Application of Cleaner Production Concepts in Urban Water Management

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Abstract

Present day Urban Water Management has come forth from the early centuries approach of water-based sanitation. Human and domestic wastes were flushed out and, once out of sight, had ceased to exist. Relative to the preceding periods in which waste accumulated just outside the dwelling, causing various kinds of nuisance, water-based sanitation was a significant hygienic improvement. Even though this approach of dumping waste had, also then, an environmental impact, the extent of the impact was almost negligible because of the very few people around. Clean water and soil remained abundant commodities.

Ample availability of clean water and soil does not exist anymore. With a world population of over 6 billion and a dramatically increased resource distribution because of the transport of resources in water, clean water or soil have become rare almost anywhere on the earth. One would think that this would have lead to reconsidering the water-based sanitation approach. To the contrary, in the past decades, water-based hygiene has developed to great heights and so has water consumption. Therefore, now we are faced with per capita water consumption figures between 130 and 500 liters per day in the western world while water consumption in the ‘south’ is growing rapidly to, potentially, the same or higher levels.

With a limit to the availability of fresh water (Cosgrove & Rijsberman, 2000), it is clear that this approach is not sustainable and water scarcity situations arise more and more frequent. Consequently, the traditional water-based sanitation needs urgent revisiting.

This paper discusses how Cleaner Production concepts, until now primarily associated with industrial production, can help making Urban Water Management more sustainable.
Introduction

Urban Water Management (UWM) can be defined as the management of all aspects of water in the urban setting. This relates to both the qualitative (hygienic) as well as the quantitative aspects of water and covers

- the provision of water for drinking purposes – this includes the recovery of the source water (groundwater, surface water, rainwater), the transport to the treatment plant, the treatment of the water to make it into potable water, and the subsequent transport and distribution to bring the water to the consumers;
- the provision of water for industrial production – this includes potentially the same steps as for drinking water; however, the finished product may be of a final quality different from that of drinking water;
- the collection and processing of the wastewater from domestic and industrial use – processing means the conversion of wastewater into a product safe from the point of view of hygiene and toxicity and, ideally, the reuse of the treated wastewater making best possible use of the useful components in the treated wastewater and of the water itself;
- water for city cleaning, green areas and fire fighting – requires water which is hygienically and environmentally safe and, a) may contain nutrients (watering), b) is available at sufficient pressure and in sufficient quantities (cleaning, fire fighting);
- management of rain water – this usually demands for the adequate removal of rainwater from streets and other city areas after showers; it could also mean the adequate storage of water for future purposes;
- resource protection schemes - to safeguard the continued and safe use of water resources.

Cleaner Production (CP) can be defined as the approach in which processes and activities are carried out in such a manner that the environmental impact thereof is as low as possible. The term Cleaner Production refers usually to improving industrial production processes so as to reduce the flow of waste products and, therefore, to reduce the impact thereof onto the environment. This implies reevaluating the need for and/or the required characteristics of the products, reconsidering the choice of raw materials, improving process efficiencies, considering in-plant reuse, recycling, recovery of waste materials, least impact treatment of wastes, and recovery of as many useful products as possible from the wastewater.

Although Cleaner Production will have a different meaning in the context of urban water, the essential elements of Cleaner Production, i.e. emphasizing the proper choice of materials to be used, improving process efficiency, reuse and recycling of materials and least impact treatment with recovery of resources, remain equally valid.

Historical background and present approach to UWM

The present Urban Water Management developed from a situation of small populations consuming small amounts of water, the presence of only small-scale industrial activities and, thus, the release of few harmful resources into the environment, and the availability of large volumes of fresh water. Consequently, neither the water consumption nor the discharge of the wastes had a measurable impact on the environment.
When populations increased, and specifically, when nearby waste discharges resulted in unhealthful conditions and outbreaks of diseases, waste needed to be discharged further away from human habitation. Therefore, waste transport came into existence using open drains and, later, pipe systems (Harremoes, 1998). For this transport to work, a certain water flow was needed so as to prevent de settling of the waste components. The required water flow in the pipe system was significant and later was a parameter in the design of the first water-based toilets. With 1) water virtually free of charge, 2) almost no economic need or environmental incentive to limit water consumption, 3) the concept that water improved hygiene, per capita water consumption rates have gradually risen to levels ranging from over 130 l/day in, for example, the Netherlands to as high as 500 l/day. Nevertheless, per capita consumption figures in urban slums can be as low as 15 l/day.

