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Module 6
The Beneficial Uses of Stormwater in Urban Areas and the Need for Change in Urban Water Management

Introduction

This module was mostly excerpted from: R. Pitt, M. Lilburn. S.R. Durrans, S. Burian, S. Nix, J. Vorhees, and J. Martinson, *Guidance Manual for Integrated Wet Weather Flow (WWF) Collection and Treatment Systems for Newly Urbanized Areas (New WWF Systems),* originally prepared for the U.S. Environmental Protection Agency, Urban Watershed Management Branch, Edison, New Jersey, December 1999. This chapter was written by Bob Pitt.

Stormwater has classically been considered a nuisance, requiring rapid and complete drainage from areas of habitation. Unfortunately, this approach has caused severe alterations in the hydrological cycle in urban areas, with attendant changes in receiving water conditions and uses. This historical approach of "water as a common enemy" has radically affected how urban dwellers relate to water. For example, most residents are not willing to accept standing water near their homes for significant periods of time after rain has stopped. However, there are now many examples where landscape architects have very successfully integrated water in the urban landscape. In many cases, water has been used as a focal point in revitalizing downtown areas. Similarly, many arid areas are looking at stormwater as a potentially valuable resource, with stormwater being used for beneficial uses on-site, instead of being discharged as a waste. One of the earliest efforts investigating positive attributes of stormwater was a report prepared for the Storm and Combined Sewer Program of the U.S. Environmental Protection Agency by Hittman Associates in 1968. Only recently has additional literature appeared exploring beneficial uses of stormwater. This section discusses some of these progressive ideas.

Stormwater as an Aesthetic Element in Urban Areas

Dreiseitl (1998) states that "stormwater is a valuable resource and opportunity to provide an aesthetic experience for the city dweller while furthering environmental awareness and citizen interest and involvement." He found that water flow patterns observed in nature can be duplicated in the urban environment to provide healthy water systems of potentially great beauty. Without reducing safety, urban drainage elements can utilize waters refractive characteristics and natural flow patterns to create very pleasing urban areas. Successful stormwater management is best achieved by using several measures together. Small open drainage channels placed across streets have been constructed of cobbles. These collect and direct the runoff, plus slow automobile traffic and provide dividing lines for diverse urban landscaping elements. The use of rooftop retention and evaporation reduce peak flows. Infiltration and retention ponds can also be used to great advantage by providing a visible and enjoyable design element in urban landscapes.

Dreiseitl (1998) described the use of stormwater as an important component of the Potsdamer Platz in the center of Berlin (expected to be completed by the end of 1998). Roof runoff will be stored in large underground cisterns, with some filtered and used for toilet flushing and irrigation. The rest of the roof runoff will flow into a 1.4 ha (3.8 acre) concrete lined lake in the center of the project area. The small lake provides an important natural element in the center of this massive development and regulates the stormwater discharge rate to the receiving water (Landwehrkanal). The project is also characterized by numerous fountains, including some located in underground parking garages.

Göransson (1998) also describes the aesthetic use of stormwater in Swedish urban areas. The main emphasis for this study was to retain the stormwater in surface drainages instead of rapidly diverting the stormwater to underground conveyances. Small, sculpturally formed rainwater channels are used to convey roof runoff downspouts to the drainage system. Some of these channels are spiral in form and provide much visual interest in areas dominated by the typically harsh urban environment. Some of these spirals are also formed in infiltration areas and are barely noticeable during dry weather. During rains, increasing water depths extenuate the patterns. Glazed tile, small channels having perforated covers, and geometrically placed bricks with large gaps to provide water passage slightly below the surface help urban dwellers better appreciate the beauty of flowing water.

Tokyo has instituted major efforts to restore historical urban rivers that have been badly polluted, buried or have had all of their flows diverted. Fujita (1998) describes how Tokyo residents place great value on surface waterways: “waterfront areas provide urban citizens with comfort and joy as a place to observe nature and to enjoy the landscape.” Unfortunately, the extensive urbanization that has taken place in Tokyo over the past several decades has resulted in severe stream degradation and disappearance of streams altogether. However, there has recently been a growing demand for the restoration of polluted urban watercourses in Tokyo. This has been accomplished in many areas by improved treatment of sanitary sewage, reductions in combined sewer overflows and by infiltration of stormwater.

