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INFLUENTS

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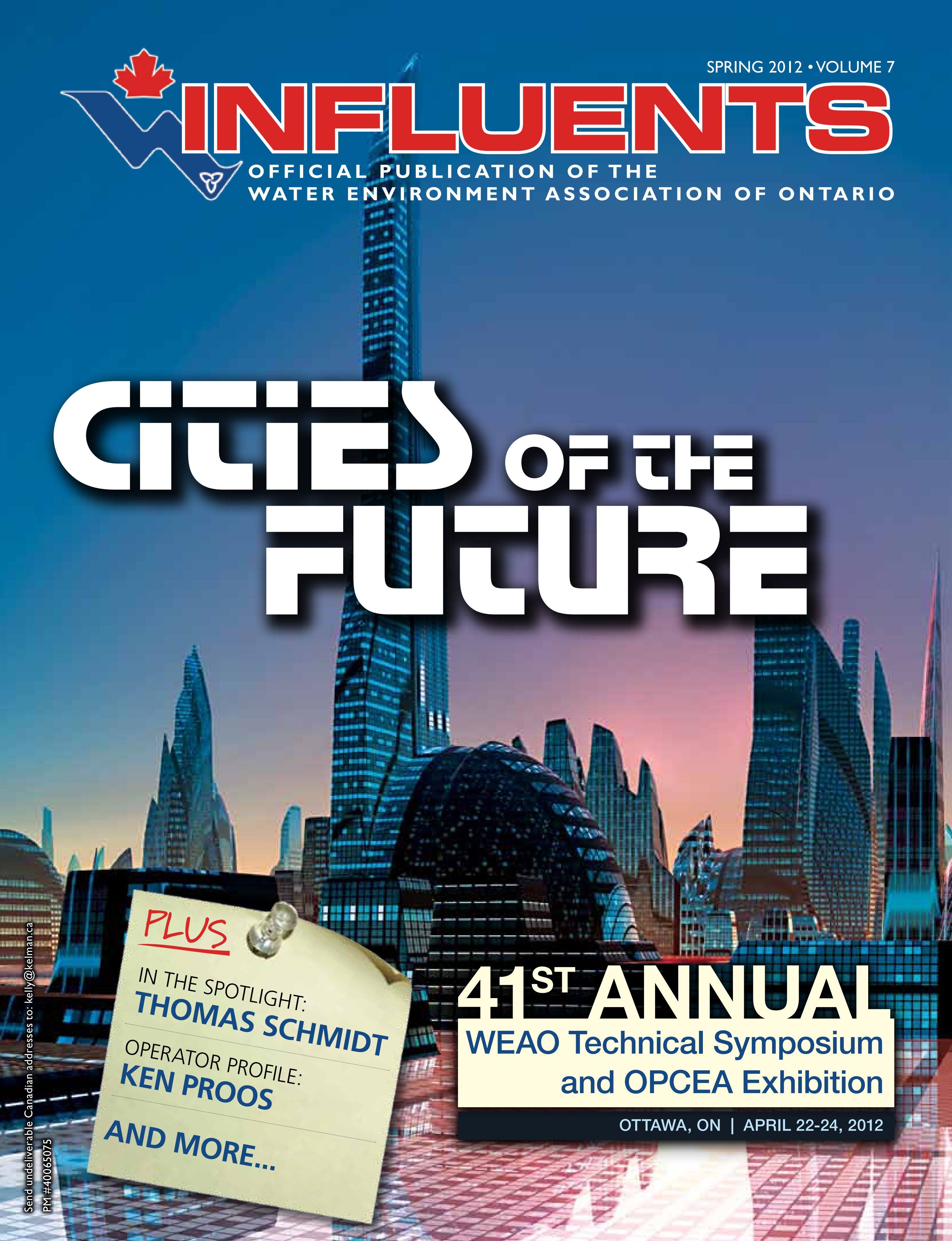

CITIES OF THE FUTURE

PLUS

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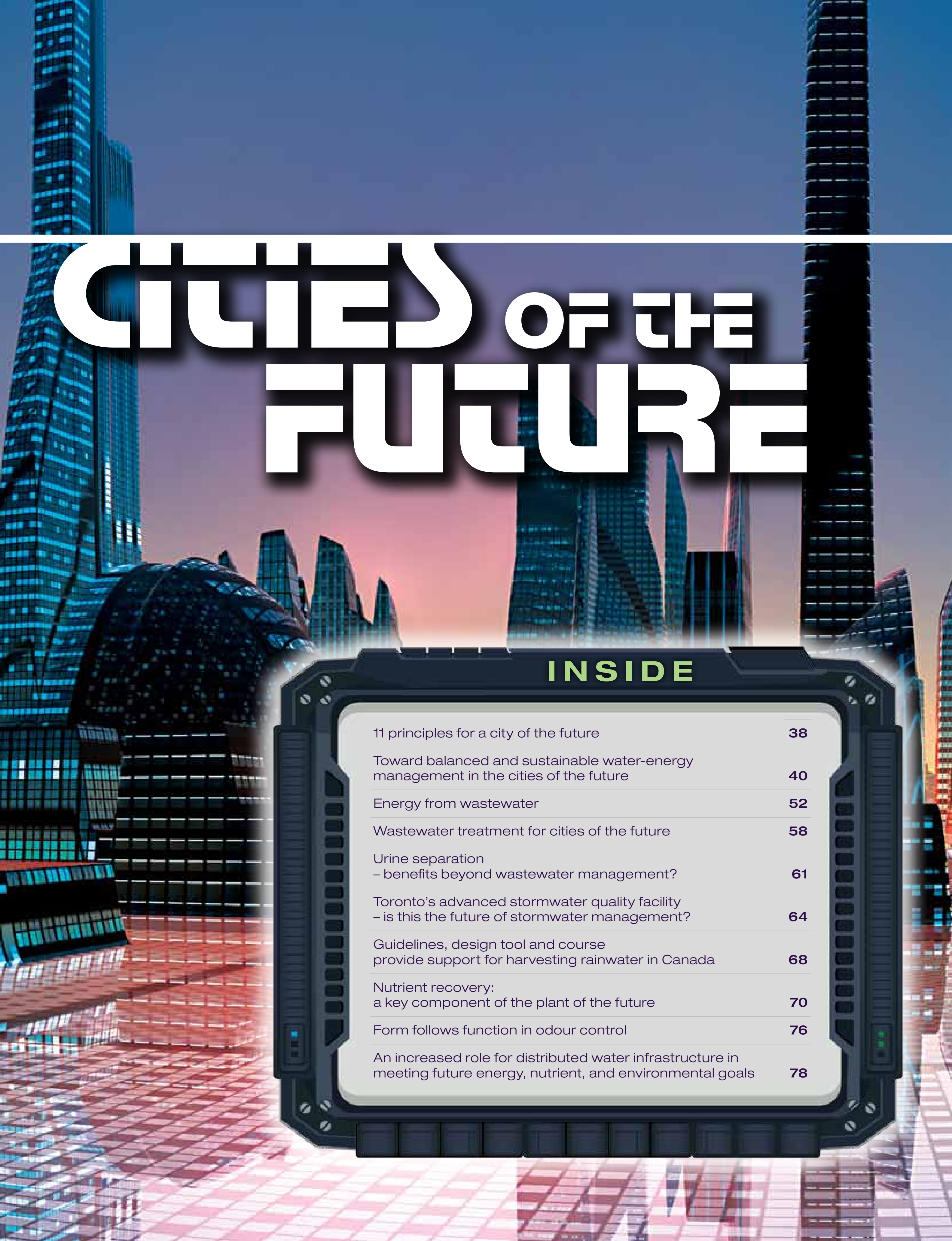

CITIES OF THE FUTURE

INSIDE

11 principles for a city of the future

International Water Association

THEME 1: LIVEABLE AND SUSTAINABLE CITIES

PRINCIPLE 1: Cities will continue to grow in population, but will be increasingly liveable. Interconnected communities will be a more common feature of cities.

Cities are complex, dynamic systems that are likely to become more complex over time. Cities will continue to offer lifestyles and opportunities—jobs, cultural attractions, recreation, and sporting attractions—that attract people in abundance. Principle 1 recognizes that people value a liveable city that provides the amenity and space to maintain local connections and healthy communities.

PRINCIPLE 2: Sustainable cities will combine a compact footprint with sustainability and liveability.

Sustainable cities of the future will become more sustainable and liveable by matching higher-density living with 'green' urban design and by linking spaces to provide easy access to other parts of the city. Lower-density living will also be available within the city to provide a range of living options.

More water-sensitive cities will be greener and, therefore, cooler. With lower 'urban heat island' effects (the tendency of urban areas to be hotter than their more vegetated surroundings), these cities will be healthier places to live.

PRINCIPLE 3: Cities will be resource neutral or generative, combining infrastructure and building design that will harmonize with the broader environment.

The urban form will generate water, energy, and nutrient by-products that can meet the city's resource demands in a way that is carbon neutral. Some cities may generate resources in excess of their needs and be able to supply demands in surrounding regions. Cities will also be designed to operate in harmony with the broader environment. For example, cities will release water into the environment consistent with natural environmental flow patterns.

PRINCIPLE 4: Sustainable cities will be part of prosperous, diverse, and sustainable regions.

Cities will not function as isolated entities. Instead they will function in harmony with their regional partners, respecting 'local identity' and valuing the flow of resources, people, and information between the two.

Cities will enjoy prosperous economies built upon sustainable communities, and their citizens will act to bring out the best in themselves and their surrounding regions.

THEME 2: THE MANY VALUES OF WATER

PRINCIPLE 5: Sustainable cities will be served by a well-managed water cycle that, in addition to public health and water security, provides for healthy waterways, open spaces, and a green city.

Water will be managed across the water cycle and watershed to deliver economic and social value for the community, and to protect and enhance environmental values and biodiversity.

PRINCIPLE 6: Sustainable cities will recognize that all water is good water, based on the concept of 'fit-for-purpose' use.

It will be recognized that water has many different values and 'fit-for-purpose' uses. All water comprising the urban water cycle (including stormwater and wastewater) will be highly valued and managed to deliver optimal environmental and social outcomes.

THEME 3: CHOICE, PRICING, AND CONSUMPTION

PRINCIPLE 7: Cities will be served by informed, engaged citizens and multi-scale governance that enables local community choice.

Communities place greater value on their resources where they have greater control over them. On this basis, water will be valued and used best when its users are informed and able to exercise appropriate levels of local choice. Communities will choose the future of their cities and the way that they live in these spaces. They will choose the pathways that they take to get to reach these goals.

PRINCIPLE 8: Customer sovereignty with full environmental and social cost.

As customers and developers, cities will be able to pursue their individual choices while ensuring sustainable outcomes by bearing the full environmental and social cost of those choices. Being fully informed and bearing the full costs of their decisions will prompt businesses and individuals to demand efficiency and affordability in the actions that shape water consumption (e.g., water-sensitive urban design in the case of builders and developers, recycled water systems, water-efficient appliances). Citizens will have a well-developed sustainability ethic that informs all of their decisions.

PRINCIPLE 9: Accurate and useful information, including smart metering.

Informed citizen choice depends upon full knowledge of the available resources, the potential benefits of different options, and ongoing performance evaluation. Cities will draw more fully on intelligent information and management systems across a full range of networks, including smart water-system design to provide information to system managers and users. These systems will synthesise data from across the water cycle and share it across utilities and customers to inform decision making.

THEME 4: ADAPTIVE AND COLLABORATIVE WATER SECTOR

PRINCIPLE 10: Sustainable cities will be served by adaptive and integrated approaches to urban development.

Sustainable cities of the future will be realized when the sectors that supply services to cities work more closely with governments, planners, businesses, and the community from the first stages of urban planning. Given the links between water, city shape and design, and energy consumption, a transformation in these and other sectors to more integrated planning will underpin the development of resilient cities in the future. This integration will occur at all scales of planning.

PRINCIPLE 11: Sustainable cities will be served by a multifaceted water-management system.

The water sector will become more diverse and dynamic, drawing on integrated solutions within the water sector, across sectors, and including government and the community. ♦

Extracted from the 2010 International Water Association Discussion Paper *IWA Cities of the Future Program Spatial Planning and Institutional Reform*, September 2010. For more information about the Cities of the Future, visit *www.iwahq.org/3p* and *www.iwawaterwiki.org/xwiki/bin/view/Organizations/+Cities+of+The+Future*.

IWA Cities of the Future program

The International Water Association (IWA) Cities of the Future program focuses on water security for the world's cities and how the design of cities—and the water management, treatment, and delivery systems that serve them—could be harmonized and re-engineered to minimize the use of scarce natural resources and increase the coverage of water and sanitation in lower-and middle-income countries.

The program's goal is to establish IWA (and its members) as an international authority and reference centre for all water-related aspects of Cities of the Future. As an international leader in the water sector, IWA has the responsibility and the ability to help cities, utilities, and the consulting and research community work together to create robust and resilient responses to these imminent changes. However, the responses that appear to be most appropriate will require new kinds of partnerships, new relationships, and a new sense of the interconnectivity between the sectors, the people, and the ecosystems that support them.

Montreal Declaration on Cities of the Future (27 September 2010)

The purpose of this declaration is to ensure that all International Water Association (IWA) activities contribute to the achievement of sustainable, resilient, and liveable cities of the future. This is urgent given the significant risks associated with climate change impacts and the rapid shift and change in world population in urban areas, particularly in developing countries.

INTENT:

- Encourage the global water community to elevate the role of water management as a central element of sustainable, resilient cities.
- Promote localized community solutions in the context of wider integrated city systems (interconnected smart systems).
- Recognize that all water is good water and that future efficiency will include matching quality to use.
- Promote water literacy in our communities to enable active participation in decision-making.
- Strive for an adaptive and collaborative water sector.
- Demonstrate leadership to other sectors in planning for sustainable cities.

ACTIONS FOR IWA MEMBERS:

- Continue to work toward achieving 100% access to safe drinking water and sanitation and making these services affordable for all.
- Actively seek to ensure that water is an equal driver for the planning of sustainable city creation and redevelopment by collaborating with planners and other sectors (e.g., transport energy).
- Focus on designing toward resource neutrality and zero-emissions technologies where energy-water relationships are optimized.
- Promote solutions that link cities beneficially with the water needs of the community, energy, agriculture, industry, and the environment.
- Actively seek to develop management and technical systems that are flexible and forward looking—robust and adaptable to new and changing requirements.
- Demonstrate and measure the contribution of the water sector to city liveability, including aesthetics, public health, environmental values, and quality of life.
- Undertake meaningful communication and education activities that support achieving sustainable and liveable cities and communities, and build the skills to measure and understand community expectations and values.
- Promote improved governance in terms of regulations, financing, and institutional arrangements that maximize opportunities and remove impediments and barriers.

Toward balanced and sustainable water-energy management in the cities of the future

Vladimir Novotny, Ph.D., P.E., BCEE, professor emeritus, Marquette University and Northeastern University and partner AquaNova LLC.

The world is undergoing rapid urbanization, driven by the population increase and migration. According to the United Nations (2010) statistical projections, the world population will increase from 7 billion in October 2010 to 9.3 billion by 2050, of which 68% will be living in urban areas. In the US and Canada, the total population in 2050 is expected to reach 493 million (446 million in the US and 47 million in Canada), and it will be 82% urban. In China, the total population between 2010 and 2050 is actually expected to drop by 46 million to 1.295 billion, but the urban population will increase because of migration and resettlement by an astounding 400 million to 1.038 billion, 80% of the total. Even more rapid growth and urbanization is expected in India, which, by 2050,will become the most populous country in the world. This rapid urbanization is giving rise to a number of megalopoli (cities with more than 5 million people) and mega-regions or continuous urban agglomeration (e.g., Toronto and the Canadian shore of Lake Ontario; New York City-New Jersey-Connecticut; Los Angeles-Orange County-San Diego). By 2050, the Hong Kong-Shenzen-Guanzhou urban megaregion in China will be home to more than 120 million people. Other extra-large urban megaregions are developing in Japan (Tokyo-Yokohama and Osaka-Kobe-Kyoto-Nagoya), India, Brazil, and West Africa (Lagos, Nigeria).

In the next 40 years, the impact of vast migration will be compounded by the anticipated adverse effects of global climate change caused by greenhouse gas emissions. The frequency of extreme temperatures, droughts, and extreme storms, has been already noticed in this century and will become worse by 2050.

