steel armour into the inlet gallery of turbines (taken from: Höll, 1997).

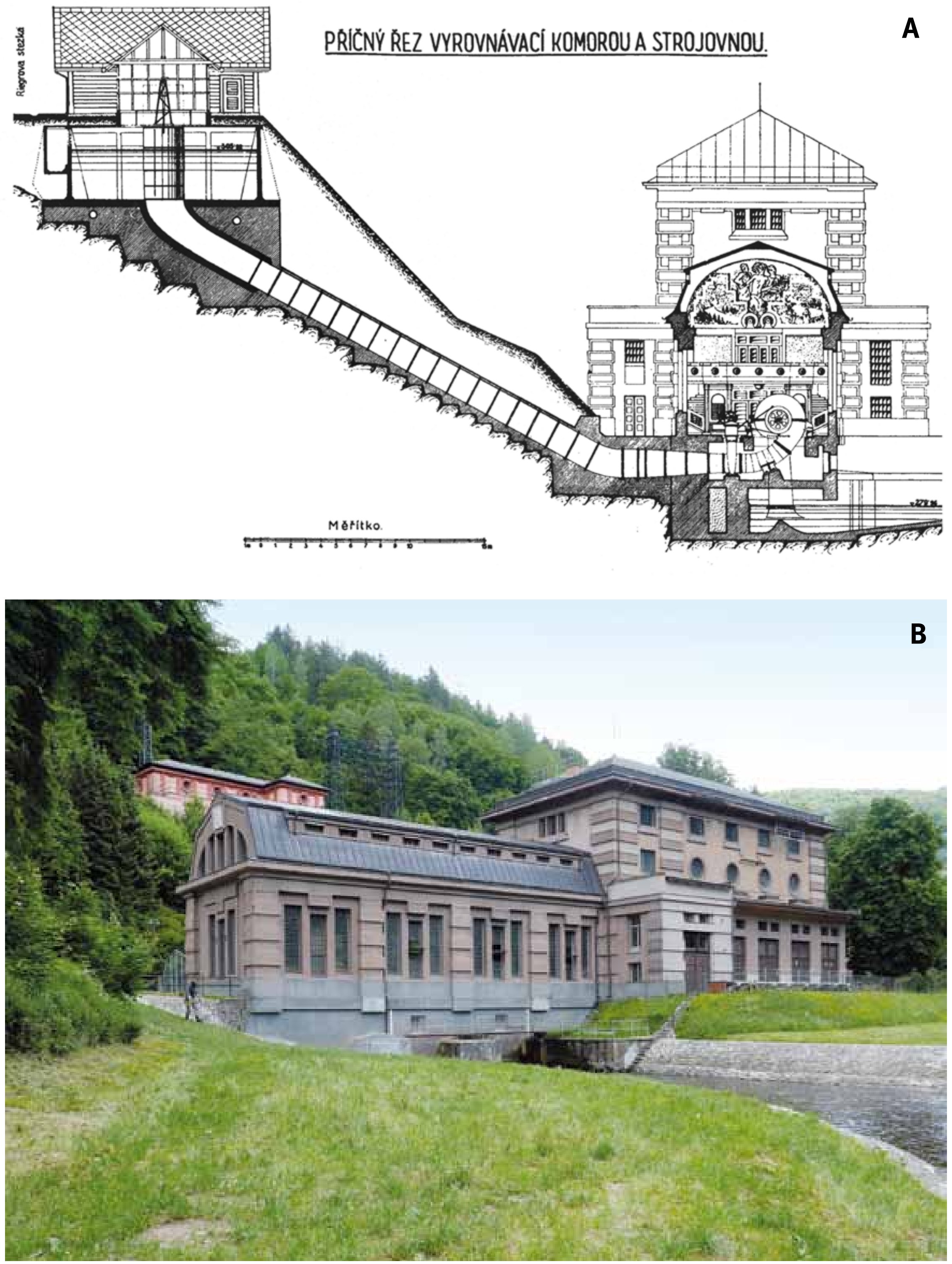


Fig. 4.152: Spálov SHPP: (A) longitudinal section of a surge chamber, supply pressure pipeline and machine room; (B) view of the machine room and surge chamber at the end of the headrace. Diagram (A) taken from: ZČE, 2000; photograph (B) by Michaela Ryšková, 2022.

Pipelines can be divided according to the way it is positioned into:

- pipeline free-standing on a terrain,
- pipeline positioned in a trench and covered with earth,
- pipeline positioned in a tunnel, gallery or shaft.

According to the material used, pipelines can be made of wood (older structures), reinforced concrete (lower pressure), fibreglass, plastic or steel.

A pressure pipeline free-standing on a terrain is at the place of directional and elevation fractures firmly attached to the anchor blocks. A pressure pipeline between anchor blocks lies on support blocks. A simple construction of a saddle support block can be seen in Fig. 4.154.

Surge chambers (see Fig. 4.152, Fig. 4.156, Fig. 4.157) are in fact free-surface reservoirs which are inserted either between a long pressure headrace with small inclination (gallery) and pressure turbine pipeline with large inclination, or between the tailrace of a turbine draught tube and long water tailrace of the power plant which is permanently or temporarily under pressure. The surge chamber is to reduce the unwanted pressure changes between the water flowing in through the long headrace and the water being abstracted by the turbines, and also to contribute to increasing the stability of the turbine control. Surge chambers that are attached to the free-surface headrace are also called regulating chambers or reservoirs (see Fig. 4.152, Fig. 4.156). Surge chambers are equipped with valves and various safety equipment.

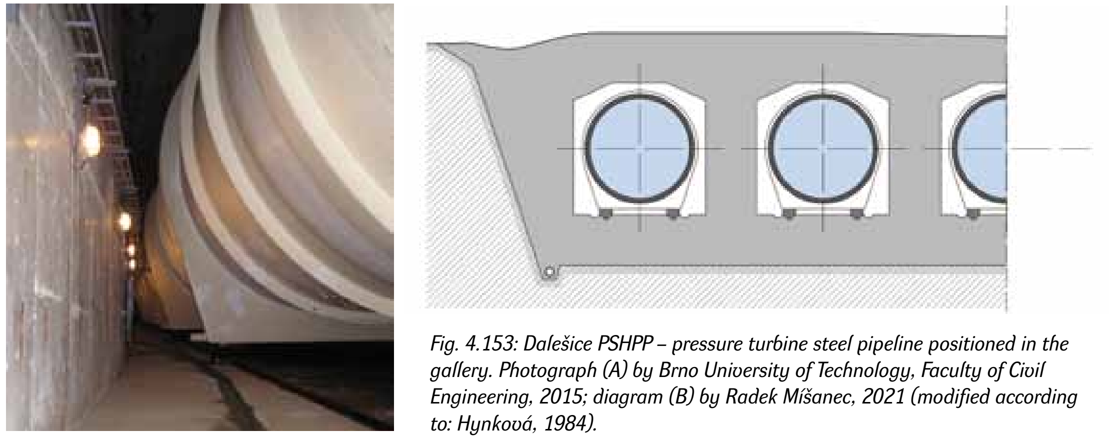


Fig. 4.153: Dalešice PSHPP – pressure turbine steel pipeline positioned in the gallery. Photograph (A) by Brno University of Technology, Faculty of Civil Engineering, 2015; diagram (B) by Radek Míšanec, 2021 (modified according to: Hynková, 1984).

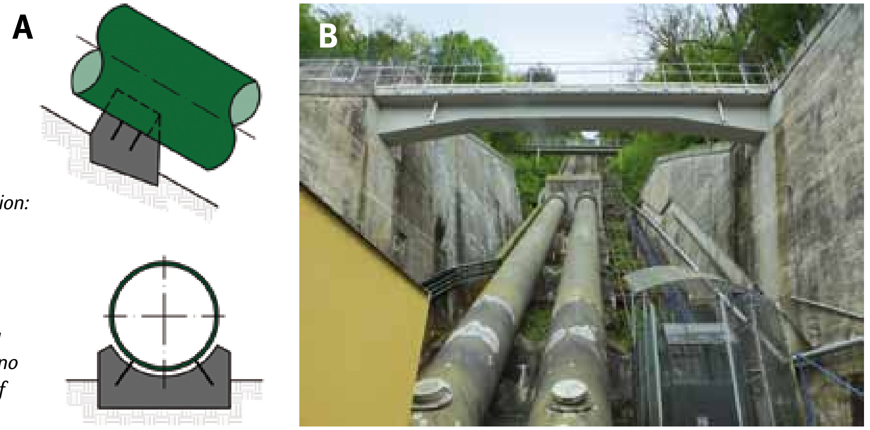


Fig. 4.154: Support block construction: (A) diagram; (B) Štěchovice PSHPP – pressure pipeline with support and anchor blocks. Diagram (A) by Radka Račoch and Radek Bachan, 2021 (modified according to: Brož̌a et al., 1990); photograph (B) by Brno University of Technology, Faculty of Civil Engineering, 2019.

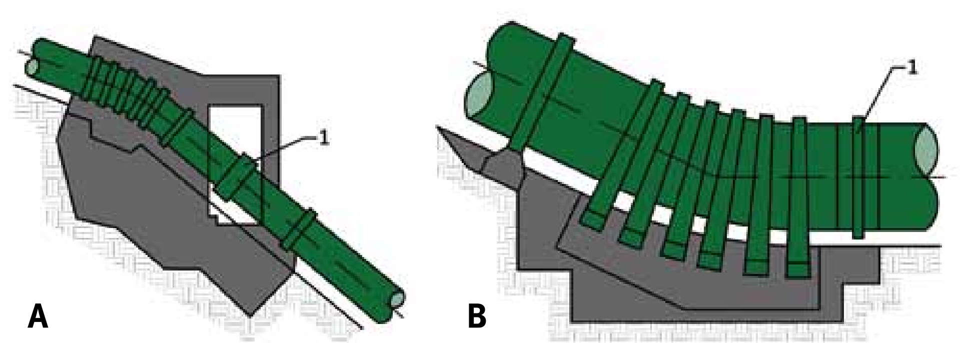


Fig. 4.155: Examples of anchor blocks construction: (A) closed type; (B) open type; 1 – compensation pipe. Diagram by Radka Račoch and Radek Bachan, 2021 (modified according to: Broža et al., 1990).

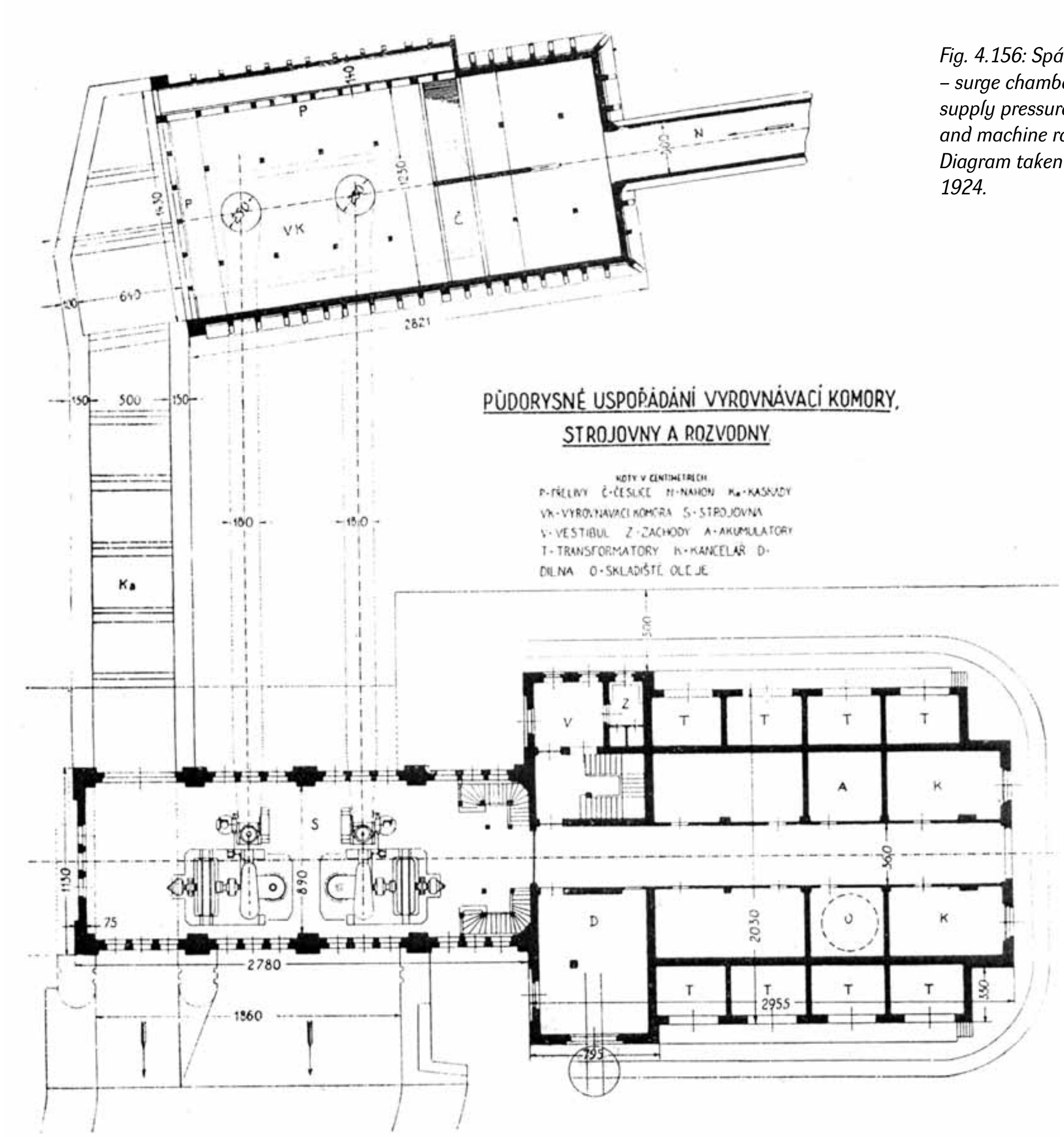


Fig. 4.156: Spálov SHPP – surge chamber layout, supply pressure pipeline and machine room of the. Diagram taken from: ZSV, 1924.

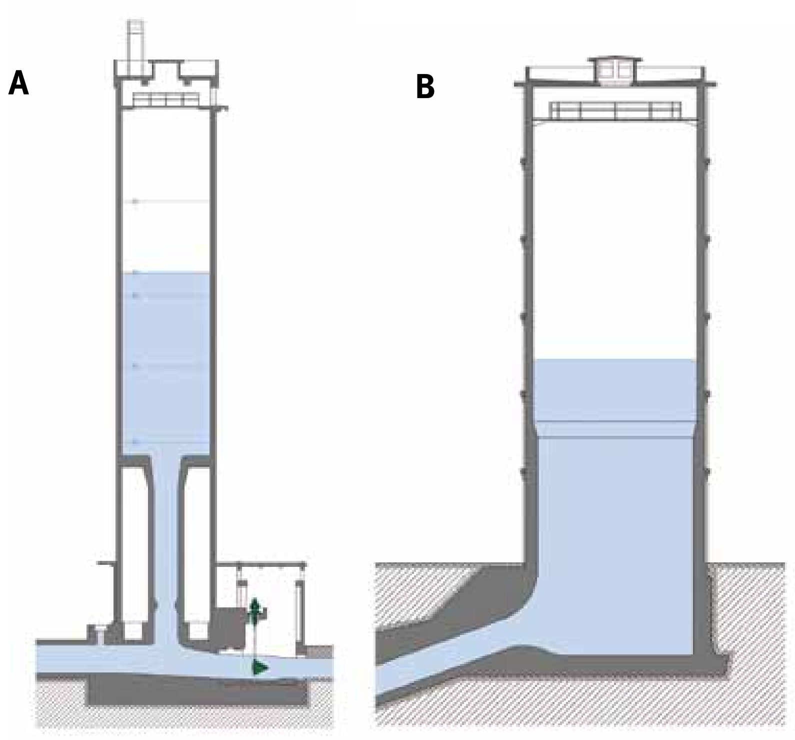


Fig. 4.157: Section of an overground surge chamber with diaphragm: (A) Práčov I SHPP; (B) Seč SHPP. Diagram by Radek Míšanec, 2021 (modified according to: Trejtnar, 1975).

4.4.6 PRODUCTION STRUCTURES (BUILDINGS)

According to the schemes of the use of a hydraulic potential, we can divide hydroelectric power plant buildings into (Broža et al., 1990; Hynková, 1985, 1984; Kratochvíl, 1956; Štoll et al., 1977; Čábelka, 1958, 1959):

- buildings of river hydroelectric power plants (weir or dam),
- buildings of derivation hydroelectric power plants (channel or pressure),
- buildings of special hydroelectric power plants (underground, buttress, pumped-storage, etc.).

According to the building location in relation to the surrounding terrain, we can distinguish overground, underground, shaft or mixed types.

According to the upper machine building layout – in the case of the overground hydroelectric power plants, buildings can be (see 4.158):

- covered, if all basic and auxiliary equipment is located inside the building (see Fig. 4.159, Fig. 4.160, Fig. 4.161),
- semi-covered, if basic equipment is located, for example, under the terrain level and there are only cranes outside (see Fig. 4.162);
- Uncovered (see Fig. 4.140), if not only cranes but also parts of machine sets are located outside (e.g.. hydroelectric alternator).

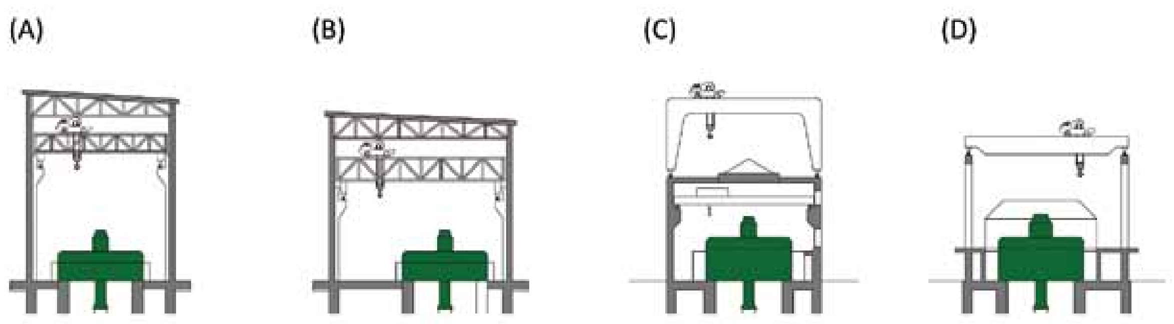


Fig. 4.158: Types of upper machine building layout: (A) and (B) covered; (C) semi-covered; (D) uncovered – without the upper structure. Diagram by Radek Míšanec, 2021 (modified according to: Hodák, 1998).

Fig. 4.159: Machine rooms: (A) Mirějovice SHPP; (B) Kroměříž SHPP; (C) Hradec Králové – Hučák SHPP; (D) Hradec Králové SHPP. Photograph (A) by Brno University of Technology, Faculty of Civil Engineering, 2014; (B) by Miloš Matěj, 2014; (C) and (D) by Michaela Ryšková, 2010.

Fig. 4.160: Machine rooms: (A) Poděbrady SHPP – under reconstruction; (B) Veselí nad Moravou SHPP. Photograph (A) by Brno University of Technology, Faculty of Civil Engineering, 2014; (B) by Miloš Matěj, 2014.

Fig. 4.161: Rudolfov SHPP – machine room. Photograph by Michaela Ryšková, 2021.

Fig. 4.162: Štěchovice PSHPP with a shaft-type machine room. Photograph by Brno University of Technology, Faculty of Civil Engineering, 2019.

Fig. 4.163: Dlouhé Stráně PSHPP – underground machine room: (A) machine room cavern during construction (B) machine room current state. Photograph (A) taken from: Höll, 1997; (B) by Michaela Ryšková, 2019.

Overground hydroelectric power plants can be used for all kinds of use of the hydropower potential of a watercourse. On the contrary, underground hydroelectric power plants can be used in the case of derivation layout with a pressure water supply to hydroelectric or pumped storage hydropower plants, whether it is a classical all-underground type or a shaft layout in deep excavations, especially at the heels of the slopes of lower storage reservoirs.

For hydroelectric power plant buildings of valley dams there are various options of how to attach them to the downstream toe of the dam by using various positions of block transformers, including power plants located inside concrete gravity dam blocks. Sometimes they can be positioned, for example, in spillway blocks of the dam; then we talk about overtopped hydroelectric power plants.

The hydroelectric power plant complex can be divided into two basic parts – production-technological and administrative-operational. Basic equipment of the production-technological part includes a HPP machine room, extra high voltage switch house and all other auxiliary technological equipment necessary for the operation of the machine set. In addition, a HPP can be equipped with premises for operation management with complete sanitary facilities, which form the administrative-operational area of the HPP.

The production-technological part of the HPP is represented by its machine room, which is formed by three interconnected parts:

- substructure,
- superstructure,
- assembly platform.

The HPP substructure is separated from the superstructure by the machine room floor. From the constructional point of view, the substructure can be seen as a hydraulic structure with specific water management requirements for its implementation, especially the method of foundation, water drainage etc. The substructure is the basic and most difficult part of a HPP. There is a run-of-river part of the machine set (inlet part of low-pressure hydraulic power plants or pressure supply pipeline, steel spiral, draught tube, etc.), turbine with its accessories, or pumps in the case of PSHPPs, located in it.

In the superstructure of the machine room there are usually located: parts of hydraulic alternators with excitation system and revolution regulators, block transformers, overhead cranes of the machine room and assembly platform usually connected with an access road, or tunnel in the case of underground hydraulic power plants. Due to the protection of the HPP equipment against atmospheric influences, the upper machine building is usually roofed and has the character of an industrial hall.

The extra high voltage switch house is usually located outdoors close to the machine room, or administrative-operational part of the HPP.

According to the HPP layout, the administrative-operational part can be either a separate building adjacent to the superstructure or it can directly be part of the upper building. Equipment required for the operation of a hydroelectric power station, such as self-consumption transformers, main low-voltage switchgear, control room, battery room, compressor station, sanitary facilities, workrooms, warehouses, offices, garages, etc., can be found in it.

4.4.7 TECHNOLOGICAL PART

4.4.7.1 Water wheels

To understand the classification of water wheels documented in the Czech lands, it is necessary to understand the basic division of water wheels based on their construction into paddle wheels, bucket wheels and wheels with incomplete buckets. Until recently, a paddle wheel was generally regarded as a solely undershot water wheel and a bucket wheel was in most cases regarded as an overshot or breastshot water wheel. However, the situation is more complicated – a paddle wheel could also have had an upper inflow and, on the other hand, a bucket wheel was also used as undershot by our ancestors although the buckets were incomplete, i.e. bottomless. A specific reverse overshot bucket water wheel which was used in mines, especially for water pumping should be also mentioned. It is formed by two rows of buckets each mounted in the opposite direction, which can be filled with water alternately according to the necessity of changing the direction of rotation of the shaft.

The correct classification of water wheels needs to be done according to two criteria simultaneously, namely structure and water flow. Taken separately, the information does not have full explanatory power and, as a result, can be highly misleading. An example of this is an overshot bucket water wheel in archive materials. In general, we understand that it is an overshot water wheel but it can also be used as an undershot water wheel with floats and shrouds, but without sole boards, which is a wheel with incomplete buckets which cannot be driven by upper inflow at all.

4.4.7.1.1 Classification of water wheels according to the water inflow

One group of undershot water wheels includes a basic type (known as "hřebenáč" in Czech), Alvan-mill ("hubenáč"), flood water wheel ("kolo povodní"), paddle water wheel ("lopatník") and an undershot wheel with floats and shrouds, but without sole boards ("vlk"). In the 1950s, other types – the Poncelet, Sagebien and Zuppinger water wheels – appeared. In practice, we can also come across water wheels that are structurally combined.

For the sake of completeness, it should be mentioned that the term paddle water wheel has two meanings. In general, it refers to any water wheel fitted with paddles but in a more specific meaning, it is used to differentiate it from the basic type of undershot water wheel (see both terms).

A group of breastshot water wheels includes bucket water wheels with an inner lining and buckets with outer lining. Bucket water wheels with an inner lining and a middle inflow can be also referred to as undershot water wheels with increased inflow. Bucket water wheels with an outer lining are based on Romuald Božek's invention and are clearly related to insufficient hydraulic head.

The group of breastshot water wheels can also include the Sagebien and Zuppinger water wheels based on the type of their flume used.

Overshot water wheels include bucket wheels ("korečník") and a flutter wheel ("belík"). During the introduction of water mills in areas with shortage of water, an overshot paddle water wheel was also used. We have such wheels documented in Central Europe in the period of the 14th century and in the Balkan countries still in the 19th and 20th centuries.

A rarity is a horizontal water wheel with a vertical shaft. The tradition of its construction remained the longest in the Balkan countries, where such water wheels were still created as completely new in the second half of the 20th century. In the case of a wooden variant with spoon-shaped paddles, it resembles rather a simple turbine. After all, there is a connection between this type of horizontal water wheel and old types of water turbines, especially the Zuppinger turbine.

We can also observe the way water wheels are mounted on the shaft – on the mortise and the straddle method. The first type consists of attaching the arms to the shaft perpendicularly (radially) on its axle so that three beams pass through the shaft mortises and after that they form six arms (known as a compass wheel). The straddle method has two variants. In the first and more widespread variant, on each side of the water wheel there were "crosses" used, consisting of two pairs of beams mounted perpendicular to each other (known as a clasp arm wheel). The centre of the cross had dimensions slightly larger than the dimensions of the octagon into which the shaft was adjusted in this place. The fixed mounting was secured by wedges. The second, less common, called "on a saddle" consisted in six arms fitting closely to the shaft which had a hexagonal shape in this place. These arms were touching each other and, at the same time, they were connected to each other.

From the second half of the 19th century, water wheels started to be mounted on a cast iron shaft using a cast iron rosette, into which points secured with metal screws fit. These also allow relatively easy replacement of the points.

4.4.7.1.1.1 Overshot bucket water wheel (ordinary)

Water falls onto it at the summit, or before the summit or even after it. Standardly, it is a water wheel with complete buckets. It uses both kinetic and potential energy of water.

From the High Middle Ages to the 20th century, the overshot bucket water wheels were built from wood. From the end of the 19th century, thanks to the relatively cheap production of rolled plate, their buckets began to be made of plate, and in around the same period, all-metal overshot buckets appeared.

To increase the output, overshot bucket water wheels were supplemented with so-called masonry breast. i.e., a trough which ensured that the water flowed out of the buckets as late as possible (see also the breastshot water wheel with a masonry breast).

An overshot water wheel can also take the form of reverse bucket wheels, i.e., two rows of narrow buckets arranged opposite to each other. It was used in the mines to operate a winch, where one shaft ensured both winding and unwinding of the rope or chain.

The group of overshot water wheels also include a specific flutter water wheel used exclusively at sawmills (Hýbl, 1922; Štěpán 1990; Štěpán and Křivanová, 2000).

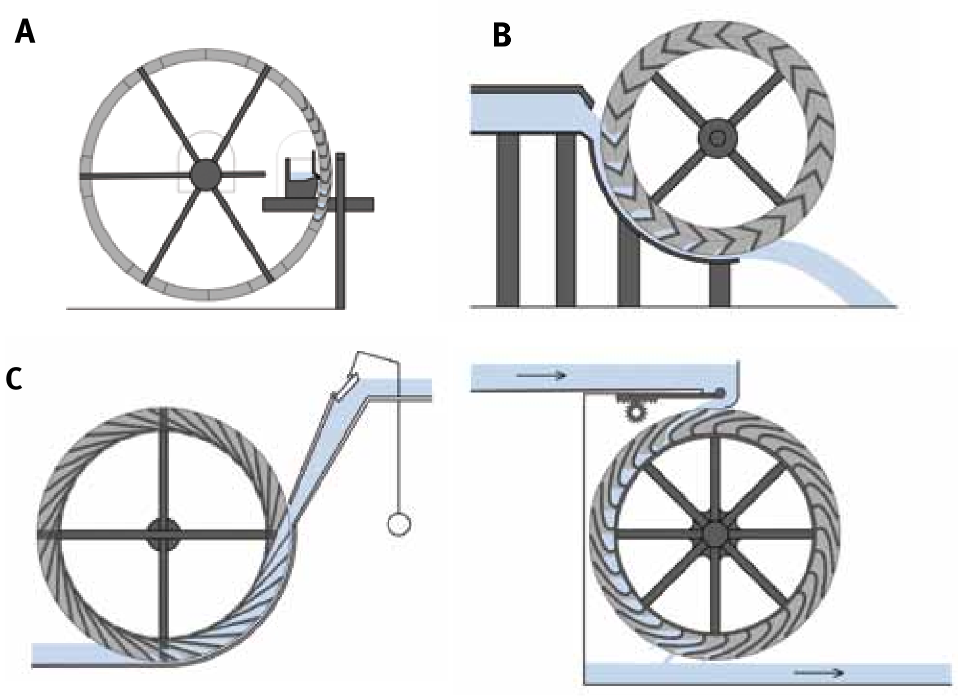


Fig. 4.164: Bucket water wheels: (A) breastshot water wheel with inner inflow, i.e., with inner buckets; (B) breastshot or overshot water wheel (water level above shaft level) with a masonry breast; (C) reverse overshot water wheel – older type on the left, newer type with rounded buckets on the right. Diagram by Radka Račoch and Michaela Mrvová, 2021 (modified according to: Hýbl, 1922, 1862; Štěpán, 1990; Štěpán and Křivanová, 2000).

Fig. 4.165: Střehom (Mladá Boleslav District) – overshot bucket water wheel. Photograph by Radim Urbánek, 2006.

Fig. 4.166: Příbram, the Drkolnov mine – water wheel 12.4 m in diameter. Photograph by Viktor Mácha, 2019.

Explanation: An overshot bucket water wheel can also be used as a breastshot water wheel. The buckets increase the use of the energy of running water.

Number of occurrences: Frequent in the Czech Republic – now almost 130 wheels, they are all newly produced pieces from the last 20 years.

Temporal delimitation: They existed from the High Middle Ages and were massively widespread from the period of the Late Middle Ages to the first quarter of the 20th century.

Typical representative: Bradlecká Lhota 41 (Semily District), Býkovice 25 (Blansko District), Střehom 12 (Mladá Boleslav District)

Unique example: water wheel in the Drkolnov mine in Příbram 12.4 m in diameter.

4.4.7.1.1.2 Overshot water wheel with a coulisse

In terms of construction it corresponds to the bucket water wheel. Water flows into it through curved channels, called coulisses, always above the level of the shaft. The curvature of the channels is set in such a way that the water flows into the buckets at an angle which ensures the maximum use of kinetic energy of water and also the fastest possible filling of the buckets (Hýbl, 1922).

4.4.7.1.1.3 Backshot water wheel

Overshot water wheel with complete buckets, water falls onto it at the summit, or before the summit but at the end of the wooden trough there is a full wall and in front of it, at the bottom of the wooden trough, there is a coulisse outflow. The water wheel does not rotate in the direction of the water flow, but vice versa. It uses both kinetic and potential energy of water. Compared to an ordinary overshot bucket water wheel, it can use a smaller flow (Sturm, 1815).

4.4.7.1.1.4 Undershot water wheel – basic type, also known as a splashing undershot water wheel

It is a paddle water wheel whose paddles in the cross section (perpendicular view of the paddle surface) usually exceed the rims on which they are mounted. In the basic variant, the paddles have a flat surface but in more developed variants our ancestors used paddles with breaks or even rounded. They can be divided, based on their number of rims, into single-rim and double-rim. Water regulation of these wheels is ensured by an ordinary sluice gate. Thanks to the sluice gate, the potential energy of water is transformed into kinetic energy. This kind of a water wheel has very low efficiency, but it is also simple to build (Štěpán, 1990).

Number of occurrences: Frequent in the Czech Republic – now over 100 wheels, they are all newly produced pieces from the last 20 years.
Temporal delimitation: They existed from the Antique period, the mass expansion on our territory falls into the period from the early Middle Ages to the beginning of the 20th century.
Typical representative: Hroznová 489/3, Prague – Malá Strana; Slup 31 (Znojmo District)

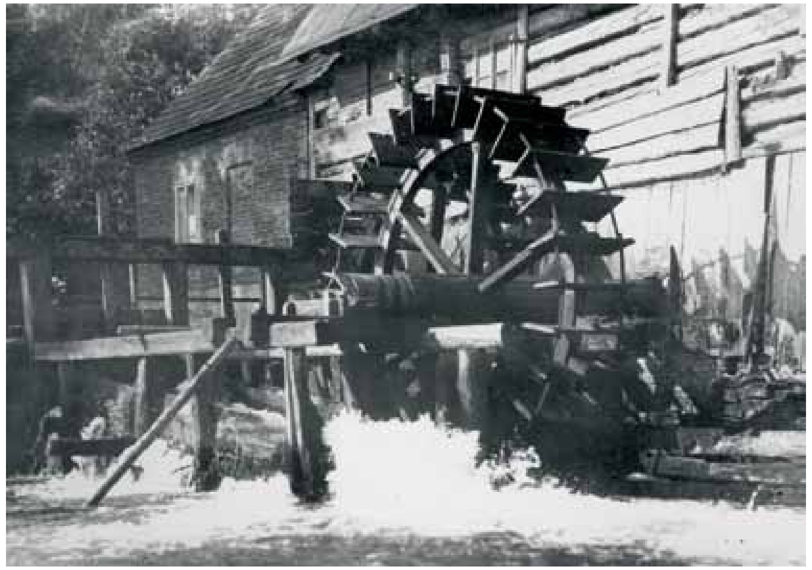


Fig. 4.167: Single-rim undershot water wheel. Photograph by Jan Popelka, subcollection of photographs-positives, Regional Museum in Vysoké Mýto, inv. No. 22D-4842.

4.4.7.1.1.5 Alvan-mill undershot water wheel

Type of an undershot water wheel with paddles, installed on the structure which enables its shaft movement in a vertical direction, so when the water level rises or falls, its immersion could be adjusted so that losses from unnecessarily deep immersion do not reduce its output below the required level (Štěpán a Křivanová, 2000).

Number of occurrences: In the Czech Republic no wheel of this type has been preserved.
Time delimitation: It was built only exceptionally from the 18th century.

4.4.7.1.1.6 Paddle-type undershot water wheel

Type of a water wheel equipped with paddles between two rims but contrary to the basic type of the undershot water wheel water wheel, these paddles do not exceed the rims in the cross section (perpendicular view of the paddle surface) (Štěpán, 1990).

4.4.7.1.1.7 Flood undershot water wheel

Very unusual water wheel based on the basic type of the undershot water wheel but with such a type of paddle structure which enables their tilting if the water reaches the level of the shaft.

Another solution of undershot water wheels consisted of using a structure that allowed lifting and lowering of a water wheel (Štěpán, 1990; Štěpán and Křivanová, 2000).

4.4.7.1.1.8 Undershot water wheel with floats and shrouds, but without sole boards

It is a very specific water wheel with incomplete buckets, i.e. bottomless. The buckets, although incomplete, increase the use of kinetic energy of water (Štěpán and Křivanová, 2000).

Explanation: Contrary to the basic type of the undershot water wheel or a paddle-type water wheel, the undershot water wheel with floats and shrouds, but without sole boards has a higher efficiency because the water cannot flow around the edges of the paddles but remains inside the bucket and transfers more of the kinetic energy of water to it.

Fig. 4.168: Aarhus (Denmark), Den Gamle By – undershot water wheel with floats and shrouds, but without sole boards, which has incomplete buckets. Photograph by Radim Urbánek, 2015.

4.4.7.1.1.9 Breastshot water wheel with a coulisse

The structure corresponds to the bucket water wheel but water flows into it through curved flumes, called coulisses, approximately at the shaft level. The curvature of the flumes is set in such a way that the water flows into the buckets at an angle which ensures the maximum use of kinetic energy of water and, if possible, the fastest possible filling of the buckets (Hýbl, 1922).

Explanation: Water wheels with coulisses were developed in an effort to increase the use of the kinetic energy of water. Contrary to other attempts, this has worked well.

4.4.7.1.1.10 Undershot water wheel with a masonry breast

The structure corresponds to a paddle or a bucket type of wheel but water from the paddles or buckets does not flow out so fast thanks to a rounded wall, i.e. a masonry breast, which encircles the water wheel around the lower and middle parts of the perimeter. From the point of view of water wheels classification, it can also be referred to as a breastshot water wheel with external inlet (Štěpán and Křivanová, 2000).

Explanation: An undershot water wheel with a masonry breast can be confused with a breastshot water wheel, especially when the inflow rises significantly to the level of the water wheel shaft.

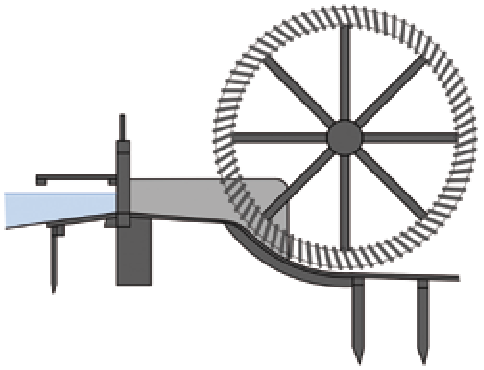


Fig. 4.169: Undershot water wheel with a masonry breast. Diagram by Radka Račoch and Michaela Mrvová, 2021 (modified according to Neumann, 1862).

4.4.7.1.1.11 Breastshot water wheel with internal inlet

This unusual type of water wheel was made by a Czech mechanician Romuald Božek for Sychrov Castle to power a fountain because there was only a minimum hydraulic head. He managed to make a structure with T buckets whose lining is located on the outside part of the water wheel. Water flows into the buckets under the level of the water wheel shaft. This solution required an important modification of the ends of the wooden troughs, which are fitted with a low partition of semicircular cross-section at this point. This ensures that the water does not flow at an obtuse angle against the bottom (lining) of the buckets but flows in an almost vertical direction, so the water wheel uses not only the potential but also kinetic energy of the water.

The solution of the breastshot water wheel with internal inlet was designed by Romuald Božek in 1865 and implemented two years later (Štěpán, 1990).

Explanation: The breastshot water wheel with internal inlet arose from the need to obtain a sufficiently powerful water motor to pump water to the fountains at Sychrov Castle with an insufficiently small hydraulic head.

Number of occurrences: In the Czech Republic they are built sporadically; a few years ago there was a new one created next to the hotel Moravia in Boskovice (Blansko District).

Temporal delimitation: The project dates back to 1865; the construction took place in 1867.

Typical representative: see number of occurrences

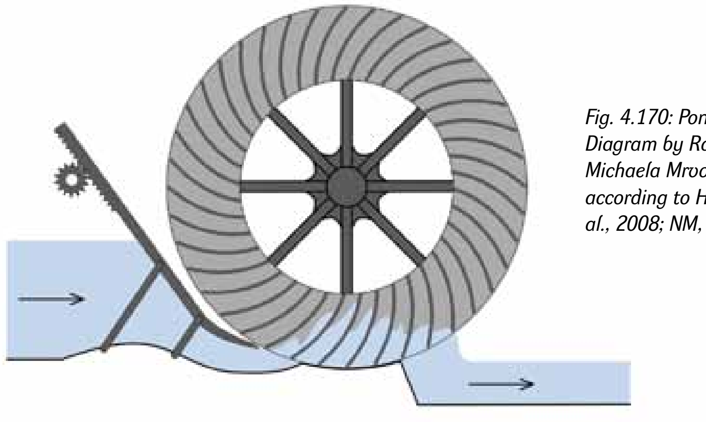


Fig. 4.170: Poncelet water wheel. Diagram by Radka Račoch and Michaela Mrvová, 2021 (modified according to Hýbl, 1922; Štěpán et al., 2008; NM, 2021).

4.4.7.1.1.12 Poncelet water wheel

An undershot water wheel with paddles curved in one direction throughout their depth. Similarly to the Zuppinger waterwheel, the shape of the paddles eliminates losses of water energy. It uses only kinetic energy of water and it can be used from a minimum hydraulic head but with a high flow. It uses in a specific way both the kinetic and the potential energy of water – water on the curved paddle runs upwards, loses the kinetic energy and by means of gravity pulls the curved paddle downwards which makes the water wheel spin. This water flows out perpendicularly downwards, therefore there must be a stilling basin, i.e., a sufficient space directly under the Poncelet water wheel and not only behind it.

The structure of this water wheel was designed by a French physicist, mathematician and engineer Jean-Victor Poncelet around 1826 (Hýbl, 1922; Štěpán et al., 2008).

Explanation: A Poncelet water wheel can be recognized in situ precisely according to the stilling basin located under the water wheel. Without a properly positioned stilling basin, the efficiency of this type of water wheel decreases rapidly.

4.4.7.1.1.13 Sagebien water wheel

An undershot water wheel with straight blades but mounted tangentially, i. e. opposite the shaft but out of its longitudinal axle. The direction of the tangential mounting of blades is always downstream. It uses both kinetic and potential energy of water. It can take advantage of high flow rates, but at the same time, a minimum head is sufficient.

This water wheel was constructed by a French engineer Alphons Eléonor Sagebien after 1848 (Hýbl, 1922; Štěpán, 1990; Štěpán et al., 2008).

Explanation: Although it is not a bucket type of water wheel, it uses both kinetic and potential energy of water.

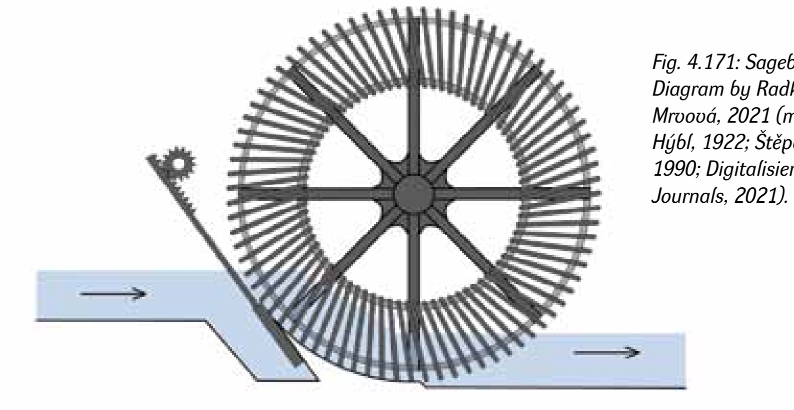


Fig. 4.171: Sagebien water wheel. Diagram by Radka Račoch and Michaela Mrvová, 2021 (modified according to Hýbl, 1922; Štěpán et al., 2008; Štěpán, 1990; Digitalisierung des Polytechnischen Journals, 2021).

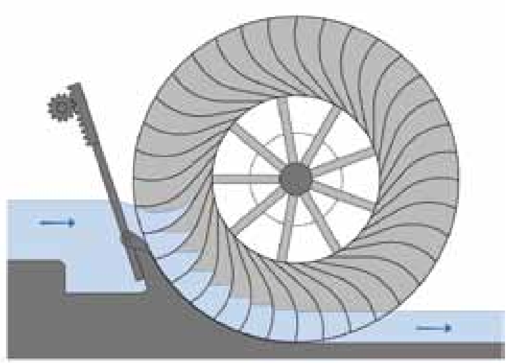


Fig. 4.172: Zuppinger water wheel. Diagram by Radek Míšanec, 2021 (modified according to: Hýbl, 1922).

4.4.7.1.1.14 Zuppinger water wheel

An undershot water wheel with blades which are straight at least up to half of their length but curve significantly at their outer end. The blades are mounted tangentially to the shaft, i.e., opposite the shaft but not perpendicular to its longitudinal axis. Water energy losses are thus eliminated by the fact that water does not hit the blades during the inflow and when they surface, no losses occur as the blades do not decelerate the wheel in the water. The efficiency of this water wheel is increased by the use of a "masonry breast", i.e., a rounded trough which prevents water from flowing out of the space between the blades too early.

This water wheel design was patented by a Swiss engineer Walter Zuppinger in 1849 (Hýbl, 1922; Štěpán et al., 2008).

Explanation: The Zuppinger water wheel is easily distinguishable from other more recent water wheel types due to the typical, pronounced curvature of the blades at their outer ends.

4.4.7.1.1.15 Horizontal water wheel

A type of a water wheel with a vertical shaft, the rotor is formed by either a wooden or a metal wheel radially separated into small chambers or composed of wooden spoons set in a hub with a slight rotation in the axis. The water flows onto them through an obliquely placed pipe, usually topped with a metal nozzle, or even just a simple and open at the top, obliquely mounted trough.

Fig. 4.173: Sibiu (Romania), Astra – horizontal water wheel. Photograph by Radim Urbánek, 2011.

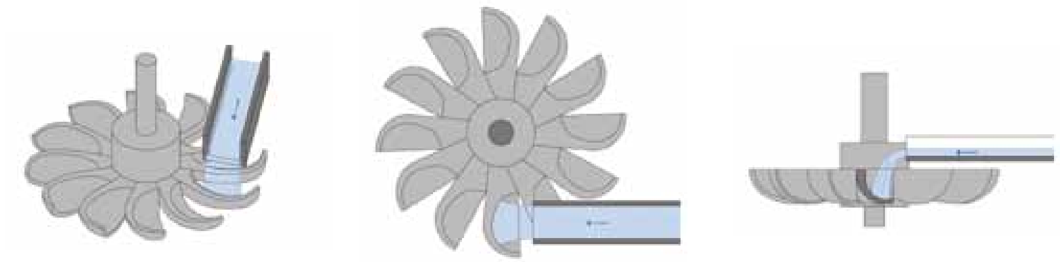


Fig. 4.174: Horizontal water wheel. Diagram by Radek Míšanec, 2021 (modified according to: Zeising, 1612).

It is common in Bosnia, Bulgaria, Croatia, Romania or Greece. However, back in the 19th century it was not a rarity, for example, in Denmark, France, Italy, Portugal, Austria (Carinthia) and Spain. In the Czech lands it was not usually built but it has been preserved in neighbouring Germany (Belidor 1782; Lastanosa 1601, 1700; Lucas, 2006; Moog, 1994; Štěpán el al., 2008; Urbánek, 2002; Zeising, 1612).

Explanation: A variant with spoon-shape paddles resembles rather a very simple turbine in appearance and function. After all, it is very close in function to a Pelton turbine, as the water changes the direction in the spoon paddles and returns in the opposite direction. So it operates on the principle of action and reaction on the paddles.
Number of occurrences: Not built in the CR.
Temporal delimitation: Used from the Antique period, for example in Romania it is built until the present day.

4.4.7.1.2 Associated structures

4.4.7.1.2.1 Anti-freezing chamber

A masonry, concrete (but also reinforced concrete) or wooden structure in which a water wheel was mounted. The name refers to its main purpose – it protected the water wheel from ice.

Most of these chambers did not have roofs but for winter they could have been closed with round logs covered with conifer branches. When there was snow, the whole area was thermally insulated. The incoming water "heated" the chamber to a temperature just above freezing point (Štěpán and Křivanová, 2000).

Explanation: The anti-freezing chamber has a variety of solutions. However, what is essential is that it contains a water wheel in its interior. If there is a water turbine present, this occurred secondarily. Nevertheless, this is quite common in the case of water-powered structures.
Number of occurrences: Very common, there have certainly been more than 1,300 structures preserved in the Czech Republic.
Temporal delimitation: It existed from the High Middle Ages but its construction certainly has an older tradition.
Typical representative: Tužín 36 (Jičín District), Rudoltice 9 (Ústí nad Orlicí District), Žďárec u Skutče 37 (Chrudim District)
Unique example: Hoslovice 36 (Strakonice District)

4.4.7.2 Water turbines and pumps

A significant variety of locations for the use of water energy entails the need to use turbines of various types, outputs, dimensions and design solutions according to specific hydrological and morphological conditions of the installation site. This fact is related to the need to introduce a uniform basic terminology, which allows precise classification and integration of the machine (Bednář, 1989).

The water turbine represents a type of water motor and as such consists of three basic parts:

- equipment for water supply to the turbine runner,
- turbine runner,
- equipment for water diversion from the turbine runner.

As it evident from Fig. 4.177 (A–C) water supply to the turbine runner is most often made up of a scroll case or spiral, which ensures an even water supply to the turbine guide vanes. A boiler water supply was also used in the past Fig. 4.177 (D). The guide vanes, together with the upper and lower blade ring, form a turbine distributor which is usually solved as a regulating and closing device of the machine. Another option, used for example in the Pelton turbine, is the solution of the water supply to the runner by means of a nozzle, in which a needle for regulating and closing the flow is positioned (Bednář, 1989). In the device supplying water to the runner, a partial or complete transformation of the pressure energy into the kinetic energy of water occurs. The runner is the working part of the water turbine. In its circular rotating blade grill, a process of converting the energy of water into mechanical energy of the rotating blade grill occurs.

The device for water diversion from the runner of full admission turbines is basically a diffuser – a draught tube. In the case of partial admission turbines, the device for water diversion from the runner is usually designed as a casing, the purpose of which is not only to catch and divert water from the runner but is usually also the supporting structure of the runner and the entire control system (Bednář, 1989).

Contemporary types of water turbines can be classified according to different aspects. We will list three of them, which are sufficient for a closer specification of any modern turbine including reverse turbines (Bednář, 1989). Depending on how the energy of water is transferred to the runner, we recognise (see Fig. 4.175):

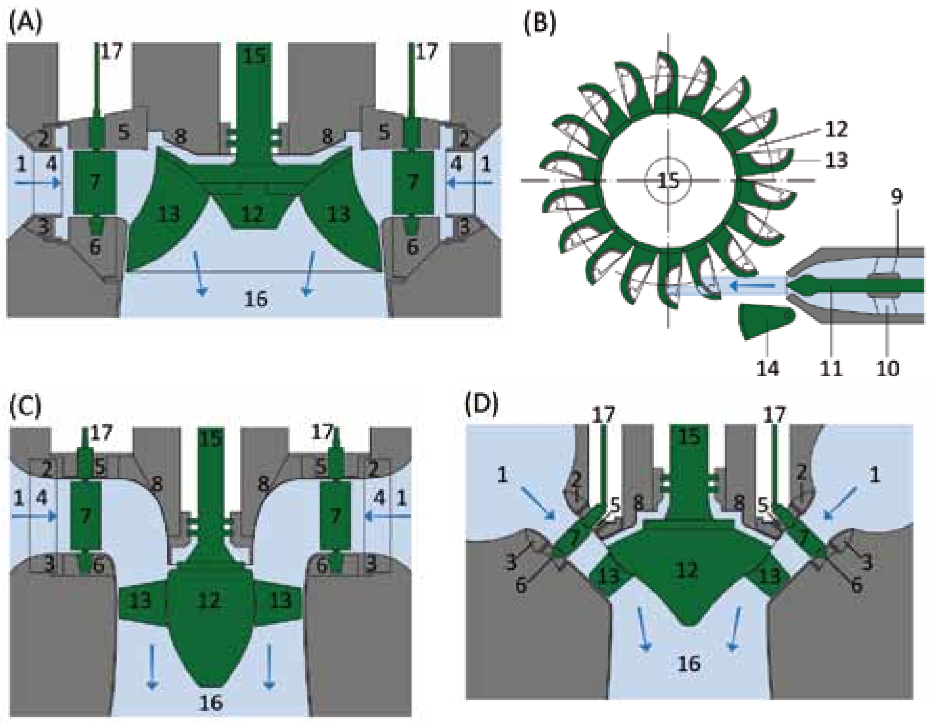


Fig. 4.175: Modern turbine solution diagrams: (A) Francis turbine; (B) Pelton turbine; (C) Kaplan turbine; (D) Deriaz turbine; 1 – spiral, 2 – upper stationary ring, 3 – lower stationary ring, 4 – stationary blade, 5 – upper blade ring, 6 – lower blade ring, 7 – guide vane, 8 – turbine lid, 9 – nozzle, 10 – guide blade, 11 – regulating needle, 12 – runner. Diagram by Radek Míšanec, 2021 (modified according to: Bednář, 1989).

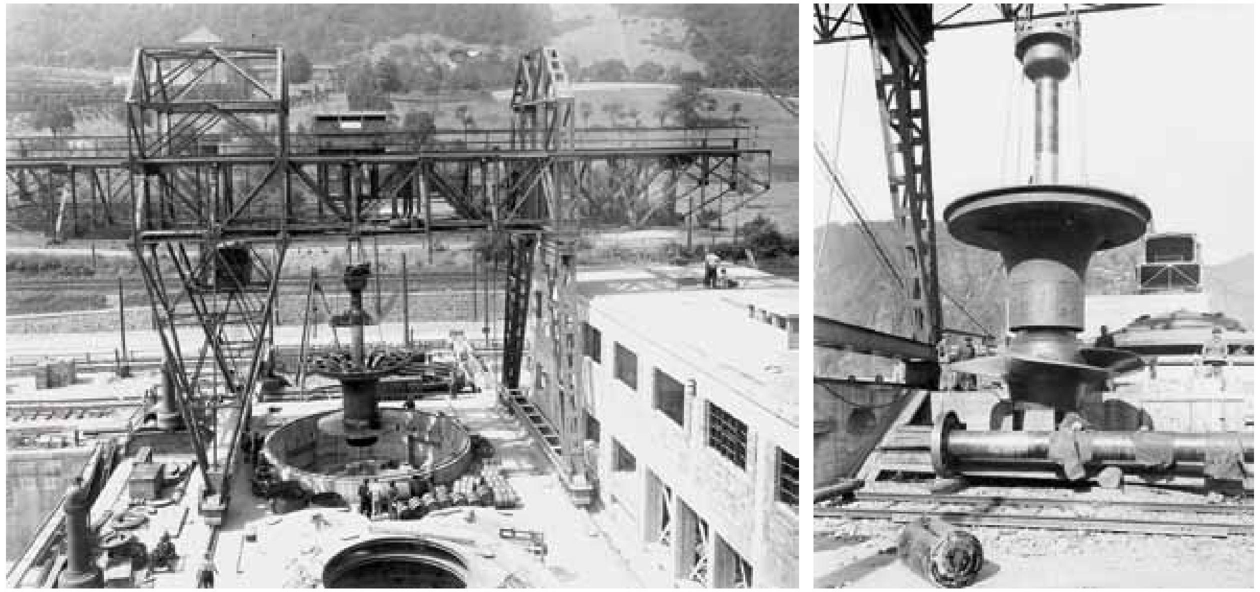


Fig. 4.176: Střekov HPP – a machine set with a vertical Kaplan turbine – installation of a runner (taken from: the Povodí Labe, s.p. [Elbe River Basin] archive).

- **Impulse turbines** where the entire pressure energy of water transfers already in the device for water supply to the runner (e.g., nozzle) into kinetic energy which is subsequently used in the runner. At the input and output of the runner there is consequently the same pressure. The water flow does not fully fill the run-of-river channels of the runner whose surrounding area must be filled with air. The impulse turbines include, for example, the Pelton turbine.
- **Reaction turbines** in which only part of the pressure energy of water transfers in guide wheel channels into kinetic energy. During the outflow from the guide wheel channels part of the pressure energy remains and this changes to kinetic only during the flow through runner blades. The hydrostatic pressure therefore reduces from the inlet to the runner channels toward the outlet, which means there is an overpressure in them. The use of the rest of the energy carried by the water flow exiting the runner at high speed is enabled by the turbine draught tube. The speed of the water flow decreases smoothly in it. Reaction turbines include, for example, Kaplan, Francis and Deriaz turbines.

According to the water flow direction through the runner in relation to the runner axis, we recognize the following turbines (Bednář, 1989):

- **Axial-flow** – the flow direction is approximately parallel to the turbine shaft (e.g., The direct-flow Kaplan turbine, the Jonval turbine).
- **Radial-flow** – the flow direction in the runner is approximately perpendicular to the turbine shaft axis. The water flow can be directed either to the shaft or vice versa. Depending on this, turbines can be:
  - centripetal – with outer water inflow with water flowing through the runner towards the shaft (e.g., slow-running – the historical Francis turbine),
  - centrifugal – with inner water inflow with water flowing through the runner away from the shaft (e.g., the Fourneyron turbine).

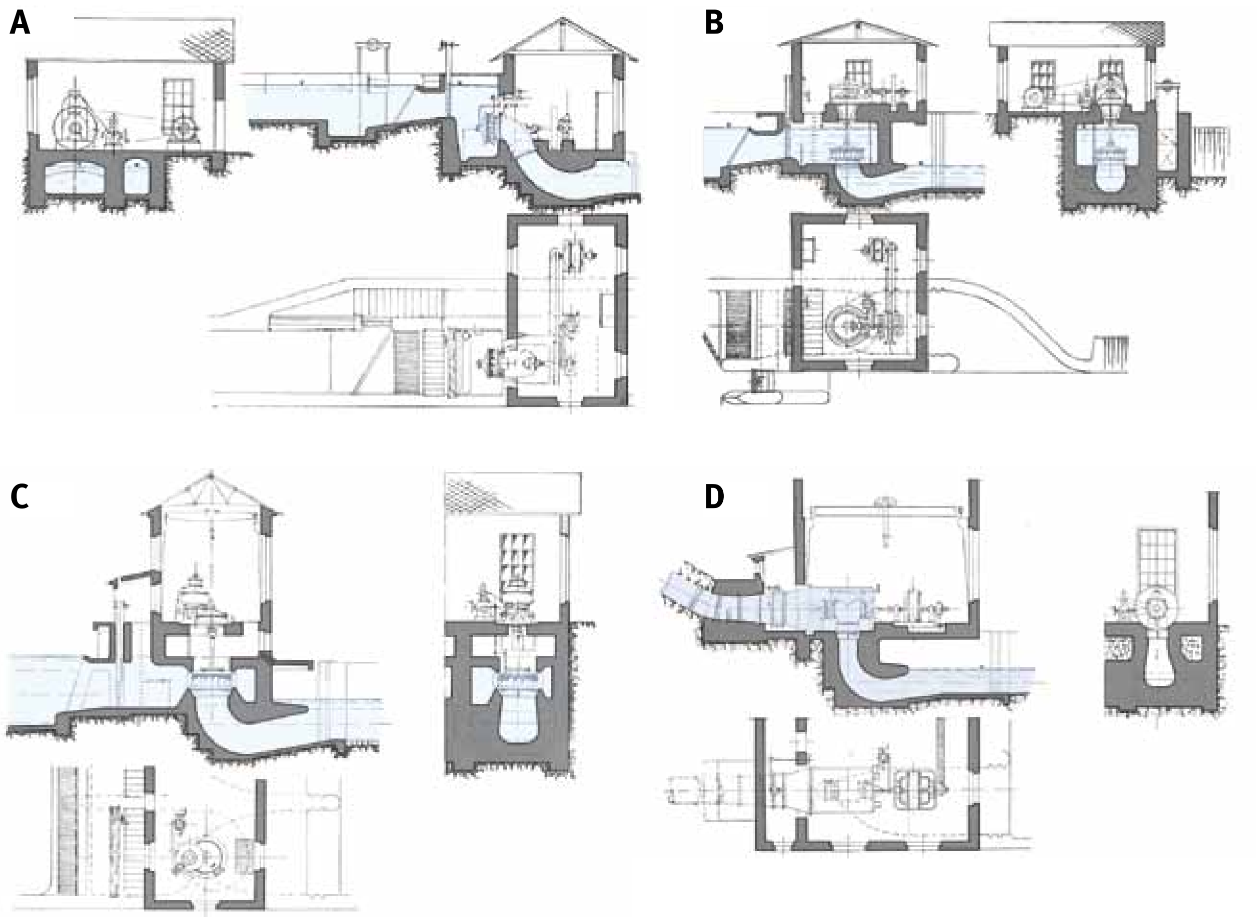


Fig. 4.177: Turbine water supply: (A) and (B) scroll case; (C) concrete spiral; (D) boiler water supply. Diagram by Radka Račoch, 2021 (modified according to: Nechleba, 1962)

- **Mixed flow** – flow direction in the runner changes from axial to radial or vice-versa (e.g., fast-running – the modern Francis turbine).
- **Diagonal-flow** – flow direction in the runner is diagonal in relation to the shaft (e.g., the Deriaz turbine);
- **Tangential** – water jet acts in the tangential direction on the runner (e.g., the Pelton turbine).
- **Cross-flow** – water enters the runner centripetally and exists centrifugally (e.g. the Banki turbine).
- **Inclined flow** – water enters on the runner blades laterally and exits in the axis direction (e.g., the TURGO turbine).

Depending on the shaft position, turbines can be divided into:
- vertical (most of the turbines except for direct-flow ones),
- horizontal (especially large direct-flow turbines),
- inclined flow (e.g., smaller direct-flow turbines).

Current water turbines used in the construction of hydroelectric power plants are based on the use of three basic variants of solutions – the Kaplan, Francis and Pelton turbines. During the operation of a hydroelectric power plant, one of the main criteria is the optimal use of the hydropower potential of the site. Therefore, the turbine accessories also include the application of a suitable regulation system. Pump or reverse turbines are also used for pumped storage hydropower plants in the case of which the function of a water turbine and a pump is combined. They can work in both ways of operation (pump and turbine) with relatively high efficiency. Aforementioned turbines are described in more detail in the following paragraphs (Bednář, 1989).

4.4.7.2.1 Kaplan turbine

The Kaplan turbine can be referred to, in accordance with the aforementioned classification, as an axial-flow reaction turbine. The runner has blades without an outer rim mounted on the hub which is connected to the shaft flange (see Fig. 4.175, Fig. 4.176). The determining dimension of the turbine is the largest diameter of the runner chamber. A characteristic feature of the Kaplan turbine is the possibility of continuously changing the angle of the runner blades during operation depending on the size of the required turbine power while simultaneously changing the opening of the distributor accordingly, which represents so-called double regulation allowing the control of the distributor and the runner. This design solution can increase the mean efficiency values within the operating mode control range (Bednář, 1989).

Other variants of the Kaplan turbine solution are also used, they are referred to as a Thomann turbine or Semi-Kaplan turbine (with an adjustable runner and fixed distributor) and a propeller turbine (with fixed runner blades and adjustable distributor) and several arrangements of direct-flow turbines. Their hydraulic profile is usually axially symmetrical with the axial distributor. The most common types of the construction arrangement of direct-flow turbines are:
- with a bypass generator,
- with a generator in the shaft (PIT),
- with a water-flow generator,
- with an outer generator (connection by belt or cone transmission, direct outlet of the shaft outside the turbine – so-called S-turbines).

Number of occurrences in the CR: Together with the Francis turbine the most widespread type in the Czech Republic.
The oldest documented representative in the CR: The first Kaplan turbine with the runner 1,800 mm in diameter was according to (Slavík, 1976) experimentally installed and tested in the power plant in Poděbrady (1920). Subsequently, this machine was moved and permanently installed at the Nymburk SHPP where it has been preserved in operation until now. Another one of the oldest installations of Kaplan turbines can be identified in the Kroměříž SHPP (1923).
The most recent use in the CR: As the last major installation can be identified the horizontal direct-flow Kaplan turbine in the PIT arrangement with the runner 5,100 mm in diameter at the Štětí SHPP on the Elbe River. Together with the České Kopisty SHPP, they represent direct-flow Kaplan turbines with the largest diameter of the runner installed in the Czech Republic.
Typical representative: A typical use of the Kaplan turbine is represented by e.g. the Vltava River Cascade HS and hydroelectric power plants on the Elbe.
Unique example: The Kroměříž SHPP, where one of the first Kaplan turbines in the Czech Republic were installed, can be described as a unique example.

