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WATER MANAGEMENT IN *RECYCLING SOCIETIES* PART I. WATER AND STORMWATER IN A CITY

In a global perspective, present water management is not in agreement with basic conditions of sustainable development oriented towards the establishment of *sustainable societies*. Facing present growth of urban population in the world, it is increasingly difficult to find and utilize new sources of water necessary to satisfy growing water demand. But in a sustainable society, safe drinking water, the most important life-supporting commodity, must be accessible to all people independently of their social and economical status and place of living. Water delivery for the residents of peri-urban and squatter areas should be considered equally important as for those wealthy. In order to begin the way towards *sustainable societies*, elimination of poverty expressed as lack of clean water should be a first priority target for actions of scientists, governments, regional and local administrators and, especially, people dealing with regional and local water management. Increase of urban areas is coupled with intensified use of natural resources for construction of buildings and technical infrastructures including water-related infrastructure. On top of decreasing common resource base this brings integrated vulnerability of life supporting systems such as local and regional water resources, agricultural land and rural agricultural food producing systems. The shape and performance of appropriate technical solutions used in water management depend on climate as well as on social, economical and cultural conditions. Future challenges in urban water management include elimination of present pollution sources, development of new technical solutions as well as logistic and organizational methods in order to eliminate present problems and create future opportunities. Humanity with its governments, population together with scientists are now confronted with a challenge of immense dimensions and dignity: to exchange present linear material flows within all sectors with circular flows. The establishment of *recycling society* will be a task for scientists representing many sciences. This task is especially important in countries of young democracies in former Eastern Europe catching up with *western standards* both in good and the worse sense of this expression. The main thesis of the paper is that all countries, including Eastern European countries, should change approach to technical development in such a way as to establish *recycling societies*. Current and emerging challenges are discussed in our two papers (part I and part II).

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1. INTRODUCTION

The main target for urban water management and related infrastructure, i.e. settlement of health-protecting living conditions in cities, was, in historical perspective, achieved by organizing material flows that moved the residuals outside the living sphere of population.

The main goal was, thus, oriented towards human needs rather than to protect the environment outside cities. In present society, the focus has changed. It is generally understood that human material- and social well-being, as well as sustainability of the societies, depend on the state of the surrounding natural environment and, especially, on the state and condition of all available water resources. It is also understood that conservation and recycling of natural resources and used materials are as important as a basic condition for the sustainability of future societies. Thus, we should concentrate our present efforts on improving water management methods and its infrastructure in order to achieve these new goals. There are two parallel ways of fulfilling the so-called *basic system conditions for sustainable society* formulated in Agenda 21 [1].

The first way is to improve the function of existing infrastructure and the technologies applied. As an example of such actions may stand on-going improvements and completion of existing wastewater treatment plants with new treatment stages.

The second way is to develop new, basically different system solutions, infrastructure and management methods that are *from the very beginning designed to fulfil sustainability system conditions*, i.e. where creation of circular material flows and conservative use of energy are an overarching target. As examples of solutions designed according to this line may stand local management, treatment and utilization of stormwater, application of separating sanitation able to recycle human nutrients to agriculture, or multiple instead of single use of construction materials. *Wastewater* is a wasted water, *solid wastes,* if not utilized, are wasted resources. Establishment of *recycling society* requires the change of infrastructure, and it will not be without problems, but it is an exciting challenge to all people. Water professionals and scientists should be actively involved in this work.

2. DRINKING WATER

In most of European countries, water supply networks cover all drinking water needs. However, even here some problems for the future can be foreseen. In several countries, the age of existing water pipes comes close to their lifetime. *Corrosion of water pipes* and *chemical impacts* result in shortening of previously expected lifetime of water infrastructure. The increasing use of new domestic, industrial and agricultural chemicals, medicines, hormones, pesticides and other previously not used substances brings new risks of water contamination. Expenditures on repairs and new constructions of urban water systems are growing. As a consequence, reduction of water consumption may become an economical necessity even in developed countries. Additional reason to reduce water use is the need to decrease wastewater flows through wastewater networks and, thus, to decrease the costs of wastewater treatment. One option is to find the way to decrease water consumption in households by influencing human habits. Technical options such as introduction of dual piping system with multiple or quality-adjusted water use are less realistic in European conditions, but it can be a viable option in several arid countries. Another future alternative may result from the changes in sanitation systems, i.e. more general use of dry- or less-water using sanitation solutions such as urine-separating or composting toilets. In future *recycling societies* clean water will not be used for flushing toilets [2].

