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AWARD

Alternative Water Resources and Deliberation processes to renew water supply strategic planning

D5.2 - Demo case#1 Implementation progress report

(UTCB)

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Project Consortium

EXECUTIVE SUMMARY

Deliverable **5.2 - Demo Case #1 Implementation progress report,** outlines the progress made up to Month 20 for Demo Case #1, located in the city of Bucharest. The deliverable is part of *WP5 - Experiencing AWRs solutions in demo cases for strategic planning*, and is specifically linked to *Task 5.2 - Demo case implementation*, with a focus on *Subtask 5.2.1 - Demo case 1 ''Circus Lake'' urban park Bucharest*, leads by UTCB.

Demo Case (DC) #1 focuses on providing Alternative Water Solutions (AWR), for Tei district in Bucharest city, to respond to the decrease of the groundwater level because of several hydrological and hydraulic factors that influence the zonal hydrological balance: climate changes revealed by the reduction of precipitation, the drastic reduction of water distribution system losses and unmonitored dewatering systems. As a direct consequence Circus Lake (Lacul Circului), considered by the citizens a Nature-based Solution (NbS) for leisure and recreation, suffered a decrease in its water level. Due to its hydraulic connection to the shallow aquifer system, the lake recharges the aquifer with rainwater captured from the park watershed. As AWR solution, it is foreseen capturing stormwater from the urban environment in the neighborhood (Tei area) and reusing it to control the water level in the lake, as a reliable ecological solution that support the aquifer recharge while maintaining the quality natural environment. This will be based on an accurate analysis of the urban water balance for the Tei area, including surface and groundwater flow, sustainable stormwater management with NbSs, such as bioretention systems and detention basins, as well as stormwater collection with aquifer recharge and consequently removal of stormwater from sewer network.

As DC#1 main objectives are to develop an accurate urban water balance for the Tei urban area based on AWRs solutions, informing and training the local administration of the Bucharest 2nd District as well as other stakeholders activating in this area on distinct AWRs solutions applied in cities strategic urban planning. The solution of controlling urban groundwater level in the Tei urban area, and implicitly Circus Lake Park water level by applying reliable AWRs solutions, is based on a quantitative water management framework as an innovative urban water management instrument on the basis of an accurate water balance (based on existing studies and models) where distinct surface water/groundwater impact scenarios (NbS implementation, infrastructure growth, climate change scenarios-horizon 2050, others) can be simulated. A nested connection with quality monitoring is developed.

The innovative framework for the urban water balance is developed by integrating three components: rainfall-runoff and urban drainage model with urban hydrogeological model, passing through the hydraulic characterization of unsaturated zone and urban fabric. A time series analysis using, among others, lumped-parameter models of the precipitation, surface water/groundwater levels and water quality data is used together with their determinants, like evapotranspiration, groundwater recharge, and groundwater pumping, to identify trends and periodic components in the observed data and interrelationships to all identified factors.

Quantitative water management analysis is developed based on previous experience in urban groundwater, vadose zone modelling as well as integrating surface water elements and rainfall-runoff phenomena. UTCB started the data collection task, further using the achievements in developing the water quantitative section together with the hydraulic characterization of the unsaturated zone and the urban hydrogeological model, integrating the hydraulic interaction between the aquifer and the urban infrastructure. Data sets acquisition is focused on rainfall-runoff and urban drainage processes in relationship with urban fabric and surface-water analysis (river, lakes).

Rainfall-runoff and urban drainage processes simulating the urban drainage, including sewage infrastructure, and identifying water accumulation areas, in various current precipitation scenarios and forecasts are currently simulated using dedicated software namely Watershed Modeling System (WMS), and GEOSTORM, (civilgeo.com/geostorm/). Using the boundary conditions and achieved knowledge of the city-scale hydrogeological model developed by UTCB (2010 - 2019), the downscaled urban hydrogeological model of the Bucharest city Tei district developed initially for (2006 - 2015) has been updated and developed for 2018. It regroups accurate area geology, subsurface urban infrastructure, and outline specific hydrogeological phenomena (e.g. groundwater – infrastructure interaction, reduction of the water distribution system losses).

From the qualitative point of view, a comparative analysis of the values of the main qualitative parameters of rainwater and stormwater with those from the aquifer and lakes is performed, as well as the possibility of local treatment of stormwater and rainwater through NbSs.

In parallel to the technical/scientific input, UTCB set-up a series of structured social engagement activities conducted to ensure transparency, stakeholder inclusion, and collaborative input into the AWR planning and design processes. Details are given in Section IV.

RELATED DELIVERABLES AND WORKPACKAGES' CONNECTION

This section details if there are any related Deliverables (e.g. interim versions, prerequisites etc.) and highlights links with the other Work Packages:

- The work carried out was based on the inputs from **WP5 - Experiencing AWRs solutions in demo cases for strategic planning** (T5.2 Demo case implementation) and especially the results concerning subtask 5.2.1: Demo case 1 - ''Circus Lake'' urban park Bucharest.
- The AWR regulatory of this deliverable is in line with Deliverable D2.1 "*AWR regulatory, policy framework and funding mechanisms*"
- The results presented in this deliverable will feed and will continue to inform the following project activities:
  - **WP3 - Patrimonial framework for AWRs assessment** (Task 3.2 - Development of Multi-Scales Multi-Actors Strategic Foresight): by supporting the development of the Strategic Foresight Framework for Demo Case #1;
  - **WP4 - Digital Ecosystem for AWRs Planning** (Task 4.1- Conception of the DST-TSD as the Digital Twin of the Project, Task 4.2 - Representation of Water contributions to Territorial Sustainable Development): by providing input on the key characteristics and operational features of the Alternative Water Resources (AWR) system in Demo Case #1
  - **WP6 - Impact maximisation** T (6.1- Communication and dissemination, T6.2- Social innovation and capacity building)

DOCUMENT INFORMATION

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VF	29/08/2025	Constantin Radu GOGU (UTCB)	Final version

TABLE OF CONTENT

LIST OF ACRONYMS

AWR	Alternative Water Solutions
CA	Consortium Agreement
DC	Demo Case
EC	European Commission
GA	Grant Agreement
NbS	Nature-based Solution
IA	Inversed Auger hole
IWA	International Water Association
UTCB	Technical University of Civil Engineering, Bucharest
WP	Work Package

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

To date, European cities are not prepared to face climate change and AWARD recognises the urgency of action due to water scarcity and climate change impacts as well as the need to engage simultaneously the society, the science and the policy into the development of knowledge and strategic water planning. Water and groundwater are crucial resources for achieving sustainability in urban areas. Despite their importance, very few studies quantify the hydraulic interaction between water and urban infrastructure, integrating distribution system losses, dewatering systems, groundwater wells, barrier effects, green/blue infrastructure, the thermal impact of constructions, shallow geothermal usage, or subsurface heat storage.

An innovative framework for the urban water balance is developed for a case study of the Tei district in Bucharest by integrating three components: rainfall-runoff and urban drainage model with urban hydrogeological model passing through the hydraulic characterization of unsaturated zone and urban fabric. A time series analysis using, among others, lumped-parameter models of the precipitation, surface water/groundwater levels and water quality data is used together with their determinants, like evapotranspiration, groundwater recharge, and groundwater pumping, to identify trends and periodic components in the observed data and interrelationships to all identified factors.

This study case analyses, from a quantitative and qualitative point of view, the possibility of capturing part rainfall and surface runoff and reusing it in urban area existing NbSs (man-made Circus Lake) as well as designing an urban district NbSs distribution to optimize the area defence against climate change. The case study is carried out on an area of 12 km^2 in the city of Bucharest. Currently, all surface runoff is captured by the sewage network and led to the wastewater treatment plant, from where it is discharged into the Dambovita River after treatment. In this way, treatment costs can be reduced, and rainwater can be reused as an Alternative Water Resource (AWR) for the benefit of the community through stabilizing the water level in the Circus Lake, proposing an optimal NbS distribution scheme for the district, and recharging the aquifer system. From the quantitative point of view, the analysis is based on the water balance drawn up for the Tei district urban area. From the qualitative point of view, a comparative analysis of the values of the main qualitative parameter’s values of rainwater and stormwater with those in the aquifer and lakes is analysed, as well as the possibility of local treatment of rainwater through NbSs.

Studies of city-scale urban surface water and aquifer water dynamics should be based on accurate urban stormwater, surface water and groundwater balance analysis including natural and human-induced water sources, geological and anthropogenic strata, and the entire set of the urban infrastructure elements. Since the knowledge of deposits located in the shallow urban subsurface is increasingly important for urban planning (Dijkstra, et al., 2019), there is a need for better classification of anthropogenic materials and their hydraulic properties. To date, there are very few published hydraulic studies on anthropogenic strata in cities, and most of them are of a pioneering nature. Previous studies developing city-scale urban hydrogeological models (Boukhemacha, et al., 2015), (Gogu, et al., 2017), (Gogu, et al., 2018) demonstrated the necessity of correctly quantifying the natural and the anthropogenic strata hydraulic conductivity to properly assess aquifer dynamics as well as groundwater recharge from precipitation.

In Romania, there is currently no coherent approach at the national and local level for the use of Alternative Water Resources (AWR). Even if in some areas the annual amount of precipitation can be said to have had a relatively small variation in relation to that of a few decades ago, nevertheless this occurs against the background of long periods of drought followed by very high intensity rains, so with large amounts of water in very short periods of time. In this way, the surface runoff on natural soils is very strong, producing floods, the recharge of aquifers through infiltration being deficient. In the urban environment, the situation is much more complex due to:

- the presence of impervious surfaces;

- the presence on the land surface of the anthropogenic material defined by Craul (1985) as urban soil, which can reach a thickness of over 10 m;
- the existence of the surface infrastructure and underground infrastructure (basements, parking lots, subway tunnels, sewage networks, water supply networks, etc.);

Sanchez-Vila (2009) highlights a series of aspects regarding the circulation of water in the urban environment both when crossing the unsaturated and the saturated zone:

- the irreversible change of the solid matrix under the foundations or underground constructions (sewage, water pipes, subway lines and stations, reservoirs, etc.) as well as the pumping or aquifers hydraulic head drawdown leads to the change of the hydrodynamic spectrum of groundwater (Figure 1);
- changes in the water cycle induced by impermeable surfaces such as roads and buildings (Figure 2) with changes in the evapotranspiration rate, by infiltrations from water supply systems or infiltration/exfiltration from sewer network, reservoirs, waste deposits (Figure 1);
- pollution of the unsaturated zone and implicitly the saturated one (Figure 1)

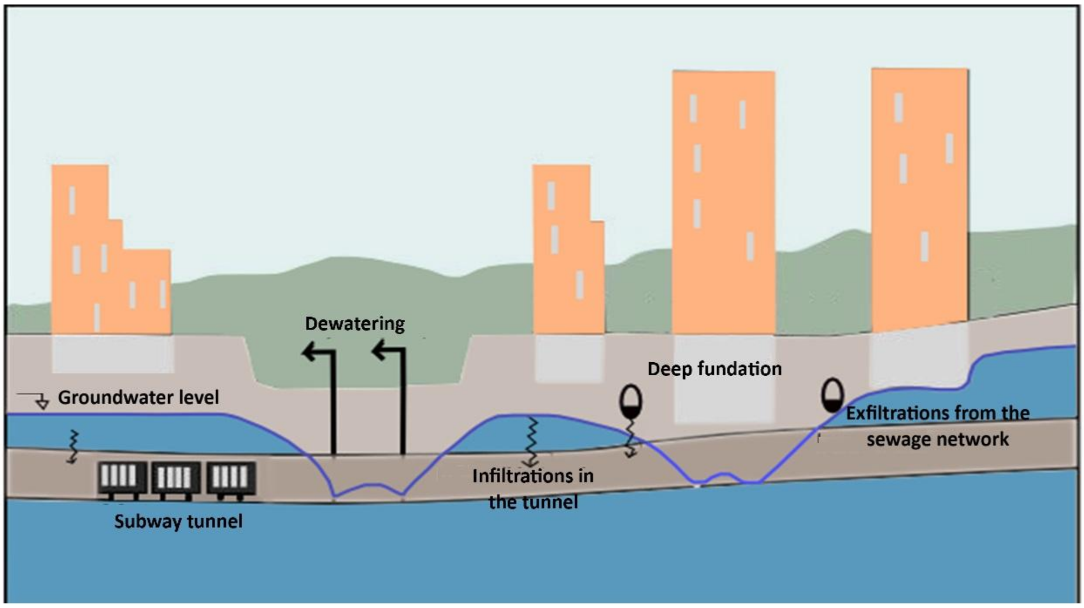


Figure 1: Particular aspects regarding water cycle in the urban area (modified after Vasquez-Sune et al, (2005)

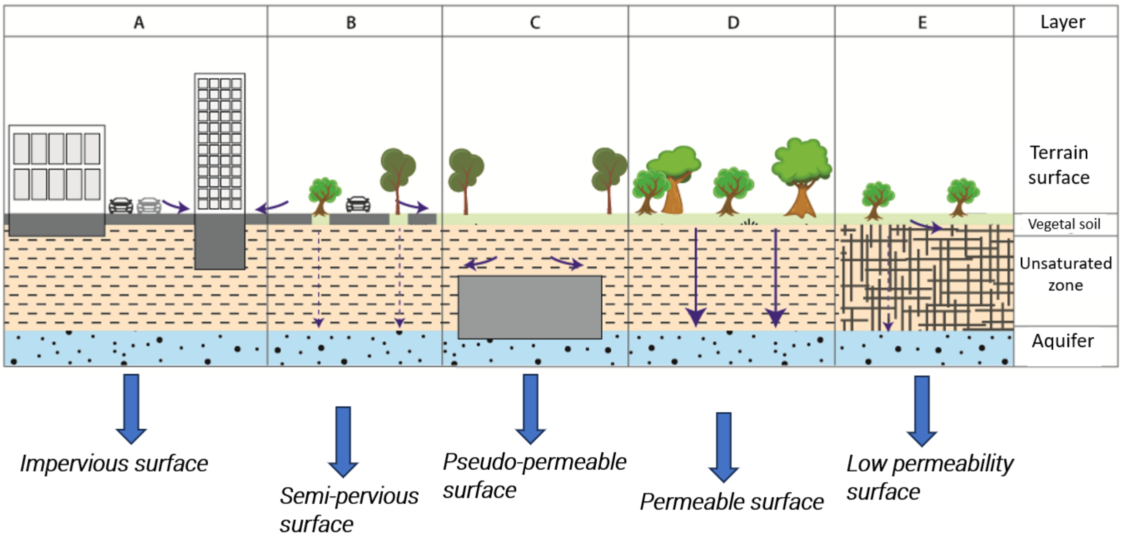


Figure 2: Rainwater infiltration depending on the urban fabric of the urban area (Gaitanaru, (2019)

The application in the urban environment of nature-based solutions (NbS) by reusing rainwater and stormwater for the purpose of maintaining ecosystems, irrigation, recharging aquifers, and others, stay as a solution to mitigate the effects induced by climate change. However, these solutions must be applied rationally in the sense that they must be based on hydrological and hydrogeological modelling, which in turn these must be based on a correct water balance. Without a proper simulation of the relationship rain-runoff-infiltration-aquifer recharge, the urban infrastructure can be affected by the increase of the groundwater level that could generate flooding (Figure 3), damage to the building foundations, occurrence of overpressures, etc. Inadequate appreciation of urban ground conditions or ignoring them, and especially not taking into account the presence of groundwater and its dynamics control in urban infrastructure planning and design, is recognized as the largest cause of construction project delays, costs overrun, as well as subsequent damage of the urban infrastructure (Foster, et al., 2019).

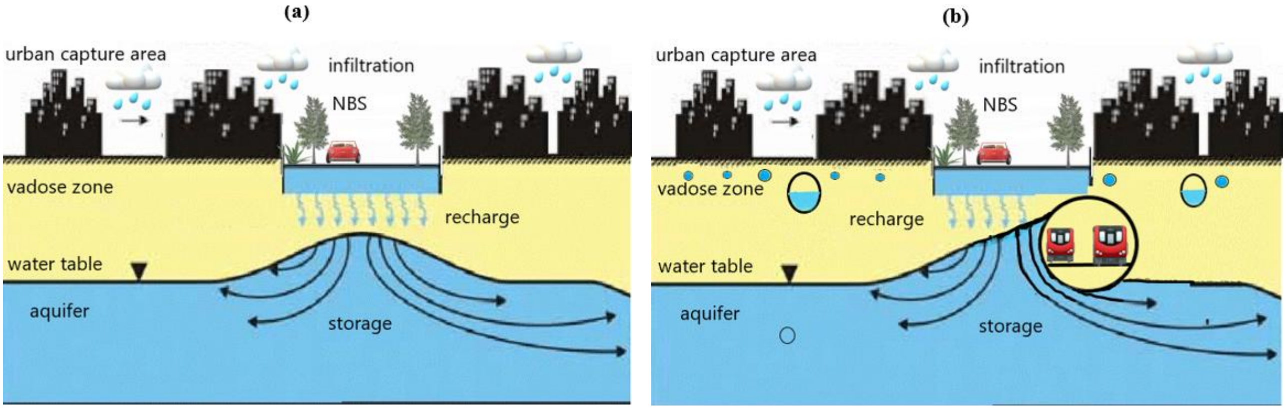


Figure 3: The effect of placing NbS in the urban environment
(a) incorrect - without taking into account the existing infrastructure; (b) correct – considering the existent infrastructure. Source: UTCB-CCIAS, Radu Gogu presentation, 2019

Thus, this study aims to achieve the following objectives:

- Development of a correct urban water balance for the Tei district (Bucharest city study area) using alternative water solutions (AWR).
- Study of social acceptability of AWR. Informing and training stakeholders, operating in this area, about AWR's distinctive solutions applied in strategic urban planning of cities.
- Dissemination of the research results through scientific works, social media, or other channels.

To achieve the objectives, the following activities are carried out:

- For the urban area in the Tei district, an urban hydrological model of the precipitation runoff is developed to quantify the volumes of water that could be captured to be reused in the control of the water level of Circus Lake (Circului Lake);
- Starting from the large-scale general urban hydrogeological model of the city of Bucharest, developed in a previous project, UTCB, with the data support from the water operator of the municipality of Bucharest (ApaNova S.A.), develop a local model of increased accuracy for the Tei district and analyse the potential behaviour of the urban aquifer system and the water volumes needed to be recharged. The model includes the losses of the water supply network, the interaction with the sewage network, the barrier effect produced by the existing subway tunnels, as well as permanent and temporary drainage systems;
- A chemical water quality framework and an on-site natural treatment scheme for rainfall and stormwater reuse will be analysed;
- A quantitative water management assessment framework is developed for the test site to match optimal green infrastructure solutions;
- A hydrological stress test is defined - regarding the maximum values of flow rates and pollutant concentrations - of urban surface and groundwater;

▪ Based on water quality parameters, the types of plants used to improve water quality and reduce toxic substances will be analysed;
▪ Urban planning schemes will be defined in District 2 of the Bucharest municipality, based on a correct quantitative balance of water management, including possible optimal implementation schemes of green infrastructure elements.