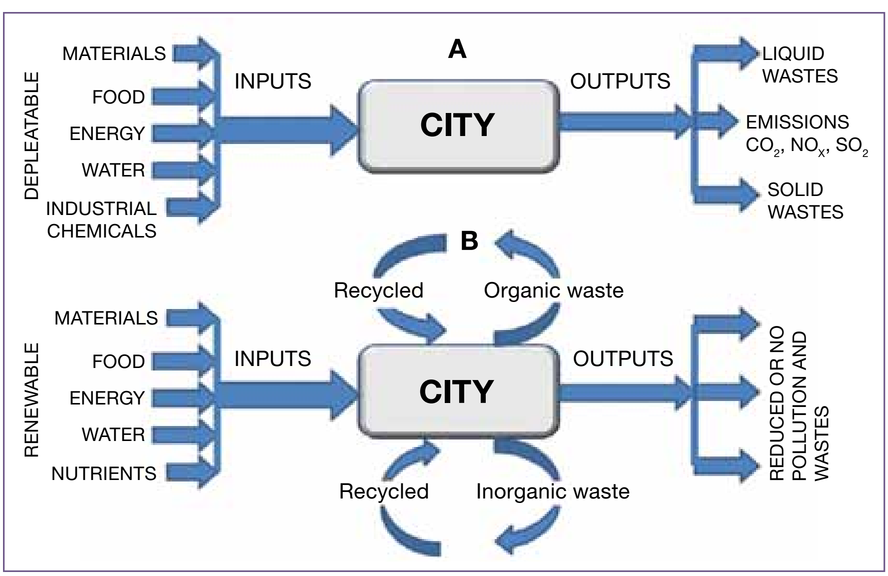

Figure 1: (A) Linear and (B) circular urban metabolism systems. From Novotny et al., 2010

Scientists and professionals realized that, if current trends in urbanization and building persisted, the demand for water and energy would increase greenhouse gas (GHG) emissions and diminish natural resources. This demand is unsustainable and, in some cases, devastating. Beneath the urban areas that have been created, old infrastructure is leaking and crumbling. The combined cost of infrastructure replacement and adaptation to climate change will exceed trillions of dollars.

The current 'fast conveyance-end-of-pipe control' water, stormwater, wastewater paradigm has forced planners and engineers to implement ever increasing imperviousness, larger interceptors and tunnels, longer transmission distances for water and wastewater, and lining, fencing off and burying the urban streams. However, because of the hard conveyance and treatment costs, infrastructures in developed countries were designed to provide only five to 10 years of protection against flooding and rather minimal protection against polluting overflows. Such systems are usually unable to safely deal with the extreme events and sometimes fail with serious consequences *(Novotny and Brown, 2007; Novotny et al., 2010)*. Most megacities in developing countries lack adequate sanitation and drainage, but following the old paradigms of developed countries would be a mistake and economically impossible.

Water and energy uses are intertwined and represent a significant portion of the total GHG emissions reaching the atmosphere. Based on US Environmental Protection Agency and Intergovernmental Panel on Climate Change (2007) statistics, about 3–7% of the total energy use and the equivalent portion of GHG emissions are attributed to water and wastewater delivery, treatment, and disposal. Far more energy unaccounted in the 3% is used for heating water. A more detailed

analysis of water use, water conservation and the impact on GHG emissions is published in *Novotny, Ahern and Brown (2010)* and *Novotny (2012).*

A new paradigm for management of urban water, stormwater, and used water, along with solid waste and energy, needs to be developed and implemented in the first half of this century, not only in the new developments, but also (by retrofitting) in the older neighbourhoods and historic centres. Water, stormwater, wastewater, solid wastes, landscape, and energy would be managed as components of one system (*Novotny et al., 2010*). Ontario and other communities in Canada (e.g., Victoria) are in the forefront of new developments and conversion of older communities toward water sustainability, as exemplified by the West Don Lands Precinct stormwater management project (see article in this issue).

URBAN METABOLISM

Water, ecological, carbon/energy, and economical footprints are linked to and are expressions of the urban metabolism defined as the 'sum of the technical and socio-economic processes that occur within the cities, resulting in growth, energy production, and waste elimination' *(Kennedy et al., 2007)*. Figure 1 shows that the urban metabolism can be linear, cyclic, or hybrid (in between). The balance or imbalance between the inputs, accumulation and growth, and waste (resulting in emissions of undesirable pollutants) determine the city's sustainability.

Typically, current urban systems are linear in terms of urban metabolism. *Daigger (2009), Novotny (2008)* and others agree that the current linear approach—sometimes called the 'take, make, waste' approach in the literature—has become unsustainable and cannot continue. The linear system discourages water reuse because the source of reclaimed water is far downstream from the city, and the current economic benefit-cost or minimum-cost evaluations do not consider important social and, in many cases, environmental costs and benefits that are traditionally considered intangible.

Decentralized cluster water and stormwater management of the cities of the future

The integration of a complete water-management (urban water) cycle that includes water conservation and reclamation, storage of reclaimed water and stormwater for reuse, used water (wastewater) treatment, and energy from waste recovery cannot be fully achieved in a linear system. The concept of clustered distributed and decentralized water management has been evolving *(Lucey and Barraclough, 2007; Heaney, 2007; Daigger, 2009)*. Not all management can be decentralized (Table 1), and the cycle cannot be fully closed. Water and energy conservation, resources recovery, reuse, and recycle are hierarchical and can be accomplished at three levels:

- house or building level;
- cluster or neighbourhood (ecoblock) level; and
- city or regional level.

Table 1: Centralized and decentralized components of future cities (Adapted from *Daigger, 2009*)

COMPONENT	CENTRALIZED	DISTRIBUTED/DECENTRALIZED IN CLUSTERS
Stormwater/rainwater management	None, stormwater management is local.	BMPs–pervious pavements, rain gardens, green roofs, surface and subsurface storage, infiltration basins, and trenches.
Water conservation	Reducing or replacing leaking pipes, system-wide education of citizens about water conservation, dual water distribution (potable and nonpotable).	Wide variety of commercial water saving plumbing fixtures and technologies for potable and non-potable use; changing from lawns to xeriscape.
Treatment	Treatment for potable use and some non-potable reuse. Integrated resource recovery facility (IRRF) for recovering clean water, organic solids, methane, hydrogen, electricity, heat, and nutrients. Growing algae for more energy production.	Fit for reuse treatment for local potable use (from local wells and surface sources) and non-potable reuse (from used water) in small cluster size water and energy reclamation units; stormwater treatment in biofilters, ponds and wetlands, effluent post treatment in ponds and wetlands. Possible source separation into black, grey water and urine flows.
Energy recovery	Methane from anaerobic treatment and digestion of residual organic solids, thermal microbial fuel cells, electricity from methane by hydrogen fuel cells.	Capture and distribution of heat and cooling energy (heat pumps); geothermal, wind, and solar energy. Small scale biogas production by digestion (outdoor in developing countries).
Nutrient recovery	Land application of biosolids, Struvite (ammonium magnesium phosphate) precipitation and recovery.	Irrigation with reclaimed water with nutrients left in it; reclaimed irrigation water distribution to parks, golf courses and homeowners backyards; urine separation and recovery.
Source separation	Treatment of concentrated black wastewater and organic solids with energy (biogas) production.	Supply of potable and non-potable water; treatment of black, grey (laundry and kitchen), and yellow water for non-potable reuse (irrigation, toilet flushing), concentration of residual used water flow with removed solids for further processing at the integrated resource recovery facility.
Landscape management	Daylighting and habitat restoration; fish management and restocking, wildlife management in ecotones, flood-plain restoration.	Stream and ecotones maintenance, installation and maintenance of BMPs, including ponds and wetlands; on and off water recreation, incorporating flood storage and extreme weather resiliency into landscape.

'Daylighting' defined

In urban design and urban planning, daylighting is the redirection of a stream into an above-ground channel. Typically, the goal is to restore a stream of water to a more natural state. Daylighting is intended to improve the riparian environment for a stream, which had been previously diverted into a culvert, pipe, or a drainage system.

http://en.wikipedia.org/wiki/Daylighting_(streams)

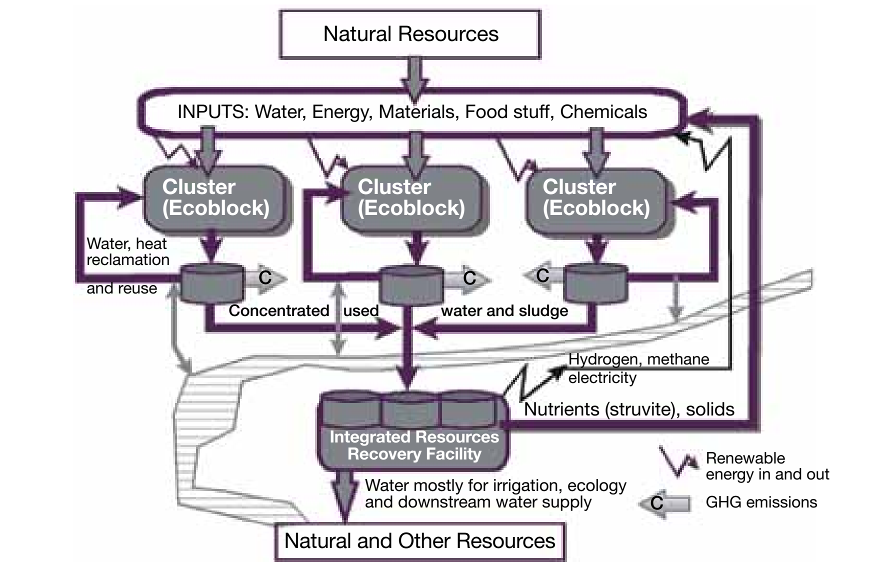

Figure 2: Distributed urban water, stormwater, and used water management system with Integrated Resources Recovery Facility

At the house level (a small apartment or commercial building), water- and energy-saving devices are installed along with outdoor sustainable landscaping (xeriscaping) with minimum, mostly natural, rainfall irrigation. Energy-saving appliances include water-saving shower heads, washing machines, low-flush toilets, and tankless water heaters. Passive energy savings include insulation, sun exposure during winter, shading on hot summer days, and green roofs wherever possible. In some cases, used water separation into black and grey would be implemented. Most future houses will likely install solar panels. Small and large electricity-producing wind turbines are already commercially available and producing energy on a large scale in Europe and China. Urine separation might be implemented in public buildings, schools, and commercial establishments and, possibly, in private houses because urine contains 75% of nitrogen and 50% of phosphorus in 1% of the total used water flow, and the nutrients from urine are easily recoverable.

A cluster or ecoblock is a semi-autonomous water-management and drainage unit that receives water and implements water conservation inside the cluster's structural components. Throughout the cluster, the unit reclaims sewage (separated or combined) for reuse, such as flushing or irrigation, and provides ecological flow to restored, existing, or daylighted streams; recovers heat energy from wastewater; and possibly recovers biogas from organic solids. Clusters may range from a high-rise building, shopping centre, or a subdivision (neighbourhood), to a portion of a city *(Furumai, 2007; Lucey and Barraclough, 2007)*, or a small watershed, which would be the most logical unit. Bringing treated stormwater and other clean water (foundation and construction dewatering, cooling water recycle blow-down, and air conditioning condensates) conveyance to surface rain gardens, ponds, grass, and naturalized channels can make existing sewers oversized and even obsolete and dramatically reduce the probability of overflows. The freed space in existing sewers can be used for fibre optic and phone cables for which the water management utility can charge a fee as they do in Tokyo and other cities.

The treatment level at the cluster level is 'fit for reuse.' If reclaimed water in the cluster is used for landscape irrigation, removing nutrients does not make sense because the nutrients eliminated from reclaimed water would have to be replaced by industrial fertilizers, which would defy the purpose of reclamation and reuse and increase GHG emissions. Toilet flushing may require reduction of turbidity, disinfection (primarily to control bacterial growth in the toilets and urinals), and adding some color, if needed. If reclaimed water is used for providing ecological flow to lakes or streams, nutrients should be recovered (e.g., by recovering struvite or urine separation) and not just removed (e.g., in sludge deposited in a landfill). On the local cluster/ecoblock scale, aquifer recharge is accomplished by infiltration of captured stormwater by best-management practices, which are the foundation blocks of the Low Impact Development (LID) concept. LID practices include enhanced rainwater infiltration (rain gardens), pervious pavements, and infiltration ponds *(Novotny et al., 2010)*.

Asano et al. (2007) suggested alternatives for retrofitting decentralized used-water management into existing urban environments. Including smaller

Colour matters

Black water is a term used to describe wastewater containing fecal matter and urine.

Grey water is wastewater generated from domestic activities, such as laundry, dishwashing, and bathing, which can be recycled on-site for such uses as landscape irrigation and constructed wetlands. Greywater does not contain human wastes (e.g., fecal material or urine).

Yellow water is primarily urine and does not contain fecal material.

(package) satellite treatment in upstream portions of the urban drainage area, used water (wastewater from the local collection system) can be intercepted and treated to a high degree required for the above-mentioned reuse options. This concept, not requiring dual or triple plumbing and separation into black and grey used water, was implemented in the Solaire Battery Park large residential complex in New York City, where reclaimed water is used for toilet flushing, irrigation, and cooling. The residual effluent with solids from the cluster water reclamation facility is then conveyed to a central (regional) treatment plant and discharged into the environment. More complicated cluster complete water management with water separation into black and grey water streams, and potentially including urine separation, is being implemented in Masdar, United Arab Emirates *(Hartman et al., 2012; Novotny and Novotny, 2012)*, and is being planned in Sweden *(Malmö, Göteborg)*.

Water reclamation on the cluster level also concentrates pollutants in the residual flow diverted to a regional resource recovery facility where recovery of methane, struvite, and energy can be done on a large scale under qualified supervision, mechanization, and computerization. Figure 2 presents the concept of an interconnected hybrid system with connections to a centralized integrated resource recovery facility (IRRF).

Did you know?

An ecotone is a transition area between two biomes, but different patches of the landscape, such as forest and grassland. It may be narrow or wide, and it may be local (the zone between a field and forest) or regional (the transition between forest and grassland ecosystems). An ecotone may appear on the ground as a gradual blending of the two communities across a broad area, or it may manifest itself as a sharp boundary line.

The word ecotone was coined from a combination of eco(logy) plus -tone, from the Greek *tonos* or tension—in other words, a place where ecologies are in tension.

Source: *www.en.wikipedia.org/wiki/Ecotone*

Restoring urban water bodies

Urban surface water bodies are not just visual assets of the community that might spur downtown or community development. Restoration and/or daylighting should be part of the overall retrofit toward sustainability of existing urban areas. Restored water bodies are a lifeline of future development serving multiple purposes such as:

- receiving residual treated reused and/or excess reclaimed water and excess clean stormwater;
- serving as a source of water for reuse: for buildings (e.g., flushing toilets), landscape irrigation, cooling, and street and sewer cleaning;
- eliminating clean water inputs into sanitary and combined sewers saves energy by reducing pumping mixed wastewater in the lift stations;

Figure 3a: Kallong River in Singapore in 2009. Picture courtesy of the CDM Singapore office.

Figure 3b: Kallong River after restoration. Picture courtesy of PUB Singapore.

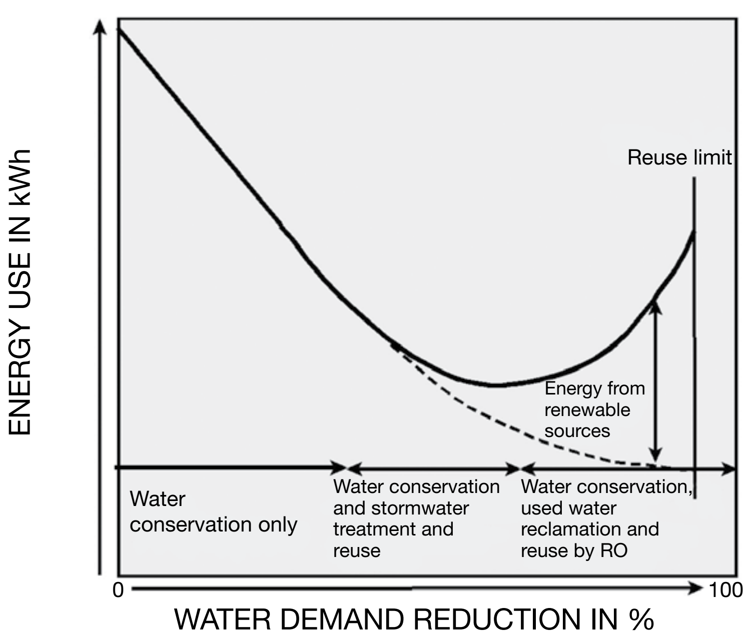

Figure 4: Three phases of the water-energy nexus without energy recovery. From Novotny (2010, 2012)

- reducing clean water inputs to the treatment facility, which will increase capacity and reduce energy use in the treatment plant (traditional regional systems) or resource recovery units (distributed systems), leading to an excess of sewer capacity;
- providing recreation, such as individual and tourist boating, swimming, recreational fishing, and enjoyment;
- revitalizing neighbourhoods and areas surrounding the water bodies and contributing to the solution of environmental injustice;
- natural, created (e.g., manmade wetlands and ponds) and restored and/or daylighted water bodies attenuate residual pollution from surrounding inhabited residential, industrial, and commercial areas and roads and highways instead of treating polluted runoff in hard infrastructure treatment plants;
- sequestering carbon in the ecotones (e.g., green buffer zones between the water body and built environment) and restored or preserved wetlands;
- in combination with landscape best-management practices, surface streams are more efficient conduits of flood water than underground drainage; and
- providing habitat conditions for a balanced aquatic life.

