FROM WINGSPREAD TO SUSTAINABLE URBAN WATERS AND WATERSHEDS

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ABSTRACT

The *Cities of the Future* concept, as it was covered by expert presentations in the Wingspread workshop, is a paradigm of integration of future, as well as older, urban developments with the landscape, drainage, transportation and habitat infrastructures. The goal is to make cities resilient to extreme hydrological events and pollution, yet provide an adequate amount of clean water for sustaining healthy human, terrestrial and aquatic lives, and optimal balanced uses for recreation, navigation and other economic uses. This concept combines “smart green” developments with controlling landscape diffuse and point pollution so that highly treated effluents and urban stormwater can be reused for various purposes such as irrigation, groundwater recharge, environmental flow enhancement of effluent dominated and flow deprived streams, and even for water supply. This evolving paradigm is based on the concept of the total hydrologic water and mass balance where all three components, i.e., water supply, stormwater, and wastewater will be considered and managed in a closed loop. *Effluent dominated/dependent streams* are the most stressed receiving water bodies; therefore, restoring and maintaining their integrity (good ecological status) and reclaiming the waters for other uses is the most difficult. Yet, in the USA the Clean Water Act does not allow downgrading the designated uses of the aquatic life protection and propagation or providing conditions for primary contact recreation. In addition to overwhelming effluent discharges, effluent domination/dependence is also caused by large water withdrawals and long distance water and sewage transfers.

Key words: Sustainability, Urban waters, Reclamation, Effluent dominated waters, Water body integrity

1. INTRODUCTION

1.1. Wingspread Workshop

In July 2006 a two and half day international interdisciplinary workshop of experts was convened in the Wingspread Conference Center in Racine (Wisconsin, USA) operated and managed by The Johnson Foundation (www.bluewatergreencities.net). The mission of the workshop, “Cities of the Future”, was to develop visionary concepts on how to ensure that cities and their water resources become ecologically sustainable and are able to provide clean water for all beneficial uses. Forty invited experts from eight countries explored the links between urban water quality and hydrology, and the broader concepts of green cities and smart growth and also addressed the current vulnerability to extreme hydrologic conditions such as the recent Hurricane Katrina or tsunami events. It was pointed out that sustainability also implies resilience of urban watersheds to extreme events. The workshop participants also addressed legal and social barriers to urban ecological and hydrological sustainability and proposed practical ways to overcome these barriers. The workshop was sponsored by the US National Science Foundation, CDM Inc, The Johnson Foundation, and the International Water Association. The presentations and discussions were aimed at establishing an agenda for achieving ecologically and hydrologically balanced water use, drainage and wastewater disposal systems, as well as the remediation of damaged water bodies and watershed landscape – all contributing to the quality of life and economic vitality of cities. The focus of the workshop was integration of landscape (green design concepts) with water and wastewater management, and incorporation of Best Management Practices for urban runoff. The outcome of the workshop and its findings are presented in the monograph edited by Novotny and Brown (2007).

1.2 Vision of the Sustainable Urban Waters and Watersheds

In the mid 2000s, one-two punches of tsunami and hurricanes struck coastal urban areas creating catastrophes of historic proportions. Although these events have occurred throughout history, the human and economic costs of these events were unprecedented. It became painfully evident that the current typical urban landscape and its drainage infrastructure could not cope with these hydrologic events and the consequences were a loss of thousands of lives, suffering and dislocation of survivors during and after these events and almost one hundred billions of dollars in damages. It is clear that coastal urban areas in many places of the world are highly vulnerable to extreme hydrological events that produce too much flow, and they lack buffering by the landscape surrounding the recipient water bodies and the cities. Under the circumstance of extreme flows, the current underground urban drainage is almost inconsequential (Figure 1) and the hydrologic connection with the landscape is fragmented or nonexistent. Scientific predictions by UN indicate that the frequency and force of extreme hydrologic events will increase with global warming.

