ARCHIVES OF ENVIRONMENTAL PROTECTION
ARCHIWUM OCHRONY ŚRODOWISKA
vol. 32 no. 4 pp. 25 - 34 2006

PL ISSN 0324-8461

THE EFFECTIVENESS OF THE STORM WATER TREATMENT PLANT AT WARSAW FREDERICK CHOPIN AIRPORT

MIROSŁAW KRZEMIENIEWSKI, ANDRZEJ BIAŁOWIEC, MARCIN ZIELIŃSKI

The Faculty of Environmental Sciences and Fisheries, University of Warmia and Mazury in Olsztyn
ul. Oczapowskiego 2, 10-719 Olsztyn, Poland

Keywords: De-icing; rainwater; melt water; total organic carbon, total nitrogen, chlorides, airport.

EFEKTYWNOŚĆ OCZYSZCZALNI ŚCIEKÓW DESZCZOWYCH Z LOTNISKA FRYDERYKA CHOPINA W WARSZAWIE

Funkcjonowanie portów lotniczych oddziałuje na wody powierzchniowe przez przedostawanie się do nich wraz ze ściekami opadowymi chemicznych środków odladzających stosowanych w okresie zimowym. Przeprowadzano badania efektywności pracy Oczyszczalni Ścieków Deszczowych (OSD) ujmowanych z terenu Portu Lotniczego Fryderyka Chopina w Warszawie w odniesieniu do następujących parametrów: zawiesina ogólna, ekstrakt naftowy, TOC oraz azot całkowity (TN). Wybór analizowanych wskaźników zanieczyszczenia podyktowany był: technologią mechanicznego oczyszczania ścieków, możliwością przedostawania się do ścieków deszczowych paliwa lotniczego oraz stosowaniem środków odladzających (glikole, octany, mocznik). W ciągu całego 2002 r. pobrano 31 próbek ścieków na wlocie oraz wylocie z oczyszczalni. Przeprowadzono analizę uzyskanych wyników w odniesieniu do okresów stosowania bądź nie środków odladzających oraz do występowania opadów atmosferycznych. Stwierdzono, że najwyższe zanieczyszczenie w ściekach dopływających występowało podczas jednoczesnego stosowania środków odladzających oraz opadów atmosferycznych i przyjmowało średnie wartości: zawiesiny ogólnej – 159,0 mg/dm^3, ekstrakt naftowy – 26,4 mg/dm^3, TOC – 446,5 mg/dm^3, TN – 142,1 mg/dm^3. Efektywność mechanicznego wydzielania zawiesin oraz ekstraktu eterowego w OSD w całym okresie badawczym była wysoka i zmieniała się odpowiednio od 51,3 do 82,7% i od 45,3 do 70,2%, co pozwoliło uzyskać stężenia na odpływie poniżej wartości normowanych tj. odpowiednio 100 i 15 mg/dm^3. Efektywność usuwania TOC oraz TN była niewielka i wynosiła odpowiednio od 3,1 do 32,6% i od 8,0 do 32,6%. OSD nie była jednak zaprojektowana do usuwania tych zanieczyszczeń. W celu ograniczenia zrzutu dużych ładunków związków azotu i związków organicznych wyrażonych jako TOC, kiedy ich stężenia przekraczają odpowiednio 30 i 40 mg/dm^3 proponuje się odprowadzanie ścieków deszczowych do kanalizacji miejskiej.

Summary

Airports maintenance exerts a considerable impact on surface waters due to an extensive use, particularly in winter, of anti-icing and de-icing chemicals, which are conveyed to surface waters with a storm water runoff. The effectiveness of the Storm Water Treatment Plant (SWTP) at Warsaw Frederic Chopin Airport was examined with reference to the following four pollution indicators: suspended solids, oil extract, TOC and total nitrogen (TN) which, in turn, were determined in view of the following factors: the technology of mechanical sewage treatment, aircraft fuel potentials to permeate storm water sewage, and the application of antifreezes and ice- and snowmelts such as glycols, acetates and urea. In 2002 thirty-one sewage samples were taken both at the inlet and outlet of the SWTP. The obtained data was analyzed with reference to the periods with and without the application of anti-icing and de-icing chemicals and the occurrence of precipitation. The highest amount of contaminant in the inflowing sewage was observed when the use of toxic chemicals was simultaneous with the snow- and rainfall and reached the following values: suspended solids – 159.0 mg/dm³, oil extract – 26.4 mg/dm³, TOC – 446.5 mg/dm³, TN– 142.1 mg/dm³. The effectiveness of mechanical disposal of suspended solids and oil extract in the SWTP was rather high and remained at the level of 51.3–82.7% and 45.3–70.2% respectively, which resulted in the contaminant concentration in the effluent below standard values i.e. 100 and 15 mg/dm³. The effectiveness of TOC and TN removal remained relatively low from 3.1 to 32.6% and from 8.0 to 32.6% respectively, which is understandable since the SWTP was not designed to remove TOC and TN. To reduce the discharge of large loadings of nitrogen (TN) and organic compounds (TOC), when its concentration excesses 30 and 40 mg/dm³, respectively, it is recommended to direct the storm water sewage to municipal sanitary sewers.