3. POLLUTION IN DRINKING WATER CONTEXT

In spite of successful efforts to deliver clean water to population in developed countries, several problems are still remaining. For example, according to US EPA Drinking Water Advisory Council, present routines in water supply do not eliminate all existing water pollution risks. Besides bacterial and virural water pollution, the increasing number and variety of chemicals used in all sectors bring new risks. The presence of some microorganisms and substances in drinking water recently discussed in scientific circles is briefly described in the following. *Giardia lamblia* and *Cryptosporidium* cause diarrhea, dehydration and intestinal disorders. For example, both parasites have been found in 87% of United State's water supply systems. Endocrine disruptors are chemical substances that damage human body by mimicking natural hormones. Damages may be expressed in cancer, birth defects and different immunological failures. Substances like herbicides (selective weed killers) and pesticides (destroying pests) are examples of endocrine disruptors. These substances are carried by surface runoff and enter water supply systems making damage even at undetectable concentrations. Chlorine and other disinfectants used in almost all households are known poisons, but their short-term use is seldom connected with illnesses. In chlorination process, chlorine combines with natural organic matter forming several carcinogenic agents, from which trihalomethanes (THMs) are most known as associated with risk of bladder and rectal cancer [3]. Arsenic is present at low concentrations in sources of drinking water, for example, in several states in the USA and in some parts of India. It may bring sickness and death from heart attack, stroke, lung disease and cancer [3], [4]. Harmful chemical compounds should not be present in drinking water in *recycling societies*.

4. STORMWATER MANAGEMENT

Technical structures in a city generate water and material flows between the city and the surrounding rural areas. These flows, that are essential elements for all types of life within a river basin, are heavily disturbed in a quantitative and qualitative sense by the human activities in cities. The city influences the runoff pattern and the state of the ecological systems not only within its area, but also in and around a whole river system downstream. Various types of water in urban areas differ substantially from the water in rural areas in their chemical composition and physical properties. Compared with rainfall water, stormwater contains much more particles and chemicals washed out by rainfall from the air and from urban surfaces. Stormwater system is composed of pipes and conduits, overflow structures, detention structures, open channels and other constructions designed to manipulate flow pattern in time and flow regime at the outlet out of the system. All these constructions require the use of natural resources and constant economic inputs. Possible changes in stormwater-related infrastructure should stimulate making of return loops which opens way for retrieval of resources deposited in stormwater streams and receiving waters.

Equalization of stormwater runoff in time may reduce damaging effects of shock loads of pollutants washed out to rivers and other water bodies. New inventions in this area such as vacuum-driven detention tanks [5] may reduce damaging shock effects of stormwater releases on aquatic life. Bottoms of the rivers downstream cities are, in many cases, covered with several meters of contaminated stormwater sludge that is gradually transported to the receiving coastal waters changing aquatic habitat in marine environment. Thousands of tones of metals are bound in the stormwater-generated sludge. This is enough to consider, as an example, that only in a small river Höjeå in the south of Sweden 760 kg of copper, 1710 kg of zinc and 310 kg of lead are deposited during one year! In future *recycling society*, rivers and lakes will probably constitute future mines of metals. Cooper, zinc, cadmium, lead and nickel are of concern in stormwater runoff because of their potential toxicity to aquatic life [6], [7].

Water-related infrastructure in urban areas, including stormwater systems, represents very large economical value. It requires constant maintenance and repairs which is associated with large economical input in order to maintain its functionality. Main stormwater conduits are usually located along and under the streets. Every pipe break and repair bring disturbance in traffic and become a source of residents' irritation. Since many of such facilities were in developed countries constructed a long time ago, large capital costs of construction do not influence the running budget of the communities. However the cost of *new constructions, maintenance and repairs will grow in the future*. Some older parts of the stormwater systems were designed for less permeable surfaces. Intensive rain events in such areas cause frequent street and basement flooding bringing traffic problems and economical losses for residents. These systems must be renovated in a near future, but this requires new investments. Construction and maintenance of such systems is an economical burden for developing countries. Thus, traditional stormwater systems should not be constructed in *recycling societies*. Stormwater should be considered as valuable resource.