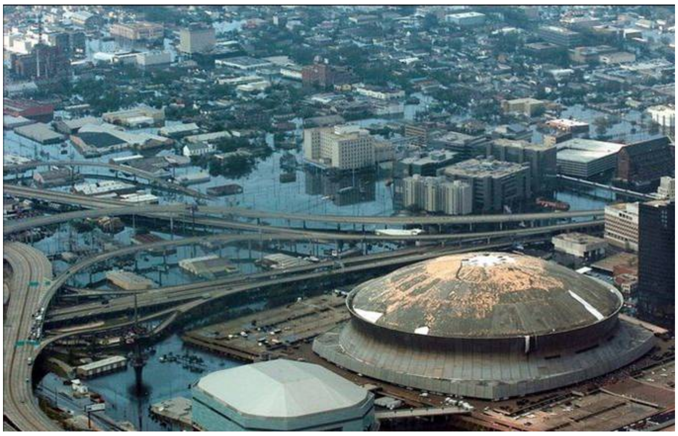

Figure 1 Impact of hurricane Katrina in New Orleans. Urban landscape, drainage and human response failed.

On the other side of the hydrological spectrum, many cities, not only in arid zones, are running out of water and biota has disappeared because of insufficient flows. The traditional response by urban planners and water engineers was to tap water resources from increasingly larger distances, which is not a new; Romans built aqueducts up to fifty kilometers long. However, in the twentieth century so much water was taken out that many rivers in the withdrawal location dried up (e.g., the Ipswich River in Massachusetts shown on Figure 2). At the same time receiving water bodies are overwhelmed by effluents at the point of discharge, creating effluent dominated water bodies. The US Clean Water Act requires all currently or previously navigable water bodies, including those that are effluent dominated or flow deprived, to be suitable for supporting aquatic life and contact recreation. Hence, both pollutant loads and withdrawals must be reduced, which requires water conservation, effluent reclamation and reuse, and a high degree of effluent treatment.

Figure 2 The Ipswich River in northeastern Massachusetts.

Sustainable development has been defined as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (Brundland et al., 1987). The *Cities of the Future* concept, as it was covered by expert presentations in the workshop, is a paradigm of integration of future, as well as older, urban developments with the landscape, drainage, transportation and habitat infrastructures. The goal is to make cities resilient to extreme hydrological events and pollution, yet provide an adequate amount of clean water for sustaining healthy human, terrestrial and aquatic lives, and optimal balanced uses for recreation, navigation and other economic uses. This concept combines “smart green” developments with the control of landscape diffuse and point pollution so that highly treated effluents and urban stormwater can be reused for various purposes such as landscape and agricultural irrigation, groundwater recharge to enhance groundwater resources and minimize subsidence of urban historic infrastructure, environmental flow enhancement of effluent dominated and flow deprived streams, and even for water supply. This evolving paradigm is based on the concept of the total hydrologic water and mass balance cycle where all three components, i.e., water supply, stormwater, and wastewater will be considered and managed in a closed loop (Figure 3). It will rely on greatly enhanced removal of organic chemicals, nutrients and endocrine disruptors from effluents and also feature the application of Best Management Practices that provide treatment, water conservation, and storage of excess precipitation for reuse. The main drivers towards sustainability are:

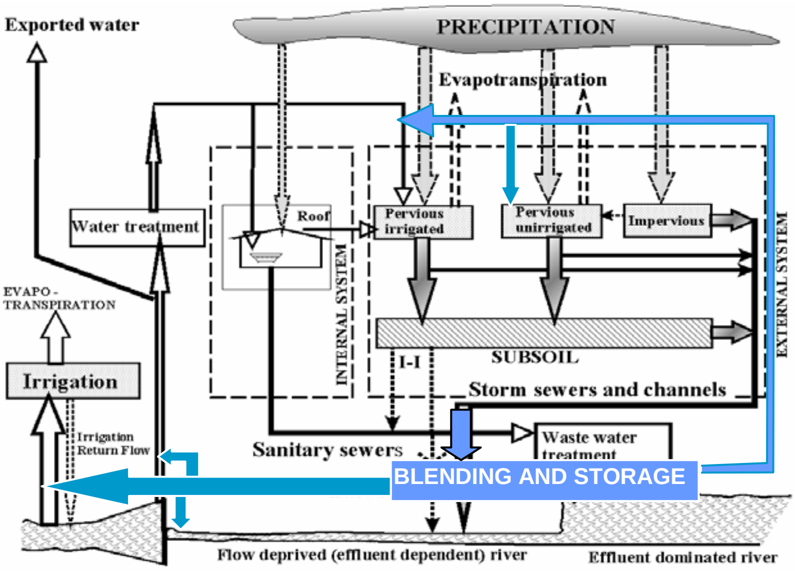

Figure 3 Schematic of the total urban water cycle. The blue arrows close the loop (based on Mitchel et al., 2003)