There are many restoration and/or daylighting projects throughout the world, and many more are planned *(Novotny et al., 2010)*. Figures 3a and 3b show restoration of the Kallong River in Singapore. Before 2010, the river was a concrete fast-conveyance channel discharging urban stormwater directly into the sea. After restoration, the river not only enhances the aesthetic and recreation quality of the city, it will also become an integral part of the freshwater supply system. Extensive urban stormwater treatment best-management practices are being installed in the watershed, and the river now discharges into Marina Bay, which was converted from a brackish estuary into a freshwater reservoir (filled mostly by urban runoff) from which water is pumped into the city's water supply reservoirs.

Water-energy nexus

In the US, based on national averages, buildings consume 40% of the energy of which 22% is residential and 18% commercial. Industries consume 32% and transportation 28% *(NSTC, 2008)*.

Providing treated water and wastewater disposal in the US represents on average about 3% of the energy use, but can be as high as 20% (California). However, within buildings, 8% of the additional energy use is for water-related processes, such as cooking, wet cleaning, and water heating. To pump and transport water and wastewater, 1% or more is needed.

The US Department of Energy (2000) published estimates of the carbon equivalent of energy produced by fossil fuel power plants. These ranged from 0.6 kg of CO_2 /kWh produced by natural gas power plants to 0.96 kg of CO_2 / kWh produced by coal fired power plants, respectively. Because 30% of energy is produced by processes that do not emit substantial quantities of GHG (nuclear, hydropower and other renewables), a weighted average of the CO_2 is 0.61 kg of CO_2 emitted per kWh of energy produced. In contrast, in France, Belgium, Austria, and other EU countries, the GHG equivalent of energy is smaller because of much higher reliance on nuclear power (France) or hydropower (Austria, Switzerland). *Vestraete et al. (2010)* used the GHG equivalent 0.21 kg of CO_2 emitted per 1 kWh of energy used. Growing use of wind and solar power in Germany, Spain, the Czech Republic, and other European countries is further decreasing the GHG equivalent of one kWh therein.

Figure 4 presents the possible relationship of water demand reduction leading to a closed urban water cycle and energy. *Novotny (2011)* suggests a hypothesis that there is a minimum inflection point beyond which further reduction of water use will increase energy demand and urban water metabolisms because of increased use of chemicals, energy, and infrastructure (materials). A relationship can be developed for relating the cost of providing water to the magnitude of the water demand. The water-energy nexus relationship has three phases *(Novotny, 2011; Novotny et al., 2010; Novotny, 2012)*:

(1) the water conservation phase in which energy and GHG emission reduction is proportional to the reduction of the high water use;

(2) the inflection phase in which additional and substitute sources of water demanding more energy are brought in, treated, and used; and

(3) rising energy (cost) phase in which energy use is increasing while water demand of the development is reduced by water recycling and multiple reuses.

INTEGRATED RESOURCES RECOVERY FACILITY

Completely distributed water, stormwater, and reuse water management system, with independently operated clusters fully reclaiming and recycling all water, are unrealistic. The cycle needs make-up water to prevent accumulation of salts and 'new' conservative contaminants (pharmaceuticals, nanopollutants, endocrine disrupting compounds) in the system and has a need for safe disposal of reject water from reverse osmosis or ultrafiltration systems. While simpler smaller cluster water and energy reclamation plants may be built in the neighbourhood, sludge management and biogas recovery may not be advisable in cluster reclamation facilities and may be objectionable to citizens living in the cluster. Developing an integrated resources recovery facility (IRRF) with a complete resource recovery accepting organic solids and concentrated excess used water and recovering water, nutrients, solids, electric energy, and heat, in much greater quantities than it is possible in the current 'water reclamation plants' is realistic, but can be a significant challenge.

Consequently, the main objectives of the IRRF could be:

1. treating and reclaiming water for:
   - ecological flow of the receiving water body,
     - beneficial downstream uses for irrigation, water supply from alluvial deposits, and recreation, and
     - groundwater aquifer recharge after additional treatment;
2. recovering phosphorus and nitrogen as struvite, chemically precipitated phosphate, and high-nutrient content solids;
3. providing water, nutrients, and carbon dioxide (alkalinity) to algal aquaculture producing biomass for biofuel and energy;
4. recovering and producing energy for heating the anaerobic treatment and fermentation units as well as the facility and buildings in surrounding urban areas;
5. producing biogas that may include methane or syngas (a mixture of carbon monoxide and hydrogen) and/or hydrogen);
6. producing organic solids for soil conditioning;
7. converting biogas and hydrogen into electricity; and
8. deriving all energy needs from on-site energy recovery, additional renewable sources (solar), and sequestering carbon.

Such facilities will generate no pollution, produce excess electricity, and will be net sequesters of carbon *(Verstraete et al., 2009)*. Good reviews of the state-of-the-art and future outlooks have been presented by *Novotny et al. (2010)*, *Novotny (2012)*, *McCarty et al. (2011)*, or *Verstraete et al. (2010)*. Laboratory- and field-tested technologies that enable to propose this revolutionary resource recovery system include:

- new developments of the more than century-old anaerobic treatment and digestion of organic solids and sludge in upflow anaerobic sludge blanket (UASB) reactors *(Lettinga and Hulshoff-Pol, 1991; Verstraete et al.,2009)*, anaerobic fluidized membrane bioreactors (AFMBR) *(McCarty et al., 2011)*, and other processes, such as anammox and membrane filtration;
- bioelectrically assisted microbial reactors (BEAMR) converting organic matter to hydrogen *(Logan, 2008)*;
- hydrogen fuel cells converting biogas (methane) to hydrogen and electricity by steam methane reforming SMR (*US DOE, 2009*);
- heat recovery from water by heat pumps and other heat reclamation devices;
- production of struvite (ammonium magnesium phosphate) fertilizer

Table 2: Water and energy balance of three alternative water/used water management. Adapted from *Novotny (2012)*.

PARAMETER	ALTERNATIVE I Traditional Linear System with no Conservation	ALTERNATIVE II Mostly Linear System with Water Conservation and Partial Reuse	ALTERNATIVE III Hybrid System With Energy Recovery and Conversion to Hydrogen
Water flow from the grid L/cap-day	551	166	50
Energy to deliver and use water kW-h/cap-d	0.55	0.17	0.113
Energy use for heating kW-h/cap-d	3.88	2.60	2.60
Energy to treat recycle at cluster level kW-h/cap-d	0	0.015[1]	0.160[2]
Heat recovery from grey water by heat pump kW-h/cap-d	NA	NA	-1.00
IRRF			
Methane recovery from UASB at IRRF kg/cap-d	NA	NA	-0.02
H_2 from methane conversion by SM R kg/cap-d	NA	NA	-0.035
H_2 from BEAMR fermenting solids[3] kg/cap-d	NA	NA	-0.02
Total energy from hydrogen kW-h/cap-d	NA	NA	-1.50
Heat recovery from effluent by heat pump kW-h/cap-d	0	-1.78[4)]	-1.20[4]
Total energy expenditure (production) kW-h/cap-d	**4.75**	**1.05**	**(-0.89)**
Carbon GHG emissions (credit) kg CO_2/cap-year	**1263**	**234**	**(-198)**
GHG credit with ½ solar heating kg CO_2/cap-year	NA	**(-55.5)**	**(-710)**

Legend:
1 Water recycle treated by microfiltration and ozonization
2 Grey water recycle treated by microfiltration, reverse osmosis, and ozonization
3 Per US EPA (2010) food and yard organic waste is 0.68 kg/capita-day and the recovery is 60%
4 Total effluent for Alternative II, IRRF effluent for Alternative III
5 Per McCarty et al. (2011)

from used water effluents and digester supernatants (*Barnard, 2007*);

- improved production of nutrient rich solids from sludge (*Verstraete et al., 2010*);
- co-digestion of sludge with other organic solids and high strength liquids (e.g., waste food and byproducts of food and beverage production, airport deicing fluids, vegetation residues, manure) (*Zitomer et al., 2008*);
- more efficient biogas and biofuel production;
- production of algal biomass and subsequently hydrogen (*James et al., 2009*); and
- new and more efficient capture of renewable solar energy by concentrated solar panels and photovoltaic cells.

A future possible IRRF alternative was conceptually presented in *Novotny (2010, 2012)* and *Novotny et al. (2010)*. Other anaerobic systems were proposed by *Lettinga et al. (1980)* and *McCarty et al. (2011)*. The produced biogas could be converted to electricity by a combustion engine and generator, or, in a more distant '2050' future, biogas and hydrogen would be generated and converted to electricity in a hydrogen fuel cell or a more efficient H_2 convertor. Energy can be recovered in a form of biogas (methane), syngas (carbon monoxide and hydrogen), heat, or hydrogen.

Nutrient recovery. Struvite (NH_4.Mg.PO_4x6H_2O) precipitation, simultaneously removing both N and P without energy from liquid used water and digester supernatant rich in nutrients *(Barnard, 2007; Cecchi et al., 2003)*, is available. On a molar basis, used water contains more ammonium than phosphate. Therefore, only about 10% of ammonium is converted into struvite. Magnesium is added to the struvite recovery process as magnesium hydroxide or magnesium chloride. Because struvite precipitates at pH greater than 9, at pH = 9 about 50% of ammonia/ammonium is unionized NH_3 and at pH >10 more than 90 % is unionized, which can be removed by volatilization, but it may be better to recover ammonium by urine separation at cluster level. After precipitation pH is adjusted back to neutral by carbon dioxide produced in the treatment process. Struvite is recovered in fluidized bed or pellet reactors.

Of note are the virtual energy savings and reduction of GHG emissions by recovering ammonium and phosphate. As quoted in *McCarty et al. (2011)*, the energy requirement for production of nitrogen fertilizer by Haber-Bosh process is 19.4 kWh/kg N produced and that for phosphate is 2.11 kWh/kg of P, respectively.

A study by *Novotny (2012)* compares three alternative communities with different water and wastewater management systems: (1) a typical US linear system with a high water demand and little or no water conservation treating wastewater in a typical aerobic activated sludge plant and sludge land filling; (2) a system with water conservation bringing water demand to that typical in Europe, with some water reuse for irrigation and toilet flushing, and treating wastewater by a nitrification/denitrification and some energy recovery from sludge digestion; and (3) a distributed closed system separating black and grey water on the cluster level with reuse and an IRRF anaerobic co-digestion of organic solids with concentrated residual flow with solids from the cluster water reclamation units. Table 2 shows the results.

Current regional wastewater treatment plants can be converted or retrofitted into IRRFs, and current tank and pipe capacities would be more than sufficient to accept these flows and other organic waste even with a moderate increase of connected population.

CONCLUSIONS

Literature indicates low-density 'American-style' suburban areas with one oversized house on 0.4 ha (1 acre) of land are the most wasteful in terms of energy use and efficiency *(Newman, 2006)*. The fact of medium-design-density development (Figures 5 and 6) being the most optimal refutes, to some degree, the utility of the 'low impact' subdivisions, which have a sole objective of minimizing stormwater impacts and result in low-density developments with high energy and automobile uses.

A daylighted and/or restored water body, including surrounding natural areas (floodplain parks, nature trails, and preserved forests) can be the centrepiece of a community. Cluster water management would provide base flow to water bodies, which, in turn, would provide reuse reclaimed water for some uses within the cluster (e.g., irrigation) and provide resilience to extreme storms. The new focus on decentralized water, used water, and stormwater management with integrated resource recovery can dramatically reduce water use and recover energy in excess over that needed to operate the system.

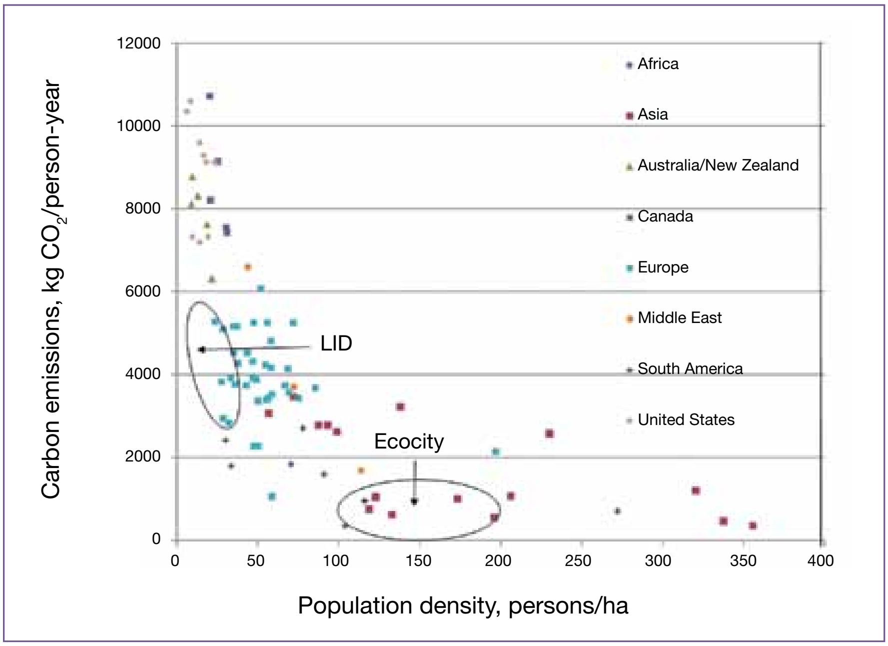

Figure 5: The effect of population density on the carbon footprint of urban areas (from Novotny and Novotny, 2012; and Novotny et al., 2010). LID-low-impact developments typical for US. The carbon footprint includes private and public transportation, heating, and electricity. Data obtained from various sources.

Figure 6: Medium-density sustainable Hammarby Sjöstad in Stockholm showing surface stormwater drainage and energy-efficient houses. Picture courtesy of Malena Karlsson, Glashusset, Stockholm.

