SWITCH

First SWITCH Scientific Meeting
University of Birmingham, UK
9-10 Jan 2006

Inclusion of ecohydrology concept as integral component of systemic in urban water resources management. The city of Lodz case study, Poland

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Abstract

Water in the urban space has been considered up to now mostly from the perspective of water supply, sewage purification and storm water management, with increasing awareness of the necessity of environmental conservation. However there has been little holistic consideration of the potential of freshwater and terrestrial ecosystems as a tool for control of the hydrological cycle in city catchments. According to ecohydrology concept, ecosystem properties should serve as a management tool to reduce hydro peaking, improve water quality and retention, and convert excess nutrients, pollutants and even sludge in to biomass/bioenergy. In parallel the enhancement of fresh water and green areas in the city space improves human health and quality of life. The location of the City of Lodz Poland, 800 000 inhabitants), it's morphological characteristics (steep between uplands and lowland areas, resulting in high slope of stream channels 5-7 ‰), compacted, highly impermeable historical development and streams (18 small streams, average $Q < 1$ m3 s-1) chanalization reduces water retentiveness in the landscape and hydrological capacity of streams. Stormwater peak inflows reduce ability of the Waste Water Treatment Plant (WWTP) to purify the sewage and negatively impact the ecosystem of the receiver – the Ner river. The WWTP faces also problems with sewage sludge utilization. The monitoring activities in the first year of the study in the SWITCH project was to provide background information for further detailed studies. The paper presents first results in the two following areas:

- Restoration of the municipal river for stormwater management, increase of water retentiveness and improvement of quality of life (Sokolowka River);
- Sewage water management for environment quality and positive socio-economic feedbacks (Ner River);

Keywords: ecohydrology, stormwater retention and quality, river habitat restoration, sewage sludge, bioenergy

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1 Introduction

1.1 Perspectives for application of ecohydrology in cities

Urbanization involves excessively forceful impact on habitats, often including their extinction and replacement with artificial structures. These transformations disrupts flow paths of energy, water and matter, within and between adjacent ecosystems, re-directing them into unsustainable, human-originated tracks. Such transformations pose major ecological consequences for freshwaters which are the receivers of the deregulated, extreme runoff and accelerated flow of water and matter from disrupted natural cycles (Zalewski, 2000a). These changes directly affects water quality and quantity in degraded catchments. Additionally, degradation of water habitats handicaps resilience of freshwater ecosystems – their ability to maintain oscillations within the steady state. Consequently, ecosystems functions and ability to provide services may be permanently amended (Krauze & Wagner, 2007). This directly affects human health and wellbeing in cities.

Degradation of environmental processes can not be compensated by application of only technological solutions, which do not address efficiently the effects of degradation of the elements of natural cycles in catchments (Zalewski, 2000b). Reduction of impacts, such as minimizing pollution or water detention, together with rehabilitation of freshwater habitats are the foremost and fundamental conditions. However considering the intensity of urban impact, they do not suffice (Zalewski & Wagner, 2005). Those measures should be supported by simultaneous procedures allowing reduction of degradation symptoms occurrence at the level of impact, by augmenting assimilative capacity of ecosystems. Thus the need for cost-efficient, integrated solutions extending technical systems for urban water management with ecological measures, that may not only improve the quality of environment but also lower costs of management and rise economic income for society (Wagner-Lotkowska at al, 2004).Such measures are considered by ecohydrology approach (Zalewski et al., 1997, Zalewski 2000b), postulating using ecosystem properties as management tool in water resources management.

Ecohydrology is a transdisciplinary approach, using the understanding of relationships between hydrological and biological processes at the catchment scale to improve water quality, biodiversity and sustainable development (Zalewski 2006). The approach implementation is based upon restoration and maintainence water circulation patterns, nutrient cycles and energy flows at a catchment scale towards optimization of the ecosystem services for society. The concept has been so far applied in variety of semi-natural and medium-disturbed catchments (e.g., Wagner-Lotkowska et al., 2005, Agostinho et al., 2005, Wolanski et al., 2006), while it's testing in the city landscape still reminds to be a challenge. Therefore, the presented project hypothesizes, that organizing the energy, water and matter pathways in cities, following the rules governing processes in the natural ecosystems, may allow to control the analogical processes in urban ecosystems, compensate effects of intense degradation in other sections of the catchments and increase assimilative capacity of environment against condensed human impact. This approach is based on three fundamental tenants: i) using synergies between catchment water cycle and dynamic of it's biotic component, ii) harmonizing existing and planned hydrotechnical solutions with ecological biotechnologies, and iii) integrating complementary synergistic measures at all scales (Zalewski, 2006).

This project is to elaborate scientific basis for a comprehensive urban water management plan and validate implementation of ecohydrology as one of the essential components of urban water management in the City of Lodz. The monitoring activities in the first year of the study in the SWITCH project was to provide background information for further detailed studies. The paper presents results after the first year of research in the two following areas: i) Restoration of the municipal river for stormwater management, increase of water retentiveness and improvement of

quality of life (Sokolowka River); and ii) Sewage water management for environment quality and positive socio-economic feedbacks (Ner River).