The Meguro and Kitazawa streams have been recovered by adding sanitary wastewater (receiving secondary treatment, plus sand filtration and UV disinfection, with activated carbon filtration and ozone treatment to provide further odor control) to previously dry channels. The treated wastewater is being pumped 17 km from the treatment facilities to the upstream discharge location in Meguro Stream. The Nogawa Stream has been restored by adding springwater produced from stormwater infiltration. Increased firefly activity has been noted along the Nogawa Stream and the adjacent promenade, providing adequate justification for these projects to the local citizens.

The quality of the treated wastewater entering Meguro Stream (at 0.35 m^3/s) since 1995 is as follows: total BOD_5: 6 mg/L; carbonaceous BOD_5: 2 mg/L; suspended solids: 0.5 mg/L; and ammonia-nitrogen: 7 mg/L. The total coliform bacteria concentrations were initially high (5,000 MPN/100 mL), and UV disinfection was therefore later installed at the outlets of the treated wastewater to the stream. The receiving water biological uses (carp and crustaceans) require the following conditions: total BOD_5: <8 mg/L; a water depth of at least 10 cm, and a stream velocity of at least 0.1 m/s. The BOD_5 goals are being met and the Meguro Stream has a 20 cm depth and a velocity of about 0.3 m/s. When storm events occur, remote valves are operated to decrease the discharge of the treated wastewater into the stream. However, the physical habitat of the stream is currently severely degraded, being concrete lined. The local residents are appreciative of the small flow in the stream, and the Tokyo Metropolitan Government (TMG) plans to modify the stream walls to facilitate groundwater recharge of the stream, to create rapids and pools for fish, and to plant trees along its banks, to further enhance the value of the stream to the local population.

Kitazawa Stream is another example of a severely degraded urban stream in Tokyo that has undergone extensive modification. The stream watershed is 10.5 km^2 and has a population of about 150,000 people. The rapid urbanization in Tokyo since the 1950s has resulted in a severe decrease in groundwater infiltration during rains. This has caused decreased groundwater levels and decreased the associated natural recharge into urban streams. By the 1960s, there was almost no natural flow in Kitazawa Stream during dry weather. The only flows present in the stream was wastewater from homes. The stream was therefore of extremely poor quality, creating an unsafe and nuisance condition. In addition, the increased development caused frequent flooding. The TMG therefore diverted the stream into an underground culvert. The aboveground area was converted into a promenade with extensive plantings. Recently however, local residents have requested the addition of a steam along the promenade. A very small flow (0.02 m^3/s) of treated wastewater has been pumped from 11 km away to create this new stream (a "two-storied watercourse"). Figure 2-1 (Fujita 1998) shows the changes that Kitazawa Stream has undergone as the watershed has developed. This new steam, however small, has created a very important element in the lives of the residents of this heavily urbanized city. Special community organizations have been established to plan and manage the area.