In the final outcome, the Triple Bottom Line (TBL) assessment over the life cycle should persuade stakeholders to implement sustainability concepts of the cities of the future. TBL is an extrapolation of the traditional cost-benefits analysis of public and private projects by including quantitative assessment of (1) environmental and/or ecological protection and enhancement, (2) social equity, and (3) economics. To evaluate resiliency to extreme events, a TBL analysis should consider: (1) flood-causing precipitation, (2) water shortages, and (3) extreme pollution, also related to global warming. The following are examples of the tangible benefits of the Cities of the Future integrated resources management:

- increased value of homes and revenues to the community;
- value of electric energy and heat produced by IRRF or cluster energy recovery unit and also from selling the excess energy to the regional or municipal grid;
- selling biogas and hydrogen to transportation companies;
- savings on fuel;
- economic value of businesses and employment of riverside commercial establishments;
- urban restoration economic effects;
- sales of recovered fertilizers and opportunity benefit (virtual) of GHG emission reduction by not using industrial fertilizers;
- savings on decreased water demand;
- savings on elimination of subsurface storm sewers and rental fees obtained for the use of excess capacity of existing sewers by other utilities and private users (e.g., telephone and cable companies);
- savings on pumping energy cost for transmitting water;
- boat launching and excursion fees and fees for recreational use of restored water bodies (e.g., Ghent, Belgium);
- fees for organic solid-waste processing;
- fees for reclaimed water (e.g., irrigation of golf courses and gardens); and
- savings on waste discharge fees and profits from selling ‘cap and trade’ energy credits (due to carbon neutrality or net sequestering) in countries that implemented nationwide payments. ♦

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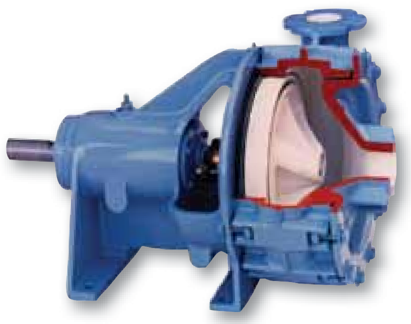

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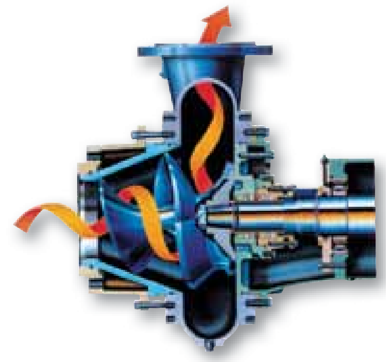

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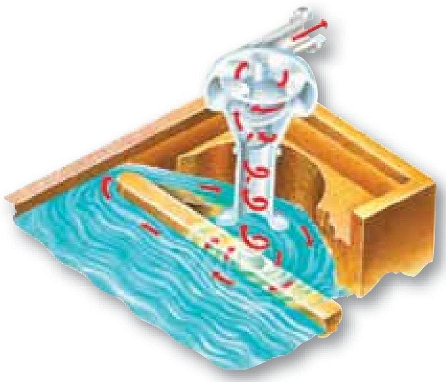

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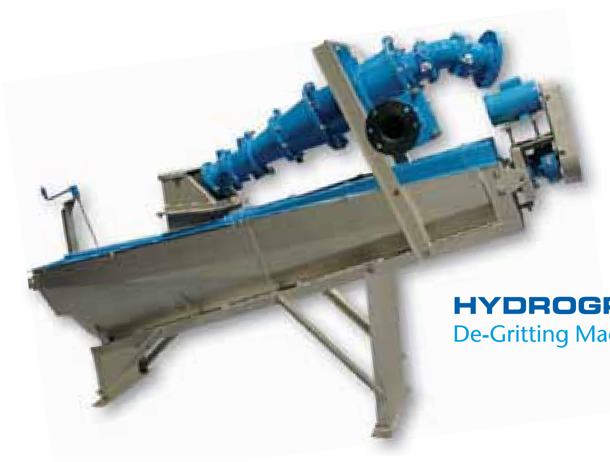

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Energy from wastewater

Nabin Chowdhury, Ph.D., P.Eng., MITACS Elevate Fellow

INTRODUCTION

Wastewater treatment is an energy-intensive process and accounts for approximately 3% of electrical energy load in most of the developed countries[1]. A conventional domestic wastewater treatment plant (employing aerobic activated sludge treatment and anaerobic sludge digestion) consumes 0.6 kWh/m^3 of wastewater treated[1]. There is a growing interest in either reducing the energy required to treat wastewaters and/or recovering energy and/or resources from the wastewater (i.e., treating wastewater as a resource). Figure 1 shows several different ways to extract energy from wastewater.

While many of these are mature technologies and are currently used by some utilities, their potential application is much greater than current rates of utilization. Efficient energy capture coupled with nutrient recovery from wastewater might convert treatment plants into net value (energy + nutrient) producers rather than just resource consumers.

ENERGY POTENTIAL

The organic load within the wastewater is the principal source of recoverable energy. The concentration of oxidizable organic and inorganic materials in wastewater is usually expressed as the COD (chemical oxygen demand), which indicates the amount of oxygen required to oxidize the materials. A typical wastewater has a COD value of 0.5 kg/m^3. Considering a theoretical 3.86 kWh energy production per kg COD oxidized to CO_2 and H_2O[1], the energy density of wastewater is 1.93 kWh/m^3.

Table 1 describes the various components of domestic wastewater and their potential as an energy source, or the energy required to recover their value as fertilizers. The organic fraction can be classified as biodegradable and refractory, and each fraction is divided into dissolved and suspended. Suspended solids may be concentrated in a primary settling tank, and the resulting primary sludge can be anaerobically digested for methane (CH_4) production, but CH_4 results only from the biodegradable fraction. Through thermal, chemical, or electrical processes, some of the refractory portion may be conditioned to transform it into biodegradable material to increase CH_4 production, but the energy cost for this may offset the gains. The soluble organic fraction cannot be separated easily by mechanical means, and so it is subjected to processes to transform the soluble compounds into suspended solids. This, however, generally occurs with little recovery of the soluble compounds' chemical energy. Although anaerobic digestion is one of the most common ways to recover energy from wastewater, there are a number of other methods being used or under development. This article examines a few of these alternative methods. Some of the most promising are the emerging technologies that allow direct biological conversion of organic chemical into electricity using microbial fuel cells (MFCs).

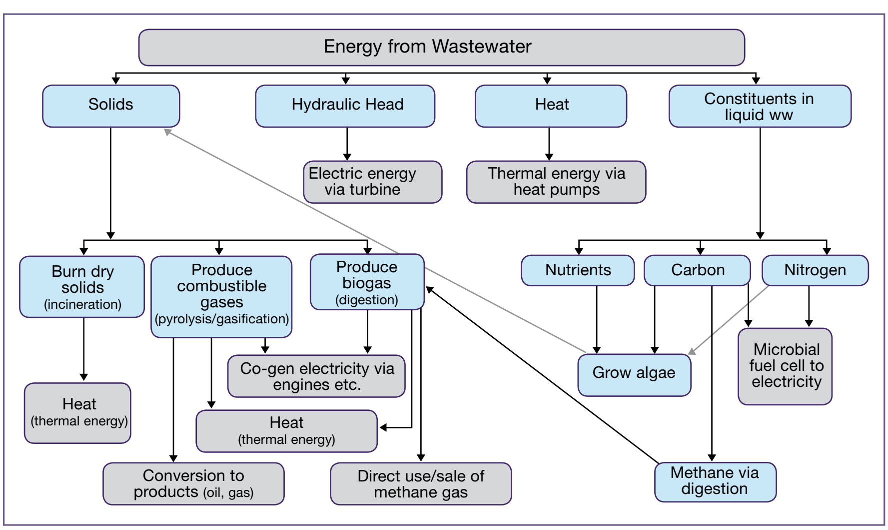

Figure 1: Energy opportunities from wastewater

ENERGY PRODUCTION FROM SLUDGE

Anaerobic digestion

Anaerobic digestion is used to stabilize the sludge generated by the wastewater treatment process, to convert the volatile solids into biogas, and to reduce the mass of disposable sludge. The biogas can be applied as an energy resource either at the wastewater treatment plant itself or elsewhere. Anaerobic digestion of sewage sludge is a common practice at large and medium-sized wastewater treatment plants. A growing interest is observed in the application of anaerobic treatment in small-sized plants (e.g., treatment capacity of <1.0 mgd or 3.8 MLD). In general, the electricity produced in anaerobic digestion is only about 28% of the original energy potential of biodegradable organics present in wastewater. Perhaps this could be increased to 40% using fuel cells[1].

Incineration

Incineration of sewage sludge results in the complete oxidation of organic compounds (including toxic organic compounds) at high temperature. Sludge incineration processes are increasingly focused on energy recovery in the form of heat (steam) or electricity. The amount of energy extraction strongly depends on the water content of the sludge, as this affects the energy required for mechanical dewatering and drying processes. Incineration is more applicable for large-scale treatment facilities. This is due to the fact that the incineration process deals with large quantities of polluted exhaust gases, which require an efficient gas treatment system. The high capital cost of the gas treatment unit makes the sludge incineration process expensive.

Pyrolysis and gasification

Pyrolysis is a thermal treatment process in which the sludge (or biomass) is heated under pressure to a temperature between 350–500 °C in the absence of oxygen. In this process, the sludge is converted into char, ash, pyrolysis oils, water vapor, and combustible gases. Combustible gases are then converted into electrical power. In addition, valuable gases can be produced as basic chemicals or as fuel. However, the presence of toxic organic pollutants in the sewage sludge makes the process for off-gas treatment difficult. In general, the process of pyrolysis and gasification is much more complicated than incineration.

ENERGY EXTRACTION FROM WASTEWATER FLOW

Biofuels production

Wastewaters derived from municipal, agricultural, and industrial activities potentially provide a cost-effective and sustainable source of algae for biofuel production. Algal biodiesel production could use municipal wastewater effluent as a source of nutrient (nitrogen, phosphorus) feedstock, which provides environmental and economic benefits. The algal lipids, principally triacylglycerol, are separated, isolated, and then converted into biodiesel by trans-esterification. Studies have shown that the energy required for algal fuel production can be reduced from 300 GJ to 24 GJ by using the nutrients available in wastewater effluents instead of chemical fertilizers[2]. Avoidance of the energy consumption in conventional biological nutrient removal accounts for a significant part of the energy savings.

Table 1: Energy characteristics of a typical municipal wastewater[1]

CONSTITUENTS	Concentrations (mg/L)	Energy potential from organic oxidation (kWh/m3)	Energy required to produce fertilizers (kWh/m3)	Thermal heat available for heat pump extraction (kWh/m3)
Refractory				
Suspended	80	0.31		
Dissolved	100	0.39		
Biodegradable				
Suspended	175	0.67		
Dissolved	145	0.56		
Nitrogen				
Organic	15		0.29	
Ammonia	25		0.48	
Phosphorus	8		0.02	
Water				7.0
Total		**1.93**	**0.79**	**7.0**

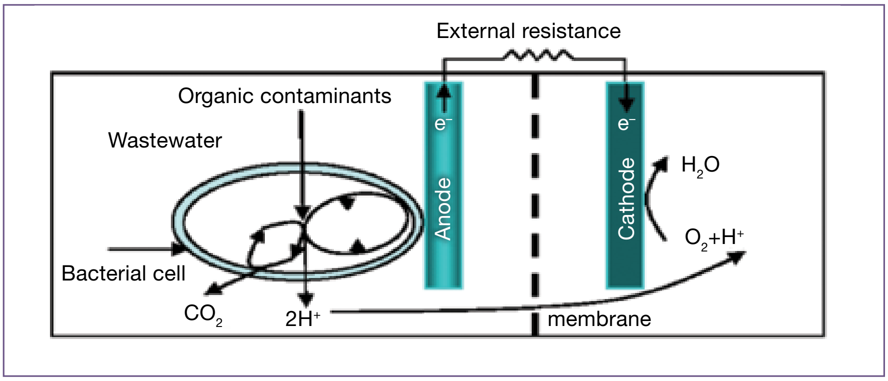

Figure 2: Simplified view of a MFC[4]

Microbial fuel cell

Microbial fuel cells (Figure 2) directly convert chemical energy into electrical energy using microorganisms, providing a method for simultaneously producing renewable energy while treating wastewater. This technology is able to extract energy from dissolved organic component in domestic wastewater. MFCs are considered superior to other energy-generating technologies (i.e., anaerobic digestion, incineration etc)[3].

The first evidence of electricity generation by bacteria in MFCs was reported by Potter in 1912. Over the past decades, the power density of MFCs has increased from less than 1 W/m^3 to over 4000 W/m^3 and potential applications of MFCs have been increasingly expanding, ranging from wastewater treatment, bioremediation to phototrophic energy extraction from algae[4].

Scaling up MFCs, generally by stacking multiple MFCs in series or enlarging the electrode surface area, is one strategy to increase the MFC power capacity. The first large-scale test of MFCs was conducted at Foster's brewery by the Advanced Water Management Centre, Queensland. Australia. The reactor consisted of 12 modules, each three metres high, with a volume of 1 m^3 [5]. Developing MFC configurations for large-scale and stable operations are challenging, as power density, fouling, and clogging become severe concerns in the long-term operations of MFCs.

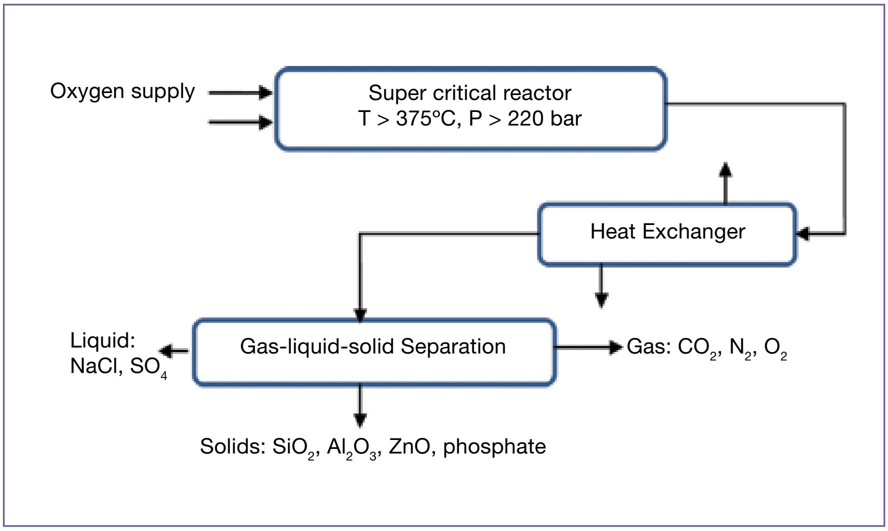

Figure 3: Supercritical oxidation of sewage sludge[6]

Super critical wet oxidation

Supercritical wet oxidation (Figure 3) occurs at temperatures and pressures above the supercritical point of water (374.2 °C and 22.1 MPa)[5]. Supercritical water has special properties, such as a superior ability to dissolve oxygen and organic compounds. The required retention time for oxidation using supercritical water is in the order of a few seconds to one minute, which reduces the reactor size significantly. Energy recovery in this process can occur directly by heat exchange in the reactor or from the exit flow of the reactor.

In comparison to sludge incineration, supercritical wet oxidation has the advantage of resulting in negligible costs for off-gas treatment. It is also not necessary to dewater the sludge before the oxidation process. Inorganics present in the treated sludge can easily be removed from the water phase as ash. Even though supercritical wet oxidation has a high potential to emerge as a sustainable and economic way of sludge treatment and heat extraction, large-scale practical experience has yet to be gained.

Hydraulic power

Turbines can be used to convert the energy from flowing water to electric current. A popular technology, applicable in more systems, is micro (mini hydro) turbines, which use low head loss to generate electric current.

Thermal energy

Thermal energy in domestic wastewater can be extracted as the temperature of the water is warmer than the air and ground. Heat pumps are used to extract this energy, which can be used by the wastewater treatment facility to offset their demand for heat. This technology works best in cold climates. For example, during the 2010 Winter Olympics in Vancouver, two athletic villages were heated by capturing the thermal energy in slow-moving wastewater.

CONCLUSIONS

A number of waste-to-energy options are available throughout the world to handle various kinds of wastes, such as aqueous waste, sludge, slurry, and municipal solid waste. An integrated approach is required to extract energy and recover multiple resources from the wastewater. The selection of an appropriate technology to convert a specific waste to energy is a crucial task that requires a detailed evaluation of the options that are available with respect to the plant's location and the characteristics of the waste. Although this discussion highlights the theoretical energy potential of wastewaters, various energy inputs are required to render the pollutants amenable to efficient energy recovery. ♦

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Wastewater treatment for cities of the future

A. Warren Wilson, Ph.D., P.Eng., WPC Solutions Inc.

WHERE HAVE WE BEEN?

In the first half of the last century, Canada's inland waters in developed parts of the country became fouled by sewage and industrial waste discharges from a growing population. To remedy this problem, existing municipal sewage collection systems were intercepted and diverted to centralized wastewater treatment plants. Over time, the sewage collection systems were expanded to serve an ever-increasing population. Simultaneously, more and/or larger centralized treatment facilities were constructed to protect the receiving watercourses.

By mid-century, many cities had installed primary treatment systems to remove gross pollutants in the form of settleable solids and BOD_5 from sewage discharges. By the end of the third quarter of the 20^{th} century, most cities had added a secondary biological treatment stage to their primary treatment plants, while smaller communities typically installed lagoon-based treatment systems to remove biodegradable organic matter. In the last quarter, the focus was on nutrient removal—specifically the removal of phosphorus—to forestall eutrophication in the receiving watercourse. In addition, a handful of municipalities discharging to particularly sensitive aquatic environments were required to remove ammonia and, in some cases, total nitrogen. Typically, the secondary biological treatment stage in the liquid stream treatment train uses some form of aerobic process, usually a variation of the 100-year-old activated sludge process.

The implementation schedules for wastewater treatment systems in coastal communities discharging to marine environments has lagged behind those of interior municipalities. For example, on the east coast, the City of St. John's, NL and nearby communities provide only preliminary screening before an ocean outfall for a population of 130,000. A similar situation exists on the west coast for the 280,000 contributors to the sewage collection system serving the Victoria Capital Region District. Plans to provide additional treatment are currently under consideration in both communities.

SO WHAT IS NEXT?

At the recent 2011 WEFTEC conference and exhibition in Los Angeles, a number of technical sessions and plant tours were devoted to various aspects of water (read 'sewage effluent') reclamation and reuse. The State of California's population is about 10% greater than Canada's population. A big problem in California is that two-thirds of the population reside in the relatively arid southern part of the state, while two-thirds of the precipitation occurs in the north. Consequently, Californians began to construct large aqueducts a century ago. They have become advocates of water conservation, and, as early as the 1960s, began to practise water reclamation and reuse widely.