I Description of the demo site

I.1 Description of the area/region

The demonstrative case (DC#1) is in the city of Bucharest (Figure 4), on the administrative territory of District 2, in the northern central area of the city. With an area of 12 km^2, this zone covers several dense urban perimeters, two large parks (Circus Park and Tei Park) and two lakes that are part of these parks. The largest part of the analysed area is located between the Dambovita and Colentina rivers that crosses the city from the NW to the SE.

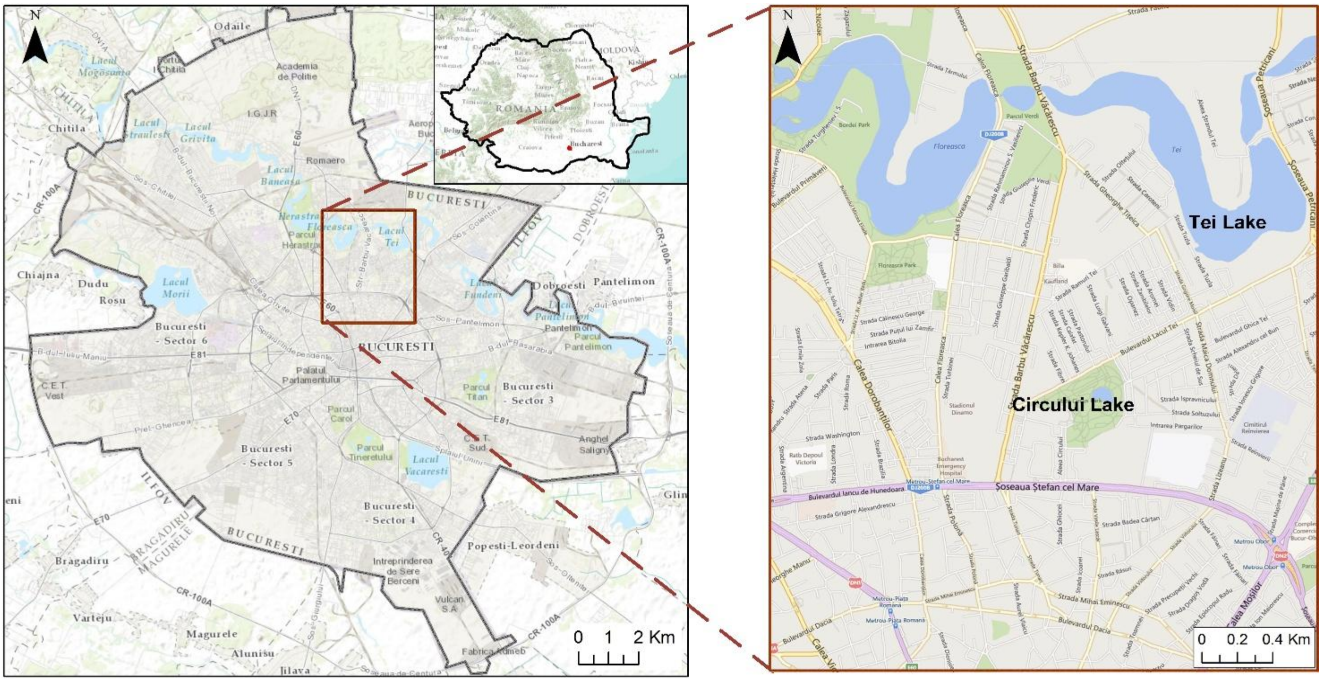


Figure 4: Location of the study area, Tei district

As can be seen in Figure 4, Tei Lake is part of a system of chained lakes along the Colentina River, connected by hydrotechnical nodes with a role in taking over floods, the water level being fluctuating from one season to another. The water level is controlled by the Romanian Waters National Administration. With an area of 0.75 ha, Circus Lake (Lacul Circului) is an element of green infrastructure, and can be seen as a NbS with the main role of recreation (Figure 5), aligned with the natural processes of the ecosystems, offering benefits for the comfort and health of the inhabitants. Due to the hydraulic connection with the shallow aquifer system, the lakes recharge the shallow aquifer with stormwater captured from the urban watershed.

Figure 5: Location of the Colentina River, Tei and Circus Lake

I.2 Challenges / needs

In the case of Circus Lake, the water level has suffered a sharp drop in the last 25 years by 1.2-1.4 m (see Figure 6). Although both lakes are in direct connection with the shallow aquifer, in this study the emphasis will be placed on the possibility of restoring and maintaining the water level in Circus Lake using alternative sources of water (rainwater) but also considering the evolution of the water level in the Tei Lake.

The problem highlighted in the last decades is the decrease in the level of groundwater in this urban area and, therefore, in the decrease of the water level in Circus Lake. This is a consequence of several hydrological and hydraulic factors that influence the zonal hydrological balance, namely:

- climate change highlighted by a modified pattern of precipitation (shorter and higher intensity periods);
- drastic reduction of losses in the drinking water distribution system;
- temporary and permanent dewatering systems (including unauthorised systems).

In the case of the Tei Lake, the water level is kept at a satisfactory level being controlled by the Colentina river hydrotechnical nodes and depends on the rainfall regime upstream of the city of Bucharest.

Figure 6: Water levels in Circus Lake between 2000 and 2024

I.3 Water resources and management

Currently the centralized water supply distribution system of Bucharest city uses only surface water. The surface water source comes from Arges and Dambovita Rivers through catchments located in the northeast of Bucharest. These ensure a total flow of about 1 400 000 m^3/day.

The main groundwater resource that is currently not used as a source for the centralized water distribution system is represented by three deep and shallow aquifers located from bottom to top as follows (Figure 7):

- The deep aquifer (Fratesti strata), located at depths between 100 m in the southern part of the city and 250 m in the northern part, is hosted by sands and gravels with cross-stratification. The water is generally potable and does not require special treatment. Currently, it is used in case of emergency situations and punctually for the food and pharmaceutical industry.
- The confined intermediate aquifer (Mostistea stratum), represented by fine and medium sands, is located at depths between 30-50 m (depending on the variation of the elevation of the land surface). The water may contain iron, manganese, nitrates above the allowed limits. Water is used for industrial or domestic purposes for private homes.

- The unconfined shallow aquifer (Colentina stratum), represented by sand with gravel, is found at depths between 7-25 meters. The cover is made of clayey material. It is usually polluted (nitrites, nitrates, organic substances). The water is used for irrigation and for industrial purposes.

The Colentina (Co) and Mostistea (Mo) aquifers are separated by a clayey intercalation (CI) of variable thickness (1-10 m), which is missing in some places and the aquifers being in direct hydraulic contact (Figure 7).

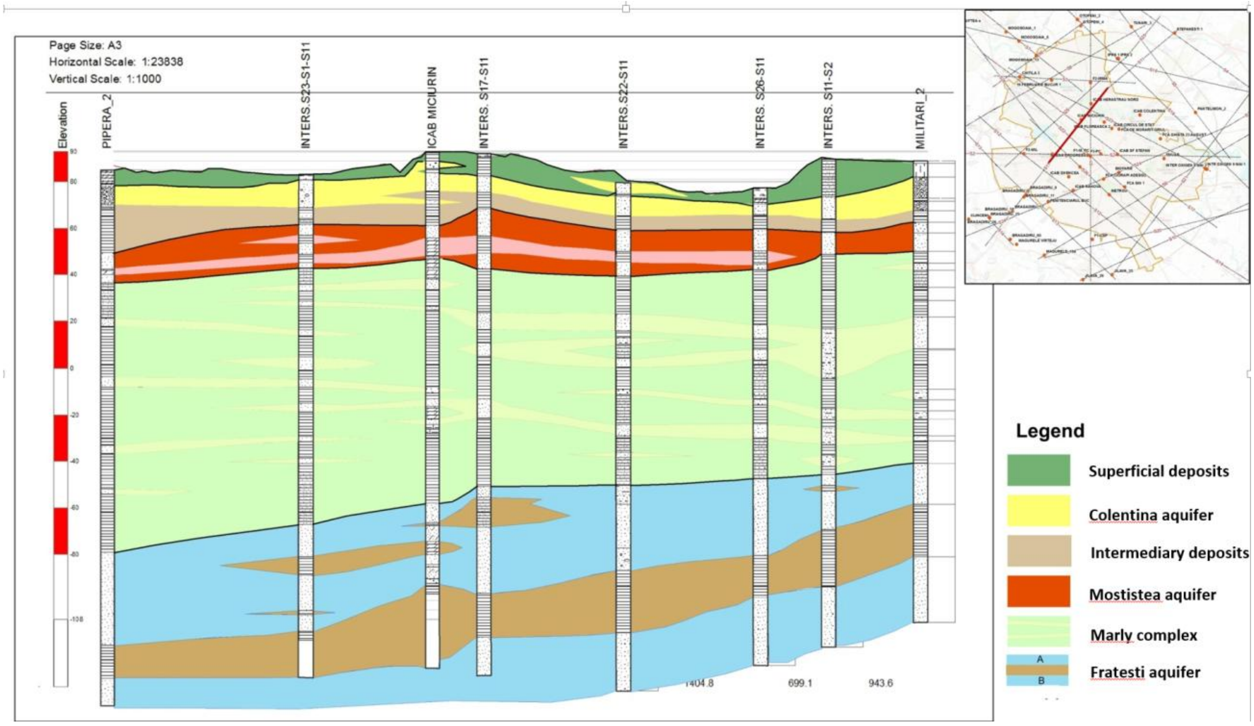


Figure 7: 2D representation of the aquifers from the upper part of the sedimentary deposits in Bucharest area (Serpescu, et al., 2013)

Currently, the water level in Circus Lake is maintained at about 1.4 m below the initial level by pumping water from the intermediate aquifer (Mostistea).

The management of water sources in terms of quantity, quality, authorization for exploitation, control from exploitation to the treatment and discharge of wastewater is done by National Administration “Romanian Waters” (ANAR).

Exploitation of water in a centralized system, maintenance of equipment, water treatment, supply pipes, sewerage network for domestic and rainwater, their treatment is done by the water operator ApaNova S.A. The mixed combined flow (mixing wastewater and urban runoff) of wastewater system of Bucharest city reaches the treatment plant with about 9 m^3/s. During heavy rains, this flow rate increases significantly and often the sewage system overflows. By capturing the water from the precipitation in the Tei District (Circus Park) area from roofs and possibly from streets, the intention is to recharge the lake and locally the Colentina aquifer layer. The goal is to maintain and possibly increase the water level in the lake and completely or partially abandon the current water supply solution of the lake (a well pumping water from the intermediate aquifer layer). In this way, the sewage network can be released from a stormwater volume, decreasing consequently the treated volumes of water arriving at the wastewater treatment plant.

The Circus Lake Park, together with the surrounding area, represents a former borrow pit from where, in the 18th and 19th centuries, the clayey material from the ground was excavated and used to manufacture bricks. Similarly, a part of the granular material from the upper part of the shallow aquifer was used in the construction activity. The excavations during that period were done until the groundwater of shallow aquifer was intercepted. With the expansion of the city, in the 20th century, most of the previous excavations in the Tei area were covered (uncontrolled) with anthropogenic material (urban soil), usually resulting from demolitions (boulders, cement, wood, bricks, glass, and others). This anthropogenic material is currently trapped in a clayey matrix, sandy dusty clayey with a variable thickness, following the morphological surface of the ancient excavations (Figure 8). Therefore, the unsaturated zone is largely made up of heterogeneous lithological anthropogenic material. The design of the Circus Lake Park (during the 50s) considered that the location should be filled with material as similar as possible to the one that constituted the initial natural soil, generally silty sandy clay. Thus, it can be said that the vadose zone in the Circlui Lake Park location is made up of homogenous lithological anthropogenic material, having hydraulic properties distinct from those of the original soil due to the irregular degree of compaction, the anisotropic horizontal and vertical effective porosity, and possible micro and macro stratifications.

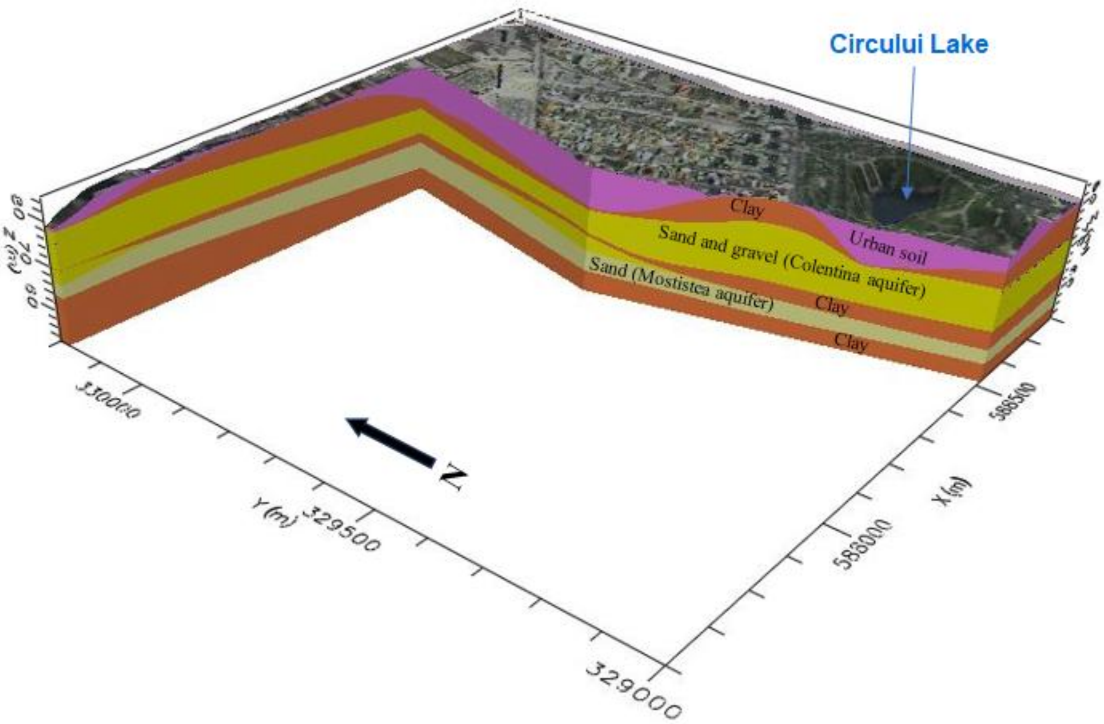


Figure 8: 3D cross-section through the natural and anthropogenic strata in the Tei area Source (Radutu, et al., 2020)

I.4 Existing AWR infrastructure in the demo case

The existing infrastructure in the study area is represented by:

- The artificial Circus Lake considered the main NbS area element for recreation, health and well-being, and Tei Park, as well as several other green areas distributed over the Tei district that can host possible future NbSs for rainwater and stormwater treatment and infiltration;
- The Tei urban district groundwater monitoring system consisting of monitoring wells used to monitor the groundwater level since 2010 whose data were used in the hydrogeological model development (see Section III.1.1).

For the entire Bucharest city, until 2019, there were 171 monitoring wells (piezometers). In 2024, 72 piezometers were still in operation, the rest being vandalized or covered due to the urban cover dynamics of the city (the land was used for other purposes by the local administration). In the study area, out of 16 monitoring wells (piezometers), four are still in operation, three for the shallow aquifer (unconfined) and one for middle one (confined). The monitoring data of these monitoring wells, located in the study area, is used within the AWARD project and the dataset corresponding to 2024-2027 (during AWARD) will be used for a possible recalibration of the current hydrogeological model.

The hydrological model needed to assess the NbS functioning regroup the stormwater data and information as mentioned in Table 1. Concerning the coupled urban hydrogeological model details are given in section III.1.2.

Table 1: Data needed for stormwater modelling

Category	***Data/Information Required***	***General description***	***Details***
Infrastructure and Drainage	Stormwater Drainage Systems	Data on storm drains, sewer systems, and culverts handling runoff.	Dimensions, shape or CAD file, inflow, outflow, losses
	Retention/Detention Ponds	Structures for temporary water storage to mitigate runoff.	Dimensions, location, and seepage rate
	Road Network	Roads, gutters, and curbs that direct water flow.	Dimensions, shape, or CAD file
	Stormwater collecting system and sewage system	Dimension and shapes of pipes and related slopes. The amount of inflow and possible losses are based on leakage.	Dimensions, shape or CAD file, inflow, outflow, losses
	Inlets, manholes	Locations, shapes, and input flow	Locations, shapes, and input flow.
Hydrological Parameters	Runoff Coefficients	Values for different land uses representing the fraction of rainfall converted to runoff.	Runoff coefficients for buildings, green areas, and streets
	Time of Concentration	Time for runoff to travel from the furthest point in the catchment to the outlet.	Time of concentration for stormwater collection/drainage systems, and streets
Regulatory Data	Stormwater Management Regulations	Local guidelines and laws for managing runoff and pollution.	Permeable runoff limit in the Bucharest
	Floodplain Maps	Historical flooding data for risk assessment.	The most endangered areas facing runoff issues based on historical records.
Water Quality	Pollutant Concentrations	Information on potential contaminants carried by runoff, such as oils, metals, and sediment.	The most dangerous contaminants in runoff and their allowable permeable limits.

I.5 Assessment of required upgrade/additions

The study regarding the possibility of using alternative water resources (AWR) is approached from a quantitative and qualitative point of view. The quantitative assessment involves the water volumes that can be used as an alternative resources and result from a correct water balance. The qualitative assessment refers to types and values of bio-chemical parameters of untreated as well as treated storm water and rain water (filtered and/or biological treatment). The term "untreated water" refers to rainwater or runoff before it has gone through a filtration or biological treatment process (NbS treatment), while treated water refers to water that has already gone through these processes. Quantitative and qualitative estimation helps choosing AWR solutions, increasing environmental protection.

I.5.1 Urban water quantitative assessment

To establish the volume of water that can be used to supply the lake and recharge the Colentina aquifer (water balance), it is necessary to simulate the phenomena of rainfall-runoff - infiltration - aquifer recharge. This involves coupling a hydrological model with a hydrogeological model. The **hydrogeological** was developed initially for 2006 - 2014 and updated for 2018 hydrogeological year within AWARD project (Section III.1.1), based on the groundwater level monitoring, using monitoring wells located in the study area (Tei district).