1.2 The City of Lodz – environmental context

The City of Lodz (Poland) is an example of urban area that expensed very rapidly in the first quarter of the XIX Century, based on natural resources (water, forests) essential for establishing textile industry in this area. Far-reaching privileges and preferential financial mechanisms offered to multi-national group of investors encouraged rapid colonization and industrialization of the small village. In the middle of the XIX century Lodz was already a second biggest polish city, after the capital of Poland – Warsaw. Collapse of textile industry in the last decades and gradual change of the City profile from industrial city to the centre for education, science and development of new technologies, changes the expectations of society, also regarding the city landscape and the quality of life. Additionally, decreased water use in the last 20 years, forcing the necessity of changing the approach to water management in the city. There is an increasing need to change the perception of the role of the water in the city.

The City of Lodz is a city of 800 thousands inhabitants (agglomeration of 1 million inhabitants), located in central Poland. The city area is divided into 18 catchments drained by small urban streams (average flow < 1 m3 s-1) with relatively high slope of stream channels (5-7 ‰). During the industrial revolution in the early 30's of the XIX century, the streams were channelized and turned underground, becoming a part of storm water system. These changes together with compacted historical development reduced water retentiveness in the landscape and streams, what particularly evidences during storm events, through increased the flow peaks in the streams. Since Lodz is equipped with a mix drainage system - combined in the centre, old part of the city and separated sewage and stormwater systems in the new, outskirt sections - the efficiency of sewage treatment is periodically diminished.

The total area of the City covers 294,39 km 2 and is characterized by very regular arrangement (Klysik & Fortuniak, 1999). The central part consist of the oldest development and impermeable surfaces cover over 80% of this area. The largest part of the city, surrounding the centre itself, is covered by a combined residential and industrial development. The outskirts are occupied by quarters of detached houses, with small proportions (less then 25%) of artificial surfaces. These districts often neighbor meadows, aggregations of forests (7% of the total area) and arable land.

Such an arrangement causes a considerable contrast in climate dynamics between the out-of-town zone and the built over area, versus those for underdeveloped suburban sections with the villa-type (residential) building development. As well as sets template of potential and constrains for ecological restoration of the city freshwater habitats. Semi natural sections of rivers with remaining of semi-natural open corridors in the city outskirts possess greater capability for successful restoration, and considered to be restored in the first place, may provide success stories for up-scaling the approach in the city. The centre part of the city with its dense historical development brings more constrains in the first place. Restoration of river in this section has to strongly relay on technical solutions and limited possibilities of sewerage reconstruction at low costs. Some of them can not be restored as they have totally disappeared due to regulation, separation from sources considerable magnitude of highly impermeable surfaces in a catchment. Degradation of freshwater habitats reduces their capacity for water retention and self-purification resulting with low water and ecological quality. Some streams are covered with historical and strategic buildings. Their restoration could be possible only while conveyed on fragmentary basis in conjunction with an overall programme of environmental and architectonic revitalization of the city.

2 Characteristics of the study sites

2.1 Sokolowka river

The Sokolowka river, crossing the northern part of the city and representing a typical urban storm water receiver. The river's natural flow gradually disappeared, being nowadays supplied mostly by around 50 storm water outlets. The main channel was regulated by concrete slabs, to straighten the course and deepen the bed for purpose of runoff detention. Nevertheless, the middle section of the river valley located in the outskirts of the city, has maintained semi natural character. Patches of meadows, wetlands and forests made this section appropriate as a pilot area for analyses best ecohydrological river rehabilitation options.
Reservoirs situated in the Sokolowka River receive nutrient-enriched stormwater, which increases their trophic state. According to bottom-up concept, this stimulates phytoplankton growth and appearance of algae or cyanobacterial blooms, which may cause limitation of ecosystem services (limit biodiversity of aquatic habitat, their recreational values) and if toxic, constitute potential hazard to users as possible carcinogens and tumour-promoters.

2.2 Ner river

The study area is located in the protective zone of the Wastewater Treatment Plant (WWTP) in Lodz in the catchments of the Ner River. The river is polluted with municipal and industrial wastewater from the Lodz agglomeration and the water quality was classified as 4th and 5th class (WIOŚ, 2005). The treated sewage (with the average outflow of 2,5 m3/s) is disposed into Ner River of natural flow about 0,3 m3/s. Consequently, the river floodplain have been severely contaminated with heavy metals and organic compounds (Andrzejewska, 2002; Koszek, 2000). The total metal concentration of studied floodplain soils is ranging from: 11 to 598 mg/kg for Zn, 7 to 390 mg/kg for Cr, 7 to 121 mg/kg for Cu and 11 to 93 mg/kg for Pb and is positively correlated with organic matter content (Bocian, unpublished data). Decrease of water use and sewage disposal after industry collapse within the last 15 years, lowered groundwater level and accelerated mineralisation of cumulated organic matter in aerobic condition at the floodplain. This resulted with leaching of heavy metals from the soil and caused serious threat of their cumulating in food chains in agriculturally used floodplain sections.
WWTP produces 70 000 ton of sewage sludge (200 tons/24 h), which causes additional economic and ecological issue. The sludge undergoes fermentation and has little water content (about 21% of dry matter). The sewage is stored on the lagoon located near the building of WWTP. The forming biogas is desulphurized and burned in the heat and power generating plant for the WWTP purposes. The composition of sewage make it possible to use it for non-food agricultural, for example in short rotation forestry (energetic willow plantation), if the heavy metals content is kept within the limits according to the polish legislation. The sludge contains high concentrations of nutrients, as the efficiency of total nitrogen and total phosphorus purifying are 59,7% and 87,2% respectively (data from WWTP, 2002).

