D5. Functional tailored prototype of Watersave$^+$ at Zoo Liberec

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Content

1. General Watersave⁺ pilot description

In the project is designed the system of water management of non-potable water in the part of Zoo Liberec. Purpose of the project is the accumulation and treatment of non-potable water with possibility of its recirculation for using in the elephant, tapirs and giraffe pavilion.

The basic principle is wastewater treatment with water accumulation, which will allow the water from the pools to be recirculated. This will maintain quality and minimize the need to subsidize water from sources. The goal is to reduce the consumption of non-potable water and water from the public water supply system, and the operation will become more independent of these sources.

The system includes the construction of a constructed wetland - vertical root filter with an accumulation space. The filter works on the principle of an aerobic biofilter, which is used for biological-mechanical water treatment and mainly removes organic pollution. A separation filter is used for mechanical pre-treatment before entering the vertical root filter, where undissolved substances are basically caught.

The system includes a containerised water treatment plant, which is located behind the wastewater treatment plant before the distribution back to the zoo. The water treatment plant includes several water purification mechanisms depending on the type of contamination:

(a) Ultrafiltration unit

(b) UV lamp

(c) Sand filter

(d) Disc filter

This will ensure microbial safety (sanitation) and the removal of residual organic pollution or suspended solids.

There are two sources of water for replenishment of the system - drainage water from under the constructed wetland = practically clean and from the Swan Pond.

The energy consumption of the installed system, in particular the container with the ultrafiltration unit, the complete electrical installation and the control system, will be provided by a photovoltaic power plant located on the roof of the entrance building of Zoo Liberec.

To support biological processes that improve water quality in Swan Pond, natural bacteria will be used during the growing season in the pond to accelerate decomposition processes in the settled sediment. The system of measures to improve water quality at Swan Pond also includes the installation of an ultrasonic transmitter to suppress the growth of cyanobacteria and green algae and floating vegetation islands that act as floating root cleaners.

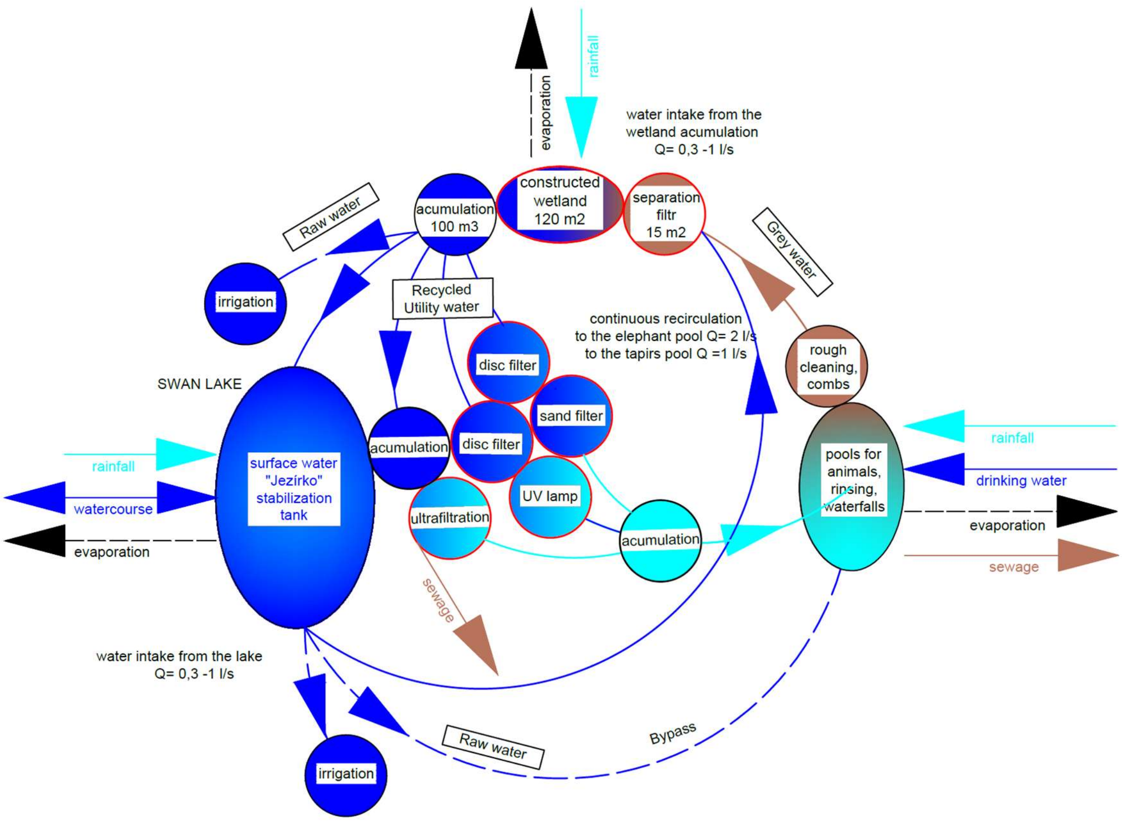
A new, added part of the Watersave⁺ system is the second container-based mobile ultrafiltration unit at Zoo Liberec, which will be tested in the treatment of surface water from the pond for flushing in the new toilet in the lower part of the Zoo. Its addition was made possible by a partial reallocation of funds in the budget of Photon Water (PWEU).

