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Constructed Wetland Systems for Serial Runoff Treatment in the Gulf of Gdansk Region

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1. Introduction

When accessing EU, Poland agreed to improve the condition of surface waters. To accomplish this goal, The National Strategy of Environmental Protection was established, where the 80% reduction of pollutants loads discharged to the Baltic Sea by 2020 is planned. Fulfilling the demands of the EU Directives requires the change of Polish regulations concerning environmental and water management [7].

The polluted rainwater creates potential threat to the environment. The rapid growth of water flow in the receiver is especially hazardous for small streams due to quickly changing load of pollutants. During intensive rainfall the pollutants are flushed from the drained area. The highest load of pollutants is discharged in the initial stage of runoff after dry weather [3, 13, 14].

The characteristic pollutants present in rainwater are suspended solids (mostly mineral), oil derivatives, substances extracted by oil ether, COD, heavy metals and chlorides. However, due to Polish regulations, only the concentrations of TSS and substances extracted by oil ether are limited in the drainage. TSS accumulates most of pollutants: COD: 83÷92%, BOD_5: 90÷95%, total nitrogen: 65÷80%, hydrocarbons: 82÷99%, lead: 97÷99%. Thus, treatment of drainage should concentrate on effective removal of TSS. It was found out, that most of pollutants in drainage waters is present in the colloidal form, which is difficult to remove by mechanical treatment [4]. Due to the diversity of type and concentration of pollutants in drainage, the adequate system of collection, retention and treatment before the discharge to receiver should be proposed in each case.

So far, the most frequently used devices for drainage treatment were separators, which removed the easily-settling pollutants and oil derivatives. Since separators are mechanical devices, they demand specialized service and maintenance. The evaluation of separators operation indicates that treatment effectiveness is fluctuating. Constructed wetlands can offer an alternative or complementary solution, which does not require frequent service and achieve good effectiveness of drainage water treatment, especially in case of TSS and heavy metals accumulated on TSS: lead: 90÷99%, copper: 60÷80% [2]. Constructed wetlands offer an additional retention volume for drainage waters and aesthetically fit in the countryside. Depending on the availability of space, terrain configuration, type of development and quantity and quality of drainage water, the optimal configuration of constructed wetland can be selected.

In the article the currently used constructed wetland systems for drainage treatment are presented. The evaluation of performance of two systems located in the drainage area of the Gulf of Gdańsk and their contribution to coastal waters protection against contamination flushed from the Threecity agglomeration is discussed.

2. Constructed wetlands performance

Constructed wetlands (CWs) take advantage of the processes imitating the natural marsh ecosystems. In the CWs, pollutants are removed by means of sedimentation, sorption, redox reactions responsible for decomposition of organic matter and nitrogen compounds removal as well as accumulation of pollutants in the biomass. Due to the high transpiration ability of hydrophytes, the outflow, especially in the summer period, can be very small. The roots and rhizomes of plants penetrate the whole depth of the bed, creating preferable conditions for the growth of microorganisms responsible for the biochemical decomposition of pollutants. The presence of hydrophytes promotes oxygen transfer to the bed. The most commonly used plants, due to the well developed roots and rhizomes system, are common reed (*Phragmite*s *australis*), *Typha latifolia* and *Iris pseudacorus*. Common reed grows fast, it is resistant to high salinity and to rapid changes of water level as well as fluctuating loads of pollutants. Constructed wetlands can be built either as surface systems (similar to natural ponds) or as the sub-surface flow beds (with horizontal or vertical flow of sewage).The CW systems may consist of one or more treatment stages [9].

The CWs for drainage waters treatment are usually preceded by retention tank, and sometimes also with oil and TSS separator.

CW systems are simple in operation and do not require specialized service. No biological sewage sludge is formed during treatment processes. The CWs are resistant to fluctuations of hydraulic loads. The drawback is the fact that full treatment effectiveness is achieved after one or two vegetation seasons.

3. Applications of CW systems in Gdańsk and Sopot

In Europe around 10 000 CW systems exist, while in Poland there is about 1000 systems [10]. Most of the existing systems serve as local or individual-house treatment systems. In the region of Gdańsk there are two CW systems for treatment of surface runoff.