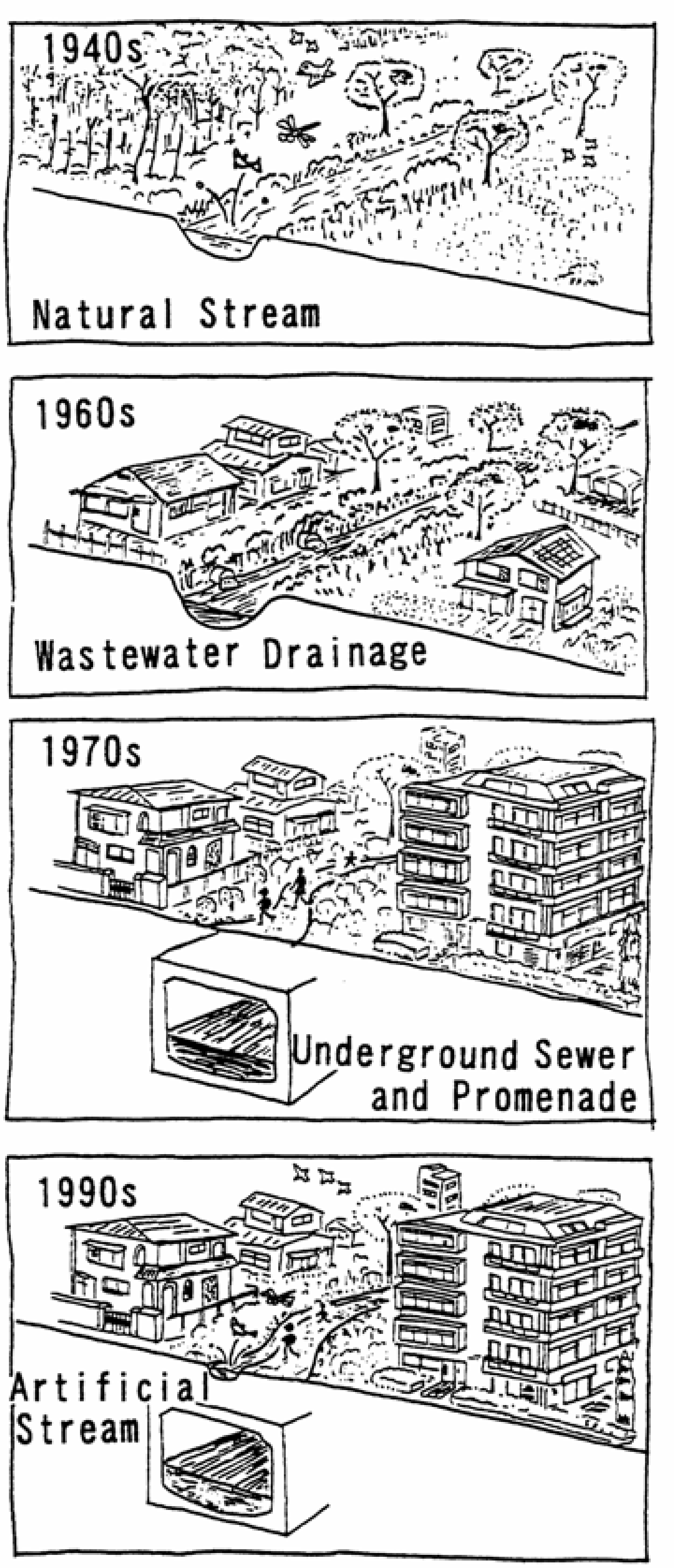

Figure 2-1. The history of Kitazawa Stream (Fujita 1998).

Another Tokyo example of urban stream rehabilitation has occurred in the Nogawa Stream watershed. The watershed is about 70 km^2 in area and has a population of about 700,000 people. Urbanization in this area also dramatically decreased the natural groundwater recharge to the stream. With development, household graywater, some sanitary wastewater, and stormwater were infiltrated into the ground and recharged the stream. When the sanitary wastewater collection and treatment system was improved in the 1980s, the stream flow was severely diminished, as a major source of groundwater recharge was eliminated. The headwater springs in the Nogawa area were of special importance to the local residents and they requested that TMG restore the dried springs. Artificial groundwater recharge, using stormwater, has been successfully used to restore the springs. Many private homes have installed stormwater infiltration devices in the area. In an example in Mitaka City, 4,000 infiltration "soakaways" were constructed during the three years from 1992 to 1995, allowing about 240,000 m^3/yr of stormwater to be infiltrated to revitalize the spring at Maruike. Koganei City residents installed more than 26,000 soakaways and 10.4 km of infiltration trenches at 5,700 homes (about 25% of all of the homes in the area). Other cities in the area have also helped residents install several thousand additional infiltration facilities. Spring flows have increased, although quantitative estimates are not yet available.

Fujita (1998) repeatedly states the great importance that the Japanese place on nature, especially flowing water and the associated landscaping and attracted animals. They are therefore willing to perform what seems to be extraordinary efforts in urban stream recovery programs in the world's largest city. The stream recovery program is but one element of the TMG's efforts to provide a reasonably balanced urban water program. Water reuse and conservation are important elements in their efforts. Stormwater infiltration to recharge groundwaters and the use of treated wastewaters for beneficial uses (including the above described stream restoration, plus landscaping irrigation, train washing, sewer flushing, fire fighting, etc.) are all important elements of these efforts, although this reuse currently only amounts to about 7% of the total annual water use in Tokyo.