1. Population growth and migration. In the next 50 years the world population is expected to increase by 50 percent and the population of the United States will increase by 100 million or 33 percent. Nearly 75 percent of the United States population today is served by municipal water supply and wastewater systems, which is expected to increase to 90 percent in the future.

2. Global climatic changes. Global warming is expected to increase the frequency and strength of tropical storms and droughts. Coastal cities will confront more flooding and rising sea levels and flood levels. More precipitation will increase diffuse (landscape) pollution loads. Increased temperature and the pollution loads stimulate shift of phytoplankton composition of surface water resources from diatoms and green algae population toward cyanobacteria that produce noxious algal blooms, harmful toxins, bad taste and odour.

3. Resource stewardship and ethics. Public demand for attaining and protecting the integrity of aquatic ecosystems has been incorporated into the environmental protection laws of many countries and increasingly into urban biodiversity programs. The vision of sustainable ecosystems galvanizes citizens and will drive future urban engineering and ecologic efforts.

4. Multiple use and overuse of urban waters. Urban waters and their corridors provide benefits for many uses. Withdrawal of water for drinking and other uses diminishes natural flows and the used water is often transferred via sewers to a discharge point many kilometers downstream. Hydraulic modification of streams to accommodate increased flood flows and navigation, damages or destroys habitat and reduces recharge of groundwater. Water demand trends outstrip prospects for water supply in many cities.

5. Hardening of the urban landscape. High imperviousness and sewers built in the last one hundred fifty years in United States cities have dramatically changed the hydrology of US urban areas. Imperviousness increases peak flows in urban streams by a factor of 4 to 10 and diminishes the base flow. Increased variability and higher frequency of bank overtopping has resulted in flooding, unstable eroding channels and a loss of habitat in many locations. Global warming will exacerbate urban heat-island effects on receiving waters, making small urban streams inhospitable for aquatic life during increasingly hot summers

6. Scale Effects. Historically, limited local water supplies were augmented by transfers of water from distant sources while sewage treatment moved from a local to a regional scale. Both trends have consequences for water bodies that will limit these strategies in the future. The transfer of raw water deprive water bodies in the source area of flow. Regionalized wastewater treatment increases the impact on receiving waters at discharge points, creating effluent dominated water bodies.

7. Improved efficiency of wastewater and storm runoff treatment Modern urban wastewater treatment is able to achieve effluent quality similar to, and occasionally better than, that of receiving waters. Small package and highly efficient and automated treatment plants for subdivisions and small communities are economically affordable in many applications. New methods have emerged and old technologies have been rediscovered for stormwater management. However, emerging pathogens and toxics including many persistent organic pollutants and endocrine disrupting chemicals offer challenges for identification, treatment and mitigation.

The key recommendations proposed by the delegates of the Wingspread workshop leading towards sustainability of urban waters were (Novotny and Brown, 2007):

1. Elevate the importance of water as a central and essential organizing element in a healthy and sustainable urban ecosystem.
2. Develop and implement new approaches to the management of urban water systems, including:
    - Moving towards an integrated system approach based on the total hydrologic cycle that addresses all of the uses of water in the urban environment;
    - Incorporate multiple benefits into all projects and programs that contribute to the economic, social, and environmental health of cities;
    - Promote new, innovative design concepts that incorporate structural solutions and natural system restoration, replication, and enhancement; and
    - Adopt adaptive management focused on prototype development, implementation, monitoring, and performance evaluation.
3. Increase the resilience and redundancy of urban water systems to resist and rebound from extreme events.
4. Create multifunctional urban landscapes that would be hydrologically and ecologically functional.
5. Combine on a regional scale the “green” urban developments with water management and water body integrity restoration and protection.
6. Support the formation of a national and international coalition of researchers, stakeholders, agencies, and government officials dedicated to establishing the new urban waters sustainability paradigm and enlarging the movement towards sustainable urban cities and their life-giving water resources.