3 Goals of the RTD Activities in the City of Lodz

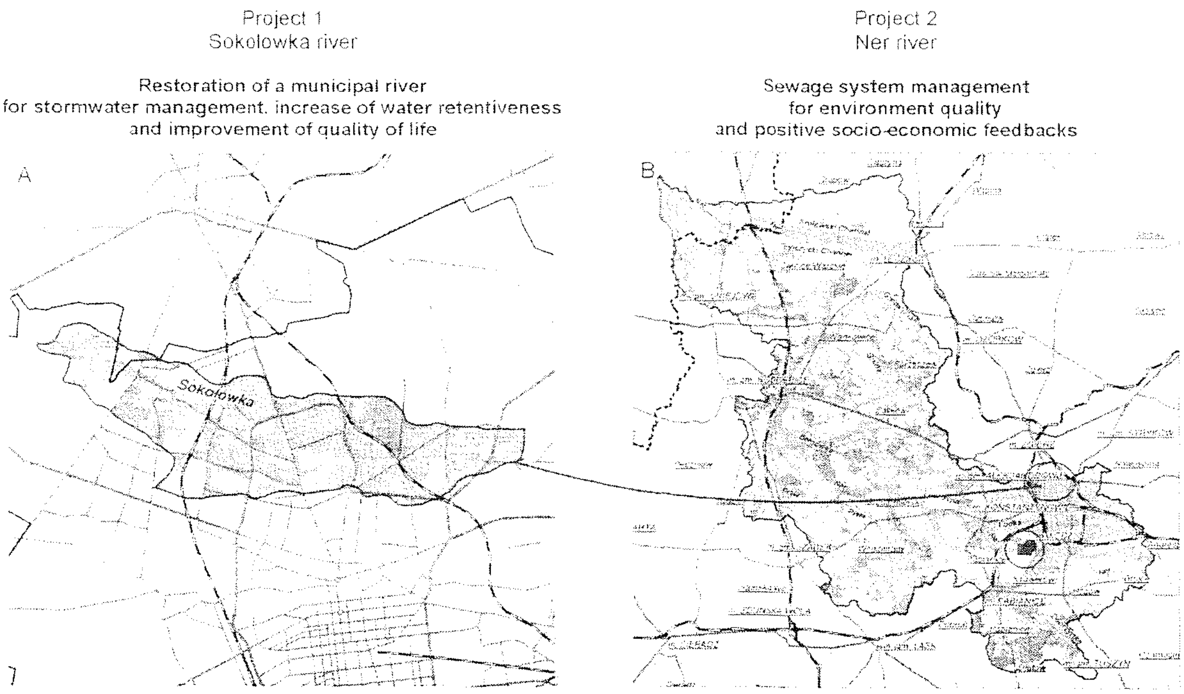
The RTD activities aims in developing scientific basis for inclusion of the ecohydrology approach as an integral element of the Integrated Urban Water Management in the city of Lodz, to reach the following final objectives:

i) adaptation of small city rivers and catchments for interception of large stormwater and pollution loads,

ii) elaboration of comprehensive concept of wastewater treatment plant management addressing issues of sewage sludge conversion into biomass, and river rehabilitation,

iii) providing socio-economic feedbacks to the city inhabitants based on use of ecosystem resources of regenerated urban ecosystems.

Selection of two pilot catchments allowed tackling a comprehensive scope of water related issues specific for the city and validate ecohydrology concept tested in meso- scale (Zalewski & Wagner, 2006, Figure 1):



44.5	Catchment area [km2]	1866,5
13,4	River length [km]	129.5
100	River channel regulation [%]	75
4	Impoundments on the main channel	-
0.55	River channel gradient [%]	0,03 - 0,2
535	Annual rainfall [mm]	499
153	Annual discharge [mm]	168
0.17 (0,03 – 15)	Flow regime [m3/s] average (min – max)	9.98 (0,74 – 97)

Figure 1: Location of urban streams' catchments on the territory of the Lodz City. The Sokolowka (northern part of the city) and Ner rivers (southern part of the city) has been appointed as demonstration areas for implementation of ecohydrology for systemic urban water management. The red point indicated the WWTP with the willow experimental plantation (64 ha). (data source: Marshal Office of the City of Lodz, elaborated: M. Grzelak).

Project 1: "Restoration of a municipal river for stormwater management, increase of water retentiveness and improvement of quality of life" – the Sokolowka river.

The restoration strategy is to apply ecohydrological solutions to address the following issues:
- reduction of the stormwater sewage flow peaks by series of ponds and reservoirs, creation and restoration of river floodplain and wetlands;
- increase of water retentiveness in the city landscape (mitigation of extreme flows, increase of groundwater level, support of city vegetation) by application of phytotechnology;
- increase of the quality of water, ecological stability of freshwater resources and increasing their carrying capacity by instream ecohydrological regulation;
- Increase of quality of life and aesthetic values in the catchment by restoration of the river corridor by creating impoundments, buffering ecotone zones and landscape management;
- improvement of human health by incorporating understanding of the relationships between the effect of green-lands and water on frequency of allergies and asthma cases into the city planning process;
- creation of attractive city spaces for development residential areas.

Project 2: "Sewage system management for environment quality and positive socio-economic feedbacks" - the Ner River.

Based on ecohyrological approach, the restoration strategy is to integrate measures at all scales and contribute to generating positive economic feedback:
- catchment scale – increase of stormwater retention at the city by increase of water infiltration, constructed wetland and restoration of rivers (related to the activity 1).
- floodplain scale – fitoextraction of heavy metals using willows for both water and floodplain quality improvement and production of biomass (bioenergy), including restoration of floodplain with native plant communities;
- local scale – application of sewage sludge for fertilization remote bioenergetic plantations (enhancement of production of biomass and bioenergy and utilization of sewage sludge for plantations fertilizing);

4 Research activities in the first 12 months of the project

4.1 Methods and scope of the research in the first year on the project

Research activities in the first year were focused on elaboration of the monitoring background for further research activities and implementation, presented in the following sections.