The leading ideas of *new type stormwater management* (called also *ecological stormwater management*) are based on the construction of a large number of small-scale detention and treatment facilities, usually integrated and constructed in such a way as to delay as well as to equalize and treat stormwater. Additional target is to improve aesthetic values of the city and to bring recreational values by introduction of park-like areas with open water surfaces and lush vegetation. It is understood that important benefits can be achieved by the use of open stormwater drainage, i.e. systems in which part of stormwater is kept on the surface in open channels and ponds where it can be attenuated, treated and possibly re-used. During the last 10 years, hundreds of stormwater conveyance and treatment facilities based on those principles have been constructed in the world. There is vast experience in operation of these facilities. Urban hydrologists begin to know treatment performance, week points, problems and ways of solving them [8]–[12], [19]. Some of Swedish communities already routinely build local systems for retrieval and reuse of stormwater in new housing areas. Consequent application of local treatment and disposal of stormwater will influence the whole infrastructure in cities. In the future, stormwater may constitute an important resource which can be reused separately or together with *gray water* for toilet flushing, irrigation of small-scale urban agriculture or even for production of drinking water. Especially, rainwater that is collected by roof gutters should be considered as a valuable resource to be used for some domestic purposes not requiring drinking water quality such as toilet flushing. In many European countries, some of these ideas are already realized in the so-called *ecological villages* oriented, by definition, towards establishment of *recycling society*.

New technical solutions used for stormwater management are not proved over the long term. It is not known if the investments in a sense of monetary values as well as natural resources bound in these constructions will not exceed total environmental benefits. There are, for example, no environmentally sound routines developed for dealing with contaminated *sludge* sedimented in ponds and wetlands. As yet, there are neither attempts nor infrastructure to capture and reuse metals and other substances present in ponds and urban streams. It is not known if the design of ponds, wetlands and ditches is done in an optimal way to take away nutrients and metals from stormwater. There is a need for further research into optimisation of stormwater constructions with respect to the design and minimization of integrated environmental effects. A growing number of local solutions being implemented in stormwater management is changing a city. Thus, integration of stormwater management is required on all spatial and temporal scales of urban and rural planning within a river basin. The *recycling societies* are confronted with new challenge – they have to develop the methods for recycling and using the stormwater of poor quality necessary for, e.g., toilet flushing or irrigation of parks and local field cultures.

Stormwater releases affect most seriously aquatic habitat of the receiving waters. The major effects of urban sediment include silting of sprawling and food production areas and unstable bed conditions [13]. Other major problems dealing with habitat destruction are as follows: rapidly changing flows and the lack of refuge areas that protect the biota during flow changes. Removal of riparian vegetation can increase water temperature and cause formation of organic debris [18].

Physical, chemical and biological processes going on in stormwater ponds and wetlands are not known sufficiently to avoid mistakes in design and operation of such ponds. For example, as in commonly known, the major process in the initial removal of phosphorous in wetland systems is its adsorption on the substrate. However, the removal of phosphorus by plants may set in motion an irreversible storage mechanism, thus contributing to general phosphorous depletion. In the controllable wetland, the phosphorus uptake is higher than its release. This requires an adequate knowledge of the removal mechanisms and hydraulics of the system. Since in the wetlands established for a purpose of stormwater treatment, the removal rate is seldom checked due to high costs of analysis, such wetlands may become saturated with phosphorous and thus they do not perform the intended work of removal or become a source of phosphorous in receiving waters [8].

New type of stormwater management with surface storage, detention ponds and wetlands must operate in the system that is closely connected with the existing, traditional stormwater pipe systems, underground detention facilities and diverting structures. These old constructions still must be maintained to be in good condition. Because part of stormwater flows have been diverted to open surface detention and treatment facilities such as ponds and wetlands, stormwater flow in conduits decreases which may bring some operational problems, and total maintenance costs may increase in the future. Because ponds and wetlands were only built during last 10 years, the costs of their long-term maintenance and periodical reconstructions cannot be accurately assessed. All above-mentioned stormwater-related problems should be solved in future *recycling societies*.