The urban **hydrological** model is in the development stage within the AWARD project. In this regard, it has been obtained data focusing stormwater management and the distribution of the entire sewer network (including the entire set of sewer pipes diameters). The water operator of Bucharest city (ApaNova S.A) provided these data as a support for AWARD project.

The coupling between the hydrogeological and hydrological (Figure 10) will be done for 2018. In order to highlight the possible discrepancies between the latest monitoring campaign of 2018 – 2019 and the current situation, the functional piezometers in the study area were identified within the AWARD project. Thus, starting in August 2024, the monthly monitoring groundwater hydraulic head (in 11 piezometers located the Tei district) of shallow and middle aquifers as well as the water level in the Circus Lake, is being carried out. The obtained values will be compared with those used in the hydrogeological model and it will be decided if it will be necessary to adjust the hydrogeological model.

Another parameter necessary for the coupling of the two models is the **quantification of the hydraulic conductivity** corresponding to the saturated state of the vadose zone. This zone shows areas with lithologically homogeneous as well as lithologically heterogeneous anthropogenic material. Since the values of this parameter can show significant differences over relatively small distances, especially in the case of heterogeneous lithological anthropogenic soil, it is necessary to determine threshold values that can be used in calibrating the hydrological model. At the same time, it is necessary to establish in situ test method to determine the values of this parameter, so that they are not influenced by the very high variability of the terrain surface conditions (presence of roots and their frequency, drying cracks, etc.).

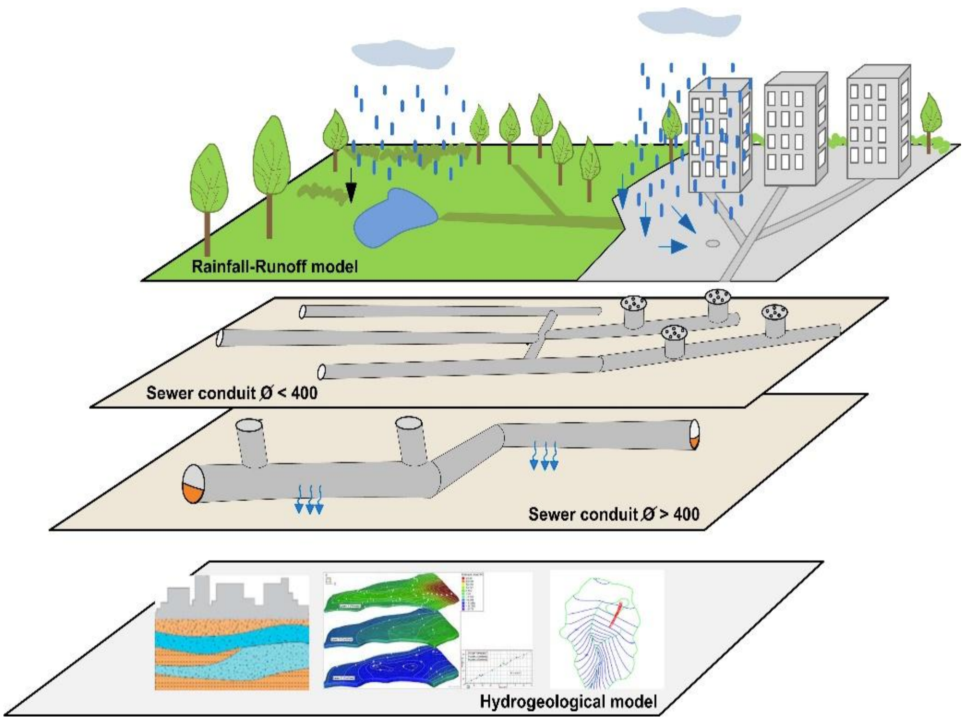


Figure 9: The conceptual model for to simulate the phenomena of rainfall-runoff-infiltration-aquifer recharge in the Tei district area

The modelling will be done starting from the border of the park, at increasing distances, in different scenarios regarding the amounts of precipitation and their intensity.

I.5.2 Urban water qualitative assessment

The water qualitative measurements imply two stages. It was expected that the values of the chemical and biological parameters of the rainwater collected from the roofs differ substantially from those corresponding to the stormwater collected from the streets. On the other hand, the values of the chemical parameters of the water collected from the roofs could have been similar to those of the water from Circus Lake, with the amendment that Circus Lake is currently also supplied by a well from the middle-confined aquifer layer and thus the initial values (unknown) have been changed. To avoid altering the ecological balance, it is required that the collected stormwater and rainwater that supply the lake be at least of the same quality as the existing one. In this sense, samples were collected for chemical and biological analysis from rainwater from the roofs and stormwater from the street, from the lake, and aquifer system, in order to be compared. Table 2 shows the elements chosen to be analysed in the first stage (first campaign). At the same time, an experimental device was designed and built (detailed in the next section) for simple water filtration through active charcoal and sand with gravel filters. Thus, samples were collected from untreated rainwater and stormwater (roof and street) as well as filtered water, according to Table 3. The obtained values were compared with each other to determine if rainwater or stormwater can be introduced into the lake/aquifer or and the type of required filtration (simple or complex).

Table 2: Chemical and biological analysed parameters

Nr. crt.	Analysis type	Element
1	Chemical	dissolved oxygen
2		pH, conductivity
3		chemical oxygen demand (COD)
4		biological oxygen demand (BOD)
5		total organic carbon (TOC)
6		phosphate
7		ammonium, nitrates, nitrites, chlorides, sulphates
8		heavy metals: Cd, Zn, Pb, Ni, Hg, As
9		polyaromatic hydrocarbons (PAHs)
10		polychlorinated biphenyls (PCBs)
11		petroleum products
12		phenol
13		pesticides
14	Biological	total coliforms, faecal coliforms, faecal streptococci

Table 3: Types of performed water analysis and sampling locations

Analysis type	Provenance	Type of water	Location	No. of samples	Filter type	No. of samples	Total samples
Chemical	Rain (CAP)	Raw (CAPB)	Roof (CAPBA)	1	Gravel&sand (CAPBAFP)	1	3
					Active charcoal (CAPBAFC)	1	
			Street (CAPBT)	1	Gravel&sand(CAPBTFP)	1	3
					Active charcoal (CAPBTFC)	1	
	Circus Lake	Raw (CALCB)	Circus Lake	1	--	--	1
	Aquifer	Raw (CAFB)	Phreatic aquifer	1	--	--	1
Partial Total 1							*8*
Biological	Rain	Raw (BAPB)	Roof (BAPBA)	1	Gravel&sand (BAPBAFP)	1	3
					Active charcoal (BAPBAFC)	1	
		Raw	Street (BAPBT)	1	Gravel&sand (BAPBTFP)	1	3
					Active charcoal (BAPBTFC)	1	
	Circus Lake	Raw (BALCB)	Circus Lake	1	--	--	1
	Aquifer	Raw (BAFB)	Well	1	--	--	1
Partial Total 2							*8*
GENERAL TOTAL							**16**

In a second stage, the analyses will be repeated on untreated raw water from roof and streets as well as water samples treated by a mini-bioretention system. This will be done only for the parameters whose values exceed the values of parameters from the lake and aquifer.

It should be noted that the mini-bioretention system will be built with funds from outside the AWARD project. These funds are expected to be provided by District 2 City Hall (one of stakeholders), with which discussions have already been held, and a collaboration protocol has been agreed. Currently, according to the law, the approval of the 2nd District Municipality Local Council is expected.

II Technical description of the upgrades/ construction plan—scope

II.1 Designs / flow chart of the final treatment loop/ water loop

The preliminary concept regarding the capture and reuse of rainwater and stormwater to supply the Circus Lake is illustrated in Figure 10.

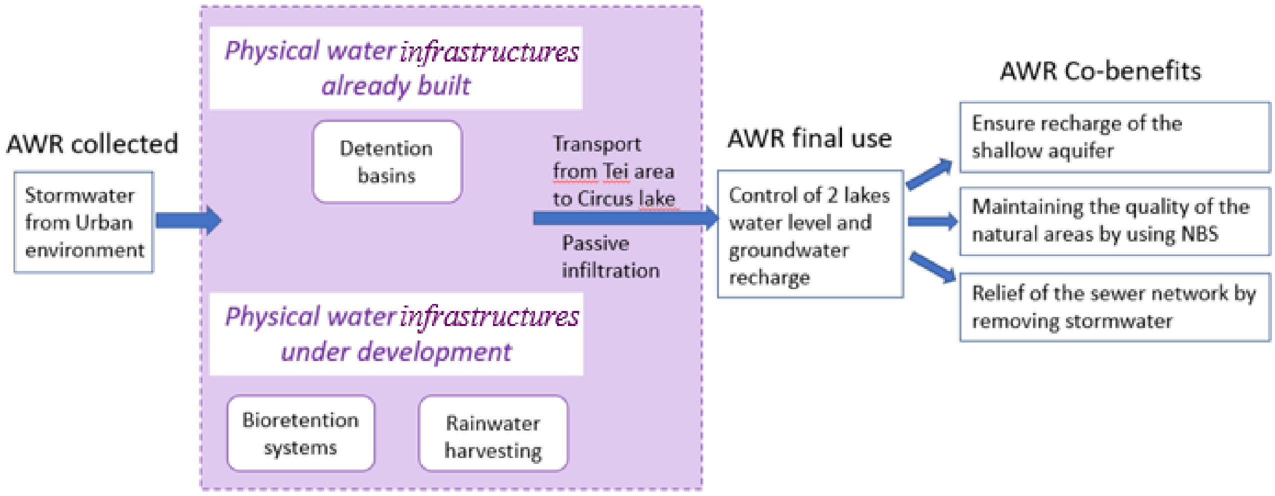


Figure 10: AWR conceptual model for Tei area

The Circus lake (Circus Lake) represents the main NbS located in the Tei area. It has a recreative role and supply the aquifer collecting water from the park watershed. To improve its functioning, additional NbS devices were designed. Their design is shown in Figure 12 (where Q (L^3/T) is the flow, and t (T) is the time).

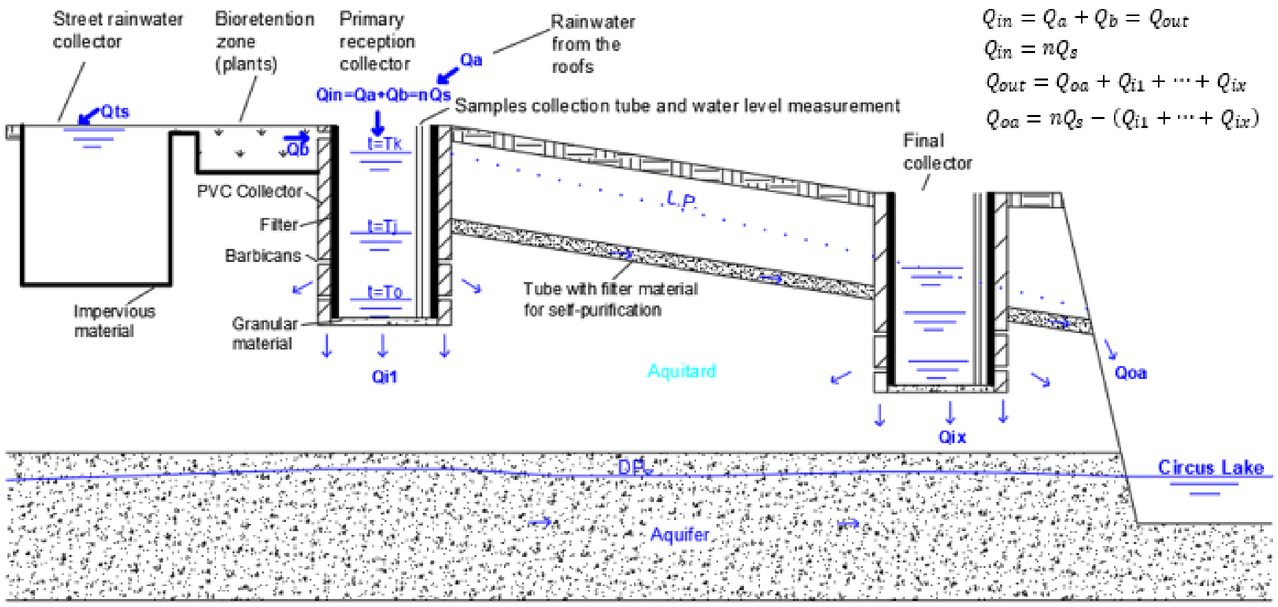


Figure 11: Conceptual design of the additional NbS devices

The shape, size, arrangement in space depend on the results of the water-balance results (based on the hydrological model and the coupling with the hydrogeological model).

II.2 Description of the construction works/ interventions

❖ Water filtration pilot device

An experimental device (Figure 12) was designed and built (Figure 13-15) to develop a comparative analysis of the water quality values resulting from a primary water filtration, through filters of active charcoal and sand with gravel. The results can be seen in Table 3.

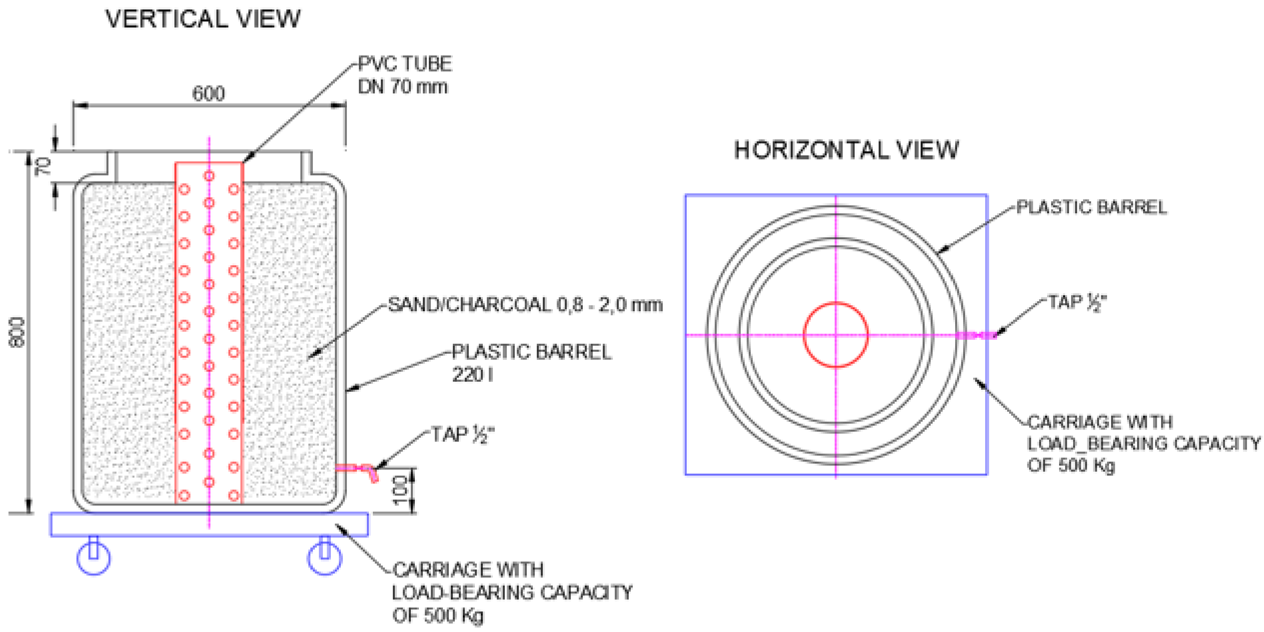


Figure 12: The scheme of the water filtration pilot device

Figure 13: Pilot device for filtering rainwater and stormwater

Figure 14: Filtering device: Sand and Gravel Filter *Figure 15: Active Charcoal Filter*

❖ Unsaturated zone infiltration tests

Six infiltration tests were carried out in locations situated in the perimeter of the Circus Lake Park (Figure 16). The unsaturated zone was tested to determine the hydraulic conductivity *K* (LT^{-1}) corresponding to the saturated state of the urban soil (anthropogenic soil). The tests are necessary to subsequently provide indicative values of the hydraulic conductivity needed to assess the unsaturated zone infiltration procedure in the variant in which part of the volume of rainwater in the area adjacent to the park will be directed to storage basins from which a certain water volume will seep into the ground, and the rest will be discharged into the Circus Lake.

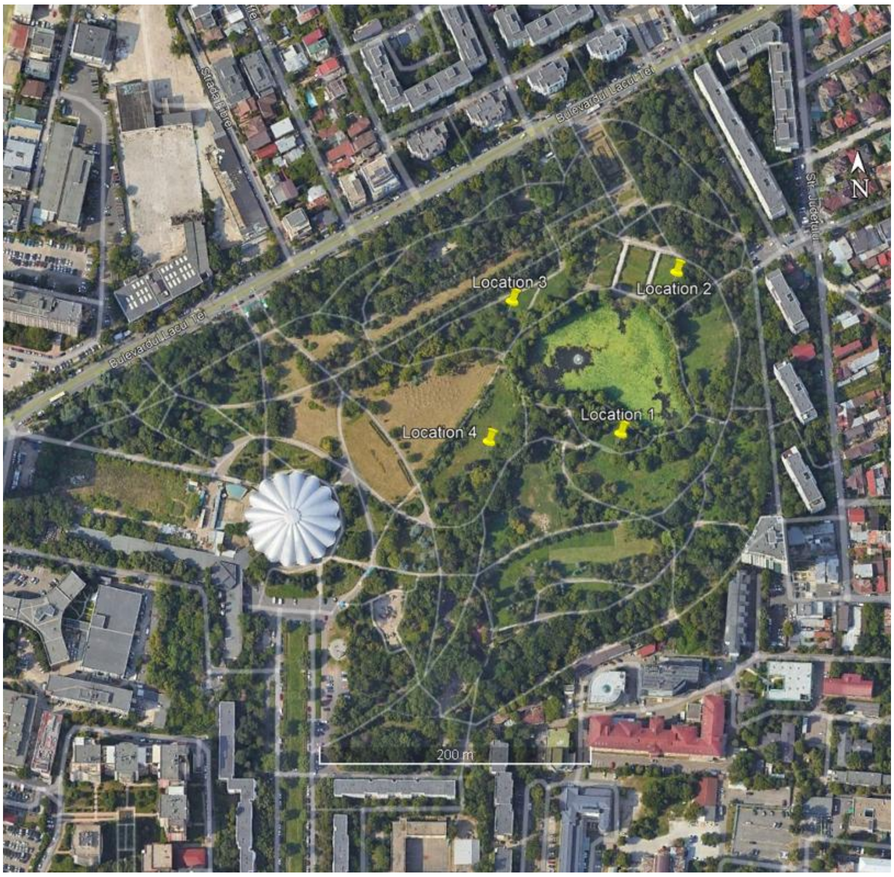


Figure 16: The positions of the infiltration tests on Circus Lake Park site

Within AWARD project, the tests were performed in three locations: Location 2, Location 3 and Location 4, according to Figure 16-20. In Location 1 (Figure 17), the tests were conducted following other research (Ghibus, 2024), and the results were taken over and used in this project.