2. EFFLUENT DOMINATED URBAN WATERS

2.1 Water-Sewage-Water cycle

At the end of the nineteenth century, industrialization and urbanization reached levels that overwhelmed the receiving water bodies with untreated effluents. During the first seventy years of the twentieth century, some urban rivers were smelly because of hypoxia in summer, unsuitable for recreation, overloaded with sludge deposits and often dense mats of sludge worms developed on their bottoms (e.g., the Lower Des Plaines River in Illinois (Butts *et al*., 1975; Novotny et al., 2007). In many places, effluent dominated rivers were covered and converted to sewers.

Karl Imhoff, a pioneer of sewerage and water quality engineering, realized one hundred years ago that once an effluent is discharged into a receiving waters it will be reused, in a more or less diluted form, as a source of water downstream. This is called the “water-sewage-water cycle” (WSW) that occurs in almost every municipal water management system with an exception of wastewater disposal into the ocean (Imhoff, 1931). Imhoff also stated that the only thing engineers can do is to maximize the distance and time between the discharge and reuse. Today, many effluent dominated streams, including some of the most difficult ones such as those formerly converted to sewers, are being “renaturalized”, “daylighted” and rehabilitated, for example the Emscher River in the Ruhr district.

In addition to point source effluent discharges, urban effluent dominated streams are also affected by urban runoff, legacy pollution in sediments and dropping groundwater tables due to imperviousness of the surface that reduces groundwater recharge.

2.2 Legal Tools for Restoration

The terms *effluent dominated* and *effluent dependent* water bodies have been used interchangeably. To distinguish between the two categories the following definitions are proposed:

- ***Effluent dominated water body*** contains more wastewater effluent than natural flows waste all or a part of a year. Effluent dominated streams do not have to be naturally ephemeral.
- ***Effluent dependent water body*** *is generally an ephemeral (either natural or due to excessive upstream withdrawals) stream in which aquatic biota and other uses of the water body are or can be sustained by treated effluents creating perennial flows.*

The US Clean Water Act and ensuing water quality standards regulations do not give agencies or dischargers a “carte blanche” to exclude effluent dominated/dependent water bodies from attaining the integrity goals. A Use Attainability Analysis (UAA) is needed if a downgrade or any change of the designated use is contemplated (USEPA, 1994). Typically, these water bodies are water quality limited which means that if all effluent controls and reasonable Best Management Practices were implemented the water body would still remain impaired and additional controls are needed.

The US Water Quality Standards Regulation provides six reasons that can be used in petitioning (through a UAA) for a downgrade of the statutory water uses defined in the CWA, i.e., maintaining integrity of aquatic life and providing for primary recreation, considering also uses for water supply and navigation (USEPA, 1994). However, § 131.10(g)(2) allows the removal of an aquatic life use, that is not an existing use (i.e., the water body has been impaired) where “natural, ephemeral, intermittent or low flow conditions prevent the attainment of the use, *unless these conditions may be compensated for by the discharge of a sufficient volume of effluent discharge without violating state water conservation requirements to enable uses to be met* (emphasis added). This rule has been interpreted by the USEPA (Region 8) to imply that “**where an effluent discharge creates a perennial flow, the resulting aquatic community is to be fully protected**” which means the integrity goals specified in the CWA shall be attained. Integrity has been defined as a condition in the stream supporting balanced aquatic life (Karr *et al*., 1986) and supporting contact and noncontact recreation. Thus, effluent dominated streams present a challenge but also a potential for restoration.

