Chapter 18
Hybrid Constructed Wetlands for the National Parks in Poland – The Case Study, Requirements, Dimensioning and Preliminary Results

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Abstract Poland is proud of 23 National Parks (NPs) which were established to protect unique European areas. Through cooperation between Life Science University in Lublin and the NPs, highly effective methods for environmental protection were introduced in Roztoczański and Poleski National Parks. One method is a hybrid treatment wetland (HTW) for wastewater treatment. HTWs, if well designed and maintained, can effectively treat wastewater generated in houses and museum buildings in the area of the NPs. In 2014, three HTWs were constructed in Roztoczański National Park (RNP) (A – Kosobudy, B – Zwierzyniec, C – Florianka). One of these installations was constructed in the shape of a fir tree (A – Kosobudy). In 2015 another one, in a turtle shape, was built in Poleski National Park (PNP) (D – Stare Załucze). Similar wastewater treatment technology was applied in all facilities. The technology consisted of three steps: (i) mechanical treatment in three

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septic tank chambers, (ii) biological treatment in two or three stages of vertical and horizontal beds, and (iii) inactivation of phosphorus in p-filter with calcium-silica rock. Since the very beginning all facilities have been monitored and the results indicate very low concentrations of pollutants in the final effluents. It can be concluded that HTWs working according to the assumed technology fulfill the strict requirements for wastewater treatment in NP areas in Poland.

Keywords Water protection • Protected areas • Biogenic compounds removal • Phosphorus removal • Wastewater treatment

18.1 Introduction

The majority of institutions dealing with natural resources protection in Poland are facing the problem of unsolved wastewater management in scattered development. Many of the buildings located in the areas of NPs have no access to local sewer systems and, therefore, wastewater is collected in cesspools (Piszczek and Biczkowski 2010). This approach is not adequate since the main function of NPs is to protect natural resources through the most environmentally friendly technologies. As a consequence, not all properties and functions of theses areas are fully protected, which could have negative social and economic impacts on the development of the region (Świeca et al. 2012). Lack of adequate infrastructure for wastewater treatment is one fundamental limiting factor for tourism in these protected regions (Batyk 2012). Thus, PNP (Poleski National Park), RNP (Roztoczański National Park) and LSU (Life Science University) in Lublin joined together to solve this problem. Through this partnership, four hybrid treatment wetlands have been constructed to treat wastewater and further constructions are planned. The main aim is to protect the surface and ground waters in accordance with the 2nd Ecological Strategy of Poland [Polish Sejm, 23 August 2001], which stresses both fresh (surface and ground waters) and Baltic Sea water protection by prevention at the source and restoration of good ecological quality.

Kadlec and Wallace (2009), Fonder and Headley (2010) and Vymazal (2005) have shown that it is possible to achieve good quality effluent and protect water bodies in accordance with the Polish Environmental Protection Law (Regulation of the Minister of Environment 2014) through the application of Hybrid Treatment Wetlands (HTWs) for domestic wastewater treatment. Over 20 years of monitoring of HTWs in Poland indicates that this type of facility is appropriate for wastewater treatment in scattered development and ensures consistently good water quality (Jóźwiakowski et al. 2015). The removal efficiency of suspended solids (TSS) and organic matter (BOD_5 and COD) is over 90 % and removal of nitrogen compounds (TN) varies from 60 to 90 % in HTWs (Börner et al. 1998; Brix et al. 2003; Gajewska 2009; Gizińska et al. 2013; Gajewska and Obarska-Pempkowiak 2008, 2011; Gajewska et al. 2015; Jóźwiakowski 2012; Obarska-Pempkowiak et al. 2011). As with all treatment wetlands, HTWs are not dedicated to effective phosphorus removal, and the removal efficiency for phosphorus usually does not exceed 30 % (Kadlec and Wallace 2009).

The aim of this study is to present the concept of wastewater management using hybrid wastewater treatment wetlands in four areas: three settlements located in the forest in Roztoczański National Park and one in the Centre for Teaching and Museum in Poleski National Park.

18.2 The Characteristics of Poleski and Roztoczański National Parks

Roztoczanski and Poleski National Parks (50°37′00″N, 22°58′00″E; 51°27′19″N, 23°10′24″E) are located in Poland in the Lublin province (Fig. 18.1). They have cultural and environmental characteristics unique to both the country and Europe.

18.2.1 Roztoczański National Park (RPN)

The Park was established in 1974 and lies entirely in Central Roztocze. It consists of mainly woodland – 10 forest reserves make up 93.81 % of the whole area. Protection of the diverse forest ecosystems of Central Roztocze was the main reason for the creation of Roztocze National Park. Currently, RPN covers an area of almost 8500 ha with strict protection of 1029 ha (12.1 %) of its area.