As part of the LIFE4ZOO project, PWEU built a real-time autonomous monitoring system at the ZOO´s inflow, pond's inflow and pond´s outflow. The system also measures F-CH parameters directly in the pond. The monitoring system enables automated measurement of F-CH parameters and water flows and their online availability.

Summary of benefits:

- Recirculated wastewater treatment for the needs of the elephant, tapir and giraffe pavilion (in the future the lower part of the zoo) has the effect of reducing the withdrawal from other water sources.
- The use of pretreated water from the Swan Pond for distribution to the non-potable distribution system for the needs of the zoo grounds (irrigation, rinsing, water supply, etc.) has an effect on the reduction of withdrawal from other water sources.
- Restriction of discharged polluted water into public sewage system

***Figure 1** – FIT4USE water recirculation scheme technology in Zoo Liberec*



2. Operational technical solution

2.1. Water Cycle

See diagram D.2.1.2.1 – Longitudinal TS (Annex 2)

Water from the outdoor elephant pool and, in the future, from the giraffe area flows by overflow into the pumped shaft Š-006, from where it is pumped by pump P-001 into shaft Š-004. From there, it flows gravitationally through shafts Š-003, Š-002, and Š-001 into the separation filter SF-001.

Additionally, water from the indoor elephant pool overflows into shaft Š-004, and water from the tapir pool flows into shaft Š-003. The tapir pool is now newly equipped with a submersible mixer with a power of 0.7 kW. The mixer is installed inside a protective pipe with a diameter of DN315.

From the separation (sand) filter SF-001, the water flows into the pulse shaft PŠ-001, where a pulse (float) valve is installed, which periodically releases water into the root constructed wetland wastewater treatment (root CWTP or RWWTP).

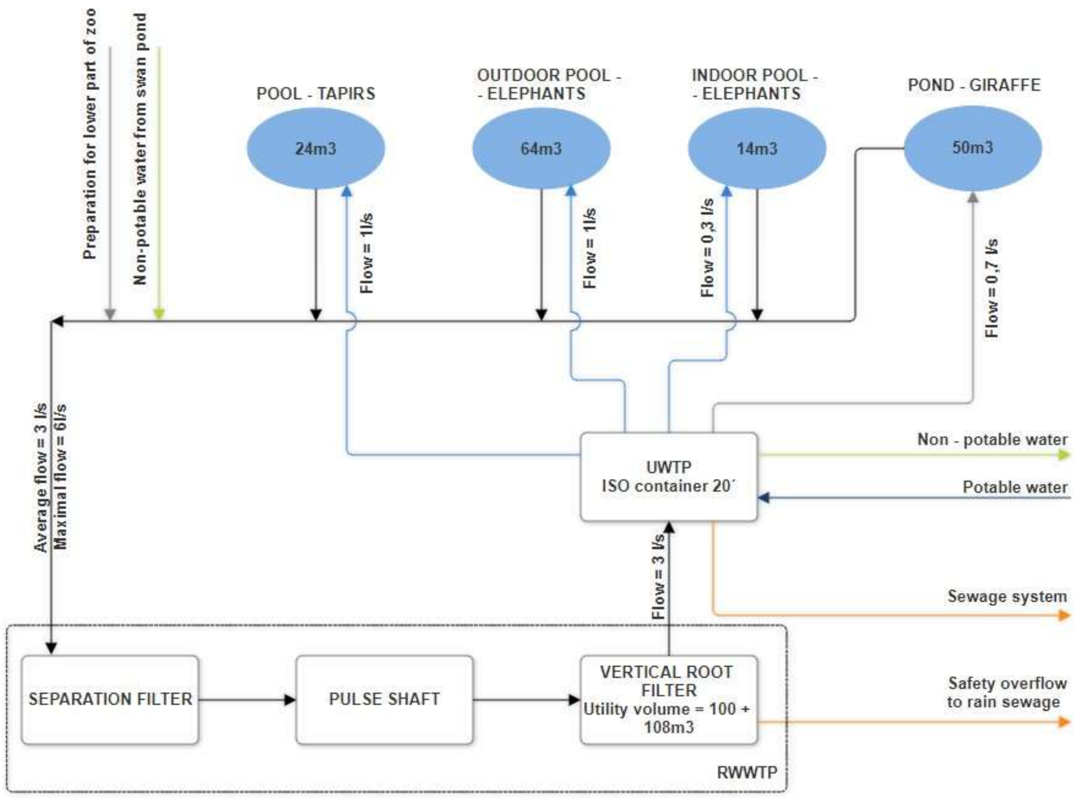
The treated water from the root CWTP is then periodically pumped by pumps P002 and P003 into the accumulation tank AN1 (with a safety overflow).

Water for replenishing the system is primarily pumped from the drainage shaft, and in case of shortage, from the Swan Pond.

The operational technical solution is shown in the complete technological scheme, which is part of technological part of project documentation – see Annex 1 to this report.

