WINTER HARBOUR PROJECT

SURVEYS AND ANALYSES

for selected environmental components, analysis of abiotic components, negative elements and phenomena in the area

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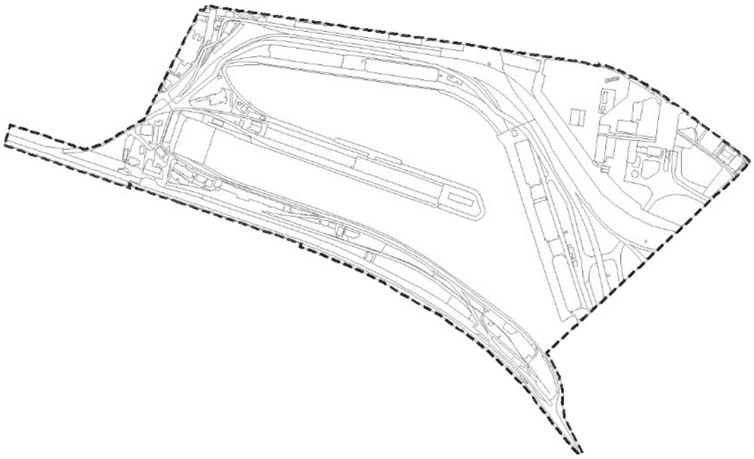

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Client:

Bratislava Metropolitan

Institute Primaciálne námestie

429/1 814 99 Bratislava

Contractor:

Krajplan s.r.o.

R. Súľovského 175/15A

013 13 Rajecké Teplice

Project team:

Ing. Milan Hodas – expertise in ecology, GIS and data processing

RNDr. Kamila Hodasová, PhD. – expertise in hydrogeology and engineering geology

Qualified persons pursuant to Section 55 of Act No. 543/2002 Coll.:

Ing. Milan Hodas

Contract number: Contract for Work Z-21/25

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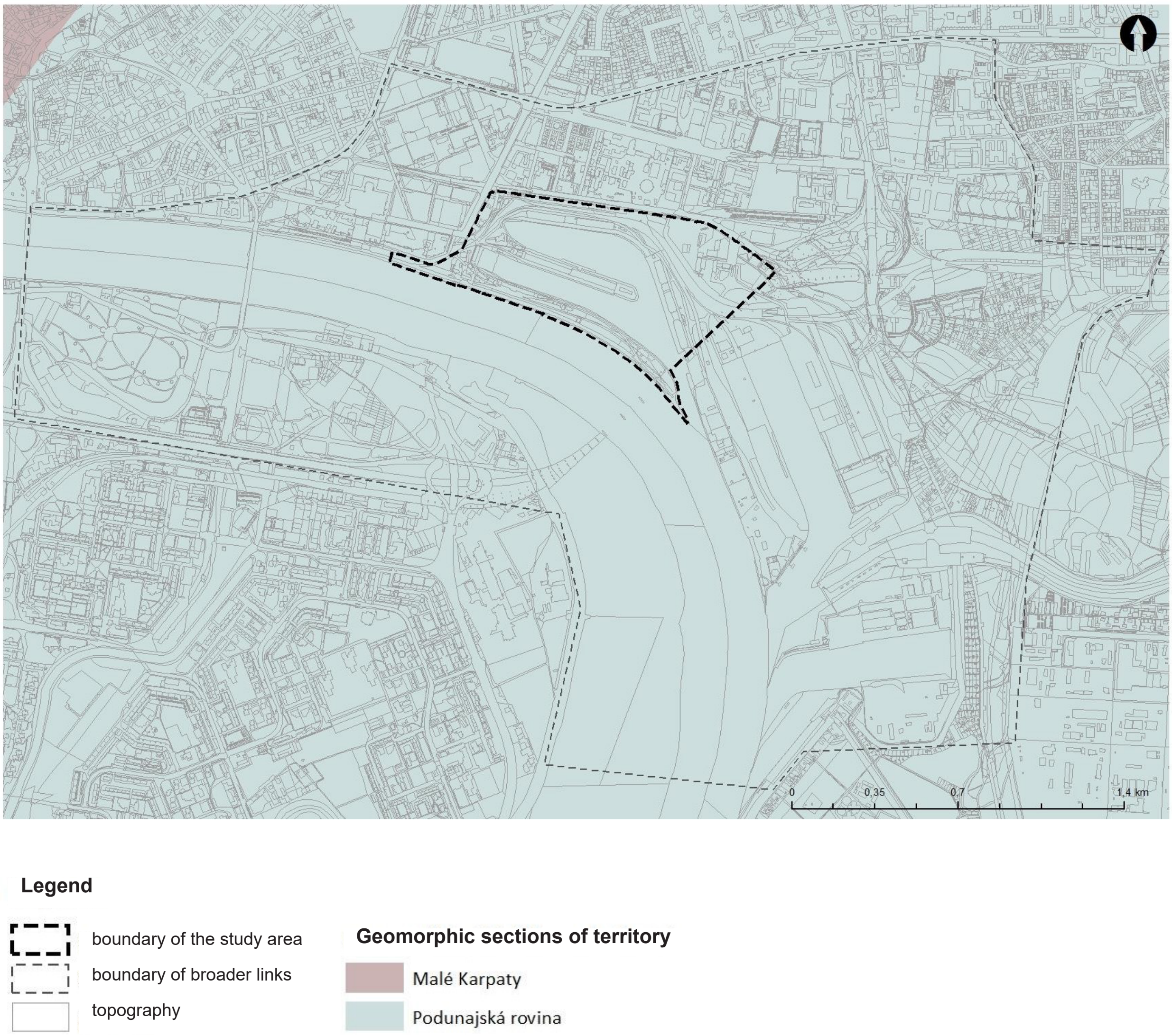
Geomorphological conditions

According to the geomorphological classification (Mazúr, Lukniš, 1986 in Atlas of the Slovak Republic, 2002), the area of the winter port in question belongs to the Alpine-Himalayan system, the Pannonian Basin sub-system, the West Pannonian Basin province, the Little Danube Basin sub-province, the Danube Lowlands region and the Danube Plain.

From the north-western side, the wider part of the area belongs to the Alpine-Himalayan system, the Carpathian sub-system, the Western Carpathian province, the Inner Western Carpathian subprovince, the Fatra-Tatra region, the Little Carpathians unit, the Devín Carpathians sub-unit and part of the Bratislava Foothills.

The following figure, 'Geomorphological Division of Slovakia', illustrates the area's classification within the geomorphological units of Slovakia.

Figure 1: Geomorphological division of the territory



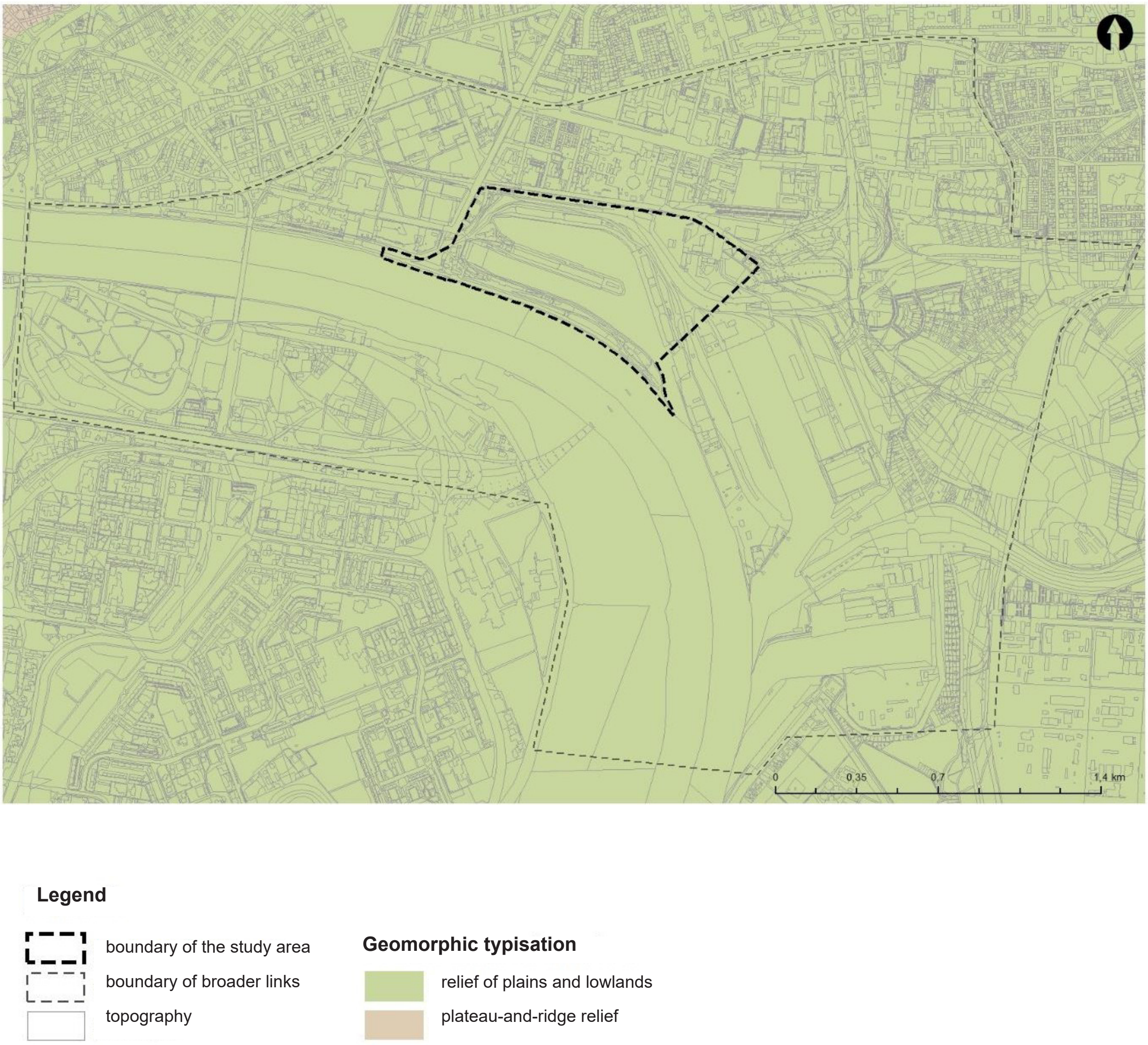
Source: Atlas of the Slovak Republic, 2002

The basic type of erosional-denudational relief is that of plains and floodplains. The basic morphostructure of the area is the negative morphostructure of the Pannonian Basin. Among the types of basic morphostructures, young morphostructures with aggradation are present. The morphological-morphometric type of relief is an undivided plain (Atlas of the Slovak Republic, 2002).

In the north-western part of the wider area under consideration, there is a plain-ridge relief with a basic Fatra-Tatra fold-block morphostructure. The basic type of morphostructure consists of positive morphostructures: ridges and wedge-shaped ridges of the core mountain ranges (Atlas of the Slovak Republic, 2002).

The geomorphological classification of the area in question is illustrated in the following figure.

Figure 2: Geomorphological classification



Source: Atlas of the Slovak Republic, 2002

The ruggedness of the area influences the overall character of the landscape, land cover, land use, landscape diversity, ecological stability, and ongoing processes (both natural and anthropogenic).

The relief ruggedness of the study area is illustrated in Figure: Digital Elevation Model.

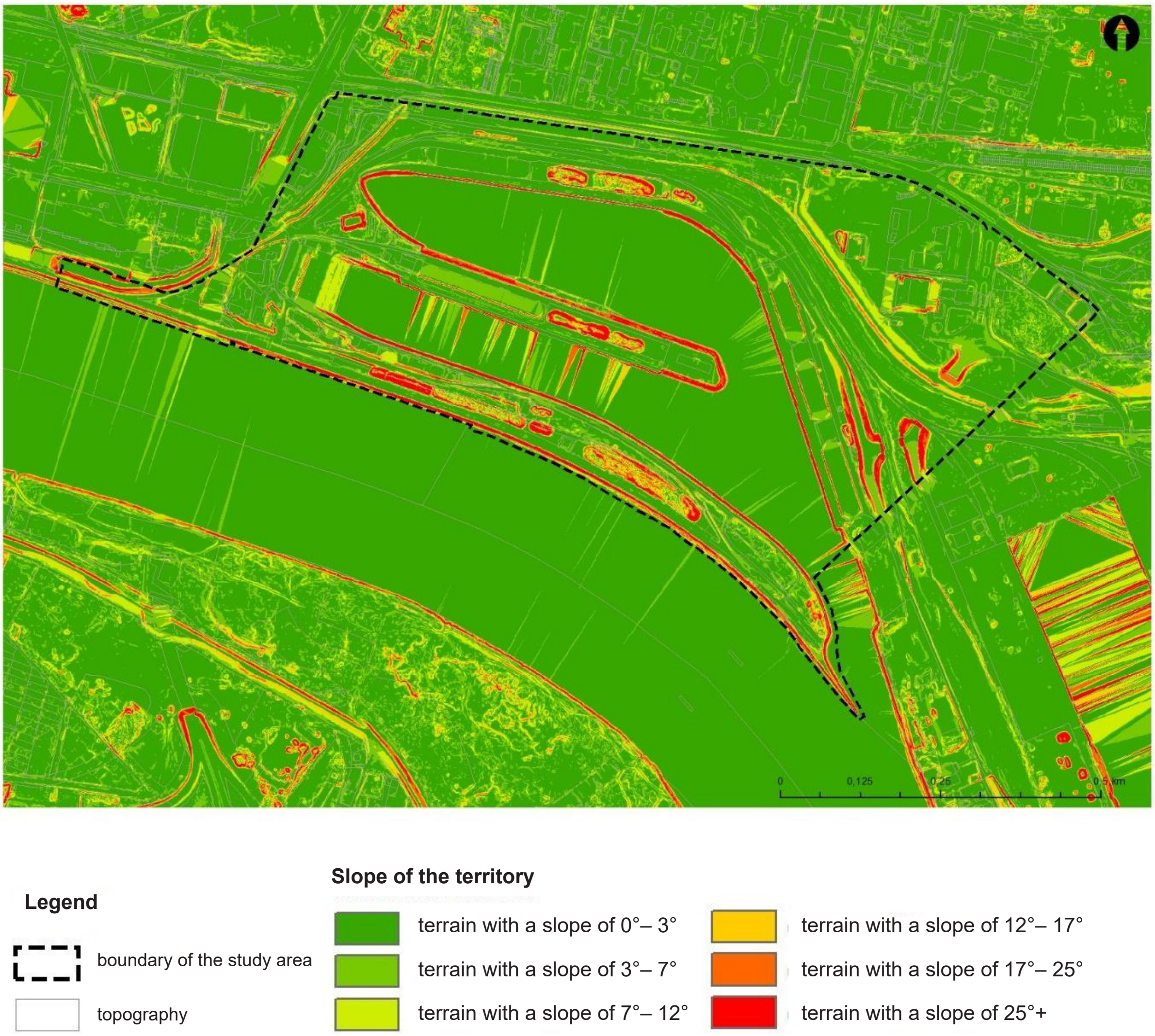
Figure 3: Digital Elevation Model

Source: https://zbgis.skgeodesy.sk

Slope gradient is a decisive parameter for the actual or potential occurrence of gravity-driven processes in the landscape (various slope modelling processes, erosion and accumulation processes, etc.).

The distribution of individual slope gradient categories in the area of interest is illustrated in Figure: Slope gradient of the area. The majority of the area lies within a gradient range of 0° to 3°.

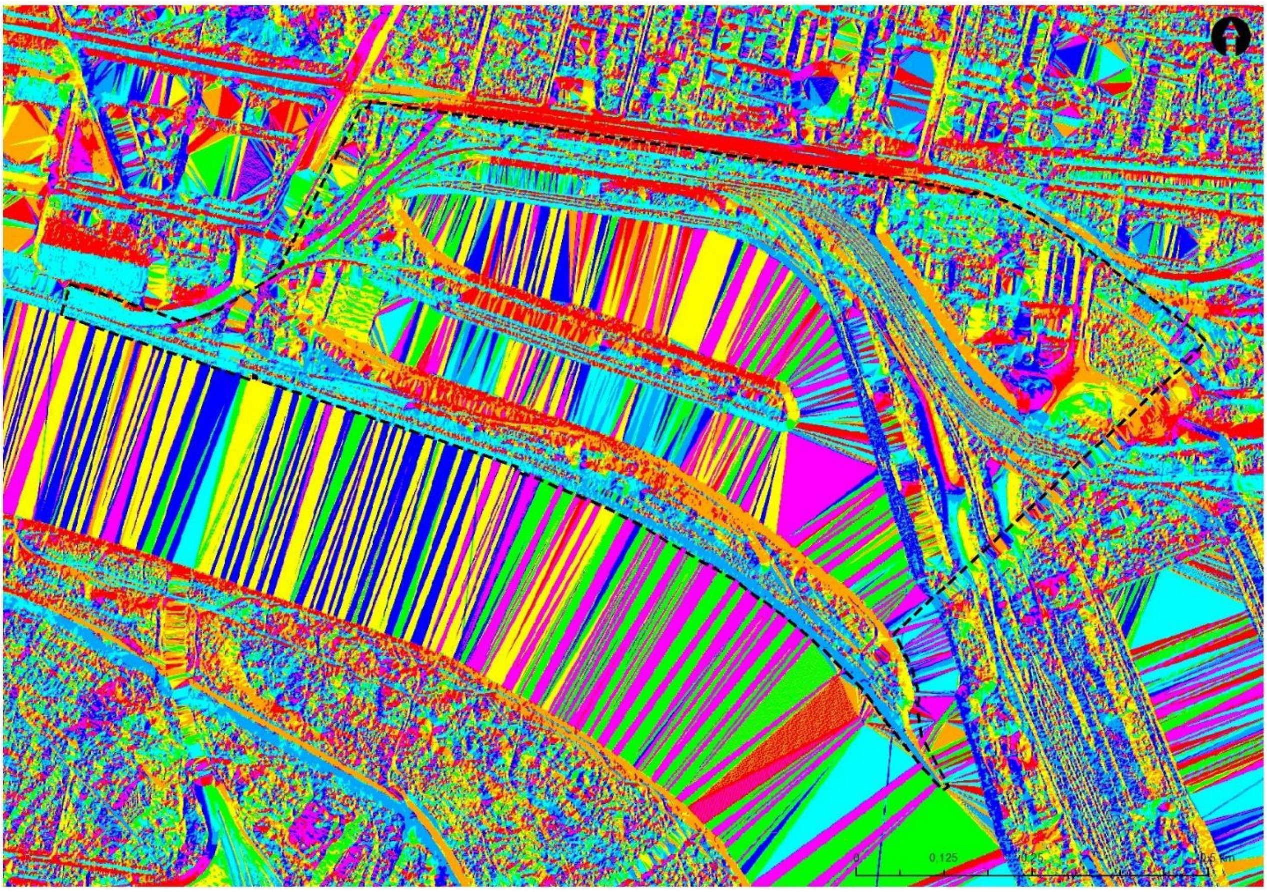
Figure 4: Slope gradient of the area



Source: https://zbgis.skgeodesy.sk

The spatial projection of the distribution of individual categories of slope aspect in the area of interest relative to the cardinal directions is shown in Figure: Slope aspect relative to the cardinal directions.

Figure 5: Orientation of slopes in relation to the cardinal directions



Legend

boundary of the study area

Slope orientation relative to the cardinal directions

north-facing slopes

north-east facing slopes

east-facing slopes

south-east facing slopes

south facing slopes

southwest facing slopes

west facing slopes

northwest facing slopes

Source: https://zbgis.skgeodesy.sk

Climatic conditions

According to the classification of Slovakia into climatic regions (Lapin et al., 2002 in Atlas krajiny SR, 2002), the assessed area belongs to a warm region, characterised by an average of 50 or more summer days per year, with a daily maximum air temperature of ≥ 25 °C. The area in question belongs to district T2, which is defined as warm, dry, with mild winters. The climatic characteristics of this district are: January air temperature above -3 °C, with over 50 summer days, and a Konček irrigation index (Iz) of -20 to -30. According to the climatic-geographical classification of climate by Kočický and Ivanič (2011), the site in question belongs to a lowland climate, within the warm climatic-geographical subtype, with average January temperatures of -1 to -4 °C, average July temperatures of 19.5 to 20.5 °C, and an annual precipitation total of 530–650 mm (Atlas of the Slovak Republic, 2002).