INTRODUCTION

The operation and maintenance of airports set numerous threats to natural environment. One of them is the impact airports exert on surface waters. Any precipitation which falls on hard surfaces such as runways, taxiways, hangars and terminals instantly produces storm water sewage, the content of which determines the drainage catchments design. Airport surfaces are polluted with solid pollutants such as dust coming from the airport and its surrounding area; carbohydrates from the petrol, oils and grease; glycols, in particular ethylene-, diethylene and propylene glycol-related substances, all of which are present in anti-icing and de-icing chemicals applied to aircraft and runways or taxiways to prevent them from forming ice and remove the ice once it has accrued.

Rainwater rinses the pollutants sediment from the airport facilities [1]. It is necessary to apply de-icing chemicals in order to ensure aircraft safety. Mechanical methods such as snow ploughs or sand distribution are neither effective nor convenient to render [5]. Urea, glycol compounds and less toxicant de-icers based on potassium acetate are contemporarily in use [6], which inevitably increases the potential harmful influence of airports on surface waters as they accelerate water eutrophication and oxygen deficits [2]. Apart from this, glycol and its biodegradation outcome such as ammonium and formaldehyde have been proved toxicant [6, 8]. Therefore, contaminated storm water from the airport needs to be directed to the storm-water drainage system to be treated there prior to its discharge into the receiving water.

The aim of this research was to determine the effectiveness of the Storm Water Treatment Plant operating at Warsaw Frederic Chopin Airport and possibly to provide guidelines for the plant's modernization. The SWTP was built directly on the Służewiecki Stream, which is a receiving water of the whole storm water runoff from the airport.

METHODOLOGY

The Służewiecki Stream drainage basin characteristics

Warsaw Frederic Chopin Airport has a capacity of about 3.5 million passengers a year and the Cargo terminal a throughput of 60 000 Mg annually. The airport is located about 7 km from the city centre. In winter, in order to meet safety regulations, planes, airport grounds and in particular runways and taxiways are treated with de-icers such as urea and glycol-based chemicals. Apart from these, chemicals based on acetates and formic acid is applied. Technical lanes, parking stands and aprons are defrosted also with calcium chloride. Only in the case of glazed frost, freezing fog and drizzle, sleet or heavy snowfall defrosting is required. The airport is equipped with a system of slush- and storm water disposal to a natural water-course called the Służewiecki Stream, whose total length reaches 13540 m with a mean slope 1.38‰. Above the airport level the Służewiecki Stream drainage catchments comprises 420 ha, which comprises mainly residential and shopping districts south-west of Warsaw. In the area surrounding the airport the Służewiecki Stream basin comprises 760.5 ha, which consists of: 188.5 ha of hard surface of runways, taxiways and car lanes; 544.6 ha of green and 27.4 ha of hangars and background facilities. Thus, an average down-flow coefficient reaches $\psi = 0.279$. The waters of the Służewiecki Stream from its source to the runoff from the airport are conveyed by a closed water canal with numerous storm-water drainage ducts attached on the way. The Służewiecki Stream receives the storm-water from the neighboring urban sprawl (Fig. 1), which results in considerable differences between a low mean water level SNQ – 0.056 m^3/s and a high mean water level SWQ – 0.57 m^3/s, and the highest water level of all reaches up to 26.71 m^3/s (the data obtained from the measurements performed hourly every day between 17.07.2000 and 23.10.2002 in the Storm Water Treatment Plant situated behind the airport on the Służewiecki Stream).