Fig. 18.1 Locations of National Parks in Poland (http://archiwum.ekoportal.gov.pl/warto_wiedziec_i_odwiedzic/Ekoturystyka/Parki_Narodowe_Polska/)

Water resources in RPN consist of fragments of flowing waters: the Wieprz river, three main streams (Świerszcz, Szum, and Krupiec), two ponds (Florianiecki and Black Pond), and a complex of ponds called Echo. These areas of surface water cover 52.6 hectares, only 0.6 % of the total area of the Park. RPN has over 3630 species of animals and 900 species of vascular plants, representing nearly half of the total groups forming the Polish flora. Among them are 70 species under strict or partial protection and a similar number of taxa considered rare in the region, and about 20 are threatened with extinction in the country (http://www.roztoczanskipn.pl/).

18.2.2 Poleski National Park (PNP)

The Park was created in 1990, within the Łęczyńsko – Włodawskie Lakeland, which is the southern part of Lublin Polesie. PNP is 9764.31 ha and was created to protect peat- wetland ecosystems. The Park protects unique biotopes in Europe, namely tundra. In the PNP, there are 140 species of northern plants. Moreover, the presence of many plant species of the Atlantic (25) and South (30) zones creates a unique flora (http://www.poleskipn.pl). There are four lakes within Poleski National Park; three of them (Moszne, Długie and Karaśne) are small, shallow, dystrophic ones, while the fourth lake is a eutrophic reservoir with an area of 130 ha (http://www.poleskipn.pl).

18.3 Water and Wastewater Management in the Area of PNP and RNP

Corporate housing and office space for villages are spread around in the area of RNP. Five buildings are located away from human settlements in forest areas, and two more are located within the village. The water is supplied by the local water supply network or from groundwater intakes. The domestic wastewater is treated in household wastewater treatment facilities or collected in cesspools and then exported to the local wastewater treatment plant in Zwierzyniec. Transport of wastewater from cesspools is very troublesome because of the costs involved, but primarily because of emissions (460 kg CO_2/year) by vacuum trucks moving along the area of the RNP.

A comprehensive program to organize the wastewater treatment in the forest settlements in the RNP was developed in 2013. The program aims to protect the groundwater aquifer (mainly water Cretaceous). In 2014, construction of three hybrid wastewater treatment wetlands and modernization of two other, already existing wastewater treatment plants were completed. For this purpose, the RNP received funding from the National Fund for Environmental Protection and Water Management in the amount of 150,355 PLN (ca. 35,000 EUR), which represents 94 % of total investments (159,273 PLN).

The Statistical Vademecum of local government (2014) indicated that in the area of the PNP (in the municipalities of Urszulin, Stary Brus, Hańsk, Sosnowica, Ludwin, and Wierzbica), 64.2–82.9 % of households obtain water from a central system, but the central sewage system only covers 18–31.7 % of households. This means that the majority of households treat their wastewater through single family WWTPs or, more likely, by cesspools. In the past, single family WWTP drainage system technology was promoted. Nowadays these installations are out-of-date and clogged and, combined with plenty of leaking cesspools, pose a risk to surface and ground water quality. All six villages located in the forest of the PNP receive water from the central water system but for economic reasons they have never been connected to a central sewer system. Thus in 2014, the idea of using wetlands to treat wastewater generated in museum and didactic buildings of the PNP was developed and the construction was completed in September 2015. The concept is based on the newest achievements of wetland technology and included all aspects and advantages of the technology to protect the environment in this unique area.

18.4 The Concept of Hybrid Treatment Wetland Construction for RNP and PNP

Hybrid Treatment Wetlands (HTWs) were constructed in the area of the RNP in the distant forest villages of Kosobudy (A), Zwierzyniec (B) and Florianka (C), and in the PNP in Stare Zaucze (D).

The general concept is based on four stages of treatment to ensure good quality of discharged wastewater to protect water bodies in highly protected areas of the National Parks. In the first stage, a three-chamber settling tank was used for mechanical treatment.

Previous studies indicated that the composition of wastewater discharged to treatment facilities in Poland is different (more concentrated) than in other countries in Europe. There are two main reasons for this phenomenon: (i) the smaller amount of water consumed in households (approximately 70 L/person/day) and (ii) poor quality of primary treatment (Gajewska and Obarska-Pempkowiak 2011; Gajewska et al. 2011, Obarska-Pempkowiak et al. 2015). For these reasons the type and construction of the settlement tank is crucial to support proper performance of the second stage – the HTW.

