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The Concept of Construction of Hybrid Constructed Wetland for Wastewater Treatment in the Roztocze National Park

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Abstract

Roztocze National Park (RNP) is one of 23 national parks in Poland. It was created in 1974 both to protect the natural and cultural heritage as well as to share the park area for science, education and tourism. In caring for the environment, the park removed asbestos coverage, performs thermo-modernization using renewable energy sources by the installation of solar panels and photovoltaic cells on the roofs of buildings, and pellet stoves are installed in boiler rooms. Part of these actions includes the application of innovative technologies for water and wastewater, related to e.g. recovery of rainwater for washing cars and the construction of wastewater treatment wetlands. RNP has been spreading for many years the knowledge about the methods used to most effectively care for the natural environment. Constructed wetland (CW) technology could be one of such methods. The current research shows that facilities working in CW technology provide high pollutant removal and full guarantee of high ecological impact with low operating cost, so they can be used to protect the aquatic environment in protected areas and valuable landscapes. The paper presents a concept of solving the problems of wastewater treatment by means of using hybrid constructed wetland in three villages in the forest of Roztocze National Park. The advantages of the proposed technology are easy and simple operation, high resistance to irregular supply of water treatment and very low operating costs compared to conventional solutions. The natural look of CWs allows easy incorporation into the existing landscape.

Keywords: hybrid constructed wetland, wastewater treatment, water protection, Roztocze National Park

Introduction

On August 23, 2001 the Polish parliament adopted the provisions of the II National Environmental Policy. One of its major objectives for environmental quality are water relations and water quality. In accordance with provisions contained in the Second National Environmental Policy actions taken in Poland should be directed to:

- prevention of pollution of surface freshwater, groundwater and the Baltic Sea, with particular emphasis on prevention at the source,
- restore groundwater and surface proper ecological status,

thus ensuring, inter alia, appropriate sources of drinking water intake.

These records correspond very well with the requirements of Directive 91/271/EEC of 21 May 1991 concerning urban waste water treatment, according to which the EU Member States are obliged to equip all agglomerations with a population equivalent (pe) of more than 2000 with sewage systems for municipal wastewater and ensure their biological treatment prior to entering the water, so as to meet the requirements set out in the Directive. However, in areas where the construction of sewerage system would not bring benefits to the environment or would result in excessive costs, use of individual systems or other appropriate measures ensures the same level of environmental protection are advised. Specific measures for the protection of water should be taken in protected areas and valuable landscapes. In such areas high-efficient wastewater treatment systems should be used to provide effective protection of the aquatic environment and high ecological impact. In recent years hybrid constructed wetlands are increasingly included as such solutions (Jóźwiakowski 2012; Obarska-Pempkowiak, Gajewska, and Wojciechowska 2012; Tomczuk and Ochrymiuk 2012). The use of such systems should be a priority in protected areas and landscapes. Protection of water and water quality in accordance with the Act on Nature Conservation of 16 April 2004 fits in with the protective activities carried out in the park's ecosystems aimed at maintaining proper health and conservation of natural habitats.[1]

The purpose of this paper is to present the concept of solving the problems of wastewater management by using hybrid treatment wetlands in three forest villages located in Roztocze National Park.

1 Characteristics of Roztocze National Park

Roztocze National Park (RNP) is located in south-eastern Poland and lies entirely in Central Roztocze. It was created in 1974 mainly of forest land — 10 forest and floristic reserves. On the RNP there are natural stands, mainly beech and fir specific to Roztocze and lower montane Carpathian. At present, it extends on the surface of nearly 8,5 thousand ha (fig. 1). Strict protection covers 1029 ha (12,1%).

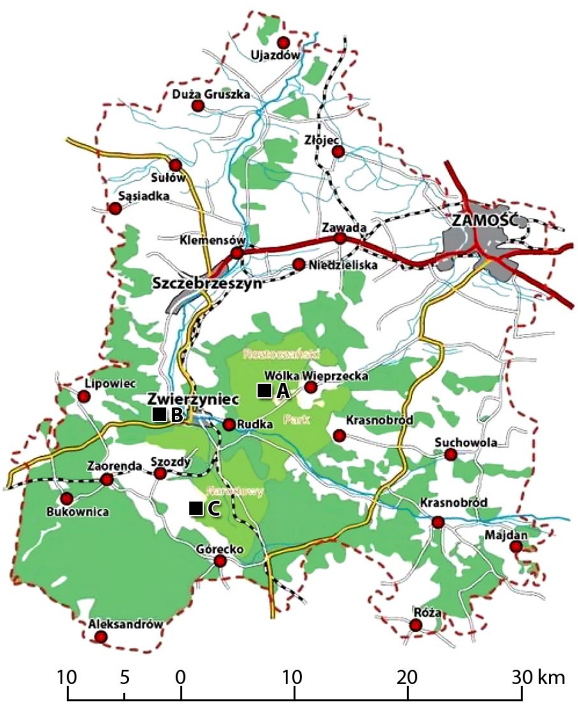

Fig. 1. Territorial scope of Roztocze National Park and the location of hybrid treatment wetlands: *A* — Kosobudy (100 a, b, c), *B* — Zwierzyniec (Biłgorajska street 9), *C* — Florianka (Górecko Stare 106 – Komanówka)

Source of the map: http://www.zwierzyniec.lublin.lasy.gov.pl/polozenie#.U_N2qaMTefI

1. See: Ustawa z dnia 16 kwietnia 2004 r. o ochronie przyrody, DzU z 2004 r. nr 92 poz. 880.

Roztocze are a long, curving band of forested hills with a width of up to 22 km, representing the European watershed. It splits water catchment of the Baltic Sea and the Black — hence its name (from Polish dialect).