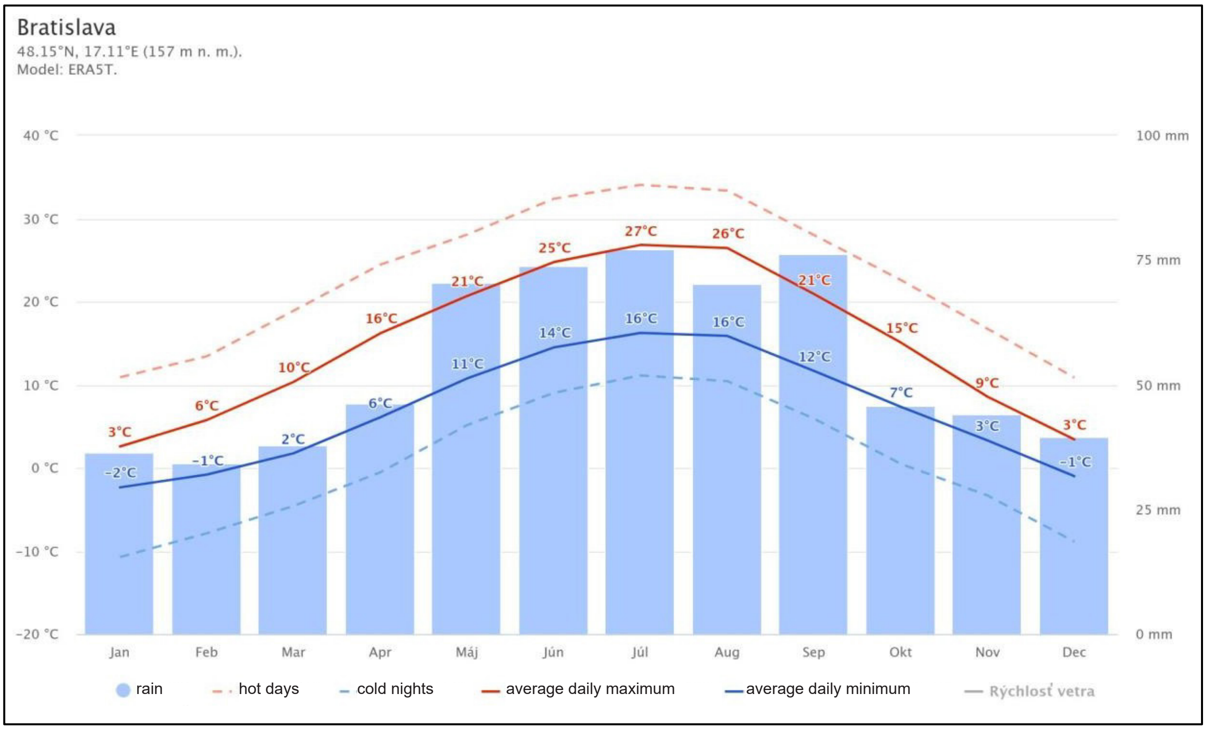
The climatic characteristics of the area in question, based on the long-term average for the years 1961–1990, are shown in the following table.

Average annual temperature of the active soil surface	11–12 °C
Average air temperature in January	> -2 °C
Average air temperature in July	> 20 °C
Average annual air temperature	> 10 °C
Average rainfall in July	< 60 mm
Average annual precipitation	550–600 mm
Average annual potential evapotranspiration	650–700 mm
Average annual number of days with fog	20–45
Average snow cover depth	< 40
Frequency of ground-level inversions	few inversion locations

Table 1: Selected climatic characteristics

The following graph shows average temperatures and total precipitation. The average daily maximum shows the highest temperature on an average day in each month. The average daily minimum shows the average minimum temperature. Hot days and cold nights show the average of the hottest days and coldest nights over the last 30 years. The graph also shows the average total precipitation.

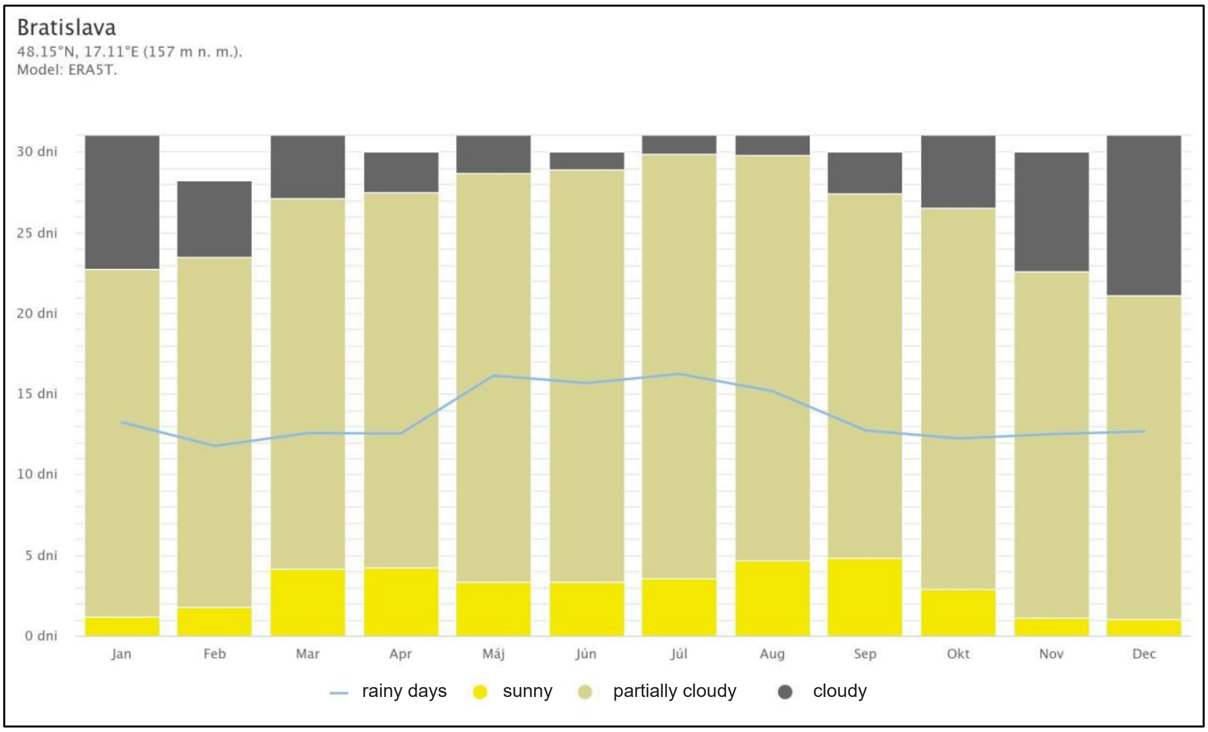
Graph 1: Average temperatures and precipitation



Source: www.meteoblue.com

The following graph shows the number of sunny, partly cloudy, cloudy and rainy days in a month. Days with less than 20% cloud cover are sunny, those with 20–80% are partly cloudy, and those with more than 80% are cloudy.

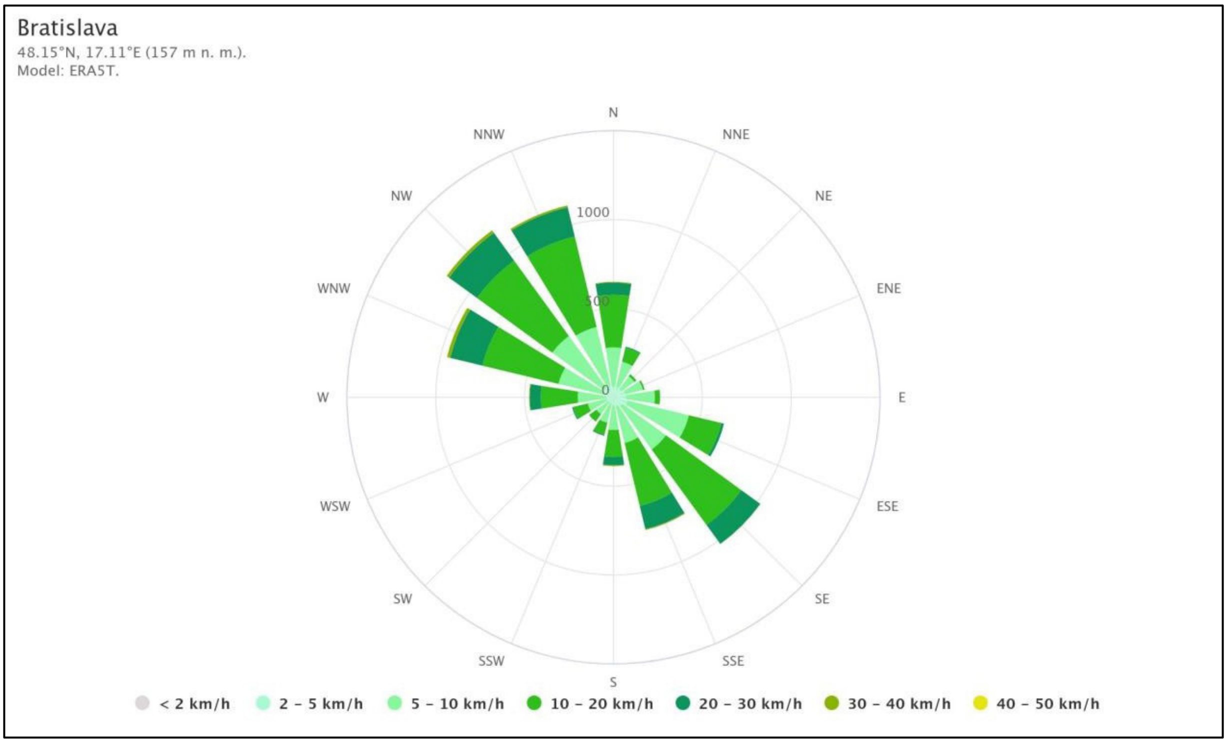
Graph 2: Cloudy, sunny and rainy days



Source: www.meteoblue.com

The following graph shows the wind rose for the area in question, illustrating the number of hours per year during which the wind blows from a particular direction.

Figure 3: The wind rose for the Bratislava area shows the number of hours per year during which the wind blows from a particular direction. (N – north (N), E – east (E), S – south (S), W – west (W)) E.g. SW: the wind blows from the south-west to the north-east NE.



Source: www.meteoblue.com

Hydrological conditions

From a hydrological perspective, the area of interest belongs to the Danube river basin. The characteristics of the Danube river basin include 6% runoff, 94% evaporation, representing 2.3% of the total area of the main river basins in Slovakia, and a runoff coefficient of 0.06 (Atlas of the Slovak Republic, 2002).

In terms of the type of runoff regime, the study area and its wider surroundings belong to a highland-lowland region characterised by a rain-snow runoff regime, with accumulation occurring from December to January and high water levels from February to April, with the highest flows in March and the lowest in September. There is a significant secondary rise in water levels in late autumn and early winter. The data provided represent a long-term average for the period 1931–1980 (Atlas of the Slovak Republic, 2002). Based on data on Danube flows from 2017–2021, the maximum flow was reached mainly in May and June, whereas the lowest flow was in September to November (ŠÚSR, 2023).

The gauging station located on the Danube in Bratislava, near the valuable area, is at an altitude of 128.43 m above sea level, with a catchment area of 131,331·10 km^2 and river kilometre 1,868.75. The monthly flow rates for 2022 are shown in the following table (SHMÚ, 2023).

Table 2: Average monthly flow (Q_m) on the Danube (Bratislava station) in 2022

Month	I.	II.	III	IV	V.	VI.	VII.	VIII.	IX.	X.	XI.	XII.	Year
Qm*	1764	1787	1297	1722	1913	1910	1418	1213	1461	1593	1243	1390	1557

*Notes: * Qm ($m^3 \cdot s^{-1}$) – average monthly flow for 2022*

Source: SHMÚ, 2023

Atmospheric precipitation in the Danube catchment area in 2023 is shown in the following table. In the Slovak Danube catchment, which has only a minor influence on the Danube's hydrological regime, exceptionally wet months were recorded in January (239%) and December (256%). June was very dry (39%) (SHMÚ, 2024a).

Table 3: Atmospheric *precipitation in the Danube catchment in 2023*

Basin		I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.	XI.	XII.	Year
Danube	mm	86	25	22	54	85	25	54	99	37	86	84	108	763
	%	239	79	59	152	135	39	80	166	64	182	174	256	129
	Δ	50	-7	-15	18	22	-39	-14	39	-21	39	35	66	174

Source: SHMÚ, 2024a

Notes: Δ – this represents the excess (+) or deficit (-) of precipitation in litres per square metre relative to the normal (1961–1990)

Geological conditions

According to the regional geological classification (Vass et al., 1988), the area under consideration belongs to the region of intramountain basins and depressions, to the Danube Basin zone and to the Gapčík Basin (third-order unit). The geological structure of the area of interest is mainly composed of Neogene and Quaternary formations (Figure: Geological conditions and Figure: Genetic types of Quaternary deposits).

Neogene sediments form the immediate bedrock of the Quaternary. They are of Pannonian and Pontian age; the boundary between these two formations lies approximately at Páleniště. The Pannonian is represented by sandy clays to claystones, mostly strongly calcareous. Within the clay formation, there are irregular layers and interbeds of fine-grained grey sands with calcareoussandy concretions. The uppermost Pannonian layers belong to the so-called Coal and Blue Series, which consists of black-grey clays, grey and brown strongly sandy silty clays with layers of finegrained sands and fine gravels. The Blue Series consists of blue-green clays with layers of light grey-green clays of varying sand content, which often transition into silty sands. The Pontian is represented by a sequence of variegated clays, green-grey, yellow-grey and rust-spotted, containing calcareous and manganese concretions. Typical of the Pontian are variegated, plastic, almost sand-free clays with layers of fine-grained sands, and occasionally coarse-grained gravel (Kordík et al., 2022).

The Quaternary is represented by fluvial sediments of Pleistocene and Holocene age. The fluvial sediments are dominated by a complex of gravels, gravels with sand, sandy gravels, and gravels mixed with fine-grained soils. In the overburden of the gravels, there are irregular layers of finegrained sands, silty sands and silty loams 1–3 m thick, locally up to 5 m, of fluvial and eolian origin. The uppermost layer consists of anthropogenic sediments – fill of various compositions and embankments (dikes, railway). The thickness of the fill is typically approx. 1.0–3.5 m, and in places where terrain irregularities are levelled, up to 5 m or more. It consists of boulders, silty gravel, aggregate, clay and a mixture of clay, gravel, construction waste and the like (Kordík et al., 2022). A more detailed description of the sediments forming the geological structure of the area can be found in the text below (www.geology.sk).

- **fluvial sediments: lithofacial unsorted floodplain clays, or sandy to gravelly clays of valley floodplains and mountain stream floodplains –** these represent the youngest and most widespreadwidespread fluvial sediments, which occur mainly in the form of valley floodplains (floodplain terraces), rivers and streams. Postglacial alluvial deposits of floodplain sediments form part of the fine-grained sedimentary surface cover of the sandy-gravelly sequence of river bed accumulation. Floodplain sediments form the lithofacially most diverse sequence, varying laterally and horizontally. At the base lies a sequence consisting mainly of clayey loams, clayey sands or resedimented gravels and sands from the upper parts of the riverbed accumulation. In the upper part of the loams, loose fine CaCO3 concretions or discontinuous thin calcareous layers occasionally occur. A chara3teristic feature of alluvial sediments is the presence of carbonates, which are found mainly in the form of microconcretions, nodules and fragments. The thickness of the alluvial sediments ranges from 1.5 to 3 m.
- **fluvial sediments: resedimented fine-grained alluvial sands –** fluvial sands of the alluvial facies are represented by sub-facies of channel-bed shoal sands and, in places, also by sands from segments of alluvial ridges. In terms of grain size, the sands of the floodplain facies are very fine-grained to silty and highly clayey. The sands are generally slightly calcareous, with low to no organic matter content. They are located on the gravel of the riverbed accumulation of the relevant watercourse and, in places, on the floodplain sediments of the flood facies themselves. Their thickness generally does not exceed 3 m.
- **fluvial-organic sediments: fine-grained, clayey to humus-rich loams of oxbow lakes and marshes –** according to preserved historical maps, the surface of the river floodplains of most watercourses (especially in their lowland and basin sections) was interspersed with a dense network of oxbow lakes. In lowland areas, four basic types of oxbow lakes can be distinguished: erosional oxbow lakes, transitional oxbow lakes with a thin sedimentary fill, accumulation oxbow lakes and buried oxbow lakes. Currently, mainly the last two types have been preserved, with young oxbow lakes filled with silty to sandy-clayey, slightly humic clays predominating. In these sediments, the original component of clays and loams mixed with semi-decomposed organic matter predominates. In lower elevations, they are often gleyed. In addition to the sediments mentioned above, alluvial silty and silty-clayey, highly humic older oxbow lakes have been preserved. In terms of grain size composition, these are again mostly sandy loams, loams to clays of blackish-grey to black colour with a large amount of poorly decomposed organic matter.

- **fluvial sediments: gravels, sandy gravels and sands of bottom accumulation on low terraces –** these emerge to the surface not only as naturally and artificially exposed areas of the riverbedaccumulations of streams within their floodplain areas, but also in the erosional remnants of their original accumulation level, now preserved in the form of low terraces forming a morphological step, on average 3–5 m high, above the floodplain surface (so-called terrace remnants). Sediments of bottom accumulation in the terraces generally exhibit high variability in grain size and composition. The petrographic composition of the gravel from bottom accumulation of streams in the terraces is highly polymictic and variable; as a rule, it is identical to the bottom accumulation in the floodplain area. Vein quartz, Lower Triassic quartzites and siliceous sandstones predominate. These are followed by granites, granodiorites, granite pegmatites, granite aplites, metamorphic rocks (gneisses and schists), and palaeovolcanics. Also abundant are vein calcites, cherts, arkoses, breccias, siliceous and calcareous sandstones of the Palaeogene and Neogene, and various types of limestones and dolomites.