2.2 Paths to Restoration

Total hydrological cycle – integrated management. Making urban effluent dominated/dependent streams ecologically and hydrologically sustainable will require total urban hydrologic and pollutant mass balance management with ecological integrity as a focus. Water supply, stormwater management, wastewater disposal, groundwater levels, and stream flow are components of the same system and should be managed in an integrated fashion with the integrity goals in focus. Figure 3 is the concept of the total urban hydrological cycle and closing the loop. The Integrated plans and management may use the following tools:

- *Water conservation*
- *Capture, store and reuse of rainwater (surface runoff) and use it for*
    - groundwater recharge
    - local irrigation (rain gardens)
    - low flow augmentation
- *Effluent reclamation and reuse*
    - for irrigation (e.g., golf courses) to decrease withdrawals
    - flow augmentation to sustain aquatic life
    - aesthetic enhancement of effluent dependent streams
    - groundwater recharge and storage for future nonpotable reuse

This concept may lead to treated effluent and stored stormwater *blending* to enhance flows and *water flow trading*. Environmental water flow trading in effluent dominated/dependent and other impaired basins is based on the idea that stored and/or recharged stormwater with subsequent base flow enhancement may partially reduce the requirement for a high degree of treatment of effluents into impaired waters, especially during low or no natural flow situations when aquatic life would be in danger. Utilities managing their waters on the total hydrologic cycle concept should get credit for, or even market to other communities, the flow enhancement achieved by water conservation and stormwater management.

Aquatic habitat restoration. Progress has been made in developing approaches that define the *ecological potential* of ecosystems, which can serve as a basis for establishing realistic goals in ecosystem restoration projects (Mitsch and Jørgensen, 1989). Essentially, the ecological potential identifies reasonable goals for rehabilitation and restoration projects in terms of reducing pollutant loads and restoring habitat quality and hydrology. Obviously, the quality of a stream reach running through a densely-populated urban area may never return to the condition of a pristine reach in a forested area. The ecological potential considers the reversible and irreversible modifications as an integral part of management. Ideally, achieving the ecological potential for an aquatic ecosystem should allow the ecosystem to conform to the standards of the Clean Water Act or the Water Framework Directive.

Recent studies that relate Indices of Biotic Integrity (IBI) and their metrics (Barbour *et al*., 1999) to multiple stressors (Yuan and Norton, 2004; Manolakos et al., 2007) revealed that habitat and other nonpollutant stresses (e.g., embeddedness and bottom substrate quality, riparian zone quality) and morphological parameters (e.g., slope, flow and velocity) may have as much or more impact on the biotic integrity of the water body as concentrations of traditional pollutants, provided that mandated control of point source discharges are in place.

Green cities – smart development initiatives. The widespread grass roots worldwide initiatives towards green development provide another impetus towards rehabilitation of effluent dominated water bodies. Biotic integrity of urban waters can be linked to good riparian habitat and conditions (Yuan and Norton, 2004; Manolakos et al., 2007) that mainly include parks and greenbelts desired by green city advocates and the population. In reverse, poor water quality and habitat make the riparian zones undesirable for green concepts. Replacing imperviousness or installing green zones and strips in streets and parking lots, an important component of green development, could be hydrologically functional and filter out pollutants and have significant pollution reduction benefits. They also are important Best Management Practices for reducing urban diffuse pollution (Hill, 2007).

Some communities have focused on reclamation and beautification of the riparian zones of partially ephemeral effluent dominated/dependent streams without attempting to fully restore the river flow and habitat to attain the ecologic potential of the water body. The San Antonio River (TX) is an example of a tremendous economic potential the green development of the river corridor can bring to a city. However, it is also an example of the gross omission the city and developers made by not including habitat and water quality restoration into the green conversion. The river is essentially an artificial lined channel with beautified riparian zone; hover, its water quality is poor and with no aquatic habitat in the channel. Therefore, there is an urgent need to find a common ground, goals and communication between urban architects, officials, urban diffuse pollution control managers and other specialists and stakeholders. Ecologically oriented ideas of urban landscape that would help to and dilute flows by green design aimed at groundwater recharge by excess runoff and improving base flow are discussed by Hill (2007) and Ahern (2007). Restoration, brownfield clean–up and greening of the urban landscape surrounding the rivers are an integral part of the restoration effort.

2.3 The lower Des Plaines River - Example of and Effluent Dominated Stream

This river is the largest effluent dominated river in the US, carrying the flows and effluents from the Chicago Metropolitan Area. It becomes the Illinois River (still effluent dominated) after joining the Kankakee River and, after crisscrossing the state, the river joins the Mississippi River. The Lower Des Plaines River is impounded and is a major inland shipping artery connecting Lake Michigan with the Mississippi River. It carries almost 60 m^3/s of treated effluent from the Chicago Metropolitan Area, while the natural low flow in the Des Plaines River upstream from the confluence with the Chicago Sanitary and Ship Canal (CSSC) is less than 4.5 m^3/s (Novotny *et al.*, 2007).