THE SOKOLOWKA RIVER: "Restoration of a municipal river for stormwater management, increase of water retentiveness and improvement of quality of life"

Surface water samples were collected weekly from April to December 2006 at 10 sampling stations at the Sokolowka River and 5 at it's reservoirs (Figure 2).
During the sampling water temperature, pH, conductivity and oxygen concentration were measured. Total phosphorus (TP) and phosphate phosphorus (P-PO4) were measured by the ascorbic acid method (Golterman et al., 1978). Total nitrogen was analyzed using persulfate digestion method (method no. 10071; HACH, 1997). Nitrate nitrogen (N-NO3) was determined using the cadmium reduction method (method no. 8039; HACH, 1997) and the ammonia nitrogen (N-NH4) – the phenate method

(Golterman et al., 1978). Chlorophyll a concentration was estimation by method based on acetone extraction and determination by spectrophomerry (Lawton et al. 1999). Additionally, monitoring included collection of water, sediments and biological samples for heavy metals, micropollutants as well as hydrological measurements.

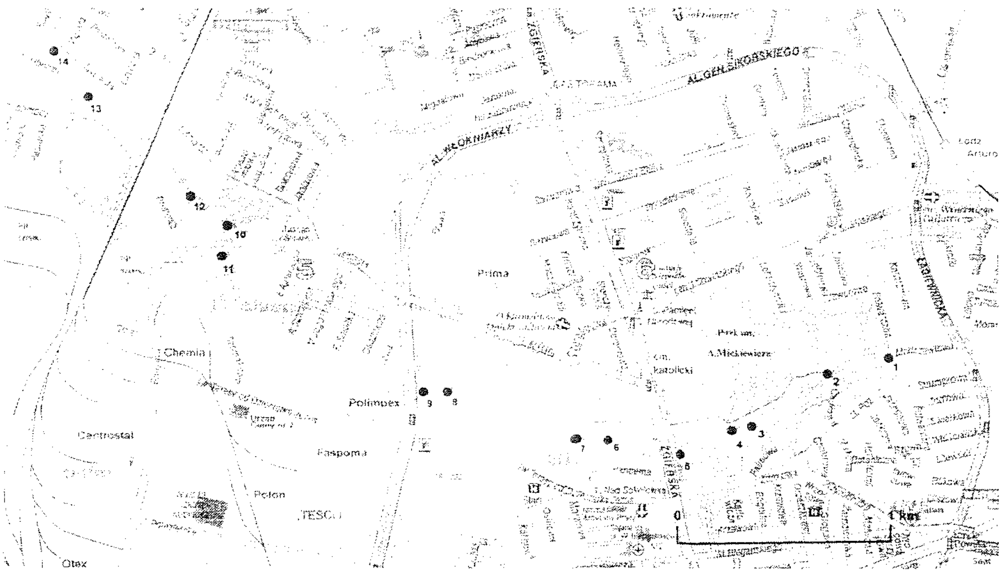


Figure 2: Location of the sampling stations (blue circles) along the Sokołowka River.

Phytoplankton species composition and biomass were measured in a 1-litre integrated water sample. Water samples for phytoplankton estimation were preserved in Lugol's solution and sedimented in the laboratory. Phytoplankton was counted using a Fusch-Rosenthal counting cell. The phytoplankton biomass (freshweight) was determined based on a volumetric analysis of cells using geometric approximation. Biomass computed in volume units was transposed to freshmass (FM) assuming the specific mass of phytoplankton as a unit (=1) (Komarkowa et al., 1995).

Samples for zooplankton analysis were filtered through a plankton net with 50 μm mesh size, preserved with a Lugol's solution and then identified and counted under microscope. Biomass for particular zooplankton genus (wet weight) was estimated on the basis of species-specific length / weight regressions (Horn, 1991).

The collected data are being quantitatively and qualitatively analyzed towards understanding of spatiotemporal patterns of pollution dispersion and appearance of eutrohication symptoms and establishment of the hierarchy of parameters determining dynamics of the reservoirs ecosystems.

Hydrological parameters were measured twice a month in November and December 2006 at 3 sampling stations using the current meter (Valeport BM002) method:

Station 1 – municipal landscape (flow 0,001 m3/s)

Station 9 – semi natural river section (flow 0,01 m3/s)

Station (below 14) – agricultural river landscape (flow 0,03 m3/s)

Additionally, in the end of the year, an automatic online hydrological and climate monitoring stations (model: WMR 928 NXN) were installed in the catchment (Figure 4). The stations will measure online the following parameters: air temperature (-40 to +60C ± 0,2C), dew point (-25 to 60 C ± 1C), sensible temperature (-85 to 60 ± 1C), atmospheric humidity (0% to 100% ± 2%), speed of the wind (0 to 56 m/s ± 2%), direction of the wind (0 to 359 deg. ±2%), rainfall (0-9999 mm ±0.2mm) and atmospheric pressure (750 hPa to 1040 hPa ± 1.5 hPa).