Because of the importance of primary treatment, the facility type was selected from already existing solutions which ensure the following requirements of removal: 40–50 % for TSS, 25–40 % for BOD_5, 20–40 % for COD, and >10 % for biogenic compounds. Fats and mineral oils should be removed with 70–80 % effectiveness. The construction of a three-chamber tank supports mechanical treatment by processes such as sedimentation and flotation as well as primary biological treatment through fermentation. Gases generated during digestion of organic matter enhance the flotation of pollutants with lower density than water (fats and oils) which are collected in the upper part of the tank. Some pathogenic microorganisms are

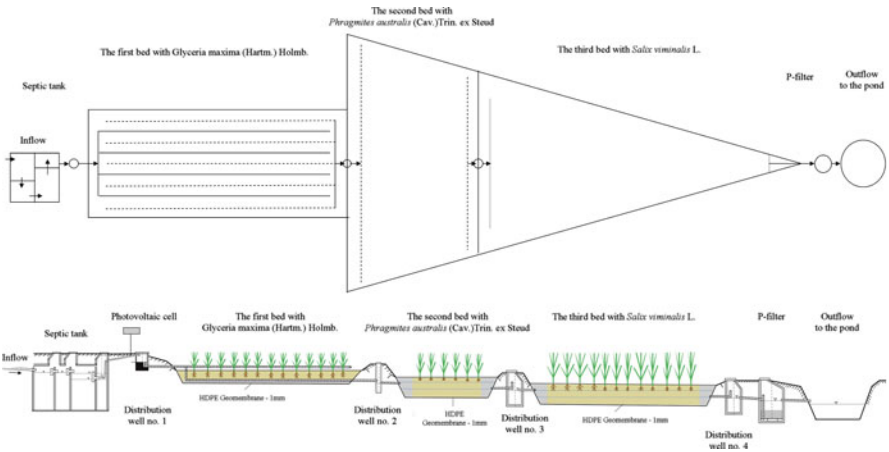

Fig. 18.2 Technological scheme and a longitudinal cross-section of a hybrid constructed wetland in Roztocze National Park – facility A (Jóźwiakowski et al. 2014)

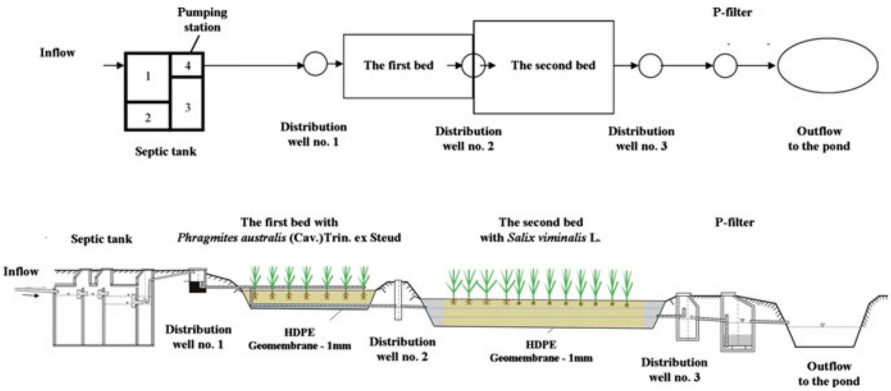

Fig. 18.3 Technological scheme and a longitudinal cross-section of hybrid constructed wetlands in National Parks – Facilities B, C, D (Jóźwiakowski et al. 2014)

eliminated during the processes that occur in the tank (Ødegaard 1998; Pawęska et al. 2011). The volume of the three-chamber tank depends on pe (person equivalent). In the case of the RNP and PNP it was predicted that the tanks should be between 3 and 8 m^3. The estimated amount of primer (digested) sludge is 3.35 m^3 in RNP and 0.985 m^3 in PNP with similar average water content of 93 %. The produced sludge should be utilized safely at a municipal wastewater treatment plant.

In the next stage wastewater is pumped to two or three subsurface flow beds for biological treatment. The general layouts and cross sections of the applied configurations of HTWs are presented in Figs. 18.2 and 18.3. To enhance treatment processes and support biodiversity, different types of macrophytes were planted in the beds. Only local species were selected. In the first bed, usually with vertical flow (VF), Phragmites australis or *Glyceria maxima* was planted. *Phragmites australis*

