ECOLOGICAL TECHNOLOGY AND MANAGEMENT
KALMAR, SWEDEN, September 22-24, 1999

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SUSTAINABLE STORMWATER MANAGEMENT AND DESIGN

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ABSTRACT

Stormwater system are necessary to convey urban runoff from a city in order to avoid floods in urban areas. Large water volumes of urban runoff bring important changes to natural water flow regime not only in a city but also downstream bringing pollution to entire river basin.. The paper gives the rationale and principles of new development within urban stormwater management. Two detailed application examples of new stormwater management are presented in the paper.

INTRODUCTION

The complexity of modern societies and their problems calls for a change in the "modus operandi" in a broad sense. It is realized that construction of traditional stormwater systems, i.e. pipes and/or large channels conveying runoff to the receiving water is expensive not only in monetary values but also in the use of natural resources, energy and industry that in themselves produce pollution. Thus, the total environmental cost of these activities may, in some cases, exceed total environmental benefits. On top of that, the large volumes of stormwater are altering the water courses downstream bringing increase in flooding frequency, sediment transport problems and pollution. By such approach we have lost control over thousands of potentially dangerous pollution elements of anthropogenic origin. The results are expressed in chemical contamination of river sediments, soils and groundwater.

STORMWATER - PAST AND PRESENT

Stormwater, i.e. rainfall runoff from urban areas was in early societies considered as an important resource. In cities of ancient Persia for example, surface water was considered sacred and was guarded by law against pollution. It was a sin to pollute water. Water in urban cisterns ("houzes") and streams ("ariks") was clean enough to use as a potable water. Stormwater from open yards of large buildings was injected directly to the underlying aquifer via deep wells. Later on, changes

https://doi.org/10.15626/Eco-Tech.1999.030

in human behaviour and intensity of life brought water pollution and degradation of this ancient water culture.

In the beginning of 19th century when the modern urban water management paradigm was established, ancient wisdom about the importance of clean water, not only in houses but also in the nature, has been lost. Stormwater was thought only as a nuisance in urban life. A conveyance approach that was established meant that stormwater should be evacuated from urban areas as soon as possible. This was achieved by construction of stormwater pipe systems and, in some locations, open channels conveying runoff downstream the city.

Problems with management of urban rainfall have their roots in concentration of population on a relatively small area. In order to make living and transportation possible large impervious areas are constructed. This results in a change of hydrological cycle.
Infiltration and groundwater recharge decreases, pattern of surface and river runoff is changed imposing high peak flows, large runoff volumes and increased transport of pollutants and sediment from urban areas. Thus the city influences the runoff pattern and the state of the ecological systems not only within the city area but also in and around a whole river system downstream.

Realization of these facts resulted that the traditional conveyance approach shifted during the 1970's to storage approach with a focus on detention, retention and recharge. Later on, during 1980's and 1990's stormwater became considered as a significant source of pollution and the main goals of stormwater management shifted to protection of the natural water cycle and ecological systems by introduction of local source control, flow attenuation and treatment mainly in natural or (mostly) constructed biological systems such as ponds, wetlands, root-zone treatment facilities.

Since then, a variety of new stormwater handling and treatment methods have been developed. It is generally accepted that stormwater should be attenuated locally. New methods are based on small-scale, environmentally sound technologies that involve natural or constructed biological systems for stormwater treatment. To such methods belong: several kinds of ponds, plant filters, surface flow through natural or constructed ecosystems, wetlands, root-zone systems, percolation facilities, soil infiltration, permeable asphalt, and many combinations of those. Thus, it is understood that important benefits
can be achieved by the use of open stormwater drainage, i.e. stormwater is kept on the surface where it can be attenuated, treated and possibly re-used.

During the last 10 years, hundreds of stormwater treatment facilities based on new principles have been constructed in the world. There is a lot of experience about operation of these facilities. We start to know treatment performance, week points, problems and ways of solving them (Fujita 1992, Wiesner 1992, 1994, Livingstone 1994, WSURD 1990). Some of Swedish communities already routinely build local systems for retrieval of stormwater in new housing areas.