- **Proluvial sediments: clays, sandy clays and clayey gravels with fragments in the upper alluvial cones –** the proluvial sediments of the upper alluvial form a transitional type between low Upper Pleistocene and Holocene alluvial cones. They occur mainly at the points where smaller streams flow into larger ones and on the edges of intramountain basins, where they border mountain ranges. Their material is unsorted, often chaotically deposited on the sediments of the bottom accumulation, or extends finger-like into its upper parts. It consists mainly of clay, sandy clay with alternating content of clayey gravel and rock fragments. Clays generally occupy the surface layer of the cones (thickness 1–2 m). The base of the cones is formed by sands and rock fragments up to 5 cm in diameter. The average thickness of the cones is around 4 m. The rock fill consists of rocks from the catchment areas.
- **fluvial sediments: alluvial flood-deposited fine-grained silty clays, fine to medium-grained sands –** flood-deposited sandy clays are, in most cases, poorly stratified, with only occasionalsigns of horizontal stratification. In terms of grain size composition, the sandy component is fine-grained to silty and heavily clayey. In some places, silty, slightly calcareous, slightly humic to non-humic clays predominate. In fine-grained alluvial clays, interbeds of organic peat sediments may also occur. Recent soils have developed on the fluvial sediments of the floodplains.
- **fluvial sediments: resedimented floodplain sandy gravels of the riparian zone –** these are sediments emerging directly to the surface in floodplains, or only in floodplain sections of watercourses.The resedimented material originates mainly from the upper gravel horizon of the riverbed accumulation of the relevant watercourse, whilst the current surface level of the riverbed accumulation, compared to its original surface, always represents an erosional reduction of approximately 0.5–4 m. The resedimented gravels lying on the bed gravels have the same petrographic composition as the latter, depending on the provenance of the river in question. Generally, Lower Triassic quartzites, siliceous sandstones and vein quartz are the most abundant in the gravels. These are followed by granites, granodiorites and metamorphic rocks (gneisses and schists); vein calcites, cherts, arkoses, breccias, siliceous and calcareous sandstones, various types of limestone, Permian sandstones and Neogene sandstones are also abundant. The pebble material is predominantly wellrounded and fresh. The average size of the pebbles is around 6 cm. A characteristic feature of resedimented sandy gravels is their frequently alternating, yet poorly defined sorting of layers of fine sand and gravel compared to the gravel of bottom accumulation. The thickness of the resedimented gravel layers ranges from 0 to 2 (3) m.
- **fluvial sediments: sandy gravels and gravels of the upper middle terraces –** are widespread in terms of both area and frequency of occurrence, although they do not reach the dimensions of the immediately younger – lower middle terraces. They generally form morphologically distinct terraced levels, interrupted by lateral tributaries. The terrace sediments are generally composed of selectively weathered, predominantly medium-grained, less fine-grained and only rarely coarse-grained, well-rounded sub-oval to oval, grey sandy gravels, whose average grain size becomes slightly finer in the direction of the streams and alternates with layers of medium- to coarse-grained, sorted grey sands. Locally, they also contain silty-sandy gravels with boulders to blocks. The material is well-sorted, graded and selectively weathered. The petrographic composition of the gravels in the terraces is highly polymictic and variable; it is generally identical to the accumulation of the lower middle terraces, and this corresponds to the petrographic

composition of the rocks of the respective provenance. Generally, vein quartz, Lower Triassic quartzites and siliceous sandstones predominate.

- **anthropogenic sediments: fill, spoil heaps and dumps –** anthropogenic sediments form extensive accumulations of construction fill, embankments, industrial and domestic waste, mining spoil heaps in areas with former and current mining activity, spoil heaps at the edges of larger quarries, and spoil heaps formed by tailings in the vicinity of smelting works. The digital map generally marks only those anthropogenic sediments which, due to their extent, thickness, shape or the nature of the material they contain, have a significant impact on the original geological and geomorphological conditions, as well as on current ecological conditions.

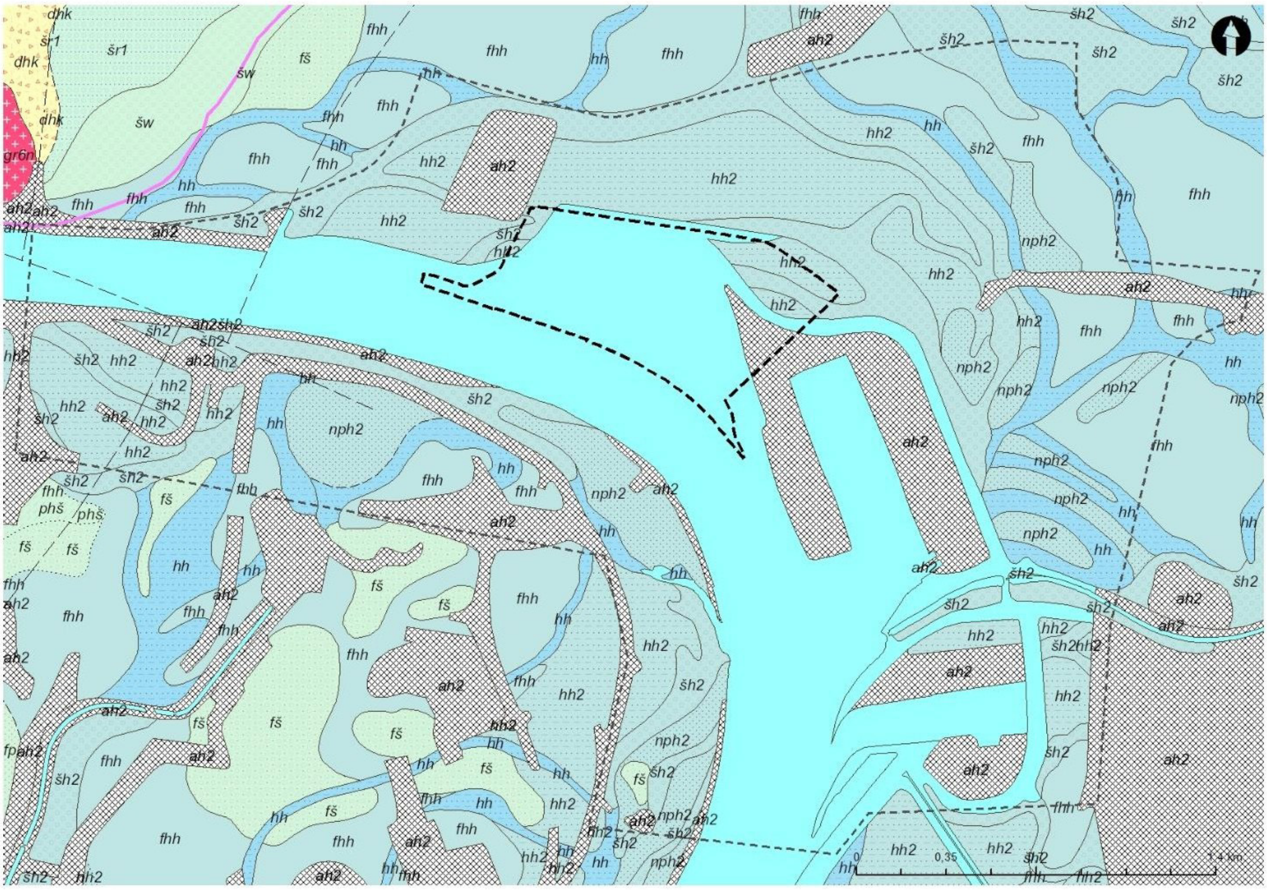
- **Deluvial sediments: predominantly clayey-stony (to a lesser extent sandy-stony) slope deposits and debris –** these are mainly erosion-gravity debris formed by the weathering of the underlying rocks and their subsequent movement down the slope along the fall line via roning, solifluction and gravitational movements, or possibly also block slides. In the internal structure of the sediments, we observe that the clays and sandy clays of this lithogenic type of slope deposits contain variable amounts of rock fragments up to boulders, which often predominate within them. The clayey-stony sediments as a whole consist of grey, grey-brown to chocolate-brown clays with a variable and mostly significant proportion of angular clasts, and in places gravitational rock blocks. The petrographic composition of the rock fragments depends on the source area. Two faintly distinct layers can be observed in the profiles. In the lower part, the sediments are generally more stony and blocky; in the overlying section, they are more clayey and gravelly, with interbedded layers of fine-grained material, clays and humic clayey soil sediments. In the vicinity of granitoids, they are more sandy. The thickness of the clayey-stony and sandy-stony slope deposits varies; thicknesses of 2–3 m generally prevail and mostly do not exceed 5 m.

- **fluvial sediments: sandy gravels and sands of the youngest horizon of bottom accumulation in the alluvial terraces –** gravelly-sandy fluvial sediments of the youngest

The horizons of the alluvial deposits emerge at the surface as erosional remnants of their original accumulation level. In the Žitný ostrov region, they emerge directly at the surface within the Danube floodplain in the form of the ‘core’ terrace of Žitný ostrov. Other occurrences consist of artificial exposures in the form of gravel pits. The core of Žitný ostrov occupies a central position and is the morphologically highest-lying area within the Danube Plain. Its sediments are buried beneath Holocene fluvial sediments. In the upper part of the core, its width reaches 15 km; in the middle and lower parts, it narrows to 4–6 km or protrudes in the form of small islands. It is composed of sandy gravels from the upper part of the middle fluvial sequence, or rather the Danube’s bottom accumulation.

- **coarse-grained muscovite, muscovite-biotite granites, granodiorites rich in pegmatites (Bratislava type) –** biotite-muscovite granodiorites are more widespread on the north-western edge of the Bratislava Massif and in the Devínska Kobyla area. These are medium-grained, uniformly grained rocks of grey-green colour with a hypidiomorphic granular texture. Plagioclases are often zoned and sericitised, with K-feldspar replacement being quite common. Quartz is the second most abundant mineral after plagioclase and is usually allotropically transformed. Biotite is poorly altered and therefore only slightly bauretised or chloritised. It is sometimes enclosed by muscovite. Medium- to coarsegrained muscovite and biotite (Ms–Bt) granites to granodiorites (biotite syenites to monzogranites) are typical of the south-eastern part of the Bratislava Massif, but also of the Staré Mesto Massif.

Figure 6: Geological conditions



Source: https://apl.geology.sk/gm50js/

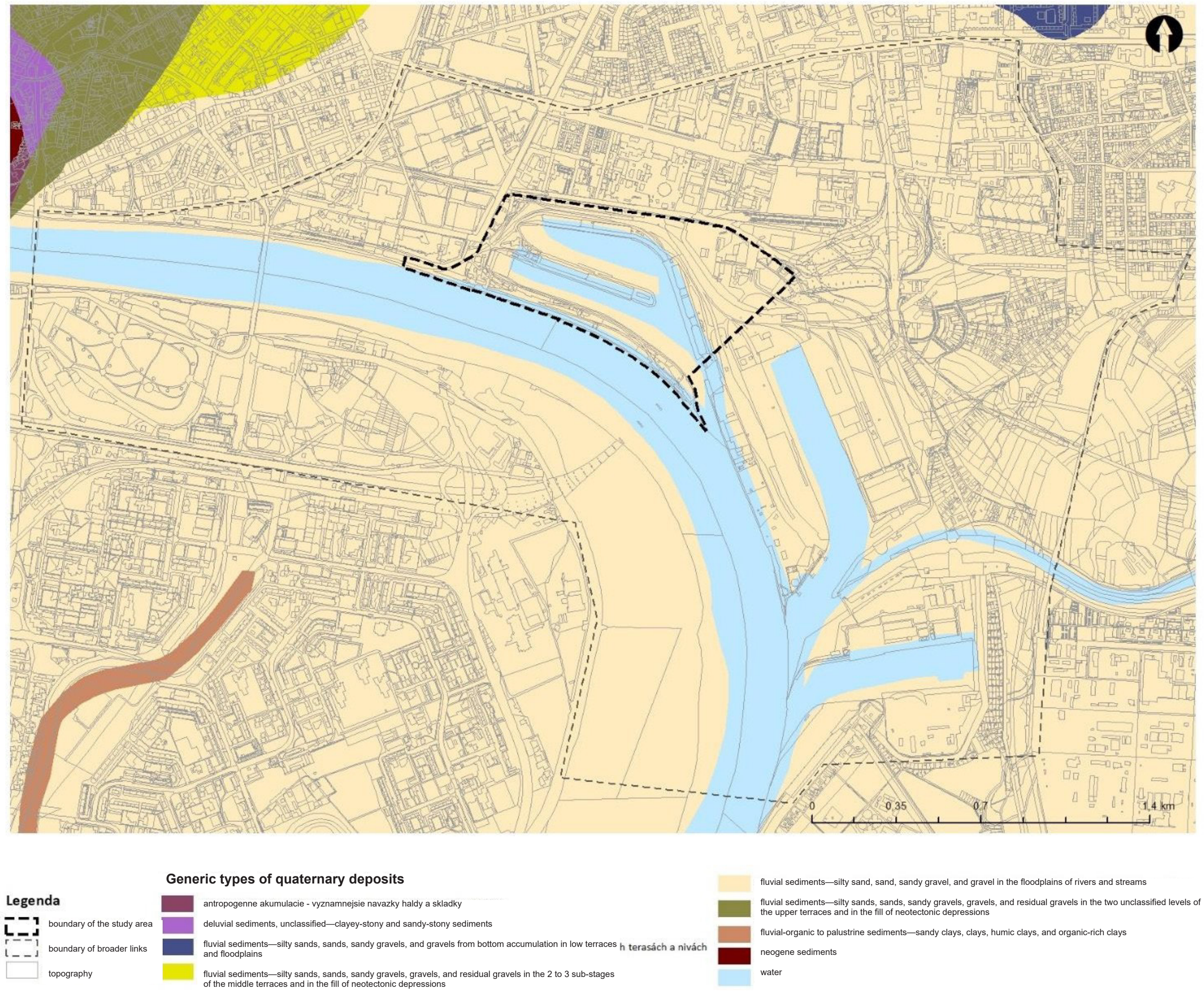
Key:

fhh – fluvial sediments: lithofacial unsorted alluvial clays, or sandy to gravelly clays of valley floodplains and mountain stream floodplains

nph2 – fluvial sediments: resedimented fine-grained alluvial sands
hh – fluvial-organic sediments: fine-grained, clayey to humic clays of oxbow lakes and marshes
šw – fluvial sediments: gravels, sandy gravels and sands of bottom accumulation in low terraces
phš – proluvial sediments: clays, sandy clays and clayey gravels with fragments in higher alluvial fan cones *hh2* – fluvial sediments: floodplain fine-grained silty clays, fine to medium-grained sands
šh2 – fluvial sediments: resedimented alluvial sandy gravels of the channel-side zone
šr1 – fluvial sediments: sandy gravels and gravels of the upper middle terraces *ah2* – anthropogenic sediments: fill, spoil heaps and landfills *dhk* – deluvial sediments: predominantly clayey-stony (secondarily sandy-stony) slope deposits and scree *fš* – fluvial sediments: sandy gravels and sands of the youngest horizon of bottom accumulation in the upper floodplain terraces *gr6n* – coarse-grained muscovite, muscovite-biotite granites, granodiorites rich in pegmatites (Bratislava type)

The spatial differentiation of the genetic types of Quaternary deposits in the wider area is illustrated in Figure: Genetic types of Quaternary deposits.

Figure 7: Genetic types of Quaternary deposits



Source: Atlas of the Slovak Republic, 2002

Engineering-geological characteristics

According to the engineering-geological regionalisation of Slovakia (Hrašna, Klukanová, 2002, ŠGÚDŠ), the area in question is composed of a formation of Quaternary sediments – the Fr. alluvial plain deposit zone. The zone is dominated by fluvial floodplain sediments – sandy loam, loam, loamy sand and loamy gravel.

Soil conditions

Anthropogenic soils are found at the site in question. Anthropogenic soils are a group of soils characterised by significant anthropogenic (cultivation or degradation) soil-forming processes – cultisols, anthrosols. The area of the proposed activity is not part of agricultural land, nor does it overlap with protected soils or soils of high quality.

The soil type to the east of the site in question is fluvisols. The soil unit comprising the wider surroundings is: carbonate cultizems, accompanied by gley fluvisols, carbonate fluvisols and light carbonate fluvisols, derived from carbonate alluvial sediments. In terms of texture, these are light soils, with a loamy texture class. They are deep soils, without a skeleton. Soil permeability is moderate and water-holding capacity is high. The area lies within a very warm, very dry and lowland climatic region.

The typological-production category is O4 (productive arable land). Based on the production potential of the agricultural land, the area falls into category 4 (69 IP points). The soil moisture regime is moderately moist (Granec et al., 1999; https://portal.vupop.sk/).

Hydrogeological conditions

In accordance with the hydrogeological zoning of Slovakia (Malík, Švasta, 2002 in Atlas krajiny SR, 2002), the area in question is located in hydrogeological region Q 051 'Quaternary of the western edge of the Danube Plain' with a predominant intergranular permeability type. In terms of the delineation of groundwater bodies in Slovakia (Kullman et al., 2005), district Q 051 belongs to the Quaternary groundwater body SK1000200P – Intergranular groundwater body of Quaternary alluvial deposits in the western part of the Danube Basin in the Danube river basin district, with a total area of 518.749 km^2 and to the pre-Quaternary groundwater body SK2000500P: Intergranular groundwater body of the Danube Basin in the Danube river basin district, with a total area of 1,043.038 km^2 (the list of groundwater bodies is also set out in Government Regulation No 282/2010 Coll., which establishes threshold values and a list of groundwater bodies). The hydrogeological character of the area is largely determined by its geological and tectonic structure. Given that the area of interest forms part of an area subject to intensive anthropogenic transformation (underground reservoirs, isolated harbour basins, river regulation), this anthropogenic influence is also evident in the hydrogeological conditions of the area.

Based on the geological structure, groundwater associated with ***Neogene and Quaternary sediments*** can be identified in the study area. From a hydrogeological perspective, Neogene sediments are less favourable, with groundwater occurrence mainly associated with layers of fine- to medium-grained sands, as well as a smaller proportion of gravels and sandstones. These rocks exhibit predominantly intergranular, and in places fissure, permeability. In this area, they are of only local significance; however, in cases where they are highly permeable and lie beneath Quaternary gravels, they can form a continuous aquifer of considerable thickness, thereby favourably influencing groundwater accumulation (Kordík et al., 2022).

Quaternary sandy gravels represent a significant aquifer with a free groundwater table. Groundwater infiltrates into these sediments primarily from the surface watercourses of the Danube and Little Danube, specifically in places where their channels and riparian deposits are not isolated or silted up. These sediments are highly permeable, with a filtration coefficient ranging predominantly from $k = 10^{-3}$ to $10^{-4} m \cdot s^{-1}$, locally up to $k = 10^{-2} m \cdot s^{-1}$, which represents very favourable conditions from a hydrogeological perspective. The groundwater level is shown in the figure: Groundwater level.

Groundwater recharge in the area is primarily provided by water infiltration from the River Danube, with atmospheric precipitation contributing to a lesser extent. The groundwater level fluctuates depending on the level of the Danube and the distance from its course. In the Bratislava– Dobrohošť section, the Danube flows significantly above the groundwater level, thereby continuously replenishing it. The influence of the Little Danube on the hydrogeological conditions of Žitný ostrov has changed over time as a result of modifications to its riverbed. Currently, the Little Danube in the section from the intake structure to the Nová Dedinka weir flows through a partially silted-up channel, with its water level predominantly above the groundwater level. However, this situation does not apply to the Prístav area (Kordík et al., 2022).

The average value of the permeability coefficient in this area is $T = 3.25 \times 10^{-4} m^2 \cdot s^{-1}$ and the filtration coefficient $k = 2.01 \times 10^{-4} m \cdot s^{-1}$. According to the classification of permeability and flow rate of aquiferous rock environments, the aquifer under investigation can be classified as a medium-flow aquifer (Class III) with relatively high permeability (Class III).