The process of water treatment and recirculation in Zoo Liberec is shown in the following block diagram in Figure 2.

Figure 2 *- Process flow diagram*



2.2. Technology

See diagram D.2.1.2.2 – UF Scheme (Annex 3)

2.2.1. Waste water treatment plant (WWTP)

Description of the function and operation of WWTP objects (separation filter, vertical root filter, accumulation space of WWTP):

The separation filter is used as mechanical pretreatment before inlet to the vertical root filter. Undissolved substances will be caught there. The vertical root filter is divided into two separate functional surfaces for operational needs. It is designed as a hydro-insulated natural reservoir containing aggregates of various thicknesses and fractions, with integration into the surrounding terrain.

The inlet to the separation filter is by means of a flexible hose, which makes it possible to change the inlet between two independent surfaces of the separation filter. The inflow will spill onto the surface of the filter and flow vertically through it. It drains through the collection bottom pipe. In particular, sediment will settle on the surface of the filter, which will be removed by the operator. In the case of a condition of impaired seepage capacity, or for a certain period of time, the second filter surface will be engaged, and the clogged filter surface will be cleaned. The cleaning of the filter will consist of the temporary removal of the plastic grates from the surface and the removal of the sediment, including a partial layer of the top filling of fraction 2/4 sand. The removed sand will be added, and the plastic grates will be returned. The sand can be washed and reused in a suitable place. It is advisable to perform the cleaning only after a certain period of time after the filter has been shut down. The cleaning period will depend on the specific conditions and pollution produced. The prediction is the renewal of ½ filter (i.e. one area of 15 m^2) per year. If necessary, the collection pipeline will be flushed using inspection chimneys.

The pulse shaft is equipped with a mechanical pulse discharger. It converts a continuous inflow into a volumetric outflow and thus enables optimal distribution of water on the surface of the vertical root filter.

The vertical root filter is a waterproofed natural reservoir that is integrated into the surrounding terrain. Its content is composed of aggregates of various strengths and fractions, and the surface is planted with wetland vegetation - see Annex 4 to this report.

Functionally, it is a non-flooded sprinkled aerobic biofilter that serves for biological-mechanical treatment of wastewater. Part of the vertical root filter is the water accumulation space in its lower, jointly waterproofed part. This space is composed of accumulation PP blocks and partially aggregate.

The vertical root filter requires only an occasional check of the seepage capacity, and possible flushing of the distribution pipe can be done using inspection chimneys. The operator removes weeds and mows grass on the airy slope of the embankment. In winter, preferably in February, it is necessary to mow the wetland plants.

The vertical root filter can also be operated in the winter, it is assumed that the treated function is only partially impaired. At least the indoor elephant pool is expected to operate during the winter. In the case of a complete shutdown of the pools, the constant quality of the accumulated water will be maintained by a small recirculation circuit of internal recirculation through the discharge pipe opening into the pulse shaft. The sprinkler function of the filter must also be maintained for watering the plants.

The pumping shaft is part of the vertical root filter. It is used to place pumps that pump water from the accumulation part of the vertical root filter further into the system. At the same time, the shaft is intended for height regulation or volume of water in the vertical root filter accumulation part and also allows to regulate the level in the filter space serving as an operational reserve storage volume.

In the pumping shaft, it is possible to change the level height using a flexible hose. In normal operation, the level will be maintained at the level of flooding of the full storage capacity - elevation 395.10 = utility volume 100 m^3. Minimal storage volume of 8 m^3 must be preserved for recirculation and cannot be used for utility distribution without recirculation. The level or the volume can also be reduced as needed. In order to use the operational reserve volume, the level will be raised up to elevation 396.02 = an additional accumulated volume of 40 m^3. This will result in a temporary flooding of the filter, which is not a problem. This state will be able to be used, for example, when one of the pools is completely drained. This saves water that would otherwise flow into the existing rain sewage system.

Parameters of WWTP:

- Accumulation volume — 100 m^3 (minimum 8 m^3 volume for recirculation must be maintained)
- Accumulation min.utility volume — 95 m^3
- Operational reserve accumulation volume — 40 m^3
- Total maximum accumulation volume — 140 m^3

2.2.2. Storage tank (AN1, AN2)

Two storage tanks - AN1 and AN2 - are proposed in the technology of the container water treatment plant. Instead of one precast tank, a prefabricated reinforced concrete prefabricated frame tank structure with external dimensions L x W x H = 2 600 x 4 770 x 3 600 mm is used. The thickness of the side walls and bottom is 150 mm, the ceiling is 150 mm thick. The tank is made of concrete C35/45 XC2, XA3, XF4. Each storage area is provided with a separate entrance.

Parameters of the storage tank AN1

- Internal dimensions L x W x H: 2 300 x 815 x 3 300 mm
- Usable volume Used: 6.4 m^3

Parameters of the storage tank AN2

- Internal dimensions L x W x H: 2 300 x 3 300 x 3 300 mm
- Usable volume Used: 22.0 m^3

2.2.3. Ultrafiltration unit

The technology of the container ultrafiltration water treatment plant is based on the wastewater treatment plant and forms an integral part of the complex water recycling system on the site Zoo Liberec.