Consequent application of local treatment and disposal of stormwater will influence the whole infrastructure in cities. In future optimistic scenarios some people claim that if the new water management methods will be generally used, the development of cities would be independent of

existing stormwater and wastewater infrastructure and distance to treatment plant (Mouritz, M, 1996).
Instead of ever growing cities, new urban-agro-industrial areas in which small urban units in balance with the surrounding agricultural land could be developed (Newman 1993, WSDRG 1990).

Stormwater constitutes an important resource possible to reuse separately or together with "grey water" for toilet flushing, or even for production of drinking water. Some of these ideas are already realized in s.c. ecological villages in many countries. Clean rainwater that is captured on the roofs should be considered as a valuable resource and not mixed with various residuals.

RECENT DEVELOPMENTS TOWARDS SUSTAINABILITY OF SOLUTIONS

Following four system conditions for sustainable development are also valid with respect to stormwater management:

1. Withdrawal of finite natural resources should be minimized.
2. Release of non-biodegradable substances to the environment must be stopped.
3. Physical conditions for circular flows of materia should be maintained.
4. Withdrawal of renewable resources should not exceed the pace of their regeneration.

The consequences of such formulations have recently entailed further significant changes in philosophy of above described approach to stormwater management in urban areas. The goals of such management are no longer limited to the local environment but also encompasses global environment and sustainable resource management. New approach involves actions within: land use policy, city and landscape planning, building construction, development control, strategic environmental assessment, economy, legislation, education and social acceptance issues, local community involvement.

With respect to stormwater management this requires:

* Planning within the total water cycle in the water basin.
* The use of storage and treatment rather than a conveyance.
* Provision of multiple use of water including recycling.
* Application of water conserving strategies i.e. protection of rainwater against pollution.
* Protection of terrestrial and aquatic habitats
* Shift from centralized to decentralized systems with recycling options open.
* Resource conservation principle must be applied.

Such an approach in a pure form is, as yet, only in our minds. However several new actions within stormwater management go in such direction. Examples can be taken from many projects recently completed or currently underway in Sweden and in several other counties in Europe, Canada, Australia and United States.

EXAMPLES OF INTEGRATED SOLUTIONS TOWARDS SUSTAINABILITY

The first example expresses well the spirit and a beauty of integrated approach to stormwater management problems. The example was presented during International Conference organized by Engineering Foundation and the Malmo Water and Wastewater Works in Malmo, Sweden 7-12 September 1997, and is from city of Malmö in Sweden.

In the city of Malmö many significant measures were taken in order to achieve closing of material flows in a city's water cycle, make water visible to general public, create viable water based ecosystems within the city limits and, simultaneously, increase aesthetic values of the land as well as economical value of residential areas around newly created water management facilities. Earlier technically rational handling of city planning including stormwater attenuation by infiltration and treatment in created wetlands have been substituted by integrated approach in which nature and aesthetic values of water are combined with positive hydrological effects such as attenuation and treatment of stormwater, maintaining existing streams and enhancing biodiversity (Gatukonturet Malmö, VA-verket Malmo and Stahre, P. 1997).

Philosophy of the solution in Malmo is still centered around source control options and local small scale solutions within the city area. But the new idea is that the process should begin already on a level of a single house, one parking lot, one street or a part of large highway system. It is considered more effective to act on stormwater sources i.e. small units of impermeable surfaces where urban runoff is first generated and where rainwater is mixed with pollutants found on the streets, roofs etc. So in Malmo, on top of already existing facilities such as traditional detention basins and infiltration facilities, a large number of small measures have been taken in dialogue with residents. To this category of measures belong disconnection of roofs of single houses in areas where soil conditions allow for local infiltration. If conditions are unfavorable, permanent of temporary storage may be achieved by constructing "swells" i.e. gravel beds below a lawn. In other places it may require change from impervious road surface to permeable asphalt. Runoff from larger roads may be directed to larger scale infiltration facilities under a gras surface between the two lines of traffic or by selective use of permeable pavements. The larger part of the solution is based on existing streams and topography of the city.
Around the city a chain of ponds and constructed wetlands was created along an existing stream. This chain constitutes an ecological zone and a beautiful park with high recreational value. It may be added that economic value of land and housing around natural and constructed water courses ponds and wetlands significantly increases.