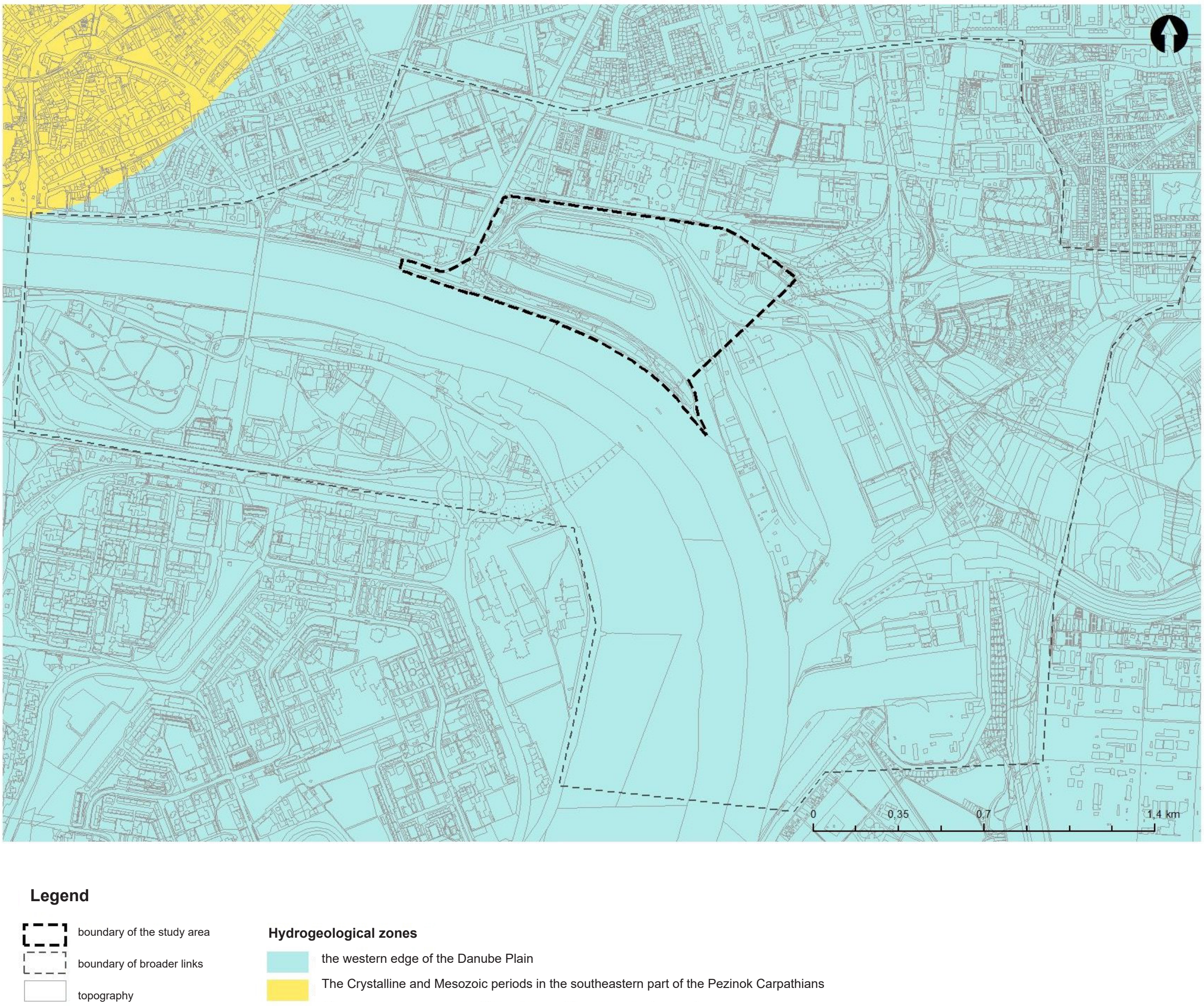
The dominant direction of groundwater flow in the area in question is predominantly south-easterly, whilst in the western part a south-westerly to southerly direction prevailed (Figure: Direction of groundwater flow).

The chemical composition of groundwater in the area is primarily influenced by the chemical composition of the Danube (so-called source water), water level fluctuations associated with phase shifts, the presence of contamination sources in the region, as well as the occurrence of iron and manganese in the rock environment, which create reducing conditions in the aquifer. Another significant factor is the calcareous nature of Quaternary sediments.

Under natural (anthropogenically uninfluenced) conditions, the study area contains basic-type fluviogenic groundwater, predominantly of the strong type (A2 > 66% equiv.), with a chemical composition of the Ca-Mg $_{HCO_3}$ type and total mineralisation in the range of 400–600 mg·l^{-1}. However, as this is an area subject to intense anthropogenic influence, the chemical composition of the groundwater is significantly altered by contamination (Hanzel et al., 2012).

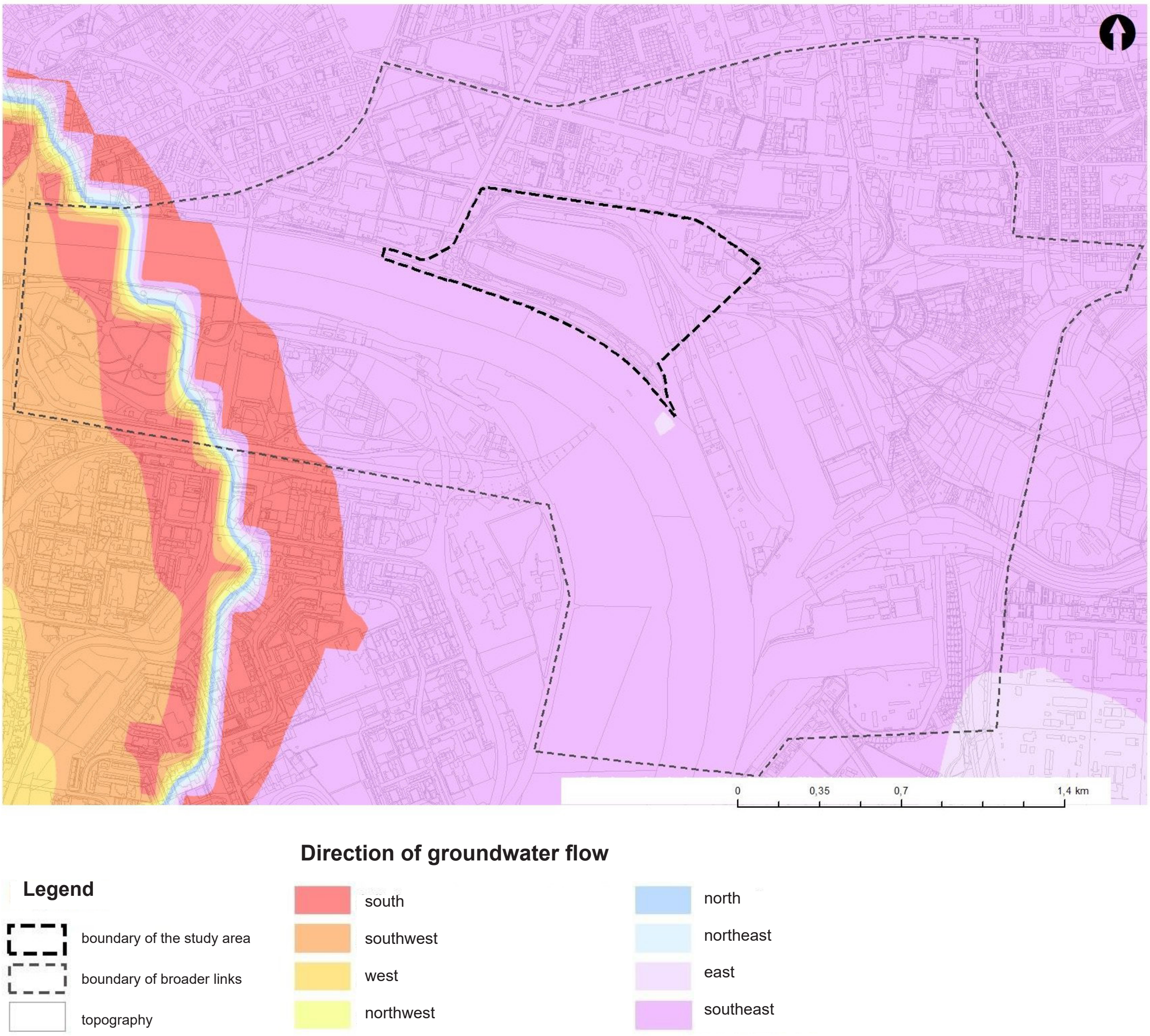
The anionic fraction of the chemical composition is dominated by sulphates, chlorides and nitrates, whilst the cationic fraction often exhibits elevated concentrations of sodium (Na^+) and potassium (K^+) at the expense of calcium (Ca^{2+}) and magnesium (Mg^{2+}).In anthropogenically influenced groundwater, undefined transitional and mixed chemical types typically occur, with S1 and S2 components dominating over the A2 component. The total mineralisation of such groundwater usually exceeds 800 mg·l^{-1} .

Figure 8: Hydrogeological regions



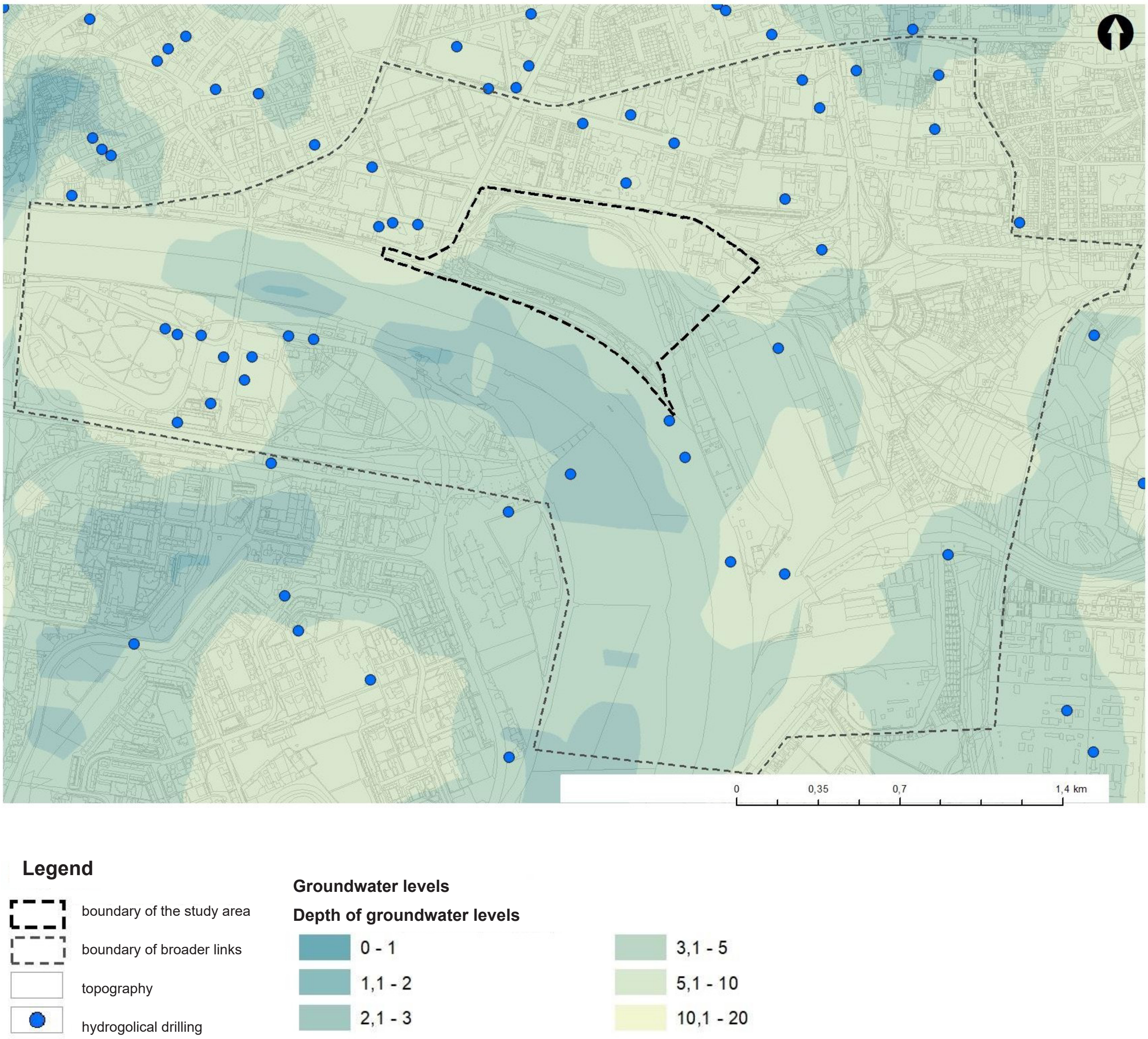
Source: Atlas of the Slovak Republic, 2002

Figure 9: Direction of groundwater flow



Source: https://app.geology.sk/gibges/

Figure 10: Groundwater level



Source: https://app.geology.sk/gibges/

Geological and hydrogeological survey

The area in question forms part of the Geological Map of the Danubian Lowlands – Danubian Plain at a scale of 1:50,000 (Maglay et al., 2018) and its Explanatory Notes (Maglay et al., 2017). The area is also part of the basic hydrogeological map of the northern part of the Danube Plain at a scale of 1:50,000 (Bottlík et al., 2013).

In connection with the survey tasks, the area of the site in question was included in the following selected reports:

- Environmental incident at the intake structure 2015–2018, remediation of the rock environment and groundwater, preparation of a risk analysis, partial final report for 2020, remediation of environmental contamination (Durdiaková et al., 2021);
- Environmental incident at the intake structure 2015–2018, remediation of the rock environment and groundwater, preparation of a risk analysis, partial final report for 2021, Bratislava – Ružinov – Malý Dunaj – intake structure, SK/EZ/B2/123, remediation of environmental contamination (Durdiaková et al., 2022);

- Environmental incident at the intake structure 2015–2018, remediation of the rock environment and groundwater, preparation of a risk analysis, interim final report for 2022, remediation of environmental contamination (Durdiaková et al., 2023);
- Site No. 204: Bratislava – Ružinov – Port (SK/EZ/B2/1904) (Kordík et al., 2022);
- Survey of probable environmental contamination B2 (1904) / Bratislava - Ružinov - Port (SK/EZ/B2/1904), detailed environmental survey, final report with risk analysis, Title of geologicaltask: Survey of environmental contamination at selected sites in the Slovak Republic (Auxt et al., 2015);
- Detailed hydrogeological survey for the project: Bratislava – cargo port area – groundwater source for the operation of the CRH concrete plant, detailed hydrogeological survey (Varga, 2018).

The wider port area has been extensively surveyed, as large-scale construction projects are underway there. Geological reports from hydrogeological and engineering-geological surveys and assessments of environmental contamination are archived on the ŠGÚDŠ Digital Archive portal.

Negative elements and phenomena

Natural stress factors and phenomena

Natural (or inherent) stress factors and phenomena include, in particular, radon risk, seismic activity in the area, slope deformations – landslides, susceptibility to water erosion, susceptibility to wind erosion, floods and inundation, and risks arising from climate change.

Radon risk

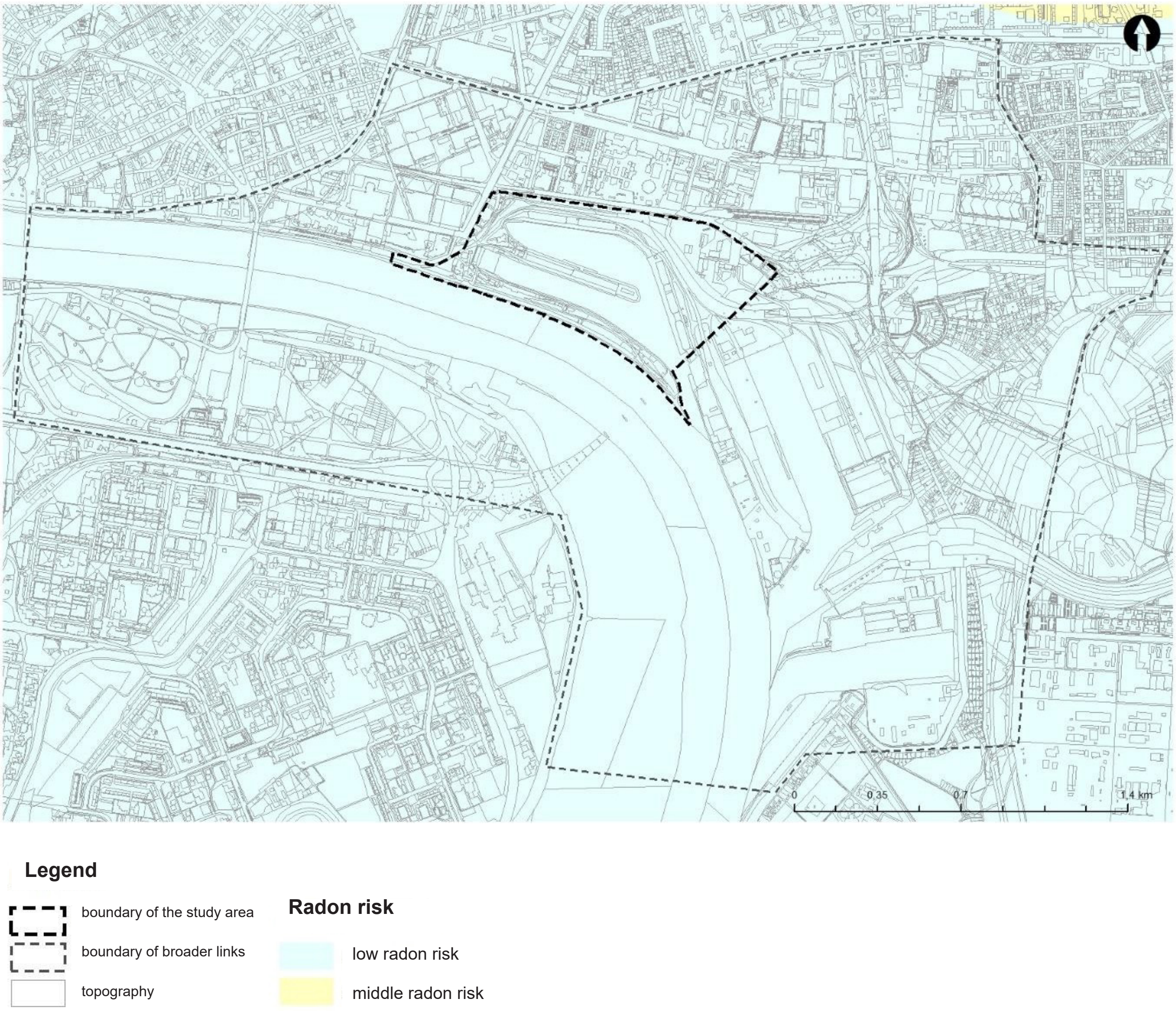
Radon, a product of the radioactive decay of radium, is commonly found in soil air. Radon cannot be detected by the human senses. It can penetrate to the earth's surface from great depths, most commonly through rock weathering and sedimentation, but also via mining works. It enters buildings through cracks in foundations, floors and walls, and through leaks in pipes. In areas with an increased risk of radon, effective measures for insulation and ventilation must be taken. Elevated radon levels can disrupt the ecological conditions for various forms of biota, including humans, in whom it causes cancer of the respiratory tract and other tissues.

Radon can also contaminate soil and groundwater, from which it is subsequently released into the air.

According to the website of the Dionýz Štúr Geological Institute (https://apl.geology.sk/radio/), the area of the winter harbour falls within a zone with a low radon risk (with a radon volume activity of < 20.00 kBq.$^{m^{-3}}$at medium substrate permeability). The wider area in the north-eastern part is marginally affected by an area with a medium radon risk (with a radon volume activity of 20.00 kBq.m^{-3} < av < 70.00 kBq.$^{m^{-3}}$at medium substrate permeability). Anti-radon measures are not necessary in such areas.

The occurrence of radon risk in the area is illustrated in the figure: Radon risk.

Figure 11: Radon risk



Source: https://apl.geology.sk/radio/

Seismic risk

Seismic hazard is the probability PI that seismic motion of level i (or I > i) will not be exceeded during a given time interval t at the selected study site. Macroseismic intensity and peak ground acceleration were used as characteristics of the seismic hazard in Slovakia. The primary source for assessing the seismicity of the area is the Seismic Hazard Map of Slovakia in terms of macroseismic intensity for a 475-year return period (GFÚ SAV, 2012) (https://www.seismology.sk/Maps/).

In terms of seismicity, the study area falls within the 6°–7° macroseismic intensity range (in ° MSK – 64) according to STN 73 0036 (Schenk et al., 2002 in Atlas krajiny SR, 2002). This intensity level in the study area corresponds to a peak ground acceleration on bedrock of 0.80 to 0.99 m$^{/s^2}$(Schenk et al., 2002 in Atlas of the Slovak Republic, 2002).