NER RIVER –Waste Water Treatment Plant:Sewage system management for environment quality and positive socio-economic feedbacks"

The activities related mostly to monitoring of 64 ha experimental willow plantation established in 2004 (Bocian, 2004) in the area of restricted exploitation of the WWTP (Figure 3).
The plantation is divided into 4 experimental fields (I, II, III, IV) planted with different varieties of energetic willow: I: Salix viminalis clones; II: Tordis (Salix schwerini x S. viminalis) x S. viminalis; III: Salix viminalis gigantea; IV: Salix viminalis (clone 192).

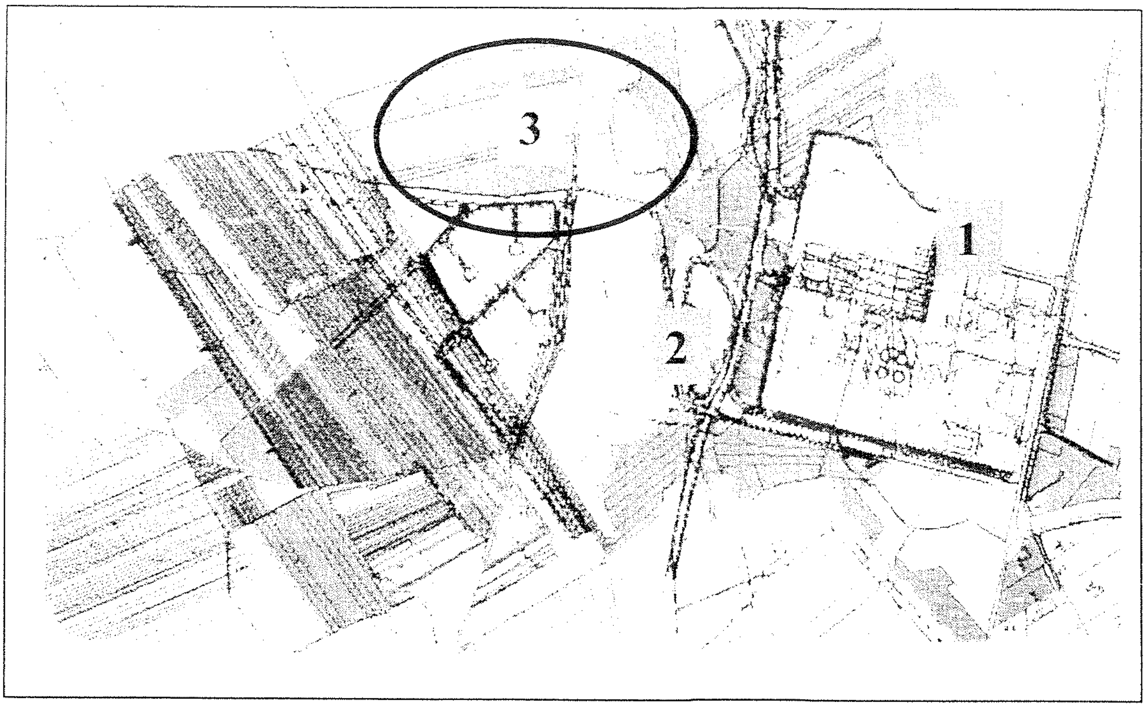


Figure 3: Location Localization of willow plantation (authors: The City of Lodz Office): 1 – The main building of Water Treatment Plant; 2 – The sludge lagoon; 3 – The experimental willow plantation.

The major aim was estimation of the efficiency of closing nutrient and anthropogenic cycles by application of ecohydrology and phytotechnology, based on the estimation of the efficiency of sewage sludge utilization in the controlled energetic willows plantations, including phytoremediation of heavy metals, estimation of biomass production and potential for biomass generation.
The applied dose of sewage sludge was calculated based on the regulations of the decree of the Ministry of the Environment (Dz.U.Nr 134, position 1140). The dose of 11,5 tons/ha/years of sewage sludge was applied, which is equal to the 3-year dose. The maximum doses have been limited by the heavy metal content.
The following parameters were measured on the permanent field of the study area:

- Survivability of willow;
- Condition of willow;
- Content of heavy metals in the plant tissues;
- Content of heavy metals in the soil with sludge.

The dry biomass (d.w.) of plant material was estimated four times during the field seasons (July, August, September, October 2006) by weighing of dry collected plant material after the vegetation season according to Ostrowska et al. (1991) and Chmielewska (1955).
The survivability of *Salix viminalis* on the plantation were measured on each experimental field by calculation the difference between the planted number of cuttings and the number of the cuttings survived after the first year of grow.
The concentrations of the following heavy metals: Zn, Ni, Pb, Cd, Cu, Co, Cr were determined in the plant tissues using the atomic absorption spectrometry (AAS) in the laboratory of the Technical University of Lodz.
The soil samples were taken from each experimental field from depths of 0 – 25 cm. The concentrations of the following heavy metals: Zn, Ni, Pb, Cd, Cu, Co, Cr were determined in the sludge and soil mixture using the atomic absorption spectrometry (AAS) in the laboratory of the Technical University of Lodz..

4.2 The first 12 months results and their implication for the future research

The Sokolowka River

Concentrations of total phosphorus and total nitrogen in reservoirs situated in the Sokolowka River exceed the border values for eutrophication of reservoirs (0.1 mg P/l and 1.5 mg N/l (OECD 1983). Annual average of TP concentrations ranged between 0.30 and 0.40 mg/l but the maximum values reached 1.84 mg/l at Station 6. Whereas annual average TN concentrations in reservoirs were between 1.53 and 2.46 mg/l, and maximum values of 18.9 mg/l occurred at Station 5 (Figure 4).
Chlorophyll a concentrations (Figure 5) confirmed eutrophic character of reservoirs (8-25 mg/m3) and some of them are hypertrophic (>25 mg/l) (Zalewski and Wagner 2004). Annual average of chlorophyll concentrations ranged between 20.2 and 48.1 mg/m3 but maximum values reached 260 mg/m3 at Station 8.