The oldest rocks in Central Roztocze formed nearly 100 million years ago, during the Cretaceous period. These are the lime-siliceous rock (opoka), gaize and marl. One of the characteristic features of the landscape — Central Roztocze was created through the Tertiary tectonic processes. Elevating Roztocze and lowering the Sandomierz Basin, the tectonic processes caused the tectonic fault line on the border of the two lands. The waters of rivers revealed the faults and formed small waterfalls called "szyptomy" or "szumy" (in Polish). After the glacier crossed from the Scandinavian Peninsula Roztocze was enriched with granite, quartzite and gneiss boulders. Water formed after the thawing of the ice layer led to the creation of river valleys, including the Wieprz valley — the largest river of RNP. In the eastern part of the park and its buffer zone there are a lot of steep, deep loess gorges and so-called "głębocznice," which are gorges formed along the dirt roads as a result of wearing down by humans and cars, which accelerated erosion (Bartoszewski and Michalczyk 2012).

RNP flora and fauna is very rich. There are here 23 forest communities, which occupy 95% of the Park, and 58 collectives and non-forest communities, which occupy the remaining 5% of the surface. Of the approximately 3000 vascular plants in Poland 1 300 species were found in RNP. There were observed 900 species of vascular plants, 230 species of lichens, 237 species of mosses and 50 species of algae. Among the fungi and plants, 89 species have protected status, and are listed in the Polish Red Book of Plants. RNP fauna is equally rich. Of the approximately 36 000 species in Poland (about 35 300 species of invertebrates and around 720 species of vertebrates) 3630 species, including invertebrates there are 3 300 species and 330 vertebrates species which can be found in RNP. Invertebrate fauna in RNP accounts for about 10% of the national fauna, and more than half of the taxa of invertebrate in the Park are the taxa representing on average 30–60% of the fauna in Poland. Invertebrates are grouped within nine higher taxon: protozoa — 37 species, nematodes — 33 species, annelids — 49 species, molluscs — 76 species, arthropods — 3 080 speciescrustaceans — 49 species, arachnids — 339 species, millipedes — 11 species, insects — 2 680 species. Vertebrates are much better represented in comparison to the national fauna and represent 46% of its resources, being divided into different clusters the number of species and percentage are as follows (undomesticated alien species included): lamprey — 1 species (25%), fish — 29 species (24%), amphibians — 13 species (67%), reptiles — 9 species (70%), birds — 225 species (50%) and mammals — 59 species (52%) (Reszel and Grądziel 2013).

418 species among the animals have protected status, 316 species are protected species, 76 species are listed in the Polish Red Book of Animals, 81 species are protected under the Natura 2000 network, 20 species are inscribed on the list of endangered animals of the International Union for Conservation of Nature, and more than 130 are protected by international conventions (Bonn, Berne and Washington's).

Due to the outstanding natural values within the RNP two areas were included in European ecological network Natura 2000: Area of Community Importance ACI: Special Area of Conservation "Roztocze Środkowe" — PLH060017 (corresponding to the boundaries of the Park) and Special Protection Area of Birds "Roztocze" — PLB060012 an area of 103503 ha, wherein the Park represents 8,2% of the area.

Within the limits of RNP there are 10 precious and endangered natural habitat types listed in annex I of the Habitats Directive, occupying 43% of its area. Among them the flagship habitats are Carpathian beech and fir forests, and 3 priority habitats: raised bogs of peat forming vegetation, bog woodland and riparian forests. Annex II of the Habitats Directive states: 4 species of plants (including lady's slipper and extinct common bryophyte — *Dicranum viride Lindb.*, 29 species of animals (including relict of primary forest — beetle *Rhysodes sulcatus*, as well as the Ukrainian lamprey, great crested newt, mud turtle, wolf and lynx). Annex IV of the Habitats Directive recorded 39 species of animals (including an increasingly rarer tree frog and endangered snake — the Smooth Snake) (Reszel and Grądziel 2013).

The Special Protection Area, of which RNP is the fundamental part, was established on the foundations of bird areas of international importance, due to the occurrence of thriving breeding populations of rare and endangered bird species on a European scale. There are observed here 37 species of breeds listed in Annex I of the Birds Directive of 74 species recorded in the area, including 18 whose breeding populations represent more than 1% of the national population: little bittern, black stork, honey buzzard, lesser spotted eagle, fodder, corncrake, owl, ural owl, tengmalm, grey-headed woodpecker, black woodpecker, middle spotted woodpecker, woodpecker, white-backed woodpecker, collared flycatcher, flycatchers small warbler and red-backed shrike (Reszel and Grądziel 2013).