Slope deformations

Geodynamic phenomena manifest themselves through the disruption of rock stability on slopes, leading to various slope deformations such as landslides, ground flows, block deformations and the like.

According to the Map of Landslide Susceptibility (Šimeková et al., 2006, ŠGÚDŠ), the site in question falls within the 'Stable Areas' zone. These are predominantly stable areas, or areas with a very low susceptibility to landslide deformation.

According to the portal https://app.geology.sk/geofond/zosuvy/, there is no documented occurrence of geodynamic phenomena such as landslides, erosion processes, karst phenomena or sediment displacement in the study area or its wider surroundings (Atlas of the Slovak Republic, 2002).

Susceptibility to water erosion

Soil water erosion plays a significant role in shaping the landscape relief as well as in the degradation of the fertility-forming properties of agricultural soils (it leads to the loosening and subsequent transport of soil particles to which nutrients and organic matter are relatively firmly bound). Water erosion manifests itself in a reduction in soil profile depth (particularly the biologically active soil layer), a loss of organic matter and nutrients, and a deterioration in soil structure.

Section 5 of the Act on the Protection and Use of Agricultural Land defines the obligation to implement measures to protect agricultural land from erosion. Long-term extreme erosion can ultimately (in the event of complete loss of soil mass) lead to the disappearance of the soil itself, with the soil-forming substrate or parent rock being exposed at the surface. In accordance with this Act, every user of agricultural land is obliged to implement permanent and effective anti-erosion protection of agricultural land by carrying out protective measures in accordance with the degree of erosion of the agricultural land (Section 5(2)). Soil protection measures are aimed at preserving the qualitative properties and functions of the soil and protecting it from damage and degradation.

The threshold values for the categories of agricultural soil erosion are classified into four categories (www.podnemapy.sk):

- no to low erosion with soil loss of 0–4 t ha^{-1} per year ^{1},
- moderate erosion with soil loss of 4–10 t.$^{ha^{-1}}$.$^{year^{-1}1}$,
- high erosion rate with soil loss of 10–30 t.ha^{-1}.year^{-1}1,
- extreme erosion rate with soil loss > 30 t.$^{ha^{-1}}$ . .year^{-1}1

Soil vulnerability to potential water erosion is expressed as the soil loss that would occur if the soil were not covered by vegetation and no anti-erosion measures were applied.

Soil water erosion is usually assessed using computational models as either potential (area susceptibility, theoretical vulnerability) or actual (real soil erosion under current land use). Among the most widely used models is the so-called Universal Soil Loss Equation (USLE) developed by the American authors Wischmeier and Smith (1978) expressed as

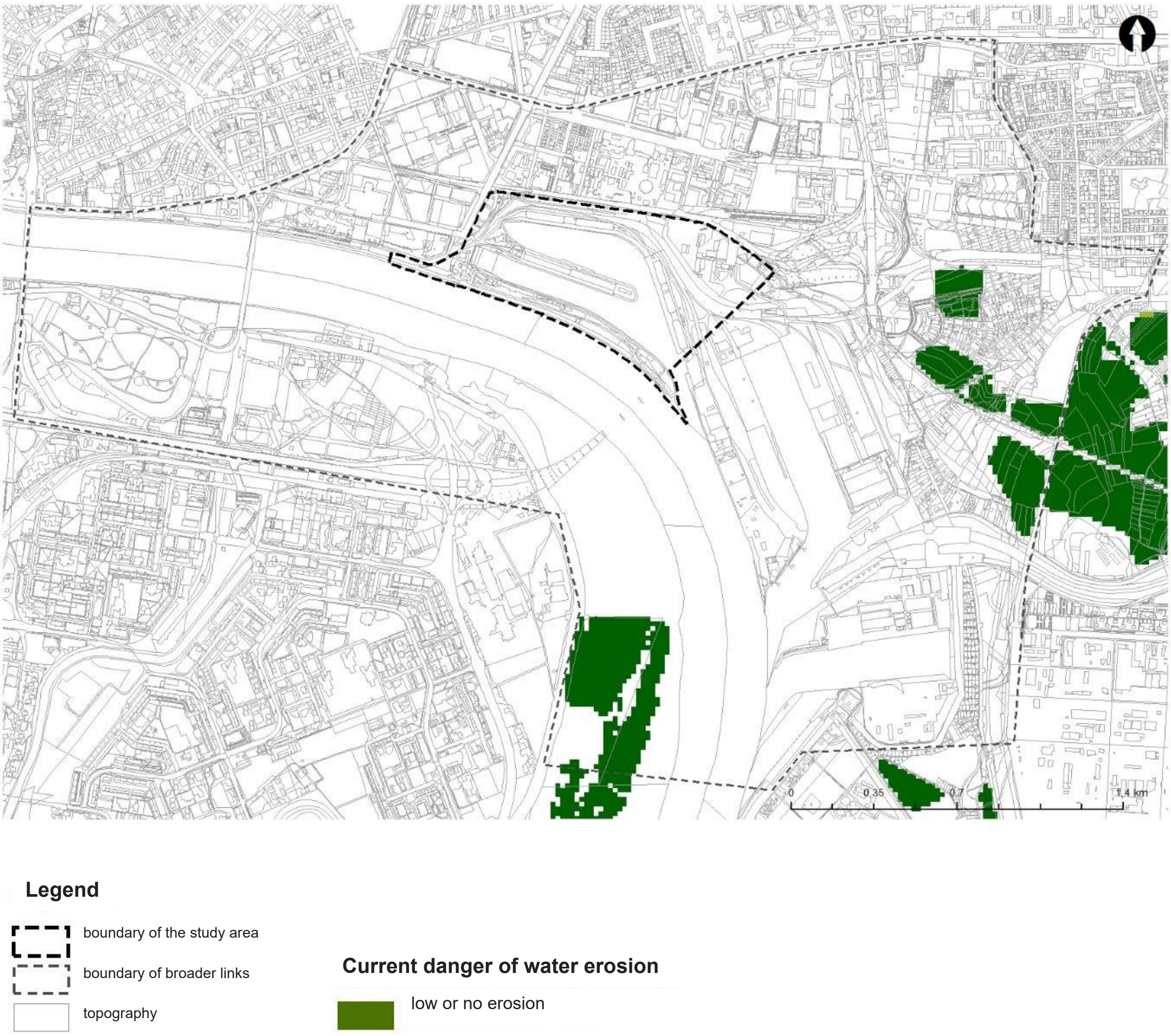
$$G = R \cdot K \cdot L \cdot S \cdot C \cdot P,$$

where G – total theoretical soil loss in t.$^{ha^{-1}}$.$^{year^{-1}}$, R – rainfall erosion factor, K – soil susceptibility factor, L – slope length factor, S – slope gradient factor, C – vegetation protection factor, P – effectiveness factor of anti-erosion measures.

This model has been adapted by several authors; for our conditions, for example, by Janeček et al. (1992) and the Research Institute of Soil Science and Soil Protection (VÚPOP) (an interactive model for calculating water erosion). The structure of the web application utilises the USLE erosion prediction model within a GIS environment. Detailed information on the erosion risk of specific arable land parcels can be obtained from the VÚPOP interactive model (www.podnemapy.sk).

The potential vulnerability of agricultural land to water erosion is illustrated in the following figure. Larger areas of low erosion occur mainly in the eastern and southern parts of the wider vicinity of the study area. Susceptibility to water erosion is a significant factor in agricultural development; as a result of intensive soil erosion, soil quality and thus fertility are reduced, leading to soil degradation.

Figure 12: Soils at risk of water erosion



Source: http://www.podnemapy.sk/default.aspx

Susceptibility to wind erosion

Wind erosion is a degradation process that causes damage not only to agricultural land and production—through the removal of topsoil, fertilisers and seeds, and the destruction of crops—but also by silting up roads and watercourses, creating wind drifts and polluting the air. Wind erosion occurs through the disruption of the soil surface by the mechanical force of the wind (abrasion), the removal of these disrupted particles by the wind (deflation) and the deposition of these particles elsewhere (accumulation).

The primary factors causing wind erosion are meteorological and soil factors. Among the meteorological factors, these are primarily wind conditions, precipitation and evaporation, i.e. wind speed and soil moisture. Soil factors include the content of non-erodible particles (> 0.8 mm) and the content of clay particles (< 0.01 mm) in the soil (Ilavská et al., 2005).

In practice, the rate of wind erosion is assessed on the basis of annual soil loss in $mm.year^{-1}$ or $t(m^3).ha^{-1}.year^{-1}$. The need for anti-erosion measures is indicated by exceeding the values of the so-called tolerable soil loss of 40 $t.ha^{-1}year^{-1}$ according to the Act on the Protection and Use of Agricultural Land.

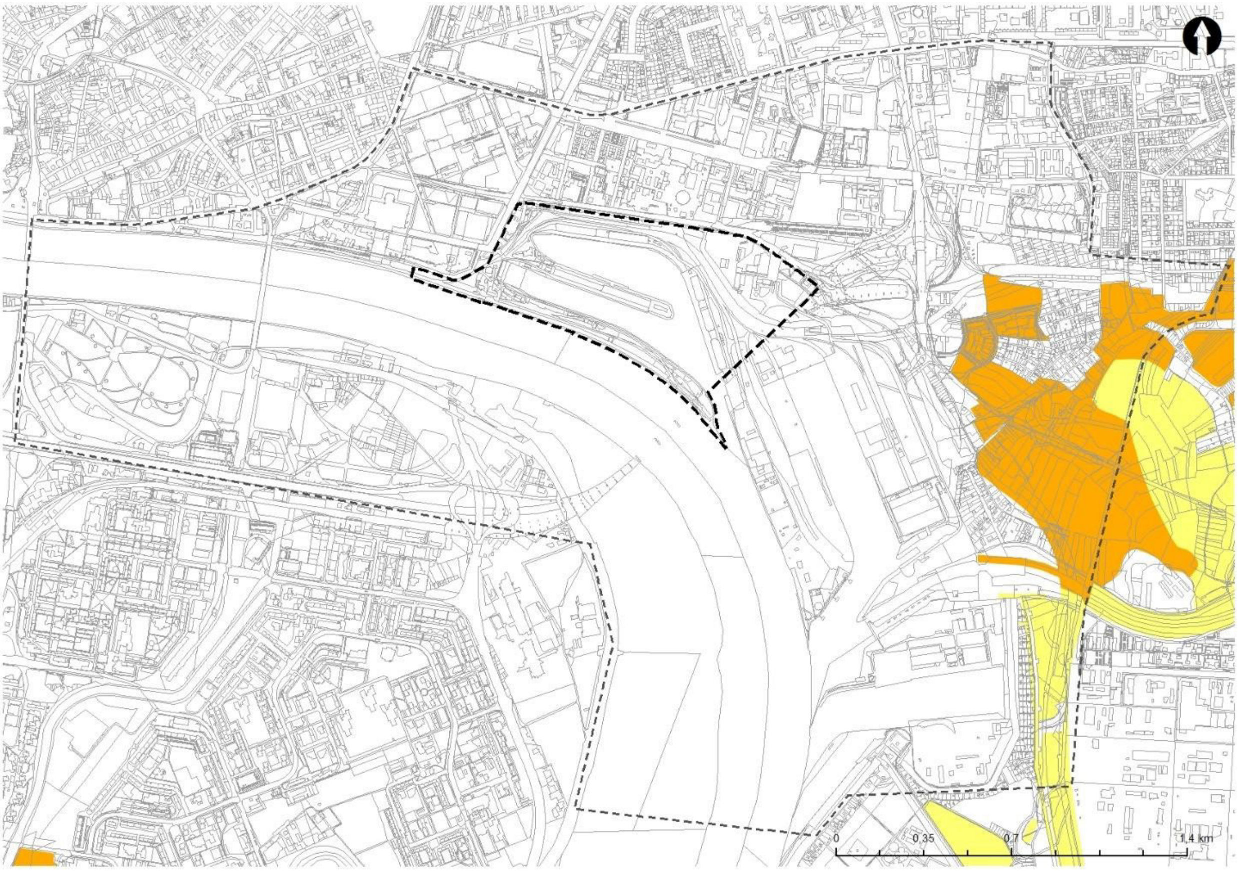
In determining potential wind erosion, data on climatic regionalisation, grain size and the characteristics of the main soil units from the BPEJ information system were used. Climatic regions and selected main soil units were graded according to their susceptibility to wind erosion (Jambor, Ilavská, 1998).

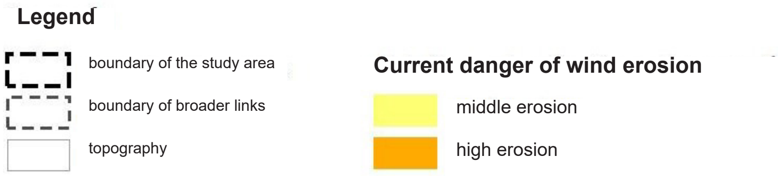
Potential wind erosion can be divided into the following categories:

- no to low erosion with soil loss up to 0.7 $t.ha^{-1}.year^{-1}$,
- moderate erosion with soil loss of 0.7–22 $t.ha^{-1}.year^{-1}$,
- high erosion with soil loss of 22–75 $t.ha^{-1}.year^{-1}$,
- extreme erosion rate with soil loss > 75 $t.ha^{-1}.year^{-1}$.

Soils at risk of wind erosion are shown in the following figure. Moderate to high erosion is mainly located to the east and south-east of the study area.

Figure 13: Vulnerability of the area to wind erosion





Source: http://www.podnemapy.sk/default.aspx

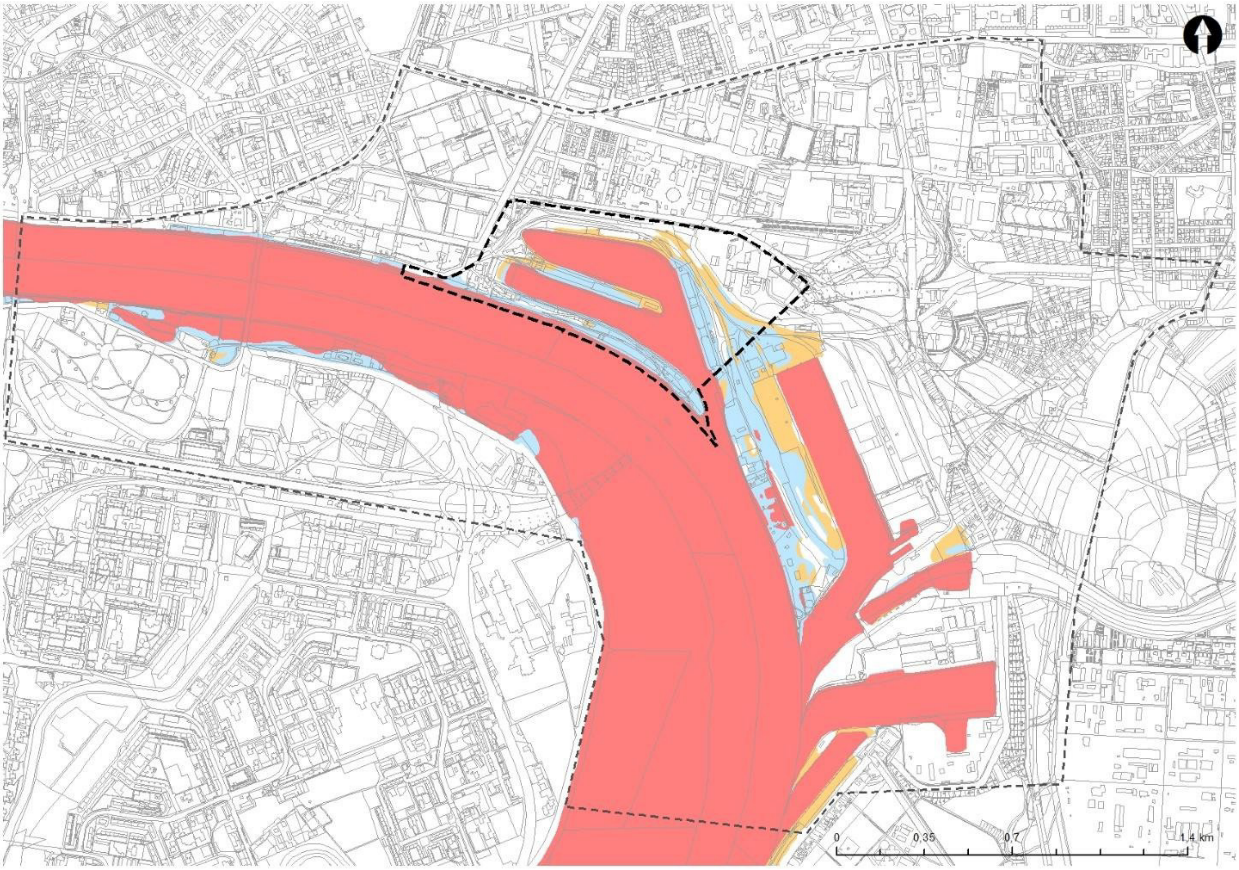
Risk of floods and inundation

According to Section 20 of Act No. 7/2010 Coll. of the National Council of the Slovak Republic on flood protection, a floodplain is an area adjacent to a watercourse which is usually inundated during floods by water overflowing from the channel. The floodplain area extending from the watercourse channel is defined by: a) the flood line of the watercourse, b) a linear structure whose purpose, or one of whose purposes, is flood protection.

As a result of heavy rainfall, watercourses may burst their banks even in areas where floodplains have not been designated. This mainly concerns small watercourses in foothill and mountainous areas, which, due to natural conditions, are prone to flooding caused by torrential rainfall. The flood risk to the affected area and the wider region is illustrated in the following figure.

Three categories of overall flood risk are present in the study area, with the majority of the area classified as being at high flood risk.

Figure 14: Flood risk



Source: https://mpt.svp.sk/

Risks arising from climate change

Risks arising from climate change for the area in question include:

Extreme weather: Increased frequency and intensity of extreme weather events, such as severe storms, floods and heatwaves.

Floods: Increased risk of flooding due to heavy rainfall and rising water levels in watercourses.

Drought: Longer periods of drought, which may affect water supplies, agriculture and vegetation.

Health risks: Increased health risks for residents, such as heatstroke, dehydration and the spread of insect-borne diseases.

Biodiversity: Threats to local flora and fauna due to changes in the environment and climate.

These risks require adaptation measures to mitigate negative impacts and ensure sustainability.

Anthropogenic stressors and phenomena

Pollution of surface and groundwater – surface water quality

Surface water

The quality of surface water in the Bratislava area is mainly affected by industrial activity, technical infrastructure and municipal wastewater, agricultural activity and shipping.

Under Slovak Government Regulation No. 269/2010 Coll., as amended by Government Regulation No. 398/2012 Coll. (hereinafter referred to as the ‘Regulation’), requirements for the quality and quality objectives of surface waters, as well as limit values for pollution indicators in waste water and specific waters, are established. Section 3 of this Regulation defines limit values for pollution indicators in waste water and specific water discharged into surface water or groundwater.

The surface water quality monitoring sites within the Bratislava area are listed in the table below. Based on the results of surface water quality measurements in 2023, it can be stated that the surface water quality requirements listed in the following table are those set out in Annex 1 to Government Regulation No. 269/2010 Coll. as amended by Government Regulation No. 398/2012 Coll. and in accordance with Annex 1 to Government Regulation No. 167/2015 Coll. According to the Government Regulation, the following parameters do not meet the general surface water quality requirements: pH, benzo(a)pyrene and cultivable microorganisms at 22 °C (SHMÚ, 2024b).