Urban Water Management can be characterized as follows:

**Drinking water:**
* Only a fraction of the potable water is used for purposes requiring potability.
* Oftentimes tariff structures stimulate the consumption of water.
* The provision of water was, and to a large extent still is, supply driven.
* Most potable water is used to flush away and dilute wastes, including pathogens and nutrients.
* Groundwater is rarely returned to where it came from, the underground.

**Industrial water:**
* Usually industries receive potable water but industrial processes may actually need a higher or lower quality.
* Oftentimes tariff structures stimulate the consumption of water.
* Most potable water is used to flush away and dilute wastes.
* Water saving is still rare as are internal reuse/recycling.

**Domestic wastewater:**
* Response to the generation of wastewater is: collect, (centrally) treat and discharge into surface water.
* Collection requires a minimum flow rate thus requiring water consumption.
* Treatment is predominantly capital-, skill- and energy intensive and, therefore, problematic in many parts of the world.
* If some type of collection is present, (partially) treated wastewater is discharged into surface water, potentially causing environmental impact.
* If a treatment plant malfunctions, there is a potential for environmental disasters.
* Useful wastewater ingredients, i.e. energy, N & P or metals are rarely recovered.
* Toxic components are removed from the liquid phase through adsorption onto sludge particles at best. But adequate treatment of sludge is rare.


**Industrial wastewater**
* Usually different process streams are mixed, complicating processing and, specifically, recovery.

**Water for city cleaning, green areas and fire fighting:**
* Requires hygienically and environmentally safe water.
* Water may contain nutrients in the case of water for watering.
* Should be available at sufficient pressure, in sufficient quantities and at the right time (fire fighting).
* Reuse of treated wastewater is rarely considered.

**Management of rain water:**
* Generally focus on quickest possible removal.
* Rain water often combined with wastewater. Positive for flushing sewer systems. Negative because of the shock load effect on wastewater treatment or receiving waters and because of dilution of useful wastewater components.
* Rain water rarely treated and used for groundwater replenishment.

**Drawbacks of present approach to UWM**

The cleaner production concept, developed over the last two decades, has generated innovative environmental thinking in the industrial sector. If we apply some of the basic principles of cleaner production to current practices in urban water services, we may realize the opportunities for drastic changes (Box 1). These changes to the present way of approaching UWM are related to its inherent contribution to resource depletion and environmental pollution:

1. Water consumption, be it domestic or industrial, is far higher than needed for consumption. Most of the water ‘consumed’ is merely used to keep waste materials in the waste collection system in suspension and, therefore, dilutes precious resources as a result of which resource recovery is at least much more complicated and, as such, a threat to receiving waters. However, this practice is gradually being reconsidered with various water conservation projects existing or under construction.

2. There is at best little control over what is being discharged into wastewater. With, generally, little awareness of environmental consequences, little institutional attention for recovery of resources, and with only degradable organics potentially removed from wastewater or wastewater sludge, remaining resources are either distributed into surface waters or into sludge. As such wastewater collection and treatment contribute to environmental pollution.

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**Box 1. A ‘cleaner production check’ on urban water management practices**

**Principle 1:** Use minimum input of resources per unit of product.
**Practice:** 130 to 500 l drinking water is supplied per capita per day, while less than 2 liters are actually used for drinking. This results in huge volumes of dilute sewage.

**Principle 2:** Do not use input materials of a higher quality than strictly necessary.
**Practice:** We use water purified to drinking water standards to flush toilets, clean floors, wash cars or irrigate the garden.

**Principle 3:** Do not mix different waste flows.
**Practice:** Already in the household various wastewater flows are combined (urine and fecal matter, grey and black water). In the sewer this is mixed further with industrial effluents, and with urban runoff. This practice makes re-use of specific components less feasible.

**Principle 4:** Evaluate other functions of by-products before considering treatment and disposal.
**Practice:** Domestic sewage is discharged into open water resources either with or without prior treatment. Only few examples of effluent re-use or (by-)product recovery from wastewater exist.
3. With increasing centralization of wastewater treatment facilities and continued growth of population centers, even the effluent from well-performing facilities causes environmental risks. For example, consider a treatment facility of 5,000,000 population equivalents (5M p.e.'s). Assume a 90% efficiency of the facility in terms of COD removal. This leaves a COD into the receiving waters of 500,000 p.e.'s., the same load as would be received from a city of 500,000. Moreover, it should be noted that a 90% COD removal efficiency is an ideal that is rarely reached in practice.

4. International donor agencies, in the business of stimulating the treatment of wastewater, should guide countries in finding country-specific sustainable solutions aimed at least environmental impact and recovery of resources. As such, much work needs to be done since often capital and maintenance intensive solutions are advocated, requiring well-trained staff.