Guidelines for the Reuse of Stormwater in Urban Areas

An obviously important consideration when examining the reuse of stormwater is the different quality requirements for the different reuse activities. Reuse guidelines are relatively rare, but Table 2-1 presents some guidance from Japan (Fujita 1998). The most serious restrictions relate to ensuring the safety of the water during inadvertent human contact. The prevention of nuisance conditions is also of concern.

Table 2-1. Quality Standards for the Reuse of Treated Wastewater in Japan (Fujita 1998)[1]

	Toilet Flushing	Fire Sprinklers	Landscape Irrigation	Recreation Use
Total Coliforms (MPN/100 mL)	<1,000	<50	<1,000	<50
Residual Chlorine (mg/L)	present	>0.4		
Color (Pt units)	No unpleasant appearance	No unpleasant appearance	<40	<10
Turbidity (NTU)	No unpleasant appearance	No unpleasant appearance	<10	<5
BOD_5 (mg/L)	<20	<20	<10	<3
Odor	Not unpleasant	Not unpleasant	Not unpleasant	Not unpleasant
pH	5.8 – 8.6	5.8 – 8.6	5.8 – 8.6	5.8 – 8.6

[1] In addition, the objectives for carp and crustaceans in urban streams include the following: total BOD_5: <8 mg/L; a water depth of at least 10 cm, and a stream velocity of at least 0.1 m/s.

Table 2-2 shows Maryland's reuse guidelines, along with acceptable use categories and per capita requirements (Mallory 1973). Only a small fraction (<10%) of the total residential water use requirements need to be of the highest quality water. Class AA water meets all U.S. Public Health Service Drinking Water Standards, class A water is very similar, except for taste and odor considerations, class B water has less restrictions, especially with respect to suspended solids, and class C water only has minimum requirements pertaining to corrosivity. All of these waters require disinfection by the state of Maryland. It is not likely that stormwater would be used for class AA uses without conventional water treatment, but lower levels of use may be feasible. Table 2-3 shows the specific maximum concentrations allowed for each reuse category, as determined by the state of Maryland, in addition to typical residential area stormwater quality. Average stormwater concentrations are presented, as needed storage would provide equalization of concentrations over short periods of time.

Table 2-2. Distribution of Maryland Residential Water Use and Required Quality (Mallory 1973)

Class	Use	Rate of Use (gal/person/day)	Percentage of Total Water Use
AA	Consumption by humans, food preparation, general kitchen use	6.5	7
A	Bathing, laundering, auto washing	31.0	36
B	Lawn irrigation	518 gal/day/acre	29
C	Toilet flushing	24.0	28

Table 2-3. Maximum Concentrations Allowed by Maryland for Different Reuse Categories, Compared to Typical Residential Stormwater Runoff (Mallory 1973)

Constituent (mg/L)	AA	A	B	C	Typical average residential stormwater quality and highest use without treatment (various references)
Total solids	150	500	500	1500	250 (A)
Suspended solids	-	-	10	30	50 (none)
Turbidity (NTU)	0-3	3-8	8-15	15-20	25 (none)
Color (color units)	15	20	30	30	25 (B)
pH (pH units)	7	6	6	6	6 to 9 (AA)
Oxygen, dissolved (minimum)	5	5	4	4	Near saturation (AA)
Total coliform bacteria (MPN/100 mL)	1	70	240	240	>10,000 (none)
Ammonia (as NH_3)	0.5	0.5	0.5	0.5	<0.1 (AA)
Nitrate (as NO_3)	45	50	50	50	1 (AA)
Phosphates	1	1	1	1	0.5 (AA)
Calcium	0.5	75	75	75	10 (A)
Chloride	50	250	250	250	<50 (AA)
Fluoride	1.5	3	3	3	0.03 (AA)
Iron	0.1	0.3	0.3	0.3	
Magnesium	0.5	150	150	150	1 (A)
Manganese	0.05	0.1	0.5	0.5	
Sulfate	50	200	400	400	10 (AA)
Arsenic	0.01	0.05	0.05	0.05	<0.05 (A)
Chromium (+6)	0.05	0.05	0.05	0.05	<0.05 (AA)
Copper	1.0	1	1.5	1.5	0.05 (AA)
Cyanide	0.01	0.2	0.2	0.2	0.05 (A)
Lead	0.05	0.1	0.1	0.1	0.05 (AA)
Zinc	5	15	15	15	0.5 (AA)