Table 4: List of parameters failing to meet the general requirements for surface water quality in 2023

NEC	STREAM	MONITORED LOCATION (MM)	River kilometre (rkm)	The following indicators do not meet the requirements, according to Annex 1:				
D002050D	DANUB E	DANUBE – Bratislava, left bank	1869	Part A	Part B	Part C	Part D	Part E
				pH				
D002051D	DANUBE	DANUBE – Bratislava City Centre	1869	pH		Benzo(a) pyrene		Cult. Microorg. At 22 °
D002052D	DUNAJ	DANUBE – Bratislava, right bank	1869	pH				

Source: Assessment of water quality in Slovakia, 2024b

Explanatory notes:
$N\text{-}NO_2$ - Nitrite nitrogen

Groundwater

In accordance with the Water Plan of Slovakia (Ministry of the Environment of the Slovak Republic, 2020), groundwater is assessed within Quaternary and pre-Quaternary bodies based on the results of quality monitoring. The presence and concentration of selected indicators such as NO_3, Na, Fe, Mn, Cr, Cu, Se, As, Cd, Pb, Hg, NH_4, Cl, SO_4 and others). During the monitoring period from 2013 to 2018, the affected Quaternary groundwater body SK1000200P was in good chemical status and the affected Pre-Quaternary groundwater body SK2000500P was in good chemical status.

For the year 2023 (SHMÚ, 2024c), based on the data obtained, the status of the affected groundwater bodies can be assessed as follows:

- In unit SK1000200P, groundwater is significantly affected by human activity. Most samples failed to meet the requirements of Ministry of Health Decree No. 91/2023 Coll. due to concentrations of total Fe and Mn exceeding the limit values, which indicates unfavourable redox conditions in the groundwater. Among the group of trace elements, long-term exceedances of the arsenic limit have been recorded at the Komárno and Kalinkovo sites. In 2023, the limit value for chloroethene was exceeded at several sites within the unit; the exceedance was most frequently measured in the August sampling. Pesticides, through the formation of metabolites, persist in groundwater over the long term, which is reflected in the ongoing recording of exceedances of limit values at several sites within this unit. In 2023, concentrations of glyphosate and promethrin exceeding the limit were recorded. The presence of atrazine, hydroxyatrazine, desisopropylatrazine and tebuconazole was also detected, albeit in concentrations below the limit value

- In unit SK2000500P, an excessive concentration of NO_3 was measured in both monitored sites in 2022. No other exceedances were recorded. At site 402290 Bratislava, the presence of specific organic substances has been recorded over the long term; in 2022, these were phenanthrene and chloroform.

According to the Slovak Republic's Groundwater Quality Balance for 2023 (SHMÚ, 2024d), as shown in the table below, the groundwater quality monitoring stations closest to the assessed area are: BA-RUZINOV (344990), BA-PALENISKO (272690), BRATISLAVA-VLCIE HRDLO (720192). The groundwater balance for the years 2022 and 2023 was calculated for the NH_4 indicators, NO_3, COD, conductivity, Cl_{Mn} , SO $^{(2-)}$, $_4$ TOC and As. The balance was favourable for all monitored parameters.

Table 5: Balance table for sites of the state groundwater quality monitoring network in 2022 and 2023 for selected indicators

No. of site	Site	Year	Conductivity	COD	Cl	NH_4^+	NO3	SO_4^{2-}	TOC	As	Total
344990	BA-RUZINOV	2022	1.31 A	4.28 A	3.28 A	5.55 A	6.66 A	7.81 A	1.62 A	14.28 A	A
		2023	1.47 A	5.71 A	3.42 A	100 A	3.87 A	7.93 A	1.81 A	13.33 A	A
272690	BA-FIREPLACE	2022	1.45 A	6.31 A	6.4 A	33.33 A	10.98 A	3.93 A	3.52 A	40 A	A
		2023	1.53 A	12 A	6.39 A	8.69 A	3.33 A	3.67 A	2.6 A	40 A	A
720192	BRATISLAVA VLCIE HRDLO	2022	2.08 A	2.6 A	5.74 A	4.76 A	100 A	7.4 A	1.53 A	21.05 A	A
		2023	2.23 A	2.14 A	4 A	7.69 A	100 A	8.53 A	1.71 A	23.52 A	A

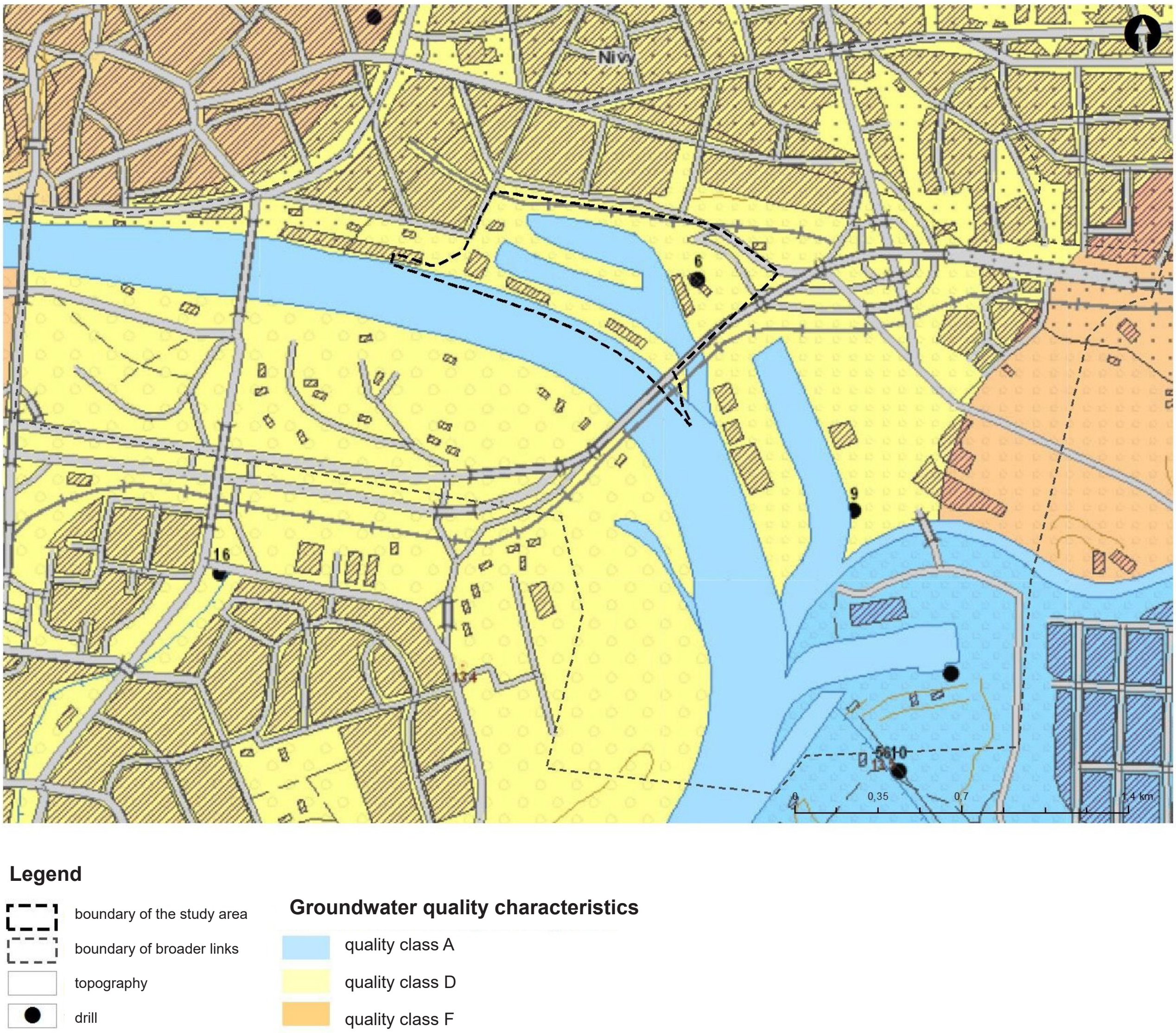
Source: Groundwater Quality Balance Sheet of the Slovak Republic (SHMÚ, 2024d)

Notes:
CODMn – chemical oxygen demand using potassium permanganate

The primary purpose of a hydrogeochemical map is to illustrate the most important qualitative and geochemical characteristics of groundwater in the first aquifer, or possibly other major aquifers. A hydrogeochemical map (Figure: Hydrogeochemical map) illustrates the qualitative characteristics of groundwater. The qualitative properties of groundwater are expressed through 8 groundwater quality classes (A to H). Groundwater quality classes are defined by grouping the limit parameters of the relevant regulation into three groups, according to their increasing toxicity and the complexity of water treatment technology (Decree of the Ministry of Health of the Slovak Republic No. 29/2002 Coll. on requirements for drinking water and the control of drinking water quality). Based on the hydrogeochemical map (Figure: Hydrogeochemical map), the area of interest is classified as quality class D. According to Gazda's classification, this is an A2 distinct type, with a chemical type of $_{Ca\text{-}Mg\text{-}HCO3}$ and a total mineralisation of 746 $mg.l^{-1}$ (https://app.geology.sk/hydrochem/).

The Gazda classification is based on Palmer's characteristics. It is suitable for assessing waters with petrogenic and mineralisation . In the case of of type A2 , these are calcium bicarbonate and magnesium bicarbonate components, and they are present in almost all waters as a product of carbonate dissolution (waters with carbonate-derived mineralisation) or, alternatively, the hydrolytic decomposition of silicates (Fľaková et al., 2020).

Figure 15: Hydrogeochemical map



Source: https://app.geology.sk/hydrochem/

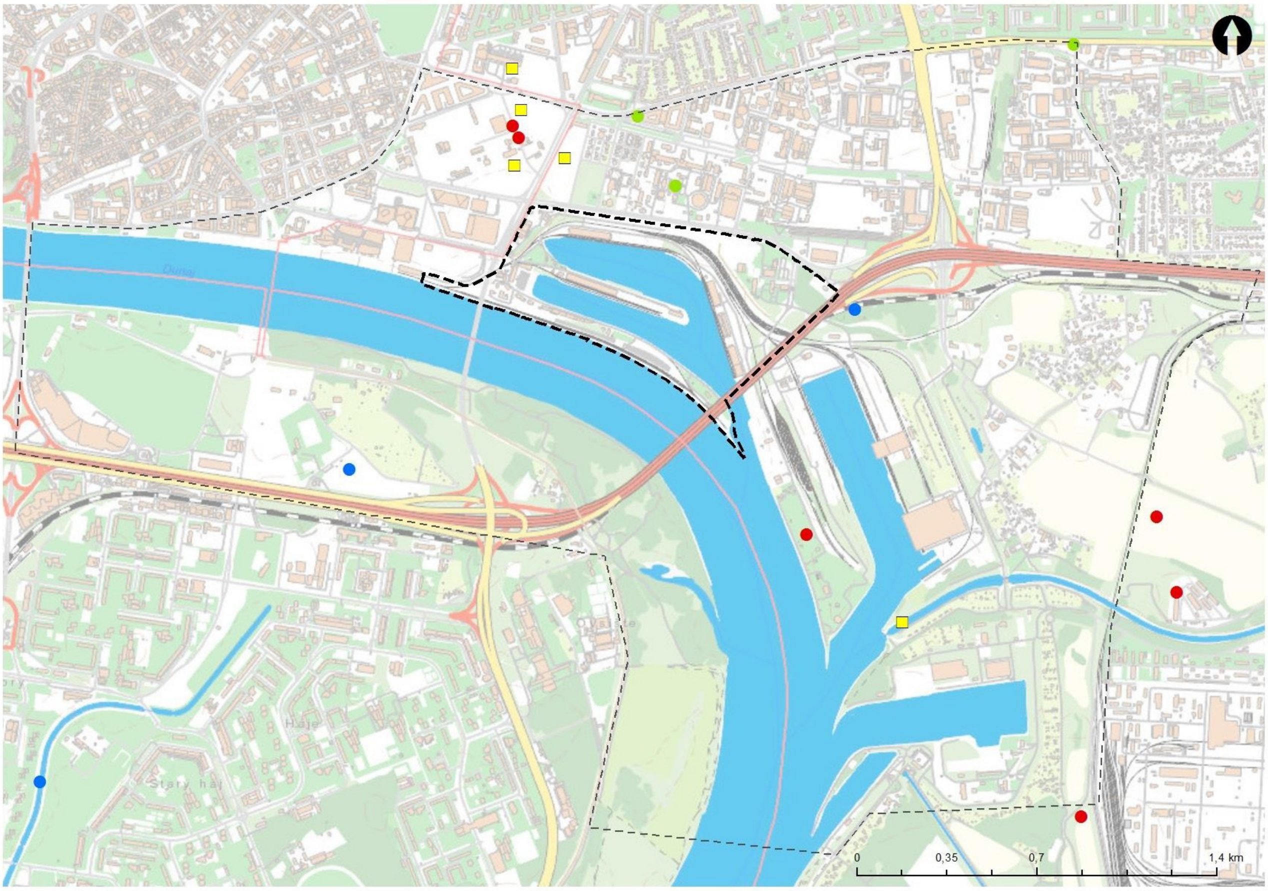
Degradation of soil resources – soil contamination, susceptibility of soils to acidification, susceptibility of soils to compaction, air pollution.

Environmental burdens

Several surveys have been carried out in the wider area of the site in question, which identified contamination of soil, rock and groundwater. There are several confirmed environmental burdens recorded in the vicinity of the site of interest, an overview of which is provided in the following figure and table.

A brief description of each environmental liability is compiled according to Enviroportál (https://www.enviroportal.sk/).

Figure 16: Environmental burdens



Legend

boundary of the study area

boundary of broader links

Environmental impact

probable environmental burden

environmental burden

recultivated / reclaimed site

environmental burden and recultivated / reclaimed site

Source: https://envirozataze.enviroportal.sk/

Table 6: Environmental burdens (https://envirozataze.enviroportal.sk/)

Identifier	Name of environmental burden	Site name	Type of activity	Priority level	Classification
SK/EZ/B5/2188	B5 (2188)/Bratislava – Petržalka – pollution near the footbridge over the Chorvátske rameno	Pollution near the footbridge over the Chorvátske rameno			Probable environmental impact
SK/EZ/B5/156	B5 (002)/Bratislava – Petržalka – DPMB site	DPMB site at the landfill			Probable environmental contamination
SK/EZ/B1/115	B1 (002)/Bratislava – Old Town – Apollo – wider area of the former refinery	Apollo – the wider site of the former refinery	processing and storage of crude oil and petroleum products	High-priority site (K > 65)	Confirmed environmental contamination; Remediated/reclaimed site
SK/EZ/B1/116	B1 (003)/Bratislava – Old Town – Chalupkova – Bottova St. – Chemika – factory site	Chalupkova – Bottova St. – Chemika – factory site	chemical production	High-priority contaminated site (K > 65)	Confirmed environmental contamination; Remediated/reclaimed site
SK/EZ/B2/122	B2 (006)/Bratislava – Ružinov – Gumon – industrial site	Gumon – plant site	chemical production	High-priority environmental site (K > 65)	Confirmed environmental contamination; Remediated/reclaimed site
SK/EZ/B1/2084	B1 (2084)/Bratislava – Old Town – Čulenova – New City Centre, Residential Tower IV	Čulenova – New City Centre, Residential Tower IV	processing processing and storage of crude oil and petroleum products; manufacture of chemicals	EZ with low priority (K < 35)	Confirmed environmental contamination
SK/EZ/B1/1986	B1 (1986) /Bratislava – Old Town – Twin City – southern part	Twin City – southern part	processing and storage of oil and petroleum products ( ); manufacture of chemicals	Low-priority EZ (K > 65)	Confirmed environmental contamination; remediated/reclaimed site

Identifier	Name of environmental burden	Site name	Type of activity	Priority level	Classification
SK/EZ/B1/2057	B2 (2057)/Bratislava – Ružinov – Twin City – northern part		electrical engineering production; fuel filling station; chemical production chemicals	High-priority environmental site (K > 65)	Confirmed environmental contamination; remediated/reclaimed site
SK/EZ/B2/1167	B2 (006)/Bratislava – Ružinov – Prievozská petrol station	Prievozská petrol station	petrol station	Not listed in the register	remediated/reclaimed location
Identifier	**Name of EZ**	**Site name**	**Type of activity**	**Priority level**	**Classification**

Identifier	Name of environmental burden	Site name	Type of activity	Priority level	Classification
SK/EZ/B2/131	B2 (015)/Bratislava – Ružinov – SPP Votrubova Street	SPP Votrubova Street	gas industry	Not listed in the register	remediated/reclaimed location
SK/EZ/B2/2171	B2 (2171)/Bratislava – Ružinov – contamination beneath the Prístavný Bridge	contamination beneath the Prístavný Bridge			probable environmental contamination
SK/EZ/B2/1904	B2 (1904)/Bratislava – Ružinov – Port	Port	storage and distribution of fuels	environmental site High-priority (K > 65)	confirmed environmental impact
SK/EZ/B2/1169	B2 (008)/Bratislava – Ružinov – ČS PHM Trenčianska	Trenčianska petrol station	petrol station	not listed in the register	remediated/reclaimed location
SK/EZ/B2/123	B2 (007)/Bratislava – Ružinov – Little Danube – intake structure	Little Danube – intake structure	product pipeline	Environmental site with medium priority (K 35 – 65)	confirmed environmental contamination; remediated/reclaimed site
SK/EZ/B2/2044	B2 (2044)/Bratislava – Ružinov – contamination in the vicinity of the planned R7	contamination in the vicinity of the planned R7	product pipeline	High-priority environmental site (K > 65	confirmed environmental burden;
SK/EZ/B2/120	B2 (120)/Bratislava – Ružinov – Čierny les	Čierny les	industrial waste	High-priority environmental site (K > 65)	confirmed environmental contamination
SK/EZ/B2/2059	B2 (2059)/Bratislava – Ružinov – I. chemical wastewater channel	I. chemical wastewater channel	chemical production; pipeline transport of chemical wastewater	EZ with medium priority (K 35–65)	confirmed environmental contamination

- **B1 (002)/Bratislava – Old Town – Apollo – the wider area of the former refinery (SK/EZ/B1/115)**

  The former Apollo oil refinery began operations in 1896. The refinery was bombed by the US Army on 16 June 1944, during which 80% of its production facilities were destroyed. According to archive data, there were approximately 54·000 $^{m^3\ of}$crude oil and petroleum products in the storage tanks, virtually all of which leaked into the rock environment. The leaked petroleum substances reached the groundwater table and were transported over long distances along its surface. These petroleum substances are currently found in the area of interest within the saturation zone, both as free-phase petroleum substances at the surface and in the form of contaminated soil (within the zone of historical groundwater level fluctuations) and contaminated groundwater. In 1945, production resumed at the refinery and, following its partial reconstruction, up to 210,000 tonnes of crude oil were processed annually during its peak production years. Crude oil processing at the former Apollka refinery ceased definitively in 1963 with the acid refining of oils, although the tanks and storage facilities on the site were still used for a short time (Jurkovič et al., 2021). Contamination of the rock environment has not been demonstrated as continuous from the aeration zone to the saturation zone. This contamination is characterised by the NEL IR indicator (non-polar extractables in the infrared region of the spectrum), $_{C10\text{-}C40}$ and PAHs (polycyclic aromatic hydrocarbons). In the aeration zone, anthropogenic fill in the contact zone (0.5–2 m) is the main source of contamination. In this horizon, all three indicators were found at elevated levels across almost the entire area of interest. In one soil sample, the lead concentration was slightly above the indicative criterion value. In the deeper horizons of the aeration zone (4–6 m), which consist of Quaternary gravels, minor soil contamination was detected in the western part of the site of interest. In the saturation zone (6 m below ground level and deeper), contamination characterised by the indicators NEL IR, $_{C10–C40}$ and PAU was identified exclusively in the north-eastern part of the site (Jurkovič et al., 2021). The environmental survey documented severe groundwater contamination in the indicators NEL IR, $_{C10–C40}$, PAU and ClU. In the north-eastern part of the site, the presence of free-phase petroleum substances (VFRL) at the groundwater table was also recorded. Excessive concentrations of NEL IR and $_{C10–C40}$ occur in the north-eastern part of the site and correspond to areas of rock contamination as well as the occurrence of VFRL. Similarly, high concentrations of pollutants from the PAU group were documented in the same parts of the site. This points to the fact that all these indicators are manifestations of a single source of contamination, the origin of which can be attributed to oil spills caused by the bombing of the APOLLO refinery. Contamination with chlorinated aliphatic hydrocarbons (ClH) on a smaller scale was documented in the western part of the study area (Jurkovič et al., 2021).