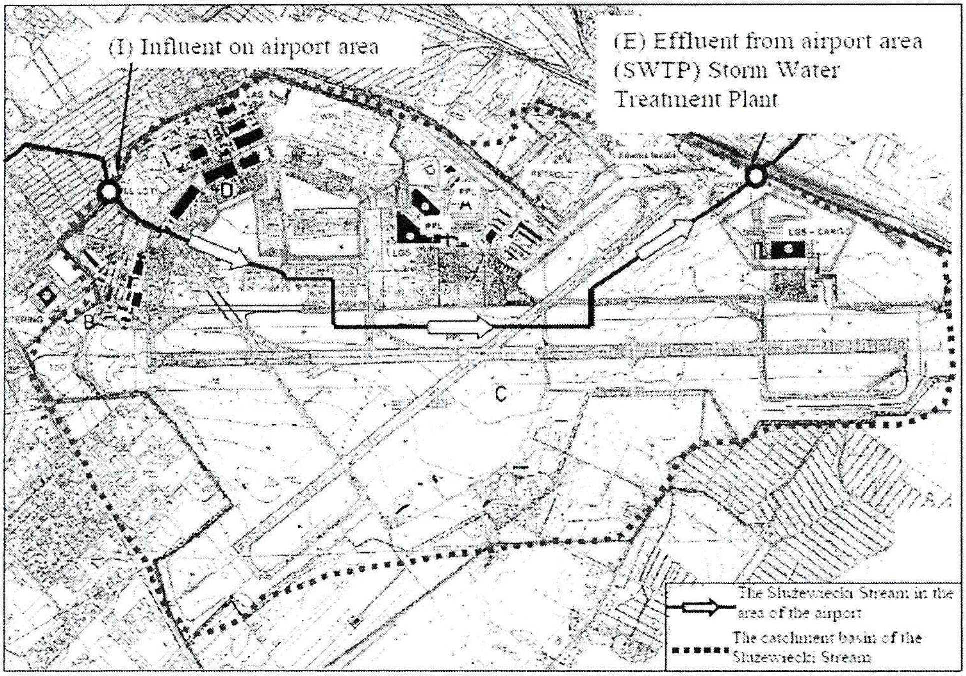
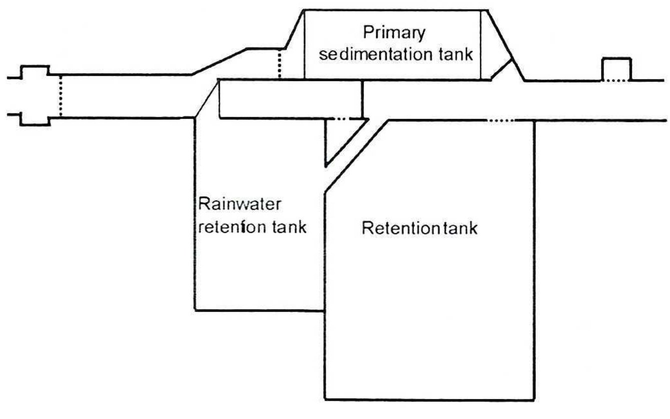


Fig. 1. Layout plan of the Służewiecki Stream in the area of Warsaw Frederick Chopin Airport

Experimental object characteristics

The Storm Water Treatment Plant was built on the Służewiecki Stream runoff from Frederick Chopin Airport. (Fig. 1) The whole volume of the Służewiecki Stream flows through this object. The technology applied in the plant allows reducing the number of suspended solids and oil-related substances which the stream carries. The technological system of the plant consists of 3 compatible courses: basic, additional and complementary (Fig. 2). The number of the courses in use depends on the stream volume. At the low mean water level and the flow below 0.3 m^3/s storm-water is conveyed mainly through the basic course, and as the volume of inflowing water increases the water mirror is raised and the water flows over the threshold to a duct leading to the additional course of the plant. Another rise of the water mirror makes the water flow over the other threshold leading to the complementary course and the relief channel. At the bottom of the channel and at the threshold height a floating partition wall was installed to direct surface layers of the water with floating oil pollutants to the basic course of the plant system. As a result, surface waters are invariably conveyed to the basic course even if the extensive water flow is led to the additional and complementary course. When the volume of the water flow in the Służewiecki Stream exceeds 0.3 m^3/s waste waters flow into a supply canal leading to the rain-water settlement tank. When the sewage water level exceeds the overflow edge of the settlement tank the additional course begins to operate. Storm-water sewage at the initial stage of the rainfall shows a high concentration of suspended solids. This part of sewage is treated by means of the storm-water settlement tank. Treated effluent flows over the overflow edge through the out-flowing duct to the main channel below the weirs. When the water level declines the storm-water settlement tank is emptied out by means of a flip open trap attached to the basic course of the plant. When the amount of influent exceeds Q – 1.53 m^3/s the sewage is collected in the retention tank, which is a basis of the complementary course. In winter the retention tank is used for slush waters storage. When the control system detects an increased concentration of total organic carbon (TOC) (40 mg/dm^3) the runoff of the basic course is closed. The slush sewage is pumped into the retention tank by means of the three sinking pumps and then conveyed to the municipal sanitary sewers.