Water reclamation and reuse facilities in California provide water for agricultural irrigation and industrial use, as well as wash water and flushing water for several municipal and commercial applications. Reclaimed water is also used for injection into barrier wells to prevent saltwater intrusion, and for indirect potable water reuse. The latter is commonly achieved by using percolation basins to recharge potable water aquifers or by blending the reclaimed water with potable surface water sources. Figure 1 shows someone assaying the reclaimed product water quality at a large groundwater replenishment treatment plant in Orange County, California.

Figure 1: The author is about to drink reclaimed product water from the Orange County Groundwater Replenishment System on October 18, 2011. He survived.

Other US jurisdictions also practise water reclamation and reuse, most notably those located in the arid southwest. It is also practised in Hillsborough and Miami-Dade counties on the Florida peninsula to prevent saltwater intrusion into depleted freshwater aquifers. Overseas, water reclamation and reuse systems are in place in Singapore, Israel, and Australia's Greater Brisbane area. The latter instance was in response to the so-called drought of the century that occurred in southeast Queensland from 2000 to 2008. Response strategies included:

- Demand management encompassing leak detection and repair, mains pressure reductions, a media-awareness campaign, household water efficiency code requirements, rigid industrial water management programs, and enforcement of staged water restrictions. At the height of the crisis, before the rains returned, the dam storage level was down to 16% of normal supply, and officials moved to stage six of a seven-stage program of water

restrictions. At stage six, the combined residential, industrial, commercial, and institutional water demand bottomed out at 120 L/cap/d.
- The addition of advanced treatment facilities to existing secondary biological nitrogen and phosphorus removal wastewater treatment plants.
- Upgrades to the water-supply grid to enable piped transfers among local communities as well as delivery of reclaimed water to the main supply reservoir upstream on the Brisbane River.
- The construction of a seawater desalination plant to supplement potable water supplies for the Gold Coast.

While such crisis conditions are not immediately evident in Canada, some arid regions in southern Saskatchewan, southern Alberta, the BC southern interior, as well as areas in the Territories receive limited precipitation. Already in Regulation 171/2007 under the Province of Alberta's *Water Act*, the provincial government has imposed a moratorium on issuing new water licenses in the Bow, Oldman, and South Saskatchewan River basins. This directly impacts one-third of the province's growing population.

A multiple barrier approach is used when implementing a system for indirect potable water reuse. The following scheme is an example of such an approach:

- Source management of contaminants discharged to the sewage collection system to eliminate or minimize specific undesirable contaminants.
- Secondary biological wastewater treatment to remove gross pollutants and biodegradable organic matter, as well as phosphorus and nitrogen.
- Microfiltration to remove fine particulate and colloidal matter.
- Reverse osmosis to remove much of the remaining soluble organic and inorganic matter.
- Advanced oxidation processes, including the use of UV radiation and ozonation and/or hydrogen peroxide to remove microconstituents, such as pharmaceuticals, hormones, nitrosamines, and other chemicals of concern.
- Stabilization of the product water to meet pH and corrosion requirements.
- Disinfection of the product water before delivery.
- Blending of the product water with the conventional potable water supply.
- Treatment of the blended water in the potable water treatment plant before delivery to consumers.

In all, it is a comprehensive and complex treatment train.

ARE THERE ISSUES WITH WATER RECLAMATION?

Yes, there are, not the least of them being public acceptance, how such systems should be regulated, and capital and operating costs. The more mundane technical issues, such as membrane fouling, brine disposal, and injection well clogging pale in comparison.

Presuming that the financial and technical issues can be overcome, the paramount requirement for a successful water reclamation and reuse scheme is public acceptance. A well-conceived and well-implemented public consultation program is essential. There are several examples of projects in the US and elsewhere from which lessons can be learned on what works and what doesn't work to gain political and public support.

In general, comprehensive regulations governing reclaimed water quality are found only in jurisdictions where water supplies are limited. Furthermore, the greater the chances for human contact during the reclaimed water use, the more stringent the water quality requirements are likely to be. The widely cited California Department of Public Health Title 22 regulations are intended for a broad spectrum of agricultural, industrial, commercial, and municipal reclaimed water uses. The CDPH has also published draft regulations for indirect potable water reuse. A revision to the current draft regulations is expected in late 2012.

The cost of producing reclaimed water for indirect potable water reuse is substantial. For example, the project cost of the 265,000 m^3/d microfiltration + reverse osmosis + advanced oxidation groundwater replenishment system completed in 2008 by the co-operative efforts of the Orange County Water District and the Orange County Sanitation District in the greater Los Angeles area was US$481 million. The production cost of the reclaimed water is US$0.73 per cubic metre. These figures do not include the cost of the secondary wastewater treatment plant that provides the feedstock to the water reclamation plant or the product water distribution cost.

BACK TO THE FUTURE?

'Sustainability' is this decade's buzzword. My laptop's dictionary tells me that 'sustainable' is an adjective meaning 'able to be maintained at a certain rate or level, conserving an ecological balance by avoiding depletion of natural resources.' In the water business, this definition evokes such issues as water quality, water conservation, energy conservation, and climate change, among others.

The feature technical presentation in the opening session of WEFTEC 2011 was the Association of Environmental Engineering and Science Professors lecture by Dr. Perry L. McCarty of Stanford University. Google him and see what you get—it is impressive. The title of his lecture was Toward Sustainability in Water Resources.

In his lecture, Dr. McCarty questioned the wisdom of continuing on the present path of intensive resource consumption wherein potable water sources are used for all purposes. As an alternative approach, he pointed to age-old practices in several Asian countries where energy is recovered from wastewater using anaerobic technology, and both the nutrient value contained in the residual sludge and the treated effluent are used for agricultural purposes. Usually, this is done employing relatively small treatment systems distributed throughout the community. He noted that there are already more than 600 anaerobic treatment systems operating on industrial wastes in the United States, so there is considerable North American experience with the technology, albeit not in municipal applications. Furthermore, recent research on anaerobic treatment methods shows much promise to reduce the resource consumption and net cost inherent with current municipal wastewater treatment practices that typically rely on aerobic methods. He thinks that anaerobic treatment systems could be the way of the future.

To support this paradigm shift, Dr. McCarty presented the following facts for typical US domestic wastewater:

- The energy requirements for treatment generally increase with increasing degrees of treatment. Approximate values are:

  - 0.6 kWh/m³ of wastewater treated in a conventional (non-nitrifying) activated sludge treatment system,
  - 0.8 kWh/m³ for nitrifying activated sludge,
  - 1.0 kWh/m³ for membrane bioreactor treatment, and
  - 2.5 kWh/m³ for treatment including reverse osmosis.
- About 1.9 kWh/m³ of energy is potentially recoverable from the organic matter in wastewater.
- Particularly when cogeneration is used for combined heat and power recovery, anaerobic treatment systems have the potential to be net energy producers compared with aerobic treatment systems.
- In aerobic treatment systems, the amount of excess biosolids produced requiring ultimate disposal is about 0.5 kg per kg of COD removed. The excess biosolids production in anaerobic treatment systems is about one-tenth of this amount or less.
- About 0.8 kWh of energy is required to produce chemical fertilizer containing the equivalent amount of nitrogen in one cubic metre of domestic wastewater.

A focus of Dr. McCarty's research is on the development of anaerobic treatment processes for typical North American domestic wastewater. The concept currently advocated is to reclaim the organic carbon in the wastewater in the form of methane gas that can be used in a cogeneration system for heat and power generation. Nitrogen and phosphorus nutrients originating in the raw wastewater would be left behind, which makes the anaerobically treated effluent especially suitable for irrigation. Near the conclusion of his lecture, he presented a process flow schematic for a treatment system consisting of:

- primary sedimentation for removal of settleable solids,
- an upflow anaerobic fluidized bed reactor with granular activated carbon as the media,
- an anaerobic membrane bioreactor also containing suspended granular activated carbon media,
- a stripping column to remove residual dissolved methane from the anaerobically treated effluent,
- an anaerobic digester to produce methane from the primary sludge, and
- a cogeneration system fueled by the produced methane gas for heat recovery and power generation.

Both anaerobic bioreactors are operated with long solids retention times (several days) and short hydraulic retention times (a few hours). Preliminary indications are that the gentle rubbing of the granular activated carbon on the membrane surfaces in the anaerobic membrane bioreactor prevents fouling of the membranes.

Such a treatment system based on the well-established anaerobic treatment process could be part of a sustainable future for either large-scale centralized treatment plants or smaller distributed treatment plants serving our cities of the future. ♦

Urine separation – benefits beyond wastewater management?

Dean M. Shiskowski, Ph.D., P.Eng, Associated Engineering Group Ltd.

Many people working in wastewater management today have some familiarity with the concept of urine separation or urine diversion. In simple terms, urine is (1) collected separately at the source through dual-compartment toilets and waterless urinals, (2) 'transported' by some means to potentially very near or more distant locations, and (3) used either as a fertilizer, subsequent to varying degrees of stabilization or pre-processing, or treated for disposal. Such countries as Sweden and Switzerland have expended notable effort to date on the topic, and pilot projects have been conducted in countries in Africa, Asia and Europe. First in the United States, the Hampton Roads Sanitation District has implemented urine separation in its new Operations Center Complex, where the district will truck the collected urine to its Nansemond WWTF side-stream struvite crystallization-based nutrient recovery facility (*Jimenez, 2011*; *Balzer, 2011*).

The recent Water Environment Research Foundation (WERF) study by *LeMonde Fewless et al. (2011)* provides an excellent summary of the global state of knowledge and experience. This work also suggests possible benefits of urine separation from a primarily wastewater management perspective, while recognizing comprehensive economic and environmental life cycle analyses will be needed to fully understand the benefits that may be realized, including:

- reduced energy requirements at wastewater treatment facilities;
- reduced nutrients, pharmaceuticals, and hormones in facility effluents;
- reduced wastewater volume generation;
- more efficient blackwater anaerobic digestion;
- integration with other decentralized wastewater management systems; and
- a potentially reduced carbon footprint compared with production and utilization of synthetic nitrogen fertilizers.

Typically, the casual questions asked about urine separation relate to the details of how it could be done, where has it been implemented, what are the social and regulatory issues, and why we should consider doing so in the first place. This article focuses on the 'why' question, beyond the points noted above, because the broad answer is often not fully understood, or at least not effectively communicated, within the wastewater community. This is an important issue because the potential benefits of urine separation may extend beyond the realm of wastewater management and into the global 'reactive' nitrogen cycle, where this latter context could be an important driver for its implementation. Therefore, the following discussion concentrates on this context.

WERF: Researching wastewater and stormwater issues

The Water Environment Research Foundation, formed in 1989, is America's leading independent scientific research organization dedicated to wastewater and stormwater issues. Over the past 20 years, it has produced 300 research reports, valued at more than $62 million.

SETTING THE STAGE

Stepping back in time to the agricultural Green Revolution of the 1960s is likely the best place to start in terms of understanding the potentially broad benefits of urine separation. Here we find that a combination of newly-developed food crop varieties grown with inorganic fertilizers and irrigation water—with improved agronomy and modern pesticides—have dramatically improved food production efficiency. Where it took almost 1,000 years for English wheat yields to increase from 0.5 to 2.0 tonne/hectare, the 20th century has provided an increase from 2 to 6 t/ha in a 40-year period (*International Food Policy Research Institute, 2002*).

A significant contributor to these gains in food production efficiency are the synthetic nitrogen fertilizers produced via the Haber-Bosch process, so named after the Nobel Prize laureates Fritz Haber (1918) and Carl Bosch (1931) (*www.nobelprize.org*). Our ability to synthesize reactive nitrogen (e.g., ammonia, NH_3) from the di-nitrogen gas (N_2) of the atmosphere and hydrogen provided by natural gas, through intensive energy application ($T = 450\ ^{o}C$, $P = 250$ atm), has resulted in an estimated two billion people being alive today because of the supplied dietary protein (*Galloway et al., 2008*).

So far so good, but herein lies a problem. As shown in Figure 1, our anthropogenic activities that produce reactive nitrogen (Nr) substantially outstrip the estimated rate of natural source Nr generation. Much of this situation rests with synthetic fertilizer production.

How much of the 'excess' Nr, from all anthropogenic sources, is accumulating in our terrestrial biosphere depends on the extent of natural biological denitrification processes that convert it back to N_2 and return it to the atmosphere. There are also significant unknowns in this question (*Galloway et al., 2004*). However, regardless of the uncertainties with the global Nr balance, the scientific community has long recognized that this excess Nr accumulates in tropospheric, stratospheric, terrestrial, and aquatic systems, driving associated processes that can cause a wide variety of human health and environmental impacts on earth (Figure 2). Clearly, there are multiple drivers suggesting we need to manage Nr more effectively.

Focusing now on the 'new' Nr used in food production, estimates suggest that only 15% of this Nr enters the human mouth, with the remaining 85% being lost directly to the environment (*Galloway et al., 2004*). Furthermore, of the Nr fraction that enters the human mouth, only 5% is used by the body, and the remaining 95% is excreted. The net result is that more than 99% of this Nr used in human food production bypasses the body and ends up directly in the environment or first in wastewater.

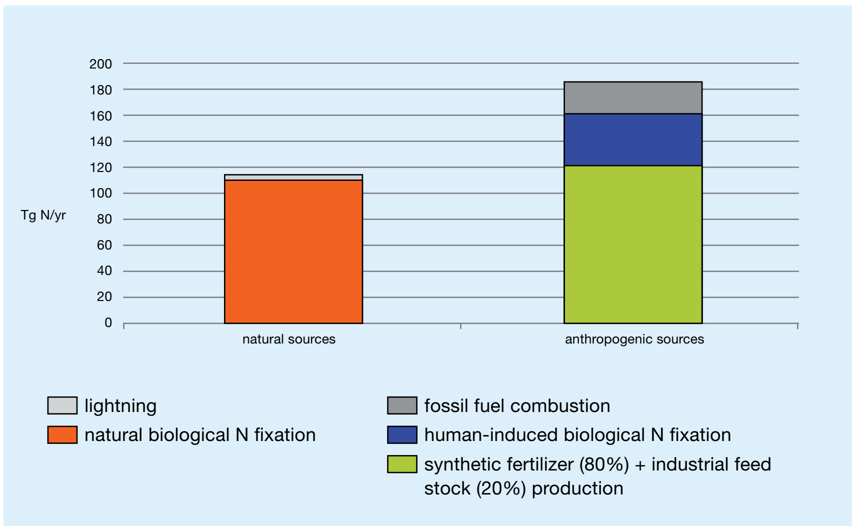

Figure 1: Global reactive nitrogen production (adapted from *Barton and Atwater [2002]* and *Galloway et al. [2008]*)

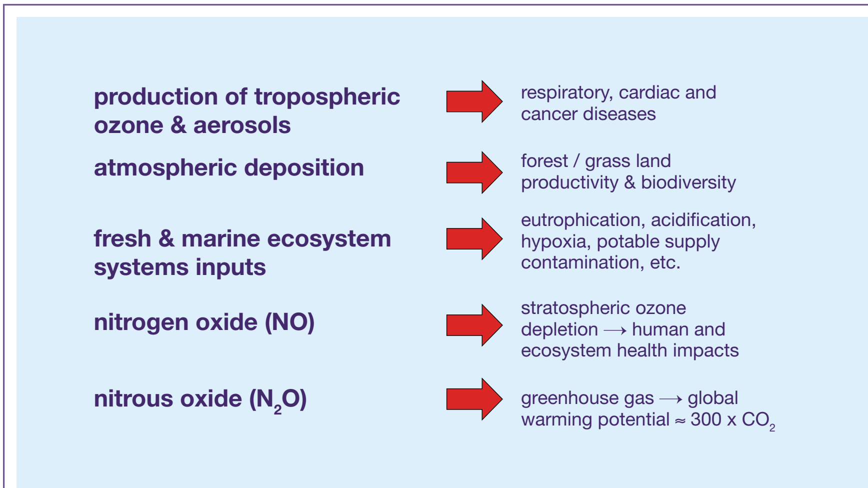

Figure 2.: Summary of potential human health and environmental impacts associated with reactive nitrogen (adapted from *Galloway et al,. 2004*). Gaseous NO and N_2O shown separately in the context of biochemically 'leaked' Nr from natural nitrification and denitrification processes.