- **B1 (003)/Bratislava – Old Town – Chalupkova-Bottova Street – Chemika – factory premises (SK/EZ/B1/116)**

  The Chemika factory produced paints and varnishes and handled various chemicals. In the western part of the site, chemicals (epoxides, polyesters, glycerine and bitumens) were distributed in their original packaging, whilst in the eastern part, chlorinated hydrocarbons, sodium hydroxide and various types of mineral acids were transferred from railway tankers. The land in the Chemika area is contaminated mainly by petroleum substances originating from the Apollo refinery and chlorinated hydrocarbons (Jantáková, 2021).

- **B2 (006)/Bratislava – Ružinov – Gumon – factory site (SK/EZ/B2/122)**

  The Gumon factory was in operation from 1911. It produced electrical insulation materials, Bakelite, Gumon, Gumonid, oil-impregnated cloth, synthetic resins and asphalt. The factory also included a chemical storage facility. Pollutants from the Gumon factory included, in particular, degreasers, formaldehyde, kerosene, acetone, epoxides, methanol and ethanol. The Gumon site is contaminated with petroleum substances from the Apollo refinery, as well as aliphatic chlorinated hydrocarbons (POX) (Jantáková, 2021).

➢ **B1 (2084)/Bratislava – Old Town – Čulenova – New City Centre, Residential Tower IV (SK/EZ/B1/2084)**

The survey followed on from previous geological work in the centre of Bratislava, particularly in the Sky Park area and the wider site of the former Apollo refinery. The area in question (100 × 160 m) lies on the edge of the contamination plume; however, the surveys confirmed that the main contamination is not spreading to the site. Petroleum substances (NEL-IČ) were detected in the groundwater and the limits for PAHs were exceeded in one sample, but no

. The planned development (Čulenova – New City Centre) includes an underground car park to a depth of 5 m, which will prevent contaminated groundwater from entering the site. Active remediation is not required, but in the event of unexpected groundwater seepage, remediation measures will need to be carried out (https://envirozataze.enviroportal.sk/).

- **B1 (1986)/Bratislava – Old Town – Twin City – southern section (SK/EZ/B1/1986)** The geological survey carried out revealed extensive contamination with petroleum substances (NEL-

  IC), chlorinated aliphatic hydrocarbons (ClU) and non-halogenated aromatic hydrocarbons (BTEX). In Section A, contamination was assessed as residual, whilst remediation works (1997–2005) improved the condition of the rock environment. In Section B, the topsoil was clean, but the groundwater was slightly contaminated with ClU and petroleum substances. In Section C, the contamination was severe, exceeding the IT limits for NEL, POX and BTEX. The survey also revealed contamination of the soil air and the spread of groundwater contamination. Both environmental and health risks were identified, with a carcinogenic risk from benzo(a)anthracene demonstrated in Section C. The proposed remediation limits were approved by the Ministry of the Environment of the Slovak Republic, with the limits established as early as 2002 being applied to Section C (https://envirozataze.enviroportal.sk/).

- **B2 (2057)/Bratislava – Ružinov – Twin City – northern section (SK/EZ/B1/2057)** The final report on post-remediation monitoring summarises the results of the geological study 'Remediation of environmental contamination – Bratislava, Twin City North. The aim of the monitoring was to assess the current quality of groundwater and confirm the effectiveness of the remediation completed in February 2020 (Jurkovič et al., 2020). Monitoring work took place from December 2020 to August 2022, with eight cycles of groundwater sampling carried out from two monitoring wells, including field measurements of the monitored parameters.

  The results of the chemical analyses were compared with the ID and IT values set out in Annex 12 to Directive No. 1/201-7 of the Ministry of the Environment of the Slovak Republic of 28 January 2015. No limits were exceeded in borehole VSS-3. In the case of borehole TS-5, however, some ClU concentrations exceed the ID and IT values, which is due to its location outside the remediated area, in front of the underground barrier wall. The ingress of ClU into the groundwater originates from a source of contamination identified outside the investigated area. These elevated concentrations do not affect the success of the remediation and are not directly related to it (https://envirozataze. enviroportal.sk/).

- **B2 (008)/Bratislava – Ružinov – Prievozská petrol station (SK/EZ/B2/1167)**
  The remediation of the environmental contamination has been successfully completed. The atmospheric and chemical survey did not reveal the presence of a contamination epicentre in the rock environment. During the reconstruction of the petrol station, the old tanks and a small amount of contaminated soil. Source of pollution was eliminated (https://envirozataze. enviroportal.sk/).

- **B2 (015)/Bratislava – Ružinov – SPP Votrubova Street (SK/EZ/B2/131)**
  The environmental site in question is listed in the Slovak Republic's Register of Environmental Sites (SAŽP) as a confirmed and remediated/reclaimed site. Despite the remediation, there remains a risk of contamination of the natural environment (http://envirozataze.enviroportal.sk). The contamination originated between 1936 and 1960, when coal gas was produced at the site using carbonisation technology. Since 2002, contamination of groundwater with organic substances (NEL, phenols, PAHs, BTEX) and POX has been confirmed. The contamination was tar-like in nature, caused by leaks of production intermediates. Remediation took place between 2007 and 2010, followed by monitoring between 2010 and 2011. No new contamination is currently anticipated. Monitoring between 2016 and 2020 demonstrated a significant reduction in groundwater contamination. Concentrations of surfactants and chlorinated hydrocarbons exceeding the limit were not recorded. Total organic carbon (TOC) fell below the limit in 2020; a single exceedance of benzopyrene in 2019 was not persistent. Despite the improvement in groundwater quality, it is recommended to continue monitoring given the proximity of the

Ba-Gumon environmental site, where significant contamination persists.

- **B2 (1904)/Bratislava – Ružinov – Port (SK/EZ/B2/1904)**

The environmental site of concern in question is registered in the Environmental Information System The site has been classified by the Slovak Republic's Environmental Burden Register (IS EZ) and the Slovak Environmental Agency (SAŽP) as a confirmed high-priority environmental burden (with an overall assessment rating of K=72) due to the continuing risk of contamination of the natural environment (according to http://envirozataze.enviroportal.sk). The site was included in the monitoring programme on the basis of the Decision of the Ministry of the Environment of the Slovak Republic, ref. no. R-AR 75/2015

dated 30 December 2015. Based on the type of activity, it falls within the category of contamination in the transport sector. The period of probable gradual contamination dates back to the last century, to the time of the Port's establishment (1916), whilst the first mention of groundwater contamination at the Port dates from 1981.

The Port was established for the purpose of transhipping various types of goods from ships, primarily onto railway sidings. As various oils, solvents and other chemicals were (and still are) used in this activity and related work, it was assumed that improper handling of these substances could have led to the contamination of soil, groundwater and surface water.

Between 2014 and 2015, a detailed geological environmental survey was carried out at the site in question, including an assessment of the risk analysis for the contaminated area. Groundwater, surface water, soil and soil air within the rock environment were assessed. The survey results confirmed, in particular, oil contamination and tetrachloroethylene (PCE) contamination in the soil and groundwater at the site. No contamination was detected in surface water. A range of remediation options was proposed, with an evaluation of the most effective remediation procedure (Auxt et al., 2015).

Exploratory work carried out in 2014–2015 confirmed contamination in soil samples at the site with the indicators NEL IČ, $_{C10–C40}$, tetrachloroethylene (PCE), BTEX and PAU. Followup exploratory work also confirmed contamination in groundwater through the presence of VFRL, as well as excessive levels of NELIČ, $_{C10\text{-}C40}$ and tetrachloroethylene (PCE) (Auxt et al., 2015).

Monitoring between 2016 and 2022 partially confirmed the results of the 2015 survey, with the exception that contamination by PCE was not verified at the site, but particularly by DCE and VC. Even after 2015, the presence of free-phase petroleum hydrocarbons (VFRL) was confirmed at the site, but unlike in 2015, only in borehole PV-1 (VN204-1 Ryba). In boreholes PV-5, PV-7, PV-8, PV-10 (VN204-5, VN204-7, VN204-8, VN204-2), oil contamination with concentrations exceeding the NELUI and TOC limits was consistently confirmed during the period 2016–2021; however, this was not identified in the final year of monitoring, 2022.

Groundwater contamination at the Cargo Port site and at the Vlčie hrdlo Shipyard site has a negative impact on the environment within the contaminated area itself; however, monitoring work has not confirmed the spread of this contamination into the surrounding area in the direction of groundwater flow.

Between 2016 and 2022, potential contamination at the site was monitored two to three times a year by taking samples of surface and groundwater from selected monitoring wells and profiles. In the reference area (in the area unaffected by contamination), borehole PV-1 (VN204-1 Ryba) and the surface water profile of the Danube upstream of EZ, located below the Apollo Bridge, were sampled. The vast majority of boreholes in the Port and Shipyard area, including profiles on surface watercourses (basins), were monitored in the source area of the contamination. In the indicative area (in the area with potential contamination impact), a domestic well in the Vlčie hrdlo allotment area (PV204-8 – Mrs Ž.'s domestic well) was monitored, as well as profile PV204-4 (Danube below the Vlčie hrdlo shipyard). Based on sampling work from the period 2016–2022, it can be concluded that there was a significant reduction in groundwater contamination at the site during the final monitoring period. In the reference borehole VN204-1 (PV-1 Ryba), although the presence of the VFRL at the groundwater table persists, its thickness in 2019–2022 was lower compared to the previous period and fluctuated only within the range of 2–7 cm. The contamination in this borehole is not caused by activities at the Port, but arose as a result of the demolition of the former Apollo refinery, which was situated to the north-west of the Port.

However, the oil contamination caused by activities in the Port, which was identified in the groundwater in the form of NELUI exceedances, persisted for almost the entire monitoring period in source wells VN204-7 (PV-7) and VN204-5 (PV-5) in the Port and in borehole VN204-2 (PV-10) in the Shipyard. Concentrations exceeding the limit values for other organic indicators confirmed in the past were not detected in groundwater samples in 2021–2022. Based on water samples taken from monitoring profiles at the site under investigation, surface water quality in 2022 complied with legislative requirements and was not affected by pollution from the Port or the Shipyard.

Remediation at the site was recommended in accordance with the State Remediation Programme EZ 2022–2027. Until remediation measures are implemented, it is proposed to continue groundwater monitoring 1 to 2 times a year (spring and autumn cycles) (Kordík et al., 2022).

- **B2 (2059)/Bratislava – Ružinov – I. Chemical Wastewater Channel (SK/EZ/B2/2059) -** The CHOV canal was identified as one of the likely sources of the detected of organic origin during the investigation of the probable environmental contamination B2 (004) / Bratislava – Ružinov – Čierny les. The only finding prior to the current survey was information regarding elevated concentrations of chlorides, NH□□ and the specific substance benzothiazole present in both wastewater and groundwater in the vicinity of the Čierny les landfill. The total length of the canal was reported as 5.6 km, which was not confirmed – the canal route is approximately 8.7 km long and its location differs in part of the section. A detailed geological survey carried out at the site of Canal I of the CHOV confirmed groundwater contamination, particularly by pesticides. No concentrations of these pollutants exceeding the limits were found in the soil or soil air. The survey work also identified groundwater and soil contamination by petroleum substances (in the area around the Little Danube) and groundwater contamination by tetrachloroethylene (the section from Gagarinova to Rožňavská Street), which, however, are most likely not associated with the CHOV canal. A risk analysis has demonstrated that there is an environmental risk at the site from the spread of groundwater contamination by pesticides as a whole (total pesticides). Based on the results of a detailed geological survey, the site is recommended for remediation (https://envirozataze.enviroportal.sk/).
- **B2 (120)/Bratislava – Ružinov – Čierny les (SK/EZ/B2/120)**
  Surveys carried out in 2014–2015 confirmed that this is an environmental site of concern combined with active sources of pollution. The contamination consists of a mass of highly diverse and hazardous waste mixed with rock material, with a volume of approximately 425,000 m^3. The landfill body thus acts as a 'reservoir' for contaminated groundwater, which may seep into the surrounding area depending on its water level. No health risks have been confirmed at the site, but there is a risk of contamination entering and spreading into the groundwater. The water quality of the Little Danube has not been adversely affected by the landfill. Monitoring work has been ongoing since 2016, which in 2022 confirmed slight contamination of inorganic origin. In 2022, a supplementary environmental survey was carried out on part of the site, aimed at more accurately mapping the extent and degree of contamination of the soil in the area of the planned investment project – a logistics and industrial park. Contamination with petroleum substances was identified, although the risk analysis did not confirm any health risks. In this part of the site, following the completion of ex-situ soil remediation, a post-remediation risk analysis demonstrated that there is no environmental or health risk present in the area. However, comprehensive remediation of the remaining environmental contamination is still ongoing, and post-remediation monitoring will only be carried out once the remediation work at the site has been completed (https://envirozataze.enviroportal.sk/).
- **B2 (2044)/ Bratislava – Ružinov – pollution in the vicinity of the planned R7 (SK/EZ/B2/2044)**
  During the survey for the R7 expressway between Bratislava Ketelec and Bratislava Prievoz, borehole VJ-26 was drilled to a depth of 15 m below ground level, where a smell of diesel was detected at a depth of 5.9–8 m below ground level. Samples from the borehole and the surrounding area confirmed contamination of the groundwater with petroleum substances (NEL-IR, NEL-UV and TOC) exceeding the specified limits. In addition to petroleum substances, high concentrations of chlorides, increased electrical conductivity and water temperature were also detected. These results are included in the environmental impact study. The risk analysis confirmed that there is no environmental or health risk to workers carrying out remediation work in the vicinity of borehole VJ-26 (https://envirozataze.enviroportal.sk/).
- **B2 (007)/Bratislava – Ružinov – Malý Dunaj (SK/EZ/B2/123)** Several accidents have occurred at the site in the past as a result of damage to the pipeline pipeline, which caused oil substances to leak into the rock formation and be washed into the Malý Dunaj watercourse. Since 1978, the site has been monitored on a long-term basis by Geotest Brno for oil leaks, with the aim of protecting the groundwater of Žitný ostrov from contamination by oil substances from the Slovnaft Bratislava plant. Geotest Bratislava spol. s r.o. is carrying out ongoing remediation work focused on eliminating the consequences of the 2001 pipeline accident. Other companies and the Public Health Authority in Bratislava are also involved in the geological survey and remediation work. An assessment of this work is carried out annually in Geotest's final reports.

As part of the project "Monitoring of Environmental Burdens at Selected Sites in the Slovak Republic", groundwater quality was monitored via monitoring wells. The results showed that groundwater contamination with NEL and chloroethene persists at the site, with concentrations exceeding the limits set by Ministry of the Environment Directive No. 1/2015-7. In addition, elevated levels of indicators such as NH_4^+, TOC, S-sulf., and surfactants, which exceed the criteria for groundwater. In soil samples from boreholes VN138-2.5 and 7, high concentrations of NEL were recorded, exceeding the specified limits (https://envirozataze.enviroportal.sk/).

Landfills

Act No. 79/2015 Coll. of the National Council of the Slovak Republic on waste and amending certain acts establishes the rights and obligations of legal entities and natural persons regarding waste prevention and waste management.

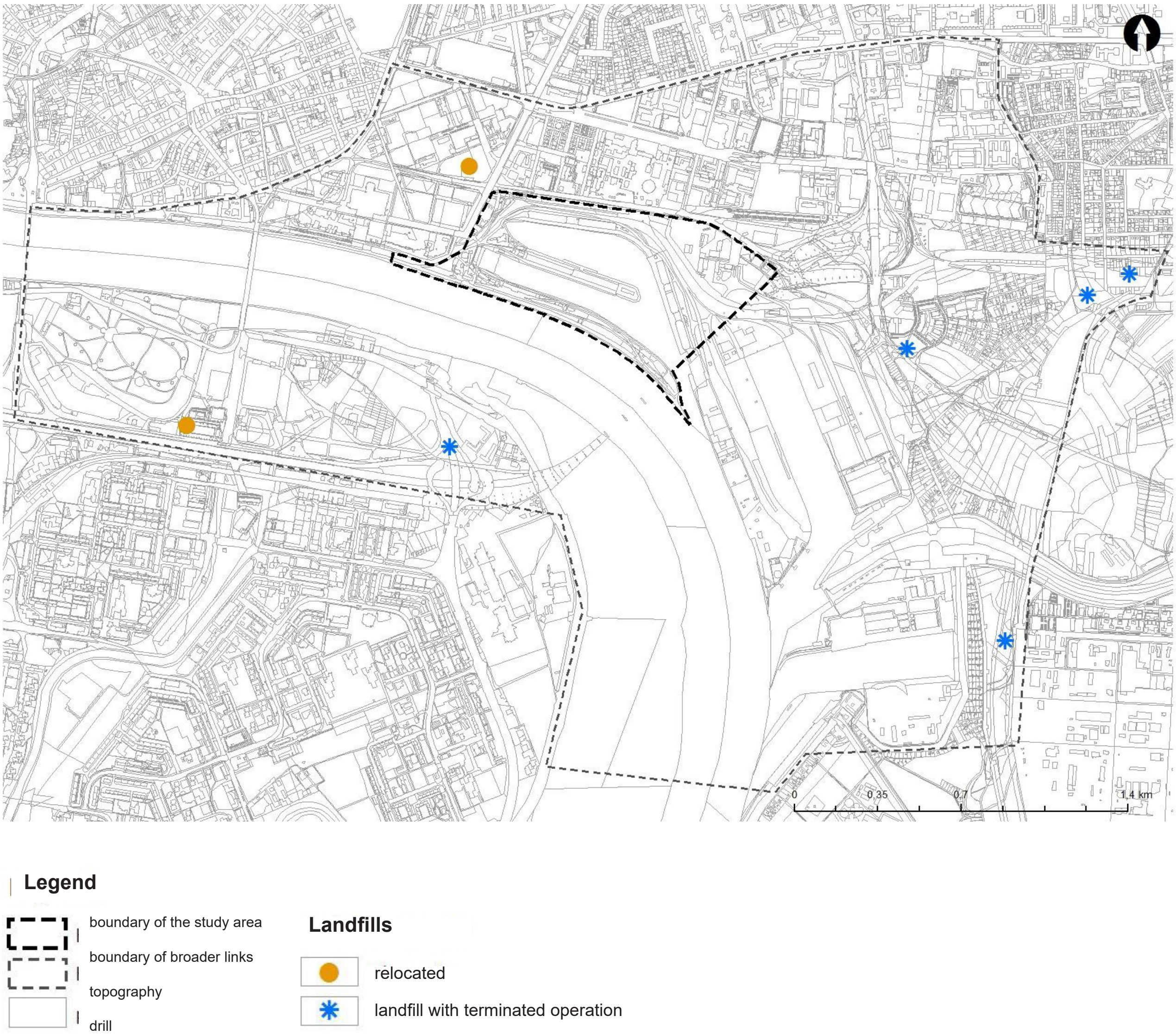
The ŠGÚDŠ portal operates a landfill application displaying point records of registered landfills. The database began to be developed intensively in 1992 as part of the Slovak Geological Survey's project 'Maps of Site Suitability for Landfills at a scale of 1:50,000' for the entire territory of the Slovak Republic. As part of this task, landfills in all districts of the Slovak Republic were registered at a scale of 1:10,000 (https://www.geology.sk/geoinfoportal/mapovy-portal/registre-geofondu/skladky/). Landfills in the wider study area are listed in the following table and shown in the following figure. There are 7 waste landfills in the wider study area, 5 of which are closed landfills and two of which have been removed.