Fig. 4.178: Production of the Francis turbine runner for the Miřejovice SHPP (taken from: ČKD Blansko company materials).

4.4.7.2.2 Francis turbine

Francis turbines are mixed flow reaction turbines. An example of a construction solution can be seen in Fig. 4.175. The runner is equipped with fixed blades (see Fig. 4.178). The determining dimension is the largest diameter at the input edge of runner blades. The power control element is a rotating distributor.

Number of occurrences in the CR: Together with the Kaplan turbine the most widespread type in the Czech Republic.
The oldest documented representative in the CR: Machines of smaller outputs started to be used from about the last quarter of the 19th century. The oldest significant installation of Francis turbines in hydroelectric power plants can be identified in the Jindřichův Hradec SHPP (1887) and Písek SHPP (1888).
The most recent use in the CR: unknown
Typical representative: The use of the Francis turbine in the low-pressure weir hydroelectric power plant (Písek SHPP, Kolín SHPP before reconstruction, Mirějovice SHPP before reconstruction, Hradec Králové – Hučák SHPP, Poděbrady SHPP), within the medium-pressure derivation hydroelectric power plant (Spálov SHPP before reconstruction, Žimrovice SHPP), as a reverse turbine in a pumped storage hydropower plant (Štěchovice PSHPP, Dalešice PSHPP, Dlouhé Stráně PSHPP).
Unique example: Francis turbines with a larger number of runners on one shaft represent a unique example, see for example the original vertical-shaft triple Francis turbine of the Štvanice SHPP (at the moment already replaced by direct-flow Kaplan turbines). Another unique example is reverse Francis turbines installed in the Dlouhé Stráně PSHPP, which represent the largest machines of this type in Europe and the second largest in the world.

Fig. 4.179: Rudolfov I SHPP – twin horizontal Pelton turbine at the time of reconstruction. Photograph by Petr Freiwillig, 2012.

4.4.7.2.3 Pelton turbine

Pelton turbines are impulse tangential turbines. The distributor in these machines is replaced by one or more nozzles. The runner is made up of a disc which has blades positioned around the perimeter and divided by a cutting edge into 2 buckets (see Fig. 4.175, fFig. 4.179).
Number of occurrences in the CR: Due to the morphology of the terrain and hydrological conditions in the Czech Republic, Pelton turbines are rather unique installations in mountain areas and in the vast majority they are micro sources.
The oldest documented structure in the CR: The oldest installations, which at the same time represent machine sets with the greatest outputs, include the Rudolfov I SHPP (1927) and the Černé jezero (1930) SHPP.
The most recent use in the CR: unknown
Typical representative and unique example: Due to the small number of installations, it is possible to mark the Rudolfov I SHPP (1927) and the Černé jezero SHPP (1930) as typical representatives and at the same time unique structures.

4.4.7.2.4 Banki turbine

The Banki turbine is a specific type of impulse turbine. It is a cross-flow radial turbine. From the point of view of its use, it is a typical turbine for small hydroelectric power plants. The turbine runner is built up of circular discs between which the runner blades are mounted around the perimeter. The water flows through the runner twice, with the first flow being centripetal and the second centrifugal. The control of the flow and output of the Banki turbine is provided by a regulator which is either a radial valve or a regulating flap (Bednář, 1989).

4.4.7.3 Electrical section equipment

The basic components of a hydroelectric power plant electrical system are:

- hydroelectric alternator,
- alternator outlets,
- generator voltage switch house,
- block transformer,
- transformer outlets,
- outdoor switch house,
- self-consumption transformer,
- electric motors of the main equipment (cranes, pumps, etc.),
- excitation system of alternators,
- auxiliary equipment (disconnectors, switches, circuit breakers, measuring and regulating devices, etc.).

For pumped storage hydropower plants, the scheme is supplemented by an engine that powers a pump or reversible turbine (Broža et al. 1990).

The basic scheme of the hydroelectric power plant has three essential parts (Štoll, 1977):

- for power generation,
- for self-consumption,
- for power distribution.

Electricity is obtained in a hydroelectric power plant by converting mechanical energy (turbines) using a rotating electrical machine on the principle of electromagnetic induction (Faraday's law).

We call all these machines generators and, according to what kind of current they produce, we distinguish (Štoll, 1977):

- alternators (alternating current),
- dynamos (direct current).

Generators working in a hydroelectric power plant are called hydroalternators; those in a thermal power plant are turbogenerators. Turbogenerators usually have a significantly higher number of revolutions than hydroalternators. According to the mode of operation, we further distinguish:

- active and reactive power generators,
- reactive power compensators,
- motor-generators operating either as alternators or as engines.

All these alternating machines can be divided into:

- synchronous,
- asynchronous.

In terms of constructional design, synchronous generators are (Štoll, 1977):

- horizontal (with horizontal shaft),
- vertical (with vertical shaft),
- with inclined shaft (e.g., for direct-flow turbines).

Fig. 4.180: Block transformers: (A) Dalešice PSHPP; (B) Dlouhé Stráně PSHPP. Photograph by Brno University of Technology, Faculty of Civil Engineering, 2019.

In the case of vertical machines, we can make the following classification according to the location of bearings:

- suspension-type vertical alternator,
- support-type alternator,
- umbrella-type alternator.

Transformers can be divided into main ones which are used to output power to the electric power network and self-consumption transformers which supply devices providing the operation of the power plant. The main transformers are either block (directly connected to the alternator) or connecting (used to connect two voltage systems).

4.4.8 FUNCTIONAL COMPLEXES

4.4.8.1 Brno, fulling machine in Husovice

Water wheels were a type of motor powering a wide range of pre-industrial production equipment, including, for example, pumps, hammer mills, mills, saw mills, stamp mills and fulling machines. A functional complex is a combination of this production equipment, water wheels and a hydraulic structure necessary for their operation.

The fulling mill, operating in Husovice on a mill race from the Svitava River, was equipped with three overshot water wheels, each of which powered one fulling mill on the principle of a stamp mill. The fulling mill, together with a weaving manufactory in Velká Nová Street and a dying manufactory in Radlas, worked for a significant textile manufactory, founded in Brno with the state support in the 1760s and later managed by Johann Leopold Köffiler, who laid the foundations of Brno's wool production (which can also be considered as a higher-level functional complex).

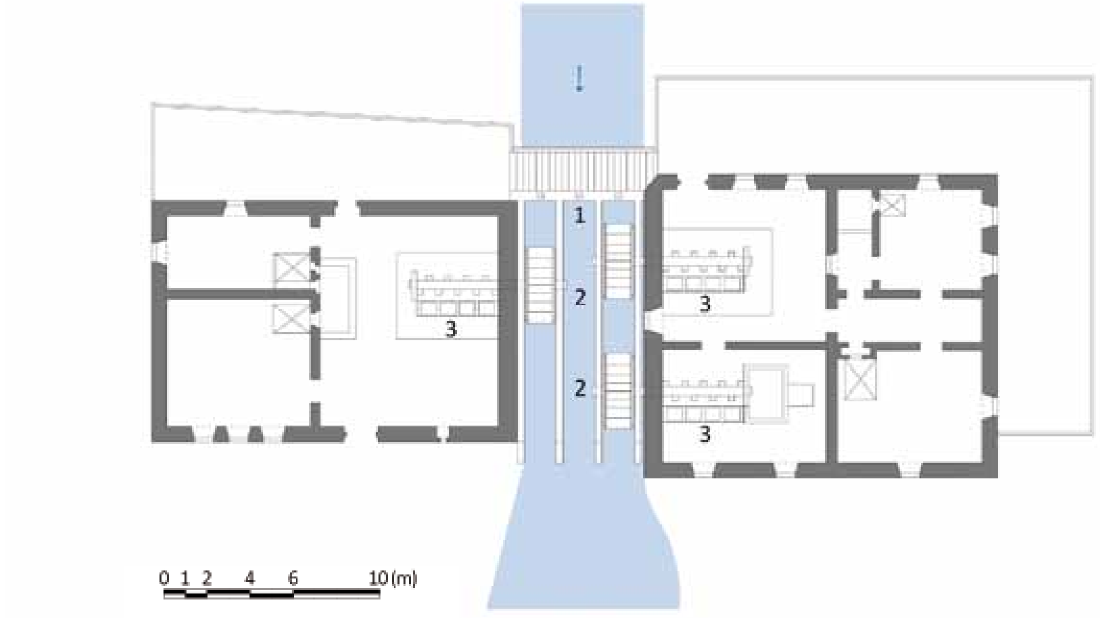


Fig. 4.181: Brno-Husovice – fulling mill, reconstruction of the state at the end of the 18th century: 1 – sluice gate, 2 – water wheel, 3 – fulling mill facilities. Diagram by Radek Míšanec, 2018 (according to: Freudenberger, 1977).

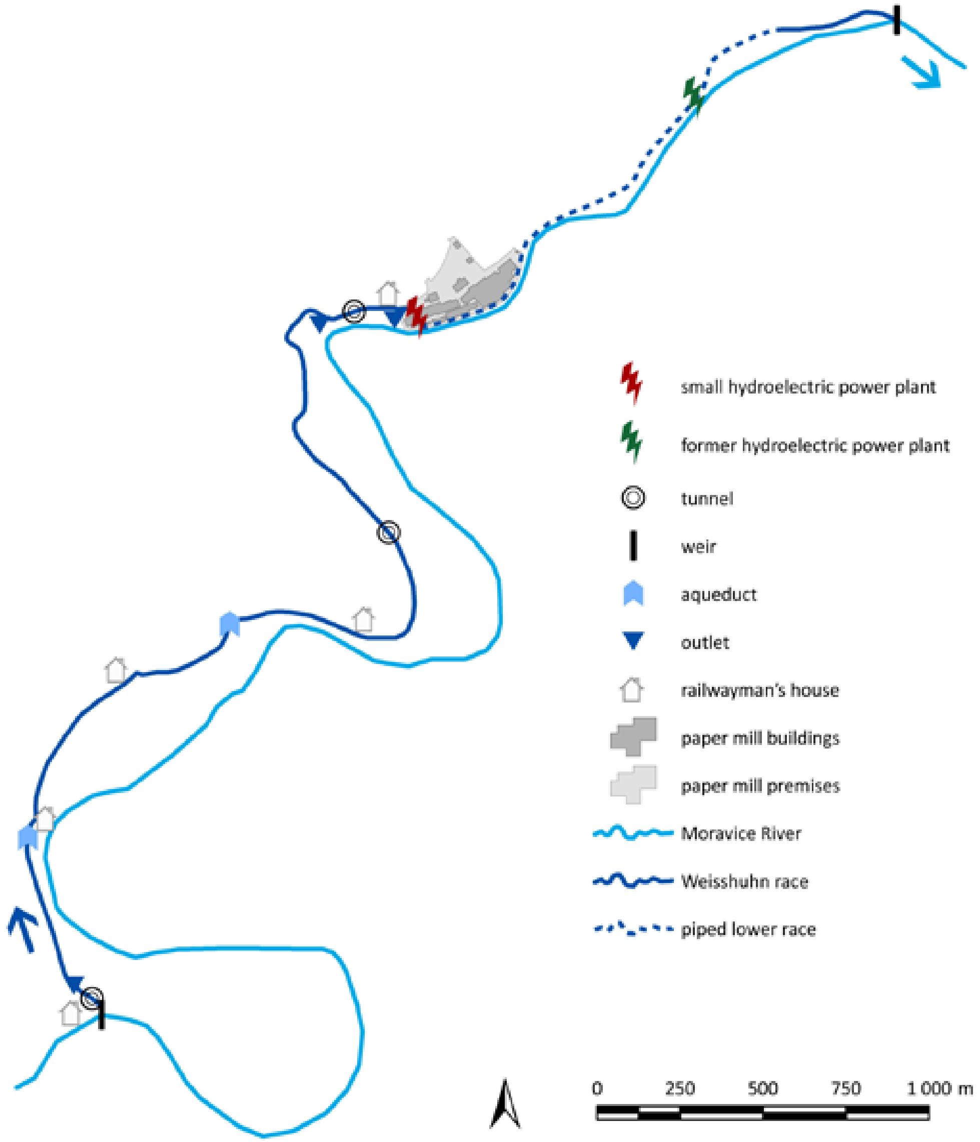


Fig. 4.182: Žimrovice – functional complex of the paper mill with individual important structures indicated. Diagram by Radek Míšanec, 2021 (modified according to: SOkA Opava, karton 1052, 1911–1914).

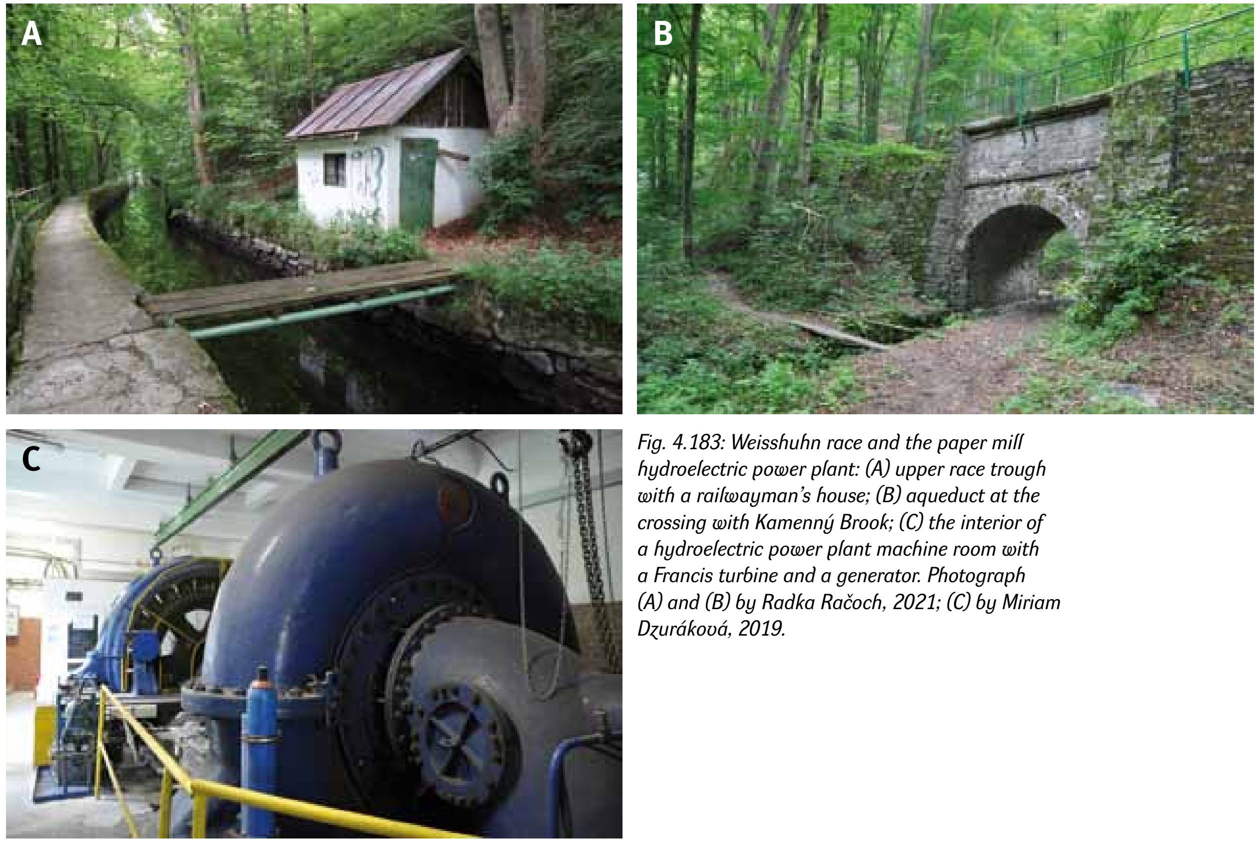


Fig. 4.183: Weisshuhn race and the paper mill hydroelectric power plant: (A) upper race trough with a railwayman's house; (B) aqueduct at the crossing with Kamenný Brook; (C) the interior of a hydroelectric power plant machine room with a Francis turbine and a generator. Photograph (A) and (B) by Radka Račoch, 2021; (C) by Miriam Dzuráková, 2019.

4.4.8.2 Žimrovice, paper mill hydraulic structure and hydroelectric power plant

The paper mill in Žimrovice is located in the valley of the Moravice River near Hradec nad Moravicí in the Opava District. This is an example of water-bound operation, the history of which dates back to the last decade of the 19th century. The company was founded by an important industrial entrepreneur Karl Weisshuhn (1837–1919), who had a paper mill and woodgriding mill in Žimrovice constructed. From the very beginning, the intention was to use modern electricity, which required the construction of a weir on the Moravice River and a mill race, which provided water supply to the paper mill and necessary hydraulic head for the power of turbines (Solnický, 2007; SOkA, karton 44, kronika).

The main element of the original functional complex is the upper race (usually referred to as Weisshuhn) leading from the weir on the Moravice River in the neck of the Moravice River meander approximately 3 km upstream of the paper mill level. At the beginning of the race itself, immediately behind the sluice gate and racks, there is a 45-metre-long tunnel, which is the longest of the three on the route which is about 3.6 km long. The race is conducted along the left slope of the valley where it overcomes two small tributaries of the Moravice River by means of two aqueducts. The trough is mostly 4–5 m wide, rectangular or trapezoidal in shape, and was originally stone-lined except for sections with bedrock. In the section between the last tunnel and the end of the mill race, there are still outlets for crashed ice and dirt, as well as a relic of a wooden trough for navigated timber. There are also railwaymen's houses located along the race. At the end of the upper race there is an inlet structure from where supply pipes to the original eight Girard turbines led, two of which were later replaced by Francis turbines. From the turbines, the water was conducted through a wastewater channel to the Moravice River, but it had to be extended due to the impoundment of water. Later on, this extended outflow was used to power wood grinding mills with a lower power plant located about 1,100 m far away from the paper mill itself (hence the name lower race). The overall length of this race in such an arrangement was 5.5 km (Fig. 4.182). Furthermore, it is necessary to add to it the section of the Moravice River from Nová Pláň, or Malá Štáhle, from where timber was transported to the paper mill, and it was therefore necessary to adopt a number of organisational and technical measures to enable navigation (Dzuráková et al., 2021; Král, 1983; SOkA Opava, karton 44, kronika; SOkA Bruntál, karton 334).

The first major change of the paper mill was its extension by a wood grinding mill with a power plant equipped with two Francis turbines on the lower race, which, however, had to be strengthened with water from the Moravice River. The operation of the wood grinding mill and later also of the power plant was gradually terminated. The production area underwent a much more fundamental change in the second half of the 1920s when the factory was completely reconstructed and the original Girard and Francis turbines of the power plant on the upper race were replaced by two more modern and more powerful Francis turbines made by the company Českomoravská Kolben with a Siemens-Schuckert generator with an output of approximately 2 × 560 kW. The plant is still in operation and has undergone several repairs and overhauls (e.g., in 1984–1985 and 1995). In connection with the replacement of the turbines, it was necessary to modify the ending of the upper race and build new supply concrete pipes.

In 1966 timber navigation was discontinued and in 1972 the company switched to processing recycled paper. In the first half of the 1990s part of the lower race was piped. Parts of the equipment were gradually modernised (hydraulic remote control), however, the upper race, as the main axis of the functional complex, has been serving the operation of the Žimrovice paper mill in its original form for 130 years (Fig. 4.183) (SOkA Opava, karton 1143, Nerealizované zatrubnění dolního náhonu v Žimrovicích v letech 1987–1990; SOkA Opava, prozatímní karton 28; ZAO, prozatímní karton 36, 1955, 1979–1980).

The functional complex of the hydraulic structure and paper mill hydroelectric power plant in Žimrovice is a bearer of a historical, technical and typological value. The hydraulic structure is also a significant landscape element which has blended into the background over the time of operation. The efforts of the current owner to preserve the hydraulic structure, supported by regular maintenance, are positive, as is the growing interest of the public. Despite the aforementioned facts, neither the Weisshuhn race nor other preserved parts of the original functional complex are heritage protected.

4.4.8.3 Dlouhé Stráně pumped storage hydropower plant

The Dlouhé Stráně pumped storage hydropower plant (DS PSHPP) is situated in the Šumperk District, in the western part of the Hrubý Jeseník mountain range where there is an over 500-m difference in altitude between the peak areas of the Dlouhé Stráně mountain and the valley of Divoká Desná Brook. The construction of the DS PSHPP began in 1978 and was completed in 1996. It is a typical pumped storage hydropower plant which takes advantage of the water accumulated in the upper reservoir without a natural inflow, filled by pumping from the lower reservoir at the time of surplus electrical power in the network.

The extensive functional complex consists of: upper and lower reservoirs (basic parameters can be seen in Table 4.1), multipurpose structure (which ends the hydraulic circuit on the low-pressure side and combines the functions of outlets from turbines with gates, flood discharge diversion gated by spillways, two bottom outlets with slide gates, small hydroelectric power plant with the Francis turbine used for operational purposes, intake structure for filling of the upper reservoir and Pelton nozzle for releasing headraces), underground pressure headraces (length 1,547 m and 1,499 m, diameter 3.6 m), underground power plant on the left slope of the Dlouhé Stráně mountain (parameters can be seen in Table 4.2), discharge tunnels, access road, encapsulated switch house on the platform by the toe of the lower reservoir dam and also extra high power voltage (400 kV) line by which the generated power is led to a switch house 52 km away in Krasíkov. (Ústí nad Orlicí District) (Pavelková et al., 2021). The location of individual parts of the structure is shown in Fig. 4.184 and Fig. 4.185.

Several reconstructions were carried out during the 25-year operation of the pumped storage hydropower plant: replacement of the asphalt-concrete casing and rehabilitation of the lower reservoir banks in the vicinity of the multipurpose structure (2007); replacement of turbine runners (2007 and 2012); modernisation of the control system (2007); removal of sediments from the bottom of the lower reservoir (2018).

The functional complex of the Dlouhé Stráně pumped storage hydropower plant is undoubtedly an admirable and, given its parameters, absolutely unique technical work at the European level, the construction of which required the cooperation of the investor of the construction, general designer and general suppliers of the constructional and technological part of the works. In spite of this, it is not possible to completely ignore a certain controversy of this construction resulting from a drastic intervention into the mountain landscape of Hrubý Jeseník, which would hardly be imaginable nowadays. Nevertheless, the ecological benefits of this hydraulic structure are indisputable, even in connection to the current spread of unstable sources of renewable energy (e.g. wind, sun).

Table 4.1: Dlouhé Stráně PSHPP – main parameters of the upper and lower reservoirs (taken from: Kopřiva et al., 1997).

0	**upper reservoir**	**lower reservoir**
Type of dam	earthfill	earthfill
Dam crest elevation [m. a. s. l.]	1,350.00	824.70
Minimum reservoir bottom elevation [m. a. s. l.]	1,322.20	-
Maximum dam height along the axis [m]	27.5	56.5
Dam crest length [m]	1,742.5	306.0
Upstream and downstream slope gradient [-]	1:2; 1:1,75	1:2, 1:1,5
Dam embankment cubage [m^3]	2.025	0.840
Total volume of water [m^3]	2.720	3.405
Max. operational fluctuation of water level [m]	21.8	22.2

Table 4.2: Dlouhé Stráně PSHPP – main parameters of the hydroelectric power plant (taken from: Kopřiva et al., 1997).

installed capacity [MW]	650
number and types of turbines	2 × reverse Francis
Produced by	ČKD Blansko
runner diameter [mm]	4,540
rated turbine flow [m^3/s]	68.6
rated pump flow [m^3/s]	54.5
maximum gross head [m]	534
turbine daily operation [h]	6.54
pump daily operation [h]	7.10
efficiency of a small cycle under the optimum operation [%]	75.1
planned average annual power generation [GWh]	998
planned average annual power consumption for pumping [GWh]	342

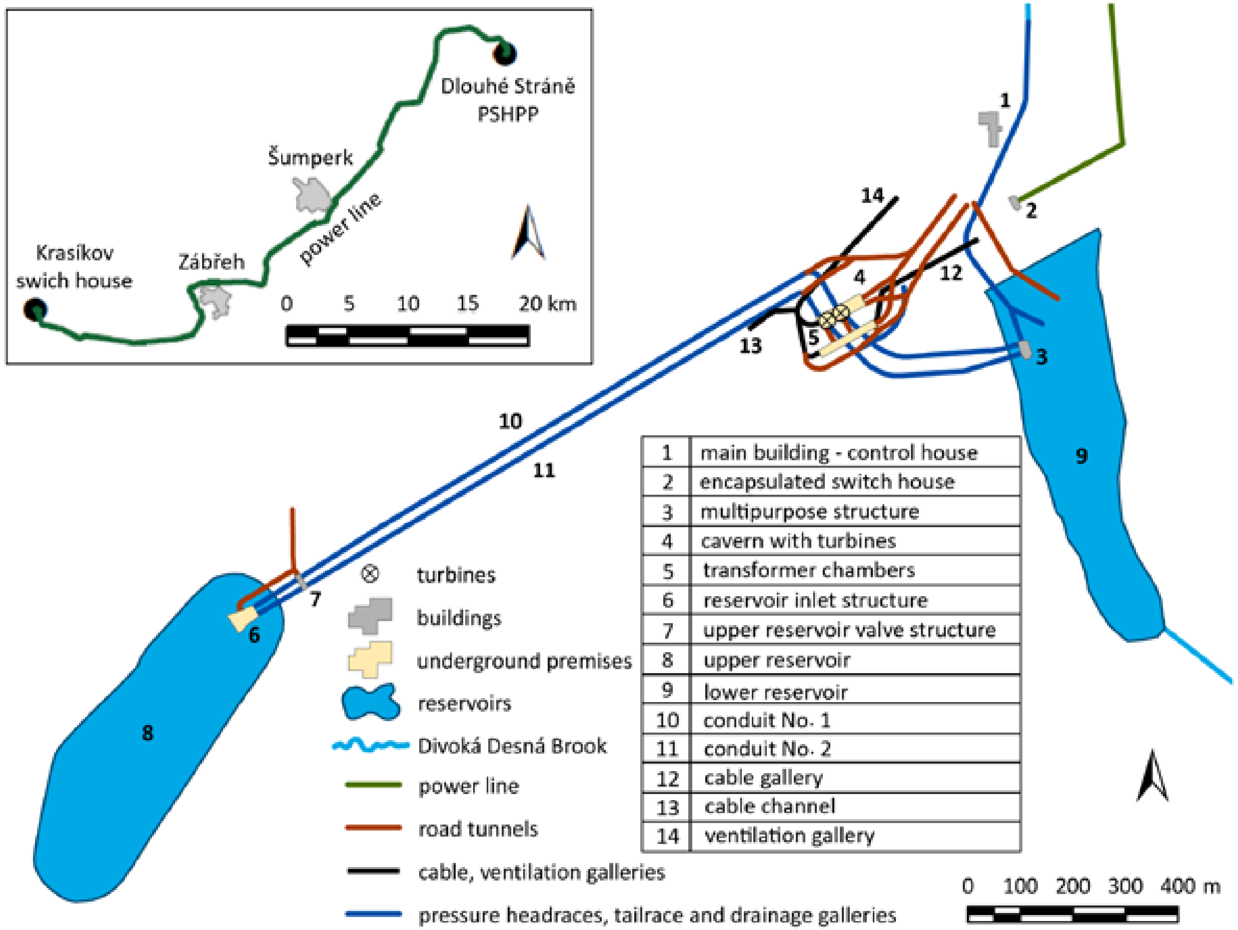


Fig. 4.184: Dlouhé Stráně PSHPP – an overview map, including extra high voltage line. Diagram by Radek Míšanec, 2021 (modified according to: Kopřiva et al. 1997; ZAO – SOkA Šumperk, Dlouhé Stráně PSHPP – overall solution of the construction; RUIAN [Registry of Territorial Identification, Addresses and Real Estate]; ZABAGED [Fundamental Base of Geographic Data of the Czech Republic]).

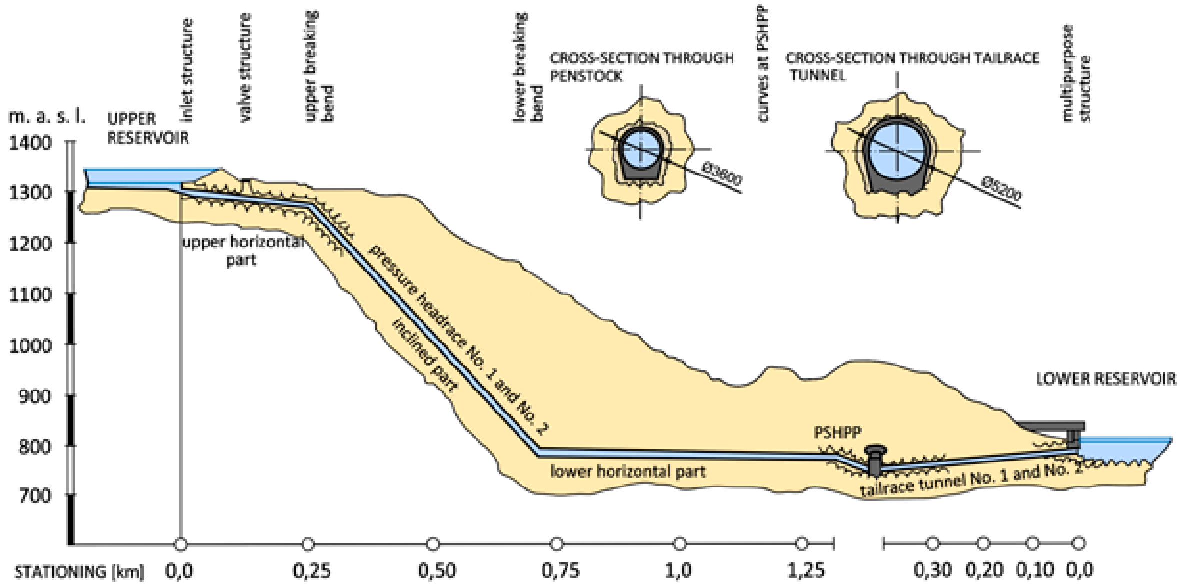


Fig. 4.185: Dlouhé Stráně PSHPP – a hydraulic circuit diagram. Diagram by Radka Račoch and Michaela Mrvová, 2021 (modified according to: Kopřiva et al., 1997).

4.4.9 EVALUATION FROM THE POINT OF VIEW OF HERITAGE PRESERVATION BASED ON SPECIFIC EXAMPLES

4.4.9.1 Rapotín, Poncelet water wheel

The Poncelet water wheel, originally designed to power a water mill (till the 1920s), later a joiner's shop. It is an undershot water wheel with increased inflow. It consists of two wooden and two metal rims. The metal rims carry blades, which are 24 in total and are assembled from plates to achieve a smooth curvature. The water wheel is mounted in a straddle method on a wooden horizontal shaft of an octagonal profile, positioned in wooden sliding bearings. The wheel is composed of both hand-crafted and industrially manufactured parts: shaft, wooden rims, filling of blades with wooden plates and their mounting into sliding bearings; metal parts were manufactured either industrially or in a workshop.

The water wheel is positioned in a former anti-freezing chamber. The shaft passes through a hole in a wall to the premises of a former mill (later a machine room of a workshop) where it was followed by a cast-iron rim and 96 hornbeam pins. Pins fit into the teeth of the cast-iron pinion with 32 teeth which is followed by the so-called front pin wheel with a cast-iron rim with 132 hornbeam pins and six arms.

Time frame: late 1860s (ca. 1867)
Produced by: unknown
Heritage protection: movable cultural monument (including associated mechanical gears, i.e., wheels with a cast-iron rim and hornbeam teeth, pinion and front pin wheel)

Evaluation:

Typological value: The Pancelet wheel from the 1860s, preserved at the place of operation, is a unique structure in the Czech Republic. Apart from that, it is an unusual combination of hand-crafted and industrially manufactured parts.

Value deriving from authenticity:

- **Authenticity of mass/material:** Largely preserved. Despite a long-term lack of maintenance, the wheel has been preserved in a relatively good shape. Several blades were cut out and some of them are infected by rot. Metal elements are oxidised on the surface.
- **Authenticity of form:** Largely preserved, the wheel has not been secondarily modified. Missing or worn out blades can be possibly added.
- **Authenticity of function:** Discontinued, the wheel is not functional. The associated water wheel has been preserved fragmentarily, the race has been largely filled in.

Fig. 4.186: Rapotín – the Poncelet water wheel. Photograph by Michaela Ryšková, 2020.

4.4.9.2 Spálov SHPP

The power plant is situated on the confluence of the Jizera and Kamenice between the towns of Železný Brod and Semily in the cadastral area of Spálov near Semily. The power plant was founded from the initiative of the provincial self-government, that after 1919 tried to create an electrification system of the Eastern Bohemia. It was put into operation in 1924. Water is supplied to the power plant from the backwater of the fixed weir on the Jizera River by a shaft (1,323 m) and concrete hillside channel (580 m) leading along the right bank to a surge chamber with two roller gates, followed by two pressure pipes. In the power plant machine room there were originally two machine sets with the Francis horizontal spiral turbine installed. Water diversion from turbines is solved by a short open channel. The machine house is adjacent to a switch house. Part of the hydraulic structure is also a free-standing house for operation, weirman and aqueduct. At present, there are two machine sets with the Kaplan vertical elbow turbine (Jandáček, 2000).

Temporal determination/date of origin: 1921–1926
Authorship: Dr. Ing. Antonín Jílek, arch. Emil Králíček; construction realisation by the company Nejedlý a Řehák (Beran and Valchařová, 2007)
Heritage protection: without heritage protection
Reconstruction:
1998–1999 – Overhaul: the original machine set was replaced by the Kaplan turbines Kössler from Austria and generators Škoda Plzeň; necessary modifications were made to the machine room, repairs to the supply channel and a new control workplace was established. The outer casing of the machine and switch rooms was also repaired.

Evaluation:

Typological value: Originally designed as medium pressure, derivation, run-of-river, semi-peak, hand-operated. Original equipment not preserved. Currently, the power plant operates with a unique original hydraulic circuit, which includes typical elements of a diversion scheme (weir, intake structure with a settling zone, headrace consisting of an inlet gallery, covered reinforced concrete hillside channel and side residual overflow with a siphon, surge chamber and pressure pipelines). In order to ensure the corresponding operational parameters of the hydraulic structure, two original machine sets with the Francis turbine were replaced by two modern machines with the Kaplan turbine. The installation took place sensitively with minimal interference into the construction part of the machine room.

Value deriving from the technological flow: The hydroelectric power plant is part of the functional complex of the Spálov hydraulic structure which allows water supply and the use of the hydraulic head for the operation of the power plant. The power plant supplies electricity to the public network.

Value deriving from authenticity:

- **Authenticity of function:** Preserved.
- **Authenticity of form:** The reconstruction of the building was carried out with respect to architectural values.
- **Authenticity of mass/material:** The replacement of the original turbine required construction modifications in the machine room (change of layout).
- **Authenticity of technical equipment:** Not preserved, the original machine set was replaced by the Kaplan turbines. One of the original Francis turbines is located in front of the power plant. A new control workplace was established in the switch house; the original one has been preserved.

Architectural value: The complex of the hydroelectric power plant buildings belongs to the late works of Emil Králíček, an outstanding architect of the geometric Art Nouveau and later cubism, and it was created simultaneously with the complex of buildings of the Union of Economic Cooperatives in Prague-Holešovice. Unlike the utilitarian economic buildings in Prague-Holešovice, the power plant building in Spálov is designed in the then popular “national style” with colourful geometric shapes on the facade (Lukeš et al., 2005).

Art-historical value: In the interior of the machine room above the gallery there is a painting by Ferdinand Rubeš with a motif probably resembling the creation of the power plant union (Beran and Valchařová, 2007).

Landscape/urban value: The complex of the power plant buildings and its hydraulic structure of high architectural quality is situated in the valley of the Jizera River. A significant landscape element, a local dominant.

4.4.9.3 Mířejovice SHPP

The Mířejovice SHPP is part of a hydraulic structure which consists, apart from the power plant, of a two-bay gated weir, two lock chambers situated in a row and a log chute. The SHPP itself is located on the left bank of the Vltava River next to a lock chamber in the cadastral area of Nelahozeves (Fig. 4.187). The original needle and overhead bridge was built in the early 20th century. In the 1920s, the weir gate was replaced by roller gates and the sluice part of the weir was replaced by slide gates. The SHPP was also built in this period.

Temporal determination/date of origin: 1900–1904 (lock and overbridge weir), 1922–1928 (power plant)
Authorship: prof. Jan Záhorský (overbridge weir from 1900–1904); architect František Sander (power plant); realisation: Ing. Feigl (realisation of the race), company Kapsa a Müller (reconstruction of the weir in the 1920s) Ing. Pokorný, Ing. Peka (power plant) (Dvořáková et al., 2008).
Heritage protection: cultural monument (1966), part of the machine set removed in 2010 (four turbogenerators)

Fig. 4.187: Miřejovice SHPP with a lock chamber. Photograph by Aleš Dráb, 2014.

Reconstruction:
1990s – general reconstruction
2009–2012 – Complex reconstruction of the SHPP technology: four out of the five original Francis vertical machine sets (TG1–TG4) were replaced by Kaplan ones; the original Francis turbine (TG5) underwent an overhaul; on the generator level there were construction modifications necessary for the installation of new vertical generators; modifications of turbine draught tube and equipment for damming the outflow from draught tubes.

Evaluation:

Typological value:

- **Exceptional parameters of structural and technological parts:** The largest hydroelectric power plant on the Vltava River at the time (Dvořáková et al., 2008).

Value deriving from the technological flow: The functional complex is composed of lock chambers, an overbridge weir and a hydroelectric power plant. Part of the Vltava waterway.

Value deriving from authenticity:

- **Authenticity of function:** Preserved.
- **Authenticity of form:** Construction modifications related to the replacement of technology have been carried out: modifications of the draught tubes of turbines, equipment for damming the outflows from draught tubes, foundations for the installation of new generators. A new handling platform was created behind the SHPP building in connection with the extension of the draught tubes.
- **Authenticity of mass/material:** The replacement of the technology required modifications in the construction part (see above).
- **Authenticity of technical equipment:** Four out of the original five Francis machine sets were replaced by the Kaplan ones. The preserved Francis turbine was overhauled. In connection with the replacement, the draught tubes were modified. The historic control room with a control panel has been preserved. A bevel gear of one of the dismounted machine sets has also been preserved (exhibited near the SHPP).

Technical value: One of the original Francis turbines from the 1920s, which underwent an overhaul, is still in operation (see also the authenticity of the technical equipment). An example of the combination of original and modern technology, based on preserving one of several identical parts of equipment and supplementing the production equipment with the current technology.

Architectural value: A complex of buildings in a unified architectural morphology with fading effects of the geometric Art Nouveau, built according to the design of the architect František Sander, author of a number of water management buildings (Dvořáková et al., 2008).

Landscape/urban value: A significant local dominant feature visible from both the Vltava banks, a significant landscape element.

4.4.9.4 General summary of the principles for the evaluation of structures for the use of hydropower

When evaluating structures for the use of hydropower from the point of view of heritage protection, the primary focus on typological criteria is essential. The evaluation of **typological criteria** of hydro-technical constructions consists of the evaluation of the uniqueness of the overall design of the hydro-technical scheme and its individual structures, i.e. constructional and technological parts. In the Czech Republic, there is not currently any unified detailed record of hydro-technical constructions with their typological characteristics. Before the required records are processed, it is necessary, for the purposes of evaluation by typological criteria, to find experts with a wide knowledge of details of constructed hydro-technical structures.

An indispensable criterion is the value of the **architectural solution**. High architectural quality is shown by hydroelectric power plants built mainly in the first half of the 20th century. The architectural rendering corresponds to the streams and tendencies of that period. Significant elements are the modelling of materials and monumentality, which stands out especially in connection with a hydraulic structure (weir, lock chamber) that represent the uniform architectural morphology. However, the attributes of architectural value should not eclipse the evaluation of the actual technological solution of particular structures.

The significance from the point of view of the **landscape** is relevant for the evaluation, especially in cases where the structure is part of a building complex (e.g., dams or locks). On the other hand, the nature of the use of hydropower was based on the specific natural and economic conditions of the given region. For example, hammer mills were created in the areas of raw material extraction, water mills near agricultural areas, etc. Therefore, a man's farming method could have imprinted, through water management infrastructure, characteristic features in the landscape and the given structure could be its historical document.

Structures for the use of hydropower (most often hydroelectric power plants) were built especially in the early 20th century and in the inter-war period in the urban environment, so the **urbanistic** value can also be an important aspect of the evaluation. It has already been said that the architectural rendering was paid considerable attention, especially in the first half of the 20th century. Some hydroelectric power plants are located in very exposed locations and their importance for the formation of urban space is therefore essential (for example, power plants on the Elbe and Orlice Rivers in Hradec Králové or the Otava River in Písek).

4.4.10 REGISTER OF LOCATIONS

Name	Protected from	Type of protection	USKP registry number	Item name according to the Monument catalogue	District	Municipality	Cadastral territory
Former HPP in Klatovy	23/05/1991	CM	44206/4-4544	former hydro power plant	Klatovy	Klatovy	Klatovy
Former mill and factory in Chrastava	09/12/2013	CM	105258	outlet part of the millrace and an anti-freezing chamber with a turbine	Liberec	Chrastava	Chrastava I
Bavorov HPP	07/05/1974	CM	23847/3-5249	hydroelectric power plant	Strakonice	Bavorov	Bavorov
Čeňkova Pila HPP	22/06/1995	CM	10033/4-4985	Čeňkova Pila hydroelectric power plant	Klatovy	Rejštejn	Svojše
Dalešice HPP	-	-	-	-	Třebíč	Slavětice	Slavětice
Dlouhé Stráně HPP	-	-	-	-	Šumperk	Loučná nad Desnou	Rejhotice
Háj near Třeština HPP	17/02/1976 01/07/2008	CM NCM	30184/8-2488 326	J. Plhák hydroelectric power plant Třeština hydroelectric power plant	Šumperk	Třeština	Třeština
Hostinné HPP	29/06/1993	CM	12320/6-5627	Labský mlýn hydroelectric power plant	Trutnov	Hostinné	Hostinné
Hrabačov HPP	26/03/1964	CM	16756/6-2624	Vejnar's power plant	Semily	Jilemnice	Hrabačov
Hradec Králové HPP (Moravský most)	20.01.1981	CM	29446/6-4538	Moravský most with a power plant	Hradec Králové	Hradec Králové	Hradec Králové
Hradec Králové HPP (Hučák)	16/01/1964	CM	34888/6-555	hydroelectric power plant on the Elbe	Hradec Králové	Hradec Králové	Hradec Králové
Hřebečníky HPP	04/12/2009	CM	103782	water mill and a hydroelectric power plant with technological equipment of a machine room	Rakovník	Hřebečníky	Hřebečníky
Kolín HPP	-	-	-	-	Kolín	Kolín	Kolín
Kroměříž HPP	30/05/2006	CM	101819	hydroelectric power plant	Kroměříž	Kroměříž	Kroměříž
Les Království HPP	18/04/1964 01/07/2010	CM NCM	24486/6-3435 349	Tešnov in Bílá Třemešná dam and hydroelectric power plant (Les Království hydraulic structure) hydroelectric power plant - Les Království dam in Bílá Třemešná	Trutnov	Dvůr Králové nad Labem	Bílá Třemešná
Libochovice HPP	01/04/1998	CM	10594/5-5623	hydroelectric power plant	Litoměřice	Libochovice	Libochovice
Litoměřice HPP	-	-	-	-	Litoměřice	Litoměřice	Litoměřice
Miřejovice HPP	31/12/1966	CM	25133/2-1424	Miřejovice hydroelectric power plant	Mělník	Nelahozeves	Nelahozeves, Veltrusy
Nymburk HPP	-	-	-	-	Nymburk	Nymburk	Nymburk
Orlík HPP	-	-	-	-	Příbram	Bohostice	Zbonické Zlákovice
Písek HPP	30/05/1991	CM	35283/3-6023	Písek I hydroelectric power plant including machinery	Písek	Písek	Písek
Poděbrady HPP	27/09/2012 01/07/2017	CM NCM	104923 415	hydroelectric power plant Poděbrady hydroelectric power plant	Nymburk	Poděbrady	Poděbrady
Práčov I HPP	-	-	-	-	Chrudim	Svídnice	Svídnice near Slatiňany
Práčov II HPP	-	-	-	-	Chrudim	Svídnice	Svídnice near Slatiňany
Prague-Holešovice HPP	21/06/2002	CM	52008/1-2294	hydroelectric power plant	capital of Prague	Prague	Holešovice
Přelouč HPP	30/12/1987	CM	26996/6-5170	hydroelectric power plant with a bridge	Pardubice	Přelouč	Přelouč
Pstruží near Merklín HPP	10/10/2001	CM	51127/4-5256	water mill	Karlovy vary	Merklín	Pstruží near Merklín
Rokytnice near Vsetín HPP	07/10/2002	CM	52019/8-4076	Křivačkárna hydroelectric power plant	Vsetín	Vsetín	Rokytnice near Vsetín
Rudolfov I HPP	01/07/2014	CM	105393	Rudolfov hydraulic structure	Liberec	Liberec	Rudolfov
Rudolfov II HPP	01/07/2014	CM	105393	Rudolfov hydraulic structure	Liberec	Liberec	Rudolfov
Řimice HPP	26/08/1981	CM	37265/8-2653	hydroelectric power plant	Olomouc	Bílá Lhota	Řimice
Římov HPP	-	-	-	-	České Budějovice	Římov	Římov
Seč HPP	-	-	-	-	Chrudim	Seč	Seč
Slapy HPP	-	-	-	-	Prague-West	Štěchovice	Štěchovice near Prague
Spálov HPP	-	-	-	-	Semily	Semily	Spálov near Semily
Stanovice HPP	31/12/1998	CM	50496/6-6044	water mill with hydroelectric power plant	Trutnov	Stanovice	Stanovice near Kuks
Střekov HPP	-	-	-	-	Ústí nad Labem	Ústí nad Labem	Ústí nad Labem
Veselí nad Moravou HPP	14/11/1994	CM	10221/7-8598	hydroelectric power plant	Hodonín	Veselí nad Moravou	Veselí nad Moravou
Železný Brod HPP	-	-	-	-	Jablonec nad Nisou	Železný Brod	Železný Brod
Žimrovice HPP	-	-	-	-	Opava	Hradec nad Moravicí	Žimrovice

4.5 THE WATERWORKS INDUSTRY

"Waterworks industry is a field dealing with the provision of water to human settlements. It examines the quality and yield of water sources, methods of accumulation and treatment of water, methods of its transport and distribution, and consumers' requirements in towns, industry and agriculture" (Korbář and Stránský, 1961). The waterworks industry is a vast technical field with a long history, which has had a great influence on the development of society and entire cultures. It is already known from history that one of the attributes of a developed civilisation is to provide a stable source of drinking water and to bring it to the centre of a given civilisation. The basic scheme of waterworks is a *source of water + supply to the consumption area + distribution to the consumer*. The individual parts of this scheme have developed and improved during history and with the advent of various technologies, but the basic premise remains.

Definitions of basic terms (Milerski, 2005):

- **collecting structures** – structures for collecting/retaining water (underground, surface and rain):
    - wells, shafts, tunnels, galleries, springs and spring tanks,
    - pumping stations (often referred to *"waterworks"* *);
- **water treatment structures** – individual structures or extensive compounds for the purification of raw water and its further treatment for the needs of subsequent distribution;
- **accumulation structures** – water tanks in general; structures for the accumulation of water before its subsequent distribution to consumers:
    - Ground, elevated** and chimney (a special type in industrial complexes);
- **distribution structures** – individual structures or whole networks intended for water transport:
    - water supply network, water mains (rather local meaning – homesteads, villages, towns),
    - waterworks system (regional or trans-regional importance – water supply to large cities or entire regions).

* "***waterworks***" *– generalised but imprecise term often used in connection with structures of pumping, treatment and accumulation of potable or non-potable water; the term waterworks is used mainly in colloquial language and in old documents including technical ones; the term should be used only in connection with a pumping station (see Klír and Klokner, 1923 – Technický průvodce pro inženýry a stavitele). It is likewise kept in the table of heritage protected waterworks structures, where it is either part of the name of the protected building (used in the declaration of a cultural monument) or a type of item in the heritage protection catalogue from which the data has been taken.*

** *The term* ***elevated water tank*** *designates structures used for the accumulation of water whose bottom is situated above the terrain (for more details see typology), including structures designated as "water towers" in old technical publications. In the historical introduction and in the table listing heritage protected structures and compounds, the term "water tower" is kept.*

4.5.1 HISTORY OF THE WATERWORKS INDUSTRY

4.5.1.1 The beginnings of water supply

The supply of drinking water was an important task for every major civilization and therefore the development of water supplies is closely linked to civilizations of Central and South America, the Mediterranean, the Arabian Peninsula and the Far East. Especially in areas with water scarcity during summer months, the issue of aqueduct construction was crucial. The oldest known aqueduct was built in 2000 BC in Assyria. Pumping wheels were mentioned in the Law of the Babylonian king Hammurabi from 1686 BC. Ancient Romans, who are known for monumental aqueducts, brought water not only to urban fountains and households but also to public baths (the first Roman aqueduct was built in 305 BC).

4.5.1.2 Historical development of water supplies in the Czech Republic

The development of water supply systems in the Czech lands is relatively homogenous. It is possible to divide it into four eras which are determined by technological development:

- **1st era** – water sources and the first private headraces (from the 12th century);
- **2nd era** – water supplies from public water supply systems (from the first half of the 14th century up to the first half of the 19th century);
- **3rd era** – discoveries in the field of hygiene and water treatment (the second half of the 19th century and the beginning of the 20th century);
- **4th era** – quality drinking water, group water supply network (from the end of the 19th century to the current time).

4.5.1.2.1 1st era – water sources and the first private headrace (from the 12th century)

Technological flow of the 1st era: water source → gravity water supply system → fountains.

The supply of water in our lands is connected with the first settlements which appeared in the area of watercourses. Water sources were also provided by wells which had been dug and rainwater and underground water cisterns. It was common that the water was carried on foot or by wheeled container. During water shortages it had to be transported from further distances. Technical innovations from the Antique period were after the fall of the Roman empire forgotten and unused for a long time. The Middle Ages triggered interest in the Antique period due to its technical innovations. Knowledge of gravitational water supply systems at monastic convents saw it introduced to Middle Ages culture. The existence of the first private headraces (ecclesiastical or aristocratic) has been known since the 12th century. Water distribution was carried out gravitationally without the need for any additional source of external power. This system wasn't dependent on accumulation of water in one place. The water was permanently allowed to flow into the place of consumption, most often fountains. The water was necessary for several types of craftsmanship professions (dyers, tanners, maltsters), served to power the mill, used for farming (provision to cattle, watering gardens), used in households for flushing away wastewater. The Roman system of spas, aqueducts and culture of living involving certain hygienic rules developed in Europe no earlier than the 19th century (Petráň, 1985).

Strahov monastery in Prague had this actual water supply system, which was built from 1142 at the same time as the other buildings of the convent. Water from springs was distributed through canals to the monastery building, to the fountain in the well house and from here to the stone trapezoidal piscina in the paradisiacal yard. A Roman aqueduct was used until the 16th century, when the springs were diverted into one new underground tunnel. (Křivský, 1997). From the 12th century Vyšehrad also had an aqueduct. In 1140, Vladislav II turned the trough leading from the well into a pipe (Jásek, 2000).

The prevailing source of drinking water remained watercourses, wells or local springs arising in the surrounding area.

4.5.1.2.2 2nd era – water supplies from public water supply systems (from the first half of the 14th century up to the first half of the 19th century)

Technological flow of the 2nd era: water source → pumps powered by water wheel → overground water tank → fountain.

The year 1215, when the construction of the aqueduct in London was launched, is considered to be the beginning of European water engineering. People in our lands and in Europe started to be supplied with water from public water supply systems on a larger scale no earlier than in the first half of the 14th century. The water supply system of the New Town of Prague is from 1348 (Hlušičková, 2001). Waterworks facilities from this era were usually operational until the 1890s, when they were either upgraded or replaced with a new facility. Along with the central water plant, wells and sub-conduits of tiny springs were used simultaneously as sources of water.

Where it was not possible to lead the water to the water supply point via gravity, a typical kind of water plant for this era came into existence which consisted of a pumping station connected through discharge piping to a water tower (or to a different kind of overground tank) from which via gravity the system of public and private fountains was supplied. Supply water mains were branched out without being interconnected. Machinery was based on water pumping under pressure by means of pumps powered by a water wheel. Pumping stations were often based on pre-existing complexes of water mills which they replaced over time at a given location.

For the second era the construction of water towers is typical (the so-called "Renaissance water towers" era, e.g. Fig. 4.188). The water tank was located on the highest floor of the tower. The towers were built as free-standing structures (e.g. Prague waterworks: Šítkov Water Tower in the New Town, 1495; Old Town Water Tower, 1427, newly built after a fire in 1576, Fig. 4.189, Fig. 4.190; Petržílkovská Water Tower in the Lesser Town, 1582–1596) or became part of the city's fortifications (Jihlava, 1389; Tábor, 1492; Plzeň, 1532; Louny, 1561; Nymburk, 1597 et al.) (Jásek, 1997).

Fig. 4.188: Examples of water towers: (A) Mělník, Renaissance water tower in Pražské předměstí, probably from the 14th century, which forms a free-standing part of the town's mediaeval fortifications; non-potable water from Pšovka Brook was pumped into its tank; it served its purpose until 1882 (Hlušičková, 2002); (B) Nymburk, the so-called Turkish tower from the end of the 16th century was built instead of an older wooden tower. Photograph by Michaela Ryšková, 2021, 2018.

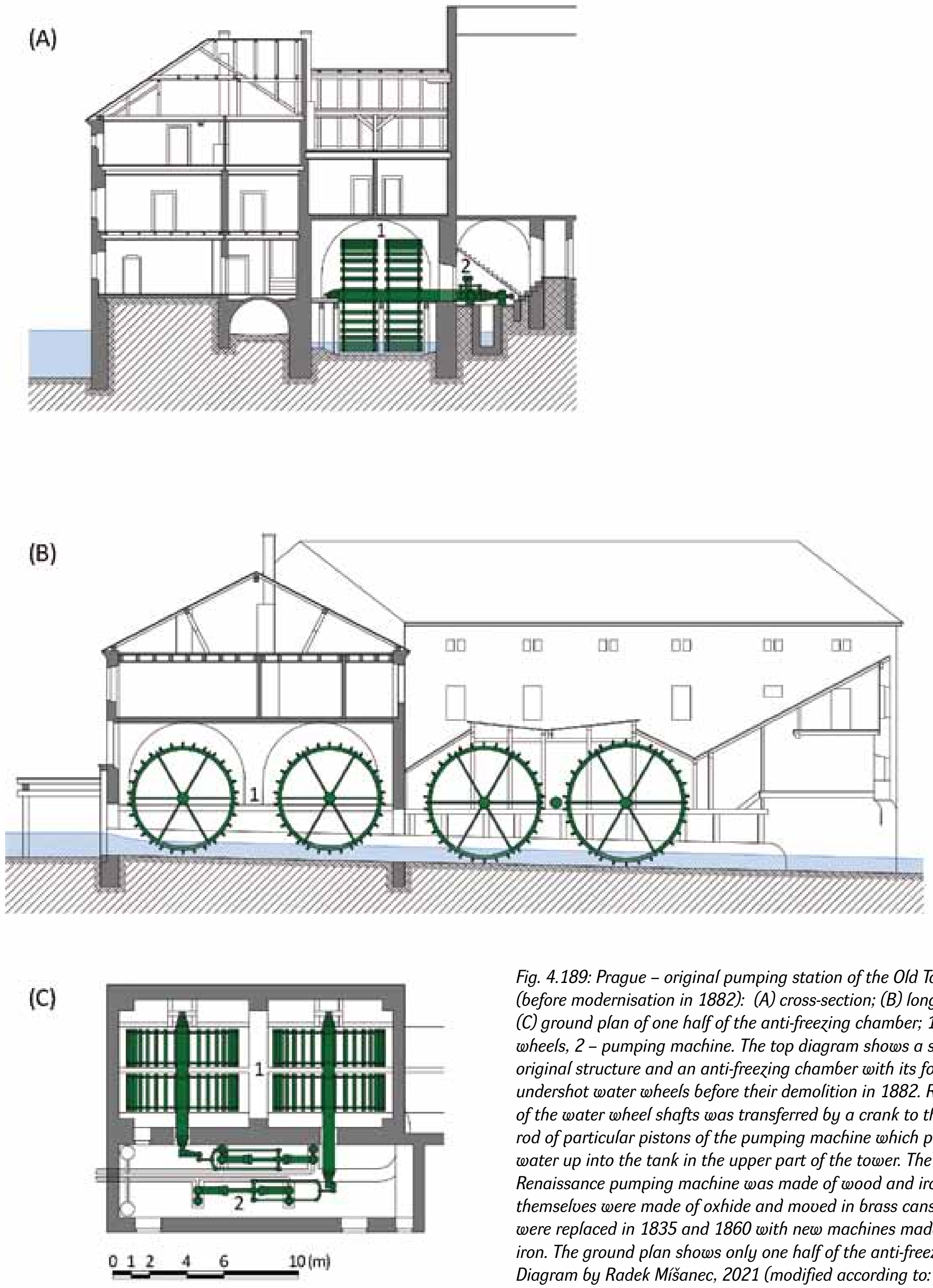


Fig. 4.189: Prague – original pumping station of the Old Town Waterworks (before modernisation in 1882): (A) cross-section; (B) longitudinal section; (C) ground plan of one half of the anti-freezing chamber; 1 – water wheels, 2 – pumping machine. The top diagram shows a section of the original structure and an anti-freezing chamber with its four original undershot water wheels before their demolition in 1882. Rotary motion of the water wheel shafts was transferred by a crank to the connecting rod of particular pistons of the pumping machine which pushed the water up into the tank in the upper part of the tower. The original Renaissance pumping machine was made of wood and iron. The pistons themselves were made of oxhide and moved in brass cans. These pumps were replaced in 1835 and 1860 with new machines made completely of iron. The ground plan shows only one half of the anti-freezing chamber. Diagram by Radek Míšanec, 2021 (modified according to: plan from PVK archive, fonds Fotoarchiv PVK, box N 11, sig. B 013a/88).

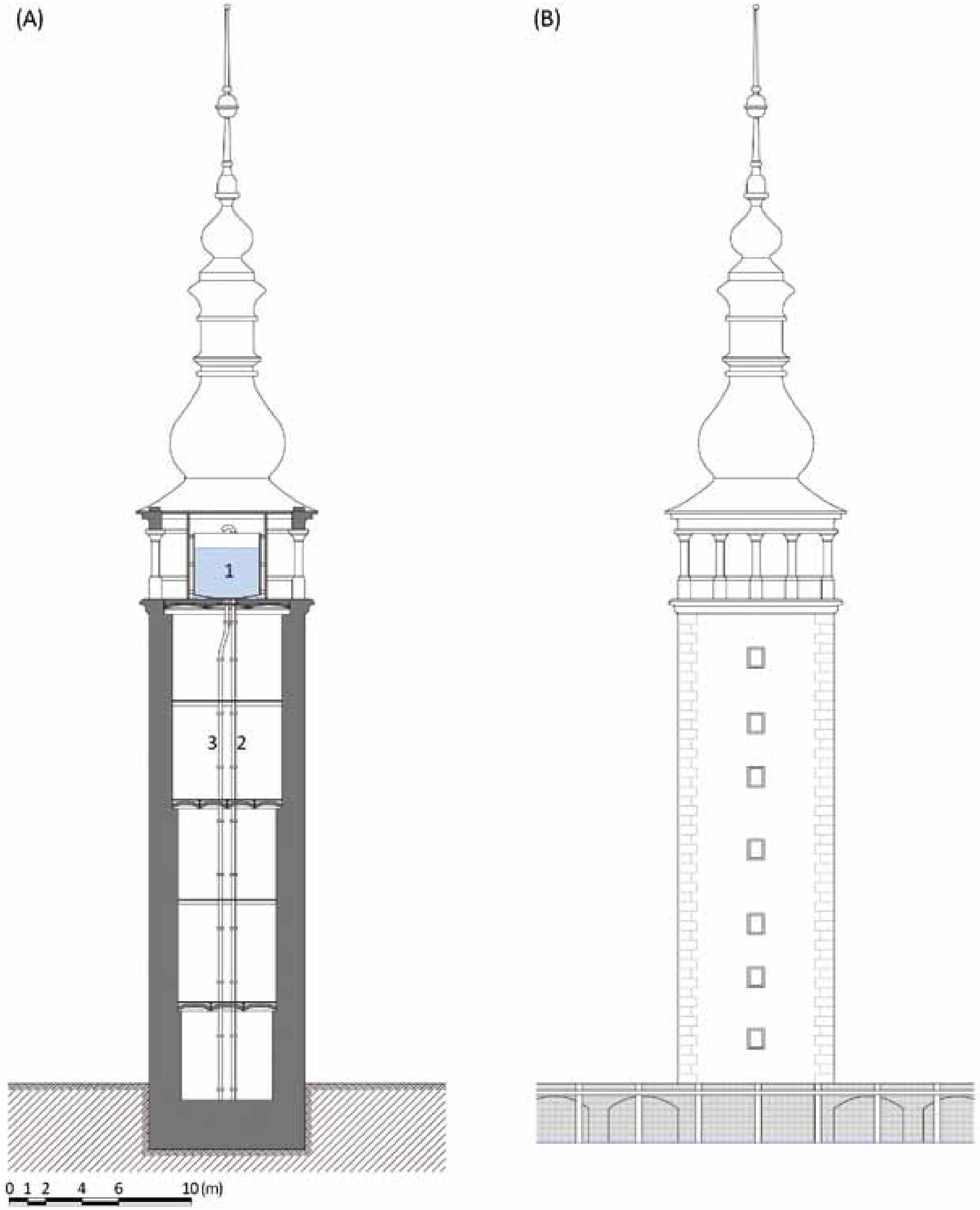


Fig. 4.190: Prague – The Old Town Water Tower was built for the purposes of the Old Town Waterworks: (A) section; (B) elevation; 1 – convex-bottom cylindrical tank, 2 – inlet pipeline, 3 – outlet pipeline. Diagram by Radek Míšanec, 2021 (modified according to: plan from PVK archive, unsign.).

An example of the system from the second era is an aqueduct in Olomouc, which was established in 1514, when King Vladislaus II of Hungary gave permission to the Olomouc chapter to carry water through pipes to Předhradí to the city fountain and canon residences. A waterworks with a water wheel was built by a mill below the St. Klára's monastery. In 1528 the water supply system was taken over by the city. In the first half of the 16th century Olomouc was supplied with water by two additional aqueducts whose pipes were powered by water mills. (Fiala et al., 2010)

Aother example could be České Budějovice, which was up to the start of the 16th century dependent on its well system. Over time contamination of underground water by faeces occurred and the first aqueduct was subsequently built, which transported water through wooden pipes from nearby ponds. At the beginning of the 18th century another aqueduct was built which was based on machine water pumping from the river to the water tower and from the tower the water was transported via gravity to the fountains. This system was modernised many times, however the principle behind the technology remained unchanged until the end of the 19th century when a new modern waterworks was built.