Due to the requirement for maximum operational safety and microbial safety of the water at the level of bacteria and viruses due to the breeding of different types of animals, it was decided to design ultrafiltration treatment plant for pre-treated water from the WWTP. The water treated by the ultrafiltration treatment plant can then be returned to the animals' pools without risk to their health and thus achieve a high water saving in the Zoo area.

Parameters of ultrafiltration technology

Maximum influent parameters for the ultrafiltration container water treatment plant:

- Maximum flow rate Qmax: 10.8 m^3/h
- Chemical oxygen demand COD_{Mn}: 110 mg/l

- Non-dissolved solids NL: 30 mg/l

Runoff parameters:

- Recovery: min. 90%
- Output water: microbially safe water
- Suspended solids NL: 3 mg/l
- Estimated quantity

Wastewater: approx. 5 m^3/d (depends on operating conditions) - to be determined on the basis of test operation)

Treated water from the WWTP (part of the pulse shaft) flows into the pumping shaft, which is structurally part of the WWTP. The water is pumped by submersible pumps to storage tank AN1, which is designed as precast concrete tank. From the storage tank AN1 water is pumped to the process line of the container ultrafiltration water treatment plant by horizontal feed pump P-004.

Subsequently, one of three processes can be selected:

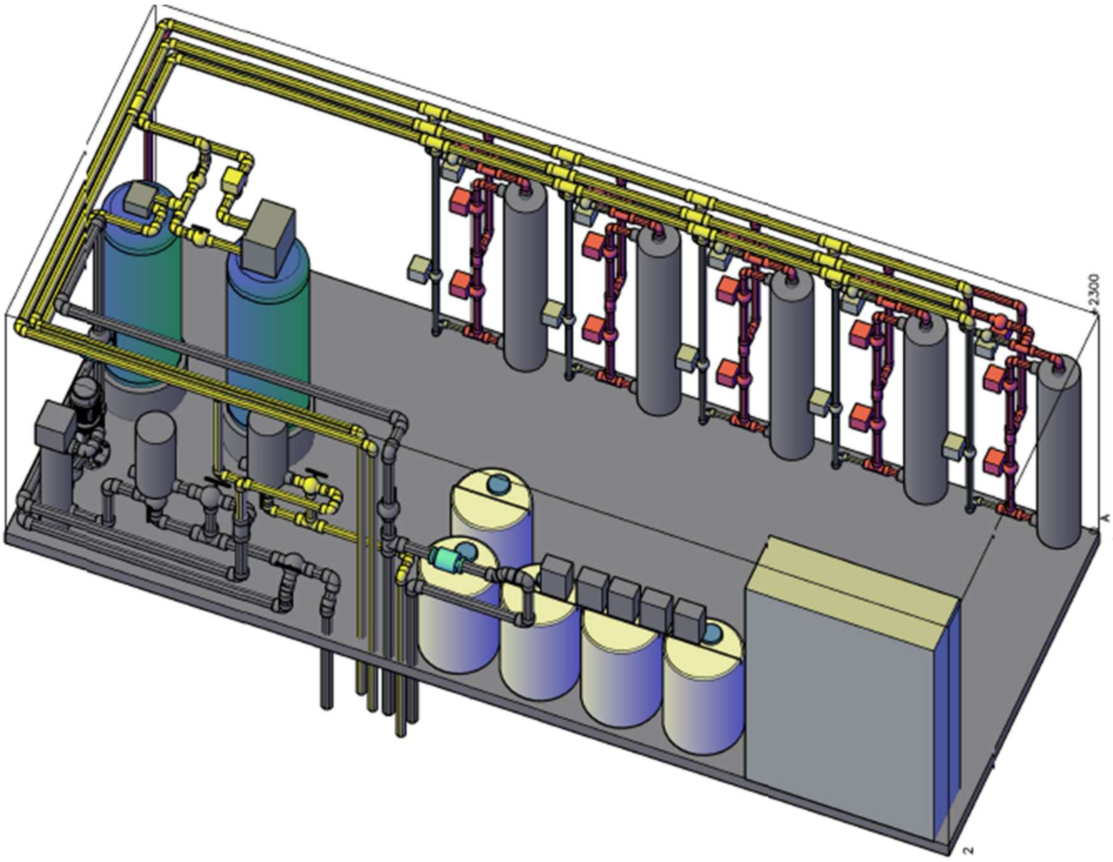
- Water flows only through the disc filter F-010 with a porosity of 130 µm, UV disinfection unit UV-001, and booster pump P-014 into the distribution system. Can be used as a backup solution in case of failure of the ultrafiltration system.
- The water passes through an automatic disc filter F-002 with a porosity of 130 µm to the InLine coagulation plant F-003, where coagulant solution and NaOH for pH adjustment are dispensed using metering pumps. The amount of water is detected by a pulse water meter and the resulting pH is checked by a pH probe and then there is again a choice:
  - Water flows only through the sand filter F-004 into the common outlet branch, where disinfection is dosed using pump P-011.
  - Water flows through the ultrafiltration membranes F-005 to F-009 into the outlet branch with disinfection. Each membrane has its own set of valves, allowing the flushing or operation of one to all five membranes individually.