The first system is located at the city ZOO in Oliwa (Gdańsk) and its role is to protect the Rynaszewski Stream flowing through the ZOO against inflow of the polluted runoff from the animals stocks and cages. The Rynaszewski Stream is the biggest tributary of the Jelitkowski Stream – one of the major inflows discharging to the Gulf of Gdańsk in this region. The conception of improvement of the quality of the waters of Rynaszewski Stream assumed treatment of polluted runoff on site – in the place where it comes from [8]. The major pollutant in the ZOO runoff was total nitrogen (mainly in the form of organic nitrogen) and, in a smaller extent, the faecal coliform bacteria. In 1992 a surface flow CW system consisting of sand filters, reed beds and ponds, of the total area of 3100 m^2 and five buffer zones of the area 6650 m^2 were built. The buffer zones role was treatment of the surface runoff from the animal stocks and cages. The buffer zones were located at the ponds edges and along the stream bed. They were planted with willow (*Salix viminalis*), and cut with ditches in order to increase the retention volume. The scheme of a CW system is presented at Fig. 2.

In Table 1 the concentrations of pollutants at selected points on the Rynaszewski Stream: the inflow to the ZOO (sampling point no. 9), the outflow from the Great Pond (no. 5), the outflow from the Oval Pond (no. 11), the outflow from the ZOO (no. 1), before and after the CW was built, are presented. Very good treatment effectiveness, especially in case of organic nitrogen (76%) was observed in the CW system.

In case of the buffer zones the removal of pollutants was also observed. The comparison of the data from the period before arrangement of the zones and after 2 years of operation (Table 2), indicated an effective removal of the total nitrogen, varying from 69.8% to 89.8%, COD_{Mn} from 46.8% to 91.3% and phosphates − 85% on average (apart from the Oval Pond, where no change of concentration was observed). However, the data from 2007 (Table 3) indicate that the treatment effectiveness of the buffer zone near Hippopotamus Pond decreased, which resulted from inadequate maintenance and conservation.

Table 1. The average concentrations of pollutants at selected sampling points before construction of the CW system (before) and after two years of operation (after), [mg/dm^3]
Tabela 1. Średnie wartości stężeń zanieczyszczeń w wybranych punktach pomiarowych przed wybudowaniem obiektu (przed) oraz po dwuletniej eksploatacji (po), w [mg/dm^3]

Parametr [mg/dm^3]	Inflow to ZOO		Outflow from the Great Pond		Outflow from the Oval Pond		Outflow from ZOO	
	before	after	before	after	before	after	before	after
Ntot	3.1	1.7	6.6	1.8	6.6	2.0	9.6	2.5
PO_4^{3-}	0.4	0.2	0.4	0.2	0.4	0.25	0.6	0.15
BOD5	–	2.8	3.2	3.0	3.1	3.4	3.5	2.8
COD_{Mn}	2.9	6.5	8.5	4.1	8.5	3.7	10.0	4.8
N- NH_4^+	0.0	0.1	0.5	0.2	0.5	0.2	1.6	0.1
N- NO_3^-	0.0	0.4	0.3	0.4	0.3	0.5	0.4	0.5
N- NO_2^-	0.0	0.01	trace	0.02	trace	0.02	trace	0.02
N_{org}	3.1	1.2	5.6	1.2	5.6	1.4	8.0	1.9

Table 2. The flow of pollutant loads before and after arrangement of the buffer zones along the bed of the Rynaszewski Stream and its inflows.
Tabela 2. Przepływ ładunków zanieczyszczeń przed i po założeniu stref buforowych wzdłuż koryta Potoku Rynaszewskiego oraz jego dopływów

Location of sampling point	Load transfer [kg/d]											
	N_{tot} before	N_{tot} after	$N\text{-}NH_4^+$ before	$N\text{-}NH_4^+$ after	Org. before	Org. after	PO_4^{3-} before	PO_4^{3-} after	$BODT_5$ before	BOD_5 after	COD_{Mn} before	COD_{Mn} after
before the Great Pond – point 6	4.4	1.3	0.4	0.1	3.0	1.0	0.7	0.1	1.6	2.0	10.4	3.8
after the Small Pond – below buffer zone C	24.0	6.5	0.7	0.5	22.1	5.1	5.7	0.7	–	9.4	21.8	11.6
after the Oval Pond – point 11	34.8	10.5	6.3	0.8	21.6	7.4	1.1	1.1	17.9	16.3	49.5	19.5
after the Hipopota-muses Pond – point 4B	46.4	4.7	11.6	0.8	23.7	2.1	3.2	0.5	12.7	9.5	24.2	2.1

Table 3. The concentrations of pollutants in the Great Pond and buffer zone at the ZOO in Oliwa [11]
Tabela 3. Jakość wód Dużego Stawu oraz strefy buforowej na terenie ZOO Oliwa [11]

Parametr [$mg \cdot dm^{-3}$]	Great Pond	Buffer zone – Hippopotamus Pond
pH	6.9	7.2
PO_4^{3-}	0.11	0.12
COD	52.9	70.4
N_{tot}	5.1	4.3
BOD_5	1.3	9.1
TSS	40.0	20.0
dissolved oxygen	10.1	11.1

In the Fig.1 the average annual flow of pollutants discharged with the waters of Rynaszewski Stream in 1991 (before construction of the CW system) and in 2006 (after 15 years of CW operation) is compared. The decrease of the total nitrogen load from 22.3 t/year in 1991 to 3.3 t/year in 2006 is especially important.