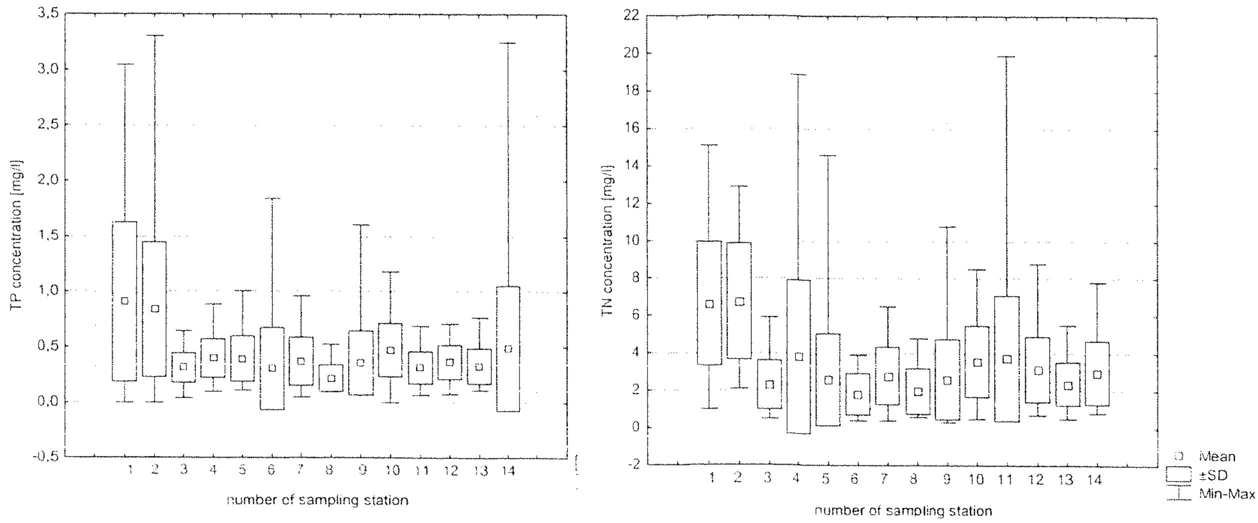


Figure 4: Total phosphorus and total nitrogen concentrations at the Sokolowka River.

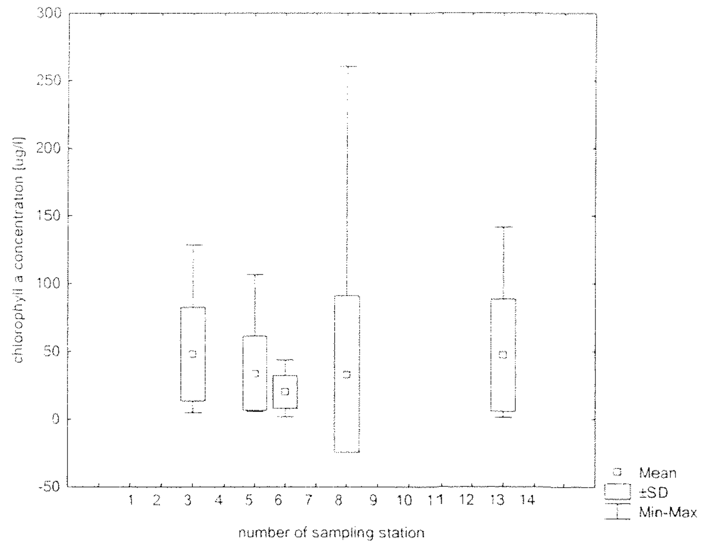


Figure 5: Chlorofil concentrations at the Sokołówka River's reservoirs.

Annual average TP concentrations in river ranged between 0.21 and 0.85 mg/l but the maximum values reached 3.30 mg/l at Station 2, whereas in reservoirs were between 0.30 and 0.40 mg/l but the maximum values reached only 1.84 mg/l at the Lower Pond.
The big differences between minimum and maximum values are observed for the first two stations. Moreover the first two stations are characterized by the similar level of average and the same time high level of TP concentration [mg/l]. The similar situation is in the case of the station number 14. The remaining stations (between 3 and 13) are relatively less diferenciated.
Annual average TN concentrations in river were between 2.57 and 7.34 mg/l, and maximum values of 18.9 mg/l occurred at Station 4, whereas in reservoirs were between 1.53 and 2.46 mg/l, and maximum values reached 14.6 mg/l at Station 5.
The situation in the case TN concentration [mg/l] is much more differentiated. The difference between average level are higher and the distance between minimum and maximum value are larger.
The results indicate that average concentration of total nitrogen and total phosphorus were higher in the Sokołowka River then in reservoirs situated on river (decreased in reservoirs but increased in river between reservoirs).
The highest nutrient concentrations were observed at first and second sampling stations along the river in the typically municipal area. The high levels of nutrients in urban area can arise from a variety of potential sources including septic tank seepage, combined sewer overflows or sanitary sewer overflows.
Chemical and physical parameters of water were analyzed with the purpose of identification of threats in the city catchments and patterns of contamination transport.
The main aim of this demonstration projects is established hierarchy of parameters influencing on enhance carrying capacity of existing reservoirs against eutrophication symptoms. Through regulation of the water dynamics in the various parts of a river basin, we can influence its hydrokinetic processes, physical-chemical properties, and in consequences biota dynamics.
Reservoirs situated at the Sokolowka River differ from each other in their properties: diversity of reservoirs age, the light intensity, and quantity of the external nutrient supply. It is able to observe how different ecosystem reacted to stress. Despite of the highest external load at Station 3, the chlorophyll a concentration spanned a similar range as the rest of reservoirs. In this long, old reservoir located at the park, phytoplankton growth was limited by isolation and high pressure of zooplankton. The lowest chlorophyll concentration was observed at Station 6, which can be explained by high density of