Figure 17: Location 1 (IA1…IA6)

Figure 18: Location 2 (IA7, IA8)

Figure 19: Location 3 (IA9, IA10)

Figure 20: Location 4 (IA11, IA12)

The infiltration tests were carried out by the inversed auger hole (IA) method. The choice of this method is based on the results of a comparative study, within the AWARD project, conducted on unsaturated anthropogenic soil using four infiltration testing methods (Ghibus & Gaitanaru, 2024). The method consists of drilling a hole at a given depth cased with a steel screen with the same diameter, filling it with water, and measuring the change of the water level at certain time intervals (Figure 21). The variation of the water column was recorded using a pressure cell mounted at the bottom of the borehole.

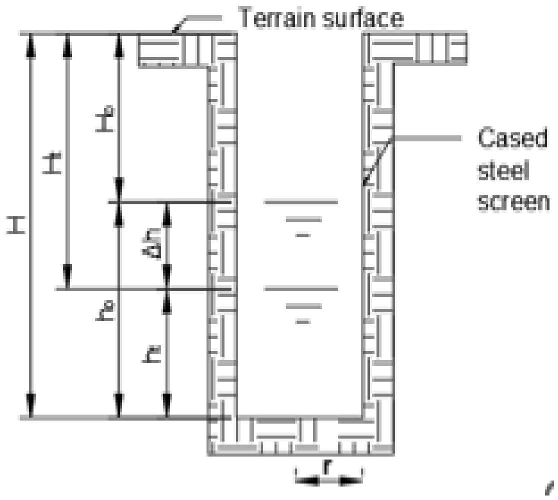


Figure 21: Inversed auger method scheme

H-borehole depth, H_o—poured water level depth, H_t—water level depth at time *t*, h_o—water column height at time t = 0, Δh—drawdown between step time t_i and t_{i+1}, h_t—water column height at time t_{i+1}.

The saturated *K* value is given by the following equation (Van Hoorn, 1979):

$$K = \frac{\log\left(h_o + \frac{r}{2}\right) - \log\left(h_t + \frac{r}{2}\right)}{t} = 1.15 \cdot r \cdot \tan(\alpha) \quad (1)$$

where *t* is time, *tan (α)* is the line gradient of $\log(h_t + r/2)$ vs. *t* and other variables are as given in Figure 15.

❖ Mini bio-retention system

The mini bio-retention system will be built within the Tei district. It is estimated that the completion of the mini-system will be done with the support of the Bucharest District 2 Municipality.

III Operation

III.1 Start-up/ Operation plan

To establish the volume of water that can be used to supply the lake as well as the shallow aquifer, it is necessary to simulate the chained phenomena rainfall - runoff - infiltration – aquifer recharge for this urban area. This involves coupling the hydrological model with the hydrogeological one through the unsaturated zone.

III.1.1 Quantification of hydraulic conductivity corresponding to the saturated state of the vadose zone

Several trials were made within each test. For the calculation of the *K* value, the data recorded at the last trial were used, the others being considered as trials necessary as initial saturation of the soil. Table 4 summarizes the values determined for each location.

Table 4: The saturated K values obtained for each infiltration test by IA method

Test location	Position of the test location (Stereo'70)		Test no.	Borehole depth, cm	Distance between tests, m	No. of trials for each test	Obtained K values, m/d	K values average on each location, m/d	Anthropic Soil Description (according with laboratory test results)
	Est, m	North, m							
1	588655	329199	IA1	66	1.7…2.8	5	0.471	1.774	Sandy silty clay, sometimes with sub-millimeter and millimeter elements of brick, concrete, charred wood
			IA2	56		6	0.736		
			IA3	30		14	1.464		
			IA4	28		21	2.159		
			IA5	48		10	1.995		
			IA6	60		24	3.818		
2	588696	329317	IA7	28	1	4	0.929	0.696	Clayey sand with rare gravel with plant residues
			IA8	50		5	0.463		Sandy clay with rare gravel and rare elements of brick, plant residues
3	588575	329296	IA9	29	0.59	4	0.811	1.084	Sandy silty clay with rare gravel and plant residues
			IA10	49		4	1.358		Sandy silty clay with rare gravel, rare brick elements and plant residues
4	588558	329193	IA11	34	1.36	3	0.705	0.760	Clayey sand with gravel, elements of brick and roots
			IA12	42		3	0.815		Sandy silty clay with rare gravel, elements of brick and roots
Average				**43.3**	**--**	**--**	**1.310**	**1.078**	--

Disturbed medium samples were collected from each borehole for grain size analysis and textural grading of the soil according to Table 5.

Table 5: The percentage distribution of the analyzed material on granulometric intervals

Location	Test	Type of material [%]			
		Fine: 0.001...0.063 mm		Coarse: 0.063...63 mm	
		Clay: 0.001...0.002 mm	Silt: 0.002...0.063 mm	Sand: 0.063...2 mm	Gravel: 2...63 mm
2	IA7	18	37	35	10
		55		**45**	
	IA8	24	42	29	5
		66		**34**	
3	IA9	29	50	20	1
		79		**21**	
	IA10	27	49	23	1
		76		**24**	
4	IA11	16	32	31	21
		48		**52**	
	IA12	29	49	20	2
		78		**22**	

It can be seen that some boreholes with lower depths (IA7, IA11) intercepted a soil with a higher granularity (clayey sand) compared to their counterparts from the same location (IA8 and IA12) where the granularity is finer (sandy clay respectively sandy silty clay). It is possible that the finer material near the surface of the ground was carried vertically by infiltration water and horizontally by hypodermic drainage. However, the highest hydraulic conductivity was obtained in the location IA10 (1,358 m/d for a sandy silty clay soil) although, according to Table 4, the percentage of coarse material is quite low (24%) which leads to the idea of a small active porosity compared to a natural soil. In this case, it can be assumed that the anthropogenic soil in the Location 3 is less compacted than in other locations with a higher percentage of coarse material (e.g. IA11 with 52% coarse material and K=0.705 m/d).

Considering the values highlighted in Table 1 and Table 2, conventionally and at a large scale, the urban soil from the Circus Lake Park could be considered by lithological point of view as "homogeneous" anthropogenic soil.

III.1.2 Hydrogeological model

In urban areas an important man-made disturbance on the water cycle is produced by: 1) the land-use change that reduces the recharge of the aquifer systems from precipitation, 2) man-made sinks induced by groundwater abstraction, drains, subway tunnels, sewer systems, and others; 3) urban infrastructure elements acting like groundwater recharge sources, as for example the water supply network losses and leaky sewer systems. Besides, human activity affects the natural hydraulic connection between groundwater and surface water.

In the last decade, a pronounced decrease of the water level has been observed in Circus Lake (Figure 4), one of Bucharest city lakes. The normal exploitation of the lake is approximately 75.00 m a.s.l. This lake is naturally recharged by the upper shallow aquifer (Colentina) of the Bucharest city. Until the current study, there were no existing measurements of water levels in the lake. Estimates of relative water level in the lake were qualitative, done through visual assessments of observers.

Currently, the water level in Circus Lake is maintained at about 1.4 m below the initial level by pumping water from a well with a flow rate of about 360 m^3/day. According to the local geological model, this well system extracts groundwater from the intermediate confined aquifer.

The direct hydraulic connection of Circus Lake with Colentina shallow aquifer justifies the need of the hydrogeological analysis of the overall regional aquifer system behavior. The level variations of the Circus Lake are directly related to the hydrological zonal cycle and the urban aquifer system. Consequently, the water level variation analysis in Circus Lake was based on hydrogeological modeling of the urban aquifer system, whose hydraulic behavior is parameterized using data obtained from measurements in-situ and data that describe the hydraulic behavior of the existing urban infrastructure in the study area. The model settings are as follows:

- Aquifer system: composed of two aquifer units (shallow and intermediate aquifers) separated by an aquitard (Intermediary deposits);
- Pseudo 3D with horizontal flow in the aquifer units (shallow and intermediate aquifers) and vertical flow in the aquitard unit (intermediary deposits);
- Steady state representing the hydrological conditions during March 2018.
- Numerical integration of the model with finite difference method using Modflow solver (Harbaugh, et al. 2000);
- Model automatic calibration via inverse modeling.

The hydrogeological model is developed for 2018 hydrological year, based on a systematic monitoring of the groundwater water level in piezometers located in the study area. This model takes into account the most important elements of urban hydrological cycle (Figure 18), namely:

- The aquifer system: two aquifer units that include the upper aquifer (shallow and intermediate aquifers) and the aquitard unit between them (Intermediary Deposits);
- Unlined surface water bodies: these are surface water bodies which are supposed to have a strong hydraulic connection with the aquifer system studied. They are represented by the 4 lakes of the river Colentina existing in the studied area: Herăstrău, Floreasca, Tei, and Plumbuita (Figure 22);
- Aquifer recharge from precipitation (quantified as mention below, by using SCS method (Unated States Department of Agriculture, 1954);
- Aquifer recharge from water supply network losses;
- The interaction between groundwater and the sewage system;
- The interaction between groundwater and deep building foundations;
- The interaction between groundwater and underground subway network.

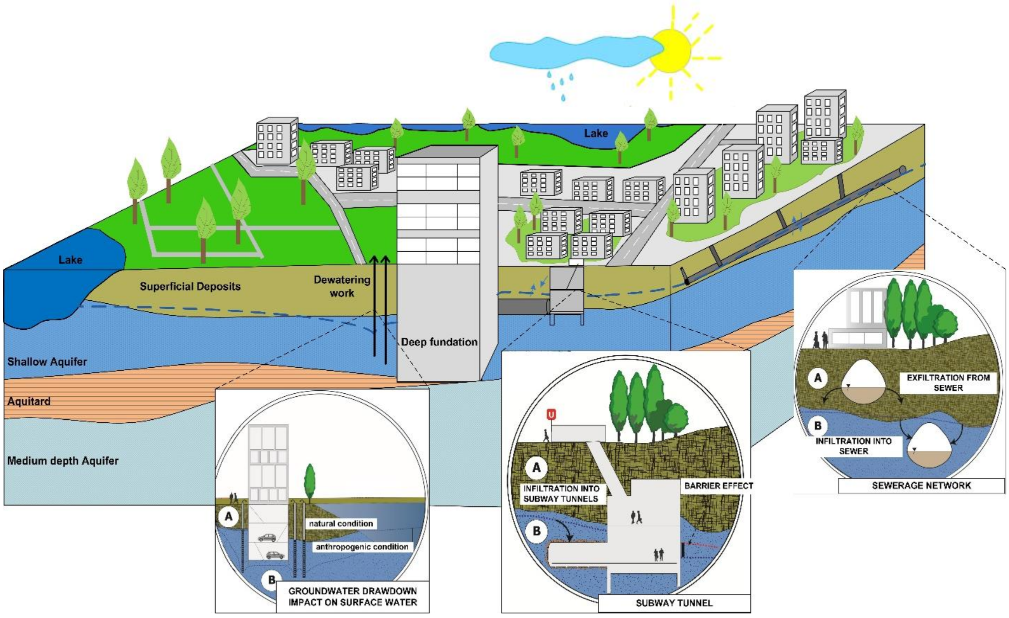


Figure 22: Hydrogeological urban conceptual model for the study area

❖ Aquifer system

Related to hydrogeological aspects, Bucharest city area is placed in a Quaternary aquifer system (Serpescu, et al., 2013) composed of 3 units: Frătești strata (lower aquifer), Mostiştea aquifer (intermediate aquifer) and Colentina aquifer (shallow aquifer) as shown in Figure 7. Colentina aquifer is an unconfined aquifer made of gravels and sands and is in direct interaction with elements of the urban infrastructure of Bucharest city. Mostistea aquifer is separated of Colentina aquifer through a clayey-marl layer (Intermediary Deposits), an aquitard unit. By developing the 3D geological model of the study area the delineation of the first two aquifer units (Colentina and Mostistea) could be achieved. The 3D geological model take into account lithological information from 32 boreholes located in the study area (marked with blue triangles in Figure 23-A with depths between 12 m and 63 m. Based on the distribution of boreholes, 11 geologic cross-sections were defined and interpreted litho-stratigraphically (Figure 23-B). Thus, based on the developed geological sections, the structural maps corresponding to the top and bottom were created, as well as the thicknesses corresponding to each aquifer layer.

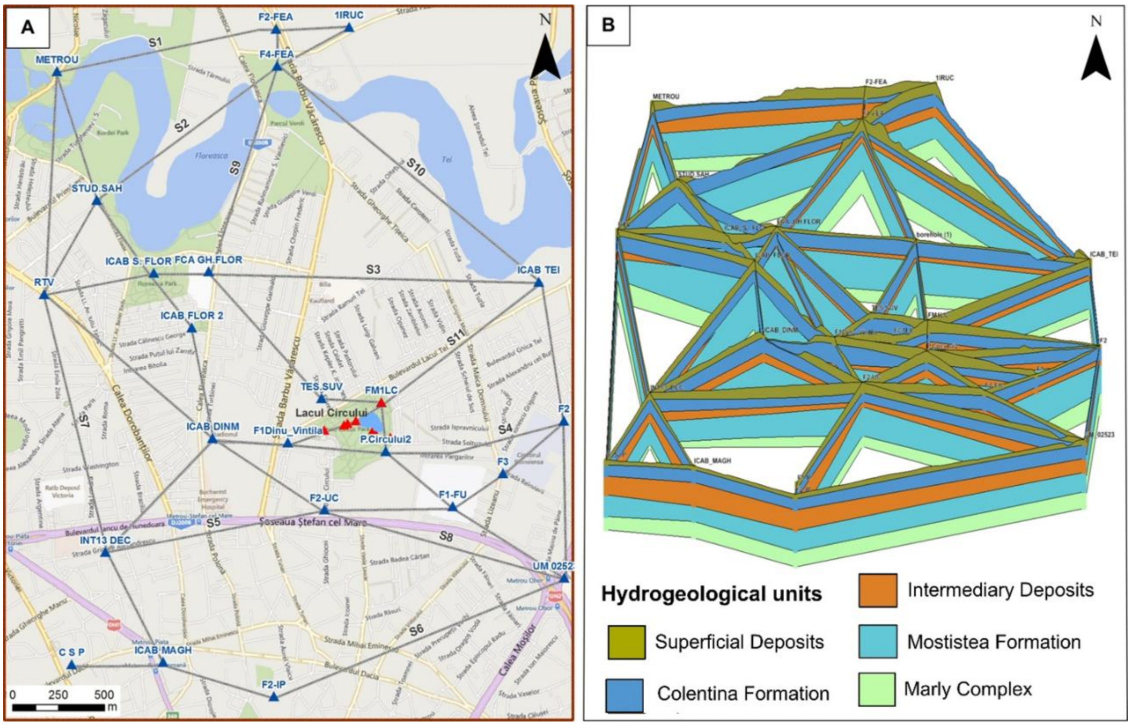


Figure 23 : Map with the boreholes location and geological cross-sections (A), 3D fence diagram of the geological cross-sections (B)

To analyze the interaction between the aquifer system, Circus Lake and the urban infrastructure elements, a two-layered flow model was developed (with horizontal flow in the aquifer layers shallow unconfined layer (Colentina) and intermediate confined layer (Mostiştea) and vertical flow in the aquitard layer Intermediary Deposits).

As the model is elaborated in steady state, the hydraulic characterization of the aquifer system was done in terms of the hydraulic conductivity. The spatial distribution of the hydraulic conductivity in the present method is determined by using pilot point method. This method requires pr-estimation of the hydraulic conductivity values at several points. These values were obtained from two sources:

- **Hydraulic tests**

Pumping tests were conducted in several wells drilled to implement a groundwater monitoring system. These tests provided hydraulic conductivity values of aquifers for the study area.

- **Lithological description-based pre-quantification of the hydraulic conductivity**

This pre-quantification relies on estimation of the equivalent horizontal and vertical hydraulic conductivities for multiple layers using equations (2) and (3) (Figure 24). These layers are taken to be the lithological log of a given borehole. This leads to punctual vales of the hydraulic conductivity (horizontal for the aquifer units- Colentina and Mostistea - and vertical for the aquitard-intermediary deposits).

$$(K_H)_{eq} = \frac{\sum D_i \times K_i}{\sum D_i} \tag{2}$$

$$(K_V)_{eq} = \frac{\sum D_i}{\sum \frac{D_i}{K_i}} \tag{3}$$

Where, $(K_H)_{eq}$ and $((K_V)_{eq})$ [L/T] is the equivalent horizontal hydraulic conductivity (vertical hydraulic conductivity) of multiple horizontal layers respectively, K_i [L/T] is the hydraulic conductivity of the layer *i* and D_i [L] is the thickness of the layer *i*.

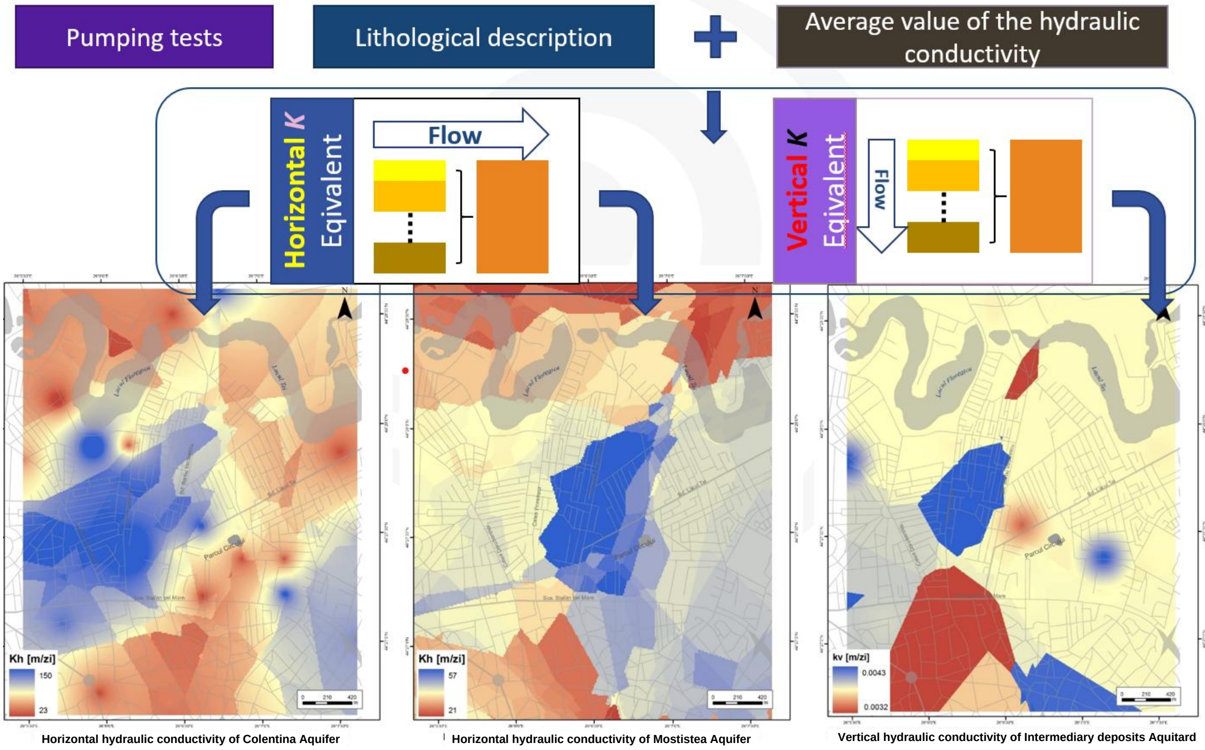


Figure 24 : Estimation of equivalent vertical and horizontal hydraulic conductivity values of multiple lithological layers.