Currently, there are efforts associated with the appointment of the International Biosphere Reserve and Stone Forest Geopark in Roztocze and the passage of the Sandomierz Basin. These projects serve to the protection, development and promotion of Roztocze. Roztocze National Park as an object of a special concern for the preservation of the environment in an unchanged form is a showcase of lubelskie environmental services, and as such should have and present the most effective solutions at the meeting point of human and the environment, including exemplary wastewater treatment technologies, for the protection of the aquatic environment, which give full guarantee of high ecological impact, therefore, measures have been taken to apply highly effective wetland systems.

2 Water and Wastewater Management in Roztocze National Park

In carrying out statutory tasks RNP uses the infrastructure inherited mostly of the former Zamoyska Ordinance. The main facilities are: RNP head office, Centre for Education and Museum, Roztocze Centre for Science Education and lodges located in the city of Zwierzyniec connected to the main water supply and sewerage. Other service housing and offices are located in ten localities in the park, including five facilities located far away from human settlements in forest areas, two more are located within the village buildings. The water in these objects is supplied by the water supply system or they have local underground water, and domestic waste water is treated in sewage discharged into the household or septic tanks, and then exported to the collective sewage treatment plant in Zwierzyniec.

The current method of dealing with sewage in some forest villages (export of sewage from septic tanks) is very cumbersome due to the incurred costs of exporting, but primarily because of emissions from vacuum trucks moving around the area of RNP. Calculations show that this type vehicular exporting waste of three objects 1 time per month, emit yearly 460 kg of carbon dioxide. Therefore, in 2013, a comprehensive program was developed to organize water and sewage management in forest villages in RNP, which aims to protect the groundwater of the main Cretaceous aquifer water level, the so-called Roztoczański. In a large part of the area it is the first and only utility level of groundwater, which is supplied primarily by precipitation.

The first stage of the program to organize water and sewage management in forest villages in RNP assumes the construction of three hybrid wastewater treatment wetlands and modernization of two existing domestic sewage treatment plants. For the implementation of the first stage of organizing water and wastewater management RNP received funding from the National Fund for Environmental Protection and Water Management in the amount of PLN 150 355, which represents 94% of the total investment (PLN 159 273). Completion of the first phase of work for the construction and modernization of the sewage treatment plant at forest settlements in the RNP is scheduled for the end of 2014, while the second stage of the ordering of water and wastewater in RNP is planned for the years 2015–2016.

3 The concept of the hybrid treatment wetlands in Roztocze National Park for wastewater treatment

The construction of the first three hybrid wetland for wastewater treatment in the RNP is planned in the forest settlements located in the following towns: Kosobudy (A), Zwierzyniec (B) and

Florianka (C) (fig. 1). The first part provides mechanical wastewater treatment in a preliminary triple chamber sedimentation tank made of concrete or polyethylene. Then it is planned that the waste water mechanically treated by the pump will be supplied to the wetland system consisting of two or three soil-plant beds, where their biological purification occurs. The final element of the wastewater will be a P-filter for precipitation of phosphorus, the treated wastewater of which will flow into a pond infiltration. Technological parameters of the proposed constructed wetlands are presented in table 1. Table 2 shows the loads of pollutants in wastewater treated in the planned facilities.

Past experience shows that the hybrid constructed wetlands are the most effective systems in place to solve the problem of sewage in rural areas without sewerage, usage of which is consistent with the principles of sustainable development and provides effective protection of the environment against pollution (Jóźwiakowski et al. [forthcoming]). The efficiency of removal of suspended solids and organic matter expressed by BOD_5 and COD in these systems far exceeds the 90% while the effects of removing nitrogen and total phosphorus range from 70–90% (Czyżyk et al. 2012;

Tab. 1. Technological parameters of hybrid constructed wetlands in Roztocze National Park

	Kosobudy	**Zwierzyniec**	**Florianka**
Number of person equivalent	20	4	10
Amount of treated wastewater Q (m^3/d)	2,0	0,4	1,0
Active capacity of the septic tank V (m^3)	8,0	4,0	5,0
Mannagrass bed (m^2)	I – 60	–	–
Reed bed (m^2)	II – 60	I – 18	I – 40
Willow bed (m^2)	III – 60	II – 30	II – 56
Total area (m^2)	180	48	96
P-filter for phosphorus precipitation (m^3)	1,0	0,5	0,75

Note: [In the journal (in both Polish and English texts) European practice of number notation is followed — for example, 36 333,33 (European style) = 36 333.33 (Canadian style) = 36,333.33 (US and British style). Furthermore in the International System of Units (SI units), fixed spaces rather than commas are used to mark off groups of three digits, both to the left and to the right of the decimal point. — Ed.]

Tab. 2. Loads of pollutants in wastewater treated in hybrid constructed wetlands in Roztocze National Park

	Kosobudy	**Zwierzyniec**	**Florianka**
Load of pollutants in raw sewage L_d (g/d):			
total suspensions TSS	600	120	300
BOD_5	800	160	400
COD	1600	320	800
total phosphorus TP	40	8	20
Load of pollutants in treated wastewater L_d (g/d):			
total suspensions TSS	70	14	35
BOD_5	50	20	25
COD	250	50	125
total phosphorus TP	10	2	5
Pollution load removed in one day (kg/d):			
total suspensions TSS	0,53	0,106	0,265
BOD_5	0,75	0,140	0,375
COD	1,35	0,270	0,675
total phosphorus TP	0,03	0,006	0,015
Pollution load removed in one year (kg/year):			
total suspensions TSS	193,5	38,7	96,7
BOD_5	273,8	51,1	136,9
COD	492,8	98,6	246,4
total phosphorus TP	11,0	2,2	5,5

Gajewska and Obarska-Pempkowiak 2009; Jóźwiakowski 2012). It is expected that the hybrid constructed wetland in the RNP will provide similar effects of pollutants removal. It is calculated that the three wetlands within one year will remove from 38,7 to 193,5 kg of total suspended solids and organic matter expressed by indicators of oxygen: BOD5 and COD in the range from 51,1 kg to 273,8 kg and from 98,6 kg to 492,8 kg respectively. In addition, it is anticipated that constructed wetlands in RNP within one year will retain from 2,2 kg to 11 kg of phosphorus (tab. 2).