As shown on these tables, residential area stormwater can be used to meet at least class A water needs, except for suspended solids, turbidity, color, and coliform bacteria. The solids, turbidity and color levels are likely to be adequately reduced through storage and associated settling, plus possible post-settling filtration. The most serious impediment for the reuse of stormwater in residential areas are the bacteria levels. Unfortunately, stormwater is known to contain pathogens that can cause illness through various exposure mechanisms. However, it must be remembered that stormwater currently comes in contact with many people during rains and runoff from roofs and paved areas are encouraged to drain to landscaped areas to reduce runoff quantities. These practices are not considered hazardous and have not shown detrimental effects. Never-the-less, total coliform bacteria levels in stormwater can be very large, much greater than 10,000 MPM/100 mL and greatly exceed reuse criteria. The criteria for reuse shown on Table 2-3 requires a maximum total coliform level of 240 MPM/100 mL for class B and C water, and a level of 70 MPM/100 mL for class A water. Drinking water (class AA water) requires a maximum of 1 MPM/100 mL. Any of these levels would be impossible to meet without significant disinfection efforts.

Another set of reuse guidelines has been developed in California and are shown on Table 2-4. These guidelines were developed for the reuse of high quality secondary domestic wastewater effluent. The median total coliform bacteria criteria are very stringent (to product the public from likely associated pathogens) and would also not be possible to be met without very significant disinfection efforts. The only uses where primary treatment alone (similar to detention) is needed, and for which no total coliform bacteria criteria are given, are for the irrigation of fodder crops, fiber crops, seed crops, and for surface irrigation of processed produce. As indicated in Table 2-4, irrigation in areas where public contact is likely requires disinfection and very low levels of total coliform bacteria.

Table 2-4. California Reuse Guidelines (Metcalf and Eddy 1991)

Use of reclaimed water	Secondary treatment and disinfection	Secondary treatment, coagulation, filtration, and disinfection	Total coliform bacteria criteria (MPN/100 mL, median of daily observations)
Landscaped areas: golf courses, cemeteries, freeways	required		23
Landscaped areas: parks, playgrounds, schoolyards		required	2.2
Recreational impoundments: no public contact	required		23
Recreational impoundments: boating and fishing only	required		2.2
Recreational impoundments: body contact (bathing)		required	2.2

Metcalf and Eddy (1991) state that primary treatment (similar to settling in a storage tank) reduces fecal coliform bacteria by less than 10%, whereas trickling filtration (without disinfection) can reduce fecal coliform levels by 85 to 99%. Chemical disinfection is usually required to reduce pathogen levels by 99.9+%, as likely needed to meet the above bacteria criteria for even the most basic water uses. Because of the risks associated with potential pathogens, reuse of stormwater in residential areas should only be considered where consumption and contact is minimized, restricting on-site reuse to classifications B and C, and only after adequate disinfection and site specific study to ensure acceptable risks. To further minimize risks, only the best quality stormwater (from a pathogen perspective) should be considered for reuse. As an example, residential area roof runoff generally has lower fecal coliform concentrations than runoff from other source areas, although very high levels are periodically observed from this source area. Therefore, stormwater "harvesting" efforts could be limited to residential area rooftops to reduce risks associated with pathogens. The following subsection explores this example of reuse.