The boreholes whose lithological description was used for the estimation of hydraulic conductivity represent the boreholes on the basis of which the geological model was developed. These boreholes were grouped according to the hydrogeological structure (shallow unconfined and intermediate confined aquifer layers and the Intermediary Deposits aquitard) for which the equivalent hydraulic conductivity values were quantified.

❖ Surface water

The developed hydrogeological model uses the lakes water level values (Table 6 and Figure 25) in the studied area measured on the 14th of March 2018. These values were used as a boundary condition for the shallow aquifer Colentina.

Table 6 : Surface water levels on 14 March 2018

Lake	Water level [m asl]
Floreasca	74.84
Herăstrău	78.72
Plumbuita	68.00
Tei	71.32
Circus	74.42

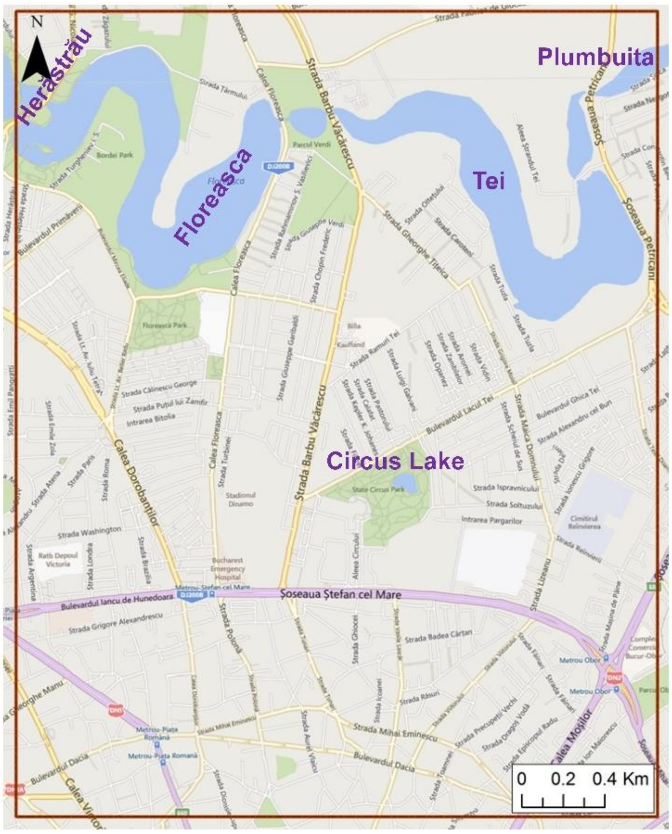


Figure 25: Surface water (lakes) locations

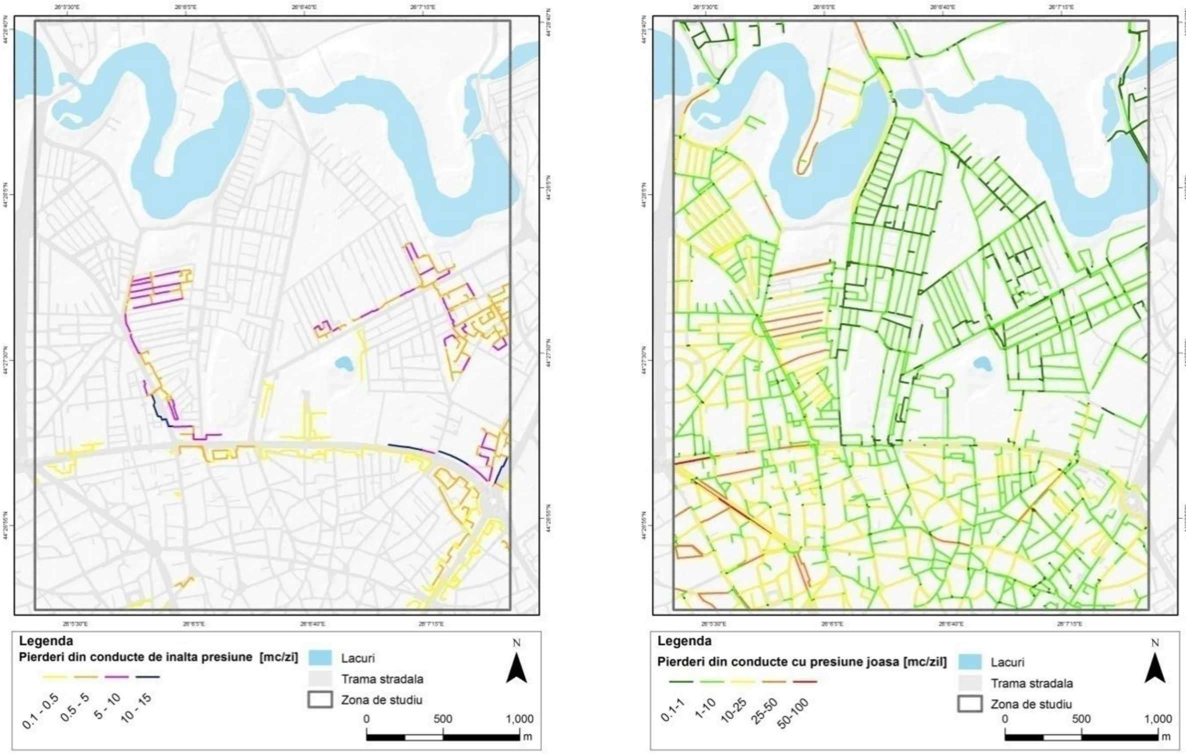
❖ Recharge from precipitations

Daily precipitation records from IMH station Bucharest (www.en.tutiempo.net) for March 2018 represented the precipitation data used to estimate groundwater recharge in the city of Bucharest.

Values of the groundwater recharge from rainfall were estimated based on the Soil Conservation Service (SCS) model (Unated States Department of Agriculture, 1954). Depending on land use in the studied area, the following values were considered for recharge from precipitation: 0.1 mm/day urban fabric, 0.15 mm/day for forest areas, 0.44 mm/day for green urban areas, 0.22 mm/day for agricultural areas and 0.13 mm/day in the case of industrial and commercial areas.

❖ The water supply network

Similar to the large cities of the world, groundwater recharge in Bucharest is made mostly of water distribution network losses and, in a lower percentage, from the interaction with sewer system. The study area has a water distribution system consisting of low-pressure pipes with a length of about 180 km (Figure 26). Losses from the water supply network are a source of groundwater recharge. The discharge of these losses has been estimated by the water operator of Bucharest city for year 2018, and the given values were integrated as boundary condition.



a) b)

Figure 26 : Losses of the water distribution network: A) losses in the high-pressure network, B) losses in the low-pressure network (SC Apa Nova București SA)

❖ The sewage network

By intersecting the geological formations surfaces with the sewage network from the study area a delineation between pipes positioned in the aquitard unit (Intermediary Deposits) and pipes positioned in the aquifer unit (shallow aquifer) was possible (Figure 27). Possible interactions between a sewage system and groundwater are the following: (i) groundwater infiltration in the sewer system (where that infrastructure acts as a discharge area) and (ii) seepage of sewage into the aquifer (in which case, the system becomes a source of groundwater recharge). Sewer system modeling using leakage factor approach under the following assumptions:

- All sewers might have defects
- Uniform distribution of defects
- Defect area is proportional to sewer’s wetted perimeter
- Sewers in the Superficial deposits are subjected to leakage only;
- All other sewers can exhibit infiltration (groundwater seepage in the pipe) or leakage.
- Sewer located total/partially in the aquifer system (shallow aquifer): Cauchy boundary condition:

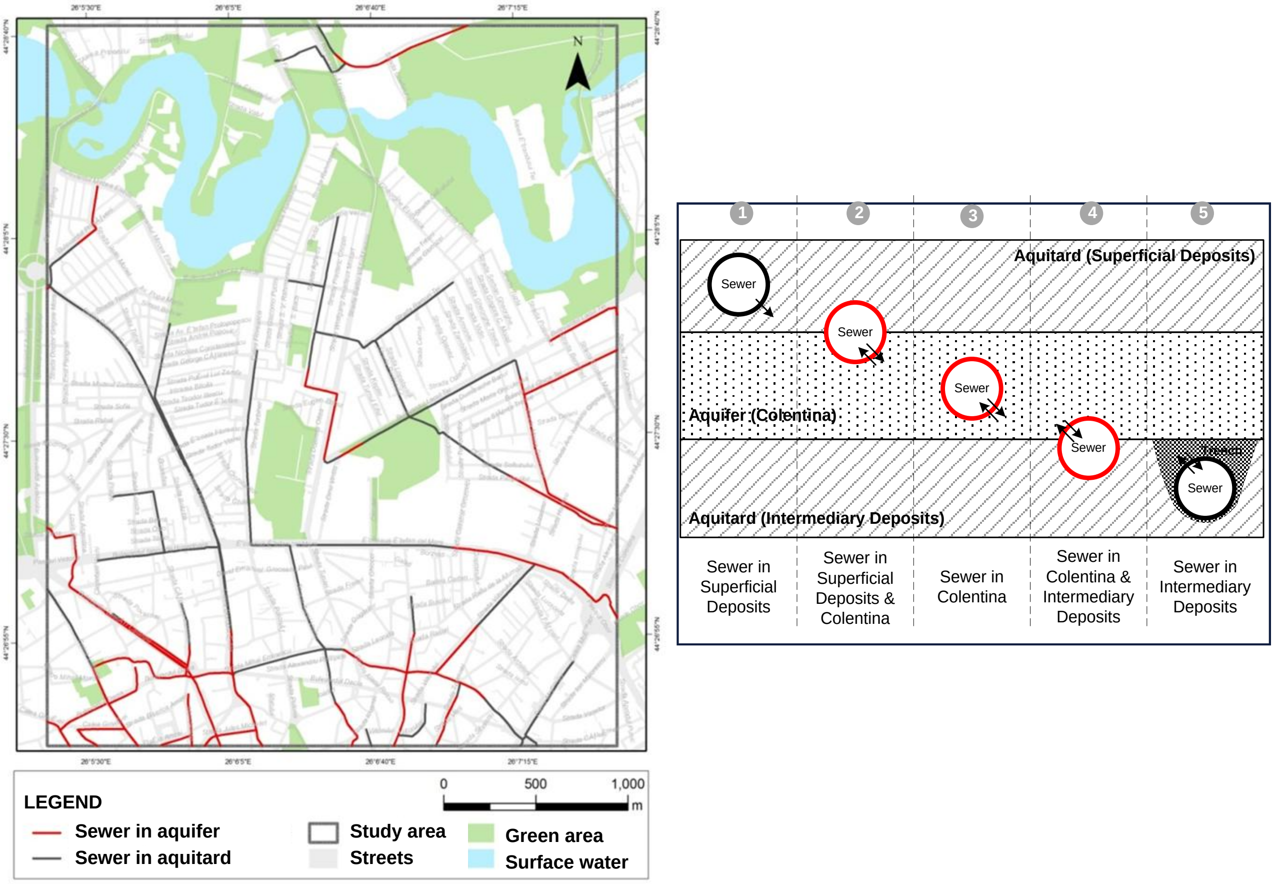


Figure 27 : Sewer pipes location in the aquifer/aquitard

❖ The subway network

The study area is crossed by a subway line segment (Figure 28). In the numerical model, the drainage effect was introduced as specified flow value along the network of tunnels and underground stations, based on the spatial distribution of flows provided by underground transport operator of Bucharest. Quantifying the hydraulic characteristic of the barrier effect (on groundwater flow), corresponding to the subway tunnels is achieved through a methodology developed by Boukhemacha et al. 2015, which is based on spatial analysis (using a GIS environment).

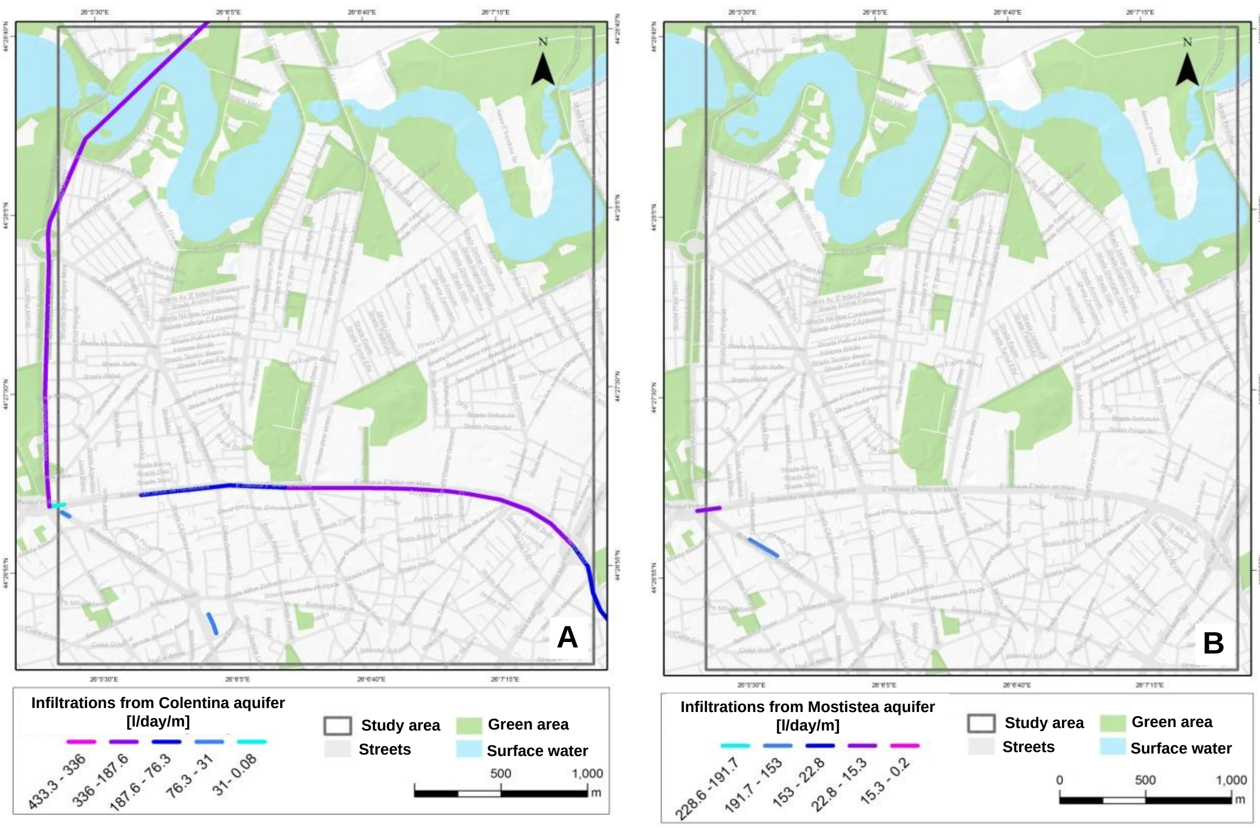


Figure 28 : Spatial distribution of groundwater infiltration rates in the metro infrastructure based on data obtained from S.C. Metrorex S.A; (a) Infiltration in tunnel segments located in the shallow Colentina aquifer and (b) Infiltration in tunnel segments located in the intermediate Mostiștea aquifer

❖ Dewatering and drainage works

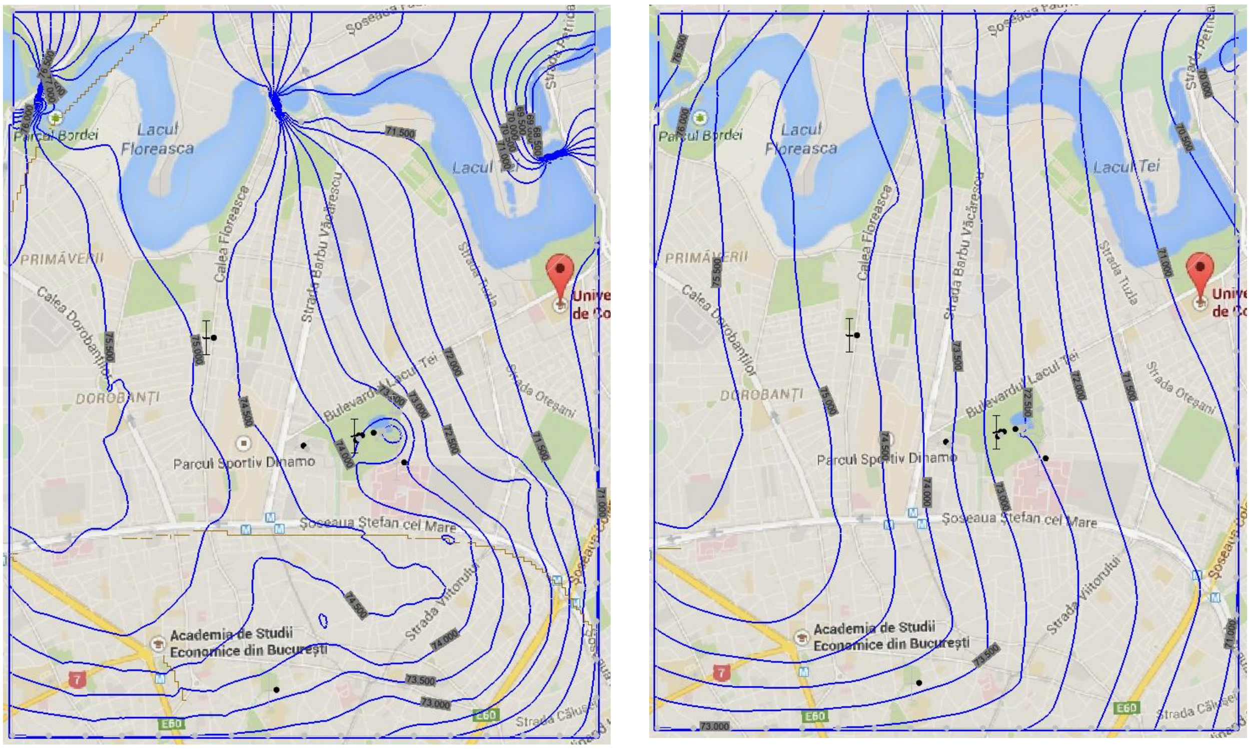
In the study area, no major constructions with a functional dewatering system in 2018 have been identified. However, it needs to be mentioned the incident registered between 2007-2009 when the water level in Circus Lake decreased dramatically. This phenomenon may be related to execution of dewatering works necessary for lowering the piezometric level of the aquifer system in order to execute construction works with deep foundations. It must also be noted that after the finalization of the deep foundation of the construction and consequently, the cessation of the temporary dewatering works, the water level Circus Lake has substantial recovered.