3.1 Construction of hybrid wastewater treatment wetlands

Each of the treatment plants will consist of four basic elements: primary settling tank, wetland system consisting of soil-plant beds, P-filter for the precipitation of phosphorus and receiver plants (fig. 2 and 3).

3.2 Primary settling tank

Primary settling tank is the primary device that should be used in wastewater treatment plants, especially in small backyards (Pawęska et al. 2011). The task of the settling tank is the mechanical and biological pre-treatment of wastewater. Mechanical treatment of raw sewage occurs in the processes of sedimentation and flotation, and biological treatment in the fermentation process. Gases produced as a result of decomposition of bottom sediments bring sediment particles to the surface, which causes the so-called build-up of scum (oils and fats). In addition, the biochemical processes that occur in the septic tank result in the destruction of most pathogenic bacteria, as well as a significant part of the human intestinal parasites (Heidrich and Stańko 2007).

Placement of on the property shall be governed by the Regulation of the Minister of Infrastructure[2] and the Act of 7 July 1994 – Construction Law[3]. The capacity of the primary settling tank depends on the number of future users of household sewage. In the case of sewage treatment proposed in RNP it should be in the range of 4 to 8 m^3. Three-chamber settling tanks were recommended (fig. 4).

From the data presented in the literature, the settling tanks provide suspended solids removal at the level of 40–94% and a reduction of BOD_5 and COD in the range of 23–66% and 20–40%, respectively (Chmielowski and Bugajski 2008; Pawęska et al. 2011).

Inherent in any product resulting from the wastewater treatment process, including domestic sewage is sewage sludge, accumulating in the preliminary septic tank. Raw sludge generated in the plants should be disposed of in an appropriate manner, because they are dangerous in terms of sanitation — including pathogenic bacteria, viruses and parasites. Their disposal may take place, inter alia, using processes such as dewatering, composting, or liming (Bauman-Kaszubska and Sikorski 2011; Malej 2000).

Septic tanks that are properly made, practically do not require any maintenance. In the case of settling tanks made of concrete, it is assumed that their durability can be several decades. The basic operating procedure is the removal of sludge and scum with a frequency which depends on the working capacity of the settling tank and the volume of influent waste water and pollution. Calculations show that during a year the three constructed wetlands in the RNP will produce 3,35 m3 of fermented sewage sludge with 93% hydration that once a year will have to be exported to the collective sewage treatment plant in Zwierzyniec.

3.3 Wetland system

The wetland wastewater treatment method is based on the biological processes taking place with the participation of micro-organisms and water plants (called hydrophyte) existing in properly designed facilities, so-called hydrophyte beds (filters) (Bergier 2003; Gajewska and Obarska-Pempkowiak 2009). Due to the specific conditions, enabling the development of hydrophytes in the soil-plant beds, an intensification of processes of oxidation and reduction occurs, which are supported

2. See: Rozporządzenie Ministra Infrastruktury z dnia 12 kwietnia 2002 r. w sprawie warunków technicznych, jakim powinny odpowiadać budynki i ich usytuowanie, DzU z 2002 r. nr 75 poz. 690.