Flow of rain water	Working elements
$Q_1 = 0.3\ m^3/s$	Primary sedimentation tank
$0.3\ m^3/s < Q_2 < 1.53\ m^3/s$	Primary sedimentation tank Rainwater retention tank
$Q_5 > 1.53\ m^3/s$	Primary sedimentation tank Rainwater retention tank Retention tank

Fig. 2. Technological scheme of Storm Water Treatment Plant at the Warsaw Frederick Chopin Airport

Experiment characteristics

The experiment was carried out between February 2002 and December 2002. During these period thirty-one samples of the stream water were collected once every other week. The samples were taken from both the inflow (I) and effluent (E) of the SWTP away from the airport area (Fig. 2). The storm-water sewage was divided into two groups according to the technology applied to the airport surface. Type (W) refers to the sewage from the surface treated with anti-icing and de-icing chemicals, whereas type (S) denotes the sewage from the period when no chemicals were applied. Additionally, since the airport exploitation depended on weather conditions the sewage was divided into two other categories i.e. the sewage collected during the dry (rainless) period (D) and wet (precipitation) period (R). Such assumptions allowed formulating the following experimental variations (Tab. 1).

Table 1. Variants of the experiment

		Weather conditions			
		Dry (D)		Rainfall (R)	
Type of exploitation of the airport area	Using de-icers (S)	SDI (summer dry influent)	SDE (summer dry effluent)	SRI (summer rain influent)	SRE (summer rain effluent)
	Without using de-icers (W)	WDI (winter dry influent)	WDE (winter dry effluent)	WRI (winter rain influent)	WRE (winter rain effluent)
		Influent (I)	Effluent (E)	Influent (I)	Effluent (E)
		Point of sampling			

The concentration of basic pollutants in the water samples was determined and compared to that recommended by Regulation of the Minister of Environment of November 29, 2002 on conditions to be met while discharging waste waters to water bodies or to soil, and on the substances particularly harmful to water environment [7] such as general suspended solids (weighing method) and oil ether-extractable substances (Soxhlet's method). Additionally, since the waters were potentially characteristic of high concentration of organic and nitrogen compounds the values of total organic carbon (TOC) and total nitrogen (TN) (using the method of infrared radiation detection, with the use of TOC 1200 apparatus by Thermo Electron Corporation) were determined. The amount of inflowing water in the Służewiecki Stream was measured on-line at the runoff from the airport area. Measurements were recorded hourly by a measuring-recording device (the Enders-Hauser's measuring sounder).

The obtained data was tested for significance by means of a program Statistica 6.0. Mean values of the pollutants removal efficiency in the SWTP were analyzed by means of ANOVA test at the significance level of $p < 0.05$ prior to a detailed analysis by the post-hoc Tukey's HSD test for unequal sample sizes.

RESULTS AND DISCUSSION

The amount of contaminated influent conveyed by the Służewiecki Stream to the Storm Water Treatment Plant at Frederick Chopin Airport depended on both the type of season and precipitation. The technology of the plant enables to remove suspended solids and oil-related substances from the sewage. The technological system was not designed to remove nitrogen and organic compounds (TOC). Thus, if any removal did occur and the pollutant concentration declined it was due to the precipitation of organic compounds into a form of suspended solids. In addition, in winter it is also possible to cut off the Storm Water Treatment Plant runoff if the organic compounds concentration in the effluent is too high, i.e. when it exceeds 40 mg/dm^3 (TOC). In such a case the runoff from the airport is automatically closed and the whole volume of storm-waters is conveyed through the retention tank to the municipal sanitary sewers.