5. STORMWATER – AN IMPORTANT RESOURCE

Let us consider the volume of water that is naturally delivered to urban areas in a form of rainfall: 100 mm of rain water on 1 km^2 of impermeable area gives 100 000 m^3 water, i.e. enough to 1830 people during one year, provided that the water use approaches 150 dm^3/day. If dry toilets are used, water consumption in households may be reduced by 70%, i.e. 5500 people may gain all necessary water from 1 km^2 and the rainfall of 100 mm/year. In other words, theoretically 182 m^2 of impermeable area can deliver water that one person needs. This amount of water is considerable, and though in practice it cannot be easily utilized, it should be considered as an important resource. Utilization of this water requires a crucial change in the applied technology of stormwater management. Traditional technology, i.e. pipes for fast removal of stormwater from urban areas, was developed for wet climate conditions, and it is considered a mistake to copy this technology in semi-arid and arid countries. In the *recycling societies*, urban hydrologists should work to develop technical methods allowing us to harvest stormwater and to make it available for less demanding purposes or, after purification, even for drinking purposes.

6. AESTHETIC VALUE OF WATER IN THE CITY

Modern stormwater management can, on top of pollution prevention, contribute to some aesthetic and recreational values of a city. Swedish hydrologist, Christer Göranson, describes these aspects in following words: *Contrast between so living, soft and organic water and so strict and rigid environment of a city gives fascinating combination that gives additional dimension to the city. If the water that comes to the city could be made to stand still for a moment, or to be visible on the surface, the city environment would be enriched and bring pleasure to all our senses* [14]. The walk around any pond or wetland constructed to attenuate and purify stormwater in a city proves that the above opinion is right. This means that urban hydrologists should work not only in cooperation with city planners, urbanists and architects, but with artists as well. As a matter of fact, there are several examples of such a cooperation [14], [15]. Bringing aesthetic values to urban environment is a honourable task carried out in order to complete *recycling society.*

7. CONCLUSIONS

In order to approach sustainable *recycling societies*, some important changes in the water-related infrastructure are necessary. Principal targets of such an infrastructure must be complemented by additional functions satisfying new targets oriented towards establishing the *recycling society* that conserves resources. To achieve this goal, educational institutions and scientific research organizations must change their curricula. All levels of societies ought to cooperate. Developments in water and sanitation management and its infrastructures should contribute to the development of routines that lead to recycling of used materials and allow their application. Especially, the routines that enable reuse of organic material in food production must be further developed and included in an integrated water management. Recent developments in, among other, *ecological sanitation solutions* are bringing hope for a radical change in management of human residuals (see, for example, ESRAY S. at al. [16]; NIEMCZYNOWICZ J., [2]; GAJDOS R., [17]). In order to achieve the new goals of a *recycling society*, new research and new organization of present societies are required.

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GOSPODARKA WODNA W ROZWOJU ZRÓWNOWAŻONYM
CZĘŚĆ I. WODA I ŚCIEKI DESZCZOWE

Postępująca urbanizacja miast jest związana z intensywnym wykorzystaniem zasobów naturalnych i rozwojem infrastruktury technicznej, w tym również systemów wodociągowych i kanalizacyjnych. Aby zachować te zasoby, wszystkie kraje – w tym i Europy Wschodniej – powinny zasadniczo zmienić podejście do rozwoju techniczno-gospodarczego, ucząc społeczeństwo zasad recyklingu. Podstawowymi aspektami, na które należy zwrócić szczególną uwagę, są: zapewnienie wody pitnej o dobrej jakości oraz racjonalne działania, gwarantujące zrównoważoną gospodarkę wodną. Szczególne znaczenie ma problem wykorzystania wód deszczowych, które na terenach zurbanizowanych mogą stanowić cenne źródło wody nadającej się do bezpośredniego lub wtórnego wykorzystania. Kolejne nowe podejście polega na ograniczeniu zużycia wody pitnej i eliminowaniu kanalizacji sanitarnej przez stosowanie nowych rozwiązań w instalacjach kanalizacyjnych, w tym toalet separujących. Koncepcje przedstawione w tym artykule sformułowali specjaliści z przodujących krajów. Dają one pogląd na te nowe kierunki rozwoju tej dyscypliny naukowej, dzięki którym można będzie realizować konkurencyjne projekty w ujęciu lokalnym i systemowym.