5. Mixed industrial waste streams make resource recovery and reuse at least much more complicated than if process streams would be kept separate.

6. Water could potentially be saved if reused water was used for city cleaning and greening purposes.

7. It is not uncommon to use precious groundwater for domestic and industrial consumption and to discharge the used groundwater into surface water. This practice contributes to groundwater depletion.

For these and other reasons a new approach is urgently needed aiming at resource conservation and reducing environmental impact of UWM.

Framework for a new approach towards UWM

From the previously mentioned comments on the present approach towards UWM and the consequential un-sustainability thereof in terms of resource conservation, environmental pollution, and its economic unfeasibility, it may be clear that a different direction is needed for the management of water in the urban context. Following key issues are discussed and solutions proposed.

1. Enhancing an attitude of resource conservation mindedness

   Although our (grand-)parents were generally raised with an attitude of thriftiness, later generations appear to have lost most of that notion: taps are left running, light are left on, whatever is not needed is dumped even though we may need it sometime later. Clearly, this notion is not sustainable and even less so with a rapidly growing world population with each individual claiming the same rights to use resources. At the industrial level, the generation of waste is not always immediately associated with process inefficiency but rather with a seemingly unavoidable side effect of production. Therefore, the drive to improve process efficiency is not necessarily very strong.

   Altogether, an attitude is to be stimulated globally that resources need to be used conservatively and with the notion that the environmental impact of the usage needs to be limited as much as possible. Examples of this in the water management field are:
   - Make water saving devices available that really stimulate water conservation. Many examples exist in the area of shower heads, kitchen taps, toilet flushing devices, etc. Moreover, dry sanitation systems are on the market for various decades and have proven to function also in urbanized areas.
   - Provide financial incentives to stimulate water conservation and to discourage water wastage at the domestic front. In order for such measures to be effective, a proper administration is essential.
   - Provide benchmark information, financial incentives, and support to the industrial front to stimulate water conservation. When industrial managers know that certain aspects of their production processes are wasteful, usually the drive to improve efficiency is available.
2. Choosing the right resources

Within the context of water management, choosing the right resources means: choosing that water quality that is really needed. For flushing the toilet, any water quality will do. For car washing, water free from pathogenic organisms will suffice. For drinking and kitchen usage, water of the highest possible chemical and bacteriological quality is needed. This means that for domestic purposes we distinguish various water qualities serving the various purposes. Clearly, providing various water qualities into residences is neither possible nor desirable. However, providing only the best water quality for all domestic purposes is equally unsuitable for reasons of resource conservation, availability and affordability. Alternative solutions could be a combination of the following:

- Make bottled water available for those usages that require the high chemical and bacteriological quality needed for human consumption and kitchen usage and provide a lesser, albeit bacteriologically and chemically safe, quality for other usages. This may seem to become financially extravagant. However, if the real cost of piping water into residences would be properly calculated (considering pipe laying/maintenance, leakage and thus chemicals and energy losses) the numbers found would become most likely equally extravagant.
- Provide, in the lower density residential areas, the needed household piping to allow for garden usage of certain parts of the water used in the household, such as bath/shower water. This water could help the fertilization of the garden while surplus water could return to groundwater.

It may be clear that some of the examples listed under 1. or 2. are valid for both industrial and urban environments.

3. Generation of waste: reconsider before considering treatment

Production of waste materials is inherent to material and energy conversion processes because 100% conversion efficiency does not exist. However, in the industrial context, production of waste points at the same time at inefficiency of conversion processes. The general wisdom response to the generation of waste is the treatment of waste. One may say that this general wisdom is so strongly entrenched that there is often no place for other alternatives. Nevertheless, both for domestic and for industrial wastes there are aspects that should be considered before considering treatment:

- Can the waste flow be reduced by modifying certain process details? Can the toxicity of the waste materials be reduced by modifying the type of (raw) input materials?
- Can the waste flow be reused or recycled (= reused after some type of pretreatment)?
- Can some of the waste materials be used (valorized) in other processes?