The machinery changed but the technical solution corresponded with the findings of the beginning of the 17th century. The water supply system (discharge powered by water wheel and gravity) remained unchanged until the 19th century.

A higher demand for potable and non-potable water, and development of water management triggered a growth in both local industry and the number of citizens in towns. New water plants, which pumped water from nearby rivers or a system of ponds, often supplied water of lower quality which became a source of epidemics.

After the waterworks operation was decommissioned, the whole water pump was removed. All that remained from these water supply systems were the water towers and fountains.

4.5.1.2.3 3rd era – discoveries in the field of hygiene and water treatment (the second half of the 19th century and the beginning of the 20th century)

Technological flow of the 3rd era: Water source → steam driven pumps → water treatment (sand filtration) → water tanks (various types) → consumption point (households, plants etc.).

The third era could be limited to the second half of the 19th century, but could also extend to the 20th century when it overlaps or, on the contrary, remains separate from the following era. It is linked to the period of industrialisation

Fig. 4.191: Prague – pumping station of the Old Town Waterworks. Photograph by Michaela Ryšková, 2022.

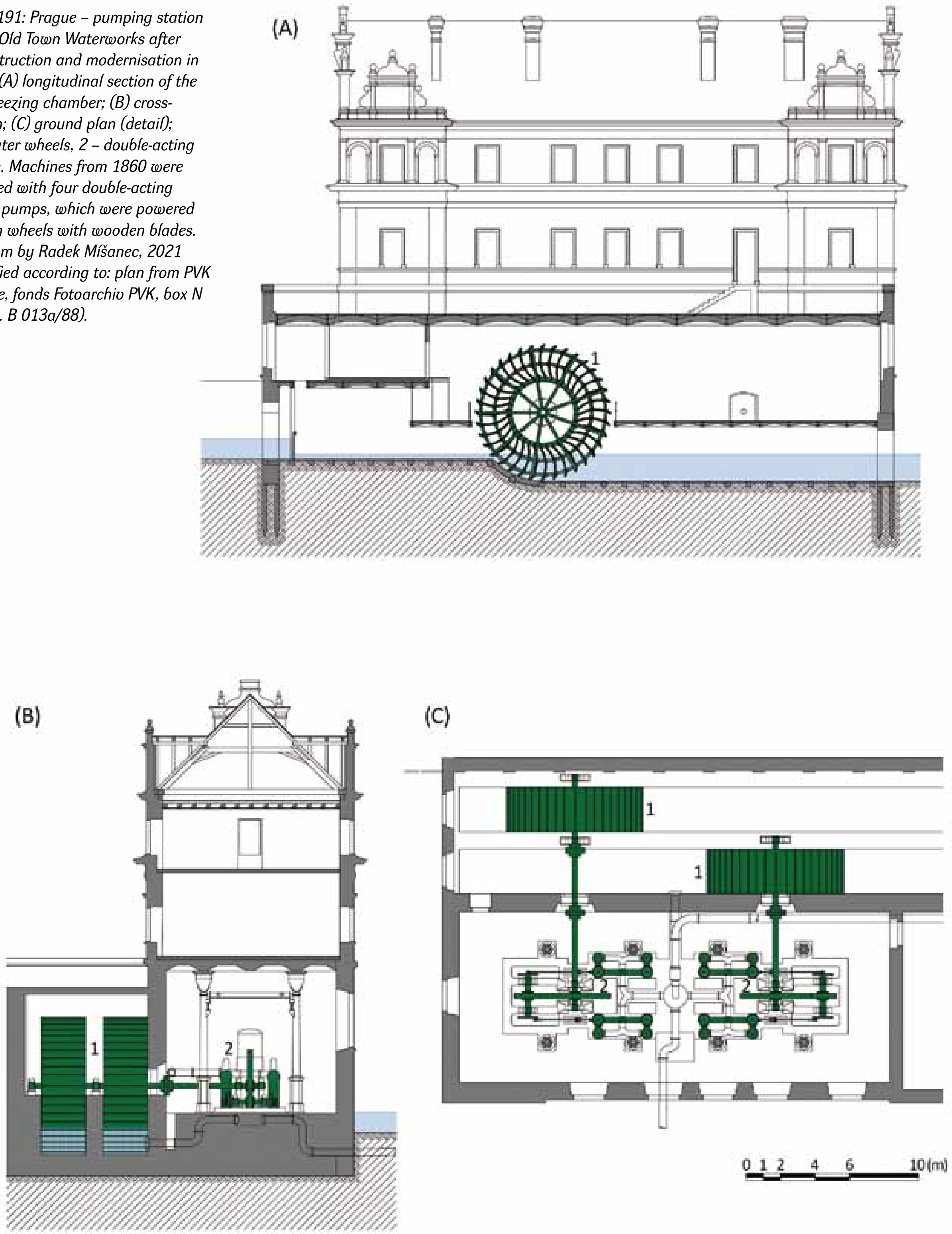


Fig. 4.191: Prague – pumping station of the Old Town Waterworks after reconstruction and modernisation in 1882: (A) longitudinal section of the anti-freezing chamber; (B) cross-section; (C) ground plan (detail); 1 – water wheels, 2 – double-acting pumps. Machines from 1860 were replaced with four double-acting Girard pumps, which were powered by iron wheels with wooden blades. Diagram by Radek Míšanec, 2021 (modified according to: plan from PVK archive, fonds Fotoarchiv PVK, box N 11, sig. B 013a/88).

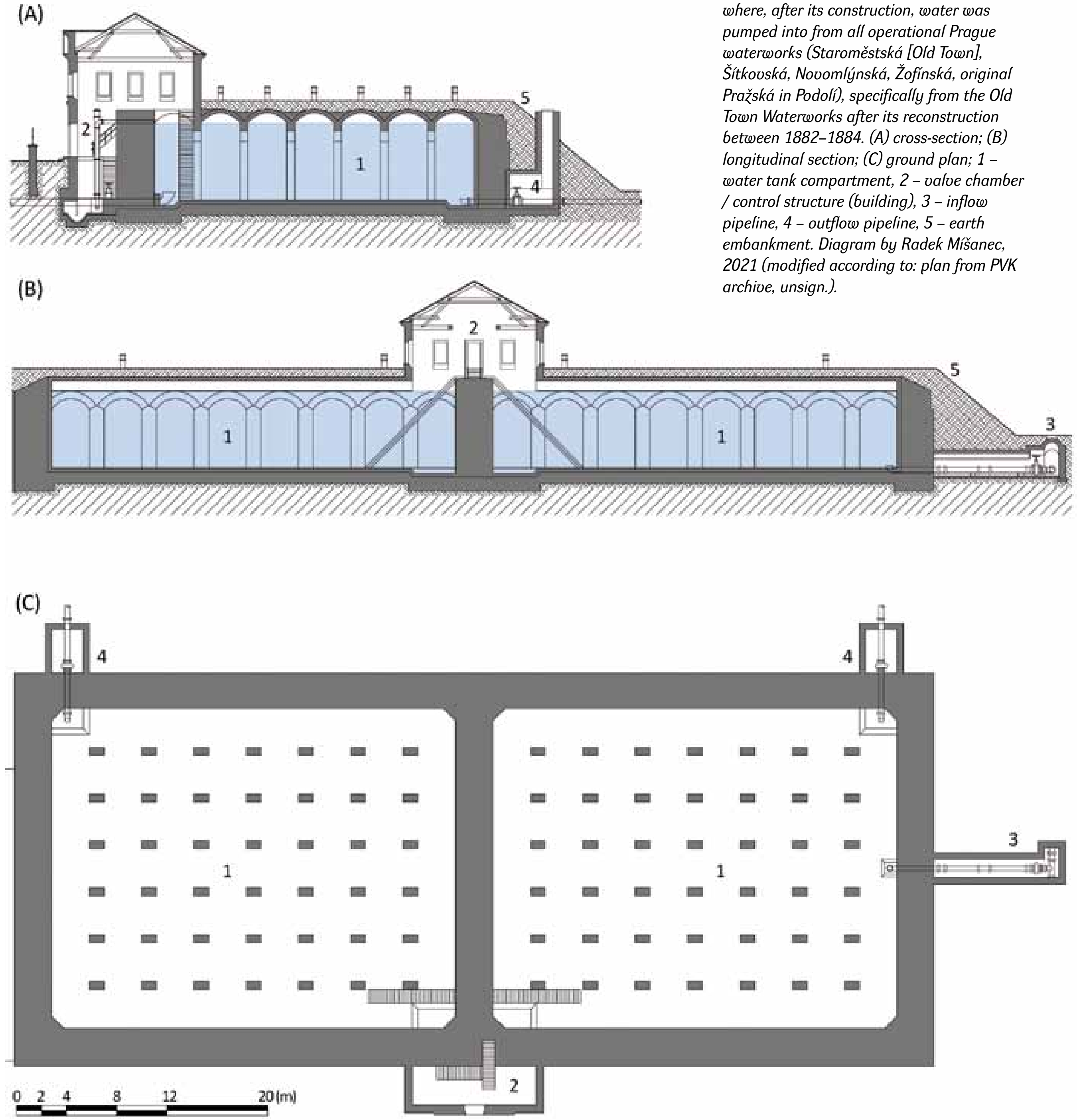
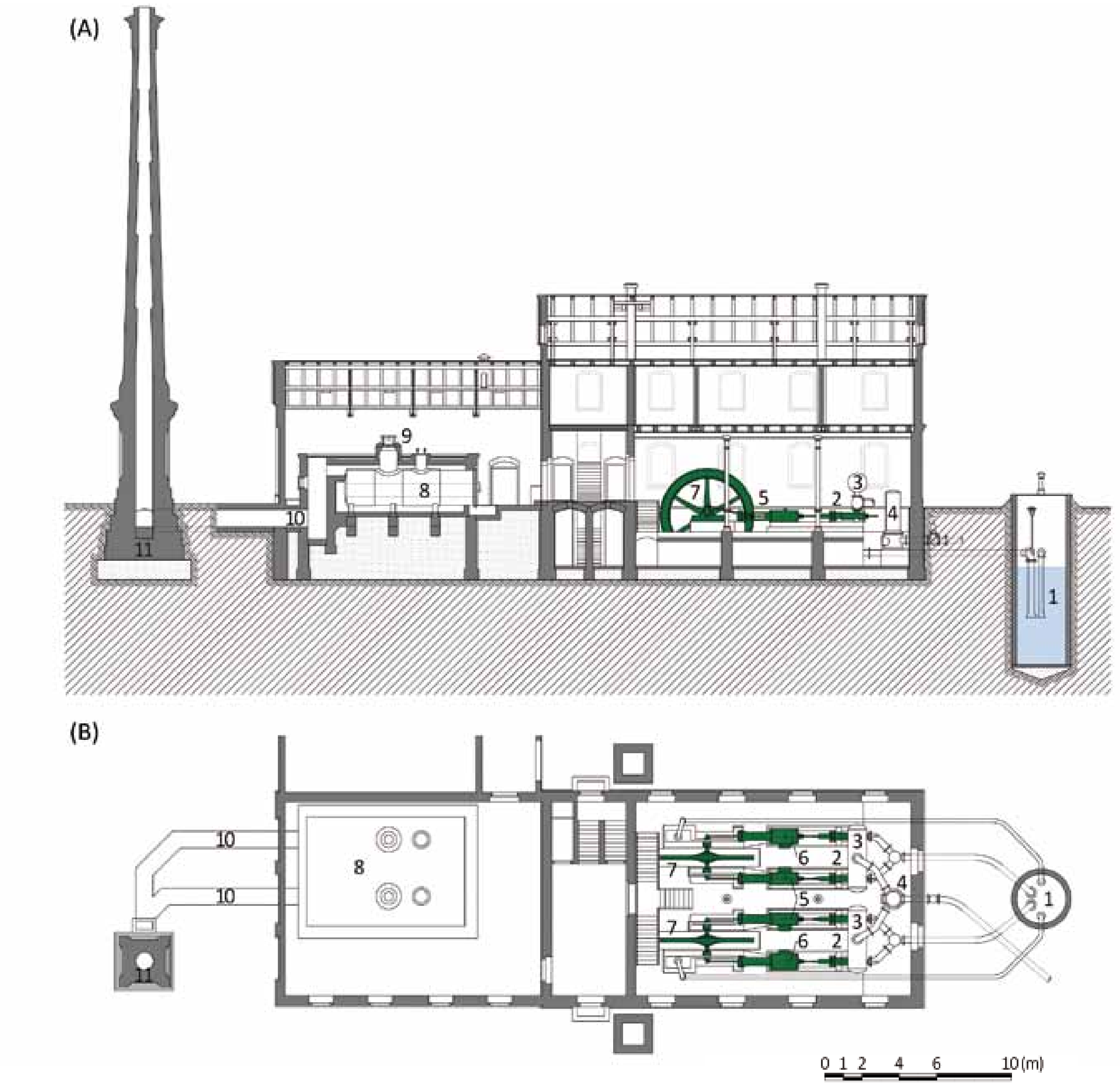
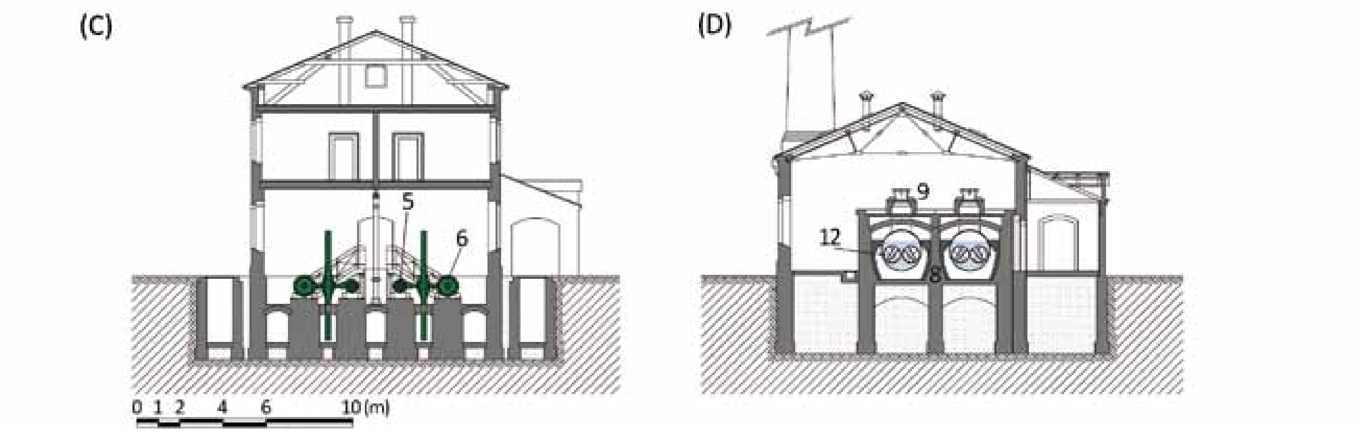


Fig. 4.192: Prague – water tank in Karlov where, after its construction, water was pumped into from all operational Prague waterworks (Staroměstská [Old Town], Šítkovská, Novomlýnská, Žofínská, original Pražská in Podolí), specifically from the Old Town Waterworks after its reconstruction between 1882–1884. (A) cross-section; (B) longitudinal section; (C) ground plan; 1 – water tank compartment, 2 – valve chamber / control structure (building), 3 – inflow pipeline, 4 – outflow pipeline, 5 – earth embankment. Diagram by Radek Míšanec, 2021 (modified according to: plan from PVK archive, unsign.).

which is interconnected with the rise in the number of inhabitants of big cities and increasing requirements concerning water supplies for the developing industry. A lot of older waterworks were transformed into more advanced operations and at the same time new ones came into existence which were built in accordance with modern principles. Next to machine mechanisation of water pumping there were also first attempts at water purification with the help of sand filtration and furthermore research into the acquired water quality in an attempt to transport purely potable water to given locations. New sources of water were searched for in addition to places of water consumption used at the time, which were not sufficient in terms of quality and quantity.





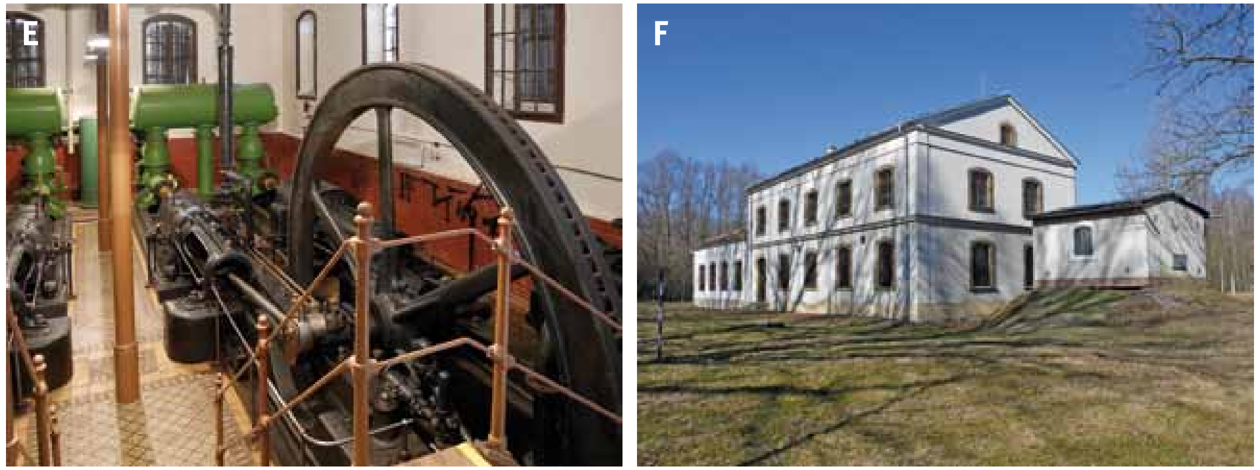


Fig. 4.193: Olomouc-Chválkovice – steam pumping station of Chválkovice waterworks from the end of the 1880s: (A) longitudinal section of a steam waterworks; (B) ground plan; (C) cross-section of the engine house; (D) cross-section of the boiler room; 1 – underground storage tank, 2 – double-acting piston plunger pump, 3 – shared water collector by a pair of pumps, 4 – surge tank for water diversion to the water mains, 6 – low pressure steam cylinder, 5 – high pressure steam cylinder, 7 – flywheel of the steam engine, 8 – flued steam boiler of Lancashire type upgraded by Galloway water-tube system, 9 – steam dome, 10 – channel, 11 – chimney; (B) exterior of the steam waterworks; (C) interior including a pair of two-cylinder double-acting horizontal steam engines with double expansion, each of which has a performance of 80 horsepower and powers a pair of piston plunger water pumps. Diagram (A) – (D) by Radek Míšanec, 2021 (modified according to: plan documentation); photograph (E) and (F) by Michaela Ryšková, 2022.

The key invention was a steam engine, which was used for pumping water from waterworks (and later also powered facilities of wastewater treatment plants) (Fig. 4.191 and Fig. 4.192). Supposedly the first use of the steam engine for water supply was connected with the use of the Newcomen atmospheric engine in London between 1726–1732. From the 1880s more high performance, more reliable and economical steam engines were used, designed by James Watt (e.g., at pumping stations in London and Paris) (Douet, 2018).

For reasons of capacity the steam engine was also introduced in older facilities, but at the same time water wheels remained in operation in many places. In local waterworks serving smaller urban localities the original power source was used more extensively than steam sources because it was possible to leave it unattended and without the necessity of systemic solutions concerning fuel supply. Water wheels were gradually replaced by more high performance types or by turbines. This process could be illustrated by the example of the now non-existent, so-called “big

Fig 4.194: Opava – waterworks complex in Jaselská street from 1875 with the original steam engine room building. Photograph by Alena Borovcová.

Fig. 4.195: Prague-Bohnice (Psychiatric Hospital Bohnice) – washhouse block No. 25. The extensive complex of the psychiatric hospital was created from 1905 to the 1930s. The author of most of the buildings, Václav Roštlapil, also designed an elevated water tank from 1908. Cold non-potable water was pumped into the tank on the top floor; below it there were two expansion tanks for regulating the pressure of the heating system; lower there was a hot water tank and further lower a tank for lukewarm water which led to the bath. Cold water flowed gravitationally downwards where it was heated by steam and it ascended by itself to the hot water tank from where it was distributed gravitationally to the complex. The waterworks was used until 1972. The original petrol station building was rebuilt into an apartment unit. Photograph by Michaela Ryšková, 2022.

waterworks" in Olomouc, which was used for close to 200 years until 1989. The pumps powered by water wheels pumped water from Mlýnský Brook to the stone water tower. The technology was continuously upgraded: in 1868 the Poncelet water wheel was installed and in 1877 performance was increased with the help of a steam engine (Kopecký, 2000).

The preserved example of a pumping station with a steam engine as power source is Chválkovice waterworks. The city of Olomouc was searching in the second half of the 19th century for a new supply of quality, potable water. With the help of boreholes a source of underground water was found in the area of Chválkovice. The project was led by construction councillor Salbach and the realisation of the project was assigned in 1889 to Corte a spol. (construction) and Prager Maschinenbau, Akt. Gesellschaft (technology). Apart from the collecting well, a multi-floored machine room was built with a boiler room equipped with two double-acting plunger pumps, joined with two horizontal two-cylinder united steam engines, and the boiler room was equipped with two flame-tube boilers with Galloway air chambers and a chimney 32 metres high (Fig. 4.193). There were staff flats on the first floor of the building. Water was pumped into a dual-chamber ground water tank made of brick masonry with a capacity of 1,500 m^3 on the Tabulový hill. The steam pumping station remained operational until 1960 when it was converted to an electric operation (Fiala et al., 2010; Hlušičková, 2002).

An interesting example is the water supply system of the town of Opava (Fig. 4.194). In 1875, a modern waterworks of the Opava Central Water Supply System was put into operation and its compound situated above the town parks in Jaselská and Karlovecká streets is still operational. The river water from the Opavice was conducted onto sand filters which were embedded under the terrain in the waterworks premises, filtered into a collection well, pumped into water tanks and from there distributed by water supply mains. The engine room was equipped with two steam boilers and pumps. Ten years later, the river was abandoned as a source due to poor quality and replaced by underground water sources (Jaktařský zářez, Sádrovcová galerie, etc.). The system was continuously intensified by the extension of the spring area or the construction of new water tanks. The full coverage of the increasing consumption of the city was enabled only by connection to the Kružberský group water supply system (SMWAK, 2021).

In the 3rd era, there were many waterworks created which served their purpose only for several decades and were subsequently shut down and replaced by modern complexes. For example, in Prague most of the Vltava waterworks were modernised and at the same time new branches created – two original Podolská waterworks (Vinohradská and Pražská), Žofínská, Smíchovská, a number of local industrial sources concentrated mostly in the area of Libeň, the original pumping stations for the Institute of Mentally Ill in Bohnice, etc. (Jásek and Drnek, 2020; Fig. 4.195). With a few exceptions when buildings were used for different purposes, the pumping stations were demolished and the site was transformed. The elevated water tanks have been preserved and have become an identification element of the locality. Ground water tanks have mostly been preserved only if they were involved in a modernised circuit.

In this era, a number of waterworks were created to supply the industrial plant, urban quarter or rural locality. From the technological point of view, they consisted only of a machine room and one pumping place in the form of an injection well. These were cases where the existing municipal distribution system did not suffice to supply even its consumption area, and therefore private operators proceeded to build their own small source. Small industrial plants, located near rivers, were able to supply more places with non-potable water at once. However, water was not suitable for the long-term supply of a bigger population. Some plants are still used or their relics remain in the landscape, such as hydraulic rams or small waterworks, powered by water wheels, which were created by a local manufacturer.

For example, the city of Plzeň had several water-supply complexes, which document a continuous transfer of operation from one era to another. In 1888–1890, Emil Škoda's company built a municipal waterworks in Malostranská street under the Homolka hill with a water source from the Úhlava River. Piston pumps, powered by a steam engine, which pumped water into four settling tanks and four English filters. In 1897–1907, a specific industrial aqueduct for drinking water for the Měšťanský pivovar (City's Brewery) was built in Plzeň, which pumped both well and river water (Fig. 4.196). During the first World War, it was connected to the municipal distribution system and together with another newly built aqueduct supplying spring water from Grubovka it worked for a long time as one of the subsidiary sources for the city in addition to the modern waterworks, which was created by the modernisation of the existing plant in Homolka (Hlušičková, 2003).

The third and fourth eras overlap in time and technology. Plants that were built at the end of the 19th century, which are still fully operational, can also be included in the last era.

Fig. 4.196: Plzeň – elevated water tank in the premises of the Prazdroj brewery from 1905–1907 was part of the aqueduct of the City's Brewery. The implementation project was prepared by Ing. Spalek and by the builder Hucl. Two iron tanks were placed above each other, one for the spring and the other for the river water. The waterworks system consisted, besides the elevated water tank from a power plant powering the river pumping station, of coarse filter, iron removal station and sand washing machine structures and the waterworks buildings by the well Na Roudné. Photograph by Alena Borovcová, 2020.

4.5.1.2.4 4th era – quality drinking water, group water supply network (from the end of the 19th century to the current time)

Technological flow of the 4th era: Water source (springs, reservoirs) → pumps powered by electric motors → multiple-stage water treatment (filtration, coagulation, chemical treatment) → ground and elevated water tanks → consumption point (households, plants, etc.).

The modern era of the potable water supply to towns began by the end of the 19th century and continually involved modernisation and realisation of new projects and the active use of sources throughout the 20th century up to the present. Strict separation of modern waterworks from previous ones is challenging. The only clue is in the resulting product – quality potable water – and this is connected with the perfection of technologies used for water treatment.

In this era, water supply systems were becoming far more comprehensive. Waterworks as such can consist of several buildings, in which there are independent pumping facilities, and further machine room, filtration, coagulation (or another stage of chemical treatment) or a subsidiary of the pumping station which pushes water to the place of consumption. Water tank complexes are diversified and one water tank connected to a possible water tank for water distribution to higher floors is usually no longer sufficient, but water is distributed to several locations. There is usually not only the water tank itself but also a pumping station structure which helps with the distribution of water to more distant locations. Elevated water tanks are almost not built any more and if so, they are in most of the cases metal globular, so-called aqua globe water towers. The vast majority of structures used for the accumulation of water are built in an underground form and the pressure necessary to pump water to more elevated places is created artificially in pumping stations.

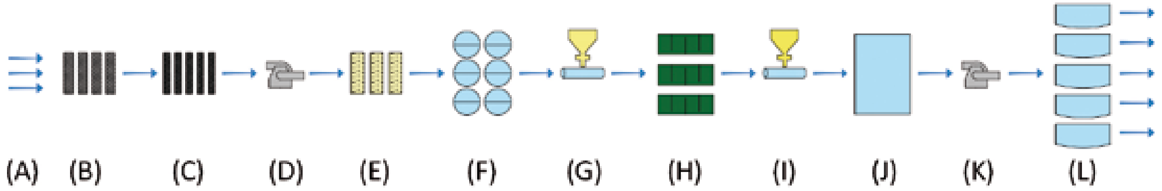


Fig. 4.197: Diagram of water treatment in the Podolí water treatment plant: (A) raw water withdrawal from the Vltava River; (B) coarse rack in the collecting structure on the Veslařský island; (C) fine rack in the water treatment plant building; (D) raw water pumping to the waterworks; (E) overflow chambers; (F) clarifiers; (G) alkalinisation; (H) filtration; (I) hygienic water treatment; (J) accumulation of treated water; (K) pumping of treated water to water tanks; (L) Karlov, Flora, Zelená Liška, Laurová, and Bruska water tanks; (M) distribution to consumers. Diagram by Radek Míšanec, 2021 (modified according to: the Prague Waterworks Museum diagram).

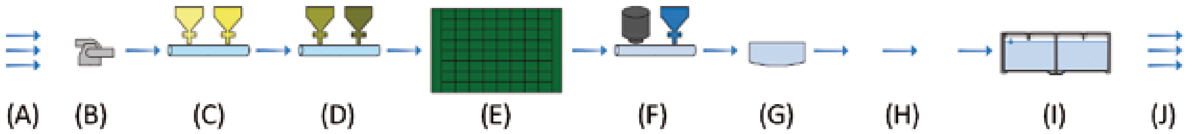


Fig. 4.198: Diagram of water treatment in the Želivka water treatment plant: (A) water withdrawal from the Švihov waterworks reservoir; (B) pumping station; (C) dosing of sulphuric acid and aluminium sulfate; (D) dosing of potassium permanganate and activated carbon; (E) sand rapid filter; (F) ozonisation, dosing of chlorine and hygienic treatment of drinking water; (G) regulation water tank; (H) water supply tunnel; (I) Jesenice water tank; (J) distribution to consumers. Diagram by Radek Míšanec, 2021 (modified according to: the Prague Waterworks Museum diagram).

As an example, we can mention three different types of waterworks, which use identical, and at the time most widespread, technology of water treatment using the French Puech-Chabal filtration system. This system was known in the Czech lands as early as the start of the 20th century but its actual application did not occur earlier than the 1920s. The system of multiple sand filtration fully utilised a natural purification process. Unlike slow sand filtration (so-called "English filters") delivered water of significantly higher quality. It still concerned non-potable water, not drinking water, which ranks it in the third era. Between 1924 and 1926 the city waterworks in Plzeň (in Homolka) applied this technology and this was also the case from 1925 at the above mentioned waterworks of the Psychiatric Hospital in Prague-Bohnice and between 1922–1929 at the waterworks in Prague-Podolí. Both in Plzeň and Podolí modernisation of water treatment to the next level with the help of chemical coagulation took place which ranks them in the fourth era (Fig. 4.197). Coagulation involves adding coagulant (an agent, based on iron or aluminium, for example $FeCl_3$), which triggers the coagulation (condensation) of impurities into a solid substance (flakes, precipitate), which it is possible to remove mechanically from water via sedimentation or filtration (Fig. 4.198 and Fig. 4.199). In Bohnice water was still used as non-potable.

Local waterworks were built next to big waterworks systems during the 20th century, which served only one location and classifying them in the modern waterworks era is complicated because they function on the principle of mechanical water pumping, which belongs to the previous era. However, the water quality is assessed as potable despite the often quite basic filtration principles which are used for treating raw water (Fig. 4.200 and Fig. 4.201). These local waterworks have been preserved in surprisingly significant numbers and are considered as solitary constructions hidden in free spaces and often reachable with difficulty. They were built in remote places, where there was a consistent lack of water and it was impossible to connect them to newly built municipal or group water supply networks. Next to other machinery systems some small support equipment has been preserved, which often consist of a small pump in the form of a hydraulic ram. The exact number of such preserved equipment is unknown – a large part has been lost in the local countryside, although a number of such equipment is even today operational (Jásek and Drnek, 2020).

Beside the separately built water treatment plants, *Shared waterworks systems*, or so-called *Group water supply networks*, started to be created in this era too. It concerns a waterworks system which has been either since the time when it was built or gradually over time designed as a water source for several independent places of consumption (see Fig. 4.202 and Fig. 4.203). Currently, some particular group water supply networks are being connected and creating so-called waterworks systems. The appearance of waterworks systems, which are in fact location-specific to the Czech Republic, dates back to the period after 1965 when the era of post-war economic recovery ended (Broncová, 2006). So-called group water supply networks started to be created from the beginning of the 20th century but their wider development took place in the inter-war period, when Czechoslovakia financially supported the creation of this kind of waterworks systems, covering up to 75% of the total cost (Cukr, 2010). It often concerns a system of one or several sources of raw water which is consequently processed in accordance with standard procedures in the process of water production. Every major water treatment plant could currently be theoretically considered as a group water supply system because practically all of them, aside from their primary objective, supply a range of local areas (Fig. 4.204).

Currently the reduction of water consumption is taking place either due to the efforts of inhabitants not to waste water or it could also be attributed to the termination of several industrial production activities, which increased water consumption enormously. Current trends in waterworks are not merely the increase in volume of pumped or treated water, but also its quality increase. At the same time the trend is an effort to gradually connect the highest possible number of superior waterworks systems, in order to flexibly respond to current climate change and supply localities with water, which at the given moment have issues with water supply. Another trend is an effort to decentralise and make independent of central waterworks systems a series of small local settlements thanks to the possibility of recycling previously consumed water and its further use in the form of so-called "greywater". Construction of large water treatment plants doesn't take place any longer and most likely their construction will never materialise anymore. On the contrary, current efforts involve using surviving waterworks compounds for the highest number of consumers and maximising the quality of supplied water thanks to the installation of new technologies (activated carbon, membrane technology, nanotechnology) which react to new threats of pollution which are not solvable by current means (hormones, medication, fertilisers).

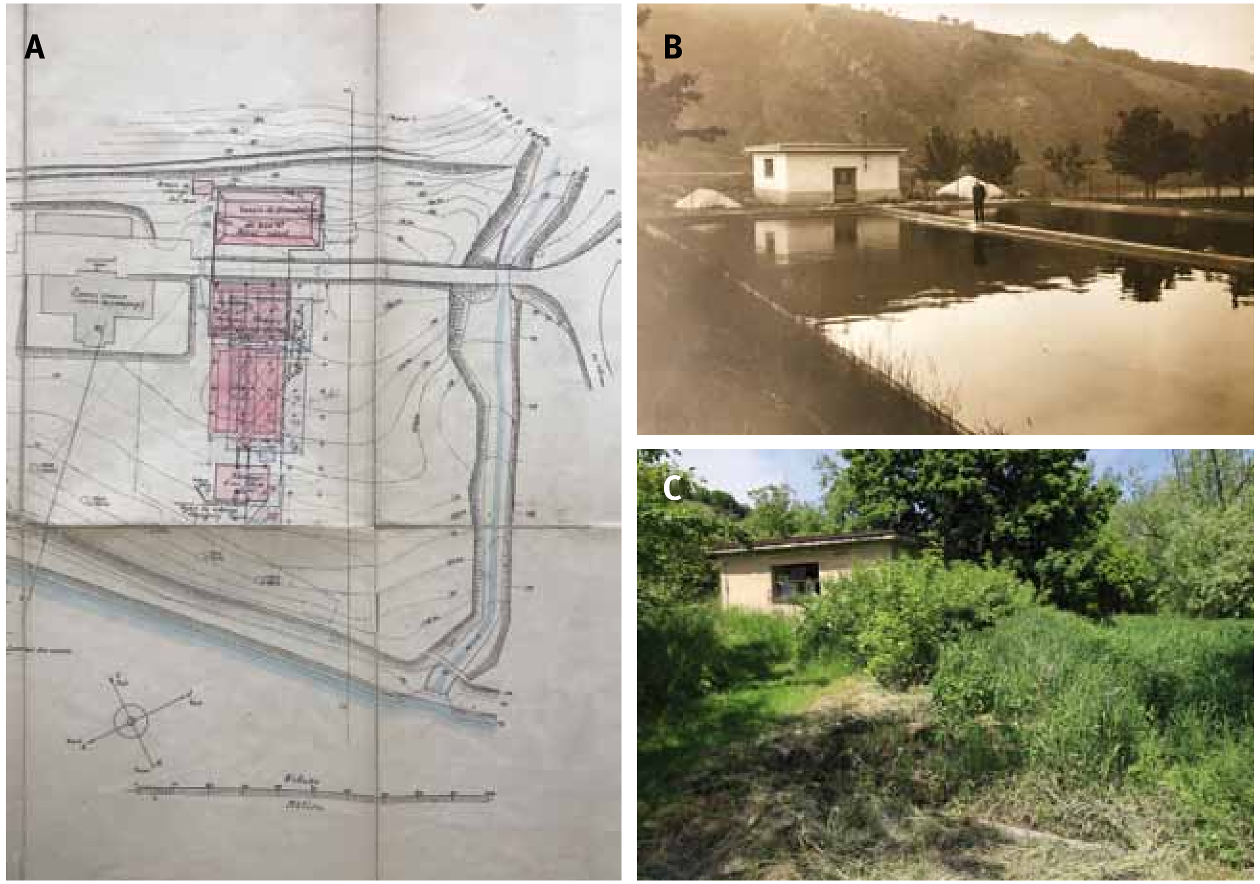


Fig. 4.199: Prague, Bohnice – private river waterworks for the use of the Institute of Mentally Ill, new filtration equipment: (A) location plan; (B) settling tanks in 1926; (C) current state. In 1925, the independently standing filtration station, which purified water pumped from the original pumping station, was launched. The system consisted of a pumping station and sand filtration system Puech-Chabal. No later than 1972 the whole system was decommissioned and the institute was connected to the city water distribution system. The machine room building is currently used as a car service facility and the filters were filled in with soil, and other buildings were either demolished or left abandoned. Photograph (A) from the PVK archive, f. PV, box 249, sign. H – 1096, f; (B) PVK archive, fonds Fotoarchiv PVK, box 16, signature OV – 239; (C) by Jan Kolář, the PVK archive, 2021.

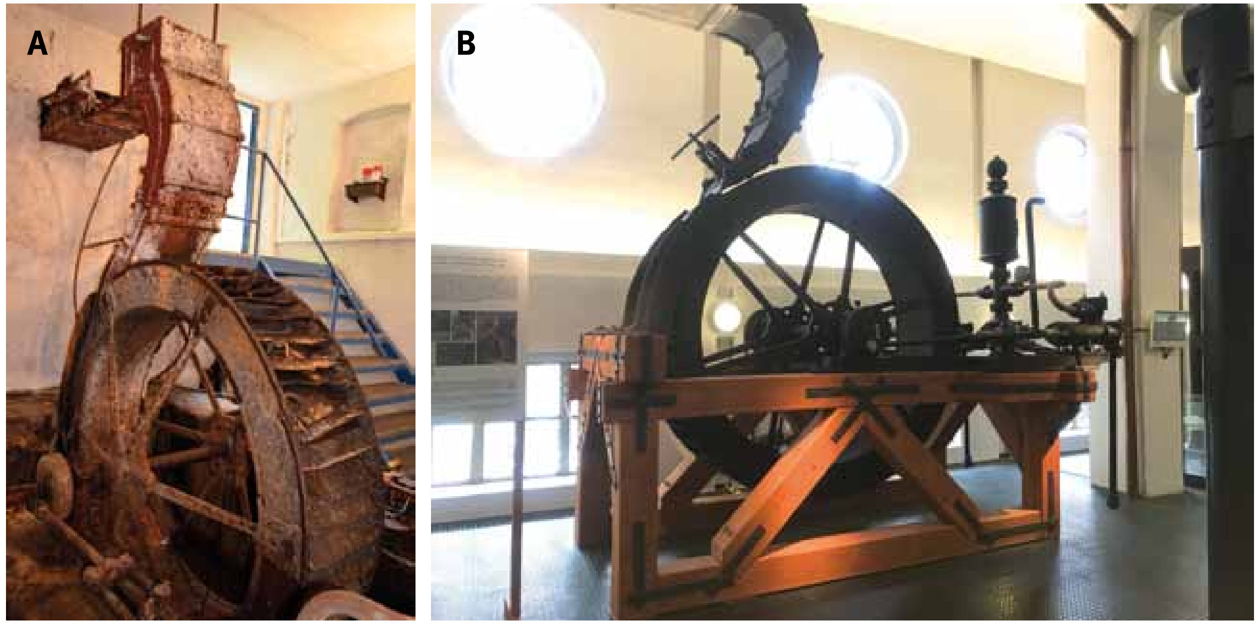


Fig. 4.200: Pavlovice u České Lípy – local waterworks was built and the machinery produced by the J. Gater – Hühnerwwasser company in 1902, when a collecting structure of potable water and a pumping station were built and the flow of Dolský Brook modified. The pumping and water transport was ensured by a horizontal double-acting pump powered by an overshot waterwheel, the so-called Gatter wheel. The original pumping set worked until the mid-1970s. (A) original state; (B) installation in the Prague Waterworks Museum. Photograph from the PVK archive, 2010 and 2018.

Fig. 4.201: Nové Dvory near Kutná Hora – hydraulic ram (pump based on the use of kinetic energy of flowing water) which replaced the original pump powered by a waterwheel probably in 1897. Up to the mid-1950s it supplied a manor and local chateau with non-potable water. The water source was a local pond, water was pushed to an elevated water tower, from where it flowed to its place of use. In the 1990s the pond was sold, the tank and half-timbered service house ended up in a desolate state and the hydraulic ram was forgotten. It was discovered, picked up and overhauled between 2014–2016 (Nové Dvory). Installed in the Prague Waterworks Museum (Muzeum pražského vodárenství). Photograph from the PVK archive.

Fig. 4.202: Káraný, Káraný waterworks – waterworks at the confluence of the Labe and Jizera, built from 1896 to 1912, launched in 1913, officially launched on 1 January 1914. It was founded to collect underground water, which appeared due to leakage of river water to suitable, in this case gravel-sand, subsoil. Naturally filtered water is captured by underground sucking wells. In the 1960s the process was complemented with artificial infiltration which was connected with direct pumping of raw water from the river through a system of outdoor sand filters. A secondary water source is a system of artesian wells. Originally it was powered by steam engines but in the 1930s it was upgraded to electric power. The waterworks is still fully operational. From the outset it concerned a local group water supply network because the original consumer base was Prague and its suburbs, and from the second half of the 20th century a range of neighbouring villages located along the main conduit were connected to the system. Photograph: the PVK archive, fonds Fotoarchiv PVK, box N 21, sign. C 083a.

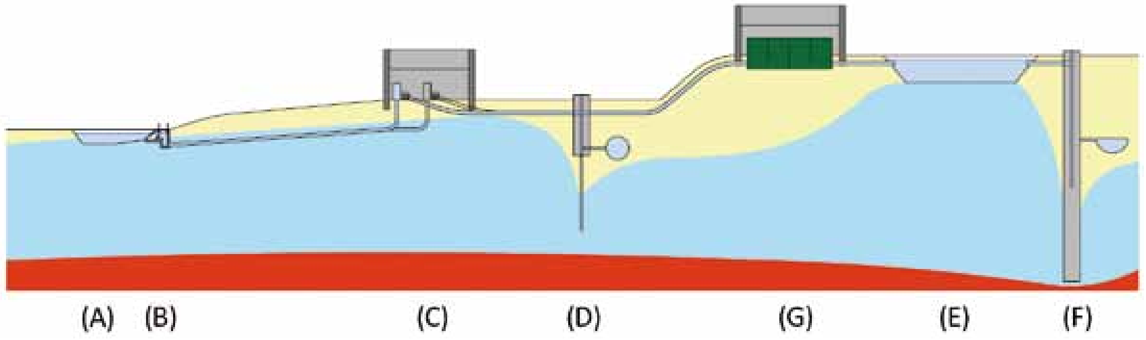


Fig. 4.203: Káraný, Káraný waterworks – diagram of water treatment: (A) weir on a lake; (B) intake structure; (C) raw water pumping station; (D) drilled wells; (E) drop caissons with horizontal collectors; (F) infiltration tanks; (G) water treatment plant with rapid sand filter, infiltration tanks. Diagram by Radek Míšanec, 2021 (modified according to: diagram of the Prague Waterworks Museum).

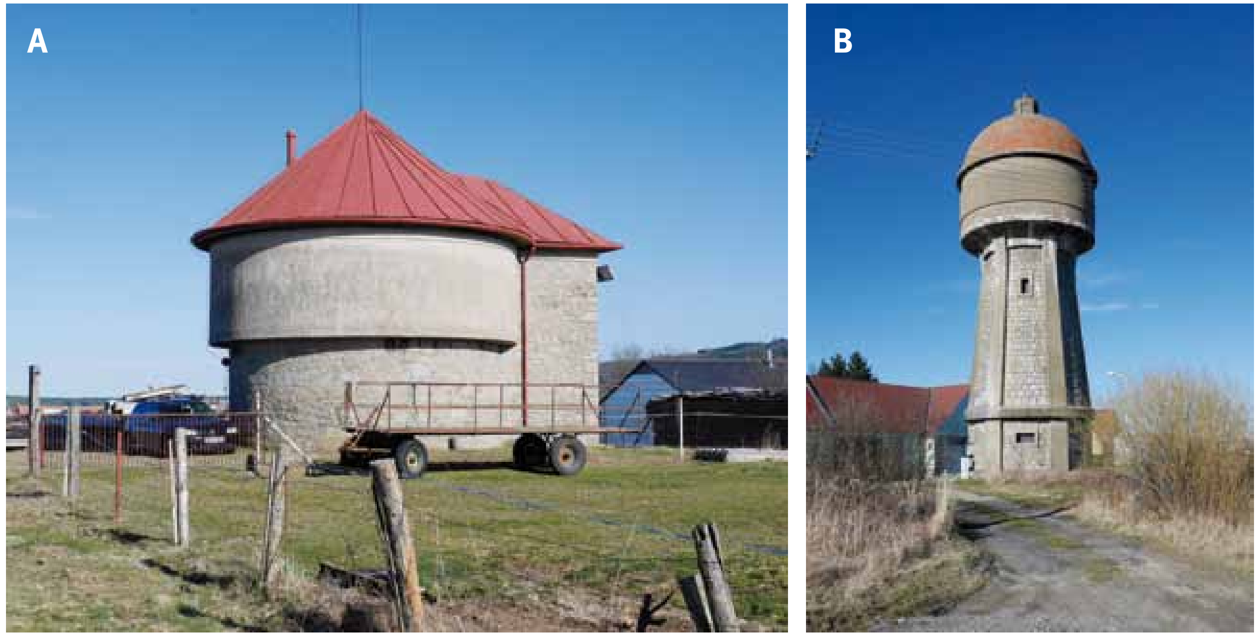


Fig. 4.204: Group water supply system of Besednice, Nesměň, Něchov and Todně – it is a hydraulic structure, which was made by joining two originally independent waterworks systems – Besednice–Nesměň aqueduct and Todně–Něchov aqueduct. The former was built between 1992 to 1925 and involved a simple gravitational water system, consisting of a pumping station on a slope of the Besednice mountain which brought the water to a water tank, and from this place to its final destination. The latter aqueduct was built between 1922 and 1924. Between 1925 and 1928 the construction of the group water supply system took place, which joined both systems into one functioning unit. The water supply system has been operational up till now and its important features are in particular four water tanks which were built together with the whole system. It concerns a ground water tank which is part of the pumping station, and two elevated water tanks in the villages of Besednice, Nesměň (A) and Něchov (B). Photograph by Michaela Ryšková, 2022.

4.5.2 TYPOLOGY OF WATER SUPPLY STRUCTURES

4.5.2.1 Sources of drinking water

The term “water sources” refers to “*sources of surface or underground water which can be or are used for various purposes and needs of society*” (Milerski, 2005).

The main source of underground water is rain water which penetrates through permeable surface layers into the underground aquifer consisting of e.g. sand and gravel of various thickness (up to several tens of metres). Confined aquifers are surrounded by an impermeable layer, composed of e.g., clay which maintains water under pressure (and water can spring from them to the surface without being pumped). Unconfined aquifers lack the upper impermeable layer – water leaves them naturally (via springs etc.) or is obtained artificially (wells, galleries, etc.) (Milerski, 2005).

The main sources of surface water are water-supply tanks, and to a lesser extent also watercourses. The surface water is, compared to the underground water, easier to be collected but more difficult to be treated (the surface water has a higher temperature, more organic substances, higher concentration of oxygen, etc. and is influenced by physical, chemical and biological processes to a greater extent than the underground water). In the Czech Republic, the use of surface water sources is predominant over underground sources (Milerski, 2005).

4.5.2.2 Water collecting structures

4.5.2.2.1 Underground water collecting structures

4.5.2.2.1.1 Vertical structures

Vertical structures for collecting underground water include wells (Milerski, 2005):

- shaft (with a relatively large volume, also used for water accumulation, water flows into the well by inlet openings on the well lining, usually up to a depth of 15 metre);
- tube wells (of small diameters);
- tube wells of larger diameters (usually bored, for extraction of water from greater depths; Fig. 4.205).

4.5.2.2.1.2 Horizontal structures

Horizontal collecting structures include (Milerski, 2005):

- tunnels and galleries (for collecting larger amounts of water, used especially in sloping terrains; Fig. 4.206);
- collecting galleries (in shallow undersurface layers by means of perforated stoneware tubes, they empty into a collecting tank).

4.5.2.2.1.3 Spring collecting structures

Spring collecting structures are not common, they serve for catching springs (Fig. 4.207; Milerski, 2005).

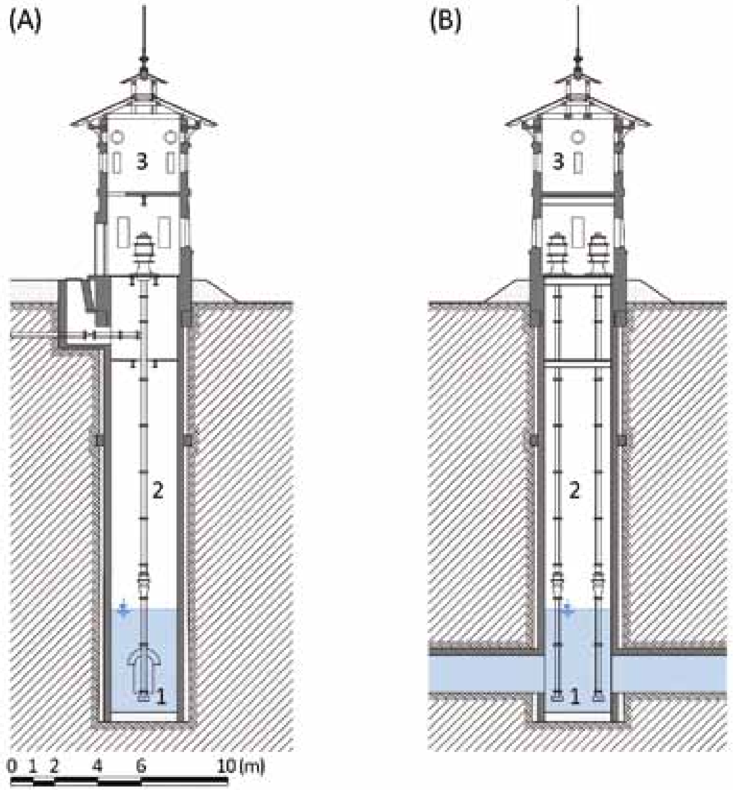


Fig. 4.205: Benešov near Prague – tube well with a pumping station: (A) cross-section; (B) longitudinal section; 1 – suction strainers, 2 – pumping pipeline, 3 – pumping station building. Diagram by Radek Míšanec, 2021 (modified according to: Klír and Klokner, 1923).

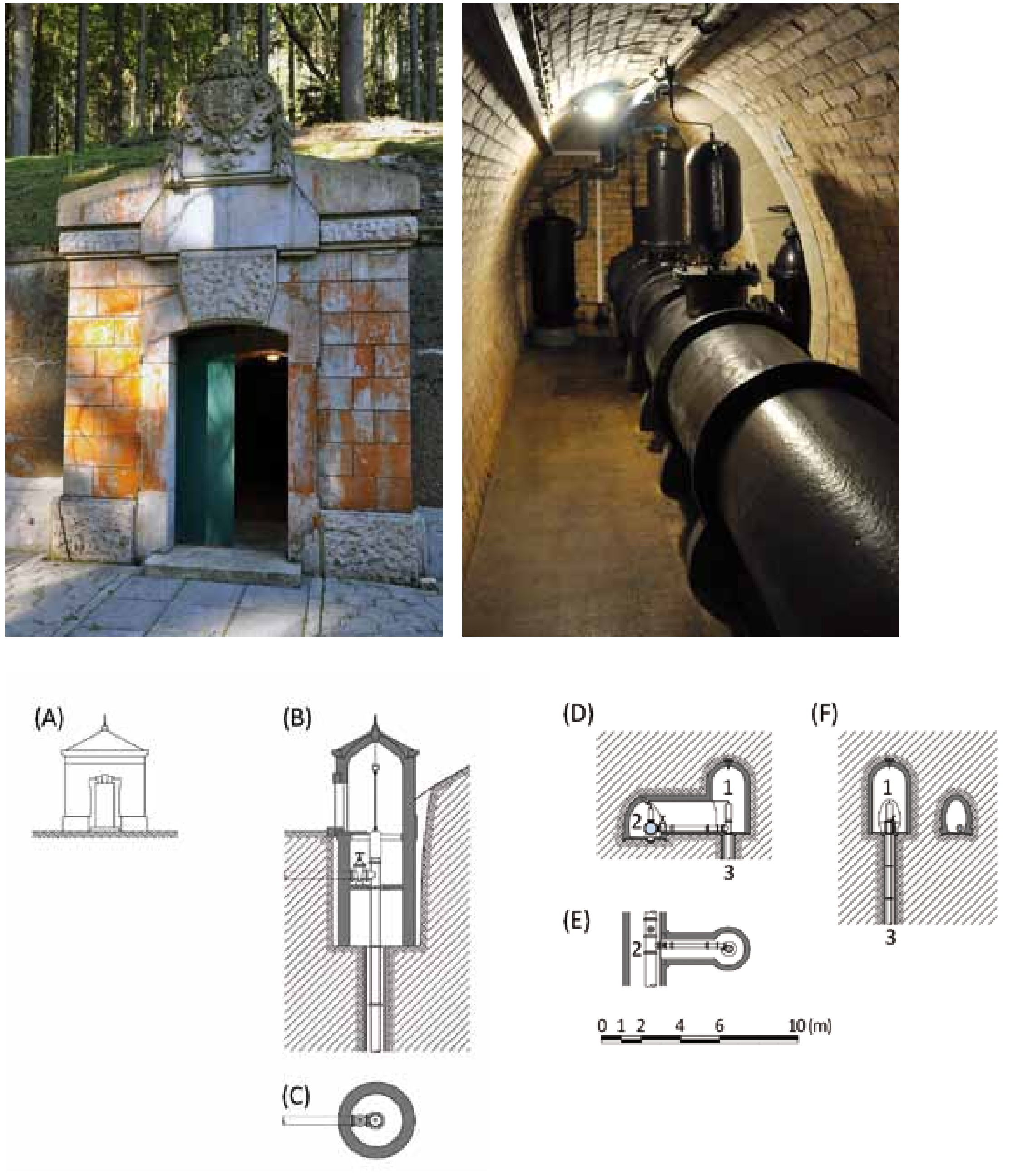


Fig. 4.206: Březová nad Svitavou – water supply tunnel of the 1st Březová conduit with siphon wells, the original cast iron pipeline from 1913; pumped water is supplied to the town of Brno by gravitational means via a 56-kilometre-long pipeline. Well A in the spring area: (A) facade of the overground structure; (B) cross-section with facilities; (C) ground plan; Siphon tunnel and collecting wells; (D) longitudinal section of the collecting well tunnel; (E) ground plan of the collecting well tunnel; (F) cross-section of the collecting well tunnel and main tunnel with pipeline; 1 – air valve, 2 – collecting pipeline, 3 – pumping pipeline. Photograph by David Honek, 2019; diagram by Radek Míšanec, 2022 (modified according to: BVK, 2013).

Fig. 4.207: Ochoz u Brna – spring tank (Kaprálova studánka) catching underground water springs in close proximity to the Říčka River. Photograph by David Honek, 2014.

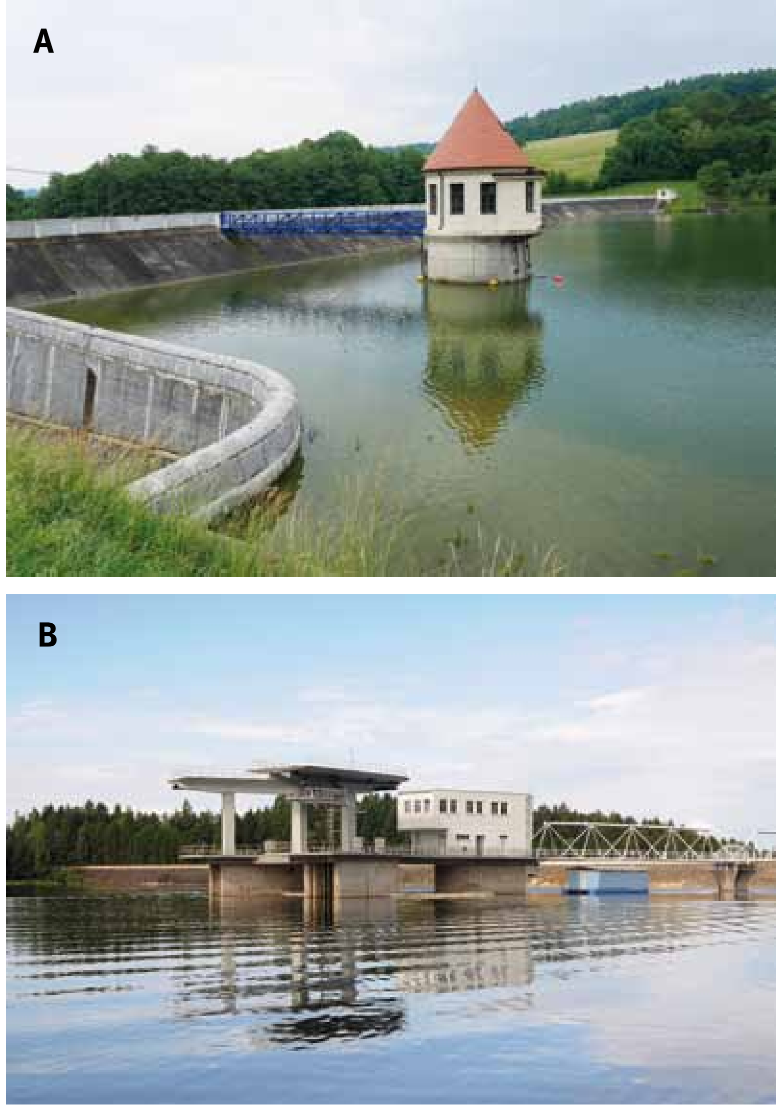


Fig. 4.208: Free-standing multipurpose structures for the withdrawal of water from reservoirs: (A) Fryšták reservoir, free-standing multipurpose structure of outlets and water-supply intakes with a machine room for the control of outlet gates in the upper part. The withdrawal of water is ensured by two pipelines at two levels. Part of the hydraulic structure is also a water treatment plant situated under the dam of the reservoir. (B) Švihov hydraulic structure, source of raw water for the Želivka water treatment plant. Free-standing multipurpose intake structure of the dam. The withdrawal of water is ensured by two intake buttresses with the possibility of five-level intakes reaching up to the bottom of the reservoir ended by an emergency overflow at the crest. Water is led into a pumping station at the heel of the dam and then into the water treatment plant (Parkán and Pěkný, 2012). Photograph (A) by Michaela Ryšková, 2020; (B) from PVK archive.

4.5.2.2.2 Surface water collecting structures

4.5.2.2.2.1 Structures for surface water collection from reservoirs and weir basins

Water collection from reservoirs is ensured by tower intake structures built either as free-standing in the reservoir area or connected with the dam (Fig. 4.208). Water withdrawal is ensured by several closeable inlet openings situated above each other. In this way it is possible to regulate the depth of the withdrawal depending on the quality of water. See Chapter *4.1.4.3 Intake structures*.

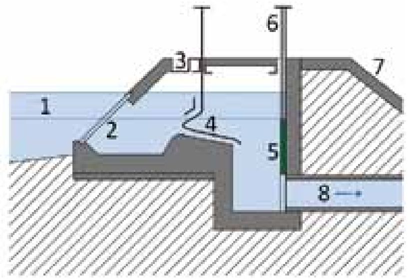


Fig. 4.209: Riverside intake: 1 – watercourse, 2 – rack, 3 – scumboard, 4 – measuring sill, 5 – shaft, 6 – sluice gate, 7 – dam, 8 – water intake piping. Diagram by Radek Míšanec, 2021 (modified according to: Milerski 2005).

4.5.2.2.2.2 Collecting structures in flowing water

The withdrawal in flowing water is carried out by riverside intakes, intakes in a river bed or intake structures situated above the bottom of a river bed.

Riverside intakes are built especially on central and lower parts of watercourses with stable banks where the withdrawal is possible even during low water levels (Fig. 4.209). Intakes in river beds are built only sporadically, they are more common in torrents. Intake structures above the bottom of a river bed are suitable for wider watercourses which have unstable banks and insufficient depth near banks (Milerski, 2005).

Number of occurrences in the CR: unknown
The oldest surviving use in the CR: unknown
The latest surviving use in the CR: unknown
Examples: Březová nad Svitavou – intake shaft of the 1st Březová conduit; Horní Planá – intake shaft; Hradec Králové – spring area “Plotiště”; Mariánské Lázně – intake structure on the hillside of the Dyleň mountain; Opava – Jaktařský zářez; Pardubice – Nemošice; Pec pod Sněžkou; Prague – intake shafts in the Kinský garden and in the Strahov monastery garden; Prachatice – well with the pumping station “Za tratí”; Prachatice – intake shafts of the “fortress water supply system”; Štěpánov – spring area; etc.; multipurpose intake structures in reservoirs: Fryšták, Josefův Důl, Želivka, etc.

4.5.2.3 Pumping stations (waterworks)

A pumping station refers to a building, or buildings, either free-standing or in a water treatment plant complex. They serve to pump raw water for a water treatment plant complex, it is subsequently used for the production of drinking or non-potable water or for pumping purified water during its distribution into the place of consumption. A raw water pumping station is an integral part of a water treatment plant and must be located close to the source of this raw water. It is usually located as a free-standing complex, but not necessarily, and its individual machine components can be located separately. Classification of pumping stations according to Kukla (1971) is as follows:

- independent pumping stations,
- pumping stations at accumulation water tanks,

- pumping stations above wells,
- pumping stations above accumulation tanks,
- pumping stations at water treatment plants.

A pumping station is located within a distribution network and is usually connected with a local water tank in a free-standing complex. It ensures the distribution of water from water tanks into a distribution network if local conditions do not enable gravitational distribution of water. A pumping station does not have to be located in a complex together with a water tank – in the case of a large distribution system, it can be connected to a distribution system and pump water as required by the pipe network. In the 1st and 2nd era, a pumping station referred to the waterworks itself, in the 3rd and 4th era, pumping stations were often separated from the rest of the water treatment plant complex and formed separate technological complexes; the subsequent technology for water treatment is situated in a more suitable location.

4.5.2.3.1 Machine rooms

A machine room refers to a structure, either free-standing or part of a pumping station building where machinery is situated, serving the raw water pumping process. In the machine room, there can be both a separate pump and a drive unit, or they can be in separate buildings. A machine room does not have to be located in close proximity to the source of raw water. The image of the machine room varies from case to case and cannot be generalised.

4.5.2.3.2 Pumps

It is machinery which is used for the actual pumping of raw water from the source. Pumps, used in water supply systems, can be divided into (DRUHY ČERPADEL, 2010):

- **Piston** (plunger):
  - single-acting – the action is carried out on one side of the piston (pump);
  - double-acting – there is working space on both sides of the piston (pump);
  - differential – they suck water like single-acting ones but push it on both strokes of the piston (pump);
  - vertical – pistons are in the vertical position;
  - horizontal – pistons are in the horizontal position;
- **Centrifugal** (impeller):
  - radial – the fluid enters the impeller parallel to the axis and exits perpendicular to the rotation axis;
  - mixed-flow (screw) – the fluid enters the impeller axially and exits diagonally (at an angle to the rotation axis);
  - hydraulic rams.