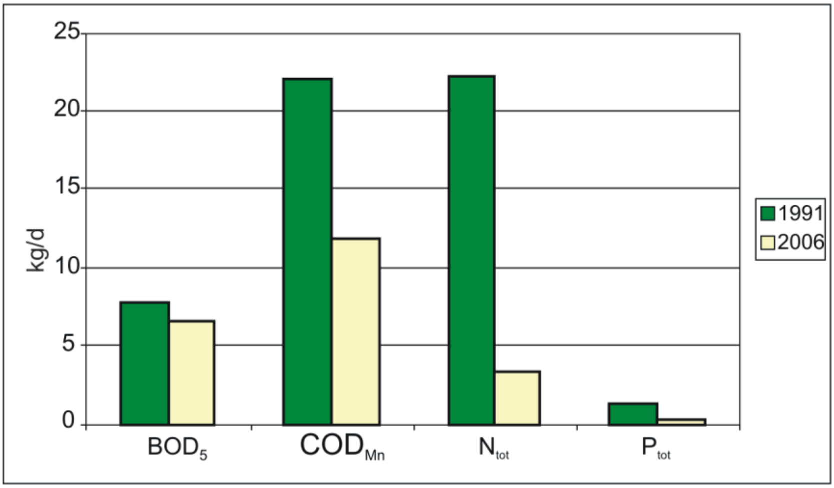

Fig. 1. Average annual load discharged by Rynaszewski Stream before construction of CW system and after 15 years of operation
Rys. 1. Średni roczny ładunek odprowadzany z wodami Potoku Rynaszewskiego przed wybudowaniem obiektu oraz po 15 latach funkcjonowania