Moreover, by mixing potentially useful resource with waste flows, one creates a larger, albeit less concentrated, waste flow. With continuous expansion of hard cover in urban areas, the flow of rain water, discharging into sewer systems, is continually increased, adding to water pollution, disrupting operation of wastewater treatment plants and ignoring beneficial uses of rainwater. One of the latter could be the use of pre-filtered rainwater for uses such as garden watering, toilet flushing and floor cleaning.
4. **Quality of waste**

The term ‘waste’ usually refers to something that has no value. Nevertheless, rarely does waste not have a value, even though that value may not be obvious. Urine, in its concentrated form, is potentially a prime fertilizer. However, when diluted, as is the case in our water-born sanitation systems, or mixed with other types of wastes, its nutritional value becomes doubtful. Similarly, wastes from certain industrial processes, may contain valuable components. For example, wastes from the tanning process contains chromium sulfate, a chemical compound that can easily be returned to the process line. However, when mixed with unhairing salts, the reusability of the chromium sulfate is very much limited.

One can speak of a ‘clean’ waste if that waste contains chemicals from one and the same process step. Stated differently, a clean waste is a waste which, after some limited upgrading, can be recycled into the process or can be reused beneficially for very specific purposes. Alternatively, when mixing waste flows from different industrial process steps, the resulting mixture is almost impossible to convert into something benign. Therefore, in order to facilitate further use

- keep waste from different process steps separated, and
- keep concentrated waste concentrated.

Implicit in the definition of a clean waste is the virtual absence of chemical species which, at low concentration, have the potential to render a material useless. For example, the presence of a heavy metal such as cadmium may prohibit the agricultural use of an otherwise clean organic sludge. With the necessity to reduce waste flows, both from industrial and from domestic origin, through reuse, recycling and treatment, it is mandatory that commercial products become cleaner in the sense of the waste materials generated. A shampoo containing cadmium for hair strengthening may have to be modified to replace the cadmium for a more benign species or be prohibited from the market. This emphasizes the important role for the environmental legislator.

5. **Treatment: maximize reutilization**

Various ways exist to help reduce the flow of waste materials. But often, a certain flow remains which needs some type of treatment. However, even then, when treatment becomes unavoidable, various alternatives exist that may make a better use of the properties of the wastes than 'just' treatment. For example:

- In aerobic treatment, organic compounds are oxidized to become, ideally, CO$_2$. For this oxidation process to occur, *i.e.*, for aerobic microorganisms to do this job, oxygen is needed. This usually requires that oxygen is brought into the system through aeration. Aeration requires the input of energy which, in certain conditions, makes this type of treatment very expensive. Depending on boundary conditions such as waste concentration, composition and local temperature, the organic compounds may also be reduced to become, ideally, CH$_4$. For this reduction process to occur, *i.e.* for fermentative microorganisms to do this job, the absence of oxygen is required and there is production of useful energy in terms of CH$_4$ (Van Haandel & Catunda, 1997; Gijzen, 1996, 1997).
• Wastewater, specifically from domestic origin, contains nitrogenous and phosphoric compounds which, if not removed in the treatment process, contribute to eutrophication of water bodies. The widespread use of fertilizer–based agriculture has already lead to a worldwide imbalance in the N and P cycles (Gijzen & Mulder, 2001). Various techniques exist for the removal of these compounds, such as nitrification-denitrification and oxic-anoxic phosphorus removal or chemical phosphorus precipitation. In the former method, besides the energy consumption for nitrification, nitrogen gas contributes to global warming, while wasting a potentially precious nutrient compound. In the later methods, phosphorus, in some form or another, accumulates in the sludge which needs to be disposed off. Another way of reusing precious nutrients contained in wastewater, is by incorporation into duckweed, a floating green macrophyte that, with the incorporation of sunlight, absorbs rich amounts of nutrients from the water. Duckweed is used as fertilizer as well as for fodder and fish feed.

• After treatment, wastewater effluent is a potentially valuable resource. Provided toxic materials have been adequately removed from the liquid phase (i.e.), the effluent can be used for crop irrigation, specifically if containing (micro-)nutrients like N, P, Mg, K, Na, F, etc.

• If sufficiently low in salts, wastewater effluent may well be used for groundwater replenishment.

6. Resources: use and reutilize nearby

It can be safely stated that the majority of human settlements on earth started out from a location where water was considered sufficiently available. Availability of water still is a prerequisite. However, because of man-induced insufficiency at and near the original place of settlement of ground- or surface water, resource water comes from ever larger distances, continuing the process of depletion. Moreover, following generally inadequate treatment, the waste is discharged into nearby surface waters and sent away, polluting the water of downstream neighbors.