The product from the ultrafiltration unit is fed into the storage tank AN2 with a volume of 24,5 m^3. Drinking water is also fed into the storage tank AN2 via an electromagnetic valve.

The storage tank AN2 serves as a water storage for backwashing of the ultrafiltration with using pumps P-005 and P-006 and as a water storage for the consumer unit. From the storage tank AN2, water is distributed further using pumps P-012 and P-013.

A Swan pond is used as a supplementary water source, in which the water level is measured by a strain gauge and the flow through the existing pump is detected by a pulse water meter. The water supply from the Swan pond to the system is provided by a solenoid valve.

Figure 3 *- Container water treatment plant*



2.2.4. Pools

The outdoor pool for elephants, the outdoor pool for tapirs and the indoor pool for elephants are designed similarly. The outlets of these pools are primarily connected to the surface, thus maintaining the full volume of the tank, a solution for continuous recirculation. In all pools, the outlet itself is fitted with a vertical grid to contain larger floating debris and excreta that will be removed by staff.

The pools are equipped with a bottom drain that will be used in the event of a full drain and subsequent cleaning or partial drainage of water from the bottom and is controlled by a valve. Partial bottom draining may be carried out at set intervals as a release of settled debris from the bottom and will depend on the operating conditions.

The cycle of draining the pools for complete cleaning will be significantly longer than previously.

The existing drains and inlets at the pools have been retained. The option to discharge to the public sewer is via a new valve with a connection.

The giraffe pond will be routed according to the custom design documents.

2.2.5. Automated control system

The control and management of the proposed system is located in the UWTP container. The container is heated and air-conditioned by an air-conditioning unit and is connected to the domestic water supply and wastewater supply and discharge. For the power supply of the technological and construction part (air conditioning and lighting of the building), an LV ground line was laid from the adjacent building in ZOO Liberec. The main switchboard is also connected by cable from the existing switchboard at Zoo Liberec and is located on the inner wall of the container ultrafiltration water treatment plant. The cables of the individual electrical distribution and electrical connections of the individual elements of the Watersave+ system are placed in a PVC protector and routed in the ground, in common trenches for pipe laying.

2.2.6 Solar system

The Watersave$^+$ prototype also includes a renewable energy source in the form of a solar system. The original assumption was that the photovoltaic system would power a small ultrafiltration unit with an output of 0.3 l/s and an electricity consumption of 2.5 kW. Following a request from the zoologist to ensure the hygiene of all recirculated water, the capacity of the UWTP was increased to 3 l/s (max. 6 l/s) with an electricity consumption of 28.3 kW, which is well above the original assumption.

Therefore, a photovoltaic system with higher capacity but without battery storage was designed for the needs of Zoo Liberec. The system is connected to the zoo's grid to avoid outages in case of adverse light conditions, especially in winter, which will subsidise the zoo's total consumption from March to October, from which the entire Watersave$^+$ circuit including the IWT will be powered.

Description of the photovoltaic system

The source of energy (power) is photovoltaic cells suitably grouped and enclosed in photovoltaic panels - JA Solar 465 Wp oriented southeast at an angle of 10°. When solar radiation of the desired intensity is incident, these panels generate a DC voltage and current of a magnitude proportional to the intensity of the incident radiation.

The panels are connected in series in strings and equipped with TIGO optimizers that set a safe low voltage (1 VDC) at their output when the PV plant's STOP button is pressed. This makes any service or fire intervention safe.

Furthermore, the strings are connected to the DC part of the inverter via surge protectors type SPD 1+2, also via the DC part of the RFVE with fuses and also with combined lightning arresters and surge arresters type SPD 1+2. The interconnecting cables of the strings are 6 mm2, single-core with double insulation.

The Solinteg MHT-30K-100 inverter provides automatic conversion of DC voltage to line voltage. The magnitude and frequency of the output AC voltage is automatically regulated according to the connected line voltage. The power supply is further transmitted from the inverter via a 1-CYKY-J 5x35 cable to the main HR switchboard.

If the power generation exceeds the consumption of the consumption point (building), overflows will occur through the respective metering point with a 4Q meter in the meter switchboard to the distribution network.

The system includes the installation of a PV STOP safety button for the eventual disconnection of the PV plant from the grid, which is located on the outer shell of the building. A socket is added in the HR switchboard for connecting the AC power supply from the RFVE.

The PV plant is monitored through the inverter application or through the optimizer application.