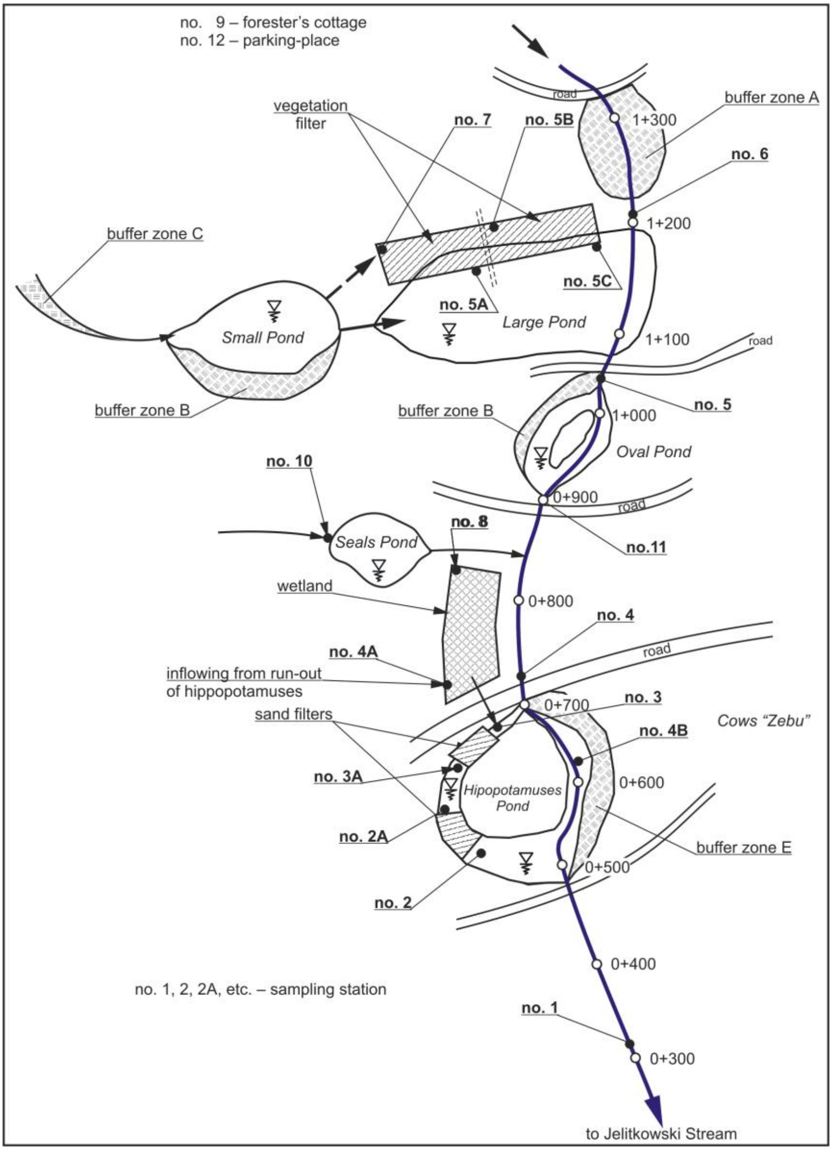

Fig. 2. The CW system at the ZOO in Oliwa, according to [11]
Rys. 2. Zespół obiektów hydrotechniczno-hydrofitowych w ZOO w Oliwie [11]

The analyses carried out by the researchers from Gdańsk University of Technology indicated that the average daily load removed in the CW system was 45.8 kg/d N_{tot} (36.8 kg/d: N_{org} and 9 kg/d N-NH_4^+), 2.7 kg/d PO_4^{-3} and 31.5 kg/d $ChZT_{Mn}$ (assuming that the average flow is 70 l/s) [11].

The second CW system was built at Swelina Stream in Sopot. The Swelina Stream discharges its waters directly to the Gulf of Gdańsk, near popular bathing places. The Stream receives the drainage waters from surrounding area. In 1994, in order to protect the Stream against pollution, a sedimentation- retention tank and vegetated sand filter were built. The filter was planted with common reed (*Phragmites australis*). The filling material of the filter was fine gravel (Fig. 3).

The treated water is collected by drainage pipes, outflows to a control well and then it is discharged back to the stream. During intensive rainfall, the first, most polluted part of drainage is collected in a retention reservoir, while the rest of water is discharged through an overflow to the stream (without treatment). The system was built in order to remove the nutrients, mainly phosphorus, and faecal bacteria discharged with drainage. After the CW was constructed, a significant improvement of the Stream quality was observed. The analyses carried out by the Regional Inspection of Environment Protection in Gdańsk indicated that Swelina Stream waters fulfill criteria of the first class waters (Fig. 4).

In the years 2006÷2009 eight Bioclere® objects have been selected and analyzed in respect of efficiency pollutants removal. From among to researched objects are both one and two-stage units (Tab. 1). Every Bioclere® installation is assigned for service different number of inhabitants, (from 10 to 500 people). If the number of people exceed 500 then parallel systems are used (for example: 4 × Bioclere® type 500 to 2000 inhabitants).

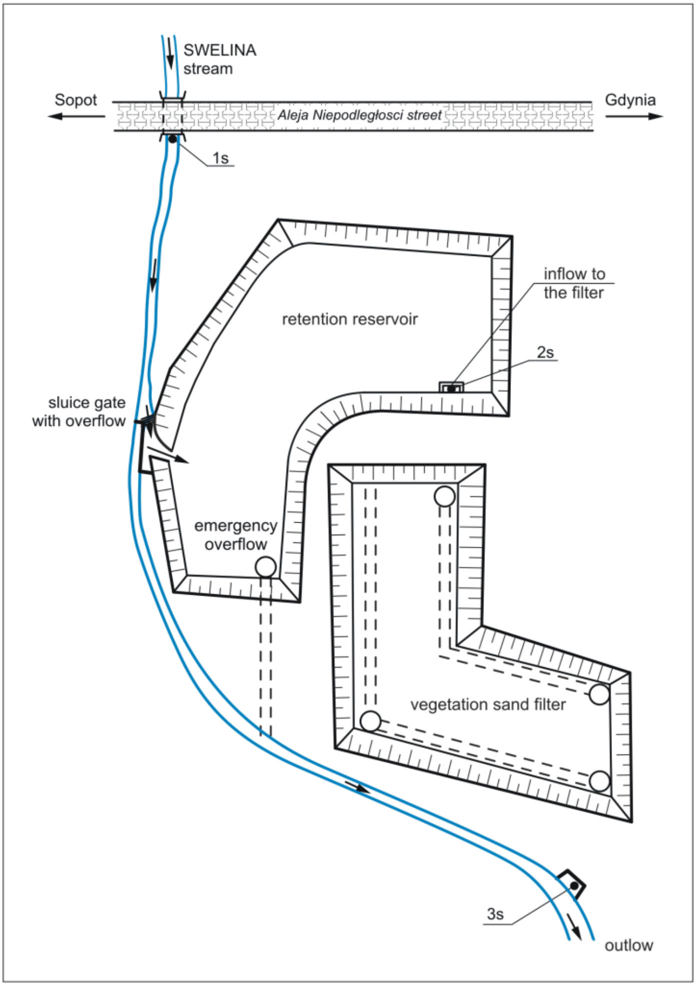

Fig. 3. The CW system on Swelina Stream, according to [11]
Rys. 3. Obiekt hydrofitowy na Potoku Swelina [11]