This appears an unavoidable vicious spiral in many countries leading to ever more disastrous environmental conditions of desiccation in one place and pollution in another. Breaking this vicious spiral requires adherence to the rule: use and reuse nearby. This implies that the full responsibility is assumed for the quality and the quantity of the resources. Thus wastewater can not be just discharged and sent away because at some point in the future it has to be used again for the provision of water. This brings about the clear constraint that wastewater needs to be treated to the highest possible standards in order not to contaminate ones 'own' surface water or groundwater aquifers. Moreover, the above rule dictates that when groundwater is used for the provision of water, this is only sustainable when groundwater levels are carefully maintained through recharge using well-treated wastewater or rainwater.

Water management in the city of tomorrow

The approach towards UWM of the city of tomorrow will be based on sustainability in all its depth. Table 1 compares various aspects of water management in the city of today with that in the city of tomorrow.
Table 1: Comparison of water management of the city of today and that in the city of tomorrow.

<table>
<thead>
<tr>
<th>Aspect</th>
<th>City of today</th>
<th>City of tomorrow</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>UWM organization</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Organizational structure</td>
<td>Separate entities for different types of water, covering entire urban area</td>
<td>One entity for ‘water’ covering entire urban area City subdivided in water management units (WMU) with high level of responsibility Water is a tradable good between units</td>
</tr>
<tr>
<td>2. Units</td>
<td>Depending on preference of water entities</td>
<td>Determined by possibilities to manage water within a unit</td>
</tr>
<tr>
<td>3. Philosophy</td>
<td>Various types of water have no relationship</td>
<td>Various types of water are part of the same cycle and serve various purposes at different times</td>
</tr>
<tr>
<td><strong>Drinking water</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Quality</td>
<td>One quality for all uses</td>
<td>One quality for drinking, a second quality for other uses</td>
</tr>
<tr>
<td>2. Distribution</td>
<td>Underground piping system, vendors</td>
<td>Drinking water through shops, second quality through piping system</td>
</tr>
<tr>
<td>3. Origin</td>
<td>From wherever available</td>
<td>From nearby</td>
</tr>
<tr>
<td><strong>Wastewater</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Quality</td>
<td>Any quality wastewater is accepted</td>
<td>Only ‘clean’ wastewater is accepted, dischargers responsible for quality of wastewater submitted</td>
</tr>
<tr>
<td>2. Collection</td>
<td>Collection from domestic and industrial origin to point of discharge or (central) treatment</td>
<td>Collection of ‘clean’ wastewater within the WMU to point of further processing Specific waste flows kept separate</td>
</tr>
<tr>
<td>3. Treatment</td>
<td>Predominantly of the activated sludge type</td>
<td>Further processing determined by the reuse/recovery options and the specific use of the water within the WMU Indirect reuse is objective</td>
</tr>
<tr>
<td>4. Discharge</td>
<td>Into nearest surface water</td>
<td>Depending on possibilities within WMU, e.g.: irrigation, groundwater recharge, surface water discharge</td>
</tr>
<tr>
<td><strong>Rainwater</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Approach</td>
<td>Removal as quick as possible so as not to have flooding problems</td>
<td>Make best possible use of this resource</td>
</tr>
<tr>
<td>2. Processing</td>
<td>Removal into sewer</td>
<td>Collection, temporary storage, followed by some type of treatment</td>
</tr>
<tr>
<td>3. Usage</td>
<td>None</td>
<td>Various options, e.g.: street cleaning, green areas, ground water recharge, or drinking/process water</td>
</tr>
</tbody>
</table>

The above described comparison is illustrated in Figures 4 and 5 (Otterpohl et al., 1998). Two communities are compared, one with a ‘once-through’ water management system (Fig. 4), one with a system where water is managed as a more or less closed-loop (Fig. 5). In Fig. 4 the community does not assume responsibility for water management, i.e. water is taken from elsewhere and, by discharging into a river, is sent elsewhere. Therefore, whether the wastewater gets proper treatment, groundwater is recharged or rainwater is harvested, is not an urgent matter to the community as long as there is no shortage of water.

In Fig. 5 the community accepts the full responsibility for the quality of the water since this water will, at some point in the future, be again its drinking water. Therefore, consumption determined by resource conservation, generation of clean wastes, proper treatment, maintaining groundwater resources, etc. is in the clear interest of the community.
In conclusion

Continuing the urban water practice in a ‘business-as-usual’ manner is unsustainable, has already, and will at very short notice, lead to significant problems related to public health, environment and, thus, economy. However, urban water management is not an issue that requires one and the same approach for all cities. In fact, a differentiated, approach is needed, per city and within cities, depending on a wide variety of factors and resulting in a tailored approach for different parts (center, suburbs, industrial zones, etc.). It is high time that urban managers recognize these needs and take the lead for an UWM approach based on real responsibility for water quantity and quality.
References