The Urban Water Budget and Stormwater Reuse in Residential Areas

Developing an urban water budget is the initial step needed when examining potential beneficial uses of stormwater. The urban water budget comprises many elements, stormwater being just one. As an example, it is possible to determine the likelihood of supplying needed irrigation water and toilet flushing water (reuse classifications B and C) from the stormwater generated from roof runoff by conducting an urban water budget. This budget requires a knowledge of all water sources and uses, and the associated quality requirements. Another important element is understanding the timing of the water needs and supplies. For example, the following lists household water use for a typical home (2 working adults and one child) in the southeast, where the rainfall averages about 50 inches per year:

- bathing 42%
- laundry 11%
- kitchen sink 15%
- dishwasher 8%
- bath sinks 12%
- toilet flushing 12%

Because this was a working family and the child was in school, bathing water use was relatively high, while the toilet flushing water use was relatively low. There were also wide variations in water use for different days of the week, with weekday water use (especially toilet flushing and laundry) being substantially less than for weekend water use. The household water use was relatively constant throughout the year and averaged about 90 gpcd (gal/capita/day), ranging from 77 to 106 gpcd. There were no water conservation efforts employed during the two year observation period. Outside irrigation water use during the dry months averaged about 50 gallons per day (for a ½ acre landscaped area) above the inside water uses listed above. Landscape irrigation may occur for about 2 months at this level of use in this area.

The estimated roof runoff for a typical 2,000 ft^2, 1- ½ level, house (roof area of about 1300 ft^2) would be about 40,000 gallons per year, for this area having about 50 inches of rain a year. The total water use for this household is about 100,000 gallons per year, with the amount used for toilet flushing being about 12,000 gallons, with another 3,000 gallons used for landscaping irrigation. For this example, the roof runoff would supply almost three times the amount of water needed for toilet flushing and landscape irrigation. None of the other household water uses would be suitable for supply by roof runoff. The rainfall varies between about 3 to 5 inches per month, with a rain occurring about twice a week on the average. Rainfall only once every two weeks can occur during the most unusual conditions (the driest months when landscaping irrigation is most needed). Therefore, a simple estimate for required roof runoff storage would be two weeks for average toilet flushing (450 gallons), plus two weeks for maximum landscaping irrigation (700 gallons). A total storage tank of 1250 gallons (a typical septic tank size) would therefore be needed. Of course, a factor-of-safety multiplier can be applied, depending on the availability of alternative water sources.

For a typical 0.5 acre residential lot in the southeast, the annual stormwater generated would be about 170,000 gallons per year. The roof would produce about 25% of this total, pavement would produce another 25%, and the landscaped area would produce about 50% of this total. Therefore, the amount of stormwater used on-site for toilet flushing and irrigation of landscaped areas would be only about 10% of the total generated. Therefore, most of the runoff would still have to be infiltrated on-site, or safely conveyed and discharged.

Other locations would obviously result in different water needs that could be supplied by runoff, depending on rainfall, soil conditions, and household water use patterns. Mitchell, *et al*. (1996) reported that on-site graywater and rain storage for re-use resulted in about 45% reductions in imported water needs, about 50% reductions in stormwater runoff, and about 10% reductions in wastewater discharges at two test developments in Australia. In most areas, Heaney, *et al*. (1998) reports that indoor water use is relatively constant at about 60 gpcd, with conservation practices, especially the use of low-flush toilets, possibly reducing this need to about 35 to 40 gpcd. Toilet flushing is about 30% of this use. In the arid parts of the U.S., landscaping irrigation can be the most important use of domestic water.

Heaney, *et al.* (1998) also reported the results of using water demand models to estimate the fraction of typical household irrigation water needs that could be satisfied by storing and using stormwater. Most eastern and west coast areas were able to satisfy their irrigation needs by storing stormwater for use on-site. Over 90% of the irrigation needs could be satisfied by stormwater re-use in the Rocky Mountain area and in the semi-arid southwest. The desert southwest was only able to supply about 25% of their irrigation needs with stormwater. Either supplemental irrigation, or the more appropriate selection of landscaping plants, would therefore be needed in these desert areas. Storage tank sizes varied widely and were quite large. Central Texas (San Antonio) required the largest tank size (25,000 gallons), while most of the eastern areas of the U.S. required less than 5,000 gallon tanks.

There are many areas that benefit from using poor quality water. A review by Paret and Elsner (1993) reported that some Florida golf courses use about 2,000 gal per acre per day of reclaimed sanitary wastewater. Other major Florida users of reclaimed sanitary wastewater include agricultural, horticultural and commercial users at about 1,500 gal per acre per day, and multifamily residential developments using about 3,000 gal per acre per day. The service fees for this reclaimed water ranged from about $0.05 to $0.64 per 1,000 gallons. Obviously, stormwater could be used for similar purposes, if stored and adequately treated. As an example, several new Veterans Affairs hospitals in the Los Angeles area are heavily landscaped using wet detention ponds holding stormwater tied into their fire fighting systems.