Viewed another way, approximately 14% of the new Nr used in food production ends up in wastewater. This is not an inconsequential fraction and, as a result, wastewater management has been identified by those examining the global Nr cycle as a potentially significant intervention, among several others, in managing this cycle. Some of the earlier ideas (e.g., *Galloway et al., 2008*) envisioned providing more of the world's population with wastewater treatment and using it to *convert* the Nr in wastewater to N_2, within bioreactors, for return to the atmosphere, thus keeping more of the wastewater-derived Nr out of aquatic environments.

But, the recent European Nitrogen Assessment (ENA) (*Sutton et al., 2011*) takes another view. The ENA estimated the 'social damage costs' of environmental Nr emissions on the European Union countries to be in the order of $250 billion/(Year 2000 mid-range value). To deal with this situation, the ENA envisions wastewater Nr *recovery* as one of seven key actions in 'developing integrated approaches to N management.' The ENA looks to wastewater Nr recovery and subsequent reuse as a means to offset and reduce anthropogenic Nr production in the first place. It notes that "… Nr denitrified in wastewater treatment represents the loss of a valuable resource …" (*Svirejeva-Hopkins et al., 2011*).

Conceptually, wastewater Nr *recovery* could be implemented 'end-of-pipe.'. For treatment facilities with anaerobic digesters, the most suitable location would be post-digestion dewatering recycle streams where ammonia released during solids digestion is concentrated. Potential technological approaches for Nr recovery at this location include stripping (air, steam), adsorption (sorption, ion exchange), vacuum distillation, and co-precipitation with phosphorus recovery via struvite (i.e., magnesium-ammonium-phosphate) crystallization (*Reardon and Machado, 2011*). Here, however, the Nr mass available for recovery is limited and represents 10 to 30% of

the total Nr arriving at a WWTF in the raw wastewater. For the purpose of this discussion, the traditional direct use of Nr bearing effluent (i.e., irrigation) or biosolids (i.e., land application) are ignored, although they do represent a form of Nr recovery.

Alternatively, wastewater Nr recovery could be implemented at-source to provide greater capture potential. The ENA implicitly recognized this reality in its advocated utilization of urine and feces (*Svirejeva-Hopkins et al., 2011*). While there is some nitrogen in fecal matter, the predominant wastewater Nr source is urine. Thus, at-source, Nr recovery largely implies urine separation and subsequent management.

URINE-DERIVED Nr RELATIVE TO GLOBAL SYNTHETIC N FERTILIZER PRODUCTION

With the argument that excess Nr is a global issue and urine separation may be one of several interventions in dealing with this issue, the question now becomes how much urine-derived Nr potential is out there? Calculating the amount of Nr that may be available in human urine, which could potentially offset synthetic N fertilizer production and use, and how it relates to synthetic N fertilizer production and use requires examination. Consider these facts:

- Not all food consumed by people is grown using synthetic N fertilizers.
- Alternately, some food is grown using non-synthetic N sources for fertilizer, such as animal manure. Furthermore, such countries as Sweden use land application of separated animal urine (*Kvarnström et al., 2006*). In addition, legume-type crops fix substantial quantities of nitrogen from the atmosphere into plant biomass and soil. Thus, aggregately, human urine contains Nr that originates from non-synthetic fertilizer sources.
- Dietary nitrogen intake varies around the world, due to social-economic reasons, which means urine unit Nr content and production varies globally. *Kujawa-Roeleveld and Zeeman (2006)* provide a literature-based range of 1.3 to 6.9 kg Nitrogen-N per person per year.

Assuming a global population of seven billion people and a lower mid-range urine unit Nr production rate of 3.5 kg, N/p-yr yields 24.5 Tg Nr/yr of potential urine-derived Nr (1 Tg = 1 million tonnes). This mass represents approximately 25% of the 98 Tg N/yr of produced synthetic N fertilizer (Figure 1).

Collection and processing efficiencies will reduce this potential, as will the practical limit of implementation in urban and rural areas. Further factors include the market for urine or urine-based fertilizer products and the relationship between its point of recovery/production and location of use as a fertilizer. But, the data suggest there is the potential to meaningfully offset synthetic fertilizer production via Nr recovered from urine and thus reduce the amount of Nr in our biosphere. In turn, such offsetting may help to reduce the negative impacts of Nr on human health and the environment in general.

MOVING FORWARD

From work done globally to date on urine separation it is clear that the industry needs to address a variety of technical, environmental, economic, and social-political knowledge gaps to fully understand what actual benefits urine separation may provide and in what application context, and, if justified, to move it beyond the theoretical to the practical. The global Nr issue, and how wastewater Nr recovery might fit into its management, needs to be part of the assessment. Engaging the wastewater management community meaningfully in the broader debate on global Nr management is key. ♦

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Toronto's advanced stormwater quality facility – is this the future of stormwater management?

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The stormwater quality facility for Waterfront Toronto's West Don Lands Precinct might just be a look into the future of stormwater quality management.

PROJECT BACKGROUND

Waterfront Toronto was created by the City of Toronto, Province of Ontario, and Government of Canada to oversee and deliver a revitalized waterfront. The waterfront revitalization project involves 800 ha of former industrial lands, the creation of 40,000 residential units over a period of 25 years with $30 billion in private and public investment. It is the largest urban renewal project in Canada and one of the largest waterfront projects in the world.

The West Don Lands (WDL) Precinct shown in Figure 1 is one of the development areas currently being revitalized, and it will be the site of the 2015 Pan Am Athletes' Village. This precinct is 32 ha and will have 6,000 residential units, as well as employment and commercial uses. The site is commuter and live-work supportive by an extension of the streetcar line to the precinct and by open access high-speed Internet in the precinct.

To allow the development to proceed, the lands had to be protected from flooding by the Don River. A flood-protection landform was constructed for this purpose. Construction of the landform blocked the land drainage that was previously directed to the river, requiring regrading of the site and a new outfall to the river at the Keating Channel, as indicated in Figure 1. The new outfall was identified through an environmental assessment undertaken in 2005. To address water quality initiatives

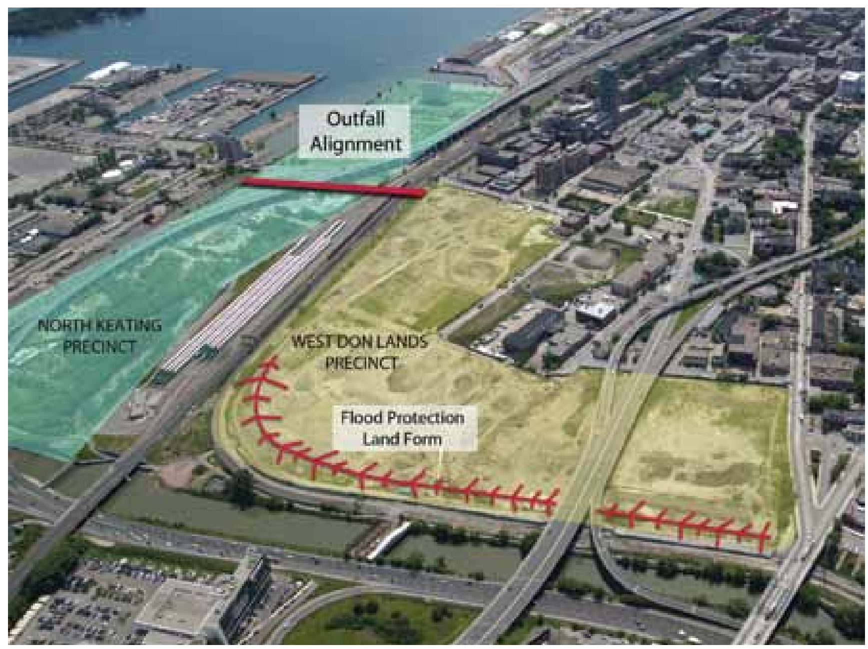

Figure 1: Project context

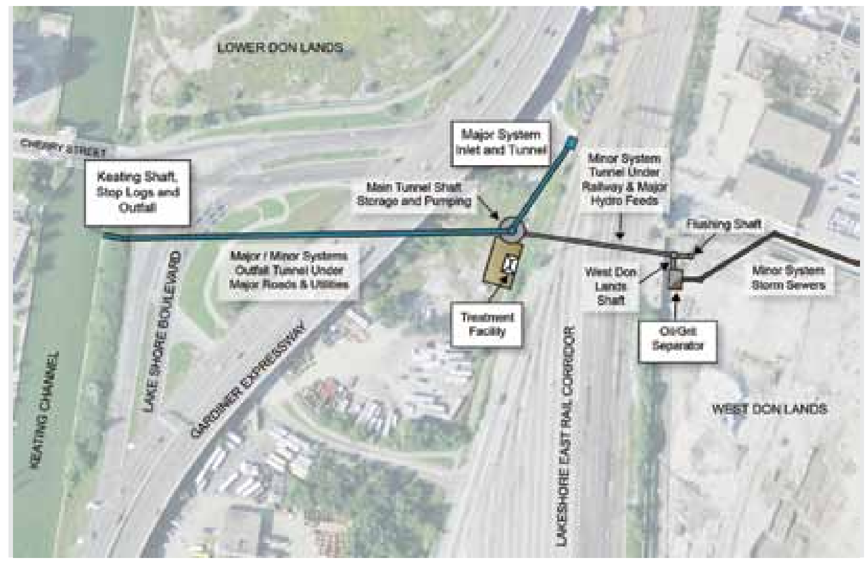

Figure 2: West Don Lands stormwater quality facility and outfall

of the City of Toronto, the environmental assessment also identified the need for a centralized oil-grit separator (OGS), filtration, and ultraviolet (UV) disinfection.

The alignment of the new storm outfall requires the crossing of the Lakeshore Rail Corridor, which is a major commuter rail line into Toronto, high-voltage underground and overhead hydro feeds, a 500 mm diameter high-pressure gas main, Lake Shore Boulevard, the piers of the elevated Gardiner Expressway, as well as the usual suite of utilities and services. The area is lakefill, so there was the possibility of encountering old wharfs, shore walls, and assorted structures. In addition, the overburden soil geotechnical and environmental conditions were poor.

For these reasons, tunneling the outfall in the bedrock was recommended. Figure 1 indicates the general alignment of the new storm outfall. Tunneling in the rock had the advantages of working in the well-known shale of the Georgian Bay Formation, avoiding the risks associated with the overburden soils.

DESIGN CRITERIA

Detailed design of the stormwater system began in 2007, and, early on, it was identified that filtration and UV disinfection would be costly and difficult to achieve within the allocated space. The need for 80% total suspended solids (TSS) removal and disinfection to 100 E.coli per 100 mL was driven by the City of Toronto's 2006 *Wet Weather Flow Management (WWFM) Guidelines*.

As the size of the filtration and ultraviolet components was a concern from a peak-flow treatment perspective, the main shaft used to launch the tunnel boring machine (TBM) could also be lined and reused to provide storage. This provided the opportunity to attenuate the flows an appreciable amount, to the point where treatment equipment could be more economically sized. The storage in the main shaft was realized by separating the storm system into major and minor system components.

The West Don Lands outfall and stormwater quality facility shown in Figure 2 consists of:

- a centralized oil-grit separator to remove trash, debris, heavy grit, and oil from minor system flows before being directed to storage;
- a minor system tunnel under the railway corridor to convey minor system flows from the West Don Lands precinct to the main shaft;
- a major system inlet and tunnel to convey overland flows from Cherry Street to the main shaft;
- a major/minor system outfall tunnel to convey flows from the main shaft to the Keating Channel shaft;
- an outfall to the Keating Channel with stop logs;
- storage and pumps within the main shaft to convey flows to the treatment system; and
- a treatment system consisting of a fine screen, ballasted flocculation clarifiers, and open channel UV disinfection.

As shown in Figure 3, the major/minor tunnel to the Keating Channel is an inverted syphon that effectively brings the 'lake' into the central portion of the main shaft. Runoff is stored in the outer portion of the main shaft and is pumped to the treatment facility. After treatment, flows are discharged to the outfall or 'lake' side of the main shaft. The underflow from the ballasted flocculation clarifier is discharged to the sanitary sewer. Should the storage shaft completely fill, stormwater would overflow a weir and be discharged untreated to the lake. The overflow weir is needed to accommodate severe storm events.

As there is not a reliable overland flow route from the West Don Lands precinct to the Keating Channel because of a sag on Cherry Street at the railway corridor, all tunnels are three metres in diameter to accommodate the major system overland flows. For periods of maintenance, the system may be dewatered by use of the stop log structure integrated into the Keating Channel shaft and the OGS.

PROJECT HIGHLIGHTS

Some of the unique aspects of this project include:

- The two oil-grit vortex separators in a parallel arrangement is the largest installation of its kind in Canada.
- First use in Ontario of a vacuum flushing shaft system that was developed in England; this system avoids having moving parts at depth.

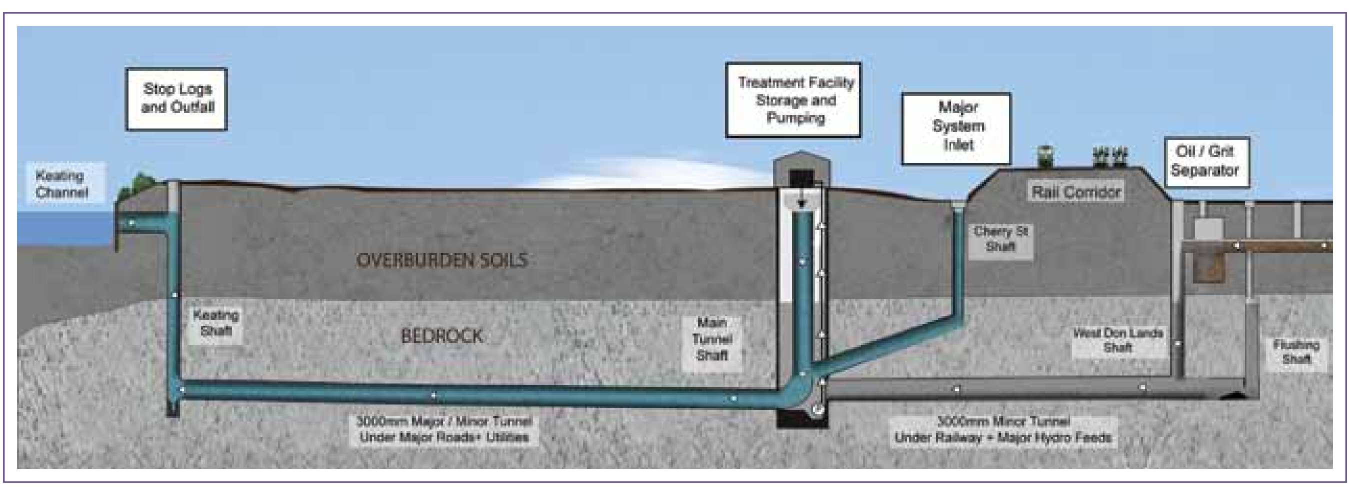

Figure 3: Tunnel cross-section

Figure 4: Stormwater quality facility under construction

- Arrangement of the tunnels allowed mining of all three tunnel headings from the main shaft for significant cost savings.
- Three of the four smaller shafts were drilled using a large steel liner to achieve time and cost savings.
- Use of the outer area of the main shaft for storage allowed flows to be attenuated (reducing treatment flow rates), and the central standpipe and weir accommodate any overflows.
- First use of the ballasted flocculation clarifier process exclusively for stormwater treatment (TSS removal) to provide a reliable effluent.
- First full-scale implementation of UV for disinfection of stormwater as required under the City of Toronto's *WWFM Guidelines*.
- A large outfall box culvert was designed to reduce velocity in the receiving navigable channel, as opposed to a baffle wall, which could impair navigation.
- Expedited tender to get to market before other tunneling projects resulted in receiving four competitive bids.
- Use of precast elements for the main shaft riser and outfall helped to speed construction to achieve the Pan Am schedule.
- Tunnelling in rock reduced risk and minimized disposal of environmentally impacted overburden soils.
- The facility footprint is extremely compact, conserving valuable development lands.
- Waterfront Toronto is committed to architectural design excellence, and the architectural design of the building has received a Canadian Architect's Award of Excellence.

Photographs of the facility under construction are provided in Figure 4.

CITIES OF THE FUTURE

To achieve the treatment objectives for TSS removal and disinfection, stormwater facilities are becoming more complex, costly, and larger in scope. Stormwater treatment, in this case, has incorporated equipment normally associated with water and wastewater treatment and has used available storage within the shaft and conveyance system to help achieve economy.

The West Don Lands stormwater quality facility and outfall project incorporates many innovations and provides a looking glass into the future of stormwater management. The City of Toronto has shown leadership in advancing their design criteria to help minimize beach closures and improve the water environment.