Basic parameters

Modul DC name plate = Power:	35,3 kW
Number of frames	76
Dimensions of solar panels	1x1 m
Annual production	29,67 MWh
Performance ratio	82,3 %
kWh/kWp	839,5

Figure 4 *- Design of photovoltaic system on the roof of the main entrance to Zoo Liberec*

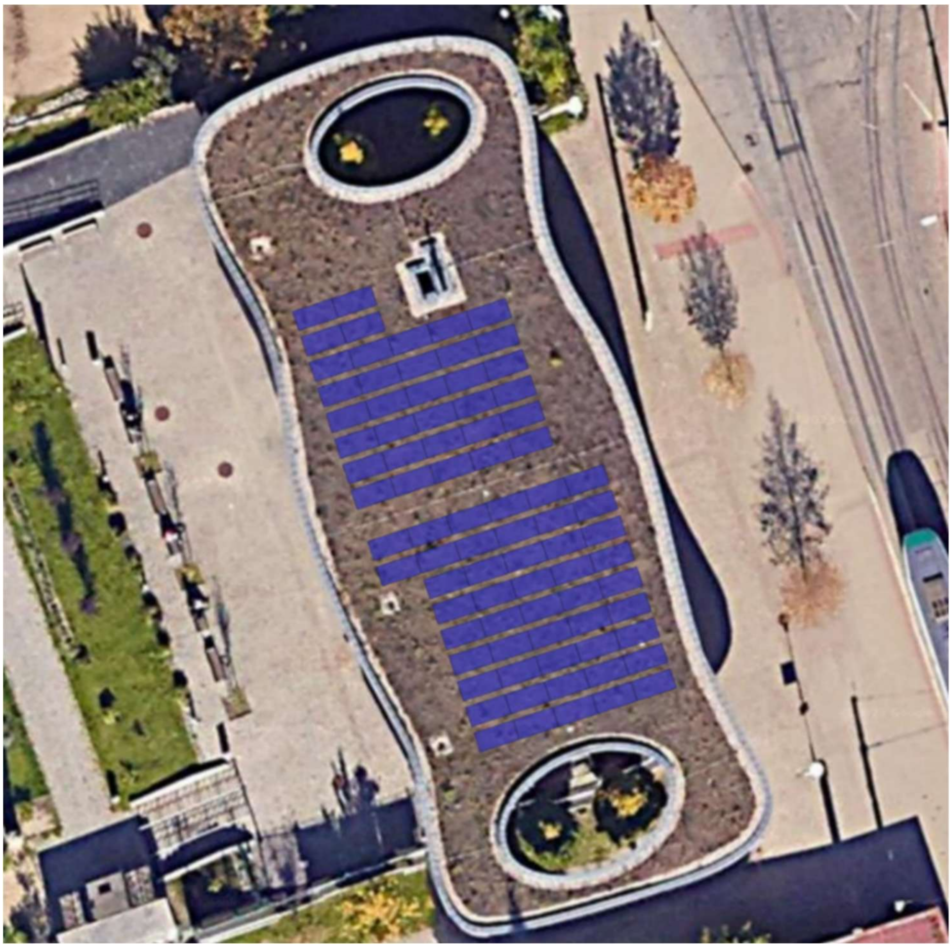
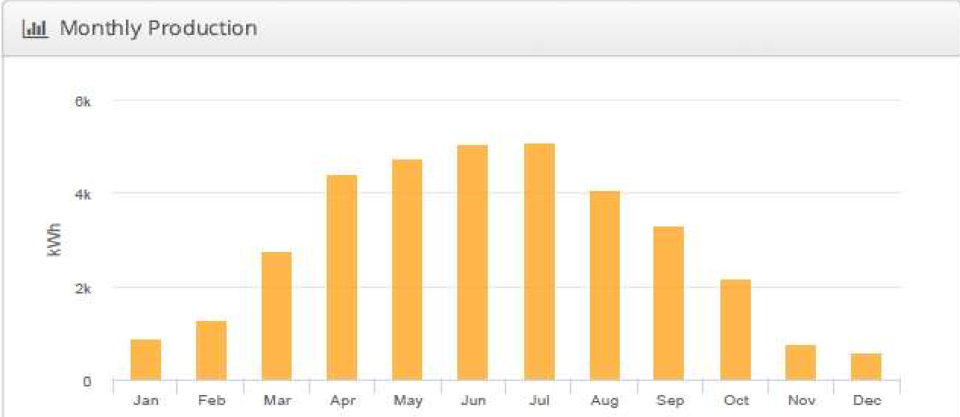


***Figure 5** – Monthly production of the photovoltaic system for Zoo Liberec*



Month	GHI (kWh/m²)	POA (kWh/m²)	Shaded (kWh/m²)	Nameplate (kWh)	Grid (kWh)
January	24.5	31.5	27.0	936.0	881.4
February	34.2	40.2	38.1	1,332.3	1,273.5
March	74.4	82.6	81.5	2,882.5	2,744.9
April	124.5	133.5	132.5	4,709.5	4,408.8
May	142.7	148.0	146.9	5,220.3	4,778.2
June	155.5	158.5	157.4	5,596.6	5,075.8
July	156.2	160.3	159.2	5,670.4	5,096.1
August	121.9	127.4	126.4	4,485.1	4,053.8
September	92.9	102.4	101.5	3,595.9	3,309.1
October	58.1	68.6	66.4	2,332.7	2,166.9
November	21.5	25.5	23.3	813.4	755.7
December	17.1	22.1	18.7	647.2	597.9

2.3. General Characteristics of Measurement and Control System (MaR)

The entire operation of the technology is managed by a UniStream control system with a touchscreen panel mounted on the door of the distribution cabinet in the technological section.
The control system allows communication with a superior system (e.g., Siemens) using one of the standardized protocols, typically MODBUS TCP/IP.