macrophytes in this reservoir of several years. Whereas the maximum of chl
was observed at Station 8, which resulted from accumulation phytoplankton b
Station 6 by stormwater.
One of function of reservoirs cascade is improving water quality in the Soko
primary results appear to confirm this hypothesis. The TP and TN concent
flowing across reservoirs. The highest reduction of nutrient concentrations
reservoir at Station 3. The TP concentration of 0.77 mg/l at Station 2 was re
Station 3. Stormwater outlets located between the reservoirs, contribute to fu
quality.

The Ner River and WWTP

Traditional sewage treatment plants often do not possess sufficient efficiency
construction and exploitation which has to be carried by local communities.
treatment by constructing willow plantations and wetlands results in more
pollutant loads and sludge utilization problems and generate additional benefits
plantations may reduce problem of sewage sludge utilization and may cont
improvement (if applied in constructed wetland systems). Additionally, it provi
of energy (bioenergy) and thus revenue for local economy while reducing outflo
fuel use. The production of bioenergy can result with quicker return of the inv
short rotation time of the plantation and high planting density. The prelimina
that wood chips from short rotation forestry (SRF) of the area to be establis
cover the energy needs for municipal buildings in the City of Lodz and elimin
sludge utilizing (Bocian, 2004). In the case of the Lodz City, high concentration
sewage sludge (Figure 6), restricts possibility of it's application in the field, un
has been decreased in the source. It is also necessary to investigate the effic
remediation by plants, which was one of the goals of the study.

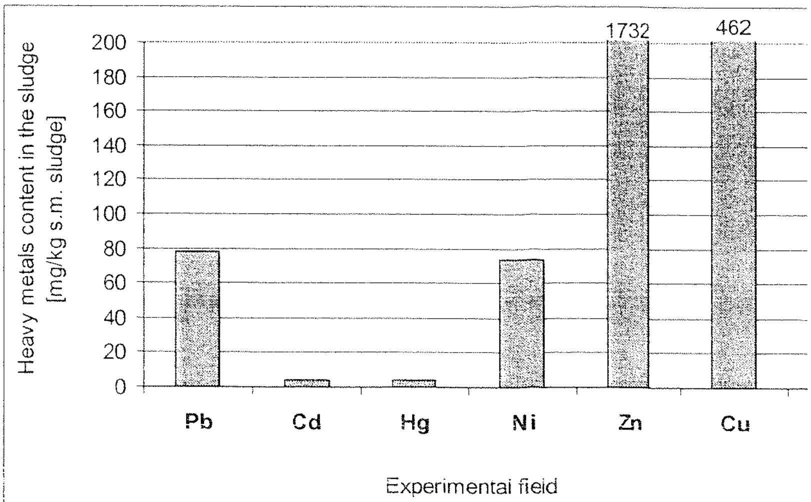


Figure 6: The content of heavy metals in the sewage sludge, before applica

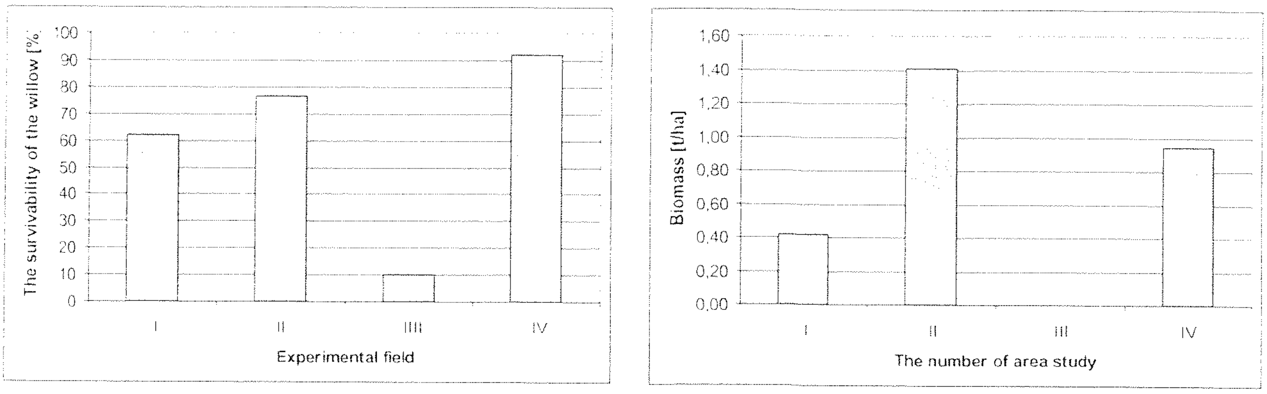


Figure 7: a) The average survivability of willow on the experimental plantation and b) the average biomass of willow obtained after first vegetation time. The biomass of willow from III area study was near the zero.