❖ CALIBRATION PROCESS AND RESULTS

In the development of the hydrogeological model created for analysing the behaviour of the interaction between Circus Lake and the aquifer system, the calibration process was achieved in steady state for the corresponding period of March 2018. The choice of the period is justified by the availability of hydrogeological and hydraulic data sets:

- piezometric levels of two aquifers units (intermediate aquifer Mostiştea and shallow aquifer Colentina) for the study area; The calibration process is based on groundwater levels measured in a field campaign on March 2018.
- measured water levels in Circus Lake and the unlined lakes from the northern limit of the study zone;
- the flow rate values of water supply losses and the groundwater interaction with the sewers system.

Introducing the hydraulic conditions imposed by the whole dataset of elements mentioned above, for the month of March 2018, the calibration process of the groundwater flow model was achieved obtaining the flow spectrum illustrated in Figure 29.



a) b)

Figure 29: Hydraulic had map of shallow aquifer (Colentina) - a) and intermediate aquifer (Mostistea) - b)

The groundwater flow in the shallow aquifer falls within the general flow for this aquifer (in the Bucharest area), the preponderance of the local flow in the analysed area being from W to E.

In the modeled area, the flow spectrum for the shallow aquifer falls between 68.4 m and 78.2 m (Figure 29). The model calibration is performed under optimal conditions, the differences between the measured and calculated piezometric levels being at most 1 cm. For the water level in Circus Lake, the process resulting from the modeling has the measured value of 74.26 m. The hydraulic conductivities values resulting from the model calibration process fall within the range of values characteristic for this aquifer, namely between 8…50 m/day and more narrowly the interval 10…30 m/day.

For the intermediate aquifer, the simulated piezometric levels range between 68.5 m and 78.3 m (Figure 29). The differences between the measured and calculated piezometric levels are less than 1 cm. The hydraulic conductivities resulting from the model calibration process fall within the range of values characteristic for this aquifer, namely between 3 m/day and 15 m/day.

The resulting flow budget form the hydrogeological model representing the groundwater recharge and discharge from the urban hydrological system components taken in consideration is given in Figure 30. This budget shows that the groundwater recharge in the study area is mostly from manmade sources (0.03 m^3/s from sewer conduits, 0.17 m^3/s from Water supply network against 0.01m^3/s from precipitations). Also, the groundwater discharge is mainly from anthropogenic sinks (0.0008 m^3/s to the sewers and 0.01 m^3/s to the subway tunnels).

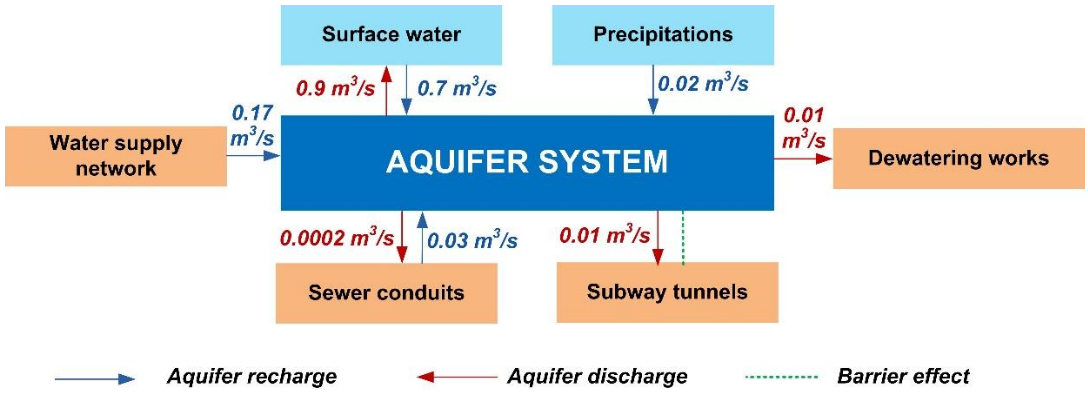


Figure 30: Groundwater budget

The decrease in the groundwater level and thus in the water level of the Circus Lake, which is directly connected to the aquifer system is a consequence of several hydrological and hydraulic factors influencing the zonal hydrological balance: climate change manifested through reduced rainfall, drastic reduction of water supply losses due to the improvement of the water distribution network in the study area and the presence of alleged dewatering systems.

III.1.3 Hydrological model

This model consists of simulating of rainfall-runoff process in the study area of 12 km^2, that is represented by green spaces areas summing 1.5 km^2, urban fabric of 9 km^2 and lakes and river of 1.5 km^2 (including the Circus Lake of 0.01 km^2). The Circus Park has an area of 0.14 km^2 (Figure 31). The annual average of precipitation rate is 657.35 mm/y.

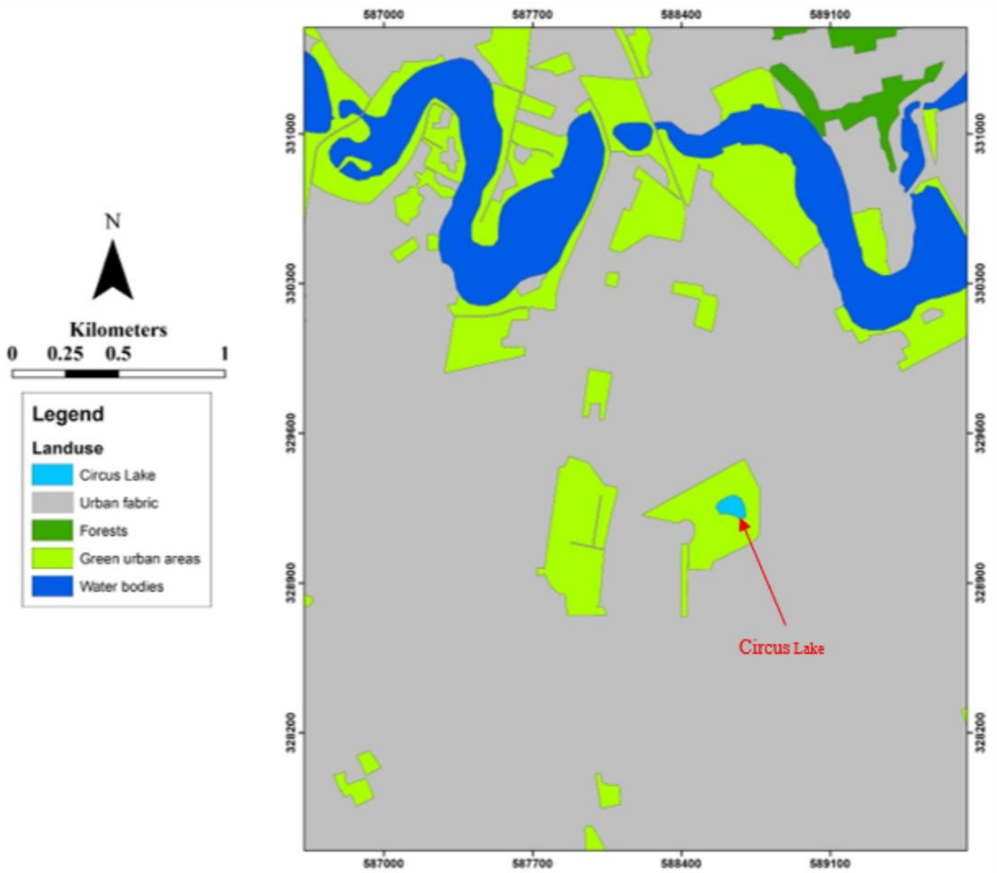


Figure 31 : Landuse in the study area (Tei district area)

For the hydrological simulation it is used WMS software (Watershed Modelling System). To date, the following results have been achieved:

- Calculating runoff flow directions.
- Providing DEM (Digital Elevation Model) file of the study area (Figure 32);
- Running TOPAZ model and establishing flow directions (Figure 33).

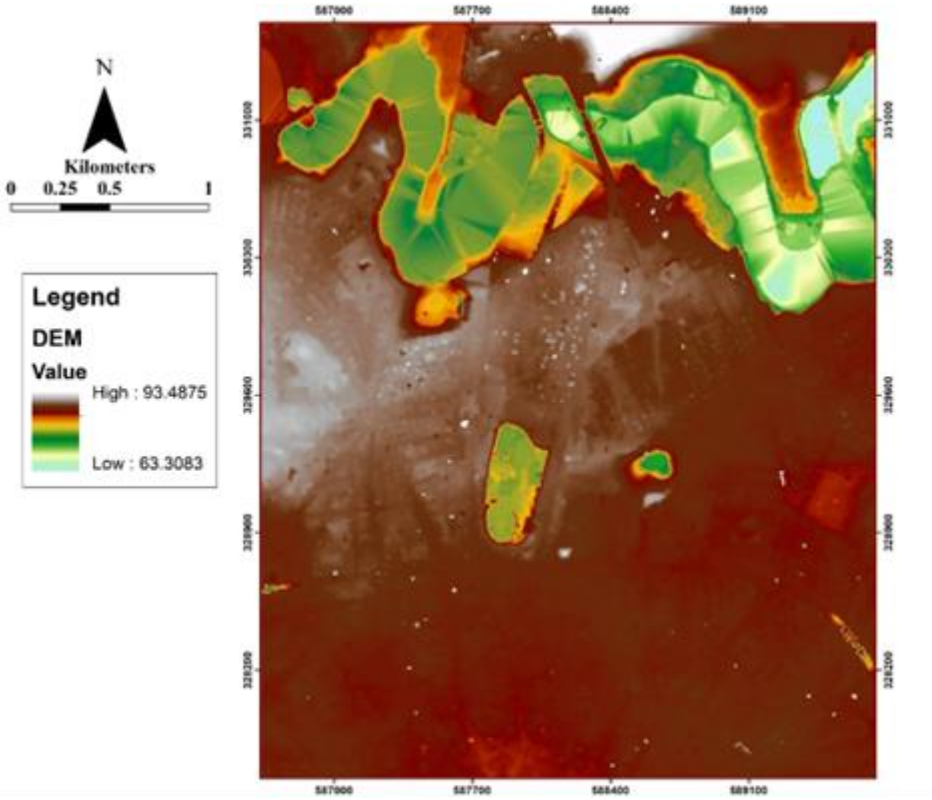


Figure 32 : The digital elevation model of the study area

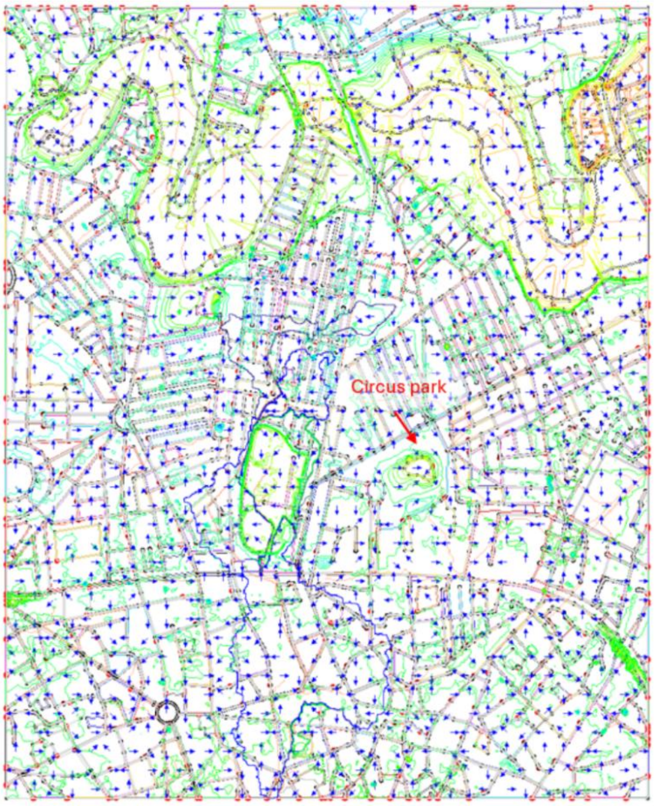


Figure 33 : The runoff flow directions in the study area

- Dividing the study area into sub-basins according to the flow directions of the runoff (Figure 34).

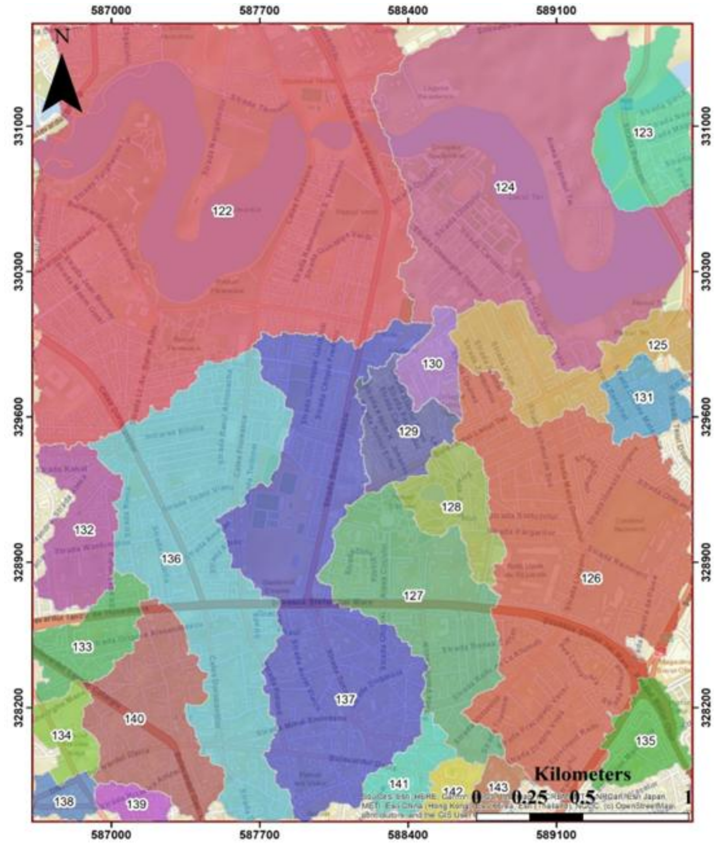


Figure 34 : Location of the determined sub-basins in the study area

Determination of runoff coefficients (Table 7) according to the land use and terrain morphology.

Table 7: The runoff coefficient values determined for each sub-basin

ID	Area (km^2)	Slope	Runoff coefficient
122	2.87	0.03	81.55
124	1.62	0.03	84.77
126	1.42	0.01	99.95
137	1.20	0.02	87.04
136	1.05	0.01	100.00
127	0.56	0.01	95.07
140	0.41	0.01	99.09
125	0.32	0.01	91.69
123	0.29	0.05	94.85
132	0.23	0.01	99.68
129	0.18	0.01	98.76
128	0.18	0.03	48.90
133	0.18	0.01	100.00
135	0.15	0.02	100.00
131	0.12	0.02	100.00
141	0.11	0.02	100.00
130	0.10	0.01	99.27
134	0.09	0.01	88.40
142	0.06	0.02	100.00
138	0.06	0.02	100.00
143	0.05	0.01	100.00
139	0.05	0.01	100.00

The sub-basin **ID137** (purple color in the above table), with a large impervious coverage, was chosen for a preliminary simulation using Rational Method and SWMM (Storm Water Management Model).

- Overlapping of the hydraulic runoff collection system in the study area (Figure 35): 4097 inlets and 176 km of sewage network.

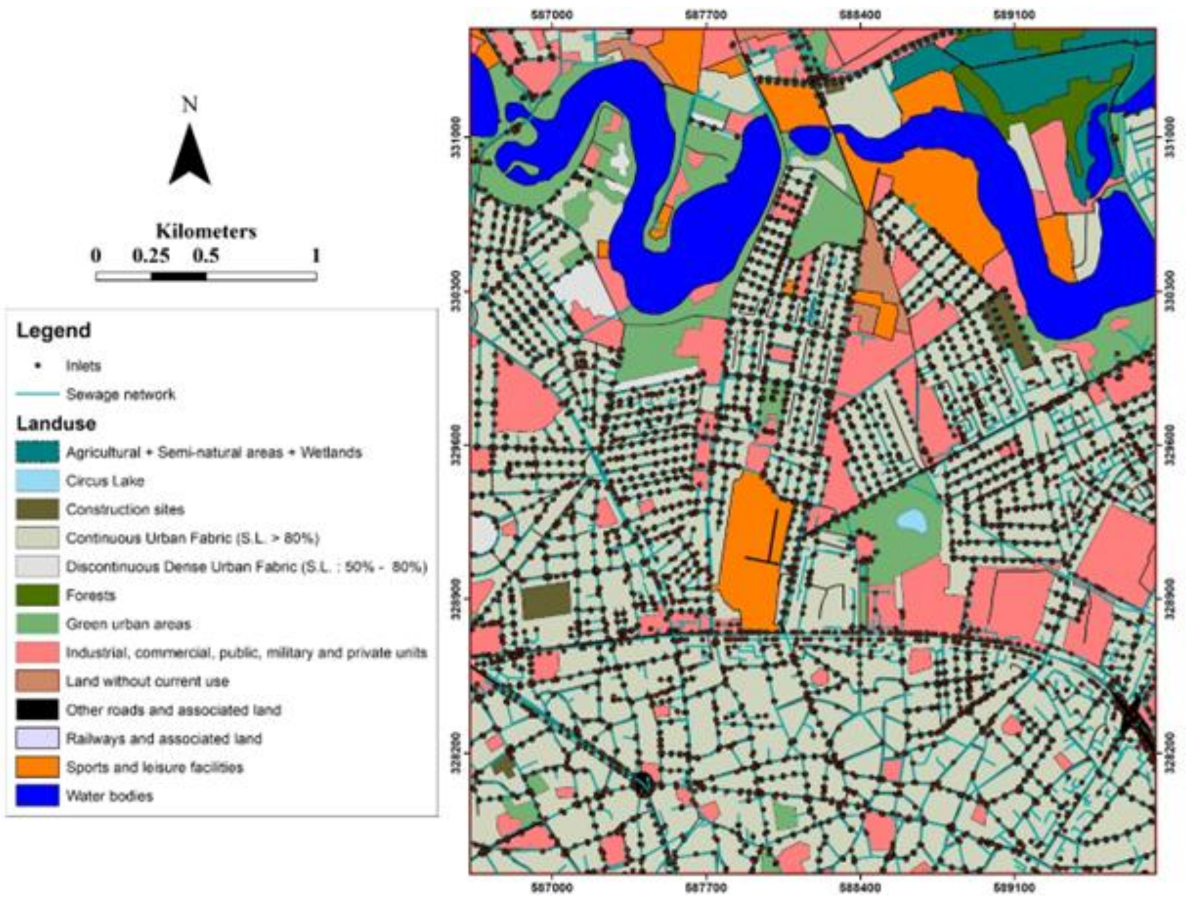


Figure 35 : The hydraulic system for runoff collection

During the next months will be performed preliminary simulations on sub-basin ID137 by different methods, and comparing the values obtained for runoff and infiltration. After that all sub-basins will be coupled to obtain the final hydrological model.