Piston (plunger) pumps were used mainly from the 1st to the 3rd era, centrifugal (impeller) pumps were used in the 3rd and the 4th era, so their use often overlapped in time. Centrifugal pumps are generally more powerful. Vertical piston pumps have not been preserved at all (one exception is the pumping machine of the town of Klatovy, conserved in the Prague Waterworks Museum), and the vast majority were replaced either by horizontal piston pumps or directly by centrifugal ones, and scrapped. Horizontal piston pumps have been preserved in the event that no later modernisation of the water treatment plant or pumping station occurred.

A hydraulic ram was a simple water pump powered by water. It uses kinetic energy of flowing water. The water flow is regularly shut off by a hydraulic ram valve, resulting impacts are used to pump water via a delivery valve to a height several times higher than the difference in water levels that powers the ram. In our territory, hydraulic rams were used to a large extent but only as individual pumping machines, built for a local settlement. Its performance prevents its use for pumping water for any larger settlements.

4.5.2.3.3 Pump drive

A pump set drive varies according to the time of origin of the pumping station, location of the machine room and the pumping machine performance demands. Types of drives used:

- water wheels (see Chapter 4.4.),
- steam engines,
- electric motors,
- combustion engines (petrol, diesel).

A water wheel was used at all times but mainly in the 2nd era and in the 3rd and 4th eras it was used concurrently with other types of drives. In the 3rd period, water wheels were still used in water distribution systems in larger cities, in the 4th period they were only used as local pumping stations serving local consumers. Steam engines were used in the 3rd and 4th eras when they replaced the water wheel drive and subsequently were replaced themselves with electric motors or combustion engines. A specific type of steam engine, used to drive pumps, cannot be generalised. In the first half of the 20th century, electric motors completely replaced all previous machinery equipment. A specific case is a drive by means of combustion engines, which has been used only exceptionally.

Number of occurrences in the CR: unknown
The oldest surviving use in the CR: unknown
The latest surviving use in the CR: unknown
Examples: Olomouc – Chválkovice; Prague – Zelená Liška (elevated water tank, pumping stations, water tanks), Vinohrady (elevated water tank, pumping stations, water tanks), Flora (a set of ground water tanks, pumping stations, chlorination plant), Bruska (water tanks, pumping stations and an administrative building); Sojovice, etc.

4.5.2.5 Water treatment plants

A water treatment plant is a general term used for a complex of structures and facilities equipped with water treatment technology. For the purposes of the data selection of property or operation records, with a potential ranking health protection of water without water treatment technology (Decree No. 428/2001), a water collecting structure is also considered to be a water treatment structure.

4.5.2.5.1 Basic water treatment processes

4.5.2.5.1.1 Mechanical pre-cleaning of raw water

It is a process which enables the capture of floating undissolved impurities of a coarse nature. This is done by using equipment which is mostly part of the pumping station, but this system is often used just before the process of mechanical and chemical water treatment.

Racks are currently used as a system of mechanical pre-cleaning of water. They have a form of grating located in the water near the surface. They are composed of gaps (pores) and screenbars. The racks are inclined at an angle of around 60 degrees, so the water flow itself lifts the impurities. The waste from racks (rackings) is continuously raked, in the past this was done manually, nowadays it is a mechanical automated process.

Screens represent an old type of mechanical pre-cleaning which was used as a protection of the inflow point (often it was a direct inflow of water into the pipeline).

4.5.2.5.1.2 Settling (sedimentation)

A basic procedure of water treatment during which both coarse and fine suspended substances are removed from water in the form of sludge. This water treatment is mainly used for cleaning sludge water in wastewater treatment plants. The shape of the tank, including all the details, is always designed to make the most of its area and volume. Sedimentation is ensured by:

- sand traps,
- rectangular settling tanks with horizontal flow,
- circular settling tanks with horizontal flow,
- settling tanks with vertical flow,
- tanks with intermittent operation,
- tanks with continuous operation.

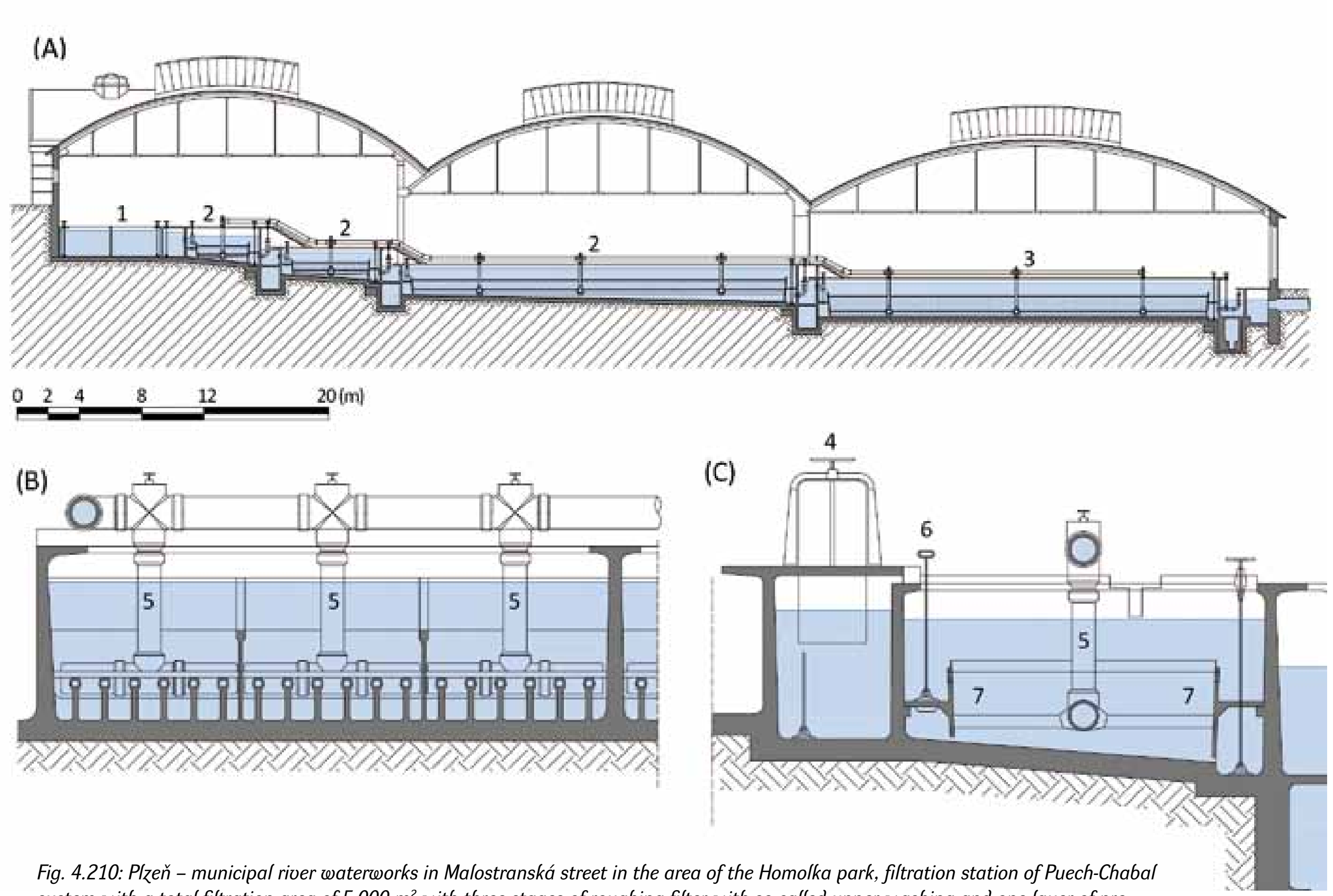


Fig. 4.210: Plzeň – municipal river waterworks in Malostranská street in the area of the Homolka park, filtration station of Puech-Chabal system with a total filtration area of 5,000 m² with three stages of roughing filter with so called upper washing and one layer of pre-filters; ground plan and section of the filtration and roughing filter building. The construction, including the construction of water tanks, was carried out by the company Müller a Kapsa, the author of the architectural design was Hanuš Zápal. (A) cross-section of the filtration building; (B) and (C) longitudinal and cross-section of the roughing filter of the primary stage; 1 – tank, 2 – roughing filters, 3 – pre-filter, 4 – sluice gate, 5 – blowing pipeline, 6 – cleaning flap, 7 – check gate. Diagram by Radek Míšanec, 2021 (adapted according to: commemorative records of the Waterworks of the City of Plzeň, new filters of the Puech-Chabal system, 1926).

4.5.2.5.1.3 Chemical cleaning (water clarification)

A process during which dissolved and colloidal substances convert into suspensions by adding suitable chemicals, which makes it possible to remove them by sedimentation or filtration. Chemical cleaning includes (Kukla, 1971):

- coagulation (clarifier, American filtration),
- carbon dioxide removal,
- iron removal,
- manganese removal,
- separation.

The process of chemical purification became part of the process of raw water treatment only in the most recent 4th era, previously it was not available. The most widespread and oldest process is coagulation (clarification) in various forms, in older publications known also as so-called American filtration. It consists in introducing the coagulant (precipitant) into mechanically pre-cleaned raw water, previously it was most often aluminium sulphate. The resulting suspension sinks to the bottom of the clarifier and is pumped out in the form of sludge for further processing.

4.5.2.5.1.4 Filtration

Filtration is a process in which suspensions are trapped during the flow of the supplied water through solid, porous medium (Kukla, 1971). It is the oldest known method of water purification, which has been used since the beginning of water collection for its further use. Sand filtration has been continuously used for water purification. While from the 1st to the 3rd era it was the primary and often the only way the water was cleaned, in the 4th era it was a supplement to the previous step of chemical cleaning. Currently, in addition to common sand filtration, other materials such as activated carbon are used as filter filling. Types of filtration (Kukla, 1971):

- slow filtration (so-called English filters),
- fast filtration (high-rate filtration),
- constant flow rate,
- decreasing flow rate,
- single-layer,
- multi-layer.

In older specialist publications, simple sand filtration, where the water is flowing through a filter medium by pure gravity, is referred to as so-called English filtration/English filters/English purification. The original filtration machinery from the beginning and mid-20th century was, in most cases, rebuilt and modernised and has been preserved only in exceptional cases (Fig. 4.210).

4.5.2.5.1.5 Hygienic treatment of water

A process of elimination of all germs and bacteria that are harmful to human health. It includes the following processes (Kukla, 1971):

- chlorination,
- fluoridation,
- ozonisation (UV and radioactive radiation).

The final stage of drinking water treatment was only used in the 4th era. The chlorination started to be used individually and randomly at the beginning of the 20th century (mostly during sudden fluctuations in raw water quality as a result of unexpected events such as floods). Its regular use can be documented from the inter-war era. Since the second half of the 20th century, the chlorination has been supplemented by other processes, such as ozonisation. A specific process is fluoridation, which was used as dental prevention, but in our territory it was only a short-term process.

Number of occurrences in the CR: unknown
The oldest surviving use in the CR: unknown
The latest surviving use in the CR: unknown

Examples: Bedřichov; Bernartice nad Odrou; Brno-Pisárky; České Budějovice – "U Vltavy" (including elevated water tank); Fryšták (from the reservoir); Hradiště (from the Přísečnice reservoir); Hrobice; Hulice (from the Želivka reservoir); Hradec Králové – Slezské Předměstí; Chomutov – "Třetí mlýn" (from the Kamenička and Křížov reservoirs; Meziboří; Mostiště (from the reservoir); Nová Říše; Olomouc – Černovír, Chválkovice; Opava; Ostrava – Nová Ves; Ostrožská Nová Ves; Písek; Jihlava – Hošov (water from the Pístov ponds); Plav (from the Římov reservoir); Plzeň – Homolka; Prague – Podolí, Smíchov Ringhoffer Waterworks (nowadays warehouses), Vršovice Waterworks; Práčov; Rožnov pod Radhoštěm; Rynholec (for the Lány Chateau); Třeboň – "Na kopečku" (incl. a well and elevated water tank); Třinec – Tyra; Valašské Meziříčí; Vrutice; Vsetín; Zahrádky u České Lípy; Zbečno (from the Klíčava reservoir); Znojmo (from the Znojmo reservoir); Žernoseky; etc.j.

4.5.2.6 Water tanks

A water tank is *"a separate structure intended for the accumulation of water consisting of one or more tanks and one or more valve chambers"* (ČSN, 1985). It is used to accumulate water and provide the necessary pressure. They can be divided into ground (with bottom height below the terrain) and elevated (with bottom height on the supporting structure) (Milerski, 2005).

4.5.2.6.1 Ground water tank

A ground water tank is *"a water tank with the bottom below the natural or planned height of the terrain, usually with filled tanks and often also with partially filled around valve chambers"* (ČSN, 1985). They can be divided into water tanks with a covered and open tank (if water quality is not important).

Ground water tanks according to the shape of the tank (Fig. 4.211):

- square,
- circular.

Classification of ground water tanks by building material (Klír and Klokner, 1923):

- brick (with a concrete bottom, or composed of inverted arches, vaulted with brick arches; Fig. 4.212);
- concrete (usually rectangular ground plan, vaulted; Fig. 4.213);
- reinforced concrete (rectangular shape with straight beam ceilings, cylindrical shape with vaulted ceiling, spherical shape with concentric tanks or tanks grouped around the valve chamber, or combined shape; Fig. 4.214).

Number of occurrences in the CR: unknown
The oldest surviving use in the CR: unknown
Examples (each is unique): Aš – Kaplanka; Brandýs nad Labem; Brno – ground water tanks under Špilberk castle, on the Žlutý hill, Stránská skála water tank; Děčín; Dobřeň; Doubravice; Domažlice; Dubá-Dražejov; Heřmanův Městec; Jablunkov – Alžbětinky; Jesenice; Jičín – on the slope of the hill Čeřovka; Kamenný Újezd; Klatovy; Kunětice; Lány;

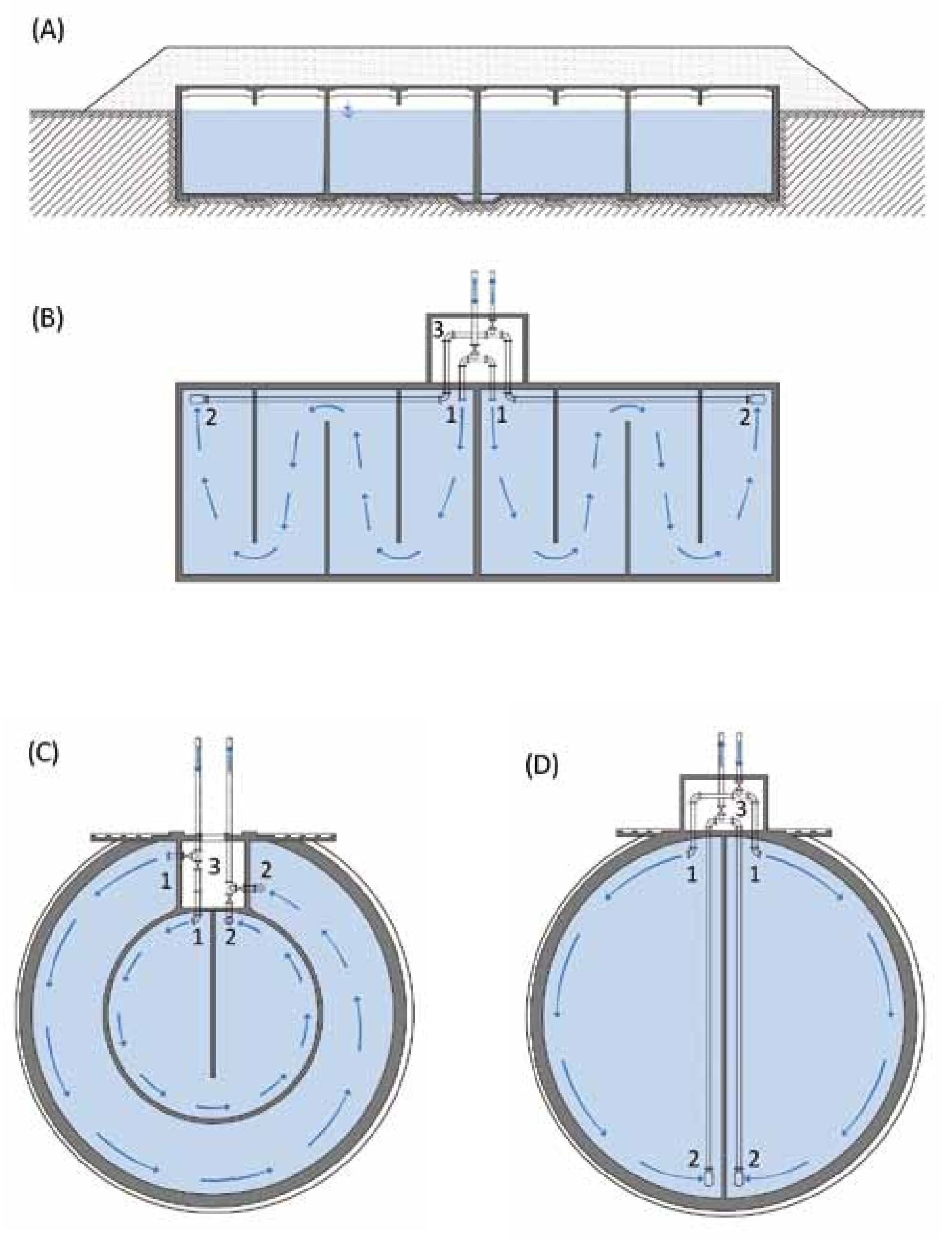


Fig. 4.211: Square and circular ground water tank: (A) square ground water tank, longitudinal section; (B) square ground water tank, ground plan; (C) and (D) circular ground water tank with two compartments, ground plan; 1 – inflow pipeline, 2 – outflow pipeline, 3 – valve chamber/control structure (building). Diagram by Radek Míšanec, 2021 (modified according to: Klír and Klokner, 1923).

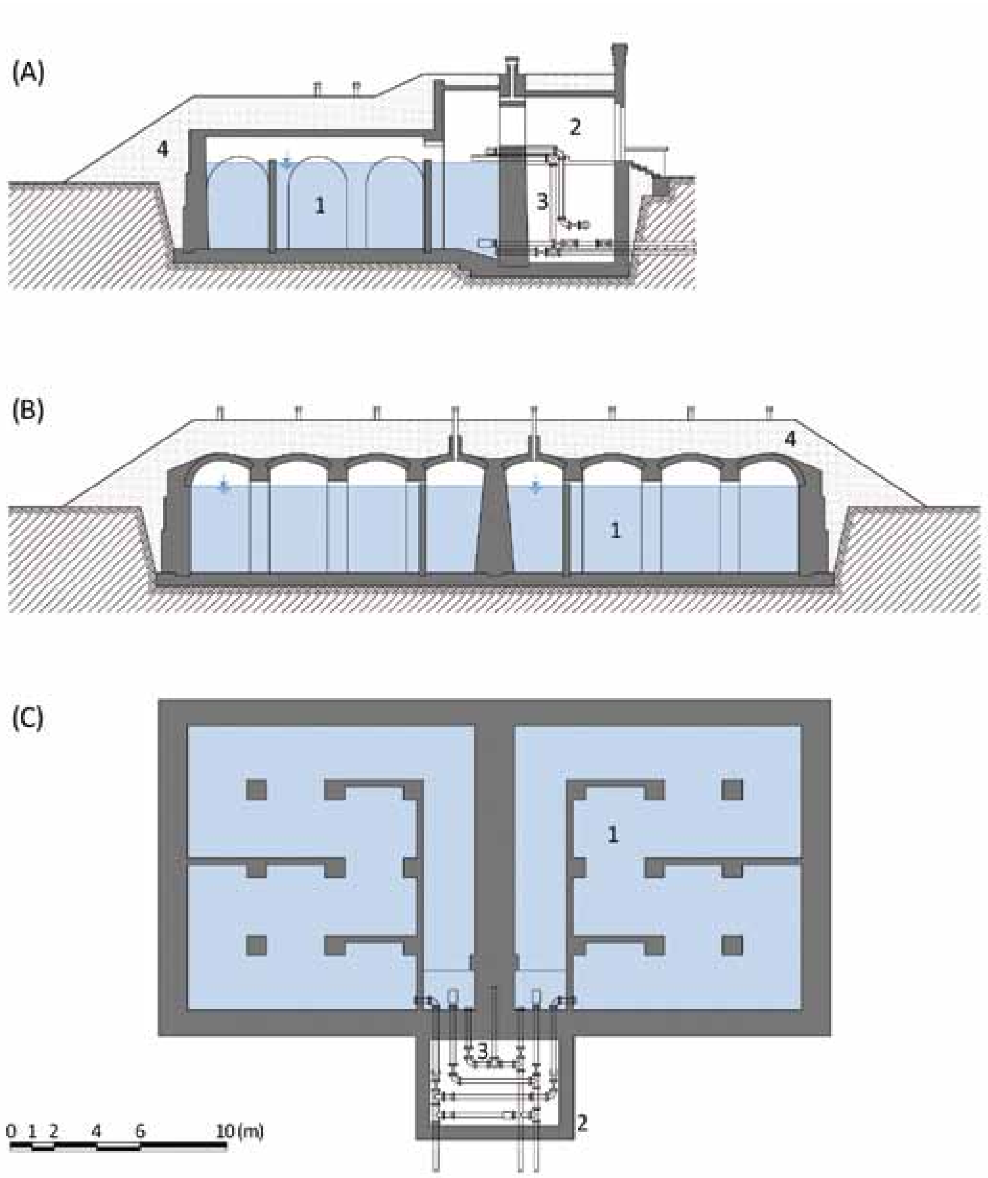


Fig. 4.212: Prague-Michle – ground water tank in Zelená Liška (part of Vršovice waterworks), an example of ground brick water tank: (A) cross-section; (B)longitudinal section; (C) ground plan; 1 – water tank compartment / water tank meander chamber, 2 – valve chamber / control structure (building), 3 – inflow and outflow pipeline, 4 – earth embankment. Diagram by Radek Míšanec, 2021 (modified according to: Klír and Klokner, 1923).

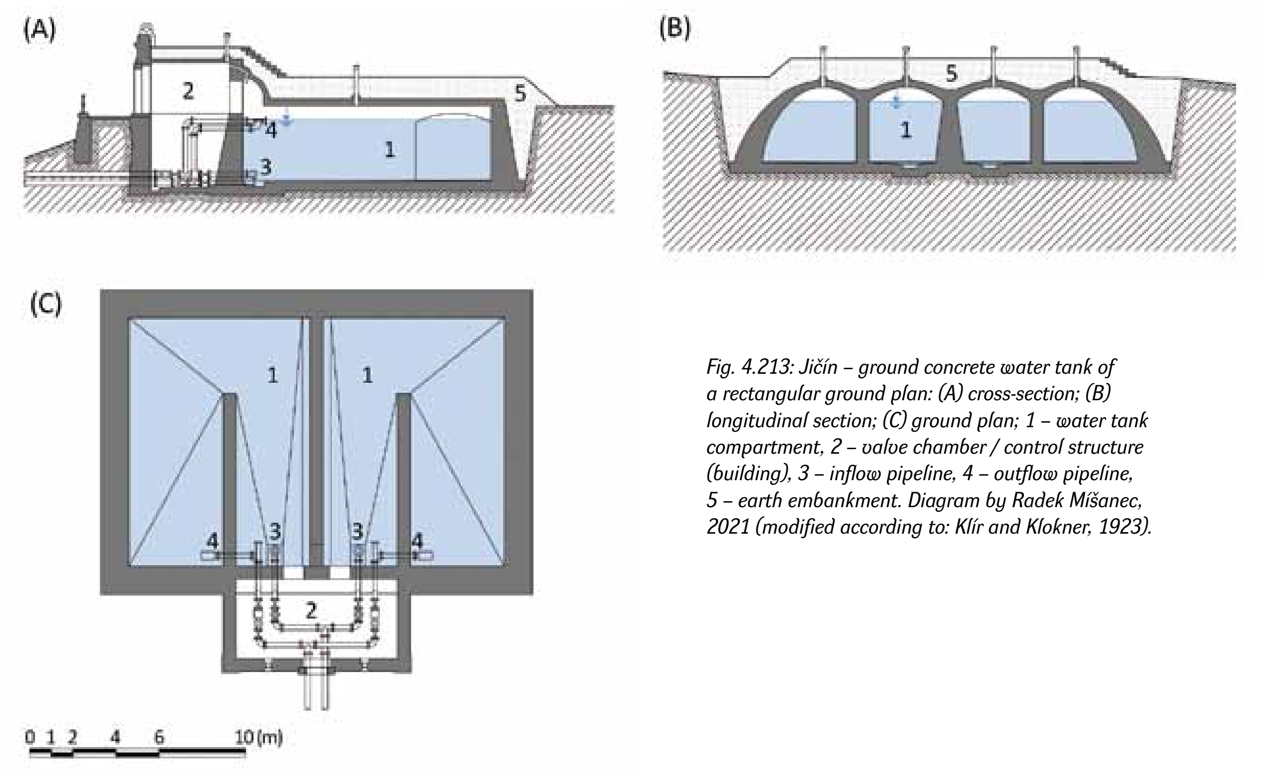


Fig. 4.213: Jičín – ground concrete water tank of a rectangular ground plan: (A) cross-section; (B) longitudinal section; (C) ground plan; 1 – water tank compartment, 2 – valve chamber / control structure (building), 3 – inflow pipeline, 4 – outflow pipeline, 5 – earth embankment. Diagram by Radek Míšanec, 2021 (modified according to: Klír and Klokner, 1923).

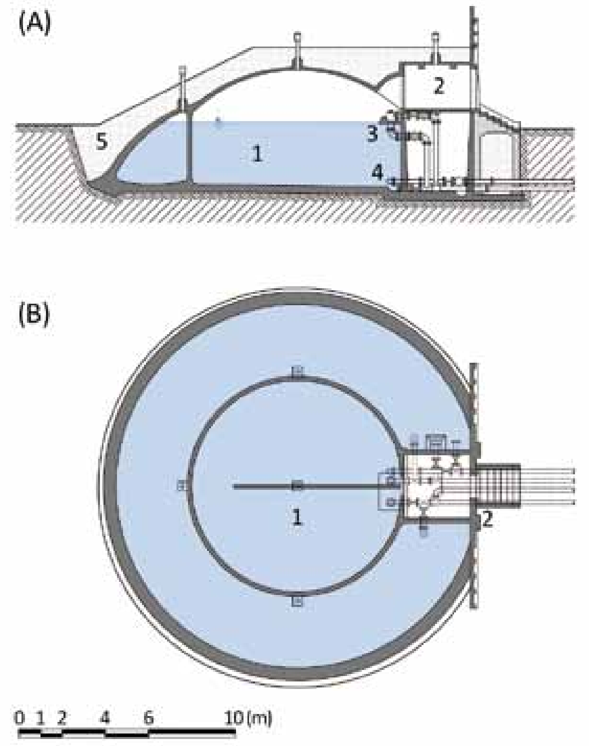


Fig. 4.214: Ground reinforced concrete water tank of a spherical shape: (A) cross-section; (B) ground plan; 1 – water tank compartment, 2 – valve chamber / control structure (building), 3 – inflow pipeline, 4 – outflow pipeline, 5 – earth embankment. Diagram by Radek Míšanec, 2021 (modified according to: Klír and Klokner, 1923).

Fig. 4.215: Ground water tanks: (A) Olomouc, ground water tank on the Tabulový hill; (B) Příbram, ground water tank Husa/U Husy, completed around 1930, it collected water from the Drkolnov mine. Photograph (A) by Michaela Ryšková, 2021; (B) by Viktor Mácha, 2019.

Lomnice nad Popelkou (incl. pumping station); Mariánské Lázně; Oldřichovice; Opava; Ostrava – Muglinov; Prague – Karlov, Cibulka, Malvazinky, Andělka, Vyhlídky; Příbram (Fig. 4.215); Most – Hněvín; Olomouc – Tabulový vrch (Fig. 4.215); Osečná; Plzeň (in water treatment plant in Homolka); Prachovice; Romanov; Rozprechtice; Sedlec near Mšeno; Sušice – Faustinka (with an observation tower); Štiřín; Šumperk – on the Krenišov hill, Vyhlídka; Tetín; Velké Losiny; Vikýřovice; Vyškov; Žatec; etc.

4.5.2.6.2 Elevated water tanks

An elevated water tank is "*a water tank located on a supporting structure*" (ČSN, 1985). Apart from water supply purposes, elevated water tanks may also be used for collecting non-potable water for technological use, agricultural purposes, extinguishing purposes or for the supply of steam traction (for the operation of steam locomotives). They can serve regulating (to regulate even inflow and uneven intake), pressure, reserve and fire-fighting functions (Kořínek et al., 2019). Railway water tanks for steam engine railway operation form a specific segment of elevated water tanks with (to a certain extent) their own development and typology (Borovcová, 2017).

According to the latest, and not published yet, research of the NAKI II project “Elevated water tanks – identification, documentation, presentation, new use“ (code DG18P02OVV010, researcher Robert Kořínek), original water tower structures are not typologically defined as elevated water tanks but as per their previous stage. Herein, their classification as elevated water tanks is maintained, as per the above definition.

The classification according to architectural styles or trends is also more pronounced in the case of elevated water tanks than other water management structures: Gothic, Renaissance, Baroque, historicising elevated water tanks, Art nouveau, modernist, functionalistic, etc. A visually exposed location associated with high-quality architectural rendering is a reason why elevated water tanks have become a symbol/characteristic of water supply systems and water distribution in general (and, in a way, also part of the image of landscape, villages and towns).

An overview of examples and constructions of elevated water tanks of Western Europe from the 1960s to the 1990s can be seen in the works of Hilla and Berndt Becher, photographers systematically documenting iconic buildings of technology and industry (mining towers, blast furnaces, gas holders, coal towers, water towers, etc.) (Becher, 1999).

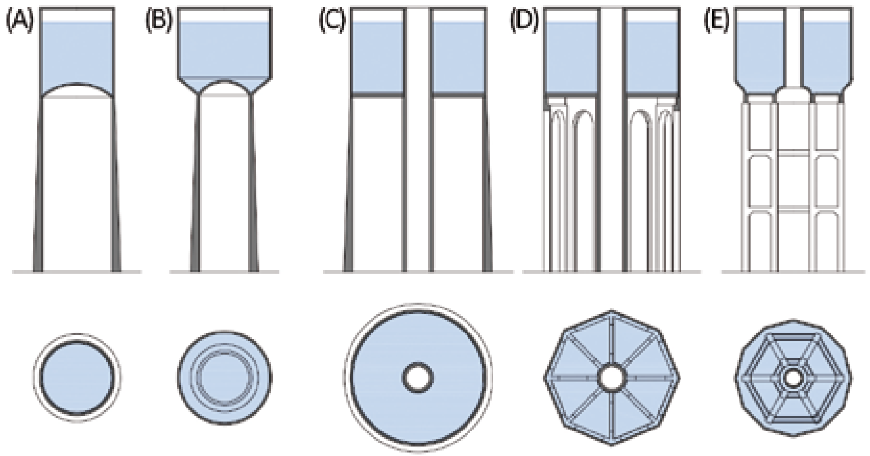


Fig. 4.216: Examples of construction solutions of water tanks with reinforced concrete structure: (A) cylindrical below the perimeter of the cistern, (B) cylindrical on a foundation wall (Intze-type), (C) cylindrical, peripheral and shaft on a double foundation wall, (D) on radial walls – solid or with openings, (E) on several pillars. Diagram by Radek Míšanec, 2021 (modified according to: Klír and Klokner, 1923).

4.5.2.6.2.1 Classification according to the supporting structure

Classification of elevated water tanks according to the material of their supporting structure (Kořínek et al., 2019; Fig. 4.217):

- wooden (the oldest elevated water tanks and temporary structures),
- masonry (originating from the 16th century made of stone, later brick and mixed masonry),
- reinforced concrete (originating from the beginning of the 20th century),
- steel (used especially for industry from the mid-19th century, from the mid-20th century also for the water industry).

Classification according to supporting structure: wall, skeleton (open), combined (Kořínek et al., 2019).

4.5.2.6.2.2 Types of tanks in elevated water structures

Classification according to the shape of the tank (Kořínek et al., 2019; Fig. 4.218):

- mushroom-shaped (the oldest shape, small volume),
- four-sided (the second oldest shape),

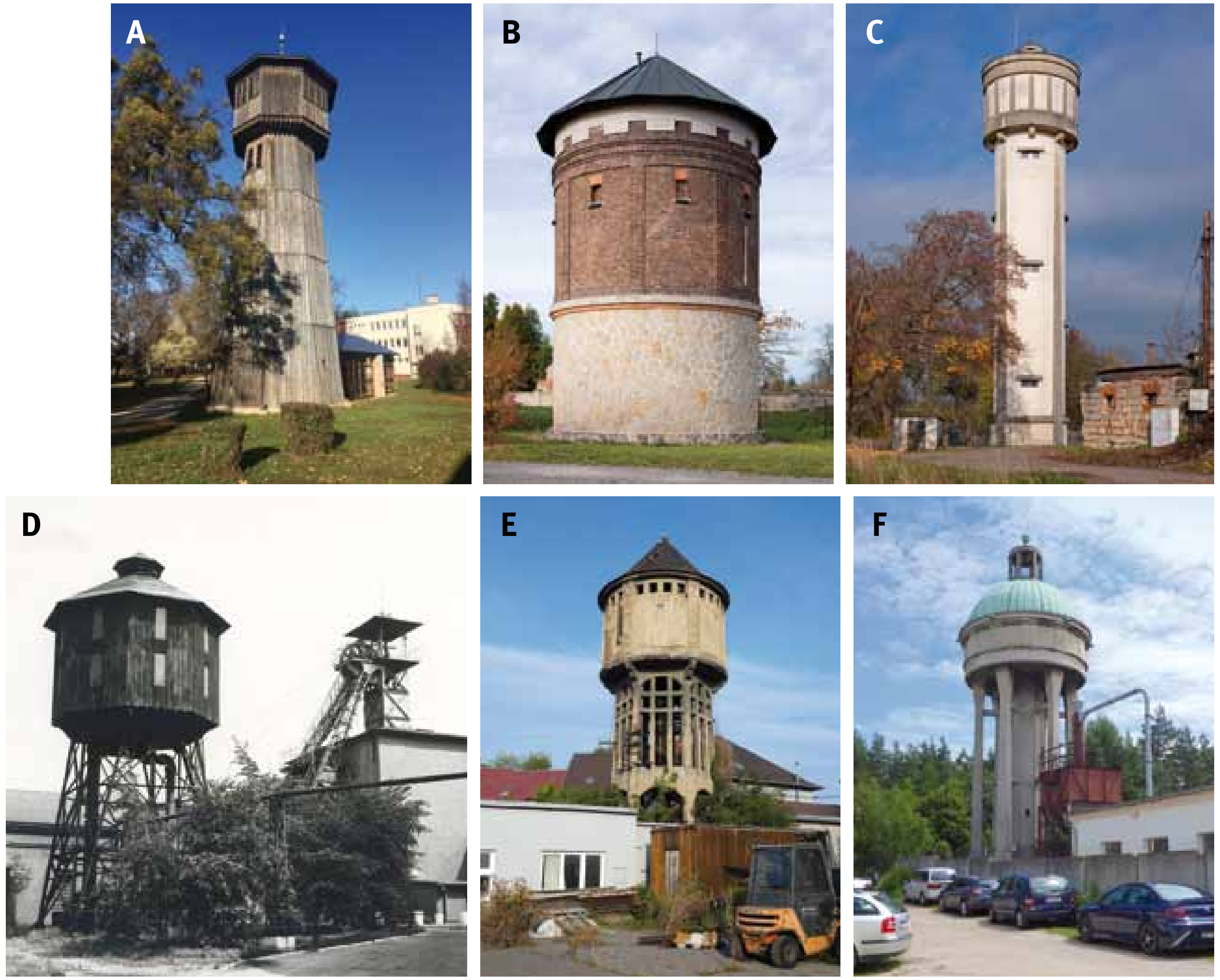


Fig. 4.217: Examples of supporting structures of water tanks: (A) Palárikovo (Slovakia), wooden elevated water tank, probably the only surviving one in Europe, after conversion; (B) Kovanec, elevated water tank with masonry wall supporting structure from stone and bricks, built in the historicist morphology according to Karel Kress’s design in 1909; (C) Horní Bukovina, elevated water tank with reinforced concrete supporting structure built in 1935 according to Ing. Fanta’s design; (D) Ostrava, Hubert mine, extinct elevated water tank with steel supporting skeleton (framed) structure and wooden cladding of the tank in the picture from the end of the 1960s; (E) Duchcov, elevated water tank with a skeleton reinforced concrete supporting structure built between 1908 and 1912 for the Engels glassworks; (F) Lázně Bohdaneč, an elevated water tank supported by a reinforced concrete combined structure, built according to Josef Gočár’s design in 1911, in the middle shank of the structure there is a staircase. Photograph (A), (E) and (F) by Michaela Ryšková, 2021, 2020, 2016; (B) and (C) by Viktor Mácha, 2018; (D) from the MCPD reprophotography archive.

- cylindrical (from the second half of the 19th century, or when two tanks are combined – a cylinder and surrounding ring),
- conical (from the second half of the 20th century; the shape of a truncated cone is used for chimney water tanks),
- spherical (used in the Czech Republic only since the 1960s),
- ellipsoid shape (rarely used),
- other (combined, or atypical shapes).

Classification according to the material of the tank (Kořínek et al., 2019):

- metal (the oldest were copper, from the mid-19th century steel),
- masonry (rare, documented in the case of the water tank in Prague-Bubeneč from 1901),
- reinforced concrete (from the beginning of the 20th century, today no longer used).

Classification according to the number of tanks (Kořínek et al., 2019):

- single-tank (majority),
- with two or more tanks:
  - for one system (Fig. 4.222, Fig. 4.224),
  - for multiple systems/purposes – e.g., potable and non-potable water).

Number of occurrences in the CR: approximately 1,500 (Database of water tanks)
The oldest surviving use in the CR: gothic elevated water tanks
The latest surviving use in the CR: unknown
Examples (incl. water towers; each is unique): Brno-Kohoutovice (Fig. 4.219); Břeclav (Fig. 4.219); Cítoliby (water tower); Heřmanova Huť (for brewery); Horažďovice; Hradec Králové; Chrast (water tower); Chudeřice (for factory); Jičín – water tower; Jablonec nad Nisou-Vratislavice (combination with coal tower); Jindřichův Hradec ("Pluhová" water tower); Kladno-Rozdělov (iron and reinforced concrete); Lázně Bohdaneč; Louny; Mělník (water tower); Mladá Boleslav (water tower); Nymburk (so-called Turkish tower and a water tower); Ohrazenice u Turnova; Olomouc – Tabulový vrch (on a 13th-floor dwelling house); Ostrava – Hladnov, Vítkovice (Fig. 4.221); Pardubice – Pardubičky; Plzeň (water tower, brewery elevated water tank); Prague – Letná, Michle (Fig. 4.220); Holešovice (for a slaughterhouse), Libeň (Mazanka), Barrandov (for film studios), Letňany (for Avia industrial area), Kbely (airport lighthouse), water towers: Staroměstská (Old Town), Petržílkovská, Novoměstská (New Town), Šítkovská, Novomlýnská, Tábor (water tower); Teplice (Fig. 4.219); Třebíč (on Kostelíček hill); Turnov (water tower); Uničov – Šibeník; Veselí nad Lužnicí; Vysoké Mýto (water tower); Krnov (Fig. 4.223) etc.

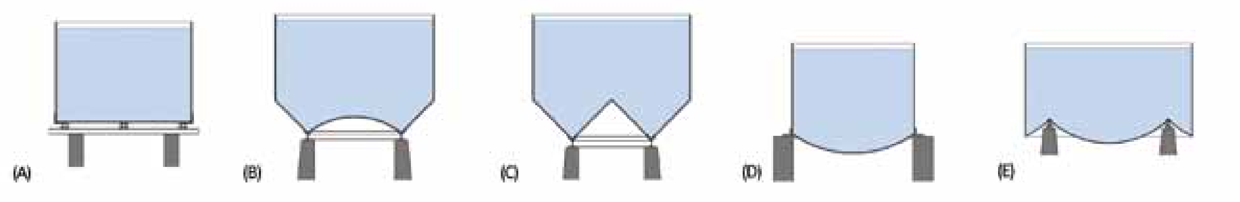


Fig. 4.218: Examples of metal tanks bottoms: (A) flat bottom; (B) bottom in the shape of a spherical calotte cambered upwards or downwards, Barkhausen; (C) and (D) bottom with an outer conical casing and inner casing in the shape of a spherical calotte or conical, Prof. Inze; (E) bottom composed of inner suspended calotte and outer conical suspended calotte, Smreker. The implementation of the last two types (D) and (E) is not documented in the Czech Republic. Diagram by Radek Míšanec, 2021 (modified according to: Klír and Klokner, 1923 and archive plan documentation).

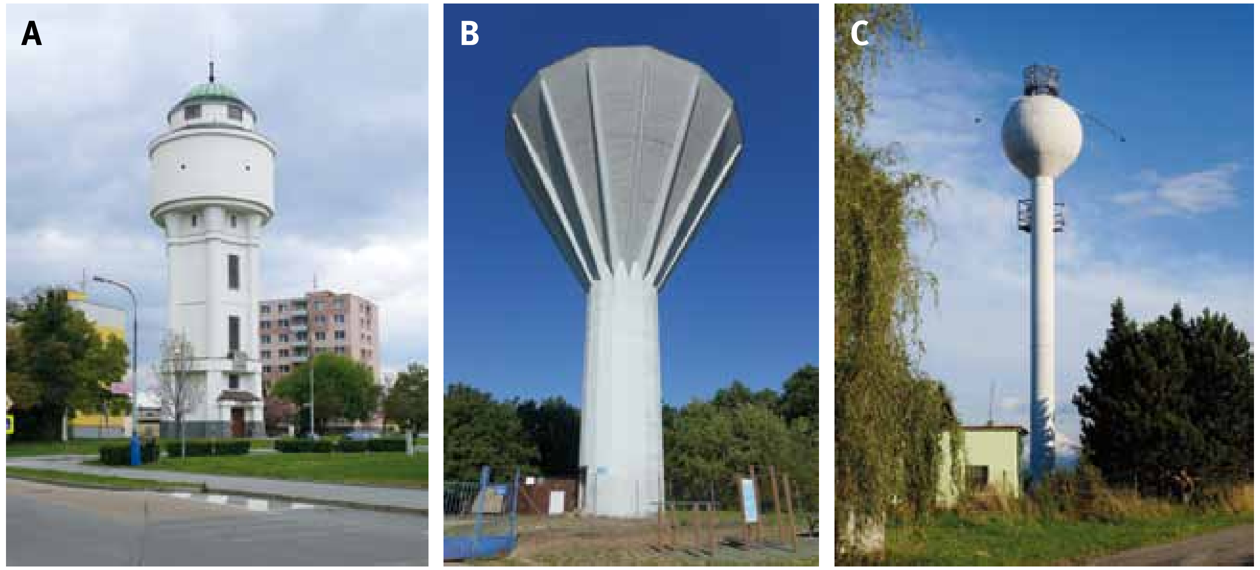


Fig. 4.219: Examples of tanks of elevated water structures: (A) Břeclav, reinforced concrete elevated water tank from 1926 to 1927 with a cylindrical tank supported by seven concrete shanks; (B) Brno-Kohoutovice, elevated water tank with a conical tank, built in 1969 according to architect Tomáš Černoušek's design; the first elevated water tank of a similar type and structure – Svampen – was built in 1958 in Örebro (Sweden); (C) Petřvald, elevated water structure with a spherical tank; (D) Sudkov, steel cylindrical chimney water tank with a conical bottom, built for extinguishing purposes at a spinning mill processing flax and cotton Ig. Seidl in 1907; (E) Teplice, elevated water structure with two metal tanks combining the shapes of truncated cones. Photograph by Michaela Ryšková, 2017, 2016, 2021, 2019, 2020.

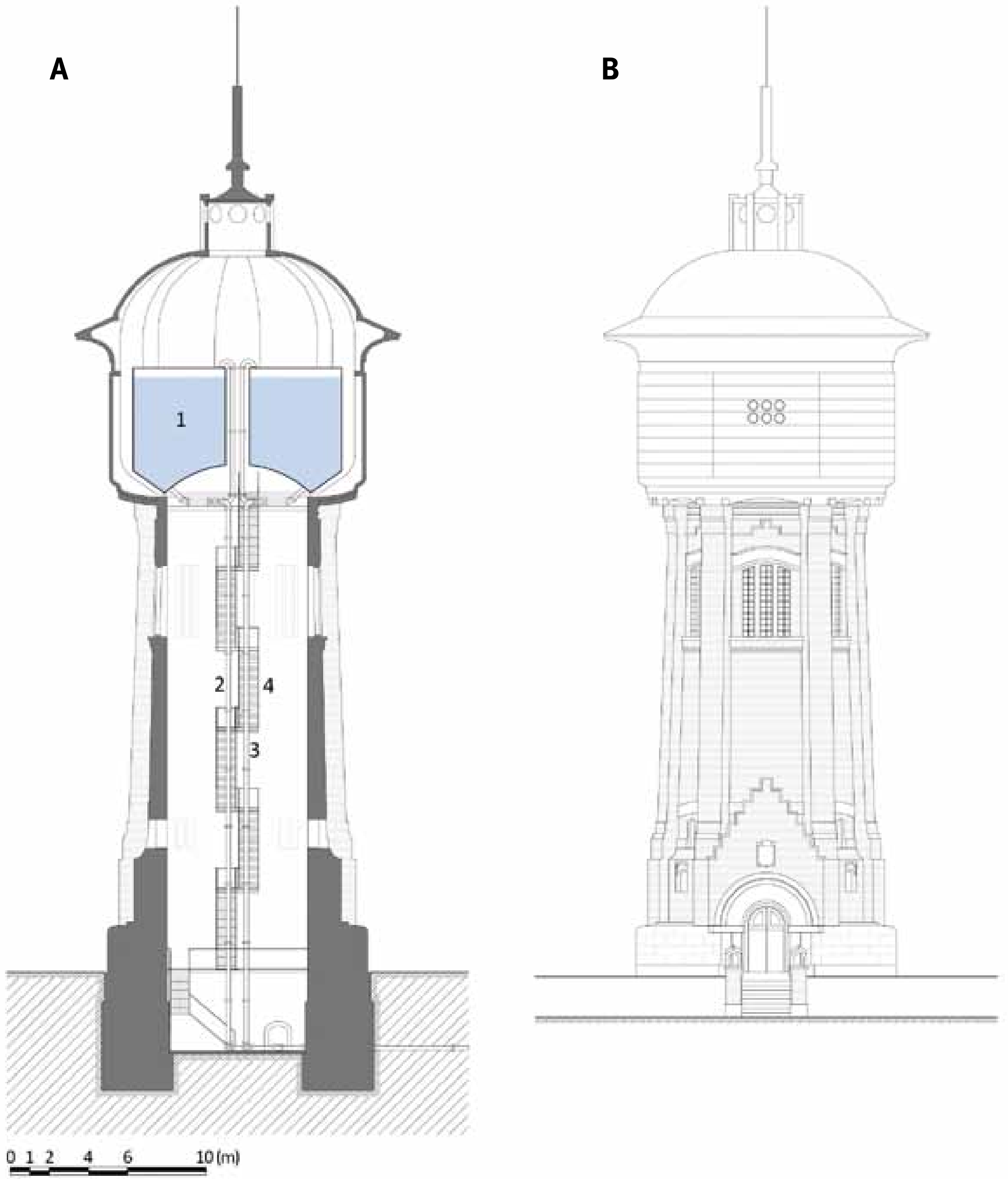


Fig. 4.220: Prague-Michle – Art Nouveau elevated water structure Zelená Liška with a cylindrical steel tank with the capacity of 1,200 m^3 was part of the Vršovice waterworks. It was built between 1906 and 1907 according to a design by Karel Kress (construction part), Vladimír Hráský (technology) and Jan Kotěra (architectural solution). It is a typical representative of elevated water tanks from the turn of the 19th and 20th centuries, with a construction corresponding to the then standards and accentuated architectural rendering of its supporting structure and casing. A similar architectural design on a different scale was used in Třeboň. A – section, B – elevation, 1 – convex-bottom cylindrical tank, 2 – inflow pipeline, 3 – outflow pipeline, 4 – access staircase. Diagram by Radek Míšanec, 2018 (modified according to: Klír and Klokner, 1923). Photograph by PVK archive, Jaroslav Beneš, 2017.

Fig. 4.220: Prague-Michle – elevated water structure Zelená Liška, (C) current state. Photograph by Jaroslav Beneš, 2017, PVK archive.

Fig. 4.221: Ostrava-Vítkovice – a unique elevated water tank in the tower of St. Paul's Church in Ostrava-Vítkovice. The town of Nové Vítkovice, founded by the Vítkovice Ironworks as a base for growing production plants, started to be built in the 1870s. St. Paul's Church with a detached tower became a significant dominant feature of its square, in addition to the town hall. The tower was built before the temple nave itself in 1882 and in its upper part there were, apart from a belfry and fire observation tower, also two tanks, each with a volume of 50 m^3. They were part of the water supply system to which residential units and other buildings of the newly built town were connected (Matěj et al., 1992). Photograph by Michaela Ryšková, 2019.

Fig. 4.222: Ostrava-Vítkovice – steel elevated water structure with two tanks. A steel elevated water tank typical for industrial companies, which, however, deviates from that era's production in terms of typology, structure and parameters. The structural design is different from the commonly built steel elevated water tanks from the production of the Vítkovice Ironworks (water tanks in Ostrava–Hladnov). What is unique is each tank being carried by a separate shank and a lift shaft situated in the third separate shank, which has been documented in the Czech Republic only in three cases. At the same time, it is one of the elevated water tanks with the largest volume in the Czech Republic. In the third national competition for the best construction with supporting steel structure organised by the Czech Association of Scientific and Technical Societies it won the main prize in the category of Technological structure for 1983. The water tank is also a dominant landmark and an important orientation point. The project and pre-production preparation was provided by Hutní projekt Praha, Ostrava plant (the general designer was Ing. Antonín Kozák) and VŽKG, k. p., Ostrava, Ing. (the vessels were designed by Pavel Klimeš) (Devátý, 1983, Soušek, 1982). Photograph by Michaela Ryšková, 2016.

Fig. 4.223: Krnov – elevated water tank on the premises of the Karnola plant. An elevated water tank with unknown date of origin and authorship intended for non-potable water for the Karnola textile plant. A low-height water structure with a cylindrical tank carried by steel shanks and an architecturally designed casing, composed of two cylinders of different scales and broken by two horizontal ribbon windows. It was demolished in 2020. Photograph by Michaela Ryšková, 2013.

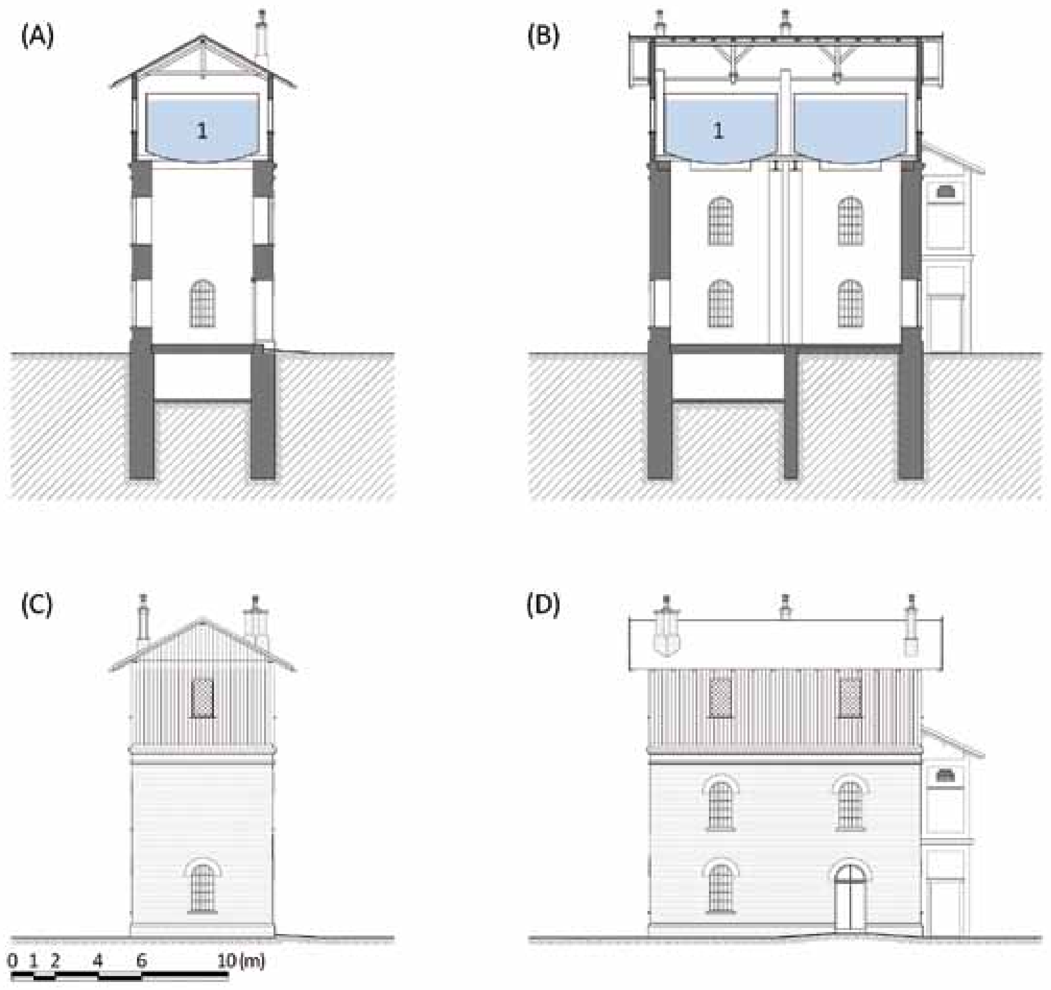


Fig. 4.224: Skalice nad Svitavou – railway elevated water tank with two cylindrical tanks, built according to the standardised project by C. k. ředitelství pro tratě of the former Společnost státní dráhy from 1910. An example of the use of an elevated water tank for other than water supply purposes. (A) cross-section, (B) longitudinal section, (C), (D) elevations, 1 – convex-bottom cylindrical tank. Diagram by Radek Míšanec, 2018 (modified according to: plan documentation).

4.5.2.7 Water supply network

A water supply network serves to supply and distribute water in a given consumption area and consists of water supply pipelines and other technical (service) structures (Milerski, 2005; Fig. 4.225, Fig. 4.226):

- shutters (spindle, stirrup gate valves) for shutting individual sections,
- valve shafts (for more than two shutters),
- air valves for air disposal (at the highest points of water mains, preceded by a shutter),
- sludge valves (sludge pipes) for water discharge (at the lowest points),
- hydrant – for water withdrawal in the event of fire; underground or overground (where there is no risk of freezing),
- support blocks (against displacement or deflection),
- protectors (when crossing with roads, on bridges, under watercourses),
- pipeline.

Special components are long-distance conduits which are high-capacity pipes used to supply drinking water from a remote water source to the treatment or accumulation site for the given consumption area. An example of this can be a long-distance conduit for Prague from the Švihov reservoir (total length 51.97 km), or a historic conduit of the 1st Březová conduit from Březová nad Svitavou to Brno (total length 57.46 km).

Number of occurrences in the CR: unknown
The oldest surviving use in the CR: unknown
The latest surviving use in the CR: unknown
Examples: Besednice group water supply network; the 1st Březová conduit; Sojovice – drainage mains; etc.
Unique examples: Letovice – relief tower; Prague-Pankrác, counter-impact/levelling tower; Prague-Radlice, anti-shock/stand-pipe tower Děvín; Bylany – aqueduct; Želnava, water distributor etc.

Fig. 4.225: Relief and stand-pipe towers of aqueducts: (A) Letovice – relief tower of the 1st Březová conduit to supply drinking water to Brno; (B) Prague – stand-pipe tower Děvín built according to architect Karel Hubáček's design, SIAL. Photograph (A) by Michaela Ryšková, 2016; (B) from the PVK archive, f. Fotoarchiv PVK, kt. N 8, sign. B 9516.

Fig. 4.226: Želnava – water distributor from 1818 was part of the local water supply system. It looks like a granite cylinder, in whose axis an opening is drilled to pour the capillary ascent of water which was conducted here from the spring area by a gravitational pipeline. The water then falls over a metal shutter into eight openings drilled around the perimeter. At the base of the cylinder, a pipe was connected to them, which distributed the water to the individual homesteads. Similar water distributors were built in the villages of Pěkná and Záhvozdí (Hlušičková, 2004). Photograph by Michaela Ryšková, 2022.

4.5.2.8 Waterworks systems

Water supply can be structured into two levels (Milerski, 2005; Fig. 4.227):

- *local system* (group water supply system), serving the water transport from water tanks of the superordinate system into consumption areas and for the distribution of water directly in the consumption area (village, town);
- *superordinate system*, involving structures and pipelines enabling the transportation of water from individual sources into the water tank of these systems (for larger units, e.g. Ostrava regional water supply system).

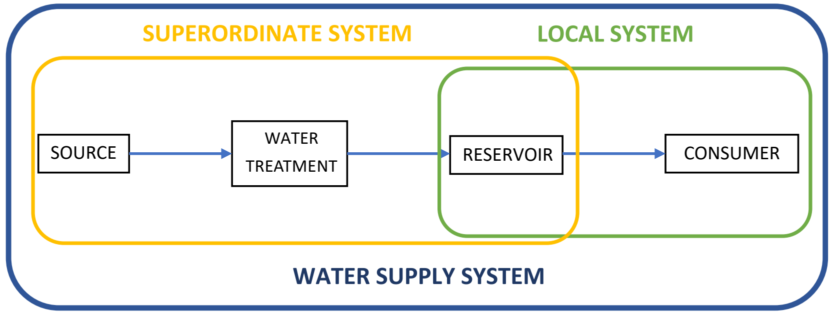


Fig. 4.227: Diagram of the whole water supply system – basic elements and classification. Diagram by David Honek, 2021.

Local systems in this conception represent the distribution part between the water treatment plant/water tank and the water consumer in the consumption area. At the beginning of the drinking water supply, it involved only a water supply from the source directly to the customer (source – mains – fountain). In later eras, water pumping and accumulation structures (water tanks) were added but it was still rather a local supply of one settlement from one source. Superordinate structures, or regional water supply systems, started to be built in the 20th century when it was necessary to ensure a stable drinking water supply to settlements. From the 19th century, settlements experienced a boom in connection with the intensive development of industry. This put more and more pressure on water sources. As the state of local sources deteriorated, it became necessary to supply water to growing towns from other and often very distant locations, which led to the emergence of so-called long-distance water conduits (Švihov/Želivka – Prague, Březová nad Svitavou – Brno, Kružberk – Ostrava). Furthermore, local systems started to be interconnected and new settlements connected to existing networks, creating large superordinate systems that often have a backbone water supply and strategic water sources. Thanks to these comprehensive systems, it is possible to ensure water supply even during crisis situations (breakdown on mains, source failure, etc.).

Number of occurrences in the CR: till 1935 ca. 30 significant water supply systems (Broncová, 2006)
The oldest surviving use in the CR: unknown
The latest surviving use in the CR: unknown

4.5.3 FUNCTIONAL COMPLEXES

4.5.3.1 Water supply of Prague (underground water, surface sources)

The capital is supplied from three independent sources, which have been created within less than 60 years. These are the Káraný waterworks, Podolí waterworks and Želivka water treatment plant.

The Káraný waterworks (Fig. 4.228) was officially launched on 1 January 1914, having been in trial mode already from 1912. It currently supplies water by three conduits – the original one from 1914, the second one from the 1930s, which is a duplication of the original mains, and the third one from the 1980s. The source of raw water is underground water naturally and artificially infiltrated into the bedrock of the Jizera River. In 1968, artificial infiltration was launched, which multiplied the amount of water pumped. Apart from the City of Prague, Káraný waterworks supplies water to a number of municipalities in the Central Bohemian Region.

Fig. 4.228: Káraný – a general view of the Káraný water treatment plant. Photograph from PVK archive, fonds Fotoarchiv PVK, digi archiv, sign. DV 125.

Fig. 4.229: Švihov – aerial view of the Želivka water treatment plant. Photograph from PVK archive, fonds Fotoarchiv PVK, box N 17, sign. B 180/00.

The Podolí water treatment plant was built in 1923–1929 and 1952–1965. The source of raw water is the Vltava River (for more details see Chapter 4.5.4).

The Želivka water treatment plant (Fig. 4.229) was launched in 1972 as the main source of drinking water for Prague and its surroundings. The source of raw water is the Švihov hydraulic structure. The water is pumped by a free-standing multipurpose structure and transported to the water treatment plant via a pumping station. The basic technology of water treatment is filtration involving destabilisation, aggregation and single-stage separation on open sand filters using aluminium sulphate. After filtration, the raw water goes through the process of ozonisation. In 1987, the extended third line of the water treatment plant was launched.

4.5.3.2 Water supply of Brno (underground water, surface sources)

The city of Brno has three main sources of drinking water – two underground and one surface (Fig. 4.230). Both underground sources are located to the north-west near Březová nad Svitavou in the Pardubice District and the underground water is pumped here from two horizons. The water has a very good quality but nitrogen concentration has increased in the upper horizon in the recent decades. The water is pumped here through boreholes of various depths and conducted to the Březová nad Svitavou water tank where it is mixed, chlorinated and then conducted farther through two long-distance supply conduits towards Brno. The older aqueduct is cast-iron and there are 18 sectional gate valves and 16 of them are equipped with a green masonry little house. The conduit is 57.5 km long, conducts water into two ground water tanks in Brno-Lesná and the overall capacity is ca 300 l/s. The second conduit from 1975 is made of steel and is 55.4 km long with an overall capacity of ca 1,140 l/s. It conducts water into a water tank on the Palacký hill in Brno but before that it is mixed with the water from the third conduit in the Čebín junction. The currently used flow of both historical conduits is ca 1,450 l/s. The third conduit, the so-called Vír regional water supply system, conducts water to Brno from the Vír I reservoir. The water from the reservoir is first conducted to the water treatment plant in Švařec and then through a 47-kilometre-long pipeline to Čebín where it meets water from Březová. The conduit started to be built in 1988 and it has been constantly expanded. Its whole length (including the main branches) is about 100 km today and it conducts water up to the village of Těšany (ca 20 km southeast of Brno) (BVK, 2013).

From the point of view of water management structures, the most valuable conduit is the 1st Březová conduit which is in principle completely original, except for some safety and control elements which had to be modernised. The evaluation of the structure is mentioned in Chapter 4.5.4.1.

4.5.3.3 Ostrava regional water supply system – Opava branch (surface source)

The Ostrava regional water supply system started to be built in 1954 when the foundation in the form of the construction of a conduit from the Kružberk reservoir was laid. The whole system consists of two main group water supply systems – Kružberský and Beskydský – with the overall length of water mains being 499.6 km (without the mains in settlements). The Ostrava regional water supply system is an important source of drinking water for a large part of the Moravian–Salesian Region but partially also for the Olomouc region and for some villages in Poland (GROUP OF AUTHORS, 1975; VRV, 1984; SMWAK, 2021).