3. See: Ustawa z dnia 7 lipca 1994 r. – Prawo budowlane, DzU z 1994 r. nr 89 poz. 414.

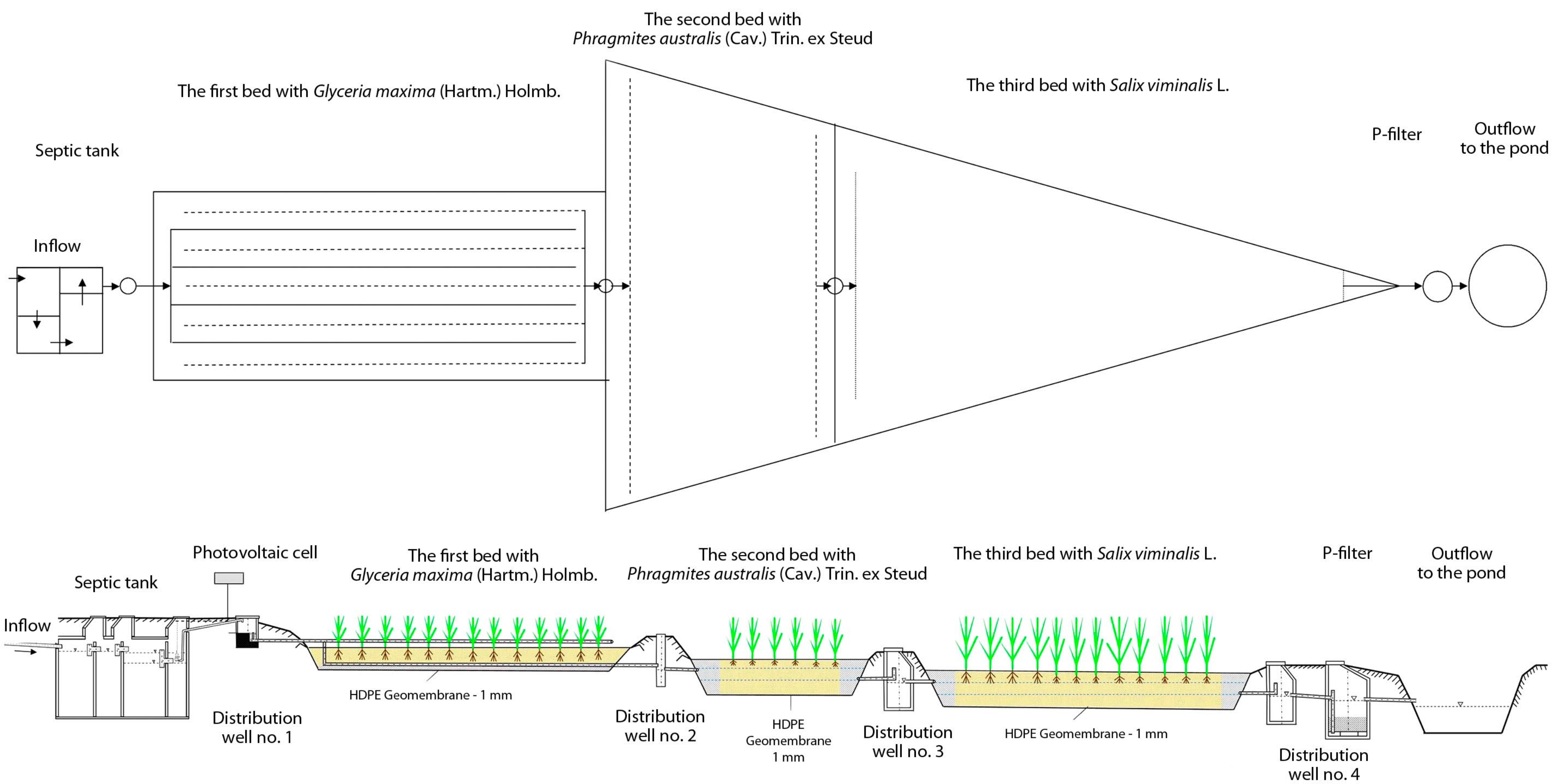

Fig. 2. Technological scheme and a longitudinal section of a hybrid constructed wetland in Roztocze National Park in Kosobudy—facility in Kosobudy

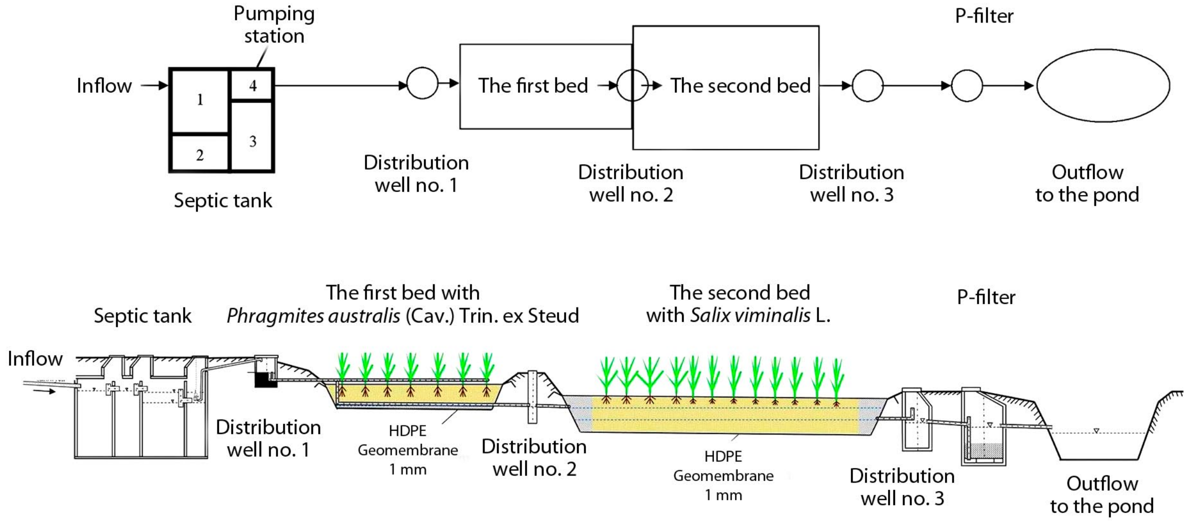

Fig. 3. Technological scheme and a longitudinal section of a hybrid constructed wetlands in Zwierzyniec and Florianka in Roztocze National Park — Facilities in Zwierzyniec and Florianka