III.2 Monitoring plan

III.2.1 Urban water quantitative monitoring

❖ Groundwater and water level in Circus Lake

The water level in Circus Lake and groundwater levels in four piezometers located in the study area were monitored starting with August 2024 (Figure 37-39). Two of the piezometers are located about 50 m northeast of Circus Lake to monitor the level of the Colentina shallow aquifer (FM2LC) and the Mostistea intermediate aquifer (FM1LC). Two other piezometers are located 460 m (F06C) and 480 m (PC1416) south of the Colentina River and monitor the Colentina shallow aquifer, with which the river is hydraulically connected.

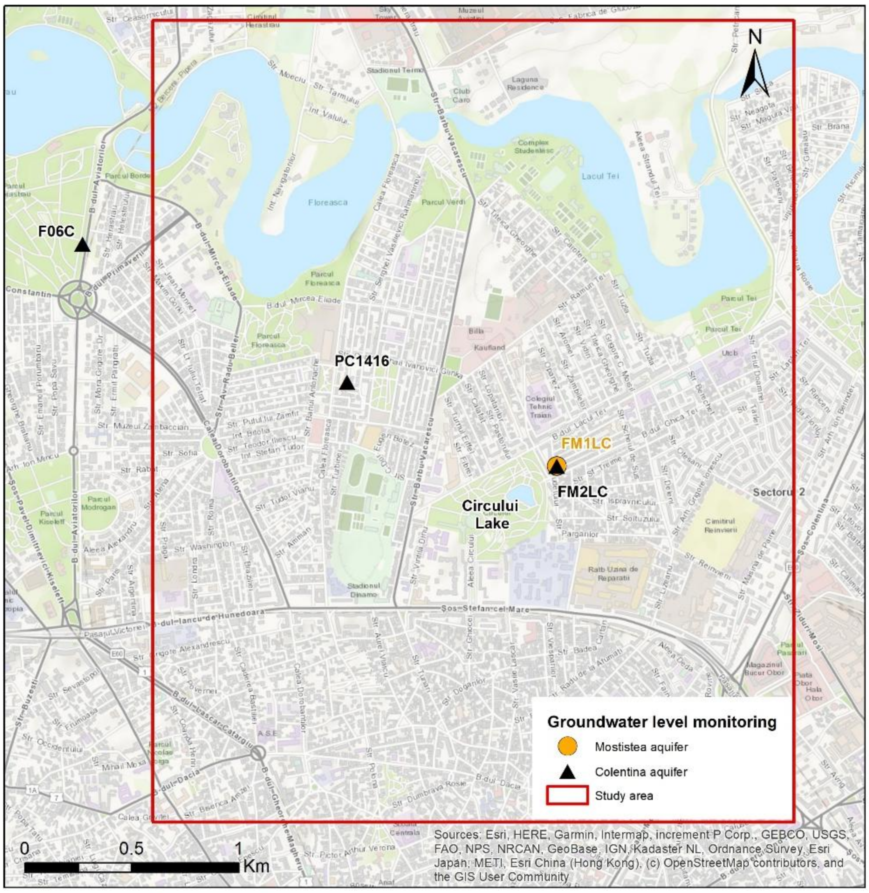


Figure 36: Map with the location of hydraulic had monitoring well in the study area (monitored since August 2024)

Figure 37: Hydraulic head monitoring

Figure 38: Circus Lake water level monitoring

The values recorded together with the total monthly precipitation values are shown as the diagram in Figure 39. It is observed that the water level in piezometers and in Circus Lake for the first 11 months monitored (August 2024 - June 2025) has a slightly increasing trend with a delay of a few days, in the case of groundwater, compared to the rainy event. Monitoring will continue for a period of at least two years, and the trend of the recorded values will be compared with that of the previous year 2018 (for which there is systematic monitoring) and it will be decided whether or not it is necessary to recalibrate the hydrogeological model.

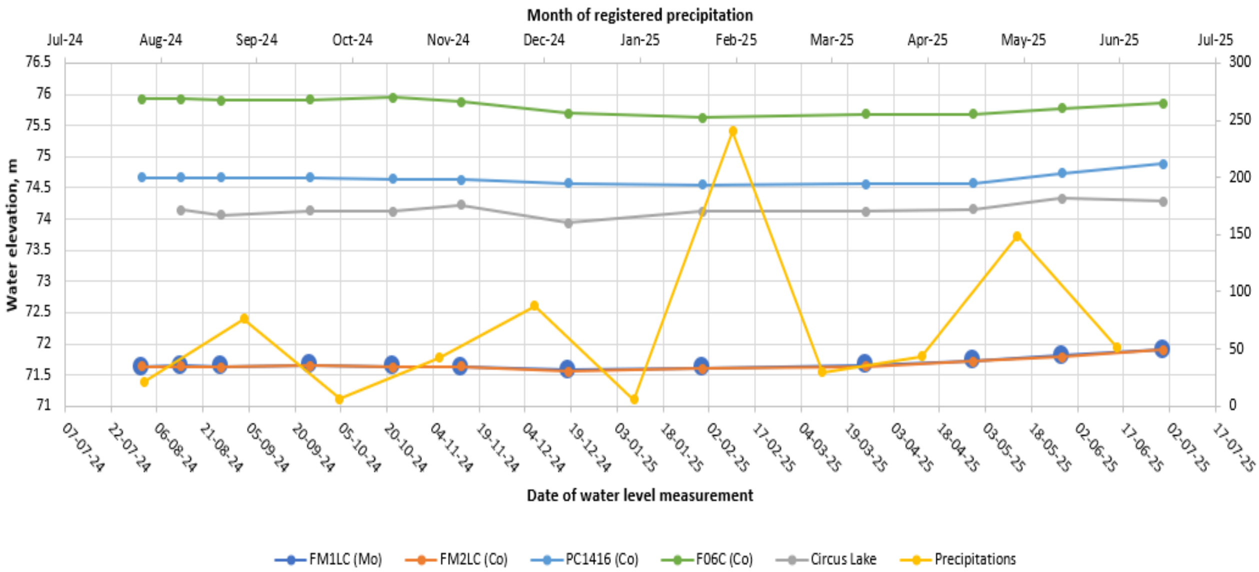


Figure 39: Surface water, groundwater elevations and monthly precipitation

III.2.2 Urban water qualitative monitoring

A first set of water analyses was performed for the water quality elements mentioned in Table 1 and according to the scheme in Table 2. Raw rainwater collected from the roof and street was kept for 18 hours in the containers and then filtered. The street area, corresponding to the stormwater runoff sampling, is concreted and has light car and pedestrian traffic.

The results of the chemical analyses are presented in the diagrams in Figure 40-45. The samples were collected after several hours of the rainy event (without taking into account the first flush), because it was considered that larger volumes of water are required for the operational NbS. The values of the concentrations of the water chemical parameters are considered representative as an average of the rainfall event.

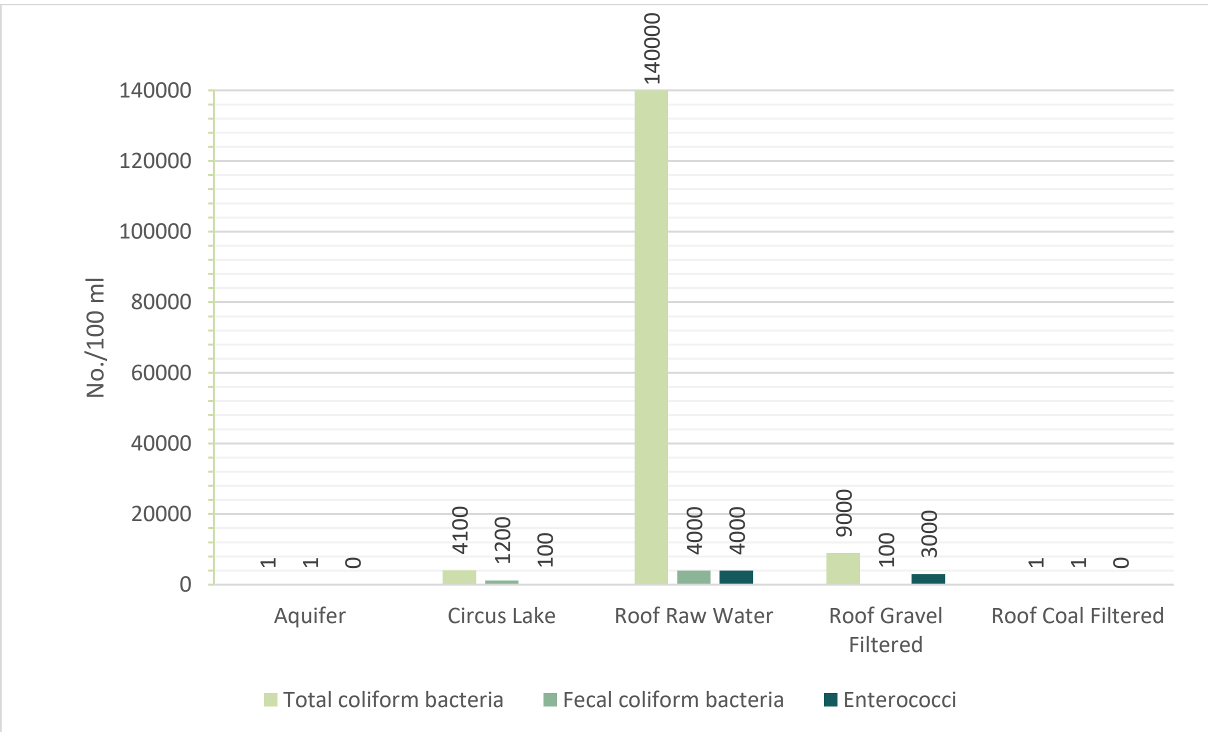


Figure 40: Comparison between the values of microbiological parameters depending on the water source and the treatment method

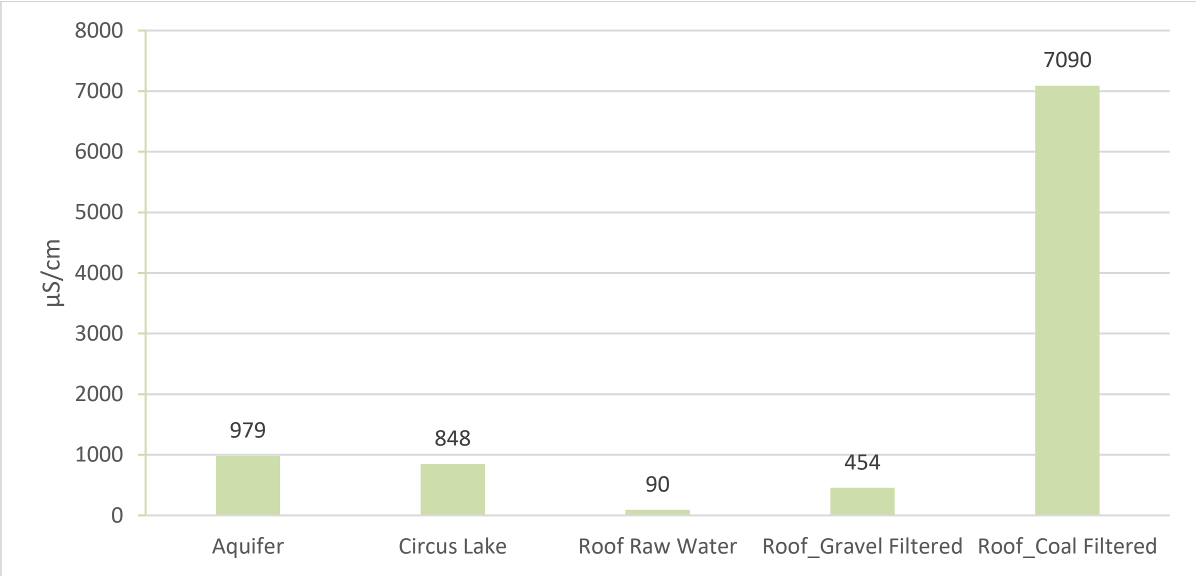


Figure 41: Comparison between the values of electrical conductivity depending on the water source and the filtration method