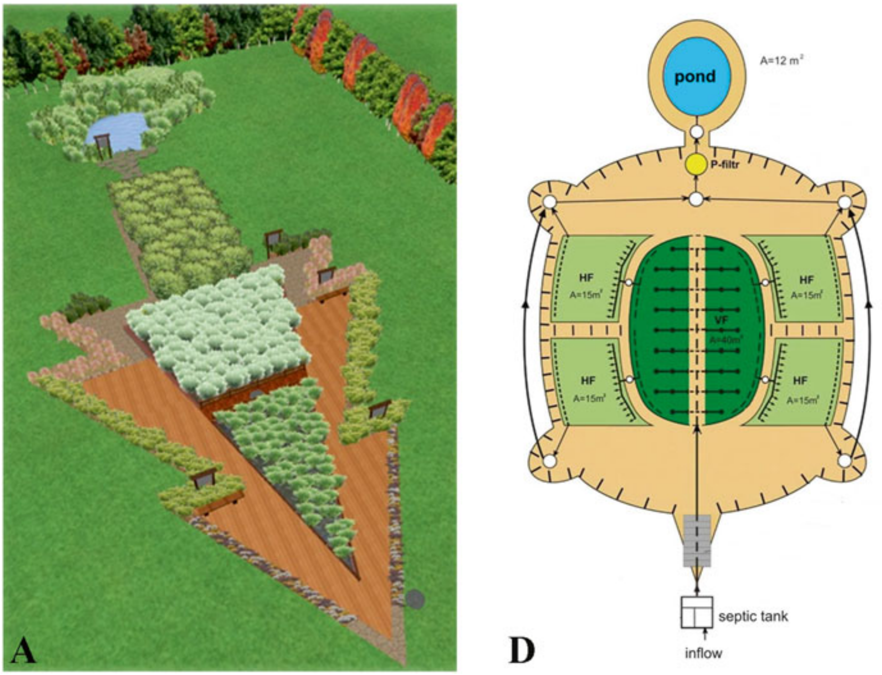

Fig. 18.4 The concept of construction of hybrid constructed wetland in two national parks in Poland: A – fir tree (RNP), D – turtle (PNP)

was planted in the second stage, which had horizontal flow (HF). *Salix viminalis* was used in the last HF stage. If the second stage was the last stage, it was planted with *Salix viminalis* to enhance evapotranspiration and minimize discharge (Jóźwiakowski 2008; Gajewska and Obarska-Pempkowiak 2009; Soroko 2001). According to Jucherski and Walczowski (2012), *Glyceria maxima* is able to remove large amounts of pollutants, especially nitrogen compounds, from the wastewater.

The third stage is a filter for phosphorus removal, and the treated wastewater is collected in a pond at the end of the system. To meet the strict requirements imposed by Polish Regulation on wastewater discharge to water bodies it was necessary to apply a special stage of treatment for phosphorus removal. The chosen technology is based on phosphorus binding with material rich in Ca^{2+} cations. The natural carbon silica rock is treated in high temperature to improve the binding potential. The P removal efficiency of this type of material can be as high as 90 % (Nilsson et al. 2013; Bus and Karczmarczyk 2014; Cucarella et al. 2007; Nastawny et al. 2015). This removal efficiency should ensure that the concentration of P in the final effluent is below the required limit of 5 mg P/L. The recipient of the final effluent is an infiltration pond where the water is collected. Depending on the conditions (hydraulic load, weather conditions, etc.) final effluent could be infiltrated into the surroundings or evaporated to the atmosphere. In Fig. 18.4 the visualization of HTWs in the shape of fir tree and turtle is presented.

Requirements to be met by final effluent discharged into surface waters and soil are defined in the Regulation of the Minister of Environment (2014). Wastewater discharged into the waters should not cause any changes which would hamper the proper functioning of aquatic ecosystems and should meet the specific water quality requirements for waters associated with their use.

To meet these requirements, the concentration of pollutants in wastewater discharged from a WWTP serving 2000–9999 pe should be as follows: <50 mg L^{-1} for TSS, a reduction of 87.5 %; <40 mg L^{-1} for BOD_5, a 92.0 % reduction; and <150 mg L^{-1} for COD, an 81.2 % reduction. The design parameters of surveyed facilities are presented in Table 18.1 and the pollutant loads are presented in Table 18.2.

Table 18.1 Characteristics of hybrid constructed wetlands in two national parks in Poland

	Roztoczański National Park (RNP)			Polesie National Park (PNP)
	A	B	C	D
Facility/Parameter	Kosobudy	Zwierzyniec	Florianka	Stare Załucze
Number of person equivalent	20	4	10	10
Flow, Q (m^3 d^{-1})	2.0	0.4	1.0	1.0
Active capacity of the septic tank. V (m^3)	8.0	4.0	5.0	3.0
Type and Area of beds				
Glyceria bed (m^2)	I – 60 (VF)	–	–	I – 40 (VF)
Phragmites bed (m^2)	II – 60 (HF)	I – 18 (VF)	I – 40 (VF)	II – 4 × 15 (HF)
Salix bed (m^2)	III – 60 (HF)	II – 30 (HF)	II – 56 (HF)	–
Total area (m^2)	180	48	96	100
P-filter for phosphorus removal (m^3)	1.0	0.5	0.75	0.5
Start up	2014	2014	2015	2015

Table 18.2 The planned loads of pollutants in wastewater in inflow and outflow

	Sites			
	A	B	C	D
Parameter	Kosobudy	Zwierzyniec	Florianka	Stare Załucze
Inflowing load (kg d^{-1})				
TSS	0.6	0.12	0.3	0.3
BOD_5	0.8	0.16	0.40	0.40
COD	1.6	0.32	0.80	0.80
TP	0.04	0.08	0.20	0.20
Outflowing load (kg d^{-1})				
TSS	0.07	0.014	0.035	0.035
BOD_5	0.05	0.020	0.025	0.025
COD	0.25	0.050	0.125	0.125
TP	0.01	0.02	0.05	0.05

18.5 Removal Efficiency of HTWs in RNP – Preliminary Results

18.5.1 Methods

The construction of HTWs in the RNP was completed in October 2014. After a few months of startup period, continuous monitoring of plants was implemented. From February to September 2015, 32 sampling events were carried out. The following parameters were measured in the collected samples of wastewater inflow and outflow:

- total suspended solids (TSS) – direct gravimetric method with paper points,
- biological oxygen demand (BOD_5) – determined using oximeter WTW Oxi 538,
- chemical oxygen demand (COD) – by dichromate method (using WTW MPM 2010 photometer, after oxidation of the test sample in a thermoreactor at 148 °C),
- total nitrogen – with AQUALYTIC PCspectro spectrophotometer, after oxidation of the test sample in a thermoreactor at 100 °C,
- total phosphorus – with WTW MPM 2010 photometer after oxidation of the test sample in a thermoreactor at 120 °C.