The development of sustainable stormwater management in city is a continuous process. Parallel with growth of the city new facilities must be constantly added. Simultaneously, the function of existing facilities must be thoroughly monitored and results evaluated. It is worth to notice that artificially created ponds and wetlands are, basically, stormwater treatment facilities. They gather and accumulate pollution. In order to maintain treatment ability, after some years, sediment must be removed and safely stored. Safe storage of conservative pollutants such as heavy metals is a better alternative than spreading them in nature without knowing where the really go. Future generation may be need them as a resource to extract the metals.

The second example is from the city of Stockholm, Sweden (Malmquist, P.A., Bennerstedt, K., 1997). The city of Stockholm is surrounded by waters that are among the cleanest in any large city. But it was shown in several investigations that in some places the water and, especially the sediments are contaminated with heavy metals and toxic organic elements. Urban stormwater runoff is identified as a major source of these pollution. As a city is developing, the new residential area is projected at Hammarby to accommodate about 15 000 inhabitants. Since new constructions must meet higher environmental standards than already existing areas, the question arises how to find the most effective methods to reduce stormwater pollution. Since it is recognized that the best way to avoid pollution is acting on pollution sources, sources and flows of Cu, Zn, Cd Pb and PAH was theoretically calculated. The study revealed that following eight alternative measures have a potential to improve stormwater quality:

1. Change of roof materials from steel to tiles.
2. Painting galvanized objects.
3. Better and more frequent cleaning of streets and gully pots.
4. Decreased traffic pollution by 50%.
5. Change street pavements from asphalt to concrete.
6. Infiltration of stormwater from housing areas.
7. Treatment of stormwater from traffic areas.
8. Better air quality and depositions from the air.

Conclusions state that by application of measures 1 to 5 it is possible to halve discharges of Zn, Cu and PAH, but will not be effective for other pollution. Measures 1 to 7 entail better reduction than 50%. Measures 1 to 7 would further reduce Zn Cd, Pb while Cu and P would marginally reduced. By application of measures 1, 2 and 7 50% reduction would be achieved but a large portion of pollutants would end up in the soil, sediment or groundwater. (Mamquist, P.A. and Bennerstedt, K., 1997)

This study is interesting because it reveals that only real source control, i.e. radical and directed change of construction materials used in the city and products used by people can bring real long-term improvement. Otherwise all our measures only move pollutants from one place to the other. But in a meanwhile we are forced to take temporary measures that give the time to future generations to create a real change by finding more environmentally sound materials and technologies. On a long term, it will be necessary to change also our habits and life style.

STORMWATER - AN IMPORTANT RESOURCE.

Consider volume of water that is delivered to the urban areas by the nature in a form of rainfall: 100 mm rain on 1 km2 impermeable area gives 100 000 m3 water i.e. enough to 1830 people during one year counting with water use 150 l/day. If dry toilets are used, water consumption of households may be reduced by 70 %, that is 5500 people may gain all necessary water from 1 km2and rainfall 100 mm/year. With other words, theoretically, 182 m2 impermeable area can deliver water that 1 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 basic change in applied technology of stormwater management. Traditional technology, i.e. pipes for fast removal of stormwater from urban areas was developed for wet climate conditions, semi-arid and arid countries make a mistake copying this technology. Urban hydrologists should work to develop technical methods how to harvest this important resource and make it available for less demanding water uses or after purification, even for drinking purposes.

It is worth to consider that rainwater pollution begins in the atmosphere and continues on urban surfaces such as streets, yards, loans, roofs, etc where stormwater is mixed with accumulated pollution from dry period, atmospheric fall-out, surface wash-off and polluted in chemical reactions in contact with building materials. Acidification of rain, originated in the air pollution, accelerates chemical contamination of stormwater. However, majority of pollutants is washed out and transported in some first minutes of the rain. Thus, significant reduction of total stormwater pollution may be achieved by taking away runoff from first minutes of the rainfall using special devices.

AESTHETIC VALUE OF WATER IN A CITY.