The field instrumentation is designed for safe operation in environments without explosion hazards.
Analog signals are transmitted via a 4–20 mA current loop. Actuating elements, particularly valves, solenoids, and similar devices, are powered by a 24 VDC direct current supply.

3. Watersave⁺ pilot management

Water from individual animals varies in the amount of pollution. In the first months of operation, only water from one type of animal will be fed into the system and the quality of the treated wastewater will be monitored after the separation filter, after treatment in the root treatment plant and after a given type of sanitation in the containerised surface water treatment plant and which type of sanitation is sufficient for safe water will be monitored. Hydraulic loading and residence time will be monitored at the root treatment plant. These variables will be carefully monitored and adjusted to optimise system performance, ensure efficient treatment and address the specific needs of each type of wastewater. The management approach will also consider the interactions between these factors to achieve the best possible results for water quality and system sustainability.

3.1. Hydraulic load and feeding strategy

At the beginning of the implementation, the hydraulic load (HL) will be set at 20 cm/day/m and gradually increased to 60 cm/day/m. The increase or decrease of the HL will be changed depending on the efficiency; reduced if signs of clogging or low performance are detected or increased if the performance is exceptionally high. The pilot will be fed continuously, the flow tested will be 5 L/s and the number of batches depend on the HL. Table 1 describes the feeding strategy of each HL.

Table 1. Hydraulic load and feeding strategy.

HL (m/day)	Q (m^3/day)	Number of batches per day	Feeding time (min)	Time between batches (min)
0.20	24	15	5	96
0.60	72	45	15	32

3.2. Hydraulic retention time

Hydraulic monitoring is conducted by measuring the volume of water flowing into and out of each system during the spring of 2025. Regular measurements will help identify variations in hydraulic behaviour, allowing for adjustments to improve overall treatment effectiveness. Table 2 describe the theoretical hydraulic retention time using the size of the system, the porosity of the filling material and the flow rate.

Table 2. Theoretical hydraulic retention time in the system.

Wetland	Porosity	Area (m^2)	Effective depth (m)	Q (m^3/day)	THRT (day)
Prototype Lbc	0.36	120	1.00	24	1.70
Prototype Lbc	0.36	120	1.00	72	0.55

Additionally, to evaluate the hydraulic retention time (HRT) in each step a tracer experiment will be conducted using Amino G, a fluorescent dye commonly used for hydraulic studies. The experiment aims to determine the wastewater flow behaviour and assess retention efficiency. The experiment will be carried out in the following steps:

1. *Tracer selection and preparation:* a known concentration of Fluorescein will be

diluted in a precise volume of wastewater to create the tracer solution.

2. *Tracer injection:* The tracer solution will be introduced as a pulse injection at the inflow of the wetland. The injection will be performed at a single time point to track its movement through the system.

3. *Sampling strategy:* Wastewater samples will be collected at different points, including inflow of sand filter, inflow of the wetland, outflow of the wetland (before entering the water treatment plant), and final outflow of the treatment plant. Frequent samples will be taken over time to capture the tracer's movement and concentration changes.

4. *Measurement and data collection:* The concentration of Fluorescein will be measured using a fluorometer, which detects fluorescence intensity. Measurements will be recorded at regular intervals until the tracer is no longer detected in the outflow.

5. *Data analysis:* A breakthrough curve (tracer concentration vs. time) will be plotted for each step. Finally, the mean HRT will be calculated based on the time required for the tracer to appear and reach peak concentration at the outflow.

3.3. Experimental schedule

The schedule outlines the procedures and timeline for testing the system with this specific wastewater source, allowing for the assessment of its performance under real-world conditions. The experimental test aims to evaluate the system's response to the characteristics of animal installations wastewater, including any potential variations in flow, treatment efficiency, and system behaviour.

Table 3. Experimental test schedule for Watersave+ pilot implementation.

Date	Activity	Description
May 01 - 31	Initial hydraulic test and preparation phase	Executed the initial hydraulic test to assess the system's flow characteristics and performance, while setting up and calibrating the system for the subsequent experimental test
June 01 – 30	Test 1:	Wastewater treatment for the elephant enclosures will be conducted through the system, operating in parallel, with a hydraulic loading rate (HLR) of 0.20 m/day.
July 01– July 31	Test 2:	Wastewater treatment for the tapirs will be conducted through the system, with a HLR of 0.20 m/day.
August 01 – August 31	Test 3:	Wastewater for the elephant and tapir will be conducted through the system operating in combine treatment, with a HLR of 0.20 m/day.
September 01 - 30	Test 4:	Wastewater for the elephant and tapir will be conducted through the system operating in combined treatment, with a HLR gradually increased up to 0.40 m/day.
October 01 - 31	Test 5:	Wastewater for the elephant and tapir will be conducted through the system operating in combining treatment, with a HLR gradually increased up to 0.60 m/day.

Each test implemented have a total of 32 samples:

- Inflow: 8
- Outflow sand filter: 8
- Outflow wetland: 8
- Outflow treatment plant: 8

The schedule will be adjusted or modified based on the system's performance and efficiency results.