In addition, the quantity of coliforms and fecal coliforms was determined according to the Polish Standards PN-75/C-04615-05 and PN-77/C-04615-07.

The efficiency of pollutant removal in the monitored beds was determined on the basis of the average values of the analyzed indicators of contamination in wastewater flowing in (Cd) and out (Co) of the beds according to Eq. 18.1:

$$\eta = (1 - Co / Cd) \times 100 [\%] \tag{18.1}$$

The results were compared with the requirements of the Regulation of the Minister of Environment (2014).

18.6 Results and Discussion

Maximum, minimum, and average values and standard deviations are given in Table 18.3 and treatment efficiency is shown in Fig. 18.5.

18.6.1 Inflow

18.6.1.1 TSS

According to Miernik (2007), concentration of TSS in raw sewage in different types of WWTPs in rural areas of Poland varied between 118 and 187 mg l^{-1}. For systems studied by Jóźwiakowski (2012), the average concentration of total suspended

Table 18.3 The characteristics of inflow and outflow wastewater in Sites A and B

Parameter	Inflow				Outflow			
	Max	Min	б	$\bar{x}$	Max	Min	б	$\bar{x}$
	Site A – Kosobudy							
TSS (mg l^{-1})	588	320	141	456	10.2	8.7	0.9	9.7
BOD_5 (mg l^{-1})	791	389	183	521	25.7	4.3	11.7	12.2
COD (mg l^{-1})	1370	680	298	965	53.0	31.0	11.0	41.7
TN (mg l^{-1})	129	80.0	21.6	104	83.0	40.0	23.3	56.3
TP (mg l^{-1})	17.6	11.2	2.7	13.6	0.5	0.07	0.21	0.21
	Site B – Zwierzyniec							
TSS (mg l^{-1})	491	233	107	360	16.0	2.0	6.5	11.6
BOD_5 (mg l^{-1})	863	338	229	534	11.8	0.7	5.2	4.3
COD (mg l^{-1})	1790	930	401	1195	134	31.0	48.3	62.0
TN (mg l^{-1})	141	104	15.4	121	14.4	1.3	5.7	9.6
TP (mg l^{-1})	29.8	16.8	5.5	22.5	1.2	0.08	0.6	0.4

б = standard deviation

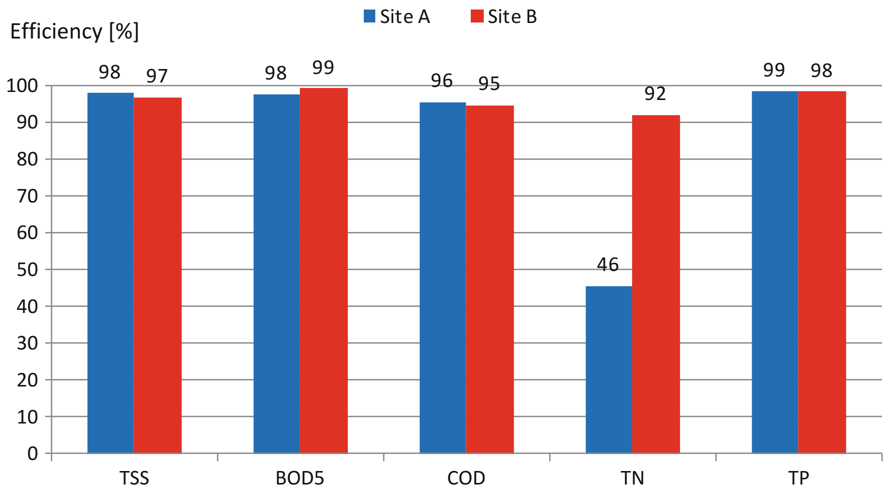

Fig. 18.5 Average removal efficiency at Sites A and B (in %)

solids in raw sewage was 120–322 mg l^{-1}. The current study shows that the average concentration of suspended solids in raw wastewater of surveyed facilities amounted to 456 mg l^{-1} and 360 mg l^{-1} for sites A and B, respectively (Table 18.3). These results were higher than those reported by Jóźwiakowski (2012) and Miernik (2007) and slightly lower than those reported by Pawęska and Kuczewski (2008). According to these authors the concentration of total suspended solids in raw wastewater at the treatment plant Brzeźno and Mroczeniu varied between 518 and 550 mg l^{-1}.