Until the beginning of the 20th century, wastewater from Chicago, including CSOs, was discharged into the Chicago and Calumet Rivers and was conveyed into Lake Michigan or directly into the lake. At the end of the 19th century the polluted discharges into the lake, which is the main source of drinking water for the metropolis, created the WSW cycle with severe public health consequences. The Chicago Sanitary and Ship Canal (CSSC), larger than the Suez Canal, was built at the beginning of the 20th century. The canal reversed the flow direction of the Chicago River from Lake Michigan (a source of drinking water for the urban area) into the CSSC and, subsequently, into the Lower Des Plaines River. The Calumet–Sag Canal, also reversing the flow of the Calumet River into the CSSC, opened in 1922. The result of these massive projects was the diversion of all wastewater effluent flows, stormwater, and CSOs into CSSC as well as a virtual elimination of any sewage overflows into the lake. By 1917, typhoid deaths (per capita) dropped to the lowest level for major cities in the nation. In 1970, the Illinois water pollution control agencies designated an inferior (Secondary Contact and Indigenous Aquatic Life) use to the CSSC and the downstream Lower Des Plaines River and assigned also inferior standards. Some of the standards such as those for temperature, dissolved oxygen, and metals did not provide a protection to prevent lethal effect of these pollutants. Furthermore, the standard for bacterial contamination was repealed.

Figure 4 The Brandon Pool on the Lower des Plaines River. Most of the river flow is treated effluent and stormwater from the Chicago metropolitan area.

An extensive and successful Use Attainability Analysis was prepared in which an upgrade from an inferior use (Second-ary Contact and Indigenous Aquatic Life) to a Modified General Use was proposed and is now being implemented by the Illinois Environmental Protection Agency (Novotny et al., 2007). The General Use in Illinois is the use complying with the CWA Section 101a integrity goals. Currently, the Lower Des Plaines River is moderately impaired due to limited sediment contamina-tion and high temperature and will recover after further actions proposed by the UAA will be carried out following the implementation of the new Modified General Use standards. After removal of the last major pollution problem (the heated discharges from power plants and implementing disinfection and, possibly, supplemental aeration), the Lower Des Plaines River may achieve the ecologic potential for stressed impounded rivers. It is expected that the lower part of the river (the Dresden Pool) will be capable of supporting a balanced biota and be safe for limited primary recreation (Novotny et al., 2007). The action plan includes common sense actions that would further reduce chemical and pathogen pollution as well as improve littoral riparian habitat of this impounded river. Some past modifications to accommodate higher flows and navigations are irreversible.

3. CONCLUSION

The Wingspread workshop addressed the objectives and research priorities of water centric urban waters and watershed management. In the terms of the water resources system optimization, the total water cycle management conceived by urban water engineers (e.g., Mitchell et al., 1996) has the objective of maximizing water availability for urban uses and may have ecological quality limits as a constraint. The Unified Management for sustainable urban water systems may reverse the focus. Achieving the ecologic potential of the receiving waters and aquifers is the moving goal, i.e., it will be approached by adaptive management. Therefore, it is necessary to develop regional total water balance models that would have attainment and maintaining (resilience/sustainability) the integrity of urban waters as a goal and optimizing the beneficial water uses for the population, reduce diffuse pollution and protect the receiving waters.

In the US, the Use Attainability Analysis and the Total Maximum Daily Load programs are the main tool for water quality management. These tools may be inoperative or inefficient for achieving sustainability because they are narrowly focused on compliance on chemical and bacteriological water quality standards. In a broader context of sustainable urban water/watershed management, it is necessary to unify the concept of urban landscape ecology (green design) and water body integrity. Addressing the problem of urban effluent dominated/flow deprived rivers is the most difficult task. Because these rivers cannot, in most cases, attain the predevelopment biotic integrity, determining the ecologic potential of the river and green ecology of the riparian zones and the watershed are the first steps.

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