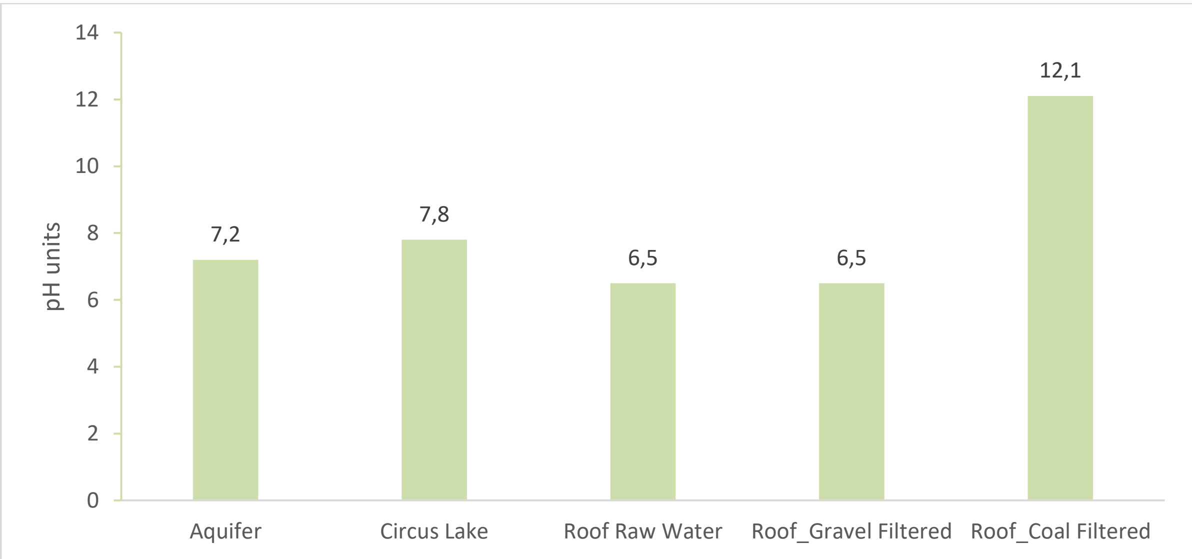


Figure 42: Comparison between the values of pH parameter

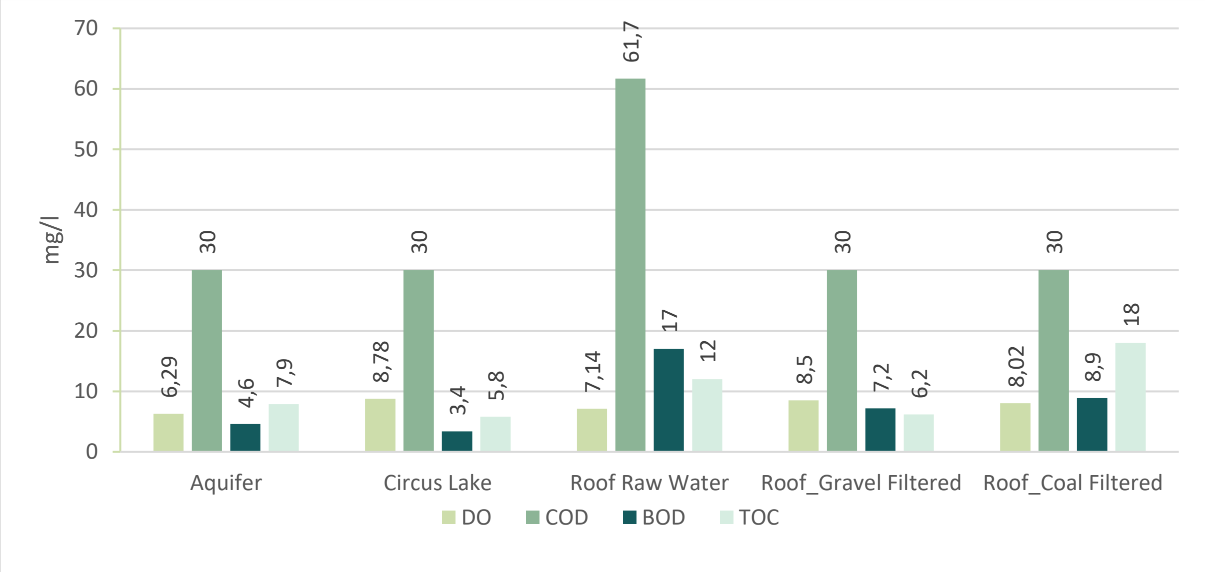


Figure 43: Comparison between the values of TOC, DO, COD and BOD

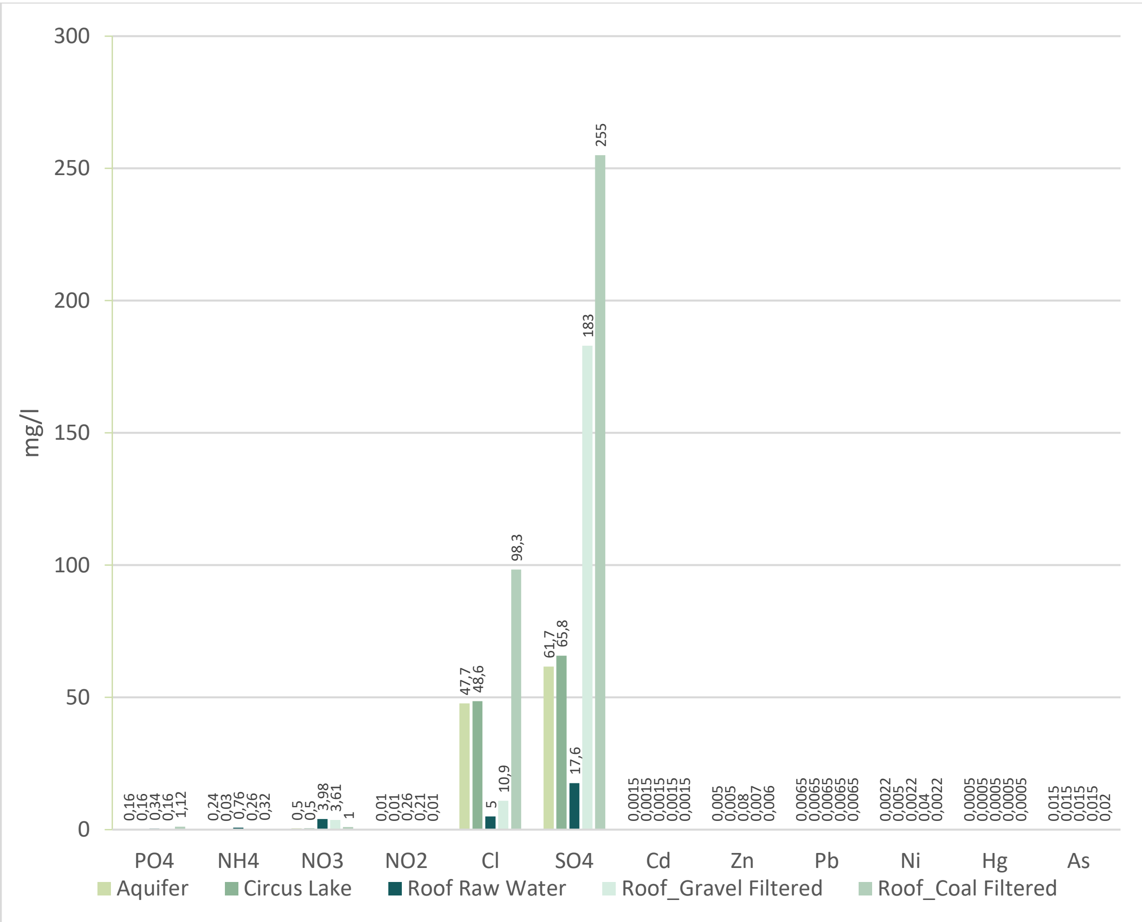


Figure 44: Comparison between the values of inorganic elements

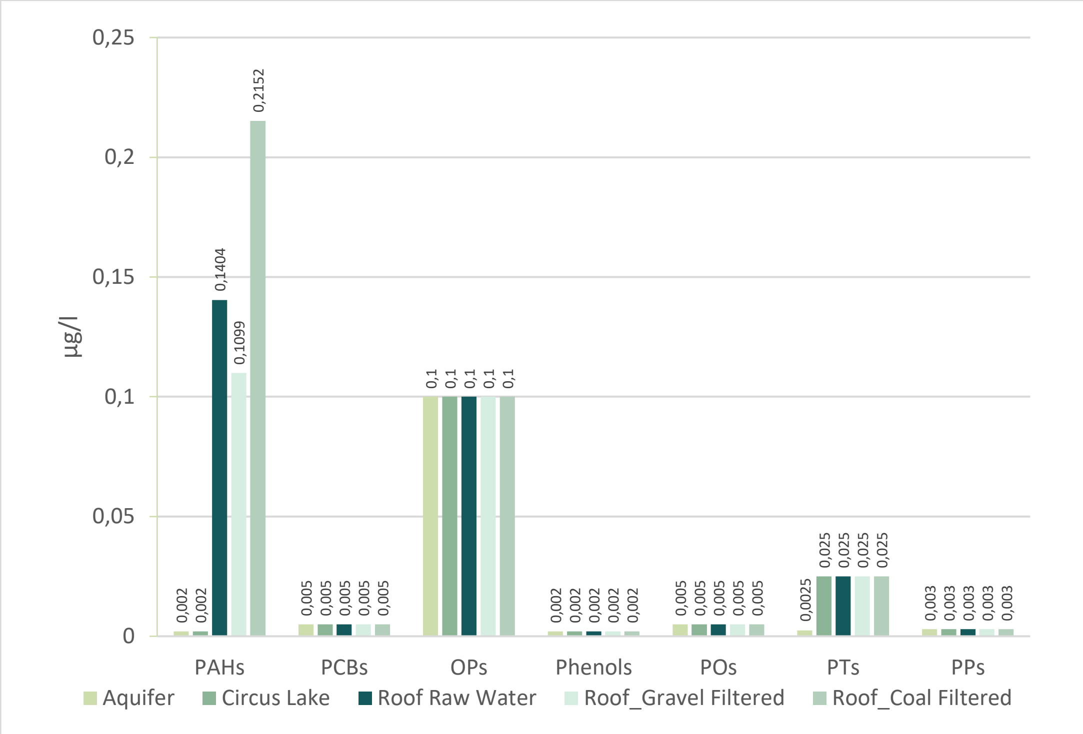


Figure 45: Comparison between the values of organic elements
PAHs - Polycyclic Aromatic Hydrocarbons; PCBs - Polychlorinated Biphenyls; OPs – Oil Products (Petroleum Products); POs - Organochlorine Pesticides; PT – Triazine Pesticides; PPs - Phosphorus Pesticides

According to the results of chemical and biological parameters the captured street stormwater varied from the captured roof rainwater and suggests that roof rainwater requires more treatment than street stormwater. Generally, the results indicated that Circus lake and roof rainwater differed and this could be likely due to the presence of microorganisms such as algae, bacteria, and protozoa, which can contribute to natural water processes; such as biodegradation by bacteria and protozoa which break down organic matter in water, some microorganisms such as biofilm-forming bacteria help trap and degrade particles such as organic matter as they settle, other processes such as nutrient cycling by algae and bacteria which participate in cycling of nitrogen and phosphorus. In contrast, roof rainwater, though possibly exposed to similar conditions, lacks this biological component/aspect. Additionally, the lake is fed by a secondary aquifer which is likely to be less contaminated, potentially improving the lake's water quality.

The results highlight that 18 hours contact time with the filter is adequate looking at the successful reduction of parameters such as heavy metals (Cd, Zn), Ammonium (NH4), Nitrates (NO3), Nitrites (NO2), total coliforms, faecal coliforms and Enterococci. The analysis of filtered raw rainwater collected from street and roof will be repeated for 6 parameters which seem to have abnormal values maybe due to insufficient previous washing: pH, Electrical conductivity (EC), Chlorides (Cl), Sulfates (SO4), Polycyclic Aromatic Hydrocarbons (PAHs). The Total Organic Carbon (TOC) were inconclusive because it was a lower concentration in roof rainwater while in gravel and sand treatment and it has been seen an increase in concentration. On the other hand, for activated charcoal the opposite occurred for roof raw rainwater activated charcoal. It had an increase in concentration while for street stormwater occurred a reduction in concentration.

The collected stormwater was from low traffic area with generally few pedestrians (light foot traffic). These results could be true for the future of bioretention systems, given that the first flush is monitored. After the treatment stage, based on these results, it could be considered compatible with the water quality in the aquifer in Circus Lake. The greatest challenge based on the initial results is the high pH and electrical conductivity (EC) for Coal. Once this is confirmed in the upcoming months, a possible option for future NbS and bioretention cell could the mixture of coal with gravel filter, to enhance the treatment performance, minimizing releases by the coal.

Thus, for the untreated water filtration devices the cleaning process has been improved and during the next months, depending on future rainfalls, the analysis will continue with 10 parameters from the initial selected 28 parameters (i.e. pH, EC, NH4, PAHs, NO3, NO2, Cl, SO4, TOC and Ni).

III.3 Problems faced

Due to the urbanized area, high degree of terrain surface impermeability, several challenges are highlighted in the application of the water balance results resulting from the coupling of the hydrological model with the hydrogeological one. Thus, for the redirection of a part of the runoff from the sewerage network to possible or existing NbS, the following problems and challenges must be considered:

- The urbanized space requires some larger or smaller transformations, which must be approved at both the administrative and legislative levels. These approvals require time, sometimes quite long, during which urban architecture may undergo significant changes, according to already existing urban plans. A correct water balance, which highlights different scenarios, can lead to a convergence of the interests of the water operator, local administration, and local communities.
- The lack of clear responsibility at the level of a local authority regarding the maintenance of the monitoring system and the performance of periodic measurements leads to difficulties in achieving a correct water balance and adopting appropriate AWR solutions. For Bucharest, it was seen that the implementation of a monitoring system based on sponsorships, research contracts, etc., was not viable over time, most of the monitoring wells being vandalized or destroyed by the arrangement of other constructions (e.g. parking lots), even if the construction of each monitoring well was authorized by the local administrator. Monitoring should be continuous and periodic to avoid gaps in the data set, and the data should be public. This would simultaneously benefit decision-makers regarding urban development, hydrogeological and geotechnical study authors, and building designers in the urban area. Urban development decisions based on a correct water balance, which in turn is based on a solid data structure, can lead to a convergence of the interests of the water operator, local administration, habitant communities and a friendly development of the city in relation to the environment.
- It can be said that the project's objectives are well ahead of the existing legislation in Romania and that the authorities must be "pushed" to adapt the legislation to the existing needs and challenges.

III.4 Technical conclusions

The activities carried out in DC#1 are following the objectives, with no deviation from the work plan proposed at the beginning of the project to date. The water balance defined for the Tei neighbourhood is under development based on the hydrogeological model for 2018 (completed), the hydraulic quantification of the unsaturated zone (in progress) and the urban hydrogeological model (at an advanced stage of completion). The water balance will represent the qualitative component used in the analysis of the NbS solutions for Lake Circului and the Tei neighborhood.

A first realization of the urban rainfall-runoff model has been achieved. Further improvements of the model will be performed during the next months. The unsaturated zone was tested to determine the hydraulic conductivity K (LT-1) corresponding to the saturated state of the urban soil (anthropogenic soil) and provided indicative values of the hydraulic conductivity needed to assess the unsaturated zone infiltration procedure. The groundwater flow in the shallow aquifer falls within the general flow for this aquifer (in the Bucharest area). The model calibration was performed under optimal conditions, the differences between the measured and calculated piezometric levels being at most 1 cm. For the water level in Circus Lake, the process resulting from the modeling has the measured value of 74.26 m. The resulting flow budget form the hydrogeological model, representing the groundwater recharge and discharge from the urban hydrological system, shows that the groundwater recharge in the study area is mostly from manmade sources (0.03 m3/s from sewer conduits, 0.17 m3/s from Water supply network against 0.01m3/s from precipitations). Also, the groundwater discharge is mainly from anthropogenic sinks (0.0008 m3/s to the sewers and 0.01 m3/s to the subway tunnels).

From a qualitative point of view an experimental device was designed and built and the first data, needed to develop a comparative analysis of the water quality values (resulting from a primary water filtration, through filters of active charcoal and sand with gravel) have been obtained. This dataset covers a wide range of parameters considered necessary to perform a first screening of stormwater and rainwater quality parameters. The collected stormwater was from low traffic area with generally few pedestrians (light foot traffic). After the treatment stage the water quality could be considered compatible with the water quality in the shallow aquifer. For the untreated water filtration devices, the cleaning process has been improved and during the next months, depending on future rainfalls, the analysis will continue with 10 parameters from the initial selected 28 parameters (i.e. pH, EC, NH4, PAHs, NO3, NO2, Cl, SO4, TOC and Ni).

A mini bio-retention system will be built within the Tei district, with the support of the Bucharest District 2 Municipality (protocol between UTCB and District 2 Municipality received the approval of the Bucharest Municipality General City Council). This system will be tested to assess the stormwater pollutants removal efficiency.

IV Social activities within DC#1 and Participation in other WPs

Throughout the implementation phase of DC1, a series of structured social engagement activities were conducted to ensure transparency, stakeholder inclusion, and collaborative input into the planning and design processes. These activities are essential for building stakeholders' ownership of the project outcomes.

1. Local Water Forum (LWF) – July 4th, 2024

On July 4th, 2024, a Local Water Forum was organized by BDG to facilitate open dialogue between project partners and local stakeholders, including local authorities, water authorities, civil society representatives, and environmental experts (Figure 46). UTCB actively participated with a detailed presentation on the DC1 scope, methodology, and expected contributions. The LWF enabled the alignment of local challenges with the broader objectives of the demonstration case.

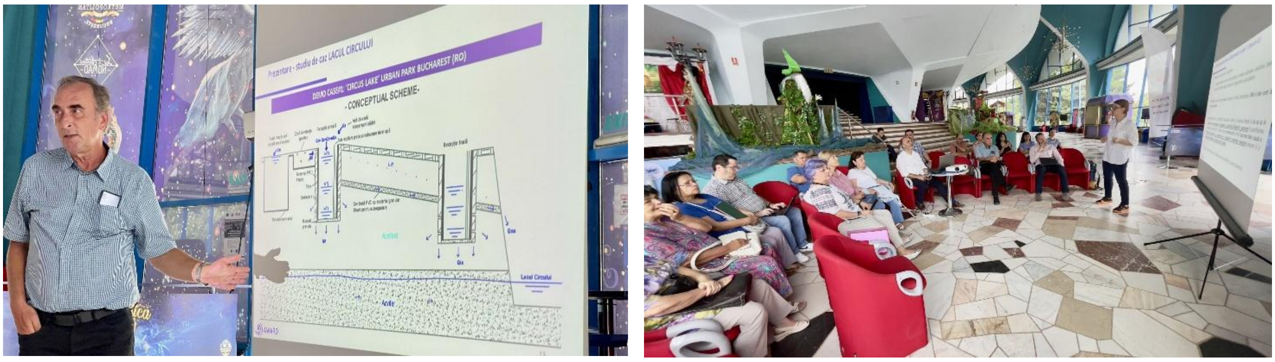


Figure 46: Photos of the 1st LWF

2. Stakeholder Meetings – February-March 2024

The main stakeholder in this project from local and national authorities, community associations and private operators are:

- District 2, Bucharest Municipality (collaboration protocol in the framework of the AWARD project signed on 30.07.2025 between UTCB and District 2 Bucharest Municipality).
- Lakes, Parks and Recreation Administration of Bucharest (ALPAB) coordinated by the Bucharest Municipality, (collaboration protocol in the framework of the AWARD project, signed on June 2024 between UTCB and ALPAB)
- National Administration “Apele Romane” (Romanian Waters)
- The water operator of Bucharest city ApaNova S.A., managed by-VEOLIA
- Tei District community

Several focused stakeholder meetings were organized in February and October 2024, aimed at presenting and refining the structure and objectives of DC1. These meetings were attended by local authorities, researchers, water administration, representatives of the local water operator, and local community organization (Figure 47). The February-March sessions introduced the DC1 objectives and activities and sought preliminary input.

Figure 47: Stakeholder meeting – presentation of AWARD project and DC1 objectives and activities

3. Technical Visit for WP3 in DC1 – October 1–4, 2024

A key milestone in the social and technical engagement process was the organization of a technical visit for Work Package 3 (WP3) in DC1, conducted between October 1–4, 2024. This visit included a series of structured interviews conducted by Paris Saclay representatives with leading institutions and experts involved in water management and green infrastructure in Romania. Interviews were held with:

- Romanian Water Administration (ANAR)
- National Institute of Hydrology and Water Management (INHGA)
- Green infrastructure researchers **–** University of Bucharest, Faculty of Geography
- Bucharest Municipality **–** Lakes and Parks Administration (ALPAB**)**
- Văcărești Natural Park Administration (APNV)
- Bucharest water operator **–** ApaNova/Veolia
- Romanian Water Association (ARA)

During the visit, UTCB delivered a presentation detailing the technical and conceptual framework of DC1. The visit offered an important opportunity for project partners to collect insights from institutional stakeholders, clarify technical assumptions, and align DC1 objectives with operational and policy frameworks on water and urban ecosystems.

4. Stakeholder Session during Project General Assembly – February 21st, 2025

During the Project General Assembly held in Bucharest on February 21st, 2025 (Figure 48), a dedicated session was conducted to engage stakeholders in a broader project update and discussion specific to DC1 (Figure 49). UTCB presented progress updates, preliminary technical results, and key policy-relevant insights emerging from the DC activities. The session allowed both internal project partners and external invitees: such as RDA representatives, city authorities, practitioners, and researchers, to discuss the DC1 intervention. This event reinforced multi-level cooperation and helped position DC1 within strategic urban development discussions.

Figure 48: AWARD General Assembly - February 21st, 2025, Bucharest

Figure 49: Stakeholder session after AWARD General Assembly - February 21st, 2025, Bucharest

These activities represent critical steps in maintaining a participatory and transparent approach to the implementation of DC1. The iterative engagement with stakeholders has contributed not only to the refinement of technical solutions but also to strengthening the institutional and community support necessary for long-term impact.

As replicating the proposed urban area water-balance analysis to support AWRs solutions in Bucharest and in other cities, several steps have been made at the national and international level (WP6, Task 6.1). Apart an active work of warning with the above mentioned target groups, a collaboration protocol has been set-up to be signed with the Bucharest 2nd District administration with the goal of implementing the AWARD proposed solutions and results replication (WP5, Task 5.2). At the international level, promoting and discussing AWARD objectives (WP6, Task 6.1), mechanisms, and results have been done within the

International Water Association (Groundwater Management Group), during the Congress in Davos (2024) of the International Association as well as during the meeting between the IWA president and the Specialist Group and Cluster Chairs (August 5, 2025).

V Final goal/Expected results

The expected results are:

- developing an accurate urban water balance for the Tei urban area by applying AWRs solutions that account for both surface and groundwater,
- controlling the groundwater level in the Tei urban area and implicitly the water level in the Circus Lake through the application of reliable AWR solutions and by relieving the sewage network from excess storm water.
- demonstration of the efficient uses of different alternative water sources, with a focus on storm water management, aquifer recharge, rainwater harvesting and water reuse,
- creating a replicable framework for urban water balance analysis to support AWR solutions and green infrastructure implementation in Bucharest and other cities.

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ANEXES

Articles and Scientific events

1. Ghibus, T. & Gaitanaru, D., 2024. A Statistical Approach for the Assessment of Saturated Hydraulic Conductivity Values of Unsaturated Urban Soils Obtained by Field Infiltration Tests. *Water,* 16(13) https://www.mdpi.com/2073-4441/16/13/1908 .

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