18.6.1.2 BOD_5 and COD

The average BOD_5 and COD concentrations in raw wastewater were 521 mg l^{-1} and 534 mg l^{-1}, respectively (Table 18.3). Miernik (2007) reported a similar value (578 mg l^{-1}) for a wastewater treatment plant in Michniów. Jóźwiakowski (2012) confirmed that COD in raw wastewater in households ranged from 509 to 562 mg l^{-1}. The average COD concentration in raw wastewater at Site A was 965 mg l^{-1}, with minimum and maximum values of 680 mg l^{-1} and 1370 mg l^{-1}, respectively (Table 18.3). Miernik (2007) also found high values of COD in the inflow (1125 mg l^{-1}) to this treatment plant. At Site B, an even higher average COD concentration of 1195 mg l^{-1}, with a maximum value of 1790 mg l^{-1}, was recorded. Obarska-Pempkowiak et al. (2013) investigated single family TWs in the Kaszuby Lake district in Poland and found that the average concentration of BOD_5 varied from 500 to 700 mg l^{-1} whereas for COD the inflow concentrations ranged between 900 and 1300 mg l^{-1}. Extremely high concentrations of COD (in excess of 1000 mg l^{-1}) and BOD_5 were discharged to TWs at four out of nine surveyed farms.

18.6.1.3 Total Nitrogen

This study found that the average concentration of total nitrogen in raw wastewater in facility A was 104 mg·l^{-1}, while the average concentration was 121 mg·l^{-1} in system B (Table 18.3). High concentrations of total nitrogen together with the large amount of organic matter in the raw wastewater could indicate a small amount of water consumed in surveyed households. Pawęska and Kuczewski (2008) obtained similar values of total nitrogen in raw sewage flowing into the Treatment Wetlands in Brzeźno and Mroczeń (Poland). Similar results were also reported by Obarska–Pempkowiak (2013), Gajewska and Obarska-Pempkowiak (2011), and Gajewska et al. (2014). The main reason for the high total nitrogen concentration is lower water consumption (approximately 80 l/day/pe instead of the 150 l/day/pe used for dimensioning of the systems).

18.6.1.4 Total Phosphorus

The average concentration of total phosphorus obtained in facility A, 13.6 mg l^{-1}, was exactly the same as that reported by Wiejak (2013). The average concentration of total phosphorus in wastewater at site B was even higher – 22.5 mg l^{-1}. According to Jóźwiakowski (2012), the concentration of phosphorus in raw wastewater is variable and can range from 29.6 to 46.4 mg l^{-1}.

18.6.2 *Outflow*

18.6.2.1 TSS

The average concentrations of total suspended solids in the effluent from sites A and B were 9.7 mg l^{-1} and 11.6 mg l^{-1}, respectively (Table 18.3). This concentration is 4–5 times lower than the limit specified for TSS in the Regulation of the Minister of the Environment [2014].

18.6.2.2 BOD_5 and COD

The average value of BOD_5 in the effluent from site A was 12.2 mg l^{-1}, while the minimum and maximum values were 4.4 mg l^{-1} and 25.7 mg l^{-1}, respectively (Table 18.3). These values were all below the permissible limit of 40 mg l^{-1}. At site B, the BOD_5 concentration was even lower, more than 8 times lower than the limit specified in the Regulation of the Minister of the Environment [2014].

The COD concentration in the discharge flowing out from the P filter at site A ranged from 31 to 53 mg l^{-1} (Table 18.3), with an average value of 41.7 mg l^{-1}. The average concentration of COD in the effluent at site B was 62 mg l^{-1} (Table 18.3) with a maximum value of 134 mg l^{-1} (Table 18.3). These concentrations were only slightly lower than the permissible value given by the Regulation of the Minister of the Environment [2014]. This may be due to the short time of operation of this facility. However, in 2015 no COD concentrations in the outflow exceeded the maximum standard limit for COD (150 mg l^{-1}).

18.6.2.3 Total Nitrogen

The concentration of TN in the effluent from site A varied from 40 to 80 mg l^{-1} with an average of 56.3 mg l^{-1} (Table 18.3). Despite the use of a three-stage system with a P filter the facility failed to completely remove nitrogen from wastewater. The limit for TN in wastewater is 30 mg l^{-1}, but only for wastewater entering lakes and their tributaries or reservoirs located on flowing waters [Regulation of the Minister of the Environment 2014]. These requirements were met by the HTW at site B where the average concentration of total nitrogen in treated wastewater was 9.6 mg l^{-1}. The limit values of this parameter ranged from 1.3 to 14.4 mg l^{-1}.