4. Water quality monitoring

Different parameters will be monitored to evaluate the efficiency of the wetland, with a focus on analysing the inflow and outflow of each system. Table 5 provides an overview of the microbiological and physicochemical parameters that will be used in the water quality monitoring process. These parameters are essential for evaluating the effectiveness of the treatment systems and ensuring that water quality standards are met throughout the testing period.

Table 4. Microbiological and physic-chemical parameters for general monitoring.

Microbiological parameters for general monitoring	**Methodology**	**Interest**
E. coli	ISO 9308	Indicator of faecal contamination
Clostridium perfringens	ISO 14189	Indicator of faecal contamination, giardia cysts and cryptosporidium oocysts
Somatic coliphages	ISO 10705	Indicator of virus
Enterococci	ISO 7899	Indicator of faecal contamination
Parasites	Microscopic and molecular analysis	

Physico-chemical parameters for general monitoring		
pH*	Electrical conductivity*	TSS**
COD***	BOD5**	TP****
NH_4^+ - N****	NO_2^- - N****	NO_3^- - N****
TN***		

*pH meter and electrical conductivity meter Crison
**Standard methods
***kit
****Ionic chromatography

Parameters for general monitoring will be assessed twice a week, while others will be analysed once a week (see Table 5). In addition to these basic parameters listed previously, targeted analyses will be conducted to assess the system's effectiveness in removing emerging contaminants of concern.

Table 5. Monitoring parameters analysed and their analysis frequency.

Frequency of analysis	Parameter	Laboratory
	E.coli	TUL
	Total coliforms	TUL
Twice per week	Enterobacteria	TUL
	Clostridium perfringens	TUL
	Coliphages	TUL
	SST	TUL
	COD	TUL
	TN	TUL
	NH_4^{-}	TUL
	NO_2	TUL
	NO_3^{-}	TUL
	PO_4	TUL
Once per week	Parasites	TUL
	BOD_5	TUL

5. Further actions

Based on the results of the initial tests, the operation of the system will be optimised.

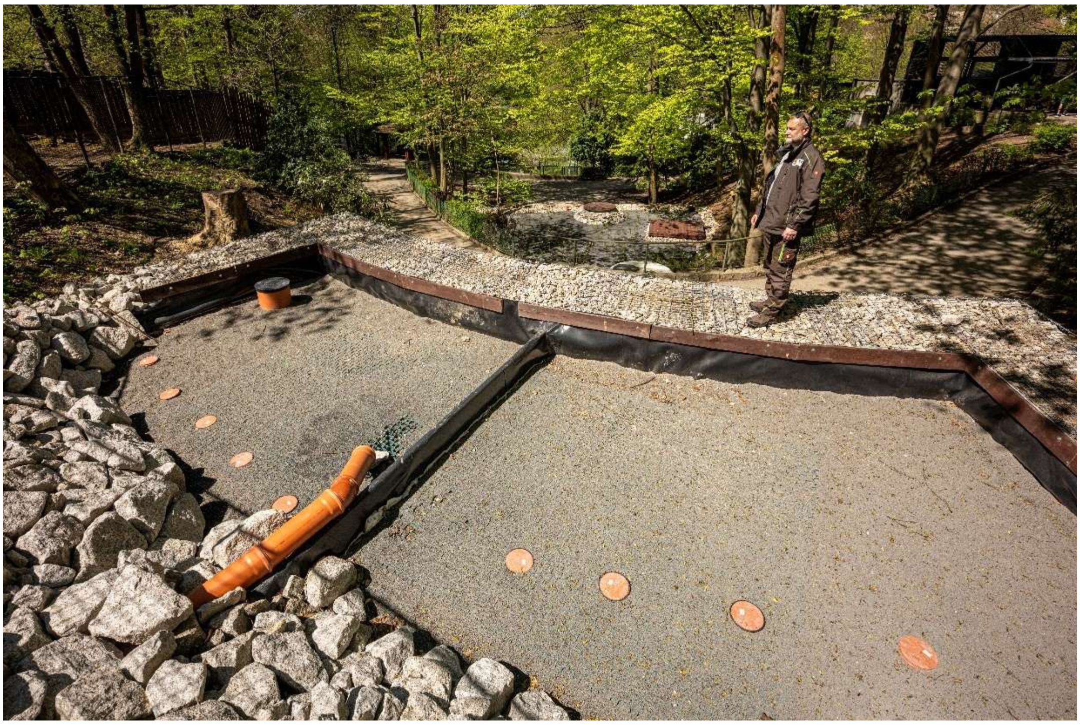
Annex 1. Photographic documentation of Watersave+ in Zoo Liberec

Construction phase of vertical root wastewater treatment plant

Construction of storage tank AN1, AN2

Finished constructed wetland with pulse and pumping shaft.

Separation filter as mechanical pretreatment



Water treatment plant unit with ultrafiltration

Measurement and control system

Tapir and white-nosed coati enclosure with a pool connected to the Watersave⁺ system.

Connection of the outdoor elephant pool to the Watersave⁺ system.