Besides on-site reuse of stormwater, dual distribution systems may be a feasible choice for many conditions. A dual water supply system includes a conventional domestic water supply system carrying class AA water for human consumption and bathing. Another water supply system is also used in a dual system carrying water of a lesser quality. This water is typically used for B and C uses, plus fire fighting. In areas having dual distribution systems, the poorer quality water is typically secondary sewage effluent that has received additional treatment, as noted above. Okun (1990) states that "throughout the world, dual distribution systems are proliferating, speeded up by policies adopted by states in the U.S. and governments elsewhere." He points out that a common feature of these water reuse/dual distribution systems is that customers pay for the reclaimed water, but at a significantly reduced price, compared to typical domestic water. He concluded that a sustainable wastewater reclamation program can only exist with cost recovery.

Even though most of the examples of dual distribution systems and wastewater reclamation are for sanitary wastewater, stormwater may be a much preferable degraded water source for reclamation (NAS 1994). Stormwater does not require nearly as high of a level of treatment, but it is not conveniently collected at one location such as at a wastewater treatment plant, nor is it available at such a constant and predicable flow as sanitary wastewater. However, the large volumes available and its generally better quality may make stormwater a more feasible water for dual distribution systems in many situations.

The Need for Change in Urban Water Management

As indicated above, stormwater can be considered a valuable resource in urban areas, not just a waste that must be rapidly discarded. Many have recognized this potential resource, as briefly outlined above. The *Symposium on Water, the City, and Urban Planning* was held in Paris, France, on April 10 and 11, 1997. The 300 participants formulated the *Paris Statement* outlining needed changes in urban water management. Even though stormwater management is usually considered a luxury of the developed countries (especially North America, Western Europe, and a few major Asian cities), this symposium stressed the need for recognizing the important role that stormwater management can play in the developing countries. Some of the major points of the *Paris Statement* are briefly outlined below:

- The marked process of urbanization in most countries, and especially in the developing world, is causing very rapid increases in water demands, often far outstripping available resources. Water management needed for sustainable urban development, let alone long-term survival of cities, requires immediate attention.

- Water related problems are affected by all elements of the water cycle, including water, land, air, and energy. Social, cultural, political, institutional, and economic aspects are integral and may even be dominant components of urban water management issues. Therefore, an integrated approach for solving urban water resource problems is necessary.

• Each city has a unique set of conditions and problems that require site specific solutions. However, a great deal of information from cities throughout the world is available for helping to solve these local problems.

• Demand management measures to encourage water conservation needs to be implemented, along with the timely consideration of environmentally sound projects to increase the availability of water when and where it is needed. Water problems are recognized mostly as temporal and spatial distribution problems, not because there is a fundamental shortage of water.

• An integrated management approach to surface and groundwaters is needed. Groundwater contamination by urban wastes must be controlled and safe recharge of groundwaters by wastewater and stormwater needs to be investigated.

• Appropriate approaches for urban drainage must consider variations in local climate, types of problems, and economic and maintenance capabilities. In addition, non-structural solutions need to be implemented as part of an integral approach to flood control in urban areas.

• There is a great need to conceive and apply new innovative solutions to solve urban water resource problems. This is especially likely and needed in areas with little drainage and sanitation infrastructure currently in place.

• The symposium recommended the creation of a single and integrated entity for coordination and management of water resources in each urban area.