It was observed that only during a heavy rainfall and only on one occasion when no anti-icing and de-icing chemicals were involved the inflow value exceeded 0.3 m^3/s and reached 0.738 m^3/s, which means that the additional course of the SWTP was launched. During the rest of the time the values were below 0.3 m^3/s, which means that only the basic course of the SWTP operated (Tab. 2).

Table 2. Parameters of descriptive statistics of flow rate [m^3/s]

Type of exploitation of the airport area	Precipitation	Parameters of descriptive statistics of flow rate [m^3/s]					
		m	N	S	Se ±	Min	Max
Using de-icers (W)	Dry (D)	0.033	7	0.023	0.009	0.017	0.076
	Rainfall (R)	0.103	8	0.118	0.042	0.017	0.287
Without using de-icers (S)	Dry (D)	0.105	9	0.074	0.025	0.017	0.240
	Rainfall (R)	0.283	7	0.251	0.095	0.044	0.738

m – mean value, N – number of measurements, S – standard deviation, Se ± – standard error, Min/Max – minimum and maximum values

During the wet season, with and without the application of anti-icing and de-icing chemicals (SRI and WRI), the mean suspended solids in the influent reached 81.6±8.1 and 159.0±43.9 mg/dm^3 respectively, and was higher than that during the dry period with and without the use of antifreezes and ice- and snowmelts (SDI and WDI) and ranged from 7.8±4.8 to 32.8±4.7 mg/dm^3. This might be due to mineral and organic suspended solids being rain-washed from the hard surfaces during the rainfall (Fig. 3). Higher concentration values of suspended solids during the period with the chemicals applied (W) as compared to the period without any chemicals (S) might have resulted from the distribution of sand on the roads and pavements or other chemicals used for defrosting. In period (W) during the rainfall the highest concentration of suspended solids in the influent was observed, the average value of which reached 159.0±43.9 mg/dm^3, which was 5 times higher than during period (W), whereas in the dry period (D) 32.8±4.7 mg/dm^3 (Fig. 3). It was stated that the concentration of suspended solids in the treated effluent did not exceed 100 mg/dm^3 recommended by the regulation [7]. This may indicate that throughout the experiment the Storm Water Treatment Plant operated effectively as far as suspended solids removal was concerned and its efficiency depended either on the period type or the occurrence of rainfall. The highest efficiency of suspended solids removal was observed in period SR, WR and WD and reached 82.7±3.1; 74.0±5.0 and 80.1±2.1% respectively. In period SD the efficiency was significantly lower ($p < 0.05$) than in the other experimental periods and reached a mean value of 51.3±21.6%, and the amount of suspended solids in the influent reached 7.8±4.8 mg/dm^3. In the summer during the rainfall (SR) the concentration of suspended solids inflowing in the Służewiecki Stream was over 10 times greater, and reached a mean value of 81.6±8.1 mg/dm³. In that period the efficiency of suspended solids removal reached 82.8±3.1% and was the highest one of all observed in that year (Fig. 3).

Throughout the experimental period the effluent waters were marked by the values of oil-related pollutant concentrations below the allowable pollutant concentrations standards [7], which are 15 mg/dm³ for storm-water sewage discharged into the receiving water. The amount of oil-related substances in the Służewiecki Stream did not exceed 40 mg/dm³ in the least favorable period WR. At that time the efficiency of the pollutants removal of the concentration 26.4±6.9 mg/dm³ reached 68.9±12.8% (Fig. 3). Analogous efficiency of oil-related substances removal was achieved in period WD 70.2±14.0%, however the amount of inflowing storm-water sewage was significantly lower 7.1±3.3 mg/dm³. In the summer during the rainy season (SR) the efficiency of oil-related pollutants removal was slightly lower and reached 63.8±7.4%, whereas in dry period (SD) the efficiency significantly dropped ($p < 0.05$) to reach a value of 45.3±27.5% (Fig. 3). It needs to be pointed out, however, that all concentrations of oil-related substances in storm-water sewage were considerably low. Even during the summer downpours their values did not exceed 15 mg/dm³, and in dry period the amount of pollutants reached the bottom edge values of the experimental method i.e. below 2 mg/dm³ (Fig. 3).