Table 7: Landfills in the wider study area

Registration number	Place name	Regional significance	Status	Status of waste record-keeping	Waste disposal records
8585	Chalupkova Street	local (up to 5 municipalities with an average population of up to 2,000)	collected	none	not listed in the register
8599	Krasovský	local (up to 5 municipalities with an average population of up to 2,000)	removed	none	not listed in the register
8600	near Seč	local (up to 5 municipalities with an average population up to 2,000)	landfill site no longer in operation	none	not listed in the register
8606	Slovnaft - Lodenica	local (up to 5 municipalities with an average population of up to 2,000)	landfill site no longer in operation	none	not listed in the register
8593	Lúčna Street	local (up to 5 municipalities with an average population of up to 2,000)	landfill site no longer in operation	none	not listed in the register
8592	Jastrabia	local (up to 5 municipalities with an average population of up to 2,000)	landfill site that has ceased operations	none	not listed in the register

Registration number	**Place name**	**Regional significance**	**Status**	**Status of waste record-keeping**	**Waste disposal records**
Registration number	**Place name**	**Regional significance**	**Status**	**Status of waste record-keeping**	**Waste disposal records**
8591	UNS	Local (up to 5 municipalities with an average population up to 2,000)	landfill site that has ceased operations	none	not listed in the register

Figure 17: Landfills



Source: https://www.geology.sk/geoinfoportal/mapovy-portal/registre-geofondu/skladky

Soil susceptibility to acidification

Acidification is generally a process in which the concentration of $H3O^{+}$protons in the environment increases, leading to its significant acidification. Natural acidification is associated with the dissolution of CO_2 in water, the dissociation of organic acids present in the soil, the biogenic activity of bacteria, or the local oxidation of sulphides. Acidification is not merely a change in pH, but involves specific biogeochemical processes in the soil (Čurlík, 1998). This author summarised the possible causes and consequences of acidification as follows (Table: Causes and consequences of landscape acidification):

Table 8: Causes and consequences of landscape acidification

Natural factors	Anthropogenic factors	Consequences
- Acidic parent rock - root respiration (CO_2, acidic components, humus) - leaching due to precipitation - natural acidic components (SO_x, NO_x, NH_x) - nitrification	- change in land use - change in agricultural practices - land improvement measures - industrial and municipal waste - dry and wet acid deposition on soils	- pH reduction - reduction in $CaCO_3$ content - acceleration of weathering - leaching or mobilisation of nutrients - biological degradation - impaired fertility - limitation of nutrient uptake by plants - mobilisation of toxic elements, mainly Al^{3+}

Land acidification is considered a long-term reversible process. The manifestations of acidification follow a natural course – initially, the process is buffered by the buffering and neutralising capacity of soils (and overlying sediments); once this potential is exhausted, acidification begins. Its rate depends on atmospheric oxygen, the action of bacteria, the presence of water, etc.

The susceptibility of soils to acidification is addressed, for example, by Bedrna (1994) and Lehotský (1990), whilst Kočická (2006) examines the landscape's sensitivity to acidification. The susceptibility of soils to acidification depends on their filtration and buffering functions. The filtration function (Table: Filtration (fixation) capacity of soil subtypes in the region) was described in the previous chapter; it consists of the soil's ability to retain (fix) various substances, mostly foreign, and prevent them from reaching groundwater or entering the food chain. The buffering function is the soil's buffering capacity, which consists of its ability to mitigate the effects of chemical substances and temperature.

The filtration capacity is significantly influenced primarily by the soil type or subtype, but also by the grain size composition, depth and skeletal content of the soil (Table: Influence of soil properties on the filtration (fixation) capacity of soil).

Table 9: Filtration (fixation) capacity of soil subtypes in the area

Soils with high filtration capacity (with a high degree susceptibility – 3)	Soils with medium filtration capacity (with a medium degree vulnerabilities - 2)	Soils with low filtration capacity (with a low degree of susceptibility – 1)
- gley chernozems - gley fluvisols	- chernozems - chernozems - brown soils	- fluvisols - regosols

Table 10: Influence of soil properties on soil filtration (retention) capacity

Soils with high filtration capacity (with a high degree of susceptibility – 3)	Soils with medium filtration capacity (with a medium degree of vulnerability – 2)	Soils with low filtration capacity (with a low degree vulnerability – 1)
- deep soils - soils with no or low skeletal content - heavy soils	- medium-depth soils - moderately stony soils - medium-heavy soils	- shallow soils - sandy soils - light soils

The buffering function (Table: Buffering capacity of soil subtypes in the area) is influenced by soil porosity, humus content, clay minerals, carbonates, as well as vegetation cover, slope gradient and microclimatic conditions.

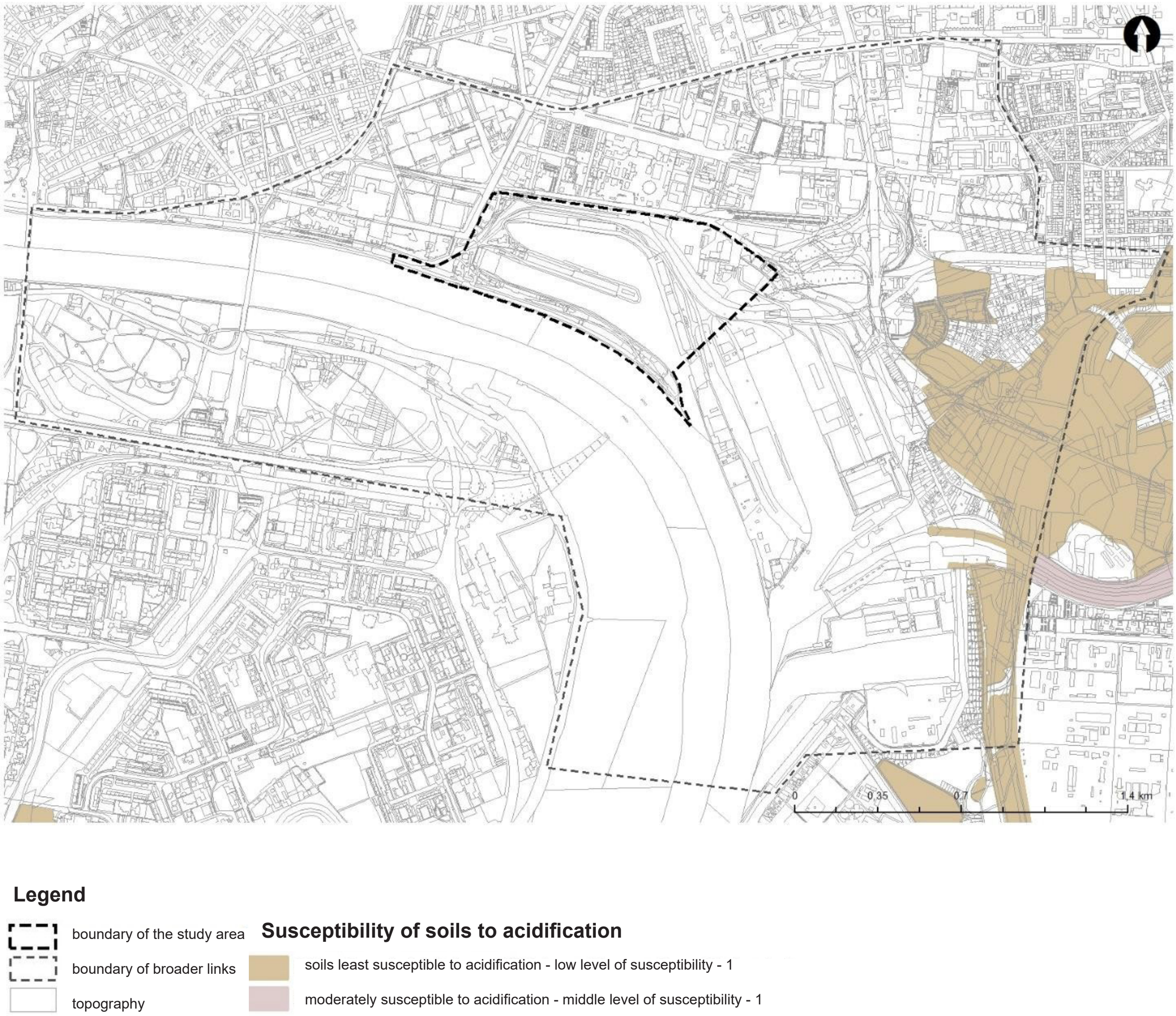
Table 11: Buffering (damping) capacity of soil subtypes in the area

Soils with high buffering capacity (resistant) (with a low degree susceptibility – 1)	Soils with medium buffering capacity (relatively resistant) (with medium degree susceptibility – 2)	Soils with low buffering capacity (susceptible) (with a high degree of vulnerability – 3)
- chernozems - chernozems	- gley chernozems - fluvisols - brown soils	- gley fluvisols - regosols

The decisive factor is the soil's ability to neutralise pH. Soils with the highest carbonate content are therefore considered the least susceptible to acidification.

Based on the above assumptions, the susceptibility of soils in the study area to acidification was determined as documented in Figure: Soil susceptibility to acidification.

Figure 18: Susceptibility of soils to acidification



Source: Atlas of the Slovak Republic, 2002

To the east and south-east of the wider study area lie soils that are least susceptible to acidification – with a low degree of susceptibility; soils of moderate susceptibility – with a moderate degree of susceptibility – are also present, albeit in smaller quantities. Soil acidification is manifested primarily in vegetation, through changes in species composition, biodiversity and land cover, and a reduction in ecological stability. At high levels of acidification, damage occurs to the inorganic component of the soil, changes in water retention and soil structure, and the replacement of nutrients (cations Ca^{+}, Mg^{2+}, K^{+}, P) with toxic elements.

Soil susceptibility to compaction

Soil compaction is a significant soil degradation process that affects the soil's productive function, as well as its susceptibility to other soil and landscape degradation processes (soil erosion, flooding). Soil susceptibility to compaction can be primary or secondary.

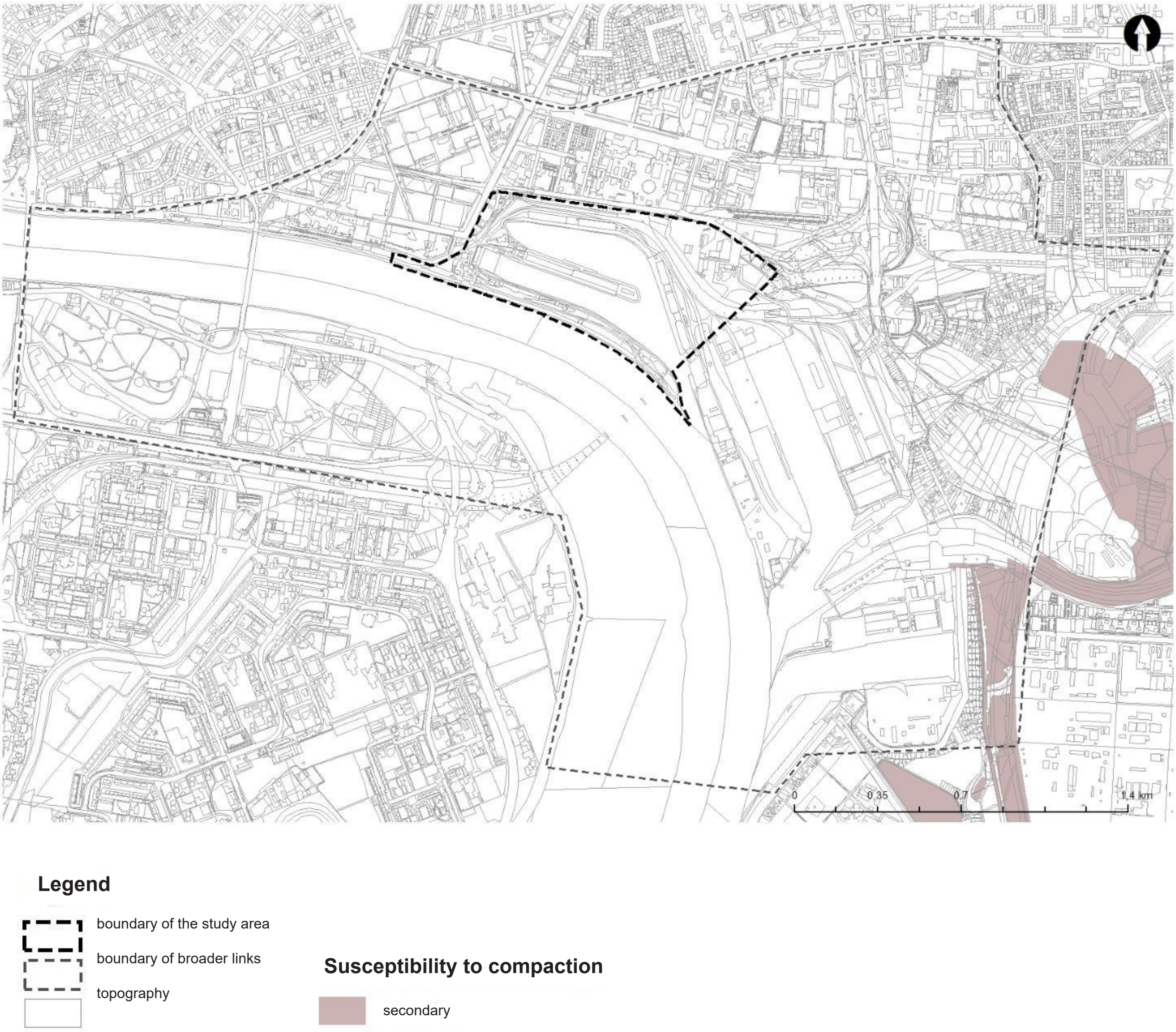
Primary compaction is determined by the genetic properties of the soil. All heavy soils (clay-loam, clay, and clay soils) are susceptible to it, as are soils with marbled and illuvial luvisol horizons (pseudogley, luvisols).

Secondary (technogenic) compaction is caused by human activity, either directly – through the pressure of agricultural machinery wheels – or indirectly – by reducing the soil's resistance to compaction through improper management, e.g. insufficient organic fertilisation, an unsuitable range of fertilisers, failure to adhere to biologically balanced crop rotations, farming methods and conditions, and so on.

To the east and south-east, within the wider area of the affected site, soils prone to secondary compaction are found. Soil susceptibility to compaction is an important factor in agricultural development; as a result of soil compaction, conditions for the development of crop root systems deteriorate, and water remains on the soil surface or runs off from it.

Soil susceptibility to compaction is illustrated in Figure: Soil susceptibility to compaction.

Figure 19: Soil susceptibility to compaction



Source: Atlas of the Slovak Republic, 2002

Air pollution

Bratislava lies at the junction of the Danube Plain, the Little Carpathians and the Borská Lowland. The specific orographic conditions of the area influence local airflow patterns, and the fragmented nature of the Little Carpathians in the Devínska and Lamačská Gate sections increases wind speeds from the prevailing directions, which has a beneficial effect on the city's ventilation. The area is dominated by westerly and north-westerly air currents with wind speeds ranging from 3 to 4 m/s.

According to Decree No. 254/2023 of the Ministry of the Environment of the Slovak Republic on air quality, the Bratislava agglomeration is designated for the pollutants sulphur dioxide (SO□), nitrogen oxides (NO_x), particulate matter PM□□ and PM□.□, benzene, polycyclic aromatic hydrocarbons (PAHs) and carbon monoxide (CO); the Bratislava Region also falls within the zones defined for these pollutants. The Bratislava agglomeration is also designated for the pollutants lead (Pb), arsenic (As), cadmium (Cd), nickel (Ni), mercury (Hg) and ozone (O_3). The city's territory has been classified as an air quality management area for the pollutants PM_{10}, nitrogen dioxide NO_2 and benzo(a)pyrene BaP (https://www.shmu.sk/sk/?page=997).

The dominant source of air pollution in the capital is road traffic. The busiest roads include the D1, D2 and D4 motorways, the R7 expressway, and the I/1, I/62 and I/63 roads.

In terms of their contribution to local air pollution, industrial sources of air pollution are of lesser significance as primary pollutants. The most significant stationary source of air pollution within the city is the Slovnaft
a in Vlčie hrdlo. Other major polluters within the city include the operations of Slovnaft a.s., Volkswagen Slovakia a.s., PPC Energy a.s., Duslo a.s., OLO a.s. and Veolia Energia Slovensko a.s. (NEIS, 2023). Sulphur oxide emissions are generated almost exclusively by an industrial source – the refinery. However, their levels have fallen significantly over the last few decades and the limit values for SO_2 concentrations in the air are not currently being exceeded, as is the case for other basic pollutants apart from NO_2. Nitrogen dioxide last exceeded the limit value at AMS Trnava toll in 2018 (https://www.shmu.sk/sk/?page=997).

According to data from the 2021 Census of Population, Houses and Flats (SODB), natural gas is the primary fuel used for heating family homes in the Bratislava conurbation; the proportion of solid fuels is the lowest compared to other zones (this is likely to be mainly for supplementary heating during transitional seasons using fireplaces).

In Bratislava, we monitor air quality at five monitoring stations. The traffic stations are located at Trnavské mýto, an area with high traffic intensity and a concentration of pedestrians in the city; another station is situated in Rača on Púchovská Street. The residential area is represented by the NMSKO station in Petržalka on Mamateyova Street; other monitoring stations are located in the residential district on Jeséniova Street in Koliba (monitoring background pollution levels in the suburban area) and right in the city centre on Kamenné námestie (monitoring urban background levels).

According to the monitoring results, the limit value for no pollutant was exceeded in 2023 in either the Bratislava agglomeration or the Bratislava Region zone. The target value for O_3 was exceeded at the suburban background monitoring station in Bratislava, Jeséniova. Long-term trends in PM and NO_2 pollution in this agglomeration and zone are declining (https://www.shmu.sk/sk/?page=997).

An overview of emissions of key pollutants in the district concerned for the last 5 years for which data is available is provided in the table below (Table: Emissions from stationary sources in the area concerned for the years 2019–2023 (NEIS, 2023)).

Table 12: Emissions from stationary sources in the affected area for the years 2019–2023 (NEIS, 2023)

Area	Emissions of pollutants (t/year)				
	TZL	**SO2**	**NOX**	**CO**	**TOC**
Bratislava II					
2023	86,294	3,554.813	2,603,635	358,828	153,534
2022	122,190	3,325,153	2,617,112	343,739	146,796
2021	116,594	2,140,164	2,402,633	427,611	154,903
2020	94,466	2,278,511	2,308,338	484,598	155,003
2019	108,245	3,047,063	1,998,311	438,979	152,611

Source: NEIS, www.air.sk

Geophysical survey

During the Second World War, the wider area around Zimný prístav was subjected to intense bombing by the US military, as it contained strategically important targets. In order to identify in greater detail any anomalies in the subsurface structure caused by the presence of unexploded ordnance or metal fragments resulting from wartime activities, the next step proposes the implementation of a geophysical survey using magnetometry. This method will enable the detection of ferromagnetic objects in the subsoil, thereby contributing to a better understanding not only of historical interventions in the geological environment but also to the assessment of potential risks associated with further research and engineering activities at the site.

Magnetometry is one of the most effective geophysical methods for investigating natural geophysical fields, namely the Earth's stationary magnetic field, and its application for various practical purposes. Magnetometry is one of the oldest geophysical methods, with the Earth's magnetic field first being used for navigation and subsequently in geology. The results of magnetometry are often used to address a wide range of tasks, such as various environmental issues; for example, the results of field capametry assist in addressing soil contamination by heavy metals. One area where this method can be applied is the resolution of non-geological issues, e.g. in the search for unexploded ordnance, various ferrous objects and the like (https://www.kaeg.sk/wp-content/uploads/2014/09/3 Magnetometria-skripta.pdf).

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