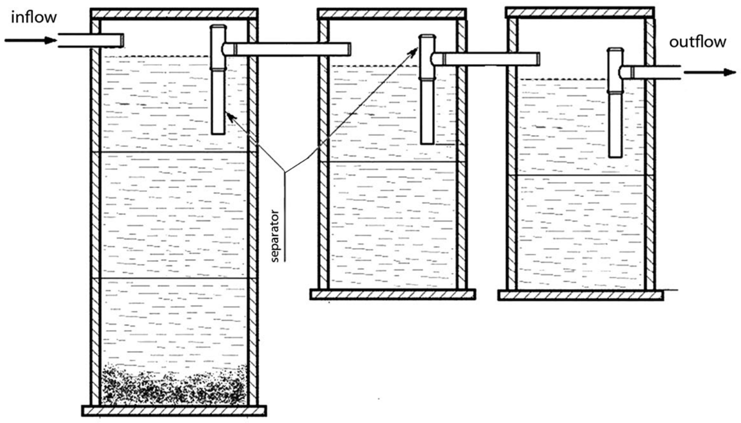

Fig. 4. Scheme of a three-chamber settling tank

by the processes of absorption, sedimentation and assimilation. These processes enable removal of pollutants from the sewage.

The most common plants in wetland systems are common reed — *Phragmites australis* (Cav.) Trin. ex Steud and basket willow — *Salix viminalis* L. There is also planned the use of manna grass — *Glyceria maxima* (Hartm.) Holmb in one of the treatment plants in RNP too. The reed is used mainly because of the extensive system of rhizomes and roots, and the ability to supply oxygen from the atmosphere to the ground in order to create conditions for the development of aerobic micro-organisms (Gajewska and Obarska-Pempkowiak 2009; Jóźwiakowski 2008). The use of willow results primarily due to the rapid increase in biomass associated with the rapid uptake of nutrients and the possibility of large amounts of water transpiration. Reed Mannagrass, in turn, has a lush root system and is highly efficient in removal of contaminants from wastewater, mainly nitrogen compounds (Jucherski and Walczowski 2012).

The research showed that during the growing season wetland systems may transmigrate into the atmosphere from 5 to 8 mm of water per day. This means that up to 900 mm of water can dissipate into the atmosphere in a period of 180 days. Transpiration of water by plants in a causes a properly designed wetland for most of the year to work as an undrained facility while improving the local microclimate (Gajewska and Obarska-Pempkowiak 2009).

The advantages of constructed wetlands systems are easy operation, high resistance to uneven flow of waste water and a very low cost of ownership compared to conventional solutions. By using different plant species sewage easily blends into its surroundings. Constructed wetlands in contrast to traditional solutions (activated sludge or biological fluid) do not produce secondary sludge. They have the ability to remove organic matter and nutrients (nitrogen and phosphorus) and specific pollutants e.g. heavy metals and some organic micropollutants. In the past main disadvantages of wetland systems included a high demand of land for the construction of the wastewater treatment plant (about 10 m^2/pe) and the time required for the adaptation of plants in the fields of land and development of the root system — about 1 year (Bergier 2003; Jóźwiakowski 2008). Nowadays the required unit area per person could be limited up to 2,5 m^2/pe when using the so-called "French sytem" or even up to 0,7 m^2/pe by using aerated, vertical subsurface flow beds (Gajewska, Wojciechowska and Obarska-Pempkowiak 2014).

Initially (until the end of the twentieth century) constructed wetland systems were built usually as a single horizontal or vertical flow of sewage. However, research has shown that such systems do not provide satisfactory results in contaminants removal, especially of nutrients. In order to increase the degree of elimination of nitrogen and phosphorus for several years multi-stage constructed wetland, so-called. hybrid systems consisting of two or three beds have begun to be used (Gajewska and Obarska-Pempkowiak 2011; Gizińska et al. 2013; Jóźwiakowski 2012; Jucherski and Walczowski 2012). Therefore, this type of technology has been proposed for use in forest settlements in RNP.

3.4 P-filter for the precipitation of phosphorous

To ensure the highest standards for the protection of surface and groundwater quality in the RNP, it was planned to use a special P-filter for the removal of phosphorus. The P-filter is placed at the end of the technological system of the proposed wastewater treatment plant, and should allow for achievement of the final concentration of P in outflow less than 5 mg/dm^3, (according to the standards required in the treated wastewater discharged into lakes and their tributaries). As substrate for P-filter natural silica-carbonate rocks are going to be used, previously subjected to decarbonisation at 900°C. The current research shows that this type of material provides more than 90% efficiency of elimination of phosphorous (Bus and Karczmarczyk 2014; Jóźwiakowski 2006; Nilsson et al. 2013).

Wastewater receiver. Receivers of three wastewater treatment plant hybrid constructed wetlands in RNP are ponds (ponds infiltration). The ponds provide a slow infiltration of treated wastewater into groundwater. They will also constitute an interesting element of the surrounding landscape, which can help to increase biodiversity in the immediate surrounding area. Conditions to be met by waste water discharged into surface waters and soil are defined in the Regulation of the Minister of Environment of 24 July 2006.[4] According to this regulation the wastewater discharged into water bodies should not cause such changes in them that prevent the proper functioning of aquatic ecosystems and meeting the specific water quality requirements for them, associated with their use. To meet the demands of the regulation the values of pollutants in the wastewater discharged from the plant in the RNP should be less than: 50 mg/dm^3 — in the case of suspended solids, 40 mg O_2/dm^3 — in the case of BOD5, 150 mg O_2/dm^3 — in the case of COD, and the elimination of these indicators should be respectively: 87,5%, 92,0% and 81,2%.