18.6.2.4 Total Phosphorus

The concentration of total phosphorus in the effluent from site A varied between 0.07 and 0.45 mg l^{-1}, with an average value of 0.21 mg l^{-1} (Table 18.3). The average concentration of total phosphorus in the effluent from site B was 0.37 mg l^{-1} and varied between 0.08 and 1.20 mg l^{-1} (Table 18.3). For both HTWs, the standard deviations were very low indicating stable removal and the concentration of TP in discharged was much lower than the required standard of 5.0 mg l^{-1} according to Regulation of the Minister of the Environment (2014). This requirement needs to be fulfilled for settlements with pe <2 000 in case of direct discharge of wastewater into lakes and their tributaries and reservoirs situated on flowing waters. The surveyed systems in the NPs are not subject to this regulation, but the HTWs are located in protected areas and thus should ensure the highest possible protection against eutrophication.

18.7 Efficiency of Organic Matter and Biogenic Compounds Removal

The average TSS removal efficiency was similar at both sites, 98 % at site A and 97 % at site B (Fig. 18.5). Similar high efficiency of TSS removal has been widely confirmed by many authors all over the world for different types and configuration of TWs (Kadlec and Wallace 2009; Vymazal 2010, 2011; Gajewska and Obarska-Pempkowiak 2011). For example, Singh et al. (2009) found that a treatment plant in Nepal eliminated 96 % of TSS, while Seo et al. (2009) reported treatment efficiency of 99 % in South Korea.

The effectiveness of BOD_5 reduction at sites A and B amounted to 98 % and 99 %, respectively (Fig. 18.5). High removal efficiency (99 %) of easily degradable organic matter was reported by Seo et al. (2009) in the facility in South Korea. Jóźwiakowski (2012) reported removal efficiency of 96 % in the treatment plant in Janów, Poland. Five HTWs investigated in North Poland by Gajewska and Obarska-Pempkowiak (2011) exhibited BOD_5 removal efficiency between 78 % and 96 % depending on the applied configuration. Single family TWs with different configurations investigated by Obarska-Pempkowiak at al. (2015) removed between 64 % and 92 % of BOD_5 during the first 2 years of operation, after which the efficiency increased to over 80 % for all facilities.

The test results presented in Fig. 18.5 confirm that hybrid systems in the RNP provide high COD removal efficiency. COD removal efficiencies at sites A and B were 96 % and 95 %, respectively. Seo et al. (2009) observed 98 % removal efficiency for COD in hybrid wetland plants in South Korea while Melian et al. (2010) observed removal efficiency of 80 % in the Canary Islands. Jóźwiakowski (2012) observed COD removal efficiency of 94 % in a treatment plant at Janów, and Gajewska and Obarska-Pempkowiak (2011) reported the removal of COD in HTWs in Poland in the range of 75–95 %.

Our study shows that the total nitrogen at site A was removed with 46 % efficiency which is much lower than the removal efficiency at site B (92 %; Fig. 18.5). Gajewska et al. (2004) reported total nitrogen removal efficiencies of 64 % and 34 %, respectively, for HTWs in Waizenfeld and Wiedersberg. Krzanowski et al. (2005)

reported TN removal efficiency during the growing and post-growing seasons at 71 % and 63 %, respectively, in a multistage TW in Muszynka. Gajewska and Obarska-Pempkowiak [2011] found wide variability in efficiency of TN removal for five HTWs in Poland, from 23 to 80 % depending on the working conditions of the facility and the season (removal efficiency was up to 12 % higher during the growing season). For a single family TW in the Kaszuby Lake district in Poland, the efficiency of TN removal in the first 2 years of operation varied from 55 to 77 % (average 60 %) and increased to 73–84 % (average 75 %) in the third year (Obarska-Pempkowiak et al. 2015).

Phosphorus removal efficiencies at sites A and B were 99 % and 98 %, respectively. The values were almost identical in both analyzed P- filters applied to phosphorus removal from wastewater. Moreover, the removal values were stable during the monitoring period, proving the high efficiency of the applied carbon-silica rock technology for phosphorus removal. The available literature results from hybrid TW systems throughout the world reveal that the average total phosphorus removal efficiency in these facilities is between 70 and 89 % (Krzanowski et al. 2005; Seo et al. 2009; Sharma et al. 2010). Jóźwiakowski (2012) achieved similar total phosphorus removal efficiency (in the range of 89–99 %) in the facility in Janów. Gajewska and Obarska-Pempkowiak (2009) recorded lower average efficiency of 47 % for phosphorus removal in five facilities filled with gravel.

The results obtained confirm that HTWs built in the NPs in Poland according to the assumed concept and construction ensure from the very beginning good treatment efficiency of organic matter, suspended solids, and biogenic compounds and consequently meet the requirements imposed by the Regulation of the Minister of the Environment (2014).

18.7.1 Efficiency of Microbiological Contamination Removal

Effectiveness in reduction of different bacteria groups at site A in February ranged from 81.54 to 99.46 %. In the treated effluent from site A the content of coliform bacteria (as the most probable number of bacteria – MPN) averaged 2.4×10^4 MPN 100 ml^{-1} and the fecal coliform content was 7×10^2 MPN 100 ml^{-1} (Table 18.4).