The Beskydy group water supply system has two central water treatment plants: one in Nová Ves near Frýdlant which treats water from the Šance reservoir, and the other one in Vyšní Lhoty which treats water from the Morávka reservoir. The total production of drinking water from both these plants is 2,650 l/s (Nová Ves 2,200 l/s, Vyšní Lhota 450 l/s). This water supply system started to be built in 1955 when the construction of the plant in Vyšní Lhota began (GROUP OF AUTHORS, 1975; VRV, 1984; SMWAK, 2021).

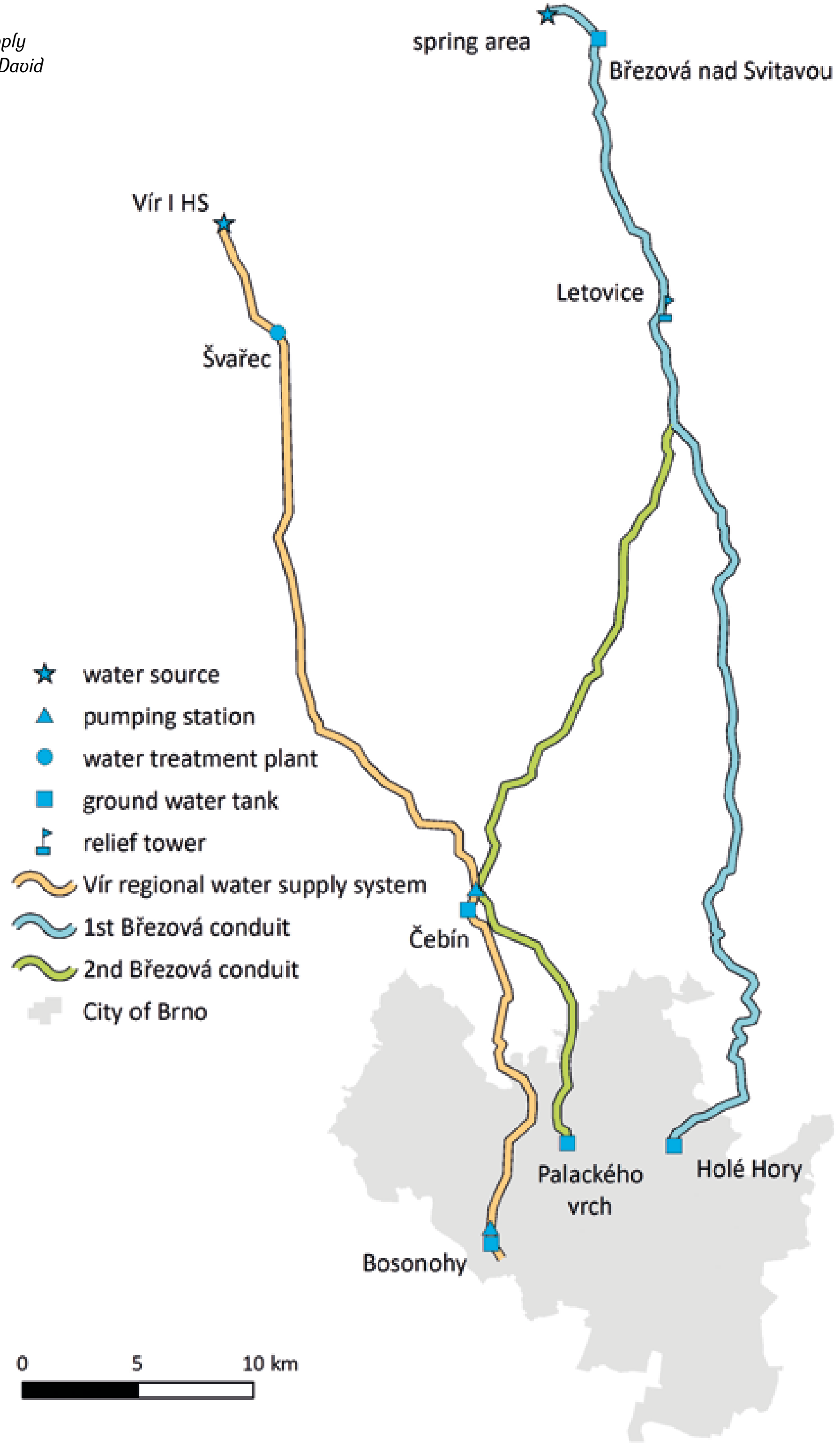
The Kružberský group water supply system is based on the Kružberk reservoir from where raw water is conducted by a 6.7-kilometre-long tunnel to a water treatment plant in Vítkov-Podhradí. The current capacity of the plant is 2,700 l/s, which ranks it second in the Czech Republic after the Želivka water treatment plant. Water is conducted farther by three main branches to the Bruntál District, surroundings of Fulnek and Ostrava District. Part of the water supply system is also the pre-inserted reservoir Slezská Harta, Lobník reservoir, Podhradí weir surge tank, five small hydraulic power plants (Slezská Harta, Kružberk, Kružberk-Podhradí, Podhradí water treatment plant and Podhradí weir) and Krásné Pole large-capacity water tank (12,000 m^3 of drinking water). This water supply system is significant especially thanks to the heritage protected water treatment plant in Vítkov-Podhradí, whose evaluation can be found in Chapter 4.5.4.2. (GROUP OF AUTHORS, 1975; VRV, 1984; SMWAK, 2021).

4.5.4 EVALUATION FROM THE POINT OF VIEW OF HERITAGE PRESERVATION BASED ON SPECIFIC EXAMPLES

4.5.4.1 1st Březová aqueduct

The idea of building a long-distance water conduit for the city of Brno (Fig. 4.231) originated at the end of the 19th century when the source on the Svratka River in Pisárky was not sufficient any more. The area of large groundwater springs near Březová nad Svitavou (in the location of the former village of Muzlov) was chosen as a suitable source because there were a number of very abundant springs that fed directly into the Svitava River. At the beginning

Fig. 4.230: Water supply of Brno. Diagram by David Honek, 2021.



of the 20th century there was a large hydro-geological research carried out, which included pumping tests, and in 1991 the construction of a 57.5-kilometre-long conduit began. Water is pumped by means of 14 drilled wells from the depth of 17 to 21 m. The maximum yield of this source is 300 l/s but pumping is only permitted up to 250 l/s. This water supply system was put into operation in 1913. It conducts water into two ground water tanks on Holé Hory, a hill in today's Brno-Lesná quarter. The quality of the aqueduct was very high, which has been reflected in the very low failure rate and the preservation of the original equipment to this day. The aqueduct route is led more or less in the alluvial plain of the Svitava River, only at three short stretches it was necessary to dig a tunnel (BVK, 2013).

Temporal determination/date of origin: 1911–1913
Authorship: investor: Brno-City
Heritage preservation: no
Reconstruction: Minimal reconstructions, the aqueduct is original cast-iron and the reconstructions were carried out mainly on the constructional parts of gate valve chambers, with an effort to preserve the original design. There were upgrades of control parts (electrification) and repairs due to pipeline failures over time, but these have been relatively few.

Evaluation:

Typological value: Based on existing research, it is probably the oldest and longest long-distance conduit in the Czech Republic (except for the Vír conduit but this is constantly being extended to connect other settlements). It is also a typical example of a cast-iron conduit in an original form, including all machinery parts.

Value deriving from the technological flow: The water supply system as a functional complex consists of collecting structures, the conduit itself, three ground water tanks, four tunnels, 16 slide chambers and a relief tower. It thus forms a complete technological flow of a gravitational drinking water conduit. No water treatment plant is installed on the aqueduct – only at the point of connection with the second aqueduct in the Březová nad Svitavou water tank the water is chlorinated to ensure the hygienic quality of the water to be farther transported.

Value deriving from authenticity: Almost all parts of the waterworks are original, including machinery equipment which was modernised over time because of remote control and safety. Its pipeline is cast-iron. The construction material of surface parts of the waterworks is also original, continuously renewed while maintaining the original architectural and material solution.

Architectural value: A set of buildings in a morphology corresponding to the date of origin with the use of historicising architectural elements and combination of facing masonry, plastered surfaces and stone elements. On some buildings there are coats of arms or reliefs of the city of Brno (slide chambers, entry portal into the intake shaft, ground water tanks).

Landscape/urban value: The waterworks does not form a distinct dominant landscape feature, only the visible parts of the waterworks (slide chambers, ground waterworks, etc.) shape, to a limited extent, the landscape in the immediate surroundings. The most distinct element is a 20-metre-high tower in Letovice which serves to relieve the waterworks and is also a dominant landmark of Letovice. From the urban point of view, there has been a significant intervention in the source area, where the original buildings of the village of Muzlov and partly of the village of Banín were gradually removed and the area of water source protection of the level 1 is either grassed (the Svitava River alluvial plain) or wooded (valley slopes). The surface of ground water tanks is also grassed.

Fig. 4.231: The 1st Březová conduit – selected parts: (A) well machinery equipment; (B) slide chamber in Blansko; (C) Letovice relief tower; (D) Březová nad Svitavou ground water tank; (E) pipeline; (F) Březová nad Svitavou gate valve chamber; (G) gate valve chamber control equipment; (H) entry into Holé hory II ground water tank and (I) Holé hory II ground water tank. Photograph by David Honek, Miriam Dzuráková, 2019 a 2020.

4.5.4.2 Vítkov-Podhradí water treatment plant

The water treatment plant in Vítkov-Podhradí (Fig. 4.232) was built between 1954 and 1962. Raw water from the Kružberk reservoir is led to the water treatment plant by a 6.7-kilometre-long pipeline. Water treatment technology needs are solved by as a single-stage coagulation filtration in an open, gravity-flow system of mixing, flocculation and filtration units. Aluminium sulphate is used as a coagulant, the pH of the drinking water is ensured by dosing lime hydrate in the form of lime water and the water is hygienically treated by chlorine and chlorine dioxide. In 2014, a small hydroelectric power plant was installed here which is used for the operation of the water treatment plant and the surplus is passed on to the energy distribution network (SMWAK, 2021; VRV, 1984).

The water treatment plant is designed as a single operating unit. Individual operating parts are distinguished by differentiated, technologically interconnected materials whose construction basis is a reinforced concrete frame structure with brick lining. The axially symmetrical layout evokes the shape of an aeroplane or a flying bird. The main entrance, lobby, administrative office and laboratory are located in the central axis, followed by the mixing, dosing and perpendicularly located workshops and garages in the tail. The wings are formed by symmetrical, perpendicular to the central axis and identical filtration facilities, built in two phases and ready for possible expansion. The facade bears an extensive relief “Water in our lives” by the sculptor Vincenc Makovský created from 1961–1964 (Borovcová, 2011; Dzuráková et al., 2021; SMWAK, 2021; VRV, 1984).

Temporal determination/date of origin: 1954–1962
Authorship: building by the architect Cyril Kajnar, Stavoprojekt Ostrava; relief by Vincenc Makovský
Heritage preservation: Cadastral Office (1974)

Fig. 4.232: Vítkov-Podhradí – water treatment plant: (A) filtration hall; (B) filtration tanks; (C) original control panel. Photograph by David Honek, 2019; (D) relief (for more photographs see Chapter 3.2, art-historical value). Photograph by Roman Polášek, 2019.

Reconstruction:

1990s – modernisation of the technological equipment, replacement of strained technological components, including parts of the building due to increased humidity and use of chemical substances
2005–2009 – modernisation of technology and reconstruction of infrastructure (complemented chlorine treatment system, installation of hydraulic flocculation, etc.)
2011 – reconstruction of the water treatment plant roof and ceiling structures in filter halls completed
2014 – small hydroelectric power plant put into operation
2015–2016 – extensive reconstruction of machinery and electronic equipment
2019 – repair of damaged parts of Brizolit facade plaster, glass panels, roofing, etc. in the dosing building

Evaluation:

Typological value: From a typological point of view, it is the first and also the last water treatment plant in the Oder River basin. The plant has exceptional parameters thanks to the unique concept of two mutually independent parts for purification and treatment of raw water, which are mirror-arranged. In addition, the plant uses the potential of the incoming water by means of an installed small hydroelectric power plant.

Value deriving from the technological flow: The water treatment plant contains all parts/systems required for raw water treatment from a surface source and it is part of the Ostrava regional water supply system.

Value deriving from authenticity:

- **Authenticity of mass/material:** Over the course of time, reconstructions and modernisation of mainly the water treatment plant machinery have been carried out. The roof was reconstructed and the ceiling structures were replaced (the original material was found unsuitable, so it was replaced with another kind of material). Due to humidity and the use of chemicals, the original windows in the staircase space and in offices were replaced with plastic windows and the plastic windows were inserted into luxfera glass panels but this was done without the approval of the heritage protection authority and has had a negative impact. The Brizolit facade plaster was partially renewed by refilling the damaged sections. For more information see Chapter 5.
- **Authenticity of function:** Fully preserved.

Architectural value: Contrary to older water treatment plants, which were built as a complex of individual, functionally separate buildings, in the case of the water treatment plant in Podhradí these plants were merged into a single unit differentiated by ground plan and material in terms of individual functions. The ground plan assumes the shape of an aircraft/flying bird, with the fuselage and cockpit/head reserved for the central entrance, offices, control room and administration (and in extension operational buildings), the wings form symmetrical filtration halls and the tail involves ancillary buildings perpendicular to the fuselage.

Art-historical value: The facade of the building bears a large relief “Water in Our Life”, the last work of the sculptor Vincenc Makovský created between 1961–1964. It consists of twenty reliefs divided into two separate blocks with a total area of 90 m^2 which do not form a monolithic whole. The dynamics stem from the distribution of the surface into unevenly sized, more or less protruding stone blocks, which carry individual themes, and from the gradation of reliefs from very shallow ones, sometimes rather linear, to higher ones. The themes were inspired by folklore songs and poetry written down for Makovský by the author Jaromír Tomeček. Incorporating works of art into public buildings is typical for the 1960s and 1970s. Makovský’s relief for the water treatment plant in Podhradí represents a high-quality and monumental sculpture work within this production and thematically directly connected with the purpose of the building (Borovcová, 2011).

Landscape/urban value: The water treatment plant building is situated on an elevated location above the village of Vítkov-Podhradí and forms a visually dominant landmark. Together with other water management structures, which are associated with the water treatment plant, it has had a great impact on the image of the whole valley of the Moravice River.

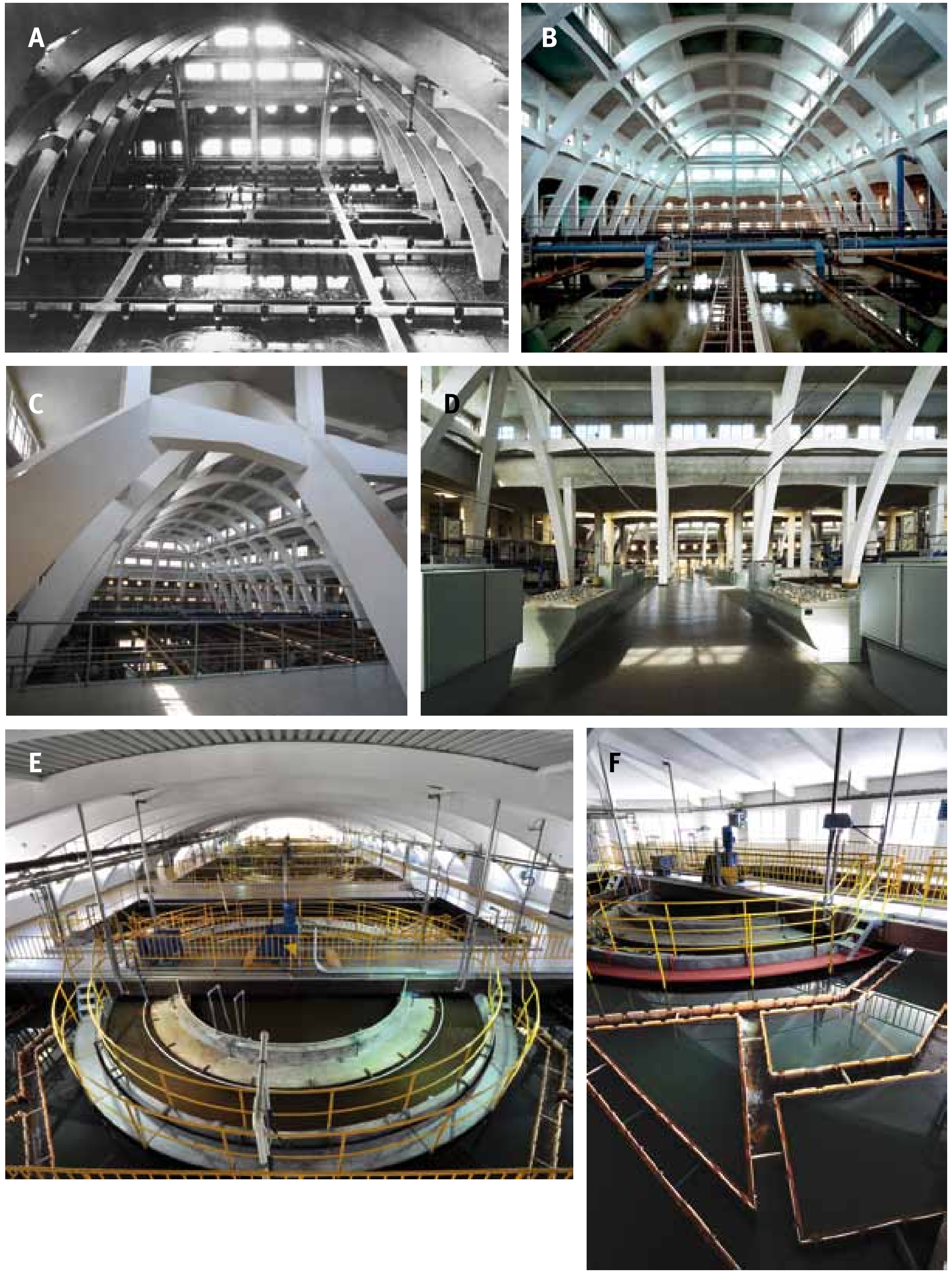


Fig. 4.233: Prague-Podolí water treatment plant: (A) original filtration hall in the 1930s; (B), (C) and (D) filtration hall; (E) and (F) clarifier hall; (G) original filtration hall. Photograph (A) – (F) by the PVK archive and Jaroslav Beneš, 2018; (G) by Michaela Ryšková, 2021.

4.5.4.3 Prague-Podolí water treatment plant

The water treatment plant (Fig. 4.233) was built in two stages in 1923–1929 (first part) and 1952–1965 (completion, the second line put into operation). Water was originally pumped directly from the Vltava River bed and from three original infiltration wells situated on the river bank and in the body of Veslařský (former Schwarzenberský) island.

The plant was conceived as a waterworks for pumping non-potable water treated by triple sand filtration of the Puech-Chabal system. As early as 1931, a coagulation line was incorporated into the system because the water treatment plant was re-evaluated as a source of drinking water and the quality of the pumped water did not correspond to this.

In 1943 the original filters were rebuilt to the Wabag system which technologically stemmed from the coagulation and replaced the original Puech-Chabal system. In 1952–1965 the construction of the whole complex was completed according to amended plans which corresponded to the transformation of the whole technology (it was put into full operation in 1967). The coagulation line, consisting of the Binar-Bělský clarifiers, was moved to the south hall and the north hall remained a filtration hall again using the existing Wabag system (Jásek, 2014).

From 2002 the plant was out of operation, classified as a backup source. After the reconstruction in 2021 it was put into full operation again.

Temporal determination/date of origin: 1923–1929 and 1952–1965 (1967)
Authorship: Investor: Pražské vodárny (first stage), Pražská vodohospodářská služba ÚNV hl. m. Prahy (expansion), original technology (not preserved): Henry Chabal et Cie; architectural design: Antonín Engel; interior layout design: Bedřich Hacar, František Klokner, construction realisation: company Karel Kress (original project), n. p. Ingstav Brno (expansion)
Heritage preservation: cultural monument (1964)

Reconstruction:

1930–1931 – built-in coagulation line
1943 – conversion of filtration to Wabag system
1952–1965 – completion of the construction of the south hall and reconstruction of the north hall; 1965 architectural project completed,
1967 – full operation; original pumping station replaced with a new one
1992–2000 – complete reconstruction, incl. the removal of glass blocks from the previous reconstruction and their replacement with the original ribbon windows
2018–2021 – reconstruction of clarifier hall and filtration hall, adjustment of two filter fields (conversion of part of sand filters to filters with granular activated carbon)

Evaluation:

Typological value: The water treatment plant was built as one of the three realisations of the Puech-Chabal system in the Czech Republic. The original technology has not been preserved. The current technology is a common two-stage separation, used for the withdrawal of raw water from surface sources

Value deriving from the technological flow: The water treatment plant contains all technological elements of water treatment.

Value deriving from authenticity:

- **Authenticity of function:** Preserved. The water treatment plant is still in full operation, modernisations are carried out in coordination with the heritage protection.
- **Authenticity of form:** Preserved.
- **Authenticity of mass/material:** Preserved. During the reconstruction between 1992 and 2000, the secondarily mounted glass blocks in the south hall were replaced with windows made on the basis of the north hall windows.
- **Authenticity of technical equipment:** The technological part has been completely replaced, only filter field casings have remained.

Architectural value: The author of the architectural design of both construction phases is the architect and urbanist prof. Antonín Engel, authors of the interior layout of the north filtration hall are prof. Bedřich Hacar and prof. František Klokner.

The unified architectural complex combines monumental forms expressed by the composition of material (typical for the architect A. Engel's work), modern construction principles and representative traditionalist morphology of the surface. Three-step roof system supported by a system of arches. A similar system was subsequently used e.g. in the Brno Exhibition Centre during the construction of a pavilion from 1928. Common features can be found in another of Engel's works from the same era – in the hydroelectric power plant Poděbrady (Švácha, 1995; Jásek, 2014).

It was selected as one of fifteen significant structures, complexes and systems representing universal values of global significance in the TICCIH comparative study of water management structures (Douet 2018). It is comparable in size, age and architectural monumentality to the R.C. Harris Water Treatment Plant in Toronto, Canada, which is included in the same TICCIH selection.

Landscape/urban value: The water treatment plant is situated on a river bank within the scope of the broader centre of Prague in the quarter of Podolí. It is surrounded by dense buildings. The original location was selected because it was not so built-up but with the gradual industrialisation of the area, the water treatment plant became an integral part of the whole quarter. It is especially visually noticeable from the river (from the islands of Veslařský ostrov and Císařská louka), from the opposite bank (viewpoint on the Děvín hill) and from the Podolí riverbank and Podolská street.

4.5.4.4 General summary of the principles for the evaluation of waterways

The evaluation of waterworks structures from the point of view of heritage preservation is difficult, especially in the case of structures which still serve their purpose and are often under the intensive influence of flowing water, chemicals and other substances during water treatment. This is reflected in the state of equipment and whole buildings. In order to comply with strict legal regulations and procedures during the treatment and subsequent distribution of drinking water to consumers, it is often quite unavoidable to replace parts or entire pieces of machinery with more modern and approved ones, which of course destroys the authenticity of these components.

An example of this is the water treatment plant in Prague-Podolí (1925–1929), which underwent an extensive modernisation and reconstruction but at the same time it still serves its original purpose. It is an example of significant monument protection during full operation, including musealisation of parts no longer used. A lot of smaller waterworks structures undergo conversion, especially elevated water tanks which can serve several functions (observation tower, building, administrative, museum or gallery structures).

From the point of view of urbanistic and landscape values, waterworks structures are often inconspicuous, sometimes hidden underground, so their impact on the landscape image or settlement is minimal, which could also be taken positively if the structures were totally utilitarian in their solution. Small Art Nouveau and inter-war water tanks are often situated in elevated locations near towns or villages and are subtly integrated into the surrounding landscape.

Water treatment plants are often associated with dams of waterworks reservoirs, so it is necessary to evaluate them in terms of this whole (in the case of Klíčava it is possible also separately because in this case they are separated by a greater distance). In spite of that there can be found several exceptions where a water treatment plant is situated in a very exposed location of a town and its urban value is fundamental (e.g., the water treatment plant in Prague-Podolí, also notable for its extraordinary high-quality architecture; another similar example is the water treatment plant in Brno-Pisárky).

The most striking waterworks structures are undoubtedly elevated water tanks situated in elevated locations within a town or in their outskirts (Prague-Vinohrady, Bubeneč, Pankrác; Jaroměř, Hradec Králové). Their urban value is extraordinary because together they form a typical town panorama – which also creates landscape value.

A frequently evaluated attribute is architectural value. This value is clearly recognisable in urban waterworks systems established from the mid-14th to the mid-19th century, and especially in water towers or fountains. Their design was based on the architectural style of that era. Waterworks complexes or water supply buildings and wastewater treatment facilities, built in response to the poor hygienic conditions of the rapidly growing industrial towns in the second half of the 19th century, adopted models used in the construction of technical and industrial structures, including historicising inspirations. Even here, one of the key moments was the introduction of steam power for water pumping and steam pumping stations became a symbol of this change, as well as of progress in solving the sanitation crisis. Particular attention was paid to the architectural rendering of elevated water tanks which formed the most visible elements of these systems, especially from the turn of the 19th and 20th centuries until World War II. At first they were built in the architectural forms of historical styles and with the advent of the 20th century in new forms of Art Nouveau, and later modernism or functionalism. With regard to water treatment plants, the one that should be highlighted is the water treatment plant in Prague-Podolí, commissioned in 1929, whose impressive architectural morphology was respected even when it was expanded in the 1950s and 1960s.

4.5.5 REGISTER OF LOCATIONS

Name	Type of protection	USKP registry number	Item name according to the Monument catalogue	Protected from	Item type	District	Municipality
aqueduct	CM	103997	aqueduct	01/07/2010	aqueduct	Pardubice	Sezemice
aqueduct	CM	106734	aqueduct across the Kamenice River	18/08/2021	aqueduct	Děčín	Česká Kamenice
Na Zmínce aqueduct	CM	26244/6-4658	Na Zmínce aqueduct	29/12/1983	aqueduct	Pardubice	Sezemice
former waterworks	CM	42819/5-1097	former waterworks	17/01/1964	water tower	Louny	Cítoliby
railway waterworks	CM	106581	railway waterworks	19/11/2020	waterworks	Plzeň-South	Kasejovice
railway waterworks	CM	101947	Czech Railways waterworks	15/09/2006	waterworks	Prachatice	Zbytiny
house with a water tower	CM	31114/4-4399	water tower	25/10/1963	water tower	Plzeň-City	Plzeň
Královský spring	CM	42903/5-244	Královský spring	18/06/1963	source	Ústí nad Labem	Řehlovice
aerial lighthouse with a water tank	CM	100966	aerial lighthouse	24/03/2004	water tank	Prague	Prague
Lesser Town water tower	CM	40341/1-1386	Lesser Town water tower	22/12/1964	water tower	Prague	Prague
Max‘s waterworks with a fountain	CM	17652/7-6009	Max‘s waterworks with a fountain	26/01/1973	waterworks	Kroměříž	Kroměříž
bridge of the Vojtěšský water supply system	CM	27718/2-1048	aqueduct of the former Vojtěšský water supply system	31/12/1966	aqueduct	Kutná Hora	Kutná Hora
railway station waterworks	CM	101000	railway station waterworks	31/03/2004	waterworks	Blansko	Skalice nad Svitavou
Novomlýnská water tower	CM	44469/1-1056	Novomlýnská waterworks	22/12/1964	water tower	Prague	Prague
railway station steam waterworks	CM	44860/6-5474	railway station steam waterworks	01/01/1989	waterworks	Náchod	Jaroměř
steam waterworks	CM	36135/8-2276	steam waterworks	06/06/1975	waterworks	Olomouc	Olomouc
steam waterworks with a cistern	CM	104623	steam waterworks with a cistern	19/01/2012	waterworks	Ústí nad Labem	Ústí nad Labem
well pavilion	CM	105321	well pavilion	05/03/2014	well	Semily	Vysoké nad Jizerou
pumping station Bruska	CM	104323	pumping station Bruska	28/04/2011	pumping stations	Prague	Prague
Renaissance well	CM	38161/1-5	well	22/12/1964	well	Prague	Prague
windlass of a well from Druzcov	CM	31470/5-4220	windlass of a well from Druzcov	06/04/1966	well	Liberec	Český Dub
old waterworks	CM	11162/7-8668	old waterworks	15/02/1996	waterworks	Znojmo	Znojmo
Old Town water tower	CM	38174/1-14	Old Town waterworks	22/12/1964	waterworks	Prague	Prague
well	CM	38266/2-1930	well called “Komenského studna”	31/12/1965	well	Nymburk	Poděbrady
well	CM	43095/5-161	well	17/06/1963	well	Ústí nad Labem	Zubrnice
well	CM	28178/6-4361	well	10/05/1972	well	Náchod	Jaroměř
well	CM	13231/8-3452	well	08/04/1970	well	Nový Jičín	Štramberk
well	CM	25227/6-2874	well	02/04/1964	well	Semily	Vysoké nad Jizerou
well	CM	19811/3-369	well	31/12/1963	well	České Budějovice	Dolní Bukovsko
well	CM	22797/4-753	well	17/01/1964	well	Karlovy vary	Bochov
well	CM	32181/4-2129	well	04/03/1964	well	Domažlice	Kout na Šumavě
well	CM	44499/1-6	well	22/12/1964	well	Prague	Prague
well	CM	31995/5-2059	well	01/09/1964	well	Litoměřice	Chotěšov
well “V Lázni”	CM	36427/3-3286	well “V Lázni”	31/12/1963	well	Pelhřimov	Senožaty
well - four	CM	20658/6-4363	four wells	10/05/1972	well	Náchod	Jaroměř
windlass well	CM	21213/6-3380	windlass well	16/04/1964	well	Svitavy	Jevíčko
well with a grid cage	CM	38910/1-480	well with a grid cage	22/12/1964	well	Prague	Prague
well with a roof	CM	105501	well with a roof	14/11/2014	well	Chrudim	Žumberk
well structure with a well	CM	51948/2-4457	well structure including an own well	17/04/2002	well	Příbram	Nový Knín
Šítkov water tower	CM	39910/1-1105	Mánes Gallery, Šítkov water tower	22/12/1964	water tower	Prague	Prague
public pump U Fitzů	CM	10949/4-4935	public pump U Fitzů	22.09.1994	well	Rokycany	Rokycany
Obří spring tower	CM	43998/5-5282	Obří spring tower	30/12/1987	water tower	Teplice	Lahošť
elevated water tank	CM	104171	water tank	27/12/2010	water tank	Nymburk	Poděbrady
elevated water tank	CM	106092	elevated water tank	22/09/2017	elevated water tank	Plzeň-South	Chlumčany
elevated water tank	CM	49750/5-5858	elevated water tank	10/02/1999	elevated water tank	Teplice	Bílina
elevated water tank	CM	101496	elevated water tank	04/05/2005	water tank	Opava	Opava
elevated water tank	CM	101521	waterworks	24/05/2005	elevated water tank	Opava	Hlučín
elevated water tank	CM	104468	waterworks	09/09/2011	water tank	Kolín	Pečky

Name	Type of protection	USKP registry number	Item name according to the Monument catalogue	Protected from	Item type	District	Municipality
elevated water tank	CM	105027	elevated water tank	11/02/2013	water tank	Kolín	Týnec nad Labem
elevated water tank	CM	104169	water tank	28/12/2010	water tank	Kolín	Kolín
elevated water tank	CM	102467	elevated water tank	14/08/2007	water tank	Jindřichův Hradec	Nová Ves nad Lužnicí
elevated water tank	CM	103508	elevated water tank	20/03/2009	elevated water tank	Plzeň-North	Heřmanova Huť
elevated water tank	CM	34572/6-4646	water tank in Na Vinici	29/12/1983	water tank	Pardubice	Pardubice
elevated water tank	CM	104819	water tank	22/05/2012	water tank	České Budějovice	Trhové Sviny
water tower	CM	41535/1-2168	water tower	26/02/1992	water tower	Prague	Prague
water tower	CM	12445/2-4237	water tower	17/02/1993	water tower	Nymburk	Nymburk
water tower	CM	10816/2-4312	water tower	07/08/1995	water tower	Benešov	Benešov
water tower	CM	101542	water tower	08/06/2005	water tower	Chomutov	Otvice
water tower	CM	47348/1-2151	water tower	03/06/1991	water tower	Prague	Prague
water tower	CM	47350/1-2154	water tower	03/06/1991	water tower	Prague	Prague
water tower	CM	43070/5-1539	water tower	17/01/1964	water tower	Louny	Žatec
waterworks	CM	102175	waterworks	09/02/2007	waterworks	Pardubice	Pardubice
waterworks	CM	35501/6-763	waterworks	24/01/1964	waterworks	Chrudim	Chrudim
waterworks	CM	103105	waterworks	12/08/2008	waterworks	Ostrava-City	Ostrava
waterworks	CM	105217	waterworks	02/12/2013	waterworks	Přerov	Radíkov
waterworks	CM	19116/6-866	waterworks	24/01/1964	water tower	Chrudim	Chrast
waterworks	CM	45094/6-1097	waterworks	06/02/1964	waterworks	Jičín	Jičín
waterworks	CM	13467/6-4685	former waterworks, native house of the author Eduard Štorch	28/05/1984	waterworks	Jičín	Ostroměř
waterworks	CM	40255/1-1334	waterworks	22/12/1964	waterworks	Prague	Prague
waterworks	CM	11096/6-5898	waterworks	02/01/1996	waterworks	Trutnov	Pec pod Sněžkou
waterworks	CM	41194/8-2742	water tower	03/01/1984	water tower	Karviná	Karviná
waterworks	CM	43984/5-5268	waterworks	30/12/1987	waterworks	Teplice	Teplice
waterworks	CM	101151	workshops for vehicle repairs, locomotive sheds and railway station of the former State Railways and Buštěhrad Railway, out of this only: waterworks	01/09/2004	waterworks	Prague	Prague
waterworks	CM	40266/1-1341	waterworks	22/12/1964	waterworks	Prague	Prague
waterworks	CM	38050/6-4669	waterworks	15/03/1984	waterworks	Náchod	Jaroměř

Name	Type of protection	USKP registry number	Item name according to the Monument catalogue	Protected from	Item type	District	Municipality
waterworks	CM	34742/8-2214	waterworks	18/04/1974	waterworks	Opava	Vítkov
waterworks – premises of the former water treatment plant and the pumping station of the Vršovice waterworks	CM	54885/1-2308	premises of the former water treatment plant and the pumping station of the Vršovice waterworks	05/08/2002	waterworks	Prague	Prague
waterworks – two waterworks pavilions	CM	105677	two waterworks pavilions	30/07/2015	waterworks	Ústí nad Orlicí	Česká Třebová
underground waterworks	CM	51001/6-6193	underground waterworks	07/06/2001	waterworks	Pardubice	Srch
waterworks called the Turkish tower	CM	41879/2-1897	waterworks – so-called Turkish tower	31/12/1965	waterworks	Nymburk	Nymburk
water tank	CM	11818/5-5801	water tank	28/03/1997	water tank	Liberec	Hodkovice nad Mohelkou
water tank	CM	22138/3-3937	water tank	31/12/1963	water tank	Prachatice	Želnava
water tank	CM	105974	water tank	17/03/2017	water tank	Havlíčkův Brod	Skorkov
water tank	CM	31118/3-241	water tank	31/12/1963	water tank	České Budějovice	Litvínovice
water tank I	CM	11888/4-4757	water tank No. I	29/01/1992	water tank	Karlovy vary	Karlovy vary
water supply system of the town of Košíř	CM	50914/1-2388	water supply system of the town of Košíř	21/03/2001	water supply network	Prague	Prague
Vidoule water supply system	CM	49597/1-2254	Vidoule water supply system	06/03/1998	water supply network	Prague	Prague
water supply conduit remains, archaeological traces	CM	18015/2-457	remains of the water supply system from Brandýsek to Budeč	31/12/1967	water supply conduit	Kladno	Dřetovice
water supply network	CM	12364/7-8463	water supply network – a set of structures	20/11/1990	water supply network	Třebíč	Jemnice
water supply network of a manor farm estate	CM	104653	water supply network of a former manor farm estate	11/02/2012	water supply network	Beroun	Liteň

Name	Type of protection	USKP registry number	Item name according to the Monument catalogue	Protected from	Item type	District	Municipality
Světluška water supply tunnel	CM	11407/1-2244	Světluška castle water supply system with a pumping station and a water tank	02/10/1996	water supply conduit	Prague	Prague
ground water tank and a pumping station	CM	105589	water tank of a water supply system for Horní Kokonín and part of Vrkoslavice	25/03/2015	water tank	Jablonec nad Nisou	Jablonec nad Nisou

4.6 SEWERAGE AND WASTEWATER TREATMENT

Wastewater treatment means removal of constituents that adversely affect the surface water into which they are discharged. A suitable method of purification is chosen according to the composition of the wastewater and quality requirements. There are wastewater treatment plants for urban and industrial wastewater purification.

In the process of urban wastewater treatment, it is necessary to remove mainly coarse, macroscopic substances, the presence of which could lead to mechanical defects and silting of structures and equipment of **wastewater treatment plants** (WWTP) in subsequent stages of treatment. These are floating particles which are trapped on racks with pores up to 0.5 mm and particles sliding over the bottom of the sewer – namely sand. Sand traps are used to catch sand and sometimes they are arranged to catch floating substances (grease) which is particularly advantageous in the case of WWTPs without settling tanks. These structures, which are part of all WWTPs, are collectively called “coarse pre-treatment”. Materials captured in this process are hygienically and aesthetically unsafe and are usually disposed of in landfills.

The coarse pre-treatment is followed by mechanical-biological or biological treatment. Mechanical WWTPs are not currently built without the following biological treatment. Mechanical treatment of urban wastewater is carried out in a settling tank. Settleable particles are separated in it. The wastewater from the mechanical treatment or directly from the coarse pre-treatment is led to the biological treatment which can be carried out in aerobic or anaerobic conditions. The only method used for urban wastewater treatment is the aerobic one. Another distinguishing criterion is the type of treatment:

- **natural**, taking place under natural conditions that are only modified in some way,
- **artificial**, taking place in reactors in which biochemical processes are intensified.

Treatment facilities, especially biological treatment, cannot be dimensioned for the maximum flows which occur during rainfall, when the flow rate exceeds the average flow rate many times, even if only briefly. There are storm tanks built to catch these floods at WWTPs which serve to separate the part of water exceeding the maximum volume (usually after the coarse pre-treatment) for which other technological facilities are dimensioned. When the storm tank is filled, this becomes a flow-through tank and works as a settling tank from which wastewater is conducted into a receiving body. The water captured in the storm tank, but also the sludge, is pumped to the WWTP after the rain subsides.

The wastewater treatment product is a sludge suspension (sludge) which needs to be further processed. Therefore, an important part of a WWTP is sludge handling and disposal.

Requirements for an urban wastewater treatment plant are to significantly reduce:

1. the concentration of suspended substances,
2. the concentration of organic, especially biodegradable, substances,
3. the amount of bacteria and other organisms,
4. and apart from that, the removal of nutrients (N, P) is usually required up to varying degrees depending on the size of the contamination source and considering the receiving body.

In the case of **industrial wastewater** it is not possible to describe a uniform scheme of treatment due to the diversity of their composition. Besides the procedures used during urban wastewater treatment, completely different procedures can be also used. During the biological treatment of water with a high concentration of organic contamination, aerobic processes are used, which are at urban WWTPs used only for the stabilisation of watercourses.

In the case of separation procedures on the filtration principle, not only racks, microstainers and microfilters are used but also semi-permeable membranes releasing only particles of a certain size or electric charge in addition to water molecules, which requires the use of higher pressures. Ultrafiltration can capture colloid-sized particles and reverse osmosis can capture even dissolved substances. Layer filtration, e.g., sand filters, is also used, trapping particles of a similar size as in microfiltration.

In separation procedures based on different densities of water and particles, besides sedimentation, flotation is also used, in which particles are buoyed to the surface either because their density is lower than that of water or because they are lifted by microbubbles of gas.

Industrial wastewater treatment also involves clarification. However, compared to drinking-water treatment, in the case of wastewater treatment, the amount of coagulants is significantly higher. In addition, other methods used are adsorption, stripping (removal of volatile substances by a stream of gas), extraction, and ion exchange. Neutralisation is used to adjust the pH. Some substances (heavy metals) can be broken down by oxidising agents, e.g., chlorine. For highly concentrated wastewater, thermal treatment (evaporation, incineration) is appropriate.

The requirements for the treatment of industrial wastewater vary considerably depending, among other things, on whether the treated water is discharged to a water receiver or to a public sewage system, where the final treatment is carried out in a municipal WWTP.

The term **mechanical treatment** of urban wastewater refers to the separation of suspended substances contained in it. However, the sedimentation process, which uses gravitational acceleration acting on suspended particles, is used to separate suspensions in the treatment of water for drinking and also in the treatment of industrial wastewater.

During the sedimentation by suspension, in the technology of water we distinguish:

- **granular sludge**, in which individual particles do not change their size and shape during sedimentation;
- **flocculent sludge**, which undergoes orthokinetic coagulation and thus changes its character during sedimentation.

The first type includes sand and a primary water treatment sludge, the second one includes a biological sludge and the sludge created during the coagulation process of water treatment.

For a basic overview of the topic, it is necessary to mention what is actually meant by aerobic and anaerobic processes.

Biological wastewater treatment consists of breaking down organic substances contained in them but only some of them are biodegradable. The process is carried out by microorganisms, mainly bacteria, for which the organic matter is a substrate. Within the biological wastewater treatment systems they are always mixed microbial culture with a greater or lesser diversity of species. In principle, we distinguish **aerobic processes**, occurring in the presence of molecular oxygen, and **anaerobic processes**, occurring in the absence of it.

Advantages and disadvantages of the anaerobic process in comparison with the aerobic process:

Advantages of the aerobic process:

- low energy consumption (no energy is spent on aeration, instead energy-valuable biogas is produced),
- lower biomass production (approx. ten times), no sludge stabilisation is required,
- low nutrient requirements (lower than the aerobic process at the same proportion as biomass production),
- possibility of maintaining a high biomass concentration in the reactor (not limited by the oxygen transfer rate).

Disadvantages of the anaerobic process:

- lower reaction rate (hence the need for a larger reactor volume),
- higher residual concentration of organic substances in the run-off (aerobic final treatment of the wastewater is usually necessary),
- sensitivity of methanogenic bacteria to external conditions (significant influence of temperature on the process rate, etc.),
- long-term incorporation of the process.

It follows that anaerobic processes are suitable for the stabilisation of sewage sludge and for the treatment of wastewater with a high concentration of organic contamination.

Wastewater treatment is a set of technological processes used to dispose of contaminants in wastewater and to reduce their concentration, these processes are carried out in a **wastewater treatment plant** (see Fig. 4.234). The whole diagram of the water flow, and sludge flow, through a water treatment plant is called a WWTP technological line.

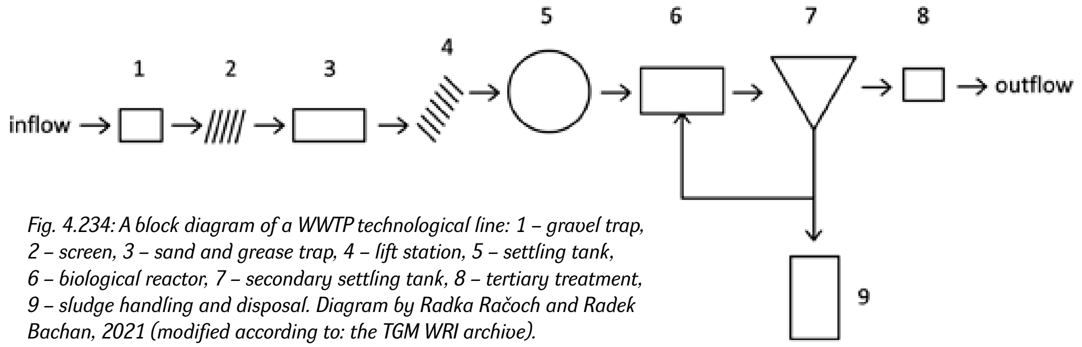


Fig. 4.234: A block diagram of a WWTP technological line: 1 – gravel trap, 2 – screen, 3 – sand and grease trap, 4 – lift station, 5 – settling tank, 6 – biological reactor, 7 – secondary settling tank, 8 – tertiary treatment, 9 – sludge handling and disposal. Diagram by Radka Račoch and Radek Bachan, 2021 (modified according to: the TGM WRI archive).

A technological line of a WWTP can be divided into two basic parts: mechanical and biological. The mechanical one consists of the removal of mechanical impurities from raw wastewater and includes protective elements of the treatment plant, i.e. gravel trap, screen, sand (and grease) trap, lift (pumping) station and settling tanks.

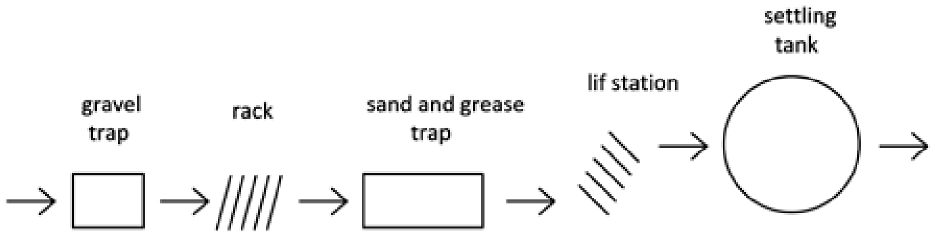


Fig. 4.235: A block diagram of a mechanical part of a WWTP technological line. Diagram by Radka Račoch and Radek Bachan, 2021 (modified according to: the TGM WRI archive).

In the biological part, the removal of organic contamination is carried out by means of microorganisms and consists of a biological reactor, secondary settling tank, and based on the technological arrangement, sometimes an activated sludge regenerating tank is added (see Fig. 4.236). Nitrogenous substances are also removed here by nitrification (oxidation of ammoniacal nitrogen to nitrate) and denitrification (reduction of nitrate and nitrite to elemental nitrogen).

Further stages of water treatment, i.e., technological lines, can be represented by structures connected with chemical precipitation of phosphorus from water, or final wastewater treatment structures (Čížek, Herel, Koníček, 1970). Detailed information on the composition of water treatment plants, variants of individual structures, etc. can be found in the bibliography mentioned below.

Basic information about water treatment structures can also be found in these technical standards: ČSN 75 6401, Sewage Treatment Plants for more than 500 of Population Equivalents (PT), ÚNMZ (Czech Office for Standards, Metrology and Testing). 2014; ČSN 75 6402, Sewage Treatment Plants up to 500 of Population Equivalents ÚNMZ, 2017; A series of other standards for smaller, domestic water treatment plants: ČSN EN 12566 (75 6404), Small wastewater treatment systems for up to 50 PT (several parts). Selected technologies are dealt with in more detail in a set of standards: ČSN EN 12255-1 to 16 (75 6403), Wastewater treatment plants.

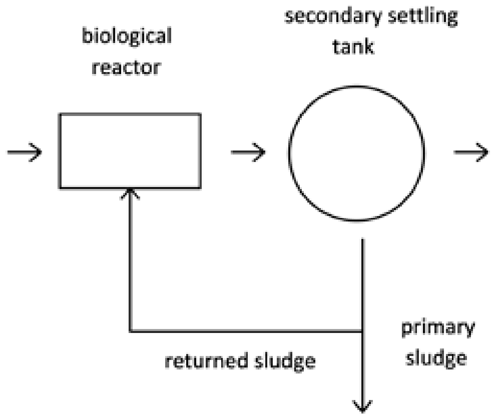


Fig. 4.236: A block diagram of a WWTP technological line: Diagram by Radka Račoch and Radek Bachan, 2021 (modified according to: the TGM WRI archive).

4.6.1 HISTORY OF SEWERAGE AND WASTEWATER TREATMENT

Addressing the issue of what to do with faeces and urine, as the main components of wastewater from today's point of view, is a problem that civilizations have been dealing with since ancient times. They have always been a source of dirt, malodour and health risks. The history of the management of these wastes is described in detail in a number of publications – Broncová (2002) can be mentioned as an example. This author also states that the beginnings of the sewerage in the Czech lands date back to the Middle Ages, when the first social facilities, so-called garderobes, were built at castles and fortresses. The first purification technologies concerned using dry pits, in which the stored waste, including the aforementioned, was basically anaerobically decomposed. At the end of the 19th century, technical amenities in the Czech lands were a reflection of the settlement structure. Water and sewerage systems were built only for burgher houses, sewerage pipes were bricked, in the case of larger profiles often ovoidal or oval (Broncová, 2002). This author's publication can also be recommended as a well arranged work informing about the development and implementation of the first sewage systems in the Czech lands. A different situation was in the field of already conveyed wastewater. In this case, the beginnings date back to the second half of the 19th century. Wanner states in his publication (Wanner, 2019): "*The systematic introduction of wastewater treatment began in Europe and England in the second half of the 19th century. In 1865, the Royal Commission on River Pollution was established to coordinate the search for suitable solutions. The Commission prepared and already in 1876 pushed through the adoption of a law to protect rivers from pollution. Another important step in the protection of water quality was the establishment of the Commission on Sewage Disposal in 1898, which also supported and coordinated the development of technical solutions. The Commission also standardised the characteristics of the pollution emitted. As early as 1908, the BSK5 method was put into practice.*" Among other countries where wastewater treatment developed, we could mention in particular Germany. Wanner says: "*In the Austro-Hungarian Empire, the situation at the turn of the 19th and 20th centuries reached a stage which required the treatment of wastewater discharged from urban sewerage systems to be started. The construction of a sewerage network and a wastewater treatment plant in Prague took place in this period too.*" The first technologies include mechanical water pre-treatment structures, various traps and settling tanks. As a biological treatment stage, the irrigation of land by wastewater, or the use of land for the disposal of this water by means of soaking, developed first, which also had a significant fertilising effect. As is known, the biologically active layer of soil contributed to the degradation of pollution of this water, including microbial pollution.

A clear history of the development and beginning of the use of basic technologies of wastewater treatment, whether it was mechanical pre-treatment, the use of biological filtration, or the beginning of the realisation of structures based on activation procedures, etc., is summarised in Wanner's publication (2019).

A detailed analysis of the history of the establishment of sewage system and construction of the old Prague water treatment plant in Bubeneč is presented in the publication Jásek, 2006. The authors Jásek, Vrbová and Palas (2009) analyse in detail the history of the disposal of the sludge produced by wastewater treatment plants in Prague and its surroundings. The long-term development of the water treatment system for Prague, currently connected with the implementation of a completely modern technological line on Císařský island, is clearly presented by Rosický (2018) and Wanner (2018).

During the 1920s and 1930s, the construction of structures or functional complexes for the wastewater drainage and treatment also took place in other settlements of the then Czechoslovakia. In the handbook published by the Ministry of Building Industry in 1951, we can find a summary and description of basically all projects known to that date, including technological schemes, results of analyses of water samples, description of experimental structures, as well as plans for the construction of new treatment plants in Prague, Brno and other cities (Bulíček, 1951). It can be considered as a basis for further development of the field in the coming decades, following the first water management plans. Broncová (2002) also provides an extensive overview of the history of the main wastewater treatment plants in the Czech Republic, divided according to regions and districts.

In summary, many advances were made in the field of water treatment, including the construction of sewage systems and water treatment plants, until World War II. The development continued after the war. Not only were water treatment systems innovated, but many regulations were also issued. The protection of the environment, aquatic ecosystems and biodiversity of aquatic species also began to develop.

Information on the current state of sewerage and wastewater treatment is provided in a statistical yearbook and in updated databases, in particular by the Ministry of Agriculture of the Czech Republic.

4.6.2 BASIC FUNCTIONAL STRUCTURES FOR WASTEWATER TREATMENT

Since the entire wastewater drainage and treatment includes a large number of structures and their formations, this chapter provides only a basic overview. For an understanding of what the particular structures represent and what purpose they serve, reference can be made to the following set of technical standards: ČSN EN 16323 (75 0162), Glossary of wastewater engineering terms; ČSN 75 0161, Water management – Terminology in waste water engineering, ČNI (Czech Standardisation Institute). 2008; ČSN EN 1085 (75 0160), Wastewater Treatment – Vocabulary, ČNI, 2007. As far as foreign publications are concerned, Smith and Scott's monolingual dictionary (2005) can be recommended for understanding the terminology and description of structures.

4.6.2.1 Sewer network, pipeline, and structures on the sewer network

The first group of structures with which waste water comes into contact after the outflow from a building is the backbone sewer network, the essence of which is the sewage pipeline. This network is equipped with the structures

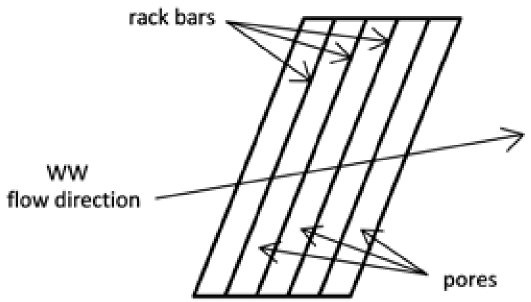


Fig. 4.237: Description of individual screen parts. Diagram by Radka Račoch and Radek Bachan, 2021 (modified according to: the TGM WRI archive).

Fig. 4.238: Coarse screen and inflow into the wastewater treatment plant with the control of gate valves. Photograph by Alžběta Petránová.

Fig. 4.239: Fine screen – machine-raked. Photograph from the TGM WRI archive.

required for the safe transfer of water (drop structure etc.), or for their merging (shaft) and reduction (relieving chambers on the uniform sewer network). Detailed information on the network implementation, materials used, operation and maintenance principles, as well as information on structures within the sewer network can be found in various publications, e.g., Čížek, Herel and Koníček (1970); Mertová, Hlavívek and Prax (2005).

4.6.2.2 Gravel trap

A gravel trap is the first structure of the wastewater treatment plant technology line and also the first structure used to protect the plant and its machinery. The gravel trap is used to remove coarse impurities that slide over the bottom of the sewer network. Heavy non-floating impurities such as gravel, debris and bricks are captured here. The gravel trap is most often incorporated in places where fine machine-raked screens are used. The impurities are cleared out usually discontinuously by means of an excavator, a grab or a gravel trap equipped with removable baskets. The captured material is disposed of by landfill.

4.6.2.3 Screens

Screens are another necessary structure which serve to protect water treatment plants. Objects carried away by the stream of raw wastewater are caught here, most often paper, wood, packaging, kitchen waste and similar impurities. The screens are made up of several metal bars of different cross-sections, called screen bars, among which there are pores (see Fig. 4.237).

Based on the width of the pores, we can divide the screens into coarse, with the width of the pores 80–100 mm, medium with the width of the pores 20–25 mm, and fine with the width of the pores up to 10 mm. Fine screens prevent overloading of the settling tank. Cleaning of the screens and accumulated material is carried out by means of machinery or, in the case of smaller plants, manually. The collected material, so-called screenings, is hygienically unsafe. During its disposal it is first dewatered. Such prepared screenings are further landfilled, burnt or exceptionally composted. In Fig. 4.238 and Fig. 4.239 different types of screens can be seen.

4.6.2.4 Sand and grease trap

The third structure used to protect a treatment plant is a sand trap. Here, sedimentation is used to remove fine gravel, sand and mineral suspensions. Sand must be removed from raw water to avoid reducing the effective volume of a sludge-digestion tank, i.e., its sand filling. Sand traps can be divided into horizontal (see Fig. 4.240 and Fig. 4.241) and vortex.

Gravel and sand deposits are hygienically unsafe materials. Sand washing and centrifuge machines are used for their treatment and subsequently the processed material is disposed of by landfilling.

Grease traps are only installed in wastewater treatment plants in exceptional cases, grease is captured in primary settling tanks as floating impurities.

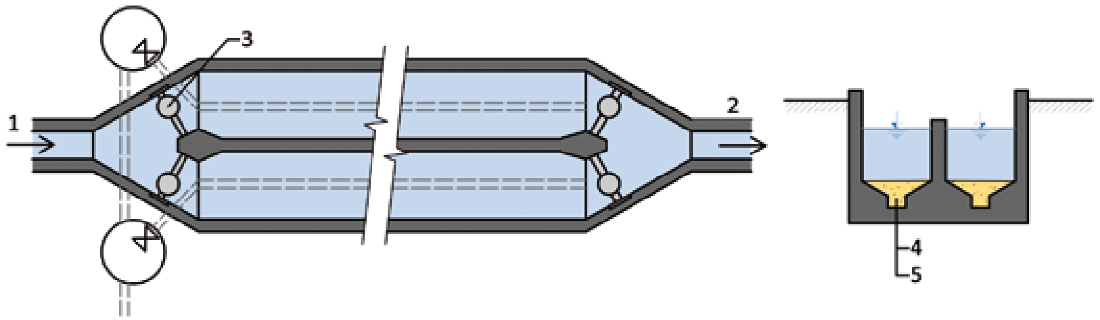


Fig. 4.240: Chamber sand trap: 1 – inflow, 2 – outflow, 3 – sluice gate, 4 – sedimented material, 5 – drainage. Diagram by Radka Račoch and Radek Bachan, 2021 (modified according to: the TGM WRI archive).

Fig. 4.241: Horizontal chamber sand trap. Photograph from the TGM WRI archive.

4.6.2.5 Lift (pumping) station

Wastewater treatment plants are mostly based on a gravitational flow of the incoming wastewater. When it is not possible to provide gravitational water flow in the entire treatment plant due to its layout, pumps are used to lift the wastewater and the subsequent purification is carried out by gravity. The pumps that are most often used to pump water to the required height are screw pumps (see Fig. 4.242) but also piston, circulation or grinder pumps.

Fig. 4.242: Screw pumps. Photograph from the TGM WRI archive.

4.6.2.6 Settling tanks

In a settling or sedimentation tank contaminants are removed on the principle of gravity sedimentation. According to the flow direction of the incoming wastewater, we distinguish three basic types of settling tanks: horizontal, radial and vertical. Settled and floating impurities are diverted by means of raking equipment into a trough for floating impurities or into a sludge-storage space from where they are pulled away from the bottom of the tank in the form of primary sludge.

Horizontal settling tanks (see Fig. 4.243) are rectangular in shape up to 40 m long and 2–3 m deep. The wastewater flows through the settling tank longitudinally or (in the case of limited space) transversely.

Radial or also circular settling tanks are round tanks with radial flow rate (see 4.244), so water is conducted to the centre of the settling tank and flows towards the overflow edge (see Fig. 4.245) where it falls over into a collecting/discharge trough. The diameter of radial tanks is up to 40 m, the depth is 2–3 m.

Vertical settling tanks (see Fig. 4.246) may have a circular or square shape. The wastewater flows into a central drum, flows through it downwards and after leaving the central drum it returns to the surface. The resulting primary sludge and impurities sink to the bottom and are collected in the sludge-storage space, from where they are subsequently pumped out. The length of a side is 3–6 m, the depth is 4–6 m.

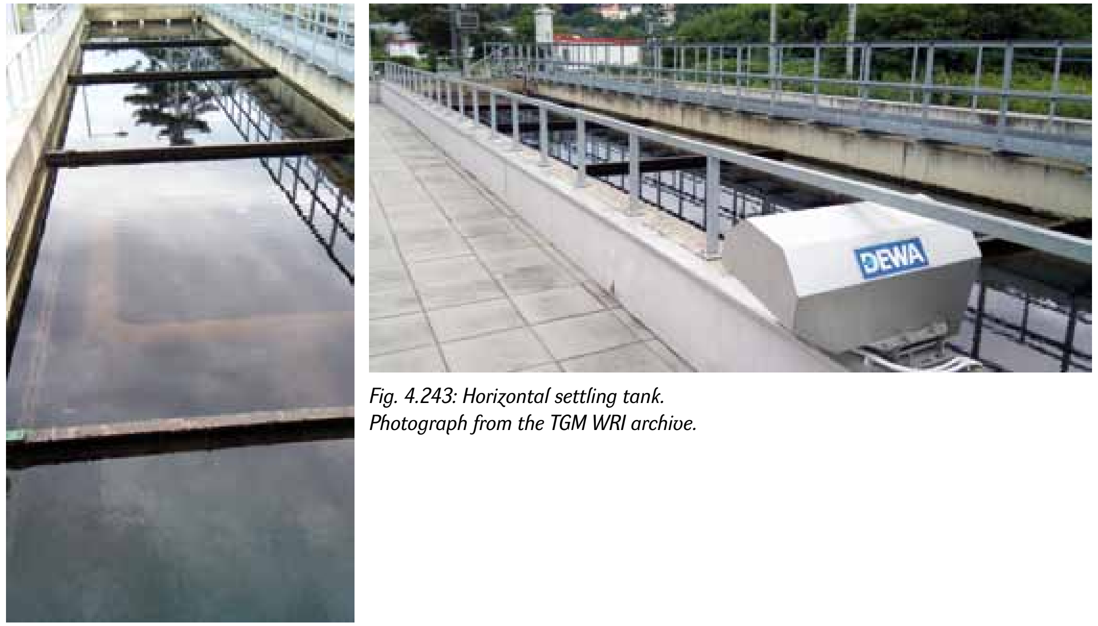


Fig. 4.243: Horizontal settling tank. Photograph from the TGM WRI archive.

Fig.4.244: Radial settling tank. Photograph from the TGM WRI archive.

Fig. 4.245: Overflow edge. Photograph from the TGM WRI archive.

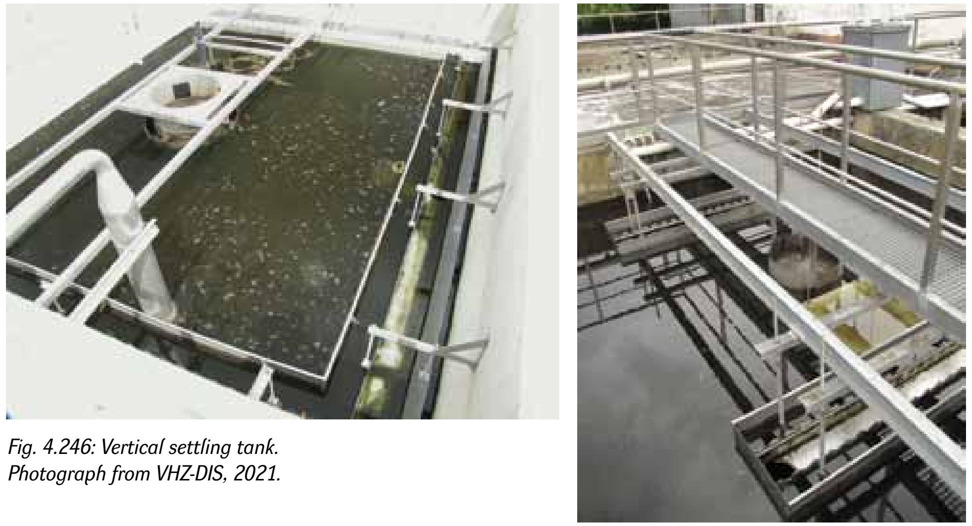


Fig. 4.246: Vertical settling tank. Photograph from VHZ-DIS, 2021.