Numerous papers were presented at the Engineering Foundation/ASCE sponsored symposium on *Sustaining Urban Water Resources in the 21st Century*, held in Malmo, Sweden, in September 1997, describing many international examples of effective urban water resources management. Sulsbrück and Forvaltning (1998) describe renovations being made to the drainage systems in Hillerød, Denmark. The town has 34,000 inhabitants, with about 600 mm or rainfall per year. The receiving water streams are quite small, being about 1 to 3 m across and have an annual average flow of about 600 L/s. About 3.5 km^2 of the drainage area has separate sanitary and storm sewers, while about 12.5 km^2 has combined sewers. The average dry weather flow to the treatment plant is about 14,000 m^3/day, and about 5,000 to 6,000 m^3 per day is lost to infiltration through leaky sewers. The amount lost through infiltration is about equal to the annual stormwater flow. Major sewer renovations are occurring to correct the leaking sewers and to minimize CSOs. Residential roof runoff is required to be infiltrated in newly developing areas, unless building moisture problems prevent its use. Industrial area runoff in new areas is directed to separate storm sewers, and detention facilities are being built to reduce stormwater flows to the streams to a maximum of 0.6 to 1 L/s/ha of drainage area. The sizes of the detention ponds range from 500 m^2 to 65,000 m^2. The total capacity of the retention ponds were 60,000 m^3 in 1997, with an additional 15,000 m^3 planned. The volume of CSOs was about 470,00 m^3 in 1990 and is expected to decrease to about 130,000 m^3 by 2001. Residential area roof runoff is not considered to cause pollution problems to soil or groundwater, while roadway runoff is usually not allowed to be infiltrated because of contamination concerns. Infiltration trenches are being retro-fitted at private homes, with labor provided by unemployed workers, who are paid by the government. The trenches are designed for a 2-year return period storm, the same as the storm sewers. The trenches for a typical 150 m^2 home range from 6 m long for gravelly soil sites to 24 m long for silty soil sites and cost about US$2,000 to construct (for a typical 9 m trench). They found that the use of combined sewers with infiltration is comparable in cost and pollutant discharges with a separate stormwater system. However, the infiltration system dramatically improves groundwater conditions, especially with the repair of the leaky sewers.

The local residents also have had a change in attitude towards stormwater management. Runoff is now regarded as a resource instead of a waste. Sulsbrück and Forvaltning (1998) state that "many small, fine, green oases have been provided at the detention pond sites for citizen enjoyment and as habitat for plants and animals."

A paper presented by Geldof (1998) at the Malmo conference on *Sustaining Urban Water Resources in the 21st Century* described changes that are occurring in the Netherlands. He stated that Dutch urban surface waters tended to be neglected in the past because of their poor water quality. However, current thinking is stressing significant changes in urban water management that will decrease many current problems (such as leaking sanitary and combined sewerage, discharges caused by peak flows, groundwater elevation variations and subsidence, and eutrophic surface waters). Two main changes are being used: changes in the sewerage systems, and increased source controls with on-site reuse of stormwater. In the Netherlands, combined sewers serve about 75% of the urban areas and have a capacity for about 7 mm or rain. Overflows occur when the rainfall exceeds this amount (as often as ten times a year). Separate sewers have been mostly built since the 1970s and now serve most of the remaining urban land area. The separate sewers solved the combined sewer overflow problems, but surprisingly did little to improve the annual mass discharges of pollutants. With separate drainage systems, none of the stormwater is treated at the municipal wastewater treatment plant. In addition, inappropriate discharges of sanitary sewage to the storm sewers are periodically found from inadvertent connections. A new system, termed an "improved separate system", was therefore developed. This drainage system consists of separate sanitary and storm drainage, but they are cross-connected with one-way gate valves enabling some stormwater to enter the sanitary drainage and be treated at the municipal wastewater treatment facility. The one-way gate values prevent sanitary sewage from entering the storm drainage. Pressurized sanitary sewerage is also sometimes used, with pumps used to discharge appropriate amounts of stormwater into the sanitary sewage system. An important aspect of the improved separate system is that only the most contaminated stormwater enters the stormwater drainage system and then the sanitary wastewater collection system for conveyance to the treatment facility. The least contaminated stormwater (typically just the roof runoff) is infiltrated on site, or potentially also used for toilet flushing, laundry, or irrigation purposes. The improved separate systems typically have a conveyance capacity to handle a 4 mm rain, which is capable of directing about 75 to 90% of the paved area stormwater runoff to the treatment facilities. Geldolf reported that a surprising side effect of source control is that it tends to upgrade people's perception of stormwater: "it becomes a pleasure rather than a nuisance." He also reports that residents have even become competitive about how they can most effectively use stormwater on site.

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