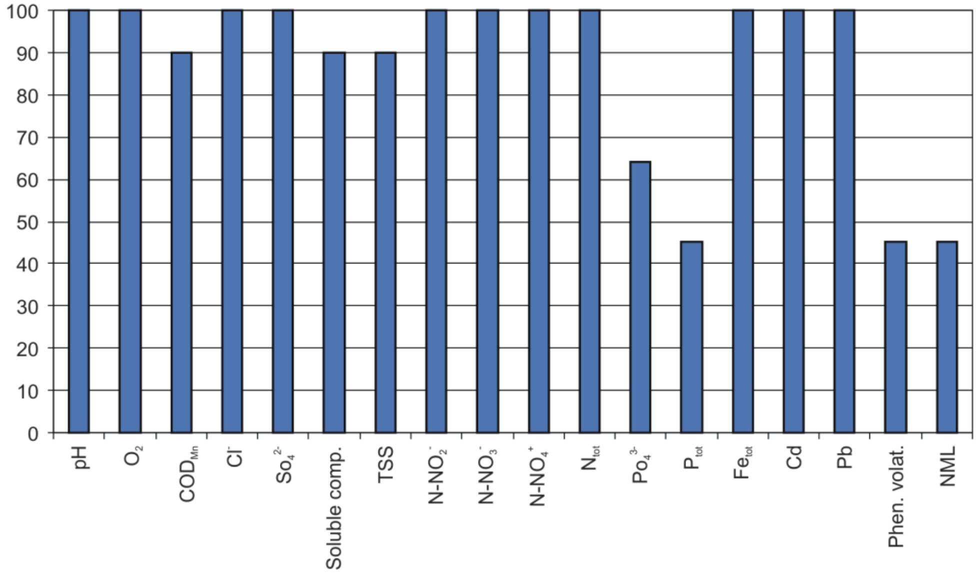

Fig 4. The percentage of first class water results (due to physical, chemical and bacteriological criteria), Swelina Stream, according to the Regional Inspection of Environmental Protection in Gdańsk

Rys 4. Procent wyników badań wód potoku Swelina w I klasie czystości według kryteriów fizyko-chemicznych i bakteriologicznych. (Źródło: Raport Wojewódzkiego Inspektoratu Ochrony Środowiska w Gdańsku)

4. Conclusions

Constructed wetland systems can be a complementary or alternative solution for the conventional methods of drainage treatment due to simple construction and low operation costs, as well as effective removal of pollutants. The CW systems have been successfully applied for treatment of sewage from aerial and point sources. They provide effective removal of TSS, organics, nitrogen compounds, heavy metals and even detergents and other specific pollutants.

In the article the examples of successful application of CW systems for treatment of aerial runoff at the Threecity agglomeration have been presented. The CW system at the ZOO in Oliwa was particularly effective in nitrogen removal. The CW system at Swelina Stream contributed to the significant improvement of the stream waters quality, resulting in the improvement of the quality of the bathing place located near its outflow to the Gulf of Gdańsk.

Acnowlegments

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INNOVACYJNA GOSPODARKA
NARODOWA STRATEGIA SPÓJNOŚCI

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Systemy hydrofitowe do oczyszczania spływów powierzchniowych w rejonie Zatoki Gdańskiej

Streszczenie

W artykule przywołano przykłady udanych wdrożeń obiektów hydrofitowych oczyszczania spływów obszarowych na terenie aglomeracji trójmiejskiej. Zespół obiektów hydrofitowych wybudowany w ZOO w Oliwie wykazał szczególnie wysoką skuteczność usuwania związków azotu. Obiekt hydrofitowy na Potoku Swelina spowodował znaczną poprawę jakości wód Potoku, a co za tym idzie i czystości kąpieliska w rejonie Kamiennego Potoku w Sopocie. Podjęte działania przyczyniły się do znacznej poprawy jakości wód Zatoki Gdańskiej w rejonach kąpielisk w Jelitkowie i Kamiennym Potoku.