4.6.2.7 Biofilters

Biofilters can be classified as one of the oldest biological water treatment technologies, besides irrigation systems by this water. As stated by Wanner (2019): "*The principles of biological filtration were formulated on the basis of the research of biological processes taking place in the soil during the infiltration of wastewater. However, the amount of bacteria in the soil was limited by a small grain size of soil particles with limited porosity. A possible way of intensifying the process of purification was to increase the grain size and porosity of the bed. Thus biological filters gradually developed from the soil filtration. At the beginning, a gritted mineral medium (sand, ground slag, etc.) was used as a carrier. Later, a plastic medium was developed, which is lighter than the mineral one, has a higher porosity and a specific surface.*" At present, this technology is used more often at small so-called package wastewater treatment plants (see Chapter 4.6.1.12), and they are also the basis of so-called reed-bed wastewater treatment plants and earth filters (see Chapter 4.6.1.13). In Fig. 4.247 and Fig. 4.248 there are examples of constructions of basic types of biofilters used as part of a WWTP technological line in the past.

A detailed overview of this older technology was described by the authors Čížek, Herel and Koníček (1970).

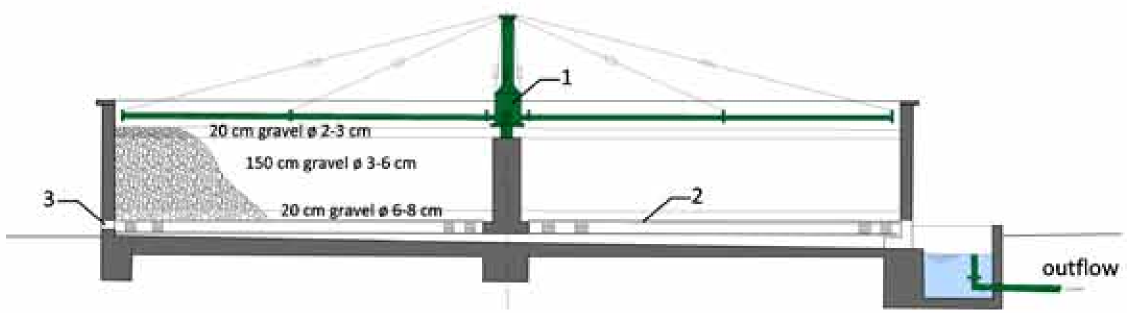


Fig. 4.247: Section of the most common type of biofilter: 1 – rotating sprinkler, 2 – permeable grid, 3 – ventilation openings, inside the structure – filter medium (sand, gravel, composition of various fractions), the picture shows an example of a basic composition of a filter medium with diameters of material grains (fractions). Diagram by Radka Račoch and Michaela Mrvová, 2021.

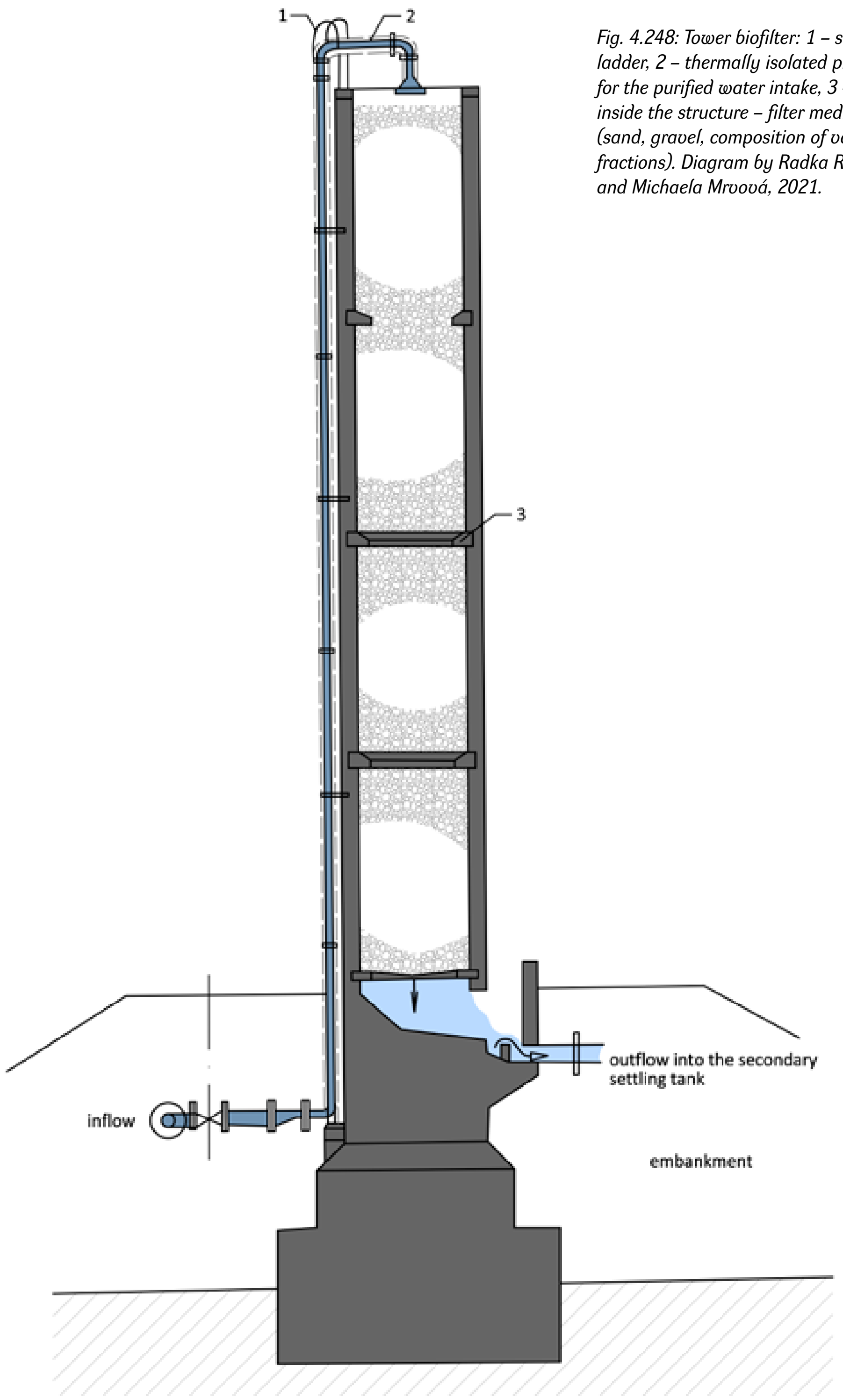


Fig. 4.248: Tower biofilter: 1 – steel ladder, 2 – thermally isolated pipeline for the purified water intake, 3 – buffle, inside the structure – filter medium (sand, gravel, composition of various fractions). Diagram by Radka Račoch and Michaela Mrvová, 2021.

4.6.2.8 Biological reactor

Another technological element is so-called **activation**, which consists of a biological reactor and secondary settling tank. In a biological reactor/activation tank incoming wastewater is treated by means of a mixed culture, so-called activated sludge. **Activated sludge** is a mixture of microorganisms in the form of zoogloea, fungus, moulds and yeasts. The composition of the activated sludge in terms of quality and quantity depends on the composition of the substrate/wastewater on which it was cultivated. After passing through the activation tank, the purified wastewater is separated from the activated sludge in a separation tank/secondary settling tank.

According to the construction and technical arrangement, the activation systems can be divided into classical activation (Fig. 4.249), two-stage activation, regenerating activation (Fig. 4.250), oxidation ditch (4.251) and circulating/carousel activation (see Fig. 4.252). These are the most common activation systems.

Classical activation

Classical activations, or also plug flow activation tanks, are the most often used. Wastewater is supplied to the activation tank at several points so that an even loading of the activation is ensured and thus also an even consumption of oxygen, which is important for the purification process.

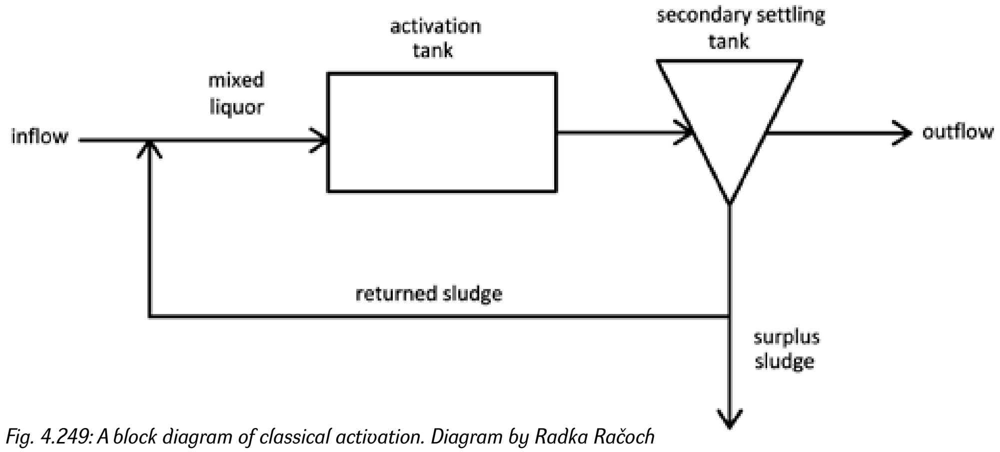


Fig. 4.249: A block diagram of classical activation. Diagram by Radka Račoch and Radek Bachan, 2021 (modified according to: the TGM WRI archive).

Two-stage activation

Two stages of classical activation in a row, i. e. activation – secondary settling tank – activation – secondary settling tank, form so-called two-stage activation. This type of purification is used in the case of highly loaded/contaminated wastewater.

Regenerating activation

Regenerating activation is classical activation supplemented by a regenerating tank in which the cultivation and regeneration of microorganisms in the activated sludge is carried out.

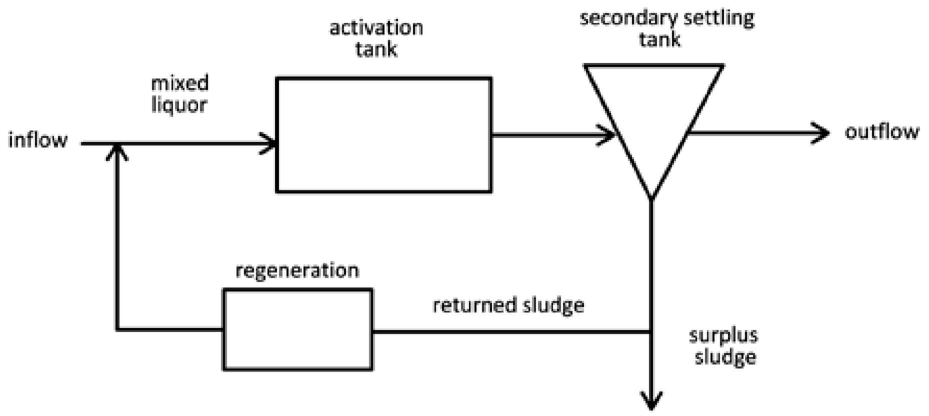


Fig. 4.250: A block diagram of regenerating activation. Diagram by Radka Račoch and Radek Bachan, 2021 (modified according to: the TGM WRI archive).

Oxidation ditch

An oxidation ditch is an oval tank with a low water column (ca 1 m) in which mechanical aeration is carried out by means of aeration elements of a shape similar to a water wheel. The oxidation ditch is demanding on space, therefore it is not much used at present.

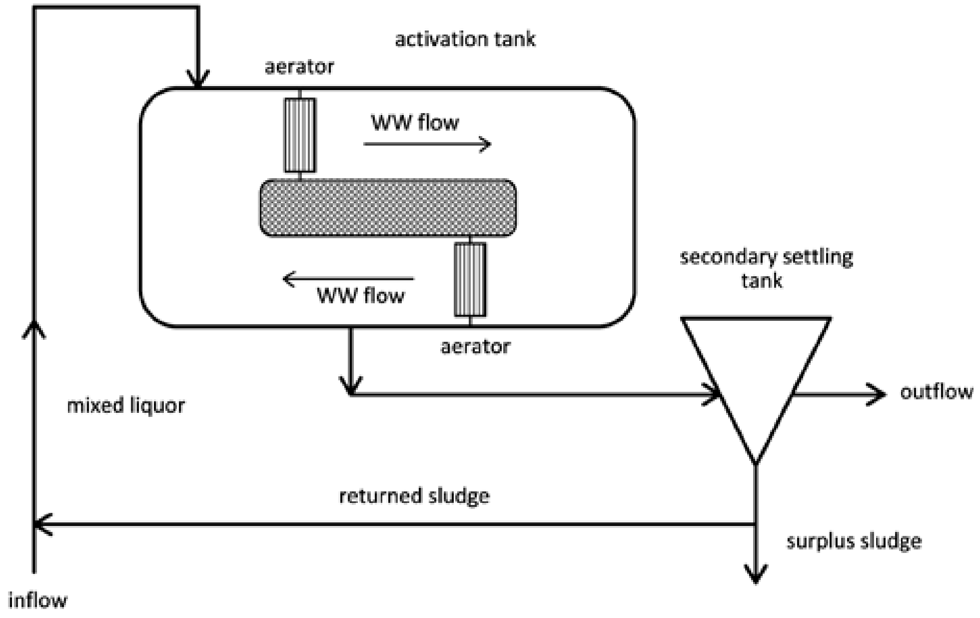


Fig. 4.251: Oxidation ditch. Diagram by Radka Račoch and Radek Bachan, 2021 (modified according to: the TGM WRI archive).

Circulating activation

Circulating or carousel activation differs from an oxidation ditch by the water column height which is 3–5 m. And aeration elements with vertical air flow are located at the bottom of the tank. This type of activation is less demanding on space than the oxidation ditch.

Types of activation can be further classified according to whether the activated sludge is free floating or on a carrier medium or in the form of granules.

Fig. 4.252: Circulating activation. Photograph from the TGM WRI archive.

4.6.2.9 Secondary settling tanks

The activated sludge is separated from the purified wastewater in secondary settling tanks. Secondary settling tanks can be divided, similarly as settling tanks, according to their type, into right-angled tanks with a horizontal flow (see Fig. 4.243), circular/radial tanks with a horizontal flow (see Fig. 4.253) and tanks with a vertical flow (see Fig. 4.244).

Purified wastewater flows out of the treatment plant directly into a receiver (see Fig. 4.254) or it is finally treated in the tertiary treatment stage. The outflow from the wastewater treatment plant is usually mounted with the Parshall flume (see Fig. 4.255) which clearly defines the outflow volume of purified wastewater.

Fig. 4.253: Settling tank. Photograph from the TGM WRI archive.

Fig. 4.254: Outflow from a wastewater treatment plant. Photograph from the TGM WRI archive.

Fig. 4.255: The Purshall flume, an ultrasound sensor for the measurement of water flow. Photograph from the TGM WRI archive.

4.6.2.10 Tertiary treatment

Tertiary treatment of water serves for the removal of dissolved phosphorus, undissolved substances, pollutants and hygienisation of purified wastewater. Biological tanks/ponds, filtration (e.g., through semi-permeable membranes), sorption (e.g. for zeolites) and exceptionally also hygienisation by means of ozonisation and UV radiation are used for the final water treatment. There are a huge number of structures and equipment.

4.6.2.11 Sludge handling and disposal

Sludge from wastewater treatment plants is processed in a sludge handling and disposal system where it is hygienised by means of thermal reactors/sludge-digestion tanks and subsequently dewatered by means of centrifuge machines and filter presses. This chapter presents one of a range of used structures – a set of a sludge-digestion tank with a gas tank (see Fig. 4.256).

Fig. 4.256: Sludge handling and disposal within a WWTP – sludge-digestion tanks and biogas collection. Photograph from the TGM WRI archive.

Dewatered and hygienised sludge can be further used in a number of other structures (e.g. sludge dryers) or it is used directly as an admixture of compost or as a fertiliser of agricultural soil.

When the sludge is processed in the sludge-digestion tanks, biogas is created and by means of a cogeneration unit it is transferred into electricity which is further used to power some electrical devices in the wastewater treatment plant (e.g., pumps) or to heat technical buildings. Unused biogas is, for safety reasons, burnt in residual gas burners.

There are no WWTP technological lines that would be the same in terms of their size, arrangement, technology or composition of the incoming raw wastewater. When dealing with specific problems, it is therefore always recommended to consult experts specialising in water treatment about the matter.

A specific group is represented by **domestic wastewater treatment plants**. Historical sources, which defined certain principles of their design, include e.g., the publications by Zavadil (1952) and Kukla (1956). At present, there are a lot of producers of standardised domestic treatment plants, or so-called package WWTPs which can be used for villages of up to several hundreds of inhabitants.

4.6.2.12 Domestic treatment plants, so-called package

Package or machine treatment plants are usually designed compactly and assembled in situ. A package WWTP (Fig. 4.257) means that it is a one-piece compact product which involves both a structure for the installation on a pre-prepared place or in a pre-prepared trench, and treatment plant technological equipment, including pumping and control technology. Biological treatment is carried out in them under aerobic (treatment plants with activation, biofilters, rotating biofilm reactors) or anaerobic (oxygen-free) conditions, or a combination of both is used. The products are usually accompanied by a corresponding type of test certificate which determines the applicability of the type, achievable water quality values at the outlet, etc. They look like closable containers cylindrical or parallelepiped in shape. Their width is 1–2 m, length 1.5–3 m and depth 1.5–2.5 m. They are usually made of concrete, steel, unplasticised polyvinyl chloride PVC-U, polyethylene, polypropylene or fibreglass.

The principle of wastewater treatment is basically the same for all types of domestic treatment plants. Simply put, wastewater flows into the tank from one side and purified water flows out from the other side. Most wastewater treatment plants have a place where sludge is deposited, and each has a blower (compressor) built in somewhere that blows air into the tank.

Fig. 4.257: Examples of domestic wastewater treatment plants (on the left, taken from: USBF Technology).

The wastewater is purified by microbiological organisms (bacteria) that live in the tank, i.e. completely ecologically, without the use of chemistry. Bacteria eat up organic water pollutants and decompose them into substances that are harmless to nature. They also need oxygen for their metabolism, which is supplied to them thanks to the blower that permanently aerates the mixture in the purification tank.

4.6.2.13 Reed-bed treatment plants and earth filters

Reed-bed treatment plants (RBTP, or vegetation reed bed treatment plants) belong among so-called extensive technologies together with earth (soil) filters and so-called stabilisation tanks. These treatment plants form another group of domestic WWTPs (see Fig. 4.258). They are artificially built wetlands planted with wetland vegetation (usually with common reed, reed canary grass, reedmace) with a defined filter medium where natural method of soil filtration is used. They are very suitable for biological wastewater treatment, especially when the wastewater source is used intermittently (recreational buildings, cottages, summer camps), when there are large fluctuations in the concentration and quantity of waste water and when diluted wastewater flows in, e.g. from a single sewerage system. However, similar to machine domestic wastewater treatment plants, they can also be used as wastewater treatment plants for small sources of pollution.

Fig. 4.258: Domestic reed-bed treatment plant. Photograph by Jaroslav Sova, 2021.

The earth filter is an analogue to reed-bed treatment plants (reed-bed filters), only the direction of the water flow is vertical. This is again a sealed tank filled with filter material. The same recommendations as for the reed-bed filters apply for isolation. The filter material of earth filters is usually finer than the one of reed-bed filters (in practice sand is usually used).

4.6.3 FUNCTIONAL COMPLEXES

In the field of water management which deals with the wastewater drainage and treatment we can find, by the nature of the field, mainly functional complexes in practice. A typical group of functional complexes is formed by wastewater treatment plants and their technological lines. Exceptions are small package WWTP or individual reed-bed and earth filters. But they can also be almost always found as a functional complex connecting a pre-treatment structure (usually a biological septic tank or a small settling tank) and a biological treatment structure (the aforementioned type of biofilter). Other exceptions are pumping stations outside WWTP premises and, for example, retention tanks on a sewer network.

This chapter shows diagrams with examples which present WWTP functional complexes of various size, from standardised structures which are produced in the form of a type series according to the size of the flow and the number of persons to be connected, to the largest WWTPs for the main urban agglomerations (WWTPs in Prague, Brno and

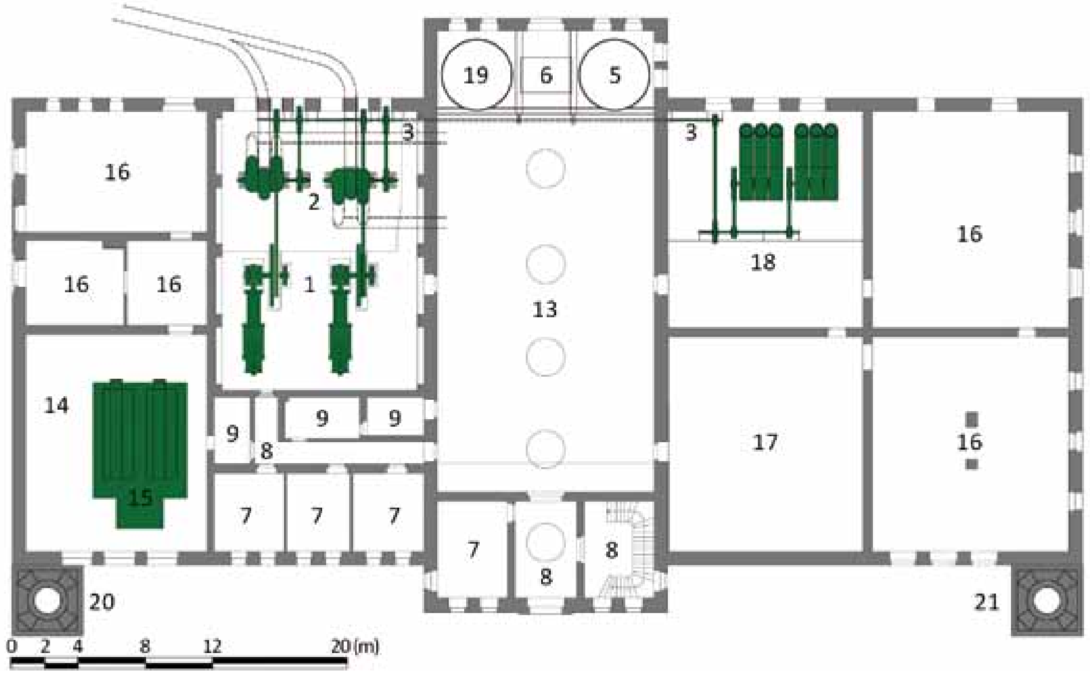


Fig. 4.259: Prague-Bubeneč, old wastewater treatment plant, ground plan of the main building: 1 – machine room, a pair of steam single-cylinder double-acting horizontal machines, 2 – machine room, centrifugal water pumps – flood control pumps, 3 – power transmission of water pumps, 4 – sand trap, 5 – sand and clean water reservoir, 6 – service lift; 7 – offices, 8 – halls, staircase etc., 9 – social and hygienic rooms, 10 – laboratories, 11 – inflow from sewers into the sand trap, 12 – outflow from the sand trap into sedimentation tanks, 13 – sand trap hall, 14 – boiler and coal rooms, 15 – two compound Cornish-type flued boilers, 16 – storage space, archive etc., 17 – switch room and storage space, 18 – piston water pumps, 19 – sludge reservoir, 20 – chimney for the removal of combustion products from boilers, 21 – ventilation chimney, sewer odour removal system. Diagram by Radek Míšanec, 2021 (modified according to: archive project documentation).

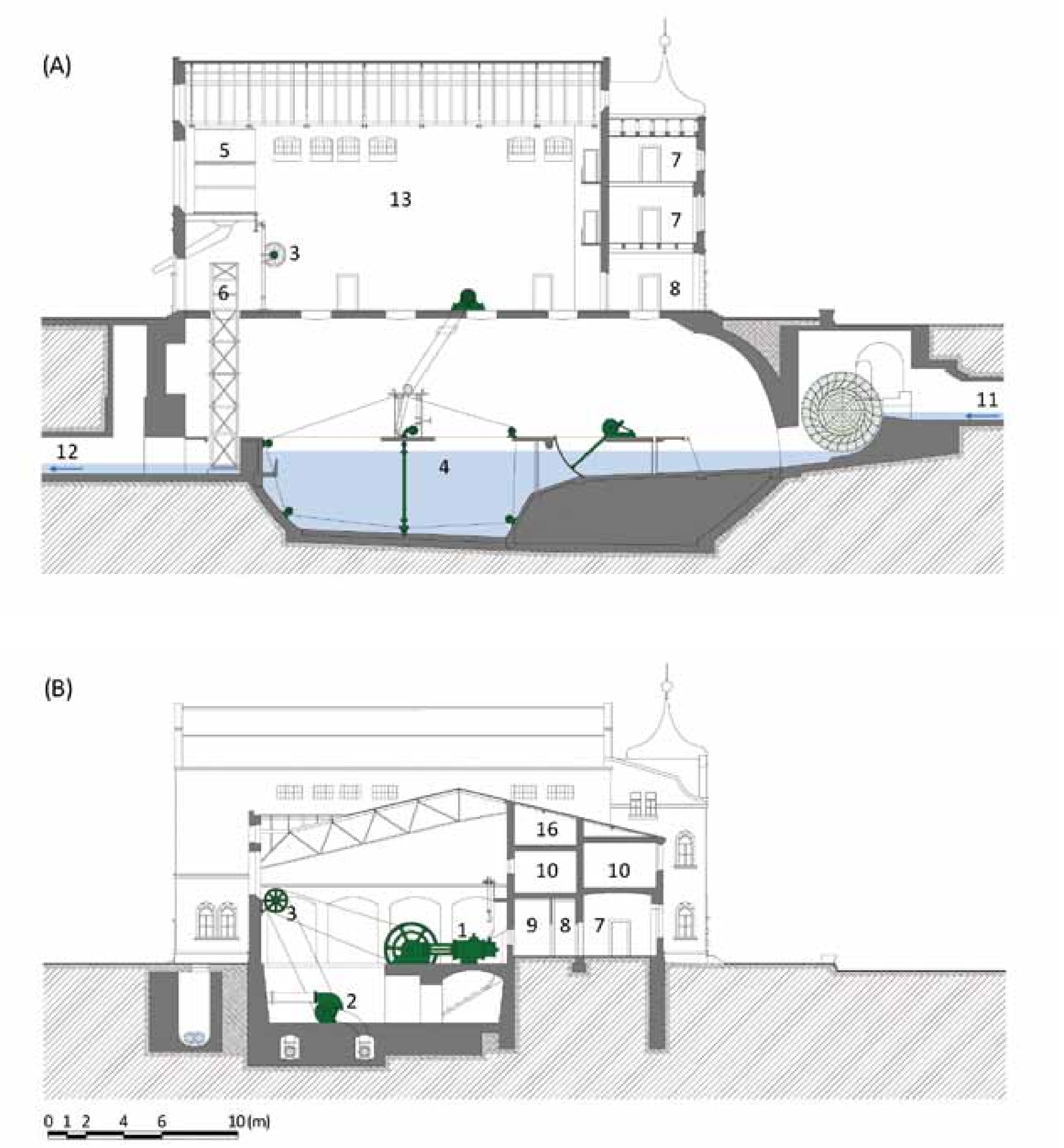


Fig. 4.260 (A) and Fig. 4.261 (B) Prague-Bubeneč, old wastewater treatment plant, a cross-section of the main building: 1 – machine room, a pair of steam single-cylinder double-acting horizontal machines, 2 – machine room, centrifugal water pumps – flood control pumps, 3 – power transmission of water pumps, 4 – sand trap, 5 – sand and clean water reservoir; 6 – service lift; 7 – offices, 8 – halls, staircase etc., 9 – social and hygienic rooms, 10 – laboratories, 11 – inflow from sewers into the sand trap, 12 – outflow from the sand trap into sedimentation tanks, 13 – sand trap hall, 14 – boiler and coal rooms, 15 – two compound Cornish-type flued boilers, 16 – storage space, archive etc., 17 – switch room and storage space, 18 – piston water pumps, 19 – sludge reservoir, 20 – chimney for the removal of combustion products from boilers, 21 – ventilation chimney, sewer odour removal system. Diagram by Radek Míšanec, 2021 (modified according to: archive project documentation).

others). For the sake of comparison of the development of functional complexes, there are also mentioned both the oldest functional complex in our territory (old Prague treatment plant in Bubeneč) and an example of an older solution of WWTPs for towns of various size (from the period of the first mass construction of water treatment plants).

4.6.3.1 Prague-Bubeneč, old wastewater treatment plant

This functional complex is described in detail in the following chapter 4.6.4 and in the publications referred to therein. This is a treatment plant of the first generation from the turn of the 19th and 20th centuries based on a mechanical wastewater pre-treatment. According to the knowledge available at the time, it also included handling and storing selected chemicals which were to be used for the chemical treatment of purified water and help the sedimentation of carried pollution (suspended solids, organic matter and partly microbial pollution). Basic information about the chemical treatment used at that time can be found in Wanner's publication (2019). Fig. 4.259 shows the ground plan and parts of the complex (without settling tanks and sludge boxes).

Fig. 4.260 and 4.261 show basic cross-sections of the main part of this water treatment plant.

4.6.3.2 Brno, wastewater treatment plant

Fig. 4.262 shows a technological diagram of Brno treatment plant from the 1970s.

Fig. 4.263 shows a technological diagram of the Brno treatment plant from the present after several reconstructions and operation intensifications have been carried out. It enables us to compare, via the example of one of the largest wastewater treatment plants in the Czech Republic, the development of the integration of water treatment and transport facilities and sludge handling and disposal facilities into a functional complex in a given period of operation.

Note – missing numbers in the diagram legend (Fig. 4.263) belong to structures from the diagram of the treatment plant from 1975 (Fig. 4.262) which were removed from service.

4.6.3.3 Historic wastewater treatment plants

This subchapter describes examples of functional complexes of selected municipal wastewater treatment plants, which were one of the first treatment plants implemented in the Czech Republic. Their technological lines are described. Today they are part of history – the treatment plants have either disappeared or have been completely rebuilt and modernised.

Boskovice – the first wastewater treatment plant was built for part of the town (about 1,700 inhabitants) based on a project from 1926, the construction was completed in 1932 as one of our first biological water treatment plants. The inflowing sewage passed through the relieving chamber and then continued through a stoneware pipe 30 cm in diameter to an inspection shaft with an overflow to the receiving body (Boskovice Brook). Adjacent structures were: bar screen, double sand trap, settling tanks with a space for sludge digestion, three separate biological filters in a building with ventilation, and an outlet into the receiving body. Free-standing sludge drying beds for dewatering of sludge from the settling tanks.

Domažlice – the first water treatment plant from the 1930s included a double sand trap with a by-pass with manually raked screens at the beginning of each section, settling tanks with a space for sludge digestion separated by the Imhoff settling tank and scumboards. The whole line is supplemented by a station for sludge pumping from settling tanks to sludge-digestion chambers and sludge drying beds. The use of ponds as a biological stage of purification was planned.

Mariánské Lázně – the first treatment plant built as a mechanical-biological technology line consisted of a storm tank (on the main sewer 50 cm in diameter there is an automatic float flood outlet installed), shaft used as a sand trap, settling tanks (two tanks of irregular shape), two-stage biological filters and secondary settling and disinfectant tank.

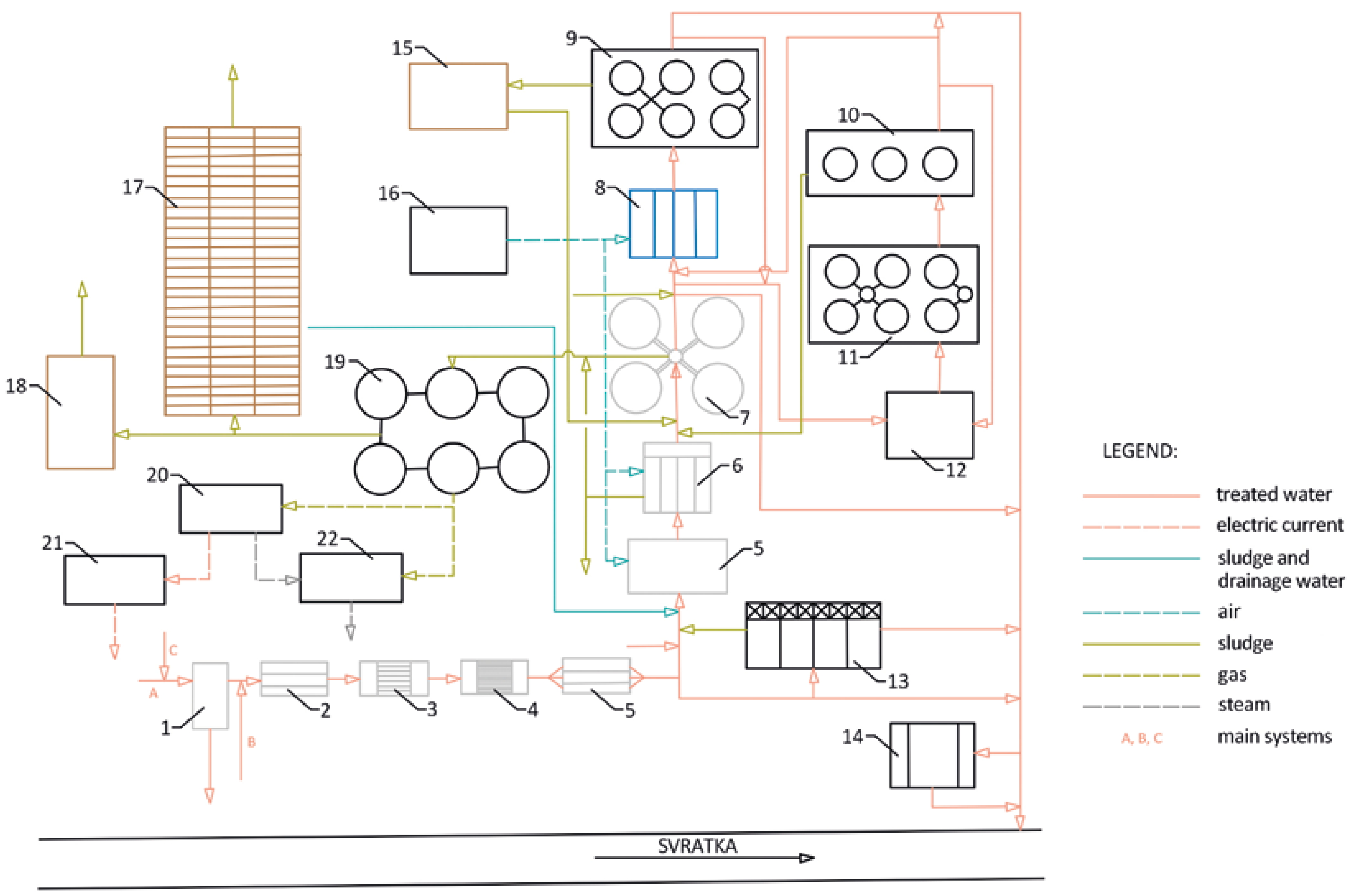


Fig. 4.262: Technological diagram (line) of Brno WWTP from 1972: 1 – overflow chamber, 2 – gravel trap, 3 – coarse screen, 4 – fine screen, 5 – sand trap, 5 – main pumping station, 6 – grease trap, 7 – sedimentation tank, 8 – activation tanks, 9 – secondary settling tanks, 10 – secondary settling tanks, 11 – biological filters, 12 – filter pumping station, 13 – storm tanks, 14 – flood control pumps, 15 – sludge pumping station, 16 – blowing station, 17 – sludge drying beds, 18 – fertiliser manufacturing plant, 19 – sludge-digestion chambers, 20 – power plant, 21 – switch room, 22 – heating plant. Diagram by Radka Račoch and Michaela Mrvová, 2021 (modified according to: project documentation provided by Brněnské vodárny a kanalizace).

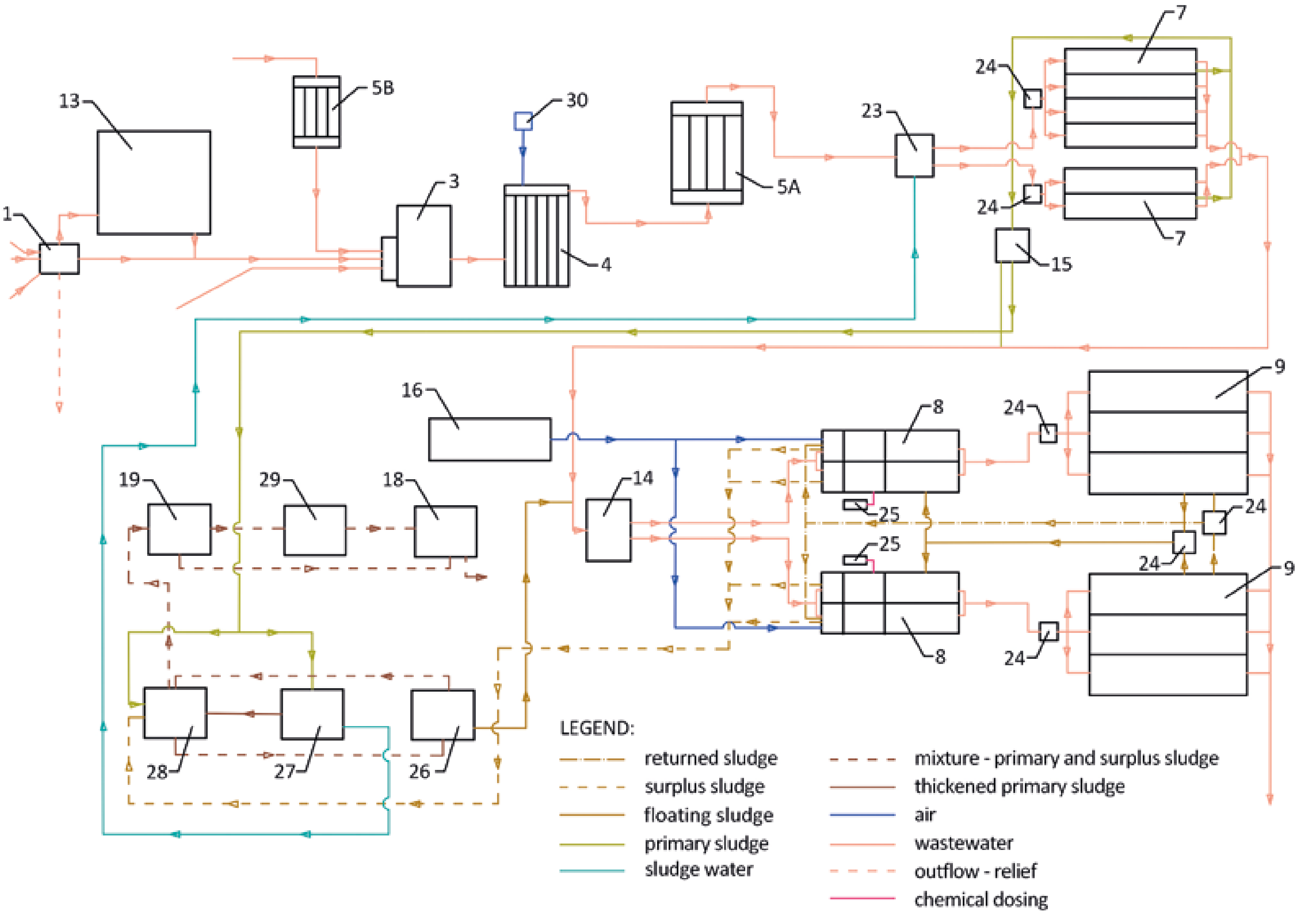


Fig. 4.263: Technological diagram (line) of Brno WWTP at present: 1 – distribution structure on the inlet, 3 – screen building, 4 – sand trap, 5A – screw pumping station, 7 – settling tanks, 8 – activation tanks, 9 – secondary settling tanks, 14 – inter-pumping station, 15 – primary sludge pumping station, 16 – blowing station, 18 – sludge dewatering and drying, 19 – sludge-digestion tanks, 23 – settling tank distribution structure, 24 – shaft and pumping, 25 – chemical dosing, 26 – flotation unit, 27 – thickening tank, 28 – flotation overflow pumping station. Diagram by Radka Račoch and Michaela Mrvová, 2021 (modified according to: project documentation provided by Brněnské vodárny a kanalizace).

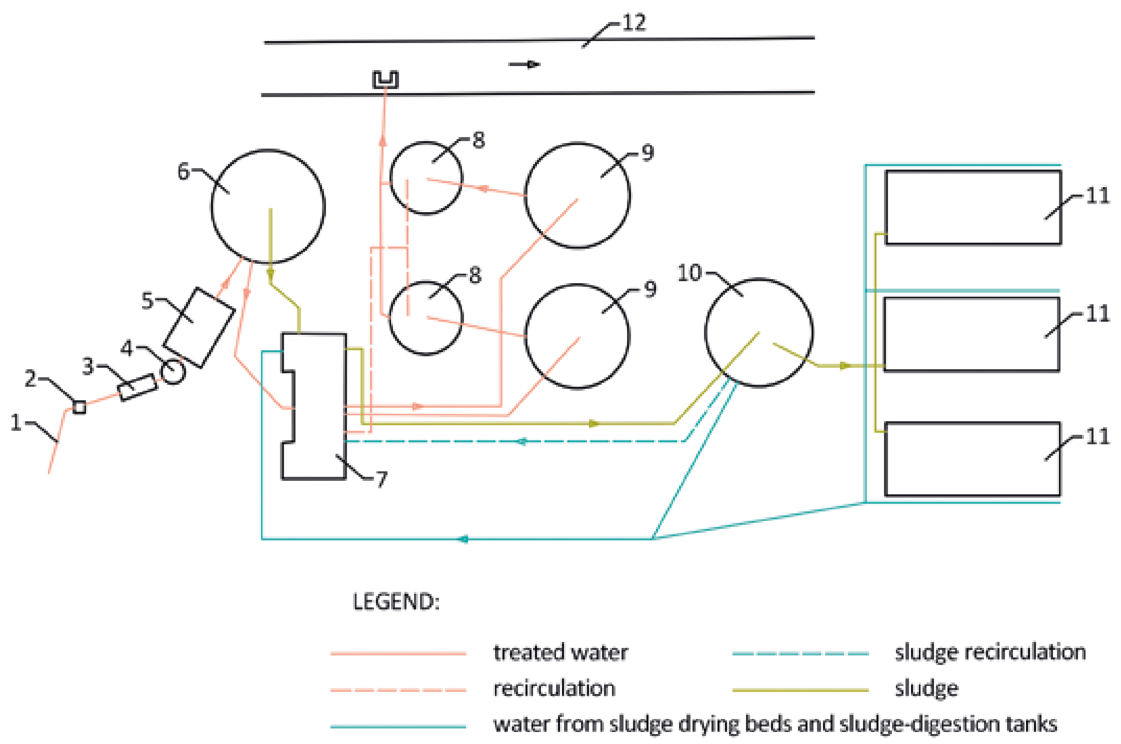


Fig. 4.264: Technological diagram (line) of Kuřim WWTP: 1 – raw water inflow, 2 – switching shaft, 3 – screen, 4 – sand trap, 5 – grease trap, 6 – DORR-type settling tank, 7 – machine room, 8 – secondary settling tanks, 9 – trickling biofilters, 10 – sludge-digestion chamber, 11 – sludge drying bed, 12 – receiver of the purified wastewater (local watercourse). Diagram by Radka Račoch and Michaela Mrvová, 2021 (modified according to: project documentation provided by Brněnské vodárny a kanalizace).

Opava – mechanical-biological treatment plant consisting of screens, sand trap, settling tanks without a space for sludge digestion, pumping station, biological filters and sludge drying beds.

Further details regarding these treatment plants are mentioned by Bulíček (1951) and Broncová (2002).

The functional complex of the original WWTP for the town of Kuřim (Brno-Country District) is presented in the form of a diagram which represents a typical example of municipal treatment plants from the second half of the 20th century using modernised biofilters as the main biological stage of treatment (Fig. 4.264).

4.6.3.4 Wastewater treatment plant of small settlements

Fig. 4.266 shows a diagram of a small activation WWTP as an example of treatment plants which have been established in the Czech Republic since its entry into the European Union.

Fig 4.267 shows a diagram of a WWTP for a bigger municipality involving biological treatment technology by means of circulating activation which is unique because there are also structures for natural ways of wastewater treatment in the functional complex, both a stabilisation tank (pond) and a large reed-bed WWTP serving for secondary water treatment. This example is from Austria where such combined treatment plants are built and used. In the Czech Republic, we can find a number of similar examples but without the final step of the secondary wastewater treatment by natural means.

4.6.3.5 Standardised wastewater treatment plants

In recent decades, a large number of wastewater treatment plants have been built as standardised structures, based on a single treatment technology but with different dimensions depending on the water flow rate or number of inhabitants connected. At present, there are a lot of suppliers of the technological part. The construction part is usually designed and implemented by other companies and is tailored to the location. Fig. 4.289 shows a basic technological diagram as a model for a selected type of WWTP forming one functional complex in a compact design. Fig. 4.265 shows a specific example of a technological complex for a given location.

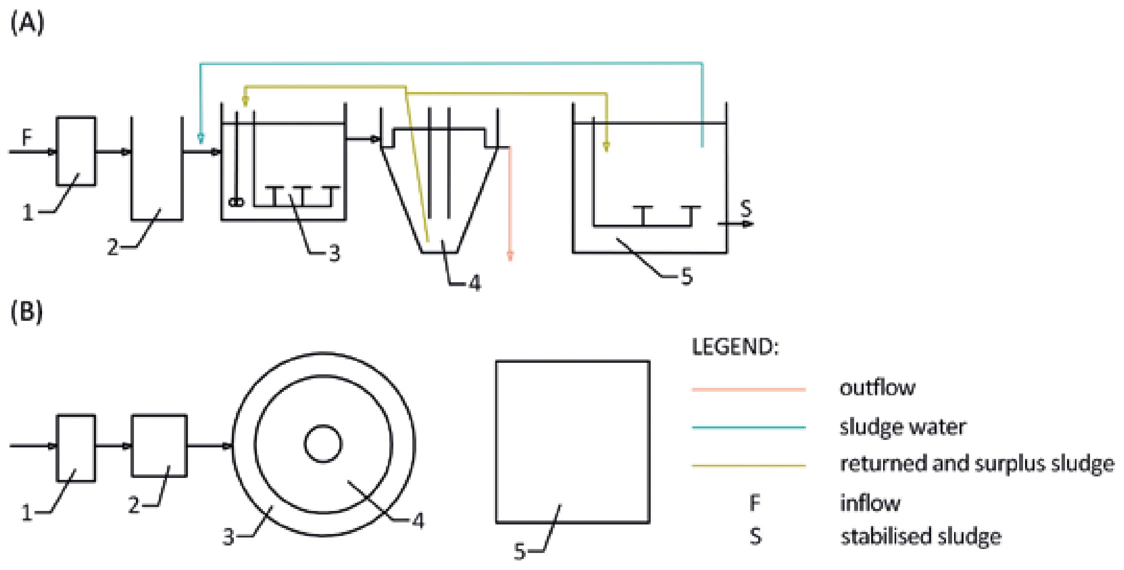


Fig. 4.265: An example of a model technology line of a standardised WWTP: 1 – coarse pre-treatment (screen), 2 – vertical sand trap, 3 – activation tank, simultaneous operation, 4 – nitrification and denitrification tank, 5 – vertical secondary settling tank, another structure outside the scheme – aerated sludge box. Diagram by Radka Račoch and Michaela Mrvová, 2021 (modified according to: provided project documentation).

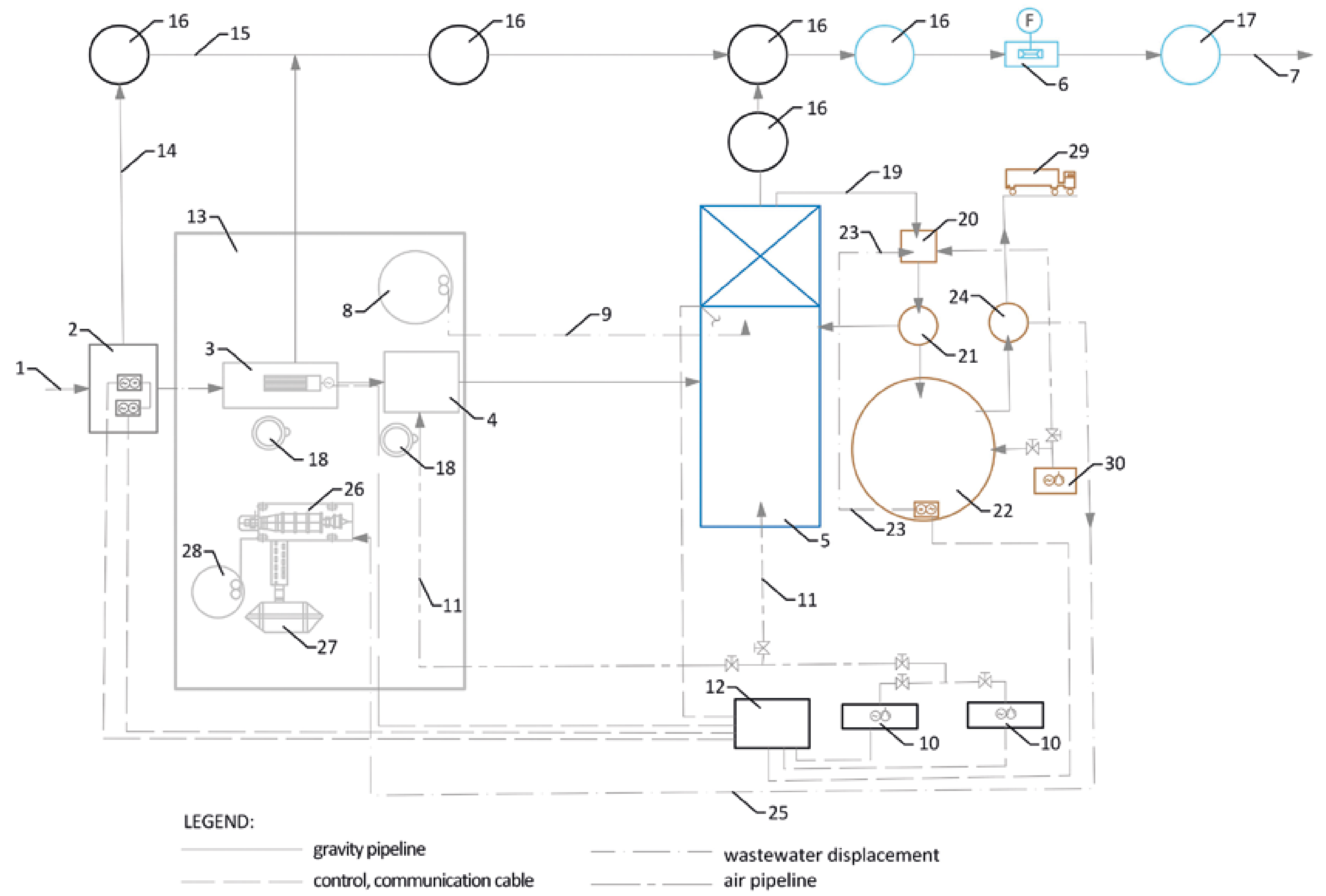


Fig.4.266: A technology diagram (line) for a village up to 2,000 inhabitants (Starovice, Břeclav District): 1 – inlet, 2 – pumping station 3 – screen, 4 – sand and grease trap, 5 – activation, 6 – measurement structure + Parshall flume, 7 – outlet to a watercourse (receiver), 8 – phosphorus precipitation storage container, 9 – pipeline for the precipitant transport, 10 – blowing station, 11 – air intake into activation or sand trap, 12 – activation control unit, 13 – operational building, 14 – emergency raw water overflow, 15 – emergency gravitational WWTP bypass, 16 –operational and control shafts, 17 – control bypass shaft, 18 – bin for screenings, 19 – returned sludge, 20 – sludge pumping station, 21 – shaft, 22 – sludge box, 23 – sludge water, 24 – shaft, 26 – sludge dehydrator, 27 – container for sludge transport, 28 – sludge flocculant storage container, 29 – surplus sludge draw-off and transport option, 30 – blowing station. Diagram by Radka Račoch and Michaela Mrvová, 2021 (modified according to: provided project documentation).

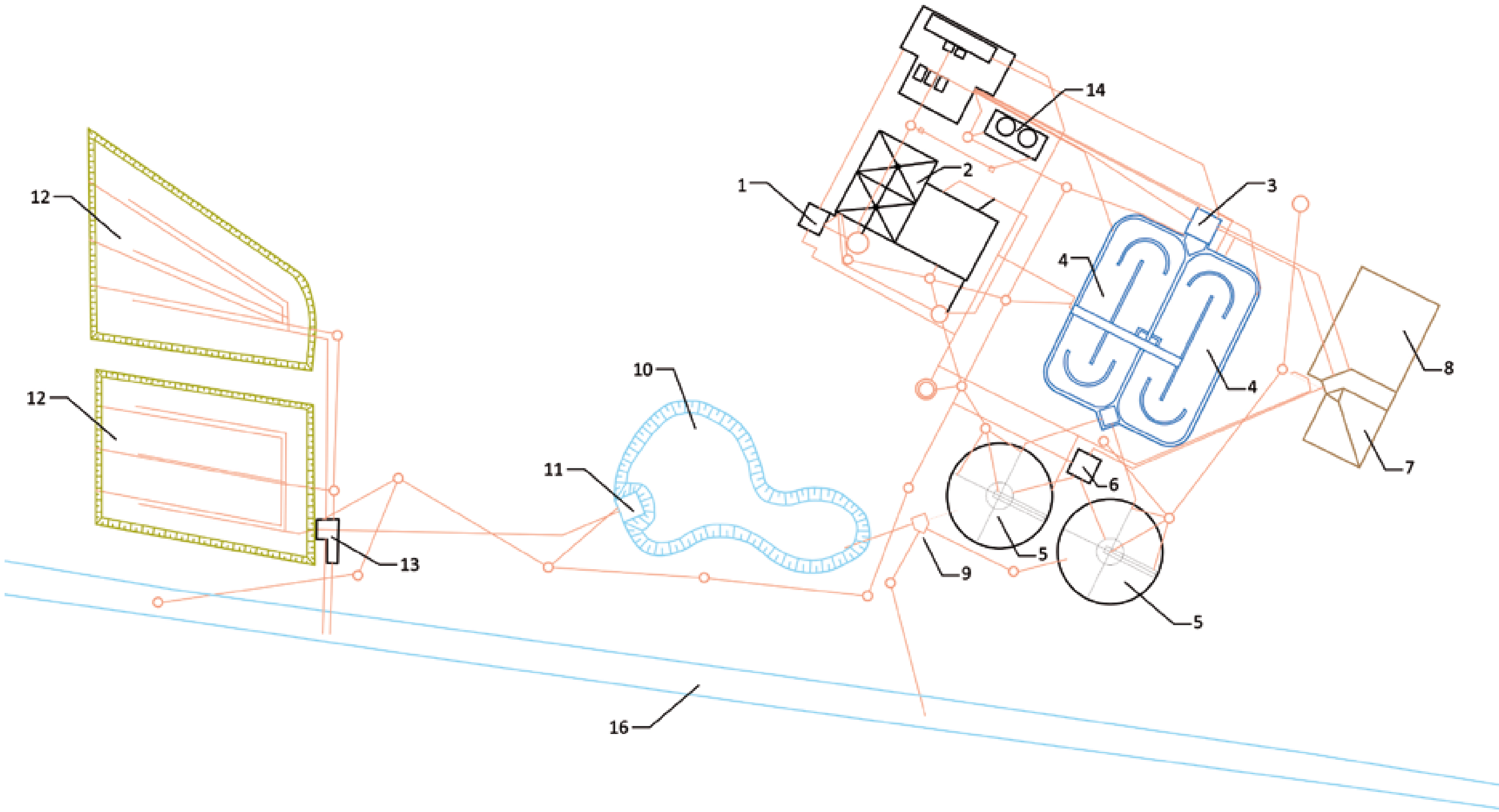


Fig. 4.267: A technology diagram (line) of a WWTP for a town up to 10,000 inhabitants (Harmannsdorf, Austria). 1 – inflow, pumping station, 2 – operational building, 3 – selector (water distributor), 4 – circulating activation, 5 – secondary settling tanks, 6 – sludge pump, 7 – sludge processing (dewatering), 8 – sludge storage space, 10 – secondary treatment and stabilisation tank of pond type, 11 – outlet biofilter, 12 – reed-bed treatment plant, 13 – control and measurement shaft, 14 – biofilter for the purification of air from the WWTP area, 15 – well, 16 – purified water receiver (local watercourse). Diagram by Radka Račoch and Michaela Mrvová, 2021 (modified according to: provided project documentation).

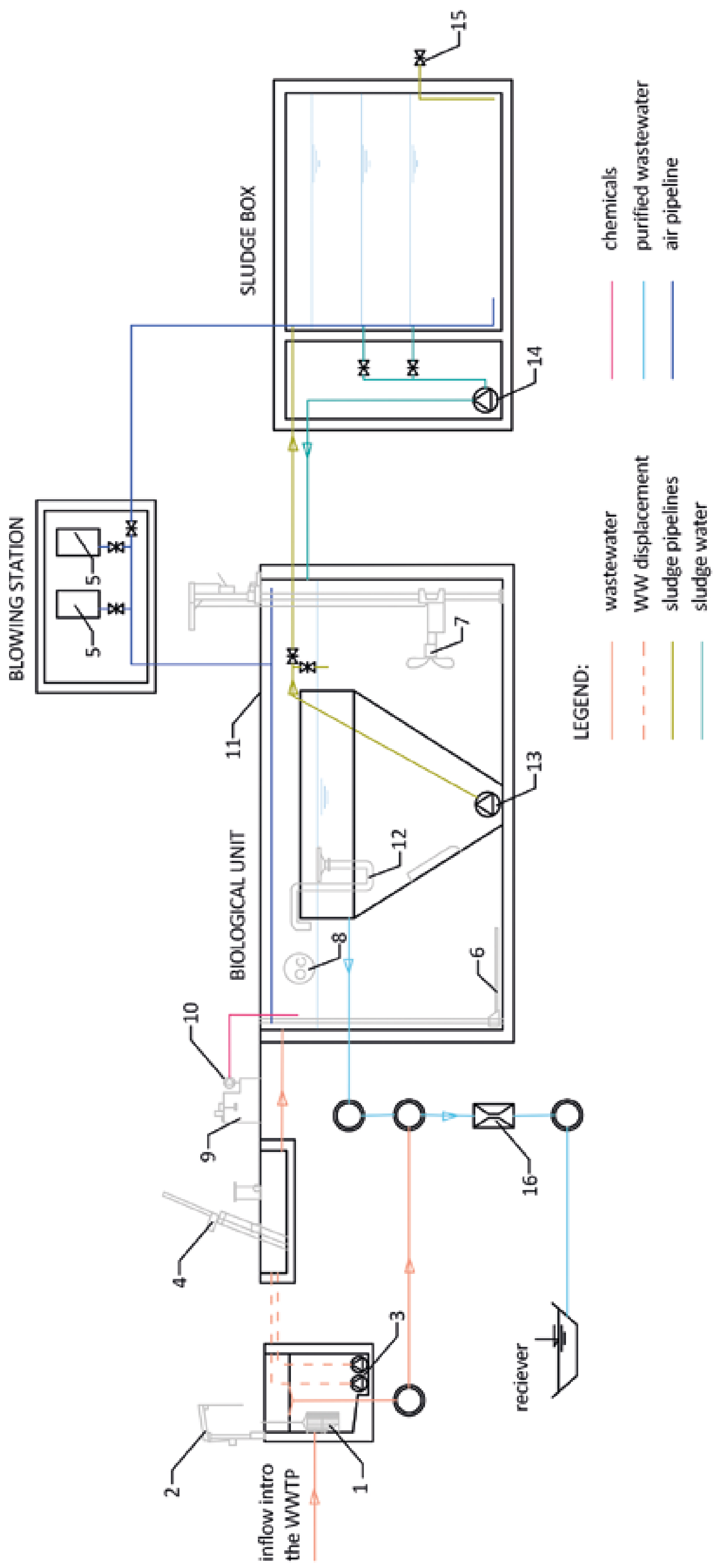


Fig. 4.268: A specific solution of a technology line of a standardised WWTP for a village up to 2,000 inhabitants: 1 – screen basket, 2 – manual lifting equipment, 3 – immersion sludge pump, 4 – mechanically raked screen, 5 – activation blowing station, 6 – activation grid, 7 – immersion propeller mixer, 8 – oxygen probe of measurement technology for activation control, 9 – storage tank for chemicals for phosphorus precipitation, 10 – chemical dosing pump, 11 – biological unit cover, 12 – secondary settling tank, 13 – surplus sludge immersion pump, 14 – sludge pump, 15 – ending, 16 – flow metre. Diagram by Radka Račoch and Michaela Mrvová, 2021 (modified according to: provided project documentation).

4.5.4 EVALUATION FROM THE POINT OF VIEW OF HERITAGE PRESERVATION BASED ON SPECIFIC EXAMPLES

4.6.4.1 Prague-Bubeneč, old wastewater treatment plant

By building the sewerage system, Prague responded to the problem of the sanitary crisis and the high pollution of the Vltava River at the end of the 19th century. Many large cities faced similar problems, but unlike most of them, Prague introduced not only a system of sewers but also a system ending with mechanical treatment, designed by engineer William Heerlein Lindley in 1894. The system consists of main masonry sewers conducting water from an area of almost 5,500 ha and a treatment plant equipped with screens for catching coarse impurities, sand traps, settling and desludging tanks and a power plant equipped with two steam engines and two boilers from 1903–1905.

Information on the development of the implementation, reconstructions and following handling and disposal of the produced sludge can be found in the publication by Jásek (2006), Jásek et al. (2009), Jiroušková (2016), Rosický (2018) and Wanner (2018).

Temporal determination/date of origin: 1901–1906 (trial operation), 1907 full operation
Authorship: William Heerlein Lindley
Heritage preservation: cultural monument (1991, scope of heritage protection: operation building, chimney 1 and 2, underground settling tanks, entry into the underground settling tanks, sludge wells 1 and 2, entry into the well; 2010, bridge of a former Field Railway), national cultural monument (2010), on the Tentative List of the Czech Republic for inscription on the World Heritage List (2020)
Authorship: project: engineer William H. Lindley, realisation: Quido Bělský company

Evaluation:

The exceptional value lies across several levels: modern progressive design, high aesthetic level of the whole system, exceptional atmosphere of the site and, finally, high degree of authenticity/originality, which was preserved after the transfer of the operation to the new treatment plant on Trója island in 1967 thanks to its partial use for the new operation (and thus avoiding the demolition of the whole old treatment plant).

Historical value: A work by William Heerlein Lindley, author of the first wastewater treatment plant in Germany, realised in Frankfurt am Main in 1887. Unlike a number of European cities, which in the second half of the 19th century solved their wastewater problems by sewerage (London, Hamburg, etc.) or by infiltration into the soil without treatment (Berlin, Gdansk), the Bubeneč wastewater treatment plant represents one of the first examples which combines both sewerage and wastewater treatment.