The average survivability of willow maintained between 62% to 92% with the exception of the area III, where the survivability was about 10% (Fig. 7 a). The biomass reached values between 0,4 t d.w./ha/year – 1,4 t d.w./ha/year (Fig. 7 b). The relatively small crop is typical for the first year estimations. The expected 3-year crops, based on literature, is expected to be considerably higher.
The highest concentration of heavy metals for the sludge sample was noted for Zn, Cu, Ni, Pb and Cr. This results from high loads of these compounds in sewage derived from some industrial companies and transport pollution. Figure 3 shows the concentrations of Zn, reaching values of about 1732 mg/kg d.w. The content of Hg was the lowest: the average value was about 3,9 mg/kg d.w. (Fig. 8).
Both in the soil and plant samples, the highest concentration of heavy metals were detected for Zn and Pb. The range of heavy metals total content in willow tissues (branches) was between 42,95 mg/kg d.w ÷ 35,84 mg/kg d.w. (Fig. 8). The values differed between species.
The efficiency of heavy metals uptake by plants was analyzed based on the relationship between the initial content in the soil (CS_0) and it's increase in the plant tissues (CV_1). The highest rates were observed for Pb, Cd and Zn (Figure 9). The absorption rate depended on the initial heavy metals quantity in the soil and absorbing capacity of plants.

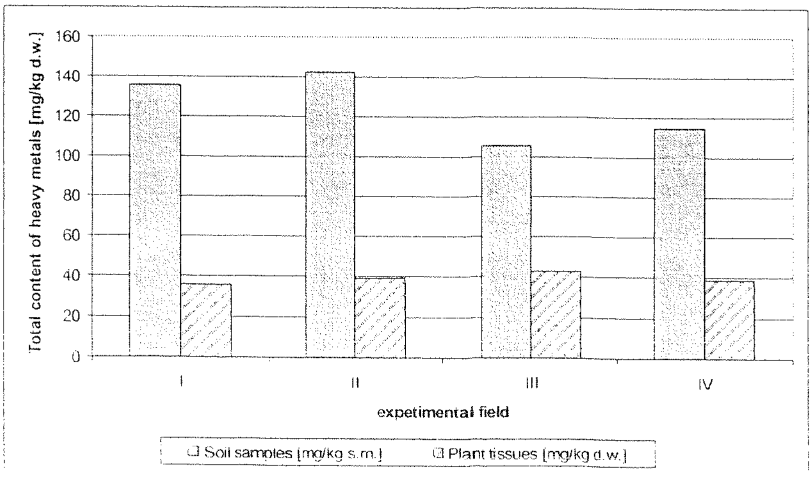


Figure 8: The average content of the total heavy metals in the plant tissues and in the soil samples on the four analyzed area with different clones of energetic willow

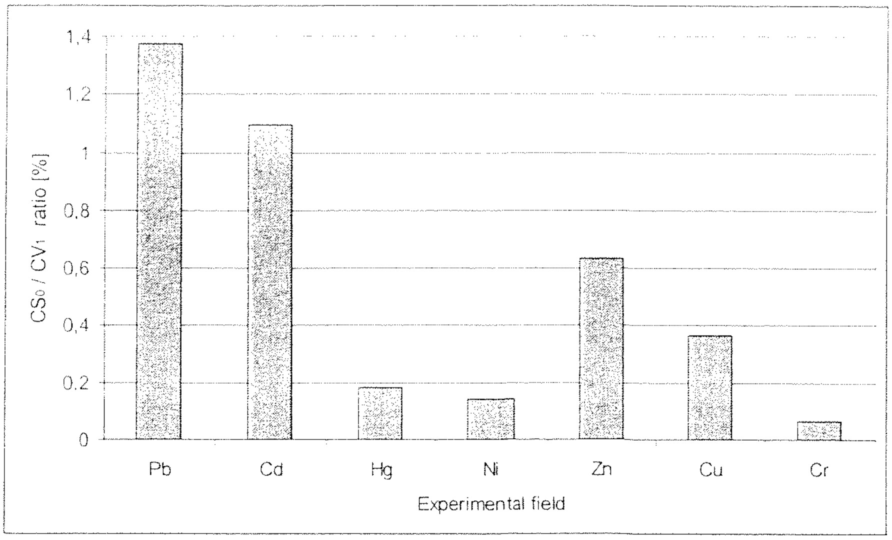


Figure 9: The efficiency of heavy metals uptake of by willow energetic from soil.

Energetic willow plantations, except for providing alternative source of bioenergy, what is concordant with of the Directive on the promotion of electricity produced from renewable energy sources in the internal electricity market (77/2001/EC), may improve the quality of the environment, contribute to reduction of the sewage sludge utilization issues and contribute to economic equation of the treatment plant operation. However the differences in biomass production, heavy metal remediation and survivability between the varieties of willow shows, that for achieving ecological and economic effects, selection of a variety best adapted to local conditions is of crucial importance. The estimation of the actual efficiency of the plantation will also require integration of the ecological effect (incl. efficiency of the area reclamation) and economical effect (including bioenergy production), as well as further estimation of the ecological effect. The future study will include evaluation of the soil microorganisms activity (soil metabolisms, Platen &Wirtz, 1999), role of rhizosphere (rhizotron, rhizobox), soil toxicity (Phytotoxkit Tigret, Microtox) and evaluation of the overall heavy metals and energy balance.

Acknowledgements

The presented research activities have possible thanks to co-operation of the University of Lodz with the International Centre for Ecology, Polish Academy of Sciences, the City of Lodz Office and the Waste Water treatment Plant in Lodz.

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