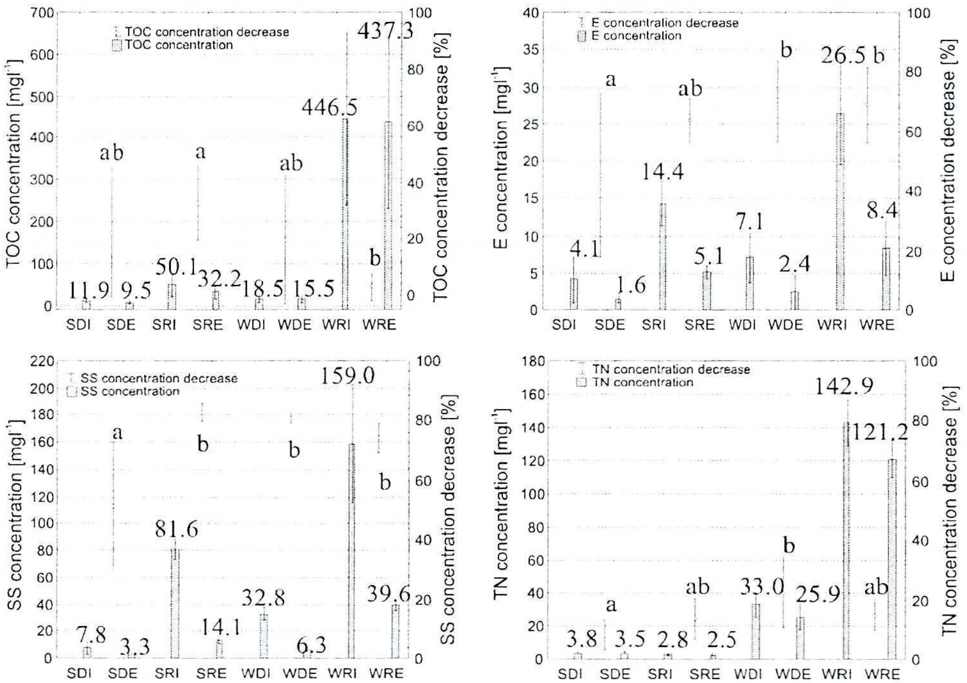


Fig. 3. Mean contaminants concentration values in storm water inflowing and out flowing from Storm Water Treatment Plant at the Warsaw Frederick Chopin Airport, and mean values of contaminants removal efficiency and its ANOVA differentiation marked by letters (a, b) with the significance level ($p < 0.05$)

No standard values limit the concentration of TOC in storm water runoff. However, since a winter season is characteristic of an extensive use of anti-icing and de-icing chemicals based on glycols and acetates the waters of the Służewiecki Stream need to be protected from the discharge of huge loads of organic compounds. That is why the SWTP was equipped with the protection system. Such a solution proved to be well-founded since the TOC concentrations of both the influent and effluent remained at the level of 446.5±204.7 and 437.3±206.2 mg/dm^3 respectively in the winter application of de-icers and anti-icing chemicals (W) (Fig. 3). A very low TOC removal efficiency, significantly different ($p < 0.05$) from the other 3 experimental periods, whose mean value reached 3.1±5.0% results from the SWTP technology being unsuitable for soluble organic compounds removal. A slight decrease in TOC values in the runoff is caused by the precipitation of organic suspended solids in the settlement tanks and the floatation of oil-related substances. As the load of organic compounds in the waters of the Służewiecki Stream was observed to decrease merely by 3.1% during the winter precipitation it may be stated clearly that high concentrations result from the discharge of antifreezes and ice- and snowmelts such as urea, glycols and acetates. During period WD the content of organic suspended solids in the total loading of organic compounds is likely to increase, which seems to be proved by low TOC concentrations in the influent i.e. 18.5±9.4 mg/dm^3 on average. That is why; a slight increase in TOC removal efficiency i.e. up to 19.8±22.8% was observed (Fig. 3). In period SR the amount of organic compounds in the storm water runoff of the Służewiecki Stream reached a mean value of 50.1±27.6 mg/dm^3. As a result of organic suspended solids sedimentation as well as the flotation of oil-related substances total removal of organic compounds was significantly higher ($p < 0.05$) than in the comparative period WR and reached 32.6±12.8%. In period SD the same value slightly decreased to reach 22.5±22.7%, which was mainly connected with a considerably lower amount of oil-related substances and suspended solids in the stream runoff. (Fig. 3)