Incorporating equipment normally associated with the water and wastewater industry may become more commonplace in the future. Equipment suppliers may find a new market and, in time, their equipment and/or processes could be tailored to the cyclic operations of stormwater treatment.

Although the West Don Lands stormwater quality facility will treat a small portion of the Don River watershed, it will provide an incremental benefit. As with most environmental issues, society must start somewhere and, over time, build on the incremental benefits achieved. With the scope of the overall Waterfront Toronto 800 ha redevelopment project taking place over the next 25 years, the increments will add up to achieve a significant environmental benefit.

Guidelines, design tool and course provide support for harvesting rainwater in Canada

Chris Despins, M.Sc., P.Eng.,Water Resources Specialist, Credit Valley Conservation

OVERVIEW

Rainwater harvesting, the practice of collecting rainwater from roofs and other impermeable surfaces for the purpose of re-use, has become increasingly popular in Canada over the past decade, growing from a niche practice to a staple for many green buildings. The rise of rainwater harvesting (RWH) can be attributed in part to green building standards, like Leadership in Energy and Environmental Design (LEED), and municipal equivalents, like the Toronto Green Standard (TGS). But, there are many other drivers making RWH part of our transition to sustainable cities.

In Ontario and elsewhere across Canada, population growth and urban intensification are placing increasing pressures on aging municipal stormwater management infrastructure. RWH and other source control measures are rapidly becoming recognized as the best means of addressing these issues — by treating stormwater as a resource, not a waste to be removed from a site as quickly as possible[1]. Another driver for RWH implementation is the need to utilize water resources more efficiently through water conservation and efficiency. For instance, Alberta is facing increasing pressures on its Bow and Elbow watersheds due to an increasing population, and inefficient use of potable water in the residential sector[2]. The use of more efficient fixtures like high efficiency toilets (HETs) coupled with rainwater re-use can free up capacity within the municipal water supply system, permitting additional growth without the need for additional water-takings from these watersheds.

In order to push for greater adoption of RWH, provincial governments, municipalities, non-governmental organizations, academia, practitioners, and industry have worked together on a variety of resources and tools to support the implementation of RWH.

Guidelines for Residential Rainwater Harvesting Systems

One such resource is the *Ontario Guidelines for Residential Rainwater Harvesting Systems* and the *Alberta Guidelines for Residential Rainwater Harvesting Systems*. These guidelines have been developed with input from the Ontario Ministry of Municipal Affairs and Housing and Alberta Municipal Affairs, and have been tailored to the regulatory environment within each province. The guidelines' documents provide a comprehensive overview of the various components that comprise a RWH system, as well as the regulatory requirements for these components, based on applicable codes and standards. The codes and standards referenced include CAN/CSA B128.1 *Design and Installation of Non-Potable Water Systems/Maintenance and Field Testing of Non-Potable Water Systems, CAN/CSA B64 Backflow Preventers and Vacuum Breakers*, the *Ontario Building Code*, *Alberta Building Code*, and the *National Plumbing Code of Canada*.

The guidelines' goal is to fill in the 'knowledge gaps' with regard to RWH by answering key questions, including:

1. the applications for which rainwater use is permitted;
2. treatment requirements (and recommendations);
3. proper sizing of rainwater storage tanks, pump and pressure systems, and other components; and
4. best practices for maintaining RWH systems.

Although these guidelines have been targeted at the residential sector, many of the best practices for the design, installation, and management of these systems are equally applicable to industrial, commercial, and institutional (ICI) sectors. The regulatory aspects highlighted within the documents are equally applicable across all sectors.

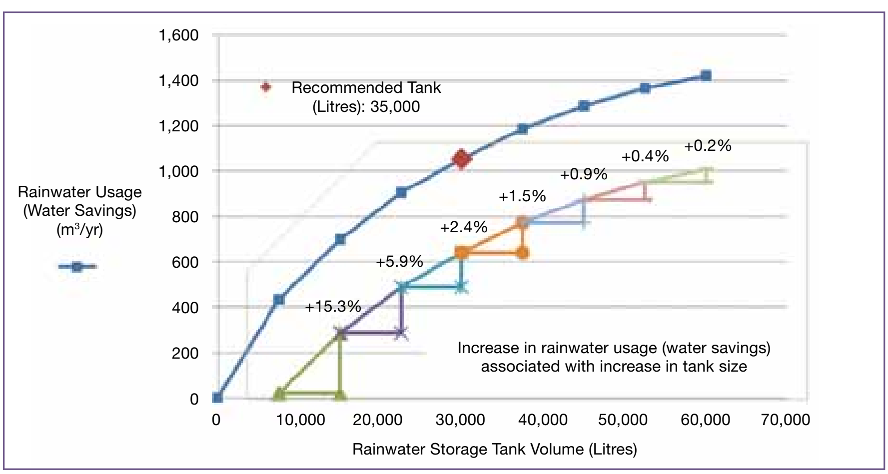

Figure 1

RAINWATER HARVESTING DESIGN AND COSTING TOOL

To further support practitioners and others implementing RWH projects, a supplementary rainwater harvesting design and costing tool has been devel-

oped with the support of various partners, including the University of Guelph and the Toronto and Region Conservation Authority. The tool was created in an Excel spreadsheet and provides a means to model the amount of precipitation that can be collected from a roof catchment, stored within a given tank size, and used within a building to meet non-potable water demands. The accuracy of this process is increased by using historical rainfall data from cities across Canada. The tool includes numerous features to facilitate the design of RWH systems, including multiple ways to size rainwater storage tanks.

Tank sizing options include:

1. selecting the size to meet all rainwater demands during a specified drought period (i.e., a tank with sufficient supply for two weeks without rain);
2. selecting a tank size to meet a specified water savings target, such as a 30% reduction in building water usage; and
3. selecting the smallest tank size while providing the greatest water savings (i.e., the most efficient and economical tank size).

An example of the output generated by the design and costing tool when using the efficient tank size recommendation feature is provided in Figure 1.

In this example, as tank size increases (x-axis), the amount of corresponding water savings (from greater collection and subsequent use of rainwater) also increases (y-axis). At low storage volumes, small increases in tank volume provide significant net benefit (i.e., +15% savings, +5.9% savings, etc.). However, this benefit tends to decrease as tank size increases. Eventually larger tanks provide diminishing returns because of constraints—the size of the roof catchment or the daily rainwater demands. Based on these principles, the design and costing tool automatically compares the water savings of multiple tank sizes and recommends the tank size that provides the greatest water savings with the smallest tank using an assigned threshold limit. In the example, any tank providing less than a 2.5% increase in savings per 1,000 litres of additional storage is rejected. This corresponds to a recommended tank size of 35,000 litres for a site with a 5,000 m^2 catchment area requiring 4,500 litres of non-potable water per day.

In addition to sizing tanks and pumps for a given project, the design and costing tool provides a detailed cost estimate based on cost figures compiled from surveys of Greater Toronto Area suppliers and data from an industry-recognized source—RSMeans. By combining both design and costing elements, the program can be a powerful tool for both practitioners and decision makers, including municipalities, property owners, and clients, to evaluate RWH.

RAINWATER HARVESTING COURSE

The third and final means of supporting practitioners, contractors and other interested parties gain insight into best practices for RWH systems is a comprehensive one-day course. The Design, Installation and Management of Rainwater Harvesting Systems course is focused upon the regulatory and technical aspects of RWH systems for both residential and ICI settings, and provides a thorough overview of the contents of the RWH Guidelines and the Design & Costing Tool. The course also includes several group exercises aimed at generating discussion among participants and how to apply the Guidelines to the design of RWH systems.

The RWH course is currently offered through the Canada Green Building Council, in partnership with Credit Valley Conservation and Toronto and Region Conservation Authority. Further details regarding the course, including upcoming dates can be found at *http://www.cagbc.org/education/*.

CONCLUSIONS

The Ontario and Alberta guidelines, the Excel-based design and costing tool, and the RWH course provide important resources to assist the design, installation, and management of RWH systems. By highlighting best practices, specifying regulatory requirements, and providing key design support with tank and pressure system sizing, these tools facilitate the successful implementation of RWH systems on a larger scale.

DOWNLOAD THESE RESOURCES FOR FREE

You can download the *Ontario Guidelines for Residential Rainwater Harvesting Systems,* the *Alberta Guidelines for Residential Rainwater Harvesting Systems,* and the design and costing tool for free at *www.sustainabletechnologies.ca.*

End notes

1 www.poliswaterproject.org/publication/426

2 www.calgary.ca/UEP/Water/Documents/Water-Documents/water_efficiency_plan.pdf

Nutrient recovery: a key component of the plant of the future

Samuel Jeyanayagam, Ph.D., P.E., BCEE; Bill Leaf, P.E.; Dru Whitlock, P.E.; Jeremy Kraemer, Ph.D., P.Eng., CH2M HILL

THE CASE FOR NUTRIENT RECOVERY

Phosphorus (P) and nitrogen (N) are essential elements of all life forms and are used by society in fertilizers, detergents, crop protection chemicals, pharmaceuticals, and many other products. However, human activity is radically changing the global phosphorus and nitrogen balances, and wastewater management can be a significant opportunity for intervention *(Shiskowski, 2011)*.

Mining of phosphate rock is extracting P faster than geologic cycles can replenish it, and, therefore, is considered 'non-renewable.' At the present rate of consumption and current economic conditions, high-quality P reserves are predicted to be depleted in about 100 years *(Vaccari, 2011)*.

Although nitrogen gas constitutes approximately 78% (by volume) of our atmosphere, it must be converted to the usable reactive nitrogen form through energy intensive processes. This high-energy chemical is then subject to significant waste in the food and energy systems of society. For example, approximately 80 to 90% of the reactive N used for food production is lost to the environment *(Shiskowski, 2011)*, and all reactive N contained in combusted fuel enters the environment.

Some of the key influences and drivers for nutrient recovery are listed in Table 1.

Nutrient recovery technologies

As shown in Figure 1, there are several potential streams within a typical wastewater treatment plant where phosphorus and nitrogen can be recovered. These streams include waste activated sludge, centrate or filtrate, final effluent, and incinerator ash. Following anaerobic digestion,

Table 1: Key influences and drivers favouring nutrient recovery

- Cost effective and sustainable strategy for resource recovery
- Offset phosphorus depletion and nitrogen loss
- Minimize struvite scaling in wastewater treatment plant equipment and piping
- Reduced recycle loads resulting in stable mainstream BNR process
- Lower air requirements for nitrification
- Reduced chemical solids production by eliminating chemical phosphorus removal
- Lower land application cost in areas where application rates are controlled by biosolids phosphorus content
- Struvite is a marketable and environmentally acceptable end-product
- Future regulations may mandate nutrient recovery, as in Sweden
- An integral component of sustainable wastewater treatment plants of the future

What is EBPR?

In the Enhanced Biological Phosphorus Removal or EBPR, the microorganisms remove soluble phosphorus from solution and store it within their cells in amounts that exceed what they need for normal growth. Once the phosphorus is stored, the microorganisms are settled out in the clarifier, and a portion of them are wasted with the waste activated sludge.

How is this similar to chemical phosphorus removal?
The method of removing the phosphorus from the system is the same: (1) tie the soluble phosphorus up in the sludge (using chemicals) and (2) waste the phosphorus from the system with the waste-activated sludge.

How is this different from chemical phosphorus removal?
With EBPR, the phosphorus is stored within the cell. In a chemical P system, the phosphorus part of chemical complex is outside of the cell. Provided the cell can be settled out in the clarifier, the phosphorus will not appear in the effluent.

The major difference is that, under certain conditions, the cell will release some of the phosphorus it stored. This is a good thing if you want to harvest the phosphorus. It is a bad thing if it goes back to the plant and ends up in the effluent.

When was Canada's first EBPR plant built?
It was built in 1982 in Kelowna, BC.

Source: *Henze, Mogens et al. Biological Wastewater Treatment. Principles, Modelling and Design*. London: IWA Publishing, 2008.

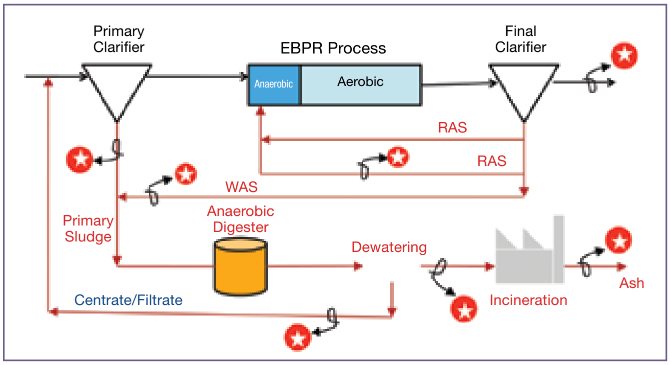

Figure 1: Potential locations for recovering nutrients

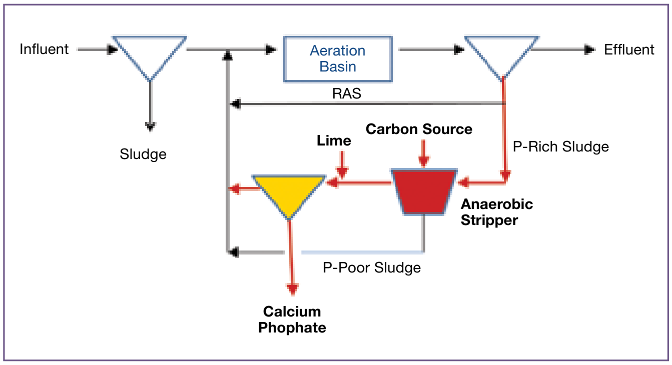

Figure 2: PhoStrip process schematic

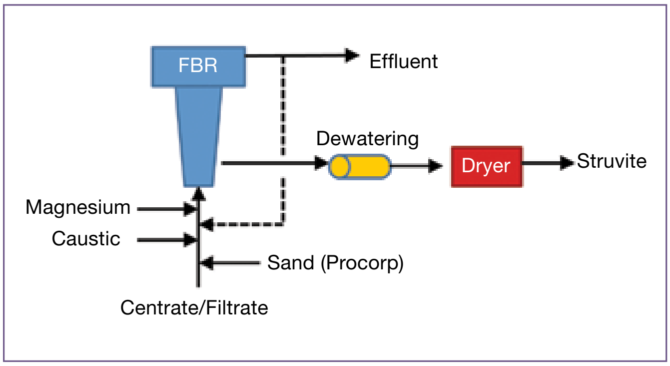

Figure 3: Generic Process Schematic

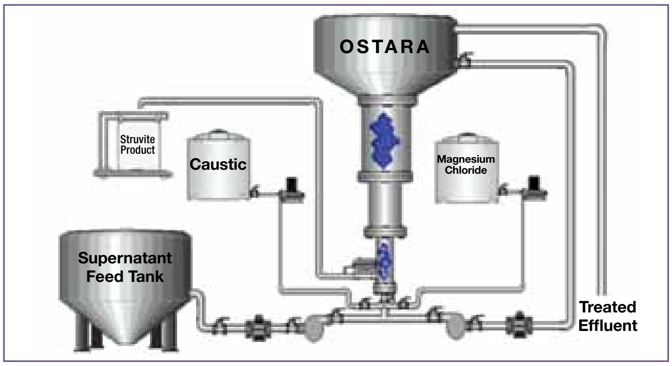

Figure 4: Ostara struvite recovery process (Ostara)

8.5% of the plant influent nitrogen will remain in the digested sludge, and 11.5% will end up in the recycle stream from sludge dewatering *(Phillips et al., 2011).* In the case of Enhanced Biological Phosphorus Removal (EBPR), the return streams following anaerobic digestion contain approximately 50% of the phosphorus. Because of the substantial nitrogen and phosphorus loads, the recycle stream from dewatering of anaerobically digested sludge has been the major focus of nutrient recovery efforts.

A number of technologies are available for recovering nutrients, with chemical precipitation and adsorption being the predominant extraction mechanisms. Brief descriptions of some approaches used or evaluated in North America are presented below.

PHOSTRIP®

The **PhoStrip**® process (Figure 2), developed in the 1970s for phosphorus removal, entails directing a portion of the return activated sludge (RAS) to an anaerobic stripper to release phosphorus to the liquid phase. The phosphorus-rich water is treated with lime to recover calcium phosphate. This strategy is typically implemented in an EBPR process, which generates sludge with excess phosphorus. A readily biodegradable organic source, such as acetic acid, is added to the anaerobic stripper to trigger phosphorus release. Several full-scale facilities use the PhoStrip® process to meet phosphorus limits. These include plants in Germany (Darmstadt) and Austria (Hofkirchen, Schalchen, and Wallang). In the US, the process is utilized by the Truckee Meadows Water Reclamation Facility in Reno, NV. The original design of the Little Patuxent Water Reclamation Plant in Maryland included the PhoStrip configuration.