In September, effectiveness of the bacteria reduction at site A increased, reaching almost 100 %. The average elimination of coliform bacteria amounted to 99.90 %, while fecal coliform removal amounted to 99.99 %. The coliform content in treated wastewater was 2.4×10^4 MPN 100 ml^{-1} and the fecal coliform content was 5×10 MPN 100 ml^{-1} (Table 18.4).

Site B showed similar efficacy as site A. The efficiency of removal of both coliform and fecal coliform bacteria at site B in February was over 99.99 % (Table 18.4) with <5 MPN 100 ml^{-1} in the outflow. In September, the treatment exhibited a slightly lower effect on the elimination of bacteria, with removal efficiencies of

Table 18.4 The effects of the removal of microbiological contamination in the analyzed HTWs in the national parks in Poland

Parameter	Site A			Site B		
	C_{in}	C_{out}	E [%]	C_{in}	C_{out}	E [%]
	18.02.2015					
Total coliforms [MPN 100 cm^{-3}]	1.3×10^5	2.4×10^4	81.54	7×10^8	<5	99.99
Fecal coliforms [MPN 100 cm^{-3}]	1.3×10^5	7×10^2	99.46	7×10^6	<5	99.99
	04.09.2015					
Total coliforms [MPN 100 cm^{-3}]	2.4×10^7	2.4×10^4	99.90	7×10^6	7×10^3	99.90
Fecal coliforms [MPN 100 cm^{-3}]	2.4×10^7	5×10	99.99	7×10^5	2.4×10^3	99.66

99.90 % and 99.66 % respectively for coliform and fecal coliform bacteria. As a consequence, the numbers of coliform and fecal coliform bacteria were higher in comparison to February, amounting to 7×10^3 MPN 100 ml^{-1} for coliform bacteria and 2.4×10^3 MPN 100 ml^{-1} for fecal coliform bacteria. According to Talarko (2003) the removal efficiency of coliform bacteria in the soil-plant filters is about 99 %. Bergier et al. (2002) reported fecal bacteria removal efficiency of 98.9 % for constructed wetlands treating domestic wastewater. Lalke-Porczyk et al. (2010) reported slightly lower efficacy of fecal coliform elimination in reed and willow beds (94.51 % and 92.07 %, respectively).

Both treatment plants in the NPs showed almost 100 % removal of bacteria from raw wastewater. Removal of bacteria is extremely important for protecting areas like national parks where the environment should not been exposed to pathogenic microorganisms. Excessive inflow of bacteria into the soil or water could have detrimental effects on the existing ecosystem. In addition, the treatment plants do not negatively affect the environment in which they are located.

18.8 Conclusions

18.8.1 General

As a result of the application of hybrid wastewater treatment wetlands in the National Parks the following effects could be achieved:

1. MATERIAL EFFECT – construction of four highly effective HTWs.
2. ECOLOGICAL EFFECT – treatment plants will provide long-term protection of the environment in a highly protected area and mitigate point source emission of pollutants.
3. LANDSCAPE EFFECT – treatment plants are well integrated into landscape in the national parks and only native plant species are used.

4. ECONOMIC EFFECT – treatment plant maintenance costs will be significantly lower than those for septic tanks and previously used activated sludge treatment plant. It is anticipated that at facilities A and D (due to the use of photovoltaic cells) the operating costs of the treatment plants will be limited only to sewage sludge disposal once a year, while in two other HTWs it will be necessary to apply electricity to power the pump. Annual cost of working pump is estimated at 20–30 PLN (6–8 EURO).
5. EDUCATIONAL EFFECT – the construction of ecological walkways at facilities A and D and the opportunity to observe the functioning of other facilities will help improve knowledge and awareness of high school students and other tourists visiting both national parks.

18.8.2 Detailed

1. Hybrid Treatment Wetlands applied in the National Parks in Poland ensured from the very beginning very effective removal of TSS (over 96 %) and organic matter (BOD_5:97–99 % and COD: 94–95 %)
2. The HTW at site A provided total nitrogen removal efficiency of 45.7 %, while the HTW at site B provided significantly higher removal, up to 92.1 %.
3. The applied configuration of HTWs with the P filters as the last stage of treatment provided more than 98 % removal of phosphorus.
4. Wastewater effluent met all the requirements imposed by the Ministry of the Environment [2014].
5. HTW systems applied in the NPs provided almost 100 % removal efficiency of coliform and fecal coliform bacteria. The numbers of monitored bacteria in treated wastewater were usually very low and had no negative impact on the natural environment in the NPs.
6. The results presented in this paper have direct relevance to the design and construction of high-efficiency hybrid treatment wetlands (HTWs).
7. HTWs for wastewater treatment can be used on a larger scale in rural areas, especially in protected areas and valuable landscapes. They represent a valuable alternative to conventional WWTPs or septic tanks (cesspools).

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WFOŚiGW w Lublinie

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