Similarly, no allowable concentration of total nitrogen TN in storm waters conveyed to the receiving water is regulated by law. However, it was decided to determine and analyze this coefficient in view of the use of urea in the de-icing and anti-icing chemicals applied to the surfaces of the runways. Such a choice proved to be valid since the results obtained in particular in period WR showed the mean concentration value of TN in the effluent at the level of 121.2±11.2 mg/dm^3. Analogously, in period WD considerably high but lower than in period WR total nitrogen mean concentrations values at the level of 25.5±8.0 mg/dm^3 were observed in the Służewiecki Stream runoff. This might have been caused by the delay in nitrogen compounds down flow as a result of the following processes occurring either simultaneously or one after another: the storage of urea in soil in the proximity of the runways; and its hydrolysis and nitrification, the intensity of which is low at low temperatures [2, 3, 9]. The concentrations of nitrogen during the periods with no chemicals applied were very low and remained in the range between 2.4 and 3.5 mg/dm^3. This may indicate that it is only the use of urea that determines the concentration of nitrogen compounds in the Służewiecki Stream. The observed low values of nitrogen compounds removal, which did not exceed 22.4±12.0%, proved that the SWTP had not been designed to remove such compounds (Fig. 3). In view of the high TOC concentrations in the effluent, above 40 mg/dm^3 in period WR, it may be stated that the system of storm water sewage disposal is operational as in the case of nitrogen. However, in period WD, due to the delay in nitrogen compounds precipitation at low TOC concentrations, large nitrogen load is likely to be discharged into the Służewiecki Stream below the SWTP. Therefore, it would be advisable to introduce a similar system as in the case of TOC. The allowable TN concentration value in the SWTP effluent should be determined according to the value established for the treated municipal waste waters discharged to water bodies. The excess of such a value, which equals 30 mg/dm^3, would require disposing storm waters to the municipal sanitary sewers.

CONCLUSIONS

The Storm Water Treatment Plant situated on the Służewiecki Stream runoff from the Frederick Chopin Airport operates effectively in terms of the removal of suspended solids and oil-related substances. These are the pollutants which the object is designed to remove.

The Służewiecki Stream receives storm waters from Frederick Chopin Airport that are contaminated with organic and nitrogen compounds being an outcome of the application of urea, glycols and acetates in de-icing and anti-icing chemicals applied to the aircraft and airport surfaces. In view of the application of organic de-icers and antifreezes the SWTP was designed in such a way as to direct the effluent with higher than 40 mg/dm^3 TOC concentrations to the municipal sanitary sewers. Still, there exists no such a system in the case of nitrogen compounds. Thus, it would be advisable to determine the allowable TN concentration value of 30 mg/dm^3, the excess of which in the effluent would require discharging storm waters to the municipal sanitary sewers.

REFERENCES

[1] Fisher D.J., M.H. Knott, S.D. Turley, B.S. Turley, L.T. Yonkost, G.P. Ziegler: *The acute whole effluent toxicity of storm water from an international airport*, Environmental Toxicology and Chemistry, **14**, 6, 1103–1111 (1995).

[2] Ilies P., D.S. Mavinic: *The effect of decreased ambient temperature on the biological nitrification and denitrification of a high ammonia landfill leachate*, Wat. Res., **35**, 2065–2072 (2001).

[3] Kadlec R.H., K.R. Reddy: *Temperature effects in treatment wetlands*, Wat. Environ. Res., **73**, 543–557 (2001).

[4] Mcgahey C., E.J. Bouwer: *Biodegradation of ethylene glicolin simulated subsurface environments*, Water. Sci. Technol., **26**, 41–49 (1992).

[5] O'Connor R., K. Douglas: *Cleaning up after the big chil*, New Sci., **16**, 22–23 (1993).

[6] Pillard D.A.: *Cooperative toxicity of formulated glycol deicers and pure ethylene and propylene glycol to Ceriodaphnia Dubia and Pimephales Promelas*, Environmental Toxicology and Chemistry, **14**, 2, 311–315 (1995).

[7] Regulation of the Minister of Environment of 29 November 2002 *on conditions to be met while discharging waste waters to water bodies or to soil, and on the substances particularly harmful to water environment* (Dz. U. 2002 no. 212 item 1798 and 1799).

[8] Turnbull D.A., J.R. Baven: *The impact of airport de-icing on a river the case of the Ouseburn, Newcastle upon Tyne*, Environmental Pollution, **88**, 321–332 (2002).

[9] Zieliński M., M. Krzemieniewski: *Application of heat energy of the packing as a factor stimulating nitrification rate in attached-growth circulating reactor*, Pol. J. Natur. Sc., **18**, 155–163 (2005).

Received: June 2, 2006; accepted: October 27, 2006.