Modern stormwater management can, on top of pollution prevention, contribute with adding aesthetic and recreational values to the city. One hydrologist described 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." (Göransson 1993). It is enough to walk around any pond or wetland constructed to attenuate and purify stormwater to see that all what he said is true. It means that urban hydrologist should work not only in cooperation with city planners, urbanists and architects, but with artists as well.

RESEARCH NEEDS.

Within the water profession developing the new principles of stormwater management, a common understanding is being achieved. New solutions should be source oriented, small scale local solutions mitigating formation of stormwater runoff and pollution should be applied. However, there is still not enough knowledge about what the environmental, economic and social effects of the more general use of these new methods will be. This is leading to several questions. Should such methods be used only in new developing housing areas or should all systems be gradually replaced? How will the general use of source control options and open stormwater drainage influence the total river basin by, for example, changed groundwater recharge and release of nutrients? It is not clear how the problem of polluted sludge sedimentation in open systems such as treatment dams and constructed wetlands should be solved. There is a need to summarize the experiences from a growing number of stormwater treatment facilities being in use in many countries for several years and gradually arrive to general guidelines, design manuals, modelling principles.

It is understood that in spite of all investments nothing disappears in nature, especially if it is non-biodegradable material as this is not easily assimilated: it is better to not mix pollutants with originally clean rainwater. Such understanding leads us to actions on small scale solutions and, thus, new stormwater management begins with small scale options. Such stormwater systems will be more complex and this is leading to more questions. Are we able to deal with growing complexity? Are there limits to our ability to handle complexity? What scale of solutions is optimal?

Results of integrated planning, which makes provisions for sustainability, should benefit the local and global environments as well as the physical and mental health of the population. The legal and social aspects of the introduction of such methods and technologies have to be given thorough attention. It is important that applied methods and technologies are understood and accepted by the people and do not violate existing laws and regulations, however, some changes in present legislation and organizational structures as well as in behavior and lifestyle might be required. The economic dimensions of the solutions, for households as well as economic entities, are equally important to consider.

It is necessary to know how to design ditches and ponds optimally to take away nutrients and metals from stormwater. For example phosphorous needs a long pond or ditch because large amounts of water will flush already settled phosphorous and it will move further on in the system.

Extended use of open drainage will influence groundwater levels and groundwater quality in a city and the river basin. Most of Swedish experiences in this field has been gained from running local disposal facilities (LOD), (Stahre 1993, Malmquist 1993). Such facilities are constructed over a very limited area but the influence on groundwater quality can be of importance. There is a need to further disseminate knowledge on this point. Changes in groundwater level as a response to extended use of novel stormwater infrastructure should be calculated assuming different extents and localities of open drainage and surface treatment. Changes of water quality can be simulated using, for example SUTRA-model. There is the need to economically evaluate evaluation of different scenarios in planning new stormwater systems in order to decide which environmental or economic conditions motivate the use of open treatment systems to either replace or complement old systems. Such evaluation should include a comparison of costs for replacement with open drainage versus renovation of existing network and for new constructions.

CONCLUSIONS

The leading ideas behind new stormwater management are based in new holistic/integrated approach and on new technical system conditions in Agenda 21 spirit. Sustainability criteria must be introduced at the level of long-term regional physical planning including the revision of already existing stormwater facilities and guidance of subsequent detailed planning and implementation of new stormwater systems. Such sustainable solutions should be put into practice in the construction of urban areas and their infrastructure.

The new principles of stormwater management require that water engineers communicate with local planners and actively participate in the current planning processes conducted by the Municipalities. Since administrative borders are not observed by water, the areal delimitation chosen for evaluation of the physical effects of the planning is the river basin. A growing implementation of local solutions in stormwater management will change the city. Thus, integration of stormwater management is required at all spatial and temporal scales of urban and rural planning within a river basin.

Preventive measures begin by reduction of runoff volumes by minimizing paved surfaces and the use of permeable or semi-permeable surfaces on streets and sidewalks, leading water from paved to un-paved surfaces, planting lush vegetation. Stormwater runoff stays on the surface in meandering ditches, is attenuated and treated in ponds and wetland ponds. New challenge is to develop methods for recycling and use of stormwater in less quality demanding uses such as toilet flushing or irrigation of parks and local agriculture.

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