Typological value:

- **Exceptional parameters of structural and technological parts:** A uniquely preserved technologically and structurally complete set of buildings and equipment of the wastewater treatment plant from the turn of the 19th and 20th centuries, with the technology of so-called mechanical treatment, consisting of sieving and settling of sludge. (Jiroušková, 2016). Besides surface structures, it includes vaulted underground premises, a preserved system of supply sewers and mechanical water pre-treatment structures, settling tanks, ventilation chimneys and sludge wells. In addition to pumps and propellant machines, the technological equipment also includes a bridge of the former field railway for the disposal of sludge from the treatment plant.
- The preservation of the old wastewater treatment plant in the vicinity of the existing WWTP and so-called new water line is also a unique evidence of three stages of development, illustrating the growing demands on wastewater treatment in urban agglomerations.
- **Exceptional occurrence within the Czech Republic**: The first important wastewater treatment building in the Czech lands and probably the only surviving one of the first half of the 20th century in the Czech Republic.

Other WWTPs were built in Vítkovice in 1906 (operating until World War I), Opava in 1913 (damaged during World War II and rebuilt in the 1960s), and Mariánské Lázně in 1930 (Jiroušková, 2016).

- **Exceptional occurrence on an international scale:** One of the few surviving wastewater treatment plants of the turn of the 19th and 20th centuries in the world. It was selected as one of fifteen significant structures, complexes and systems representing universal values of global significance in the TICCIH comparative study of water management structures (Douet 2018).

Value deriving from the technological flow: The wastewater treatment plant has been preserved to the full extent in which it ceased its operation in 1967. The heritage preservation covers only the structures and equipment from the first construction phase. The demolition of the chlorination plant from the 1930s, which was carried out in 2021, had a negative impact on the value of the technological flow and its integrity. It would be desirable to extend the heritage protection to all the structures that formed the technological flow at the time of the end of the operation (e.g., screen building, sludge wells, entrance structures to the underground, etc.).

Value deriving from symbol: An extraordinary significance for the water management field and environment protection in the global context.

Value deriving from authenticity:

- **Authenticity of function:** Not preserved. The loss of the original function is counterbalanced by the authenticity of mass, form and technology which would not have been preserved if the original function had been maintained.
- **Authenticity of form and mass/material:** Preserved. The main building and settling tanks have been preserved in the authentic state, with minimal secondary interventions.
- **Authenticity of technical equipment:** A significant part of the machinery and interior equipment has been preserved: sludge pumps from 1901 made by the First Bohemian-Moravian Machine Factory in Prague, a suction pump in the gravel and sand trap, flood control pumps and propellant machines, which are formed by two horizontal steam engines with a differential piston made by the Prague's Breitfeld-Daněk Machine Factory from the beginning of the 20th century which were supplied with steam by two Cornwall-type flame boilers, and electric motors (Jiroušková, 2016). There is also project documentation and extensive photo documentation available.

Architectural value: High-quality industrial architecture representing the forms used at the time of its creation with lingering influences of historicism and signs of the emerging Art Nouveau. The monumentality of the underground premises stands out over the elegant forms of the exterior, with refined artistic modelling of architectural details, supported by the quality craftsmanship.

Fig. 4.269: Prague-Bubeneč. Old wastewater treatment plant: (A) and (B) steam engine machine room; (C) boiler room. Photograph by Viktor Mácha, 2019.

Landscape/urban value: The treatment plant is located in the southern neighbourhood of the extensive area of the existing WWTP and so-called new water line on Císařský island, from where it is separated by the Vltava navigation channel. It is the dominant landmark of a small industrial zone along Papírenská street, delimited in the south-west by the railway corridor to Ústí nad Labem opposite to the built-up area block of Bubeneč, and in the south-east by the distinct hillock Pecka, behind which the Stromovka Park begins. In panoramic views from, for example, Baba or Bohnice this area is not much visible. The built-up area is mostly utilitarian, urbanistically and architecturally worthless. The urban value of the site will be accentuated in the planned future transformation of the area, as the Art Nouveau buildings of the treatment plant with two tall chimneys, together with the opposite historicising factory building, will form the compositional basis of the new quarter and give it a very distinctive identity.

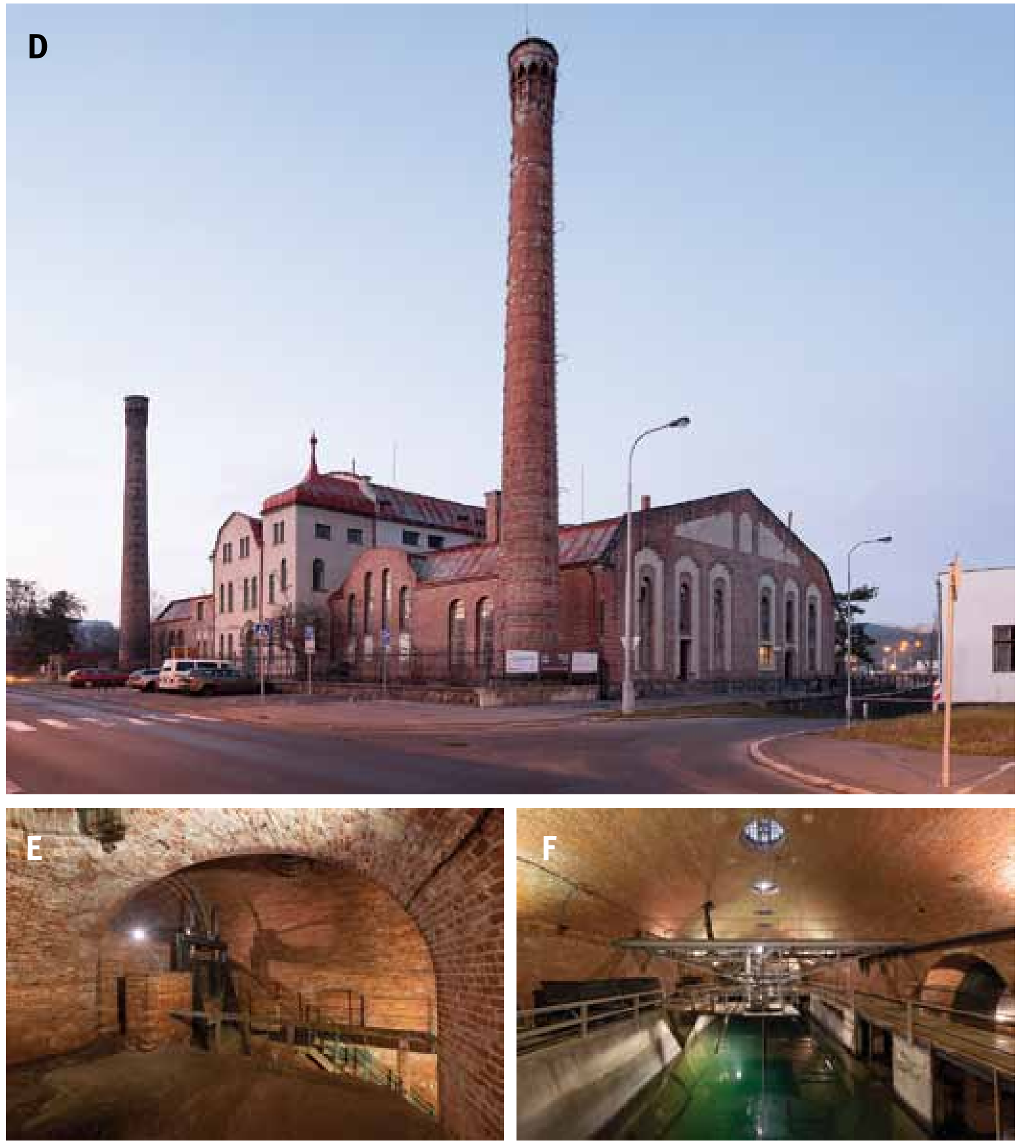


Fig. 4.269: Prague-Bubeneč. Old wastewater treatment plant: (D) overall view; (E) sewer sluice gate; (F) sand trap. Photograph by Viktor Mácha, 2019.

4.6.4.2 General summary of the principles for the evaluation of drainage and wastewater treatment structures

For the decision whether sewerage, wastewater transport and treatment structures should be preserved or heritage protected, it is necessary, as is the case of structures from other groups of water management, to have a comprehensive assessment based on many criteria.

The first criterion is the historical value, i.e., whether it is a structure from the period before the outset of the development of wastewater drainage and treatment in the middle of the 19th century or whether it is the first structure of its kind in our territory or whether the structure or equipment represents the first realisation in the Czech Republic (or Czechoslovakia).

The typological value is another criterion to be taken into account in the assessment. It means it might be the only one or one of a few preserved examples of a structure or equipment of the given type (unique structure, typical representative, typical configuration of a technological solution, technology line arrangement, model solution). Another criterion is represented by the value of functional continuity (the use of a structure continues in an unchanged way). Within the scope of this value, we recommend positively assessing even those structures that have undergone a partial modification which does not have any impact on the overall arrangement and character (e.g., replacement of a pump, aerator, railings, pipework), which is a regular necessity in the case of structures getting in contact with wastewater.

The technical value is a criterion assessing the technical solution itself, which may be original compared to a standardised solution, e.g., position in the terrain (and related modifications to the structure), materials used, modifications to the structure representing a breakthrough in the solution.

An equally important criterion is the architectural value. Even technologically similar buildings or their functional complexes can differ significantly in their construction and architectural rendering.

Wastewater treatment premises have predominantly utilitarian character and have always been located as far as possible from built-up areas because of the odour associated with the operation. The location of wastewater treatment plants and associated structures is always limited by the requirement to discharge the treated wastewater. This is usually the nearest lowest situated location by a watercourse, or in some cases a pond. Therefore, they usually do not have an urbanistic impact (one of the exceptions is the old WWTP in Bubeneč and the new WWTP on Císařský island in Prague), in the landscape they have at best a neutral effect but more often rather disturbing, so it is necessary to look for ways of how to hide them from view – for example by a tree alley. This measure can also act as a protection of the intravilan against the spread of odours if it is situated in an appropriate direction.

The preservation and possible protection of structures associated with the sewerage and wastewater treatment is a question of compromise between the requirements for the wastewater discharge and treatment, which are constantly changing and above all becoming stricter, the requirements for operation and the protection of heritage values. This is analysed in more detail in Chapter 5.3.

It can be assumed that it will be difficult or impossible to preserve functional structures without any intervention in the future.

One of the possible ways to preserve visual information about the technological line of the treatment plant, or about individual structures and their interconnection, is to create a digital 3D model in addition to the creation of classical 2D diagrams and photo documentation. The benefit is especially the possibility of observing the model from different angles and visualisation of various details. Fig. 4.270 and Fig. 4.272 document procedures of the creation of a model from pictures of the locality of a small municipal treatment plant and large urban municipal treatment plant, which were taken by means of a drone. Part of the documentation of the photographs taken by the drone is also the localisation of predetermined points in the terrain in the area of the site using a precise GPS station. The data is subsequently photogrammetrically processed and analysed by means of a suitable computer technique. Fig. 4.271 and Fig. 4.274 then show possibilities of various displays of the analysis results and model creation. In such

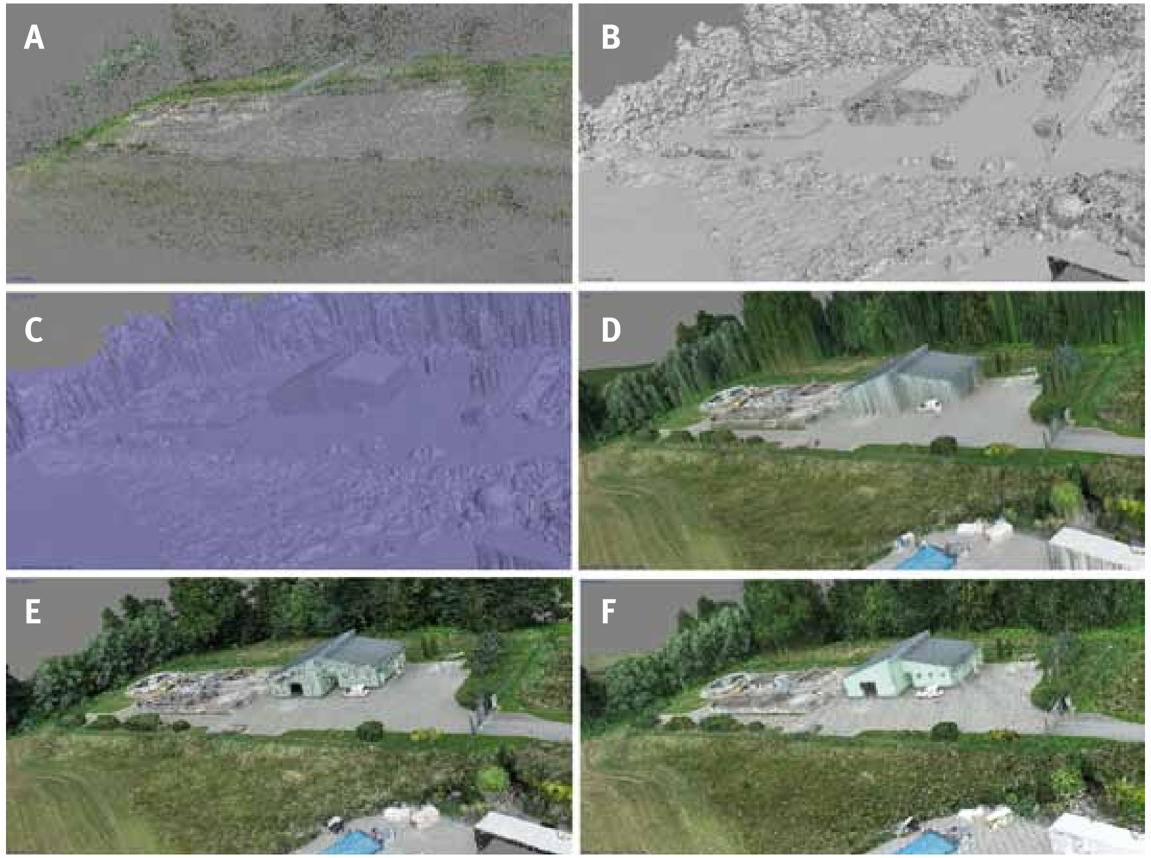


Fig. 4.270: Individual steps of the genesis of the 3D model of a small WWTP: (A) identification of common points in individual photographs; (B) creation of point clouds; (E) creation of a wire model; (D) matching a colour scale of individual photograph to the 3D model; (E) model texturing; (F) final texture touches. Radek Bachan, 2021.

Fig. 4.271: Various displays of the 3D tiled model of a WWTP. Radek Bachan, 2021.

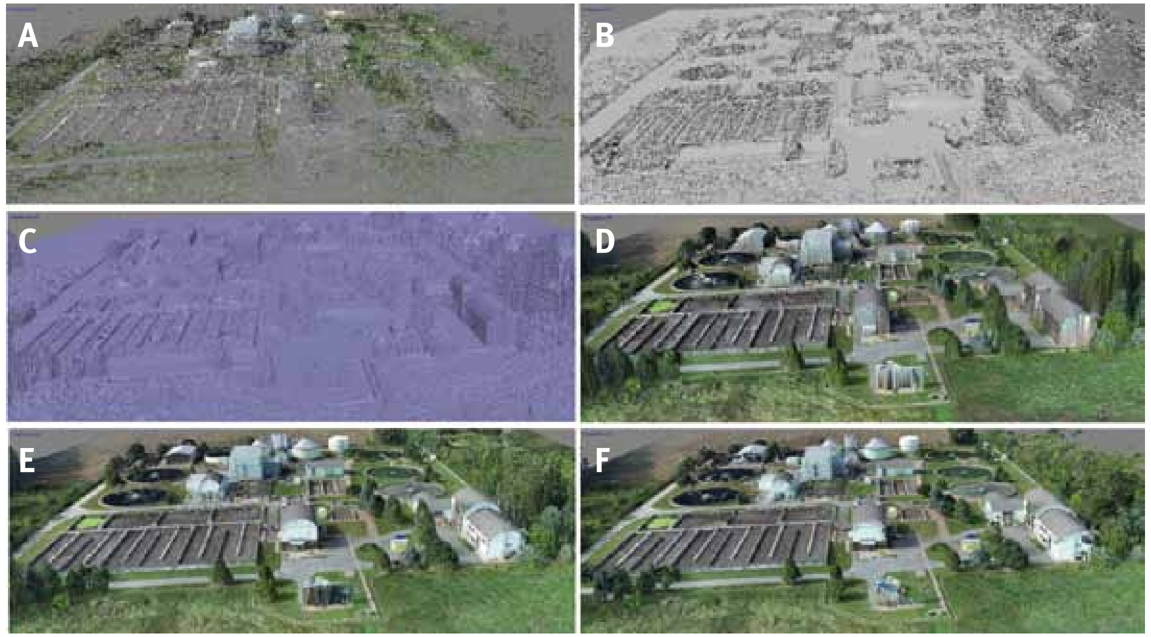


Fig. 4.272: Individual steps of the genesis of the 3D model of a large municipal WWTP: (A) identification of common points in individual photographs; (B) creation of point clouds; (E) creation of a wire model; (D) matching a colour scale of individual photograph to the 3D model; (E) model texturing; (F) final texture touches. Radek Bachan, 2021.

Fig. 4.273: A cutout of the final 3D model of the WWTP. Radek Bachan, 2021.

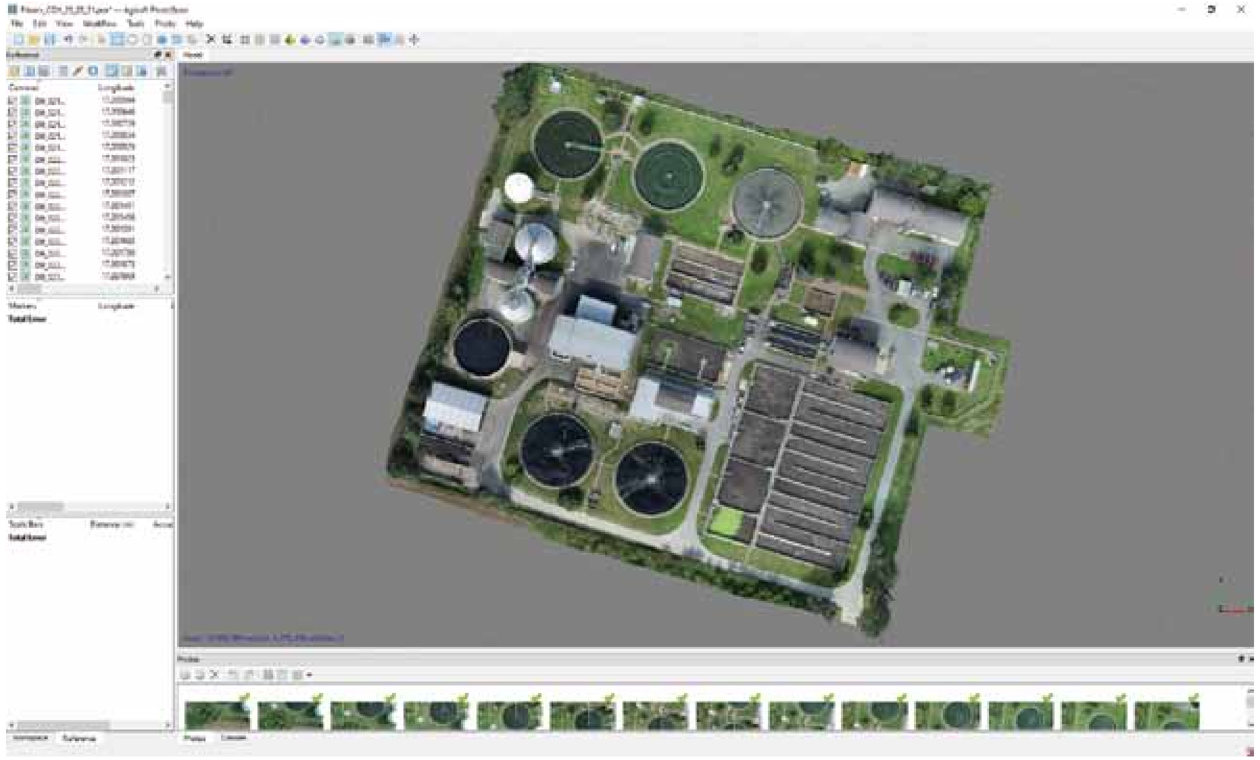


Fig. 4.274: A perpendicular view of the WWTP premises. Radek Bachan, 2021.

a way it is possible to preserve information on selected locations, e.g., before and after the reconstruction. This can partially compensate for the fact that it will not be possible to preserve a given structure or set of structures due to the requirements for the overall reconstruction (for more details on this problem see Chapter 5.3).

4.6.5 REGISTER OF LOCATIONS

Name	Protected from	Type of protection	USKP registry number	Item name according to the Monument catalogue	District	Municipality
Wastewater treatment plant in Prague-Bubeneč	26. 4. 1991 1. 7. 2010	CM NCM	11886/1-2148 364	Wastewater treatment plant	Capital of Prague	Prague 7 (Prague-Bubeneč)
Underground drainage system	12. 12. 1994 31. 8. 1961	CM part of heritage reservation	11917/3-6073 PR 1007	Sewer network	Jindřichův Hradec	Slavonice
Wastewater treatment plant in Brno-Modřice	---	---	---	---	Brno-City	Brno

5. GENERAL PRINCIPLES AND EXAMPLES OF PRESERVATION, RENOVATION AND NEW USE OF WATER MANAGEMENT STRUCTURES

The following chapters provide a brief overview of approaches for dealing with water management structures with a heritage value, including structures which serve their original function and structures which have lost their function and have been preserved for new uses or museum purposes.

Chapter 5.1 presents some examples from domestic heritage protection and focuses on the ways of combining operational requirements and heritage values, or on the restoration and reconstruction of historic buildings which have lost their function.

Chapter 5.2 presents, in examples from both the Czech Republic and abroad, possible approaches for dealing with water management structures after they have lost their function: examples of musealisation of a whole or its parts (if a historic structure or equipment is part of a functional plant), or transformation for a new, different use.

5.1 WATER MANAGEMENT STRUCTURES IN THE CZECH REPUBLIC AND ABROAD WITH A HERITAGE VALUE – RENOVATIONS, RECONSTRUCTIONS AND ADJUSTMENTS (EXAMPLES OF BOTH GOOD AND BAD PRACTICE)

5.1.1 OSTRAVA-NOVÁ VES, WATER TREATMENT PLANT

Municipal waterworks and water treatment plant in Nová Ves (Fig. 5.1) was built in 1907–1908 according to the design of engineer Ulrich Hubr and architect Karel Schwager. Water from 35 tube wells was sucked into a collecting well and from there it was pumped into an iron removal station and then into a cleaned water tank. Its distribution to a water supply network was originally ensured by piston pumps, replaced in 1927 with electric high-pressure centrifugal pumps. From 1969 water was supplied to Ostrava by a group water supply system from reservoirs at the foothills of the Beskydy and Jeseníky mountains. The waterworks was then decommissioned and its machine room demolished. The complex still serves as a water treatment plant (Matěj, 2022). In the former deacidification station (Babylon), which served its purpose only for a short time, there is a waterworks museum today.

The complex, built in 1907–1908 was designed in a uniform romantic architectural morphology with Art Nouveau elements using a combination of plastered surfaces, facing masonry and half-timbering. In the machine room there have been a lot of original construction details preserved, e.g., ceramic wall tiling, ceiling wooden barrel vault, segment elements of internal facades (cornices, lesenes, window sills, etc.), Art Nouveau doors, gallery railings, spiral steel staircase with railings, etc.

Six structures of the complex are heritage protected: machine room (plot No. 101), deacidification station, so-called Babylon (plot No. 182), workshops (plot No. 163), ancillary structure (plot No. 164), dwelling house (plot No. 156) and administrative building/corner villa (plot No. 98).

Evaluation: The most important values of the complex are architectural and urban values. The complex combining forms of industrial architecture from the turn of the 19th and 20th centuries with contemporary architectural trends is also a dominant landmark which forms corner areas of Ostrava's busy roads and is an important orientation point of the city. Since the original function has been reduced (including the demolition of the original machine room of the pumping station) and the equipment has been continuously modernised, the requirements of the heritage protection are aimed at preserving the architectural and urban values. Later extensions do not disturb the original environment and remain in the background.

Fig. 5.1: Ostrava – water treatment plant, overall view. Photograph by Roman Polášek, 2019.

Renovation, development of the complex and the impact on heritage values: Cooperation of the owner (Ostrava-City, used by SMVaK) with heritage authorities is exemplary in the long term, both in terms of the protection of cultural monuments and their environment. From 2010 all buildings in use were gradually renewed while preserving the character of the buildings, materials and colours of the facades (the same materials were used, e.g. roof covering, new windows were made of wood with articulations derived from preserved historical photographs, etc.). In the machine room, a copy of the interior entrance door was installed using restoration techniques.

Fig. 5.2: Ostrava – water treatment plant, machine room. Photograph by Viktor Mácha, 2019.

Since the complex still serves its purpose, technological equipment has also been renewed, or modernised. In 2011 pumps in the basement of the machine room were replaced, which required construction adjustments of concrete foundations. In 2015 a transformer station was renewed and part of the technology, which did not require construction interventions in the historic part of the building, was replaced, as the necessary changes were made in the newer, utilitarian extension. Adjustments were also made outside the heritage protected buildings – foundations of disused tanks were removed and the roof and facades of the modern administrative building were restored (Fig. 5.2).

Since 2019 the construction of a modern, large-capacity, two-stage filtration building has been under consideration which will be visible from a long distance from the intersection of Plzeňská and 28. října streets. This will involve the demolition of the gatehouse and several technical buildings. In 2021, Ing. arch. Petr Kunrát's study (the third in order), dealing with a scale, mass and materials not competing with the forms and architectural morphology of the original structures, was approved.

5.1.2 VÍTKOV-PODHRADÍ, WATER TREATMENT PLANT

The water treatment plant in Vítkov-Podhradí (Fig. 5.3) is situated in the Moravian–Salesian Region near the town of Vítkov, approx. 18 km south from Opava and since 1974 it has been heritage protected. The water treatment plant was built between 1954 and 1962 together with the Kružberk hydraulic structure with which it is connected via a 6.7-kilometre-long tunnel. Raw water from the reservoir is treated here and turned into drinking water and is further distributed towards Ostrava, Fulnek, Bruntál and Přerov.

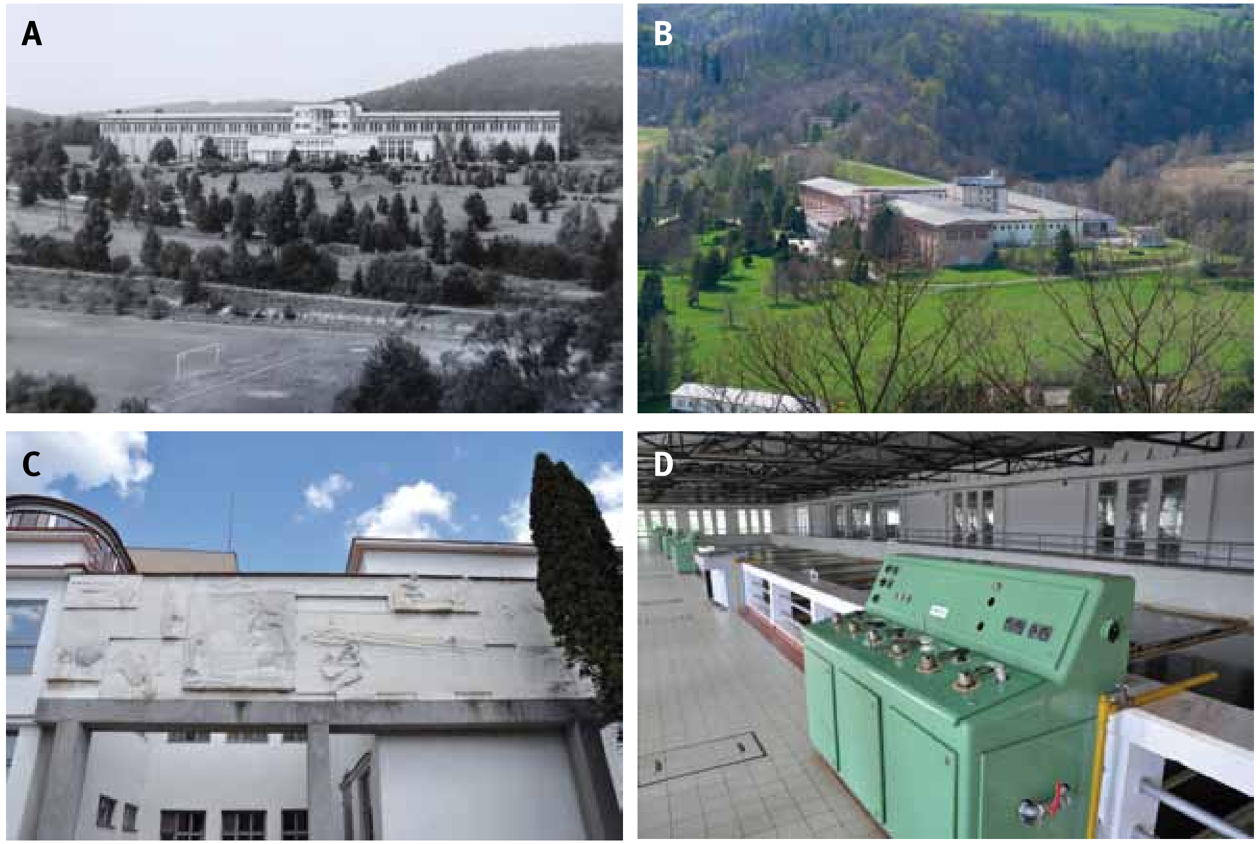


Fig. 5.3: Vítkov-Podhradí – water treatment plant: (A) original appearance (taken from: ČVVS, 1972); (B) current appearance; (C) part of Vincent Makovský's relief; (D) control panel. Photograph by Miriam Dzuráková, 2019.

Renovation, reconstruction and the impact on heritage values: The water treatment plant was declared a cultural monument as early as seven years after the construction had been completed, in 1974. This reflects the fact that Vincent Makovský's work (relief on the facade of the main building) was highly appreciated in terms of its artistic value already in this period. However, the heritage protection does not apply only to this work of art but to the whole building with which it is connected.

Some elements of the building were not chosen prudently though and the craftsmanship was not exemplary in many cases. According to the 1963 report, subtle metal windows in the filtration halls did not seal well, not all shutters were functional, etc. Long-term exposure to highly concentrated moisture causes their gradual corrosion. At the same time, the preservation of the original subtle frames is one of the requirements of the heritage protection authority because they co-create the lightness of the shell. Their replacement with plastic windows (some of the windows were replaced without the approval of a heritage protection authority) have had a negative impact on the exterior of the building.

The original roof above the filtration halls and their extensions have been replaced for being in serious disrepair. The original steel bar joists were painted with red lead and the soffit boards contained asbestos. For hygiene requirements, the replacement with a replica (with surface working carried out before the installation in situ) instead of the original red leak paint blasting was permitted. The soffit has not been renewed which has been reflected in the overall effect of the hall – its clear height has been reduced and with it also the impression of "purity".

Filtration technology has also been modernised and connected to new drains and concrete bottoms of tanks. The operation automation is associated with the abolition of the control panel function.

The water treatment plant on Vítkov-Podhradí is an example of finding a compromise between the requirements of operation and heritage protection. In the case of technology, the authenticity of function is superior to the authenticity of material and technical equipment. In the case of buildings, finding a compromise means the building should remain a document of the architecture of the time, and the values it has, not only as a "background" of a work of art but also on its own, should not be degraded.

5.1.3 HOŘÍN, LOCK

The lock (Fig. 5.4) was built by Vojtěch Lanna's company between 1903 and 1905. The author of the technical solution was Antonín Smrček and the author of the architectural design was František Sander. The main purpose of the construction was to make the Vltava River navigable up to Prague and thus also to compensate for the shortage of waterborne transport in Prague in comparison to the expanding transport on the Elbe River. The impossibility of making Vltava navigable in the last several-kilometre-stretch between Vraňany and Mělník provoked the necessity of constructing a lateral canal and a lock in order to overcome a height difference of 10 metres between Vraňany and Hořín. Making the lower Vltava River navigable was of great importance for the economy of Prague and its surroundings.

The lock is situated in the southern outskirts of the village of Hořín. The structure has a small (in the east) and a big (in the west) lock chamber. Two bridges with surbased arches, formed by a reinforced concrete vault faced with granite blocks and Cyclopean masonry, covers the lower lock head. The lower lock head is adjacent to a lower lock cut area from the north and the upper lock head is adjacent to an upper lock cut from the south. Banks at a slope of 1:2 are reinforced by stone paving. The bank level designed to be walked on is at the level of bridges. Lock gates are interconnected with stone staircases curved towards the canal.

Evaluation: It is a very valuable example of a structure for water transport from the beginning of the 20th century both from the point of view of architecture, design and technology, and craftsmanship. The lock is a dominant feature in the landscape. It is visually connected directly with the panorama of the Mělník Chateau, is part of the panorama of the Elbe and Vltava confluence and represents extraordinary architectural and monumental values. The lock structure is extraordinary and unique in its appearance as a Romantic stone gate for boats entering the mouth

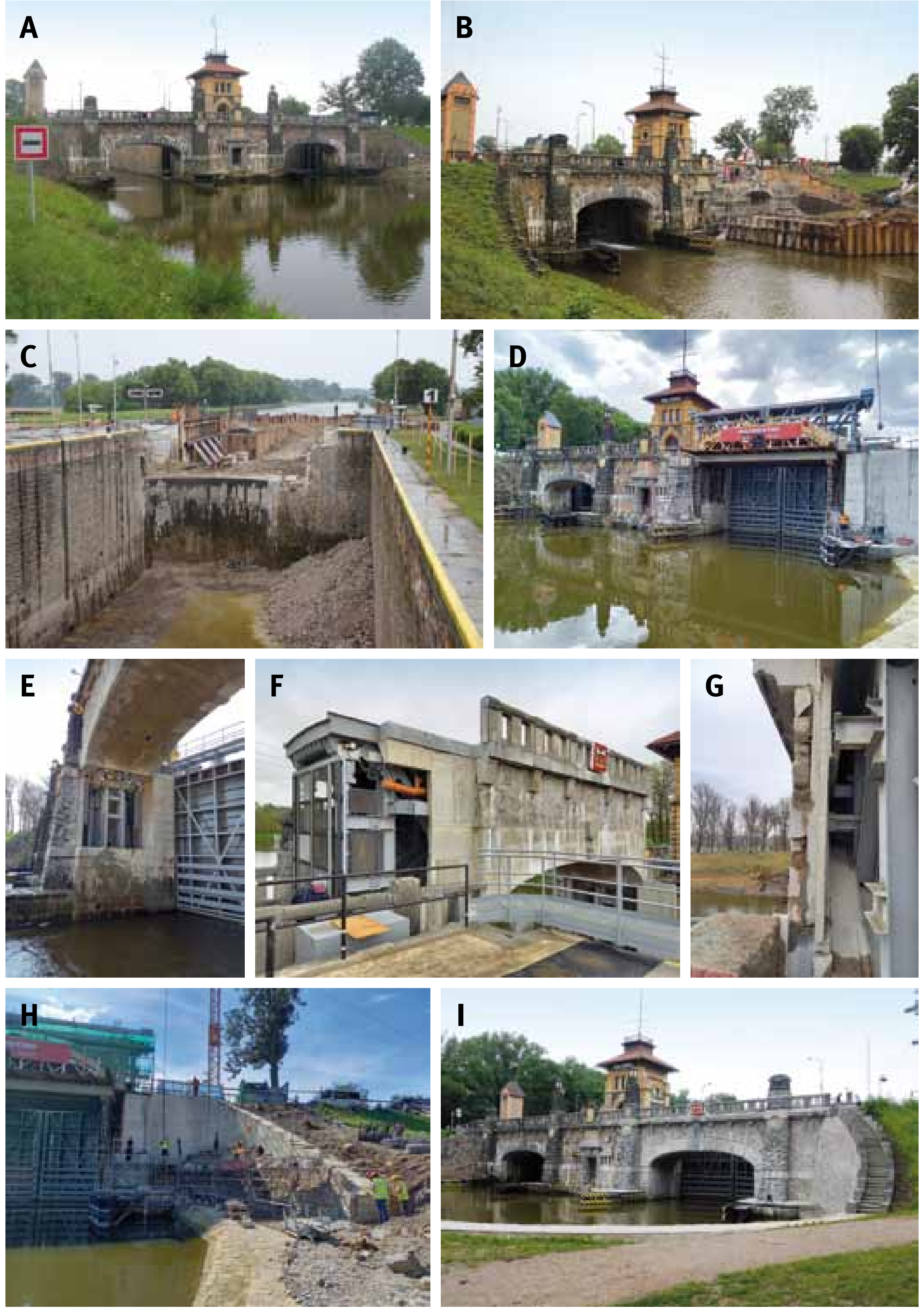


Fig. 5.4: Hořín – lock in the course of reconstruction: (A) state before the reconstruction; (B) and (C) dismantling of original structures and stone cladding; (D) to (F) new moveable bridge and lock chamber structures; (G) and (H) installation of the original facing on a new reinforced concrete structur; (I) current lock appearance. Photograph (A) – (H) by Otakar Hrdlička, 2021; (I) by Michaela Ryšková, 2021.

of the Vltava River. It is made of huge stone blocks which cover its reinforced concrete structure. Individual elements are very precisely crafted.

Reconstruction and adjustment to new parameters and the impact on heritage values: The purpose of the “Adjustment of the Hořín lock chamber head” was to ensure the required parameters of the Vltava waterway on the Vraňany–Hořín Navigation Canal, specifically the Hořín big lock chamber, which enables using the waterway in the section Mělník–Prague for big boats and ships for transport of oversized cargoes of the width of 12 m and navigation height of 7 m. The original big chamber was built for boats of the width of 11 m and navigation height of 4 m.

The main obstacle for raising the navigation height was a firm reinforced concrete bridge faced with stone not allowing lifting. Therefore it had to be removed. The original stone cladding and all visual elements – railing, cornices, pylons, etc. – were dismounted. Before being dismounted they had been documented and numbered in detail. Subsequently, the bridge was removed and a new steel truss bridge mounted on hydraulic pistons enabled its lifting from the original position to the position of the navigation height of 7 m. The original stone cladding and dismounted elements were mounted back on this new structure by means of concrete boards. In this way an approximate visual imitation of the original bridge (one metre wider) has been created, which is in its original location at the lower position and can be raised by 5 m in 5 minutes when a large ship passes through. In the centre of the bridge, stone cladding and railings have been added as a replica of the original.

Furthermore, it was necessary to extend the usable width of the passable chamber profile, for which the extension of the upper and lower heads was sufficient. The chamber itself was wide enough. The original western structures of both heads were dismantled, the stone facing documented and numbered. Both heads were newly made of reinforced concrete, moved by 1 m to the west and faced by the original stone cladding with the missing, or partially damaged, elements replaced. New steel gates 12 metres wide were installed in both heads.

The authenticity of function has been maintained at the cost of losing authentic structures and technical solutions of the time within the scope of one of the two locks and the bridge structure above it. Proportions have been changed. This fact is most evident on the northern facade of the lower head, which has been composed using axial symmetry since its origin. Planned construction adjustments contradict this principle. This is one of the reasons why the expert statement of the National Heritage Institute as well as the decision of the Municipal Authority’s heritage executive body took a negative stand on it. Only the Central Bohemian Region’s heritage department approved the plan by its decision.

From the point of view of the realisation itself, the construction was quite successful. The contractor, company Metrostav, a. s., approached the construction very responsibly and carefully, with an effort to meet the requirements of heritage protection. The dismantling of the stone cladding and elements was carried out gently. Technological procedures and methods of anchoring original elements on new, reinforced concrete structures must have been searched for directly during the course of construction works and adapted to the actual reality. The addition of new stones was successful, both in terms of material and the way it was processed in order to adapt to the original design. In the end, it was possible to achieve a state when the bridge in its lower position is indistinguishable from its original appearance. It is also possible to compare it with the neighbouring bridge with a head before the lock chamber which has not been modified.

5.1.4 ZNOJMO-OBLEKOVICE, WEIR

A stone weir in Znojmo-Oblekovice (Fig. 5.5) is part of a set of weirs on the Dyje River which originally served for mill operation. The weir was constructed in 1928 and is one of the oldest in the Dyje River basin. It is located approximately 2 km downstream the Dyje River from the weir by the Louka monastery in Znojmo and it served as an impoundment structure for a race in Nesachleby (PMO, 2019a).

It is a fixed stone weir with a wooden beam structure 96 long. The weir body and the area downstream of the weir are formed by a rubble mound and the overflow surface is formed by flat stones. The weir sill is made of stone.

Fig. 5.5: Znojmo-Oblekovice – reconstruction of the weir in Oblekovice on the Dyje River: (A) foundation of a new weir heel, October 2018; (B) replacement of the weir body beam grid, November 2018; (C) original parts of the wooden beam structure; (D) reconstruction completed, January 2019. Photograph by Miriam Dzuráková, 2018, 2019.

Evaluation: One of the oldest weirs in the Dyje River basin. During the reconstruction the weir was heritage-protected, i.e., from 5. 7. 1989. On the basis of a judgement of the Supreme Administrative Court, case No. 5 As 157/2019 - 27 of 13/11/2020 (on so-called late entries), the weir is not a cultural monument any longer (Monument catalogue, 2021). However, thanks to appropriately selected materials and procedures during the reconstruction it was possible to preserve the heritage values of the weir, especially the authenticity of mass and form. So, the weir can fully perform its function for many more years.

Renovation and the impact on heritage values: The reconstruction of the weir body was carried out between September 2018 – January 2019. The repair consisted of the removal of the weir heel and foundation of a new one. The weir body was cleaned. The beam grid from the last overall repair of the weir in the 1970s was replaced with a new one, including the overflow edge beam and its anchoring. Stones in the overflow surface caverns and rubble mounds in the downstream area of the wear were also added (PMO, 2019a). Since it is a non-manipulable weir, all works were carried out at full flow, third by third.

5.1.5 RUDOLFOV, HYDRAULIC STRUCTURE AND HYDROELECTRIC POWER PLANT

The Rudolfov hydraulic structure was constructed in the valley of the Černá Nisa River between 1925 and 1929. The author of the technological project was Ludwig Hamburger, the construction part was designed by architect prof. Artur Payr. The extensive hydraulic structure (see Fig. 5.6) consists of: 1) SHPP I in a house No. 63 with a high-pressure turbomachinery; 2) surge tanks with an arch gravity dam made of granite blocks, 63 m long and 14.6 m in height, with a cascade, stilling basin, safety spillway 12 metres wide, controlled by flap gates with a concrete counterweight and structure of a medium-pressure small hydroelectric power plant II; 3) gravel obstruction for catching sediments in the Černá Nisa trough; 4) pressure pipeline 700 mm in diameter in the upper part, 675 mm in

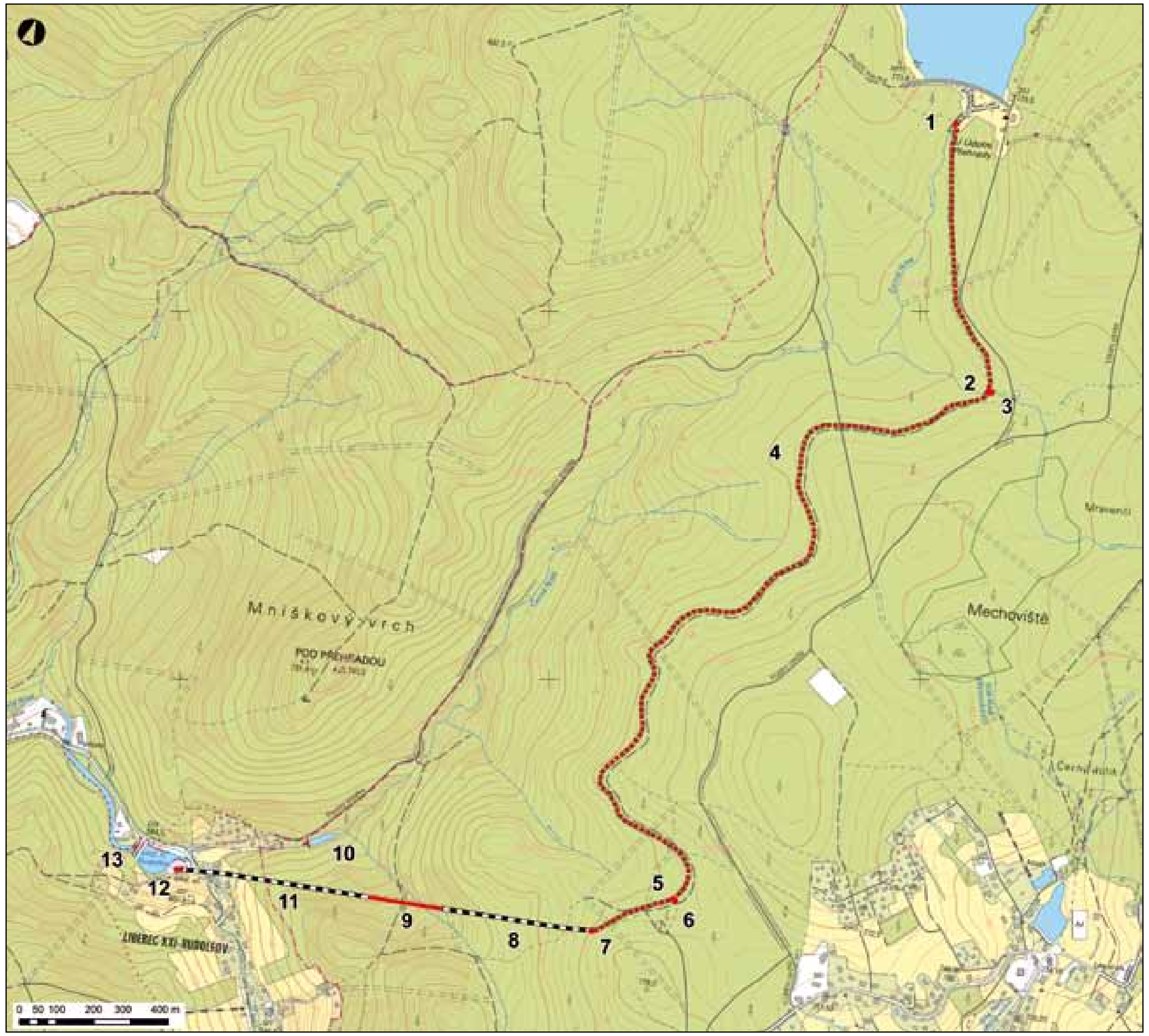


Fig. 5.6: Rudolfov – diagram of the hydraulic structures: 1 – small measuring weir and inflow conduit, 2 – 1. aqueduct, 3 – 1. tank,4 – underground conduit, 5 – 2. aqueduct, 6 – 2. tank, 7 – water cutoff, 8 – pressure pipeline, 9 – overground section on pillars, 10 – gravel obstruction with a cistern, 11 – pressure pipeline, 12 – peaking power plant, 13 – run-of-river power plant (modified according to: National Heritage Institute, Liberec branch, 2019).

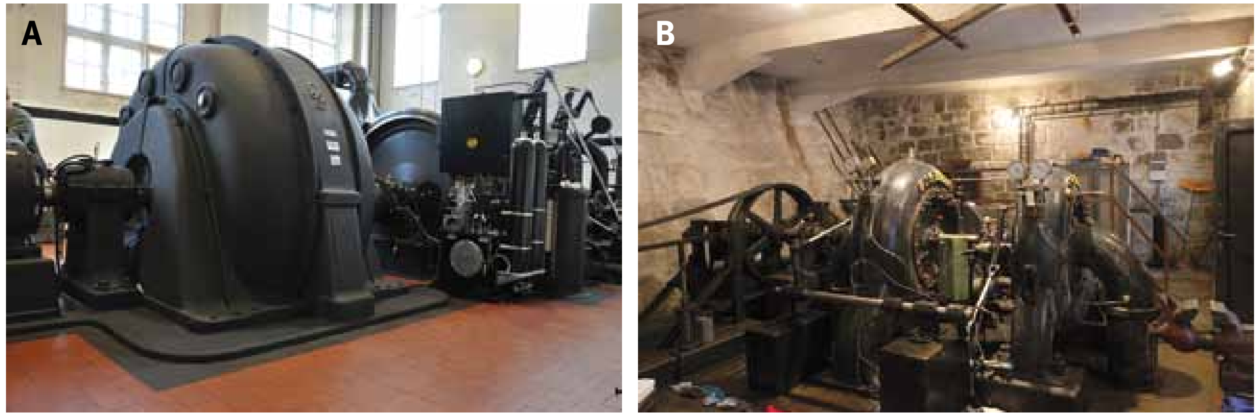


Fig. 5.7: Rudolfov SHPP – machine room interior: (A) Rudolfov I SHPP with the Pelton turbine; (B) Rudolfov II SHPP with the Francis turbine. Photograph by Petr Freiwillig, 2014 (A), 2013 (B).

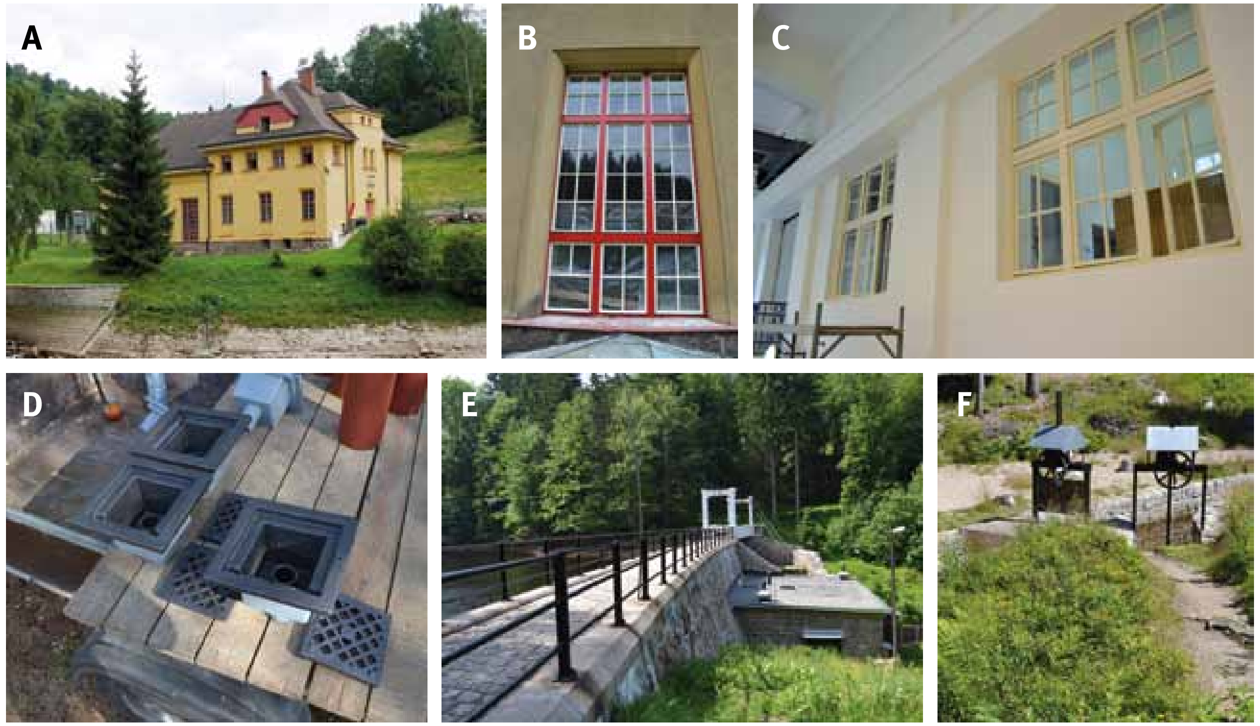


Fig. 5.8: Rudolfov – reconstruction of the hydraulic structure and power plant: (A) facade after renovation; (B) new simple exterior glass panels in the machine room with the facade before renovation; (C) interior glass and door panels were preserved in the original form and overhauled; (D) renovation of a non-functional system of a surge chamber dam with refurbishment and graphite painting of dewatering elements; (E) dam after the painting of railings with the SHPP II building had been completed (on the right); (F) renovation of all collecting structures on the conduit. Photograph by Petr Freiwillig, 2020.

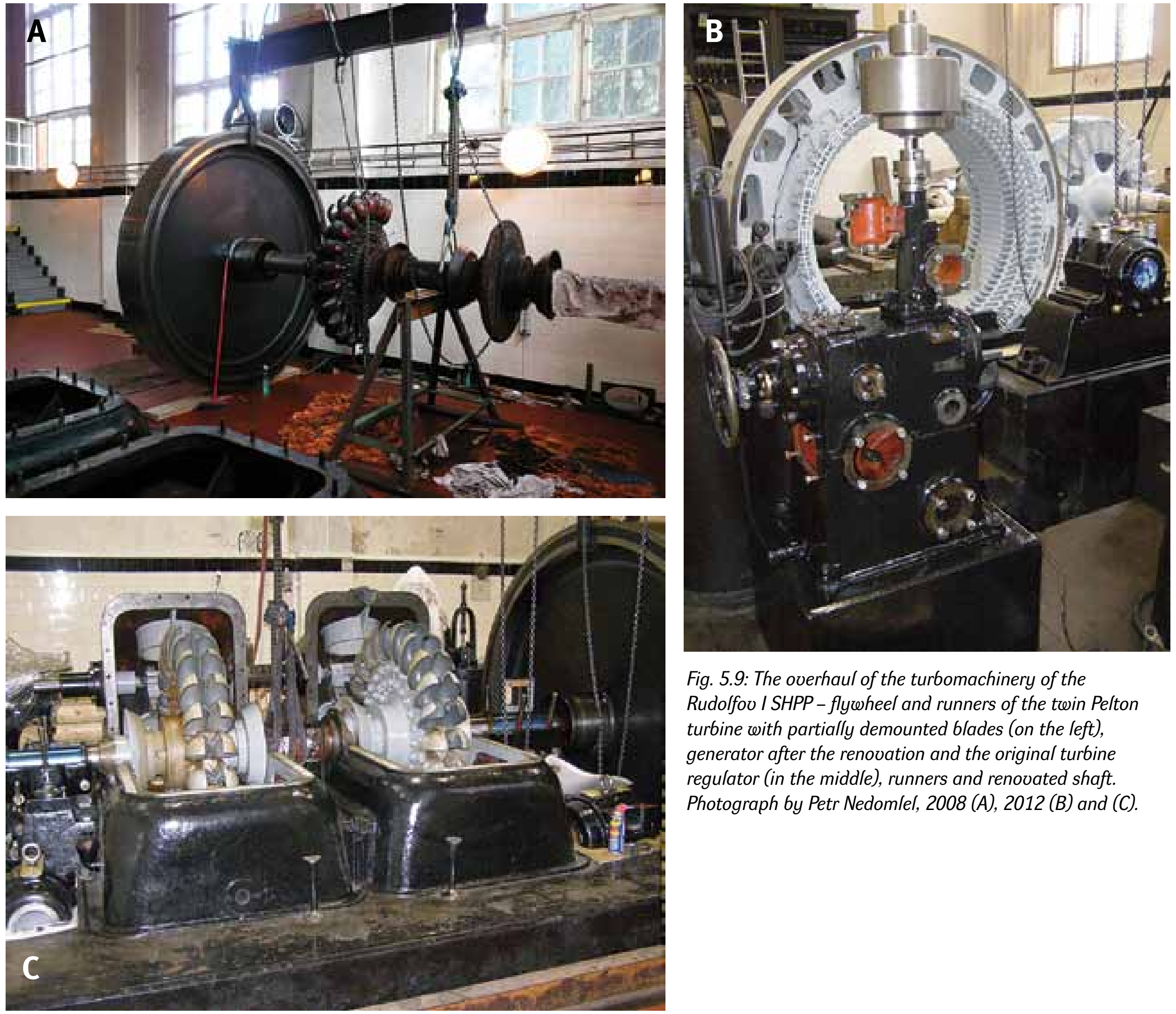


Fig. 5.9: The overhaul of the turbomachinery of the Rudolfov I SHPP – flywheel and runners of the twin Pelton turbine with partially demounted blades (on the left), generator after the renovation and the original turbine regulator (in the middle), runners and renovated shaft. Photograph by Petr Nedomlel, 2008 (A), 2012 (B) and (C).

the medium part and 650 mm in the lower part which is partially overground, led on concrete supports, close to the power plant it is positioned in a groove and filled; 5) surge chamber, desludging sluice, residual overflows and fine screens; 6) ca three-kilometre-long rectangular-profile conduit formed by a covered reinforced concrete canal, with tanks for catching sediments, with reinforced concrete aqueducts and collecting structures with sluice gates; 7) and measuring spillway and inlet intake structure with a scumboard, coarse screens, closing sluice gate and desludging sluice (Freiwillig, 2013).

The SHPP turbomachinery has been in operation since 1927. The Siemens Schuckert three-phase synchronous generator operates at rated revolutions of 500 rev/min, apparent power output of 1,200 kVA, voltage of 5,500 V and power factor cos φ 0.5 to 1.0. It is powered by the original twin horizontal Pelton turbine produced by J. M. Voith (Fig. 5.7 (A)). The hydraulic head is 171 m, absorption capacity 650 l/s, output 980 kW. The turbine operates at rated revolutions of 500 rev/min. Water supply to each runner is ensured by two nozzles. The regulation was originally supplemented by a braking nozzle acting against the direction of rotation of the turbine but this was removed in the 1950s. In the SHPP machine room there is the original and functional control panel with a marble board.

The power output from the SHPP is ensured via a switch room (22kV). The turbomachinery is handled by a gantry crane (Freiwillig, 2013).

The SHPP II machine room is adjacent to the downstream face of the surge tank dam. It is a simple structure from masonry without plaster, with reinforced concrete beam ceiling and mono-pitched roof. The horizontal twin spiral Francis turbine produced by J. M. Voith in 1927 (Fig. 5.7 (B)). The hydraulic head to the turbine is 8.5 m, absorption capacity 466 l/s and 234 l/s. The original Siemens asynchronous generator with the output of 50 kW was in 1993 replaced by an ELIN synchronous generator with the voltage of 380 V and output of 58 kW, with power transmission from the turbine driven by belt.

The structure of the SHPP I No. 63 is built as a traditionalistic brick building of a rectangular ground plan with the dimensions of 26 × 14 m. Vertical structures are made from bricks with reinforced concrete beam ceilings.

Evaluation: One of the most important values of the cultural monument (heritage protected since 1. 7. 2014, Monument catalogue, 2021) is the value of technological flow (completely preserved complex of two power plants and the associated hydraulic structure), technical value of individual facilities, value of authenticity (function, mass and preserved equipment) and the architectural value.

Renovation and the impact on heritage values: The Rudolfov hydraulic structure was overhauled between 2018 and 2020 (Fig. 5.8). It included the renovation of the facade, replacement of sheet covering, glass and door panels, interior renovation, hydroisolation and repavement of the surge tank dam crest, paint renovation, reprofiling and painting of the reinforced concrete structure of the automatic counter-weight shutter on the dam, roof covering and sheet covering of the Rudolfov II SHPP – under the dam, renovation of the fountain, renovation of the underground conduit including new optic cables, repair of all collecting structures with sluice gates on the conduit. The reconstruction did not include replacement of the SHPP I roof covering which had been carried out shortly before the structure was declared a cultural monument in 2014 (Fig. 5.9). Between 2012 and 2013 the high-pressure turbomachinery of the SHPP I was overhauled. The repair of the SHPP II is getting ready.

The too brief project documentation did not address a number of details which had to be dealt with during the construction itself. In spite of that the reconstruction can be considered as successful. Most of the problems were overcome in cooperation with the contractor (Labská strojní a stavební společnost Pardubice, s. r. o.)., investor (Povodí Labe, s. p.) and the National Heritage Institute.

5.1.6 ŽĎÁRSKÝ POTOK, SPLASH DAM ON SPLAVSKÝ BROOK

The splash dam is located in the Hrubý Jeseník mountain range in the valley of Splavský Brook, ca 5 km northwest from the village of Žďárský Potok. The reservoir was constructed probably at the end of the 19th century even though plans for its construction are older (Fig. 5.10). In the middle of the stone dam from timber-framed masonry there is a flow section 2.5 m wide formed partially by a sluice wall. There is a slickenside from boulders and concrete under the dam. At the top of the dam there is random rubble pavement with concrete tuckpointing. Above the flow section there is a wooden bench. At the maximum level of water surface the submerged area is 385 m^2 and capacity 665 m^3.

Evaluation: It is a remnant of a whole system of reservoirs and modified river beds which were used for timber navigation from logging sites to processing sites (in this case to the sawmill in Stará Ves at the confluence of the Podolský and Stříbrný Brooks), as historical evidence of the economic activities in the area. It had been characterised by a great degree of the authenticity of mass.

Renovation and the impact on heritage values: In 2014, the renovation of the reservoir was carried out, whose investor was Lesy ČR, s.p. The renovation consisted in the extraction of sediments from the retention area, removal of vegetation from the downstream side and crest of the dam, and repair of the dilapidated dam body (Fig. 5.11). The foundation of the upstream side of the dam was after the extraction of sediments covered with concrete and reinforced with a slope protection net. The dam crest was lowered by about 40 cm along its entire length. In the flow section in the middle of the dam there was a reinforced concrete core made, which was strengthened with

Fig. 5.10: Rudolf Rieger's diagram from 1863 with the original splash dam on Splavský Brook (taken from: SZA, Olomouc branch).

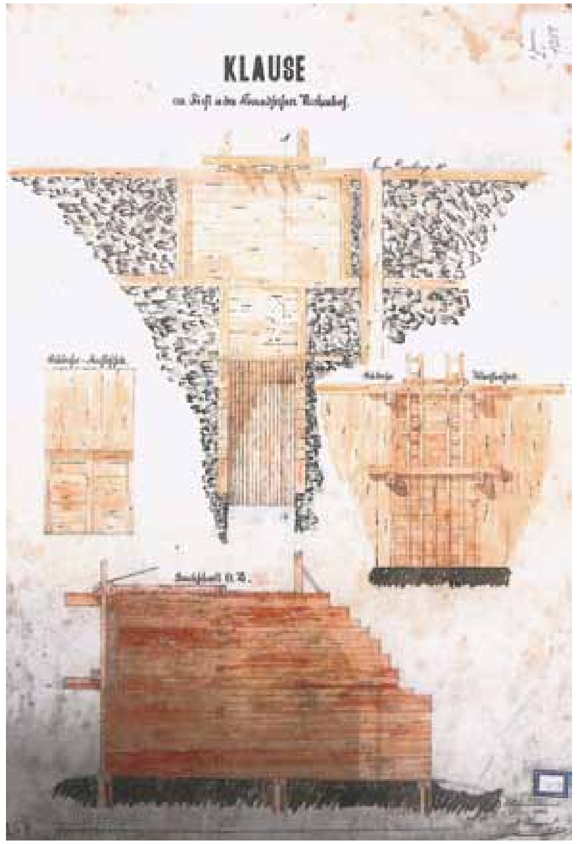


Fig. 5.11: Žďárský Potok, renewal of the splash dam on Splavský Brook: (A) remnants of the original dam; (B) repaired dam from the upstream side; (C) middle part of the dam with the flow section; (D) overall view of the dam from the downstream side; (E) original outlet piping. Photograph (A) and (B) taken from: Rymarovsko, 2021; (C), (D) and (E) by Martin Caletka, 2021.

reinforcing steel and faced with random rubble with tuckpointing and a sluice wall on both sides. The upstream side of the dam was cleaned, mortar joints were taken out and repointed. Missing stones were added. Impregnated beams were added to the existing pockets in the timber-framed masonry on both sides of the dam. On the downstream side under the flow section there was a 6.6-metre-long slickenside made from random rubble. The terrain on the downstream side was filled and sloped up to the upper edge of the dam.