3.5 Operating rules of hybrid wastewater treatment wetlands

Wetlands during operation require routine rounds performed by the owners of facilities with a frequency of once a week, and periodic maintenance and care procedures. Supervision and control are to detect abnormal plant operation, damage or wear to particular elements or devices, detect and notify of a malfunction, as well as protect against devastation by unauthorized persons. The activities that must be performed during operation of hybrid constructed wetlands are:

- emptying the chambers of the primary settling tank of the sludge (at least 1 time per year)
- control the pump dosing sewage to bed I (once a week) and its maintenance

4. See: Rozporządzenie Ministra Środowiska z dnia 24 lipca 2006 r. w sprawie warunków, jakie należy spełnić przy wprowadzaniu ścieków do wód lub do ziemi, oraz w sprawie substancji szczególnie szkodliwych dla środowiska wodnego, DzU z 2006 r. nr 137 poz. 984.

- controlling the level of sewage in the second and third bed by raising (in the summer) and lowering (in the winter) tubes with a movable knee
- annual slicing of plants from beds (late winter — in February or March)
- weeding beds of soil-plants, especially in the initial period of wastewater operation (1–2 years)
- controlling wire patency and the evaluation of the accuracy of sewage flow
- exchange of P-filter for removing phosphorus (every 2–3 years)

Conclusions

Implementation of wastewater treatment wetlands in forest settlements in Roztocze National Park is essential, since the construction of collective sewage systems is not economically reasonable. A lot of sewage treatment plant solutions are currently offered on the market. So far, the cheapest technology was most often chosen, consisting of primary settling tank and distribution drainage. Many years of research and experience in Poland, Germany, France and other European countries demonstrate that these systems do not provide effective protection of the natural environment. The method of infiltration of wastewater in the ground is not a method of treatment, but a way to get rid of it, mostly ineffective and dangerous. Distribution drainage may instead be used as the final element of technological systems in domestic sewage (Karczmarczyk 2013; Mazurkiewicz and Pawlak 2009).

Poland is characterized by scarce resources of clean surface and underground water and its ability to take the load of pollutants is generally small (Jaszczynski, Sapek, and Chrzanowski 2006; Rossa and Sikorski 2006). Therefore, when planning any investments in water and wastewater management effective technologies must be chosen, ensuring high environmental impact. Selected technologies should also be characterized by low cost and simplicity of operation during many years of use.

Existing research results and practical experience indicate that hybrid constructed wetlands are one of the most effective technologies and should be used to solve the problem of sewage in areas without sewerage, especially in protected areas, as they allow effective and long-term protection of the environment against pollution. Building of hybrid wastewater treatment constructed wetlands in RNP will achieve the following effects:

- The material effect — 3 innovative and highly-efficient hybrid constructed wetland wastewater treatment plants will be created.
- The ecological effect — the treatment will provide long-term protection of the environment in the legally protected area and will contribute to a significant reduction in emissions of pollution from point sources to the environment and to improvement of the purity of groundwater.
- The landscape effect — the treatment will be well integrated with the landscape of RNP, as they will use indigenous plant species, namely: reed manna grass, reed and willow.
- The economic effects — constructed wetlands operating costs will be significantly lower than the use of septic tanks or wastewater treatment with activated sludge. It is anticipated that the facility A (due to the use of photovoltaic cell) operating costs of sewage treatment will be limited to exporting sludge to the collective treatment — once a year, and in the other treatment facilities it will be necessary to apply electricity to power the pump. It is anticipated that the annual energy costs at the pump in each of the treatment plant will be about PLN 20–30.
- The educational effects — hybrid constructed wetland wastewater treatment plants will be incorporated within an educational package of RNP, and the opportunity to observe their operation will help to increase knowledge and awareness of students at different educational levels, tourists visiting RNP and local governments operating in Roztocze.

References

Bartoszewski, S., and Z. Michalczyk. 2012. "Roztoczański Park Narodowy." In *Wody w parkach narodowych Polski*, edited by R. Bogdanowicz, P. Jokiel and J. Pociask-Karteczka, 264–279. Kraków: Instytut Geografii i Gospodarki Przestrzennej Uniwersytetu Jagiellońskiego.

Bauman-Kaszubska, H., and M. Sikorski. 2011. "Charakterystyka ilościowa i jakościowa osadów ściekowych pochodzących z małych oczyszczalni ścieków w powiecie płockim." *Inżynieria Ekologiczna* (25):20–29.

Bergier, T. 2003. "Mechanizmy usuwania zanieczyszczeń w oczyszczalniach hydrobotanicznych." *Inżynieria Środowiska/Akademia Górniczo-Hutnicza im. S. Staszica w Krakowie* no. 8 (2):237–249.

Bus, A., and A. Karczmarczyk. 2014. "Charakterystyka skały wapienno-krzemionkowej opoki w aspekcie jej wykorzystania jako materiału reaktywnego do usuwania fosforu z wód i ścieków." *Infrastruktura i Ekologia Terenów Wiejskich* (2):227–238.

Chmielowski, K., and P. Bugajski. 2008. "Efektywność usuwania zanieczyszczeń w osadnikach gnilnych typu „Duofilter"." *Infrastruktura i Ekologia Terenów Wiejskich* (5):41–49.