5.1.7 BLATNÁ WATER DITCH

The Blatná Water Ditch, or "Priviledged Blatná hereditary water ditch in the area of the town of Horní Blatná" (Anderle et al. 2015) is an extensive hydraulic structure with a slightly variable function operated in the long term and more or less continuously. Its original main function was water transport for energy (e.g., mine pumps or stamp mills drive) and technological (especially water for the separation of ore fractions during the navigation in stamp mills) purposes for mining and processing plants in Horní Blatná and surroundings. The extent of use for similar plants in the area between Boží Dar and Ryžovna is uncertain although we know from written resources – especially disputes over water – and from the existence of sections of parallel ditches at Bludná that there were efforts to use the water of the Blatná Canal even before it reached Blatná itself. Later, the canal had a similar function although

Fig. 5.12: Blatná Water Ditch – damaged sections of the water ditch: (A) affected by erosion and washing out; (B) endangered and damaged by woody plants in the proximity of the race trough. Photograph by Miloš Rozkošný, 2020.

Fig. 5.13: Blatná Water Ditch: (A) forest part of the watercourse, state before reconstruction; (B) historic boundary mark on the border of the watercourse plot; (C) trough after the removal of worn out timbering; (D) ramming of the trough new timbering; (E) Blatná Water Ditch near Kozí Sejfy just above Horní Blatná, example of neatened bank armouring uncovered by the construction; (F) water ditch near Kozí Sejfy above Horní Blatná, example of sedimentation profile (the oldest one?) of the river bed uncovered by the construction. Layers of carbons and the absence of clay insulation are evident at the bed sitting on yellow coarse stone material. Layers of alluvial sand are also well distinguishable. Photograph (A) – (D) by Jakub Chaloupka, (E) and (F) by Ondřej Malina, 2021.

the purpose was not connected with mining anymore but rather with common technological operation of early industrial plants.

It was very likely founded in connection with the location of Horní Blatná whose shortage of technological and energetic water must have been evident as early as it was founded in 1532. It has been documented that the construction of the canal dates back probably to the 1540s.

Together with nearby Boží Dar, established at the same time, Horní Blatná has a clear operational link to the existence of the canal. Water which served some of the mining and processing plants of the town of Boží Dar was, after having the work done, conducted from the Černá River to the Blatná Water Ditch so that it can serve Horní Blatná. Based on the extent of the surviving ditches, it seems that the system connected to the Blatná Water Ditch was quite extensive and part of its catchment area extended to the right bank of the Černá River up to the Saxon border.

Evaluation: The heritage value stems in the case of the Blatná Water Ditch first of all from its operational continuity with a clearly documented beginning in the 16th century. On the other hand, the operation continuity has resulted in repeated reconstructions, so a large number of structures are already younger, especially from an extensive reconstruction from 1926–1928. Nevertheless, during the present reconstruction, it turns out that a lot of structures or substructures have been preserved from the 18th century. Older structures have not been proved so far.

The uniqueness of the Blatná Water Ditch resides in its extent and operational link to two established Renaissance mining towns of Horní Blatná and Boží Dar. With its long-operating length of 13 km, it is an excellent example of technological ingenuity, but also of foresight in the context of sustainable land use which has survived even the decline of mining. It is also one of the most significant examples of the colonisation landscape of the early 16th century, showing the interconnection of the mining industry, mining towns with a strong commercial and economic component, as well as architectural and artistic works.

Thanks to its long-term continuity, the entire ditch is accompanied by a numerous set of boundary markers of various ages, which undoubtedly contributes to the historical and thus monumental value of the work.

Renovation and the impact on heritage values: The subject of the reconstruction is the renovation of the water management function of the structure – limitation of uncontrolled water flow and sedimentation and also discharge of acid water from the Boží Dar peat bog outside the water reservoir for drinking water of Myslivna on the Černá River. Another goal is the renovation of controlled water flow which is an integral part of the operation essence of the whole monument.

Twenty years ago the structure underwent an overall reconstruction along almost the entire length of the stream. At that time, the technical condition of the structure corresponded to the absence of sufficient maintenance during the second half of the 20th century. The ongoing reconstruction is extensive and it mainly consists in replacing aged wooden structures and repairing stone structures. All wooden structures are new, from the last large reconstruction, in the case of stone structures they mostly represent the result of the last reconstruction from the 1920s. The aim of the current reconstruction is to maintain the function of the works in its current route and form. At the same time, research and documentation of situations revealed during the construction take place which helps deepen the knowledge. Therefore, the reconstruction should not have a negative impact on heritage values of the works.

The goal of reconstructions is to maintain the authenticity of function and form. The authenticity of material has not been maintained, wooden structures and stone elements come from the reconstructions of a race in the 1920s and at the end of the 20th century.

From the point of view of water management, it is necessary to point out several processes which can influence the works in the future. The renewed trough is damaged by water erosion and washing out at some places (see Fig. 5.12). In this case a continuous maintenance consisting in filling missing aggregates and repair of pale fences would be desirable. Much more serious is the damage caused by leaving the forest cover to nature-based management, probably for nature protection reasons, with woody plants in the immediate vicinity of the river bed eroding the banks over time, which leads to disruptions in the transverse profile. Tree uprooting has also been observed which has a devastating impact on the river bed (see Fig. 5.12). The danger lies in the fact that water can find a new route in these locations and the historical course of the canal can thus be disrupted. A measure to deal with this problem would be a continuous maintenance of the river bed and use of a bank line as another route.

5.2 OPTIONS FOR MAINTAINING WATER MANAGEMENT STRUCTURES AFTER DECOMMISSIONING – CONVERSION, MUSEALISATION

5.2.1 RJUKAN (NORWAY), VEMORK AND SÅHEIM HYDRAULIC POWER PLANTS

The Vemork power plant (Fig. 5.14) was constructed under the Rjukanfoss waterfall and put into operation in 1911. It was equipped with ten Pelton turbines, each reaching a power of 500 HP (at that time it was the largest power plant in the world). The remaining part of the hydraulic head was used by the Såheim power plant, located further downstream, which was put into operation in 1915 with nine turbines with generators with the overall power of 167,000 HP, thus surpassing the Vemork power plant's world leadership. Moreover, one machine set was installed inside an artificially made cave situated on the slope above the power plant, designed as a water storage tank for the power plant, which represented a very early example of such a solution at the time.

The Såheim power plant (Fig. 5.14) constructed by the company Norsk Hydro, and its production was intended directly for a chemical factory producing artificial fertilisers. The Birkeland/Eyde electric furnaces for nitrogen extraction were positioned directly on the upper floor of the monumental building.

Both power plants have obtained heritage protection at a national level between 2003 and 2011 and in 2015 the whole complex was inscribed on the World Heritage List. Apart from both power plants and associated hydraulic structures (tunnels, dams, etc.), it also includes transport systems (for the transport of the local production by railway and water) and social infrastructure (for more detail see Taugbøl, 2016).

Both power plants still serve the generation of electric power. The Vemork power plant is now a museum with well-preserved original equipment; new technology was put into the mountain massif. The Såheim power plant has been modernised: out of the original equipment one machine set made by the company Oerlikon and one by Asea have been preserved. In the cave above the power plant there is another preserved machine set which is no longer in operation. Nowadays, the production is ensured by three modern Francis turbines. The electric furnace hall was adapted to a gymnasium.

The high rating reflects several aspects: high degree of authenticity of mass, form, technical equipment and function; high degree of technical and typological value, which includes the parametric leadership achieved by both plants at the time; integration in functional complexes and system links; and, of course, traditional architectural and urban values.

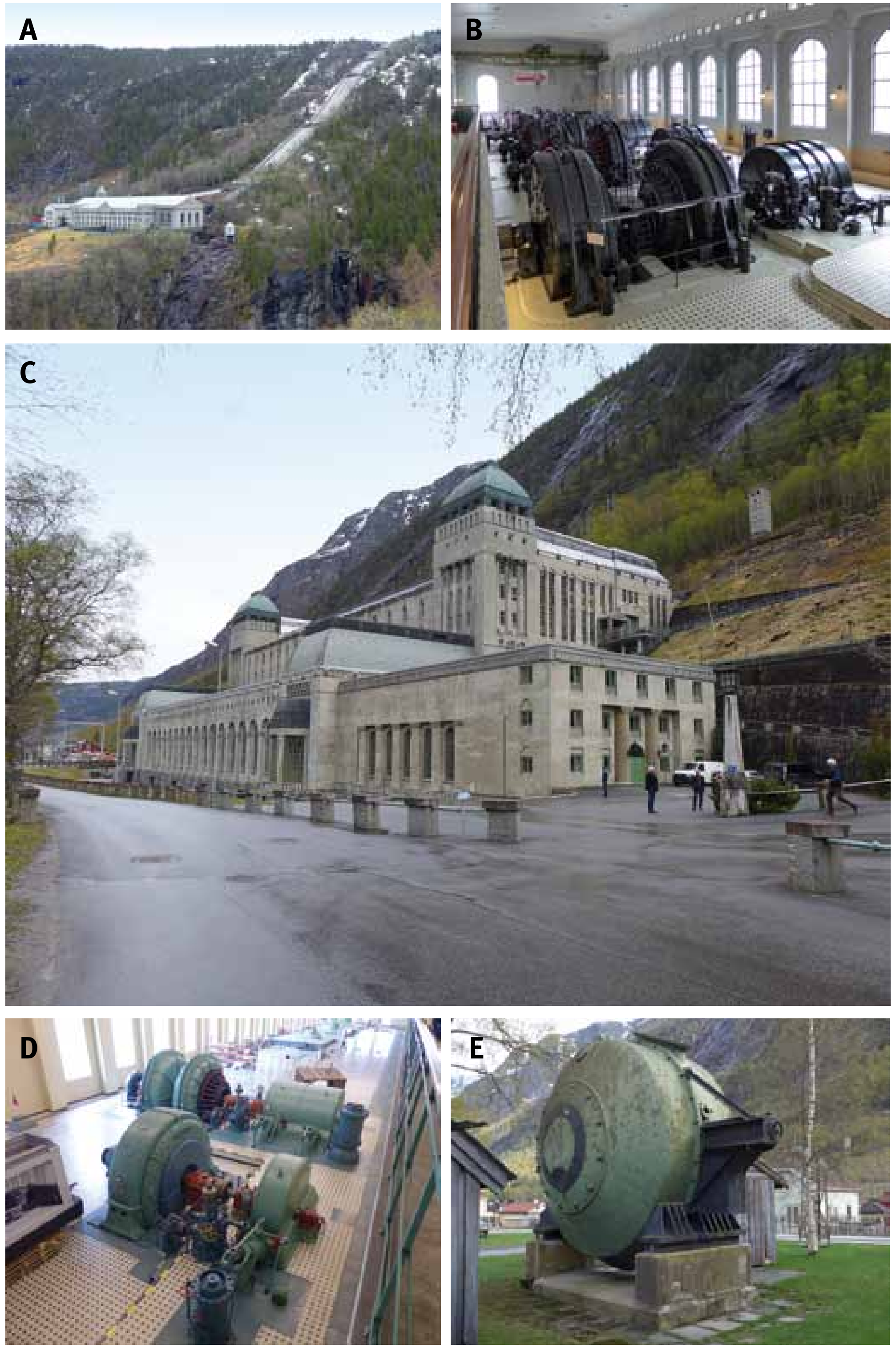


Fig. 5.14: Rjukan (Norway): (A) and (B) Vemork hydroelectric power plant; (C) and (D) Såheim hydroelectric power plant; (E) Birkeland/Eyde electric furnace. Photograph by Michaela Ryšková, 2015.

5.2.2 BERLIN (GERMANY), FRIEDRICHSHAGEN OLD WATER TREATMENT PLANT (ALTES WASSERWERK FRIEDRICHSHAGEN)

The ater treatment plant on the shore of the Müggelsee lake (Fig. 5.15) was built to supply water to Berlin in 1889–1899. The project was designed by the English engineer Henry Gill, like the older two waterworks Stralauer Tor and Tegeler See. Part of the design was the pumping station by Müggelsee and also a temporary pumping station in Lichtenberg. The construction was carried out in several phases on the area of 7,000 m^2. The architectural design in neo-Gothic style was, after Henry Gill's death, finished by the Berlin architect and constructor Richard Schultz. The system was put into operation in 1893 with a daily production of 86,400 m^3. It was the biggest and most modern system in Europe at that time. In 1895 the construction of the first six filters and a tank for cleaned water was completed. The whole system was completed in 1899 when six steam machine rooms were in operation here to power pumps. Water was pumped from the Müggelsee Lake, in 1898 two wells were added and in 1904–1909 the operation gradually switched to groundwater captation by means of 350 bores. In the 1920s the operation was modernised with a partial transition to electric power and the daily capacity increased to 320,000 m^3 of treated water. In the 1950s, the steam operation completely ceased and slow filters were also cancelled. Due to the low-quality of the lake water, since the 1960s only groundwater has been used. The overall modernisation of the water treatment plant took place in 1979–1981 and 1983 when new halls, filtration stations, etc. were built. The operation was transferred to a new plant, which was further extended in the 1990s. (Das Wasserwerk Friedrichshagen)

Fig. 5.15: Berlin (Germany) – Friedrichshagen old water treatment plant: (A) steam engine room of a pumping station from 1893, whose operation stopped in 1979; (B) boiler room; (C) chimney; (D) machine room. Photograph by Michaela Ryšková, 2019.

In the disused area, there was a museum founded in 1987, which specialised in the history of water supply and the sewerage system in Berlin. It is situated in an old steam machine room and in adjacent buildings. The boiler room equipment was removed but the building has been preserved. Apart from the museum exhibition, the museum tour also includes a steam engine room with simulated operation and a tour of a well structure from 1904–1909.The picturesque complex on the shore of the lake has become a venue for cultural and social events. Former filtration buildings have been rebuilt to serve other functions.

The Friedrichshagen former water treatment plant is an example of a symbiosis of a modern operation with a historical environment. New operations were built in the vicinity of original operations and the latter were preserved and used for new functions. Museum expositions, supported by an authentic environment and steam engine room with a simulated operation is a good example of the coexistence of functional operation, valuable industrial heritage and education.

Fig. 5.15: Berlin (Germany) – Friedrichshagen old water treatment plant: (E) and (F) collecting well; (G) former water treatment plant; (H) museum exposition – wooden well from the 14th century discovered during the archaeological research carried out in 1987; (I) wooden water pipes. Photograph by Michaela Ryšková, 2019.

Fig. 5.16: Malnisio di Montereale Valcellina (Italy): Antonio Pitter hydroelectric power plant. Photograph by Michaela Ryšková, 2016.

5.2.3 MALNISIO DI MONTEREALE VALCELLINA (ITALY), ANTONIO PITTER HYDROELECTRIC POWER PLANT (MUSEO DELLA CENTRALE IDROELETTRICA DI MALNISIO)

The Antonio Pitter hydroelectric power plant (Fig. 5.16) is one of the first large hydroelectric power plants in Italy, constructed in the valley of the Cellina River at the foothills of the Alps in 1900–1905. Water supply to the power plant was enabled by damming up the Cellina River and the water from the reservoir to the power plant was led by a long channel with bridges and tunnels. The system, whose author was Aristide Zenari, also included two other power plants located farther downstream, which were put into operation in 1919. The power plant was equipped with four Francis turbines by the company Riva-Monneret with Tecnomasio Italiano Brown-Boveri alternators with the output of 2,600 HP. It has been named after engineer Antonio Pitter who designed the electro-mechanical part. The complex of three power plants supplied energy to Venice and to the Veneto and Firuli Venezia Giulia regions.

The power plant was never modernised and was in operation until 1988. After being decommissioned, it was reconstructed and since 2006 it has been accessible to the public (Museo, 2021).

5.2.4 WROCŁAW (POLAND), NA GROBLI WATER TREATMENT PLANT

The first waterworks systems in Wrocław were founded in the second half of the 13th and at the beginning of the 14th centuries. In 1387, there was a water wheel for pumping water in operation (it is said to be the oldest system in Eastern Europe). In the first half of the 19th century, in connection with the rapid development of the city, a complex water supply was realised. In 1864, a decision was made regarding the realisation of a project by English engineer James Moore, modified by urban architect Johann Christian Zimmermann. Between 1866–1871, there was one of the most modern waterworks of the time constructed on the confluence of the Oder and Olawa Rivers. River water was cleaned in sand filters, pumped into an elevated water tank and from there distributed to the network. In 1904, groundwater started to be used more often and river water was used only in emergency situations.

The complex is formed by a large water tower of a square ground plan (with tanks of the volume of 4,150 m^3), steam engine room and boiler room with two boilers, chimney, workshops and filtration station (Fig. 5.17). The operation was ensured by two steam engines made by the local company Woolf-Ruffler in 1879 and two pumps. In 1924, the drive was replaced with steam turbines, which were in operation till the 1860s. Apart from steam engines and a steam turbine, pumps from the turn of the 19th and 20th centuries and overhead cranes have also been preserved (Szlaki kulturowe, 2019).

The steam pumping station with the elevated water tank was closed and is being rebuilt to a museum. In the neighbouring ground tank for cleaned water with the volume of 4,000 m^3, which was used till 2011, an educational centre, Hydropolis, was opened in 2015. Its aim is to provide information about water on the Earth and its importance, and about water engineering (Klimek, 2018). Although the exterior of the water tank has been renewed with

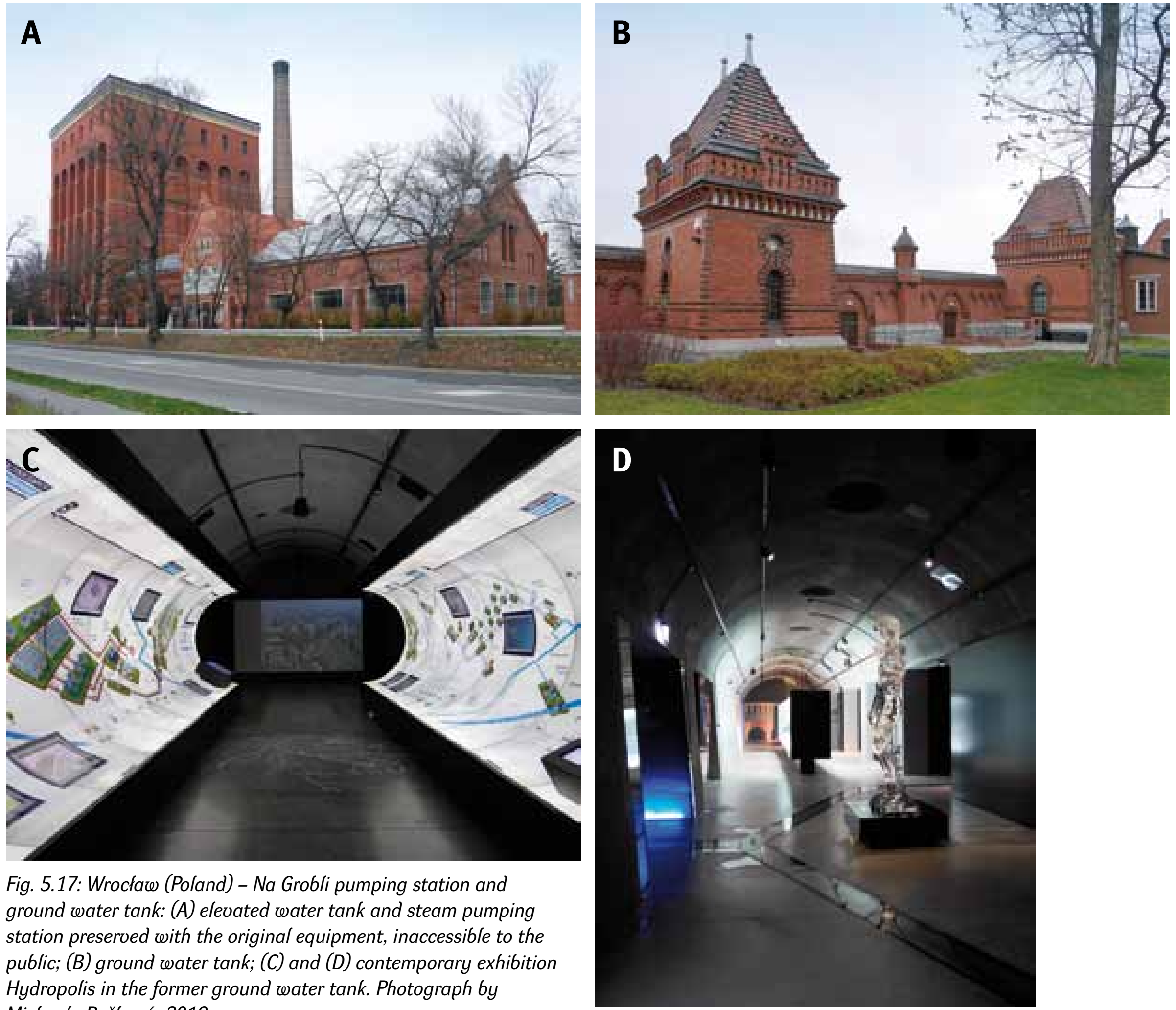


Fig. 5.17: Wrocław (Poland) – Na Grobli pumping station and ground water tank: (A) elevated water tank and steam pumping station preserved with the original equipment, inaccessible to the public; (B) ground water tank; (C) and (D) contemporary exhibition Hydropolis in the former ground water tank. Photograph by Michaela Ryšková, 2019.

the aim of rehabilitating the original architecture and its quality, in the interior the original structure and function of the building has been completely suppressed. The character of the environment has been completely obscured by the built-in mobile screens and the installation of attractions of a multimedia exhibition.

Although the built-in exposition is removable, the decisive aspect of the evaluation is the complete obstruction of the original environment, its uniqueness and genius loci for the creation of an interchangeable exposition.

5.2.5 COPENHAGEN (DENMARK), GROUND WATER TANKS AND A PUMPING STATION

Ground water tanks (so-called Cisternerne) and a pumping station (Pumpehuset) in Copenhagen were built in 1856–1859 as part of the system which was to improve the quality and increase the volume of drinking water supply to the rapidly developing city of Copenhagen. Until then, water had been conducted into the city through wooden canals from lakes north of Copenhagen. However, the quality of untreated surface water was deteriorating, which was evident in the increasing incidence of epidemic diseases, such as cholera in 1853 (Nielsen et al., 1909). In the same year, a project of a modern system of water supply was approved with sand filters, steam pumps and cast-iron canals using water from the surrounding lakes. The project was planned by Danish engineer Ludwig A. Colding and British expert on hydraulic structures James Simpson was asked to check it and supervise the construction. The original project was so well prepared that Simpson contributed only a few insignificant changes to it (Nielsen et al., 1909).

The city water supply was based on the transfer of water from the Damhussøen Lake located on the western edge of Copenhagen to the St. Jørgen Sø Lake in a broader centre of the city through the artificial Ladegård Canal. From here the water was pumped through a pumping station in Vesterport to ground water tanks in Søndermarken (near the Frederiksberg Palace). In spite of their names (Sø – lake), both water areas are artificially made reservoirs. Damhussøen was constructed as early as the Middle Ages and from 1618 it played an important role in supplying water to Copenhagen (Nielsen et al., 1909). Since 1893, when quality water-bearing layers of limestone bedrock of the eastern part of Sjælland were discovered, Copenhagen has been supplied solely by underground water (Nørregård et al., 1959).

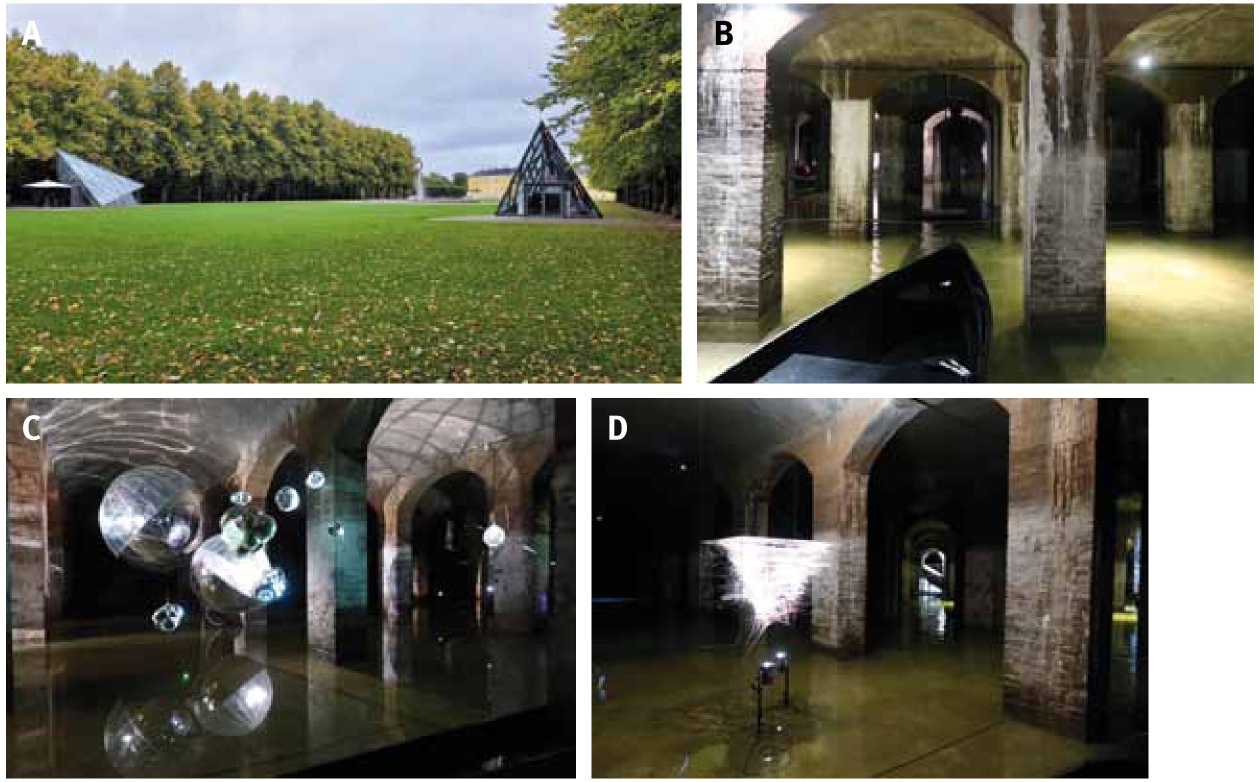


Fig. 5.18: Copenhagen (Denmark) – ground water tanks (Cisternerne) in Copenhagen: (A) glass pyramids in the Søndermarken park as an entrance into underground area; (B) underground area of water tanks; (C) and (D) multimedia exhibition "Event Horizon" by the Argentinian artist Tomás Saraceno. Photograph by Miriam Dzuráková, Viera Dedíková, 2021.

Fig. 5.19: Copenhagen (Denmark) – pumping station (Pumpehuset): (A) former machine room building, today a venue for concerts; (B) water inspector's former residence, today kindergarten premises. Photograph by Viera Dedíková, 2021.

Ground water tanks are located on the Frederiksberg hill, 31 metres above sea level (the highest point of Copenhagen), from where they have provided clean drinking water gravitationally to new multi-storey buildings in Copenhagen, which was essential for the development of the modern city. At the beginning, the water tanks were open and formed a spectacular water surface in front of the Frederiksberg Palace. However, in 1891 they were covered with a concrete structure to prevent the risk of contamination and infection (Nørregård et al., 1959). At the same time, a lawn with a central fountain was created, which is part of the park in Søndermarken till today (Fig. 5.18 (A)).

The inner space of water tanks is divided into three interconnected rooms of the same size, 150 m long in total. Walls are formed by thick granite blocks, pillars supporting the ceiling are bricked, floor and ceiling are concrete (Fig. 5.18 (B)). The ceiling is 4.2 m high and at the maximum depth of water of 3.7 m the rooms could contain about 16 million litres of water (Nørregård et al., 1959).

The water tanks ceased to serve their function in 1933 and in 1981 they were completely emptied. Within the European Capital of Culture initiative, local enthusiasts started to use the area of the water tanks for various cultural events in 1996 (HistoriskAtlas, 2021). In 2001, the area of the water tanks became the Museum of Modern Glass Art and at that time the two glass pyramids were created (Fig. 5.18 (A)), serving as an entrance into the underground area.

In 2013, the Frederiksbergmuseerne institution started to manage the water tanks and opened them for exhibitions and multimedia installations, which use and support specific conditions, character, acoustics and climate of these underground structures and interact with their architecture, atmosphere and history (Fig. 5.18 (C–D)). Projects of addressed artists or architects are always designed specifically for a given location.

The pumping station (Pumpehuset) in the Copenhagen quarter Vesterport (between Axeltorv and H. C. Andersens Boulevard) was at the time of the opening in 1859 the first Danish pumping station. It was operational till 1951 (Nørregård et al., 1959). The complex of buildings included a central two-storey machine room (Fig. 5.19 (A)) connected with a one-storey boiler room, coal warehouse, administrative premises but also flats for employees and the inspector's residence. All buildings of the complex are built from yellow bricks with camber windows (the Danish royal family's colours were used in the construction, i.e. red and yellow) according to N. S. Nebelong's design.

The complex underwent the first complete reconstruction in 1987 (another in 2011) and the machine room building became a venue for various music events (Pumpehuset, 2021). Administrative buildings and the inspector's residence are used as a kindergarten (Fig. 5.19 (B)). So, the whole complex has a new valuable use, while the authenticity of form and mass has been preserved as much as possible during the reconstruction. The inner technological equipment has not been preserved, with the exception of the former machine room (today a music hall), where there is a torso of an old crane at the end of the hall, according to which the hall is also named (Kransalen). In 2007, the complex was declared an industrial heritage monument and in 2010 it was included in the list of monuments (HistoriskAtlas, 2021).

5.2.6 PLZEŇ, WATER TREATMENT PLANT, PUECH-CHABAL FILTRATION STATION

The city industrial development, connected with the increasing number of inhabitants, encouraged in the 1880s the municipal authorities to build a new waterworks (Fig. 5.20) to supply sufficient amount of drinking water for Plzeň. It was put into operation in 1889 and was fully completed in the following year. It included a pumping station (with steam machine room) which pumped water from the Úhlava River, water treatment plant with four settling tanks and a filtration station with four English filters) and bricked ground water tank on the Homolka hill (with the volume of 6,500 m^3). In 1904–1906 the settling tanks were replaced by slow filters in order to increase the capacity. However, the water quality was problematic. Therefore as early as 1908, the construction of a filtration station of the Puech-Chabal system was negotiated with the Paris company Puech-Chabal. The proposal was implemented in 1924–1926. The filtration station with the total area of 5,000 m^2 was equipped with three stages of roughing filter with so called upper washing, i.e. washing impurities off the surface (with gravel filling of graded roughness and washing by means of pressure air and water) and one layer of pre-filters (with sand filling and washing by means of pressure air and pressure water). The author of the architectural design was Plzeň architect Hanuš Zápal, the construction including reinforced concrete tanks was carried out by the Prague company Müler a Kapsa. The building has the shape of a cascaded triple hall (taking advantage of the sloping terrain), covered by segmental roofs with a steel structure, manufactured by Škoda Works. The filtration process was completed by older slow filters. In 1933, coagulation and chlorination processes were added to increase the water quality.

The water treatment plant under the Homolka hill was continuously modernised. In the 1960s, a new chemical water treatment plant was constructed. The Puech-Chabal filtration was decommissioned in 1997 after it had been replaced with modern technology constructed in 1986–1996 (Jásek, 2000; Domanický, 2003; Beran a Valchářová, 2013).

Its values lie mainly at a technological level (one of the three realisations of the Puech-Chabal system in the Czech Republic, preserved in an authentic condition) and on the level of authenticity (of material and form), in terms of both the Puech-Chabal filtration technology (patented in 1907–1910) and the building itself (including a number of original structures and details – paving, tiling, mosaics).

In spite of that it is not heritage protected.

After decommissioning, an alternative use was sought. In 2001–2002, it was negotiated about a possible location of a museum of historic vehicles, variants of this solution were dealt with in student works of prof. Šenberger's atelier at the Czech Technical University. The intention was abandoned for technical reasons. The building of the filtration station was finally let out and used as fish storage tanks without any major adjustments. Gravel and sand were extracted from some pools with regard to individual species of kept fish. The original piping was used for the central distribution of air without disrupting the image. Due to inadequate wiring, new wiring is gradually being built. It was necessary to create an operational corner (stainless steel tables, boiler, introduction of drinking water, etc. in accordance with regulations and requirements of the Regional Veterinary Administration). Water management (abstraction and discharge) is a relatively big problem because it is a non-standard solution which is not precisely defined in the Water Act and there is a conflict of several possible interpretations.

Fig. 5.20: Plzeň – the Puech-Chabal filtration building: (A) main entrance and the highest situated north-eastern hall; (B) the lowest situated south--western hall; (C) – (E) documentation from the course of cleaning of individual tanks; (F) and (G) overall views during current operation. Photograph (C) and (D) by Jan Mikač, 2015, (A), (B), (E) – (G) by Michaela Ryšková, 2020.

The use of the building, which is by its cascading arrangement and system of built-in tanks closely linked to the water treatment technology for fish storage tanks, is an example of a conversion that is based on structural characteristics and capacity possibilities and does not require drastic interventions, removal of the original technology or expansion. It is a “soft option” approach.

The building’s condition is not ideal – it was awaiting a new use for almost twenty years and the maintenance was underfunded. The building is leaking, some parts of the roof are infected with wood-decay fungus. It is necessary to count on a restoration, whose impact on the heritage values may be more significant than the current use.

5.2.7 PRAGUE-LETNÁ, ELEVATED WATER TANK

Water supply to the capital of Prague at the end of the 19th century was ensured by a number of waterworks complexes using mainly water from the Vltava River. The City Council was trying to bring about a comprehensive change in the water supply to the suburban municipalities gradually joining Prague since 1873. The reconstruction of the Nové Mlýny waterworks in 1878 enabled, in association with the construction of the Chain Bridge of Franz Joseph, to conduct water to lower parts of Holešovice on the left bank of the Vltava River, which joined Prague in 1884. For upper parts of Holešovice and Bubeneč there was a waterworks complex in Letná built, which served to supply non-potable water. A separate small water tank of the municipality of Bubeneč supplied drinking water to public water pillar fountains only.

The original complex consisted of the elevated water tank itself (Fig. 5.21), a pumping station and a ground water tank. The construction was completed in 1888 by the company of Karel Hübschmann and František Schlaffer to the order of the Prague Municipality according to the project of architect Jindřich Fialka. The construction of the ground meander water tank with a capacity of 3,059 m^2 was carried out by František Kindl. The pumping station, whose construction was completed at the same time as the construction of the elevated water tank, was equipped with the technology of the company Breitfeld-Daněk a spol. In the proximity of the pumping station there was a residential house for the staff built. The station supplied water not only to the adjacent elevated water tank but also pumped water into a water tank in Petřín and also supplied water directly into the waterworks network for Letná and Hradčany. The six-storey elevated water tank with a facade made in the High Neo-Renaissance style with high quality arts and crafts components, accentuated on the fifth floor by a peristyle with an ornate arcade, had a ringed cylindrical tank with the capacity of 197 m^2 on the top floor. There was an inner pipe going through the centre of the tank, used for conveying exhaust gases from the boiler room of the steam engine. The complex is complemented by a preserved cast-iron fence and a cast-iron water pillar fountain, originally located in Na Slupi street in the New Town. The elevated water tank served its purpose only until 1913 when it was decommissioned due to worn out technology. Subsequently, the structure was used as flats for employees of the waterworks and from 1976 as the Centre for children and young people. The underground water tank, which was demolished in the 1970s, was in operation until 1926. In 1992, the elevated water tank was declared a cultural monument. (Jásek, 1997; Jásek a Drnek, 2020; Kohout a Vančura, 1986; Hlušičková, 2003)

The elevated water tank, which has retained its external appearance almost unchanged, can be considered (together with the Vinohrady waterworks) as one of the two representatives of distinctive neo-Renaissance waterworks buildings in the territory of the capital in terms of architectural evaluation. The historical value in relation to the water supply of the city and surrounding villages at the end of the 19th century is unquestionable. Although out of the technological equipment there have been preserved only fragments of vertical pipes, the inner portion of a chimney and an imprint of a ring-shaped tank, which were fully respected during the renovation, it helps with the identification of the water management function. From the typological point of view, the water tank belongs to typical representatives of elevated water tanks from the end of the 19th century. Although it is typical, in terms of uniqueness it has an exceptionally installed chimney flue passing through the centre of the elevated water tank and leading to the top of the roof as probably the only one in the Czech Republic.

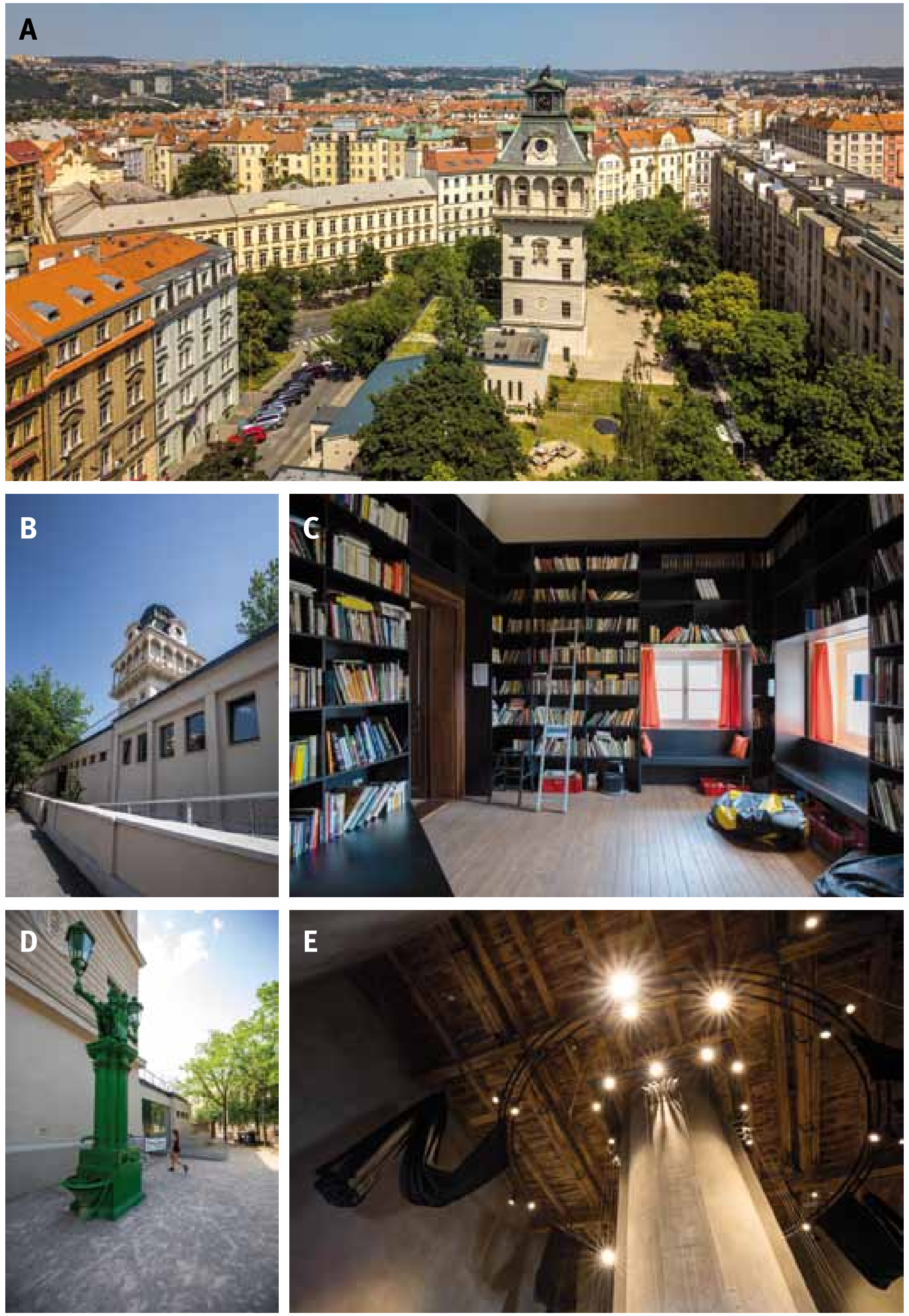


Fig. 5.21: Prague-Letná – elevated water tank, conversion: (A) overall view; (B) wheelchair accessible entrance; (C) library; (D) cast-iron water pillar fountain with a minimalistic extension; (E) chimney passing through the centre of the water tank. Photograph from the National Heritage Institute archive.

In 2016, a renovation based on the design by the atelier Petr Hájek architekti, which can be considered as exemplary, was started. Apart from preserving the last function related to the use of the space for the needs of the Centre for children and young people in the quarter of Prague 7, the main principle of the renovation was the conservation of all preserved craft elements, regardless of the time of their creation, from original historical building components to Bakelite handles from the recent period. Besides the usual use of individual floors as exhibition halls, there are some unique installations, such as a periscope on the roof using the original chimney or the Foucault pendulum in the staircase area. Adjacent ground floor extensions are fully used for the needs of leisure time activities or a kindergarten. The minimalist modifications contrast perfectly with the ornate facade of the elevated water tank, which has been reverently restored as an antiquity. For the high quality of the restoration work and the cultivated new use, the restoration was awarded the Patrimonium pro futuro prize by the National Heritage Institute in 2019.

Fig. 5.22: Prague-Libeň – Na Mazance elevated water tank – after reconstruction and conversion into a flat. Photograph by Michaela Ryšková, 2022.

5.2.8 PRAGUE-LIBEŇ, ELEVATED WATER TANK

The elevated water tank "Na Mazance" in Prague-Libeň (Fig. 5.22) was constructed in 1903–1904 according to František Schafler's design for the accumulation of water from the Káraný conduit. The elevated water tank is 42 m high and on the upper floor there is an iron reservoir with a storage capacity of 178 m^3. The romanticising rendering, rich in architectural details, works with a distinctive articulation using contrasting materials: the Cyclopean stone and facing masonry of the shank and smooth plastered surfaces of the cylindrical upper part (for the tank). The elevated water tank was operational until the 1960s when the first repair of the facade was carried out, interior equipment was dismantled and several architectural elements and details on the facade were removed. In 1991, the elevated water tank was declared a cultural monument. In 2008, a luxury maisonette built according to the design of the atelier Faber Project was presented and the renovation of the exterior was executed based on photographs from 1905 (Jásek and Beneš, 2000; INDUSTRIÁLNÍ TOPOGRAFIE, 2021; PAMPRAHA, 2011; Kořínek, 2012).

5.2.9 BRNO, GROUND WATER TANKS AT ŠPILBERK

Two ground water tanks at Špilberk Castle in Brno were built in connection with the waterworks system of Brno, the foundations of which were laid by the construction of the water treatment plant in Pisárky and ground water tanks on the Žlutý hill. Two new waterworks tanks were built into the eastern bastion of the castle fortress. The

Fig. 5.23: Brno – ground water tanks in Špilberk: (A) south-eastern bastion of Špilberk Castle; (B) newly built entrance; (C) lapidarium exhibition in the older water tank from 1870–1871; (D) exhibition in the water tank from 1900; (E) a lot of the original, today non-functional, elements have been preserved; (F) new staircase. Photograph by Michaela Ryšková, 2021.

older brick water tank from 1870–1871, built together with a pumping station (above Pelicova street) according to engineer John Glynn's design, has a capacity of 928 m^3, and dimensions of 9 m × 7 m × 25 m; the younger concrete one from 1900 has dimensions of 9 m × 12 m × 25 m and a capacity of 1,234 m^3 (Hlušičková, 2001; Borský, 2019; Fig. 5.23). The water tanks ceased to serve their purpose after the 1st Březová conduit had been launched (1913).

Between 2017 and 2019 an overall reconstruction was carried out and the water tanks were modified according to the project by the Architectural Office Radko Květ for the Lapidarium of the Brno City Museum (permanent exhibition called "Temple of the stone"), launched in 2020. (Hlušičková, 2001; Borský, 2019). The originally independent water tanks were connected and a new entrance was built. While the exterior modifications followed the desire to respect the environment, the new structures of staircases and penetrations in the interior are distinguished by a contemporary architectural style. A lot of original elements, referring to the original function of the structures, have been preserved (DRUHEBRNO, 2016; ČT, 2020; Fig. 5.23). The interconnection of the underground "temples" with the installation of sculptures allows both the genius loci and the installed works of art to stand out.

5.2.10 TŘEBÍČ, ELEVATED WATER TANK

The elevated water tank on the Strážná hora mountain (480 m n. m.) in Třebíč (Fig. 5.24), so-called Kostelíček, was built in 1936–1938 according to the design of the Brno company Ing. Oldřich Nikel as part of the project of the group water supply system from the spring area of Stařečský Brook. The water tank accumulated water for the highest parts of the town of Třebíč (and others) and water was supplied by a 13-kilometre-long waterworks piping from the so-called 1st spring area (a system of galleries in the woods near the small town of Heraltice). The reinforced concrete water tank is architecturally modelled in a distinctive and unusual way by the asymmetric elevation of the tank cylinder outside the axis of the service shank.

Due to the connection of the area to the water supply conduit from Vranov (1962) and Mostiště (1966), the water tank ceased to be used. From 2010 there were negotiations going on regarding its new use (until then it had been used only as a telecommunications tower) and, in 2015, its overall reconstruction took place. Nowadays, the interior premises serve as a waterworks museum in Třebíč and the upper platform as an observation terrace (Hedbávný, 2015; INDUSTRIÁLNÍ TOPOGRAFIE, 2021).

Fig. 5.24: Třebíč – "Kostelíček" elevated water tank on the Strážní hora mountain. Photograph by Michaela Ryšková, 2021.

5.3 PROPOSALS FOR IMPROVEMENT IN HERITAGE PROTECTION AND CARE OF WATER MANAGEMENT STRUCTURES IN THE CZECH REPUBLIC

A typological overview of structures, introduced in this methodology, could be considered as a basis for systemic protection of water management structures in the Czech Republic which primarily stem from their typological, historical and parametric values. The same importance may be granted to ranking them in terms of technological flow, functional complexes and systemic relations. These criteria have been emphasised sporadically in proposals for heritage protection of water management structures so far.

It is necessary to mention another criterion, namely the authenticity of function. Continuity of operation of a number of water management structures is on its own one of the most important values even if we consider the risks involved in the combination of protection and functional use of the structure. Searching for compromise tends to be challenging especially when it is necessary to adjust the works according to new technological and safety parameters in order to keep it operational. And It is necessary to admit that the impact on heritage values could be very significant.

The Jevišovice dam, (Fig. 5.25), can be given as an example of where it is necessary, for safety reasons, to equip the lower outlets with gates on the pipeline, including the service building on the downstream face, and to increase the capacity of the safety spillway. Both such interventions will result in a significant change in the appearance of the heritage protected structure. However, these are legitimate requirements aimed at ensuring the safety not only of the hydraulic structure but also structures and property below it. Therefore it is necessary to look for a suitable compromise solution.

Another example is the adjustment of the **Vltava lateral canal lock chamber in Hořín**, necessitated by new technical parameters of waterborne transport (for more details, including picture documentation, see Chapter 5.1.3). In order to facilitate the passage of bigger boats than for which the chamber was designed at the beginning of the 20th century, widening took place and raising of the head of one of the two original lock chambers, and the original fixed bridge structure was replaced with a hydraulically raised steel structure. The new bridge structure is a visual copy of the original bridge, including the stone cladding, with the aim of preserving the architectural quality of the works

Fig. 5.25: The Jevišovice dam – structure for handling bottom outlets. Photograph by Michaela Ryšková, 2020.

Fig. 5.26: Křemžský Brook – On the left, a view of the lowest situated navigation lock. On the right, a view of one of the contemporary bridges – prefabricated concrete. Photograph by J. Hansová, 2021.

as a whole. The second chamber remained preserved without any modification of its parameters. The authenticity of function here is superior to the authenticity of mass and form and the negative impact on them could be perceived as one of the phases of the development of this structure.

The different interests of heritage preservation and environmental protection could also collide. Water management buildings and structures deal with natural sources, mainly in the natural environment, in the countryside. For this reason, they must respect natural laws as well as changing (namely increasing) requirements for their protection, as can be seen in the example of **Křemžský Brook in Southern Bohemia**.

Křemžský Brook was in the 19th century regulated and the slope of its bed was lowered by building several stone bed drops in order to prevent the water from taking huge boulders to the nearby the Vltava River during periods of flood discharge. Despite the fact that these bed drops are not officially designated as a cultural heritage, there is substantial documentation about them due to their preserved condition and uniqueness and therefore they have huge potential to be regarded as part of cultural heritage in future (Hansová, 2021). Throughout more than 100 years of the existence of this modification, with the presence of rich flora, these bed drops have become part of the brook and landscape. They are perceived by tourists and local inhabitants more like a natural creation and for this reason they are a frequent destination of visitors (see Fig. 5.26). This locality is also part of the Blanský les Protected Landscape Area. The watercourse itself is managed by the Povodí Vltavy enterprise, which, in accordance with contemporary requirements for the environmental condition of water bodies, requested a feasibility study for the naturalisation of this watercourse and passage for aquatic animals in its longitudinal direction. The designer proposed the removal of most of the bed drops, and also further modifications of the trough beyond the original natural conditions, according to current trends in design practice based on the technical standards and methodologies (in this case, methodologies of watercourse revitalisation especially). Due to a negative response from the public, the Povodí Vltavy enterprise has refrained from implementing this proposal so far (Kubát, 2021).

At the same time it turned out that a discussion among experts from different fields could also positively contribute to the solution, the result of which could be the suggestion of some compromise which would help comply with current requirements concerning the use of the works and at the same time preserve, at least partially, the historical solution of the structure, while preserving its functionality and engagement in the newly created functional unit. In the case of Křemžský Brook it concerned assessment of the proposed change so that part of the structures would remain preserved, or partially modified.

Another example is the **Blatná Water Ditch** (for more details see Chapter 5.1), where a clash of interests can be expected between the conservation of the structure and its functionality on the one hand and the management of neighbouring plots of land in woods and protection of natural locations on the other. As a consequence of the expansion of environmentally sound forest lands, the structure of the race is being locally disturbed in forest areas. It would be desirable to set up such management which wouldn't create pressure on the water ditch and would enable its preservation, or possibly continuous delicate care provided via technical means. The space required along the channel could be used as a path for pedestrians.

The crucial clash could be expected in the case of the requirement for preservation of the construction or function of structures which serve for the drainage and treatment of wastewater, concerning in particular technological units of **wastewater treatment plants**. In fact, during the whole second half of the 20th century, and during the last two decades in particular and even today, there is a trend of a gradually increased requirement concerning treatment of such water and removal of increasingly expanding amounts of pollutants. It concerns development of legislation and setting of the required maximum concentration of pollution. This in fact leads to a situation where crucially significant overhauls of both particular structures and also parts of the whole technological units of water treatment plants take place, and it often starts right from the structures of the sewer network (e.g., retention tanks, relieving chambers). Current practice is based on the replacement of technological installations, particular components of technologies, modifications of building structures, changes in the technological flow of water. There is no exception when using existing structures for new purposes, during which the existing structure is completely decommissioned. Preservation of the old wastewater treatment plant in Prague-Bubeneč is from this point of view a rare case because, for various reasons (especially for the increase in capacity, technological changes), the building of a completely new water treatment plant took place. We can currently even talk about the presence of three water treatment plants in the same place (Wanner, 2018). A similar example is localisation of three independent technological units (preservation of two historical pumping stations originating in different eras and one modern water treatment plant) next to each other in the city of Hamilton (Ontario, Canada). The possibility of preserving old structures in a place is limited

Fig. 5.27: Selmice (near the premises of the stud farm in Kladruby nad Labem) – the rest of the structures of the historical pumping station of irrigation water. Photograph by David Honek, 2021.

Fig. 5.28: The fitting of the secondary settling tank damaged during the renovation of the water treatment plant. Photograph by Miloš Rozkošný, 2021.

by requirements for freeing up space and directing the purified water to the appropriate receiver (watercourses, lakes, ponds).

It is necessary to focus attention on particular small water management structures and construction elements, which could be found in abandoned or impaired countryside, or directly in the water management premises. Such structures, elements or objects are often evidence of certain historical phases of solutions to specific requirements regarding water management (for example, water supply, management of technological processes, treatment of water properties). The current owner or business operator doesn't need to know their historical value and that's why there is a threat of their complete extinction and destruction. As examples, we can mention the **Selmice pumping station of irrigation water**, not far from the premises of the stud farm in Kladruby nad Labem, which is notable for its relatively unusual construction. Currently, however, it is lost in undergrowth on the banks of the Elbe River and it is also damaged by vandalism and by flytipping (Fig. 5.27).

Another example of particular technological units and equipment, which are in danger of possible removal despite the fact that they could at the same time appropriately serve as examples of technical solutions of their era, are the fittings of a secondary settling tank of the wastewater treatment plant (Fig. 5.28), which was carelessly damaged during the renovation of the water treatment plant, or equipment meant for management of the operation of the water treatment plant, which can still be found on the premises of the water treatment plants, which are waiting for major renovations (Fig. 5.29).

To conclude, we would like to recommend developing stronger ties between national heritage care and professional organisations in this specific field, for example, CzWA (Czech Water Association), Česká vědeckotechnická vodohospodářská společnost (Czech Scientific and Technical Water Management Society) and others, which gather a significant number of professionals at some informal platform including civil servants and scientific workers who work in the field of water management but also in follow-up fields (hydrobiology, hydrochemistry, microbiology, geography, etc). Deepening mutual contact could offer new perspectives to water managers on dealing with water management structures and functional complexes and finding agreement on heritage preservation of this field for the future.

Fig. 5.29: Now historical equipment for the management of the operation of the water treatment plant. Photograph by Miloš Rozkošný, 2021.

6. CONCLUSION

This publication is primarily intended to serve as a tool for orientation in the field of water management from the perspective of heritage protection. Water management structures and complexes that belong to the category of technical monuments (industrial heritage) are evaluated using both traditional heritage management criteria and also specific criteria. This methodological guide applies these general and specific criteria to a broad range of water management sites, describing the differences between them both with regard to the relevance of the individual criteria and with regard to the degree to which these criteria are met.

The typological overview presented here can be viewed as a basis for the systematic protection of water management structures in the Czech Republic, drawing primarily on their typological, historical and parametric values. An equally important consideration is the place occupied by these structures within the technological flow (process), functional entities and systemic interconnections. Up to now, these criteria have only been sporadically accentuated in proposals for the legal heritage protection of water management-related sites.

It is also necessary to mention another important criterion – functional authenticity. The decision on whether a site or structure is declared a cultural monument is taken by the Czech Republic's Ministry of Culture (pursuant to Act no. 20/1987). The decision includes an assessment of the values mentioned above as well as the authenticity of the site and the technical equipment and its structural and technical condition. If a site is still functioning, or has undergone alterations, this is often considered an obstacle to the granting of heritage protection. However, it is important to emphasize that a large number of water management sites still perform their original function, and this continuity of function does not in fact represent a barrier to the granting of protected status; in fact, it embodies a very important heritage value in its own right.

In the international context, the principles applied to the evaluation of industrial heritage have been formulated in numerous works of specialist literature and in internationally accepted documents (TICCIH). The differences in how individual countries deal with their industrial heritage are rooted in the degree of knowledge that has been attained, as well as in each society's approach to the values identified. We can witness a wide spectrum of approaches, ranging from full respect for identified values (including the unique atmosphere of the location, the genius loci) to the partial or complete suppression of these values as a consequence of a failure to understand the original functions and typological values represented by a particular site/structure, or due to inappropriate creative ambitions. Nevertheless, in the evaluation of industrial heritage we can witness an ongoing trend which is entirely in line with the content of this publication: a general shift away from the protection of individual sites or structures and towards the protection of entire systems and functional entities; this trend is reflected in (and also influences) the selection of successful candidates for inscription on the World Heritage List.

This publication is intended mainly for use by heritage experts and state administration employees. It is a tool for orientation in the field of water management and for the evaluation of water management sites and structures from the perspective of heritage management. It presents information of relevance for the identification and assessment of typological value; this is a key criterion when evaluating all examples of industrial heritage, and the focus here is on the typology of key aspects of water management. The publication also provides a basis for field surveys and the evaluation of their findings, as well as for the selection of important examples of water management structures and sites for legal heritage protection. The examples presented in it offer a comparative overview of individual types of structures/sites.

Jablonec nad Nisou – the Mšeno dam. Photograph by Michaela Ryšková, 2021.

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7.2 ARCHIVAL SOURCES

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Povodí Labe, s. p., company archive

Povodí Vltavy, s. p., company archive

PVK, fonds Fotoarchiv PVK

Státní okresní archiv Bruntál (State District Archives Bruntál), fonds Okresní úřad Rýmařov, inv. no. 574, box 334

Státní okresní archiv Opava (State Disctrict Archive Opava), fonds ONV Opava, inv. no. 904, box 1143

Státní okresní archiv Opava (State Disctrict Archive Opava), fonds Okresní úřad Opava II (1992–2001), box 28

Státní okresní archiv Opava (State Disctrict Archive Opava), fonds Okresní úřad Opava, inv. no. 873, box 1052

Státní okresní archiv Opava (State Disctrict Archive Opava), fonds Sonnek Ladislav Mgr., box 44, chronicle Papierfabrik Zimrovitz 1891–1941

Státní okresní archiv Šumperk (State Disctrict Archive Šumperk), fonds ONV Šumperk, Kouty nad Desnou, PVE Dlouhé Stráně – Souhrnné řešení stavby, Hydroprojekt – odštěpný závod Brno, vh 1611/13

VUT v Brně, FAST, archive

Výzkumný ústav vodohospodářský T. G. Masaryka, v. v. i. (T. G. Masaryk Water Research Institute, p. r. i.), archive

USBF Technology, company archive

Zemský archiv Opava (Provincial Archive in Opava), fonds Vratimovské papírny, Vratimov, závod Žimrovice, box 36

Zemský archiv Opava (Provincial Archive in Opava), Olomouc branch, fonds Velkostatek Janovice, inv. no. 9502

7.3 MAP SOURCES

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2. rakouské vojenské mapování. [1 : 28,000]. 1836–1852. Český úřad zeměměřičský a katastrální (Czech Land Surveying and Cadastral Authority).

2. rakouské vojenské mapování. [1 : 28 000]. 1836–1852.

7.4 COMMON LEGEND OF DIAGRAMS

LEGEND:

⬛	Concrete	🟩	Electrical parts, metal, machinery
▦	Masonry	🟦	Water
▩	Stone	▨	Foundation
🟨	Earth	▦	Rock foundation
🟫	Dam seal		

8. LIST OF ABBREVIATIONS

ASME	The American Society of Mechanical Engineers
AWS	Das Augsburger Wassermanagement-System (web portal)
BVK	Brněnské vodárny a kanalizace, a. s.
CM	cultural monument
CR	Czech Republic
ČSN	Czech technical standard
ČT	Česká televize (Czech Television)
ČÚZK	Český úřad zeměměřický a katastrální (Czech Office for Surveying, Mapping and Cadastre)
ČVVS	Česká vědeckotechnická vodohospodářská společnost (Czech Scientific and Technical Water Management Society)
DČ	Druhy čerpadel (Pump types – web portal)
DN	Diameter nominal
D-O	Danube-Oder canal
DPJ	Digitalisierung des Polytechnischen Journals (web portal)
DSK	Dolnoslaskie szlaki kulturowe (web portal)
EU	European Union
FAST	Fakulta stavební (Faculty of Civil Engineering)
HistoriskAtlas	Danish cultural institution (ABM)
Hmax	maximum water level
HN	Hospodářské noviny
HPP	hydroelectric power plant
HS	hydraulic structure
Hv	height position of outlets
ICOMOS	International Council on Monuments and Sites
ICOLD	International Commission on Large Dams
MCPD	Metodické centrum průmyslového dědictví (Methodological Centre of Industrial Heritage)
MMB	Muzeum města Brna (Brno City Museum – web portal)
MKH	Montanregion Krušné Hory (Ore mountains – web portal)
MK	Ministerstvo kultury České Republiky (Ministry of Culture of the Czech Republic)
MZE	Ministerstvo zemědělství České Republiky (Ministry of Agriculture of the Czech Republic)
MŽP	Ministerstvo životního prostředí České republiky (Ministry of the Environment of the Czech Republic)
NCM	national cultural monument
ND	Nové Dvory (web portal)
NM	Museum.Digital:Deutschland (web portal)
NPÚ	Národní památkový ústav (National Heritage Institute)
OSU	University of Ostrava
PAMPRAHA	Odbor památkové péče hl. města Prahy (Department of Heritage Conservation of the Capital City of Prague)
PK	Památkový katalog (Monument catalogue)
PLA	Povodí Labe, s. p. (Elbe River Basin)
PMO	Povodí Moravy, s. p. (Morava River Basin)
POH	Povodí Ohře, s. p. (Ohře River Basin)
PSHPP	pumped storage hydropower plant
PVK	Pražské vodárny a kanalizace, a. s.
PVL	Povodí Vltavy, s. p. (Vltava River Basin)
RBTP	reed-bed treatment plants
SFPD	San Francisco Planning Department
SHPP	small hydroelectric power plant
SMVaK	Severomoravské vodárny a kanalizace, a. s.
SOkA	Státní okresní archiv (State Disctrict Archive)
TGM WRI	T. G. Masaryk Water Research Institute
UNESCO	United Nations Educational, Scientific and Cultural Organization
USKP	Ústřední seznam kulturních památek (Central list of cultural monuments of the Czech Republic)
VČE	Východočeská energetika, a. s.
VHS	VHS Olomouc
VRV	Vodohospodářský rozvoj a výstavba, a. s.
VŠB-TUO	Vysoká škola báňská – Technická univerzita Ostrava (Technical University of Ostrava)
VUT	Vysoké učení technické v Brně (Brno University of Technology)
VÚV	Výzkumný ústav vodohospodářský T. G. Masaryka, v. v. i. (T. G. Masaryk Water Research Institute, p. r. i.)
VV	Věžové vodojemy (Elevated water tanks – web portal)
WIKI	Wikipedia.org (web portal)
WWTP	wastewater treatment plant
ZAO	Zemský archiv Opava (Provincial Archive in Opava)
ZČE	Západočeská energetika, a. s.
ZSV	Zemský správní výbor (Provincial Administrative Commitee)

9. SUBJECT INDEX

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