Czyżyk, F., K. Pulikowski, M. Strzelczyk, and K. Pawęska. 2012. "Efektywność oczyszczania ścieków bytowo-gospodarczych w oczyszczalniach gruntowo-roślinnych i glebowo-roślinnych." *Woda – Środowisko – Obszary Wiejskie* no. 12 (4):97–108.

Gajewska, M., and H. Obarska-Pempkowiak. 2009. "20 lat doświadczeń z eksploatacji oczyszczalni hydrofitowych w Polsce." *Rocznik Ochrona Środowiska* no. 11:875–888.

———. 2011. "Efficiency of Pollutant Removal by Five Multistage Constructed Wetlands in a Temperate Climate." *Environment Protection Engineering* no. 37 (3):27–36.

Gajewska, M., E. Wojciechowska, and H. Obarska-Pempkowiak. 2014. "Najnowsze doświadczenia i aplikacje metody hydrofitowej w gospodarce komunalnej." *Gaz, Woda i Technika Sanitarna* (7):264–268.

Gizińska, M., K. Jóźwiakowski, A. Pytka, and M. Marzec. 2013. "Wstępne badania nad skutecznością usuwania zanieczyszczeń w 4-stopniowej hybrydowej oczyszczalni gruntowo-roślinnej." *Gaz, Woda i Technika Sanitarna* (2):47–50.

Heidrich, Z., and G. Stańko. 2007. *Leksykon przydomowych oczyszczalni ścieków*. Warszawa: Wydawnictwo Seidel-Przywecki.

Jaszczynski, J., A. Sapek, and S. Chrzanowski. 2006. "Wskaźniki chemiczne wody do picia z ujęć własnych w gospodarstwach wiejskich w otulinie Biebrzańskiego Parku Narodowego." *Woda – Środowisko – Obszary Wiejskie* no. 6 (2):129–142.

Jóźwiakowski, K. 2006. "Próba zwiększenia skuteczności usuwania fosforu w modelu oczyszczalni ścieków." *Inżynieria Rolnicza* no. 10 (5):249–256.

———. 2008. "Skuteczność funkcjonowania oraz zalety i wady trzcinowych oczyszczalni ścieków." *Zeszyty Problemowe Postępów Nauk Rolniczych* (532):111–119.

———. 2012. "Badania skuteczności oczyszczania ścieków w wybranych systemach. Rozprawa habilitacyjna." *Infrastruktura i Ekologia Terenów Wiejskich* (1):1–232.

Jóźwiakowski, K., Z. Mucha, A. Generowicz, S. Baran, and J. Bielińska. [forthcoming]. "The Use of Multi-Criteria Analysis for Selection of Technology for a Household Sewage Treatment Plant following the Idea of Sustainable Development." *Archives of Environmental Protection.*

Jucherski, A., and A. Walczowski. 2012. "Wpływ wybranych makrofitów na skuteczność oczyszczania ścieków w stokowych złożach filtracyjnych gruntowo-roślinnych." *Problemy Inżynierii Rolniczej* no. 20 (1):115–124.

Karczmarczyk, A. 2013. "Ocena wybranych technologii stosowanych w przydomowych systemach oczyszczania ścieków na podstawie słów kluczowych inżynierii ekologicznej." *Przegląd Naukowy – Inżynieria i Kształtowanie Środowiska* no. 22 (3):311–322.

Malej, J. 2000. "Wybrane problemy przeróbki osadów ściekowych." *Rocznik Ochrona Środowiska* no. 2:39–69.

Mazurkiewicz, J., and M. Pawlak. 2009. "Rozwiązania techniczne systemów rozsączania ścieków w przydomowych oczyszczalniach." *Instal* (12):61–66.

Nilsson, C., R. Lakshmanan, G. Renman, and G.K. Rajarao. 2013. "Efficacy of Reactive Mineral-Based Sorbents for Phosphate, Bacteria, Nitrogen and TOC Removal — Column Experiment in Recirculation Batch Mode." *Water Research* no. 47 (14):5165–5175. doi: 10.1016/j.watres.2013.05.056.

Obarska-Pempkowiak, H., M. Gajewska, and E. Wojciechowska. 2012. "Zastosowanie hydrofitowej metody oczyszczania ścieków na świecie i w Polsce." *Gaz, Woda i Technika Sanitarna* (2):87–91.

Pawęska, K., K. Pulikowski, M. Strzelczyk, and A. Rajmund. 2011. "Osadnik gnilny – podstawowy element przydomowej oczyszczalni ścieków." *Infrastruktura i Ekologia Terenów Wiejskich* (10):43–53.

Reszel, R., and T. Grądziel. 2013. *Roztoczański Park Narodowy. Przyroda i człowiek.* Zwierzyniec: Roztoczański Park Narodowy.

Rossa, L., and M. Sikorski. 2006. "Odpływ wybranych substancji z obszarów zabudowy wiejskiej." *Woda – Środowisko – Obszary Wiejskie* no. 6 (1):335–347.

Tomczuk, B., and D. Ochrymiuk. 2012. "Ocena efektywności gruntowo-roślinnych oczyszczalni ścieków na podstawie wyników rocznego projektu badawczego." *Inżynieria Ekologiczna* (28):57–67.