STRUVITE RECOVERY

A literature review reveals that struvite (magnesium ammonia phosphate [MAP]) was observed in digested sludge supernatant lines as early as 1939 *(Doyle and Parsons, 2002).* Plants converting to biological nutrient removal continue to experience operation and maintenance problems with struvite scaling. Key factors that affect struvite formation include the availability of the three major ions in a molar ratio of 1:1:1 of Mg^{+2}:NH_4^+:PO_4^{3-} and optimal pH in the range of eight to 10. Recent efforts have focused on recovering struvite under controlled conditions. This provides the dual benefits of minimizing unintended struvite scaling and recovering a clean fertilizer product containing nitrogen and phosphorus.

Figure 3 shows a generic process flow diagram. Typically, a chemical feed of magnesium chloride is needed to provide magnesium, which is usually the limiting element, as well as caustic to achieve alkaline pH conditions. Following chemical addition, the filtrate or centrate enters a fluidized bed reactor (FBR), which is the heart of the process where struvite crystals are formed. Product is withdrawn periodically from the FBR, dewatered, dried, and stored. The FBR effluent is returned to the

Table 2: Struvite recovery systems available in North America

TECHNOLOGY	FEED STREAM	EXTERNAL INPUTS	LOCATION
Ostara	Centrate/Filtrate	$MgCl_2$, NaOH	Operational • Edmonton Gold Bar, AB • York, PA Under design/construction • Thames Water, UK
Ostara (WASSTRIP)	WAS or Centrate/Filtrate	$MgCl_2$, NaOH	Operational • Durham, OR • Nansemond, HRSD, VA Under design/construction • Rock Creek, OR • Saskatoon, SK • Madison, WI
Multiform Harvest	Centrate/Filtrate	$MgCl_2$, NaOH	Under construction • Boise, ID • Yakima, WA
Procorp	Centrate/Filtrate	$MgCl_2$, $Mg(OH)_2$, NaOH, Sand	Operational • Two industrial facilities in North America • Several in Europe & Japan

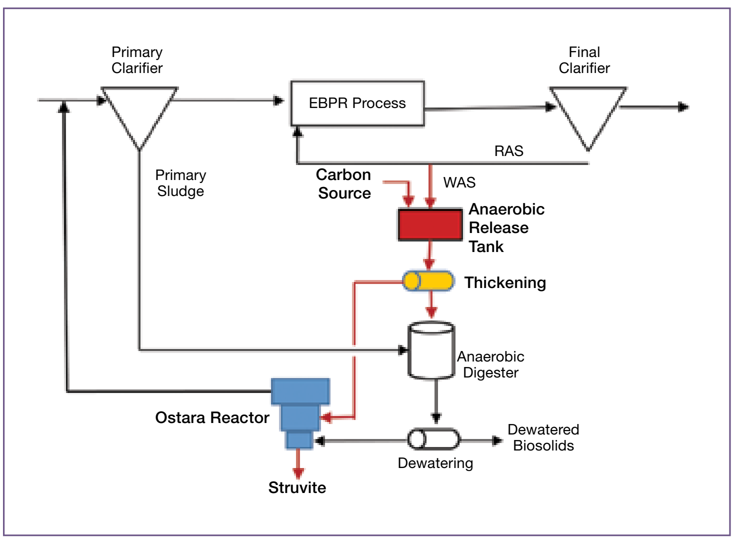

Figure 5: WASSTRIP® struvite recovery process (Ostara)

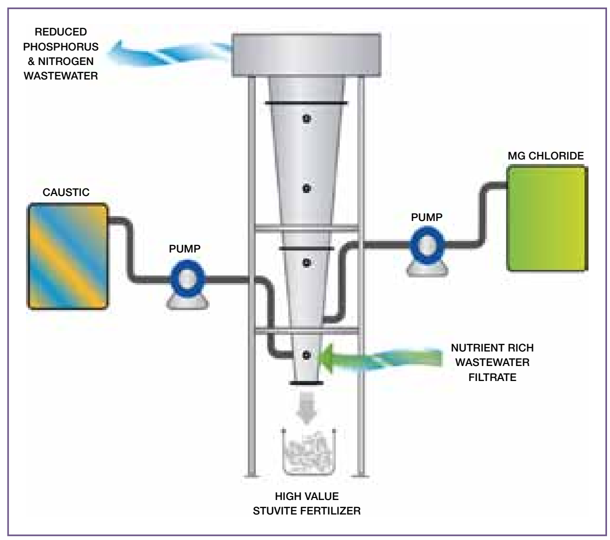

Figure 6: Multiform harvest struvite recovery process (Multiform Harvest)

main stream process. The struvite end-product has commercially desirable formulation of phosphate-P (12.7%) and ammonia-N (5.7%). It is a slow-release fertilizer and dissolves slowly over a nine-month period

Three suppliers market struvite recovery systems in North America using proprietary FBRs. Key features of the available technologies are compared in Table 2, together with facility locations. The locations presented are for the systems applied to municipal or industrial treatment facilities.

Ostara

In the Ostara system, the nutrient-rich centrate/filtrate flows up through a fluidized bed of preformed fine particles of struvite granules, which serve as seeds for pellet growth. As shown in Figure 4, the technology also includes an internal recycle from the top of the bed back to the reactor feed area at the bottom. Ostara takes responsibility for marketing the final product. The resulting revenue to the utility may, in some cases, offset the operating cost of the struvite recovery system.

A recent modification of the Ostara process is the WASSTRIP® configuration (Figure 5), which entails anaerobic stripping of the phosphorus from WAS followed by thickening and struvite harvesting from the centrate. The main advantage of this approach is that phosphorus is removed prior to digestion, thereby minimizing the potential for struvite scaling upstream of dewatering.

Multiform harvest

The struvite recovery system provided by Multiform Harvest is similar in concept to Ostara. However, it does not involve an internal recycle (Figure 6). This technology was originally developed for treating swine wastewater and has been adapted for treating dairy wastewater. Multiform Harvest's marketing strategy entails blending the struvite product prior to marketing. The utility has the option of sharing the cost and revenue of the marketing efforts.

Procorp

Procorp uses the Crystalactor® technology developed in Europe and is offered there by the DHV Group. Like the Ostara process, it uses a fluidized bed reactor. However, the reactor is a cylindrical vessel (Figure 7), offering little or no change in up-flow velocity, which must remain adequate to levitate particles large enough to suit the market needs. Very small particles are not retained, and the reactor must be seeded with an external source of heavy material, such as sand (40–50 mesh). While Procorp does not participate in marketing the end product, it can assist in identifying market outlets in the local community.

ADSORPTION TECHNOLOGY

In addition to struvite precipitation, phosphate can also be captured by adsorption. The Asahi Kasei Chemical Corp. of Japan has introduced an adsorbent resin of metal oxide and polymer that is highly selective for phosphate than competing ions commonly found in municipal wastewaters *(deBarbadillo et al., 2011)*. As illustrated in Figure 8, the phosphorus recovery strategy comprises three stages. In the adsorption stage, filtered final effluent is fed through a column charged with the adsorbent, and phosphorus is removed. In the desorption stage, an alkaline solution is passed through the column, and the phosphate ions are desorbed. In the recovery stage, desorbed phosphate ions are separated from the desorbing agent by adding lime, which recovers phosphorus as calcium phosphate. The alkaline solution can then be used again in the desorption stage. This adsorption technology achieves low effluent phosphorus concentrations.

AMMONIA RECOVERY TECHNOLOGY

A significant fraction of the influent nitrogen is found as ammonia in the centrate or filtrate stream following anaerobic digestion. The Ammonia Recovery Process (ARP) marketed by ThermoEnergy is a two-step process that combines flash vacuum distillation with ion exchange to remove ammonia. As illustrated in Figure 9, centrate/filtrate undergoes pH adjustment to shift the ammonium-ammonia equilibrium toward ammonia gas formation. Following pretreatment to remove contaminants, vacuum (flash) distillation is used to capture the ammonia that would readily volatilize.

The effluent stream with reduced ammonia nitrogen content (approximately 300 ppm or less) is treated by ion exchange, which selectively adsorbs the ammonia. The adsorption columns are regenerated using either brine or sulfuric acid. The spent ammonia-laden regeneration solution is stripped of ammonia

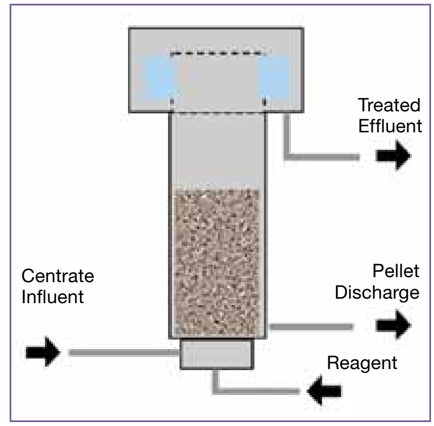

Figure 7: Crystalactor® struvite recovery process (Procorp)

to produce a commercial-grade solution of ammonium sulfate. The ARP scheme is presently under consideration in New York City.

Another technology that recovers ammonia from dewatering centrate/filtrate as ammonium sulphate is AmRHEX, which is under development in Ontario by 3XR Inc. This system uses

Table 3: Other nutrient recovery technologies *

TECHNOLOGY	ORIGIN	FEED STREAM	CHEMICALS USED	END PRODUCT
KREPO	Sweden	Centrate	H_2SO_4, NaOH, Fe	$FePO_4$
Kemicond	Sweden	Centrate	H_2SO_4, NaOH, H_2O_2	$FePO_4$
Seaborne	Germany	Centrate	H_2SO_4, NaOH, $Mg(OH)_2$	Struvite
NuReSys	Germany	Anaerobic effluent	NaOH, $MgCl_2$	Struvite
PHOSPAQ	Netherlands	Centrate	MgO	Struvite
Rem-Nut	Italy	Effluent	NaOH, $MgCl_2$	Struvite
Phosnix	Japan	Centrate	$Mg(OH)_2$, NaOH	
P-Roc	Germany	Centrate	Tobermorite (Ca source from industrial waste)	$Ca_3(PO_4)_2$
BioCon	Denmark	Incinerator ash	H_2SO_4	H_3PO_4
SEPHOS	Germany	Incinerator ash	H_2SO_4, NaOH, Lime	$AlPO_4$, $Ca_3(PO_4)_2$
SUSAN	Europe	Incinerator ash	H_2SO_4, NaOH, $Mg(OH)_2$	Fertilizer product

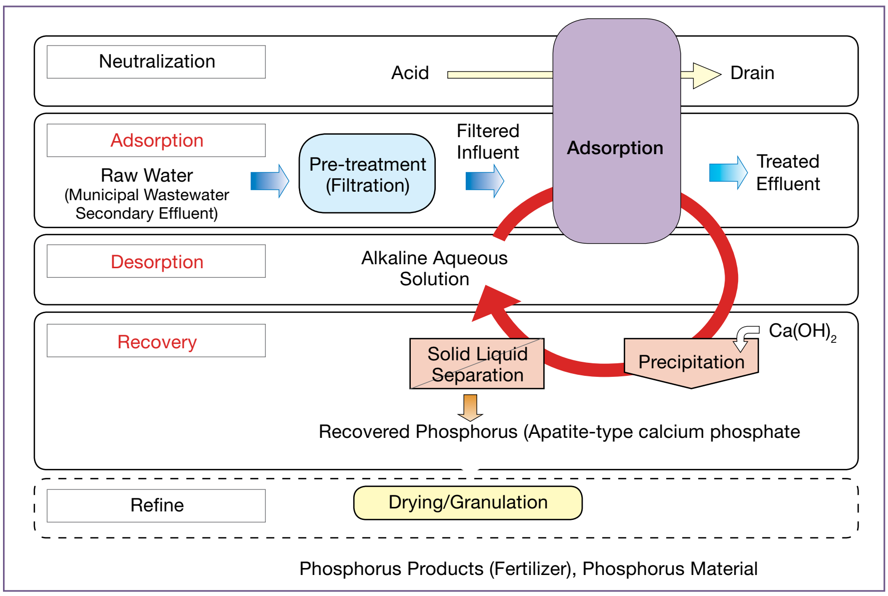

Figure 8: Asahi Kasei adsorption process *(deBarbadillo, 2011)*

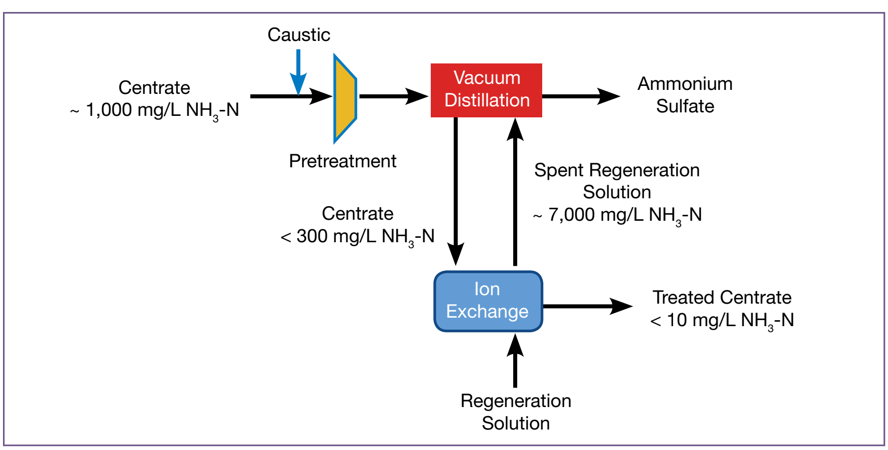

Figure 9: Simplified ARP schematic (ThermoEnergy)

a rotating contactor of proprietary media to facilitate volatilization of the ammonia in the centrate/filtrate compartment of the reactor with subsequent scrubbing from the gas phase in an acidic compartment to form ammonium sulphate.

OTHER NUTRIENT RECOVERY STRATEGIES

Several other nutrient recovery approaches are in various stages of development. A few examples are summarized in Table 3. The table shows that these technologies recover nitrogen and phosphorus in various chemical forms.

THE PLANT OF THE FUTURE

The wastewater treatment plant of the future must continue to remain true to its core principles of public health and environmental protection. However, our practices must evolve to cope with the realities of the 21st century, including rapid population growth and urbanization, diminishing natural resources, and climate change. These pressures are forcing our global society from a comfortable position of abundant resources to a stressful position of scarcity and have triggered a global response. For example, Sweden has mandated the recycling of 60% of P in wastewater and China has applied

a 135% export tariff to conserve its P deposits.

Already, our industry is undergoing a paradigm shift: utilities are beginning to view wastewater and sludge not as a waste requiring treatment and disposal but as a valuable resource: a sustainable plant is being conceived as a 'resource recovery facility.' Nutrient recovery is currently being explored as a cost-effective and environmentally sustainable strategy for resource recovery.

Nutrient recovery from wastewater in itself will not offset a significant portion of the global nitrogen and phosphorus demand. It can, however, be combined with other strategies to make a difference. These other strategies may include reducing nutrient loss through improved agricultural practices, urine separation and direct use as liquid fertilizer (urine represents less than 1% of the raw sewage, but contains more than 70% of the nitrogen and 60% of the phosphorus), encouraging diets containing less nutrient-intensive foods, and also applying these same concepts to our animal management systems, as animal waste represents a huge nutrient pool, much larger than human waste.

Therefore, the wastewater treatment industry can and should become a leading proponent of the recovery of phosphorus and nitrogen—the essential elements of life. As we move forward, our resource recovery facilities can be a sustainable contributor to the resources society needs every day: water, nutrients, and energy. ♦

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Form follows function in odour control

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Continued rapid urbanization has significantly influenced the adoption of odour control at wastewater collection and treatment facilities. Interestingly, urbanization has not only created greater need for odour control, but has also determined the direction of technology development, the physical location, and the structural configuration of odour emission control systems.

According to sources in Wikipedia, it was the 'form follows function' declaration of American architect Louis Sullivan in 1896 that led to the development of the steel skyscraper in Chicago in the late 19th century. In the utility world, higher population density creates a continuing need for expansion of wastewater treatment facilities within the urban environment, while urban sprawl causes residential encroachment of existing wastewater treatment facilities. The 'form' of odour-control selection follows the evolving 'function' of odour-control requirements at the wastewater treatment facility.

As recently as 20 years ago, municipalities were loath to apply scarce capital toward odour control, particularly when plants had been sited at large distances from urban centres to avoid nuisance factors for the population. As urban sprawl encroached on the plants, it was not uncommon for plant management to claim that since the plant was there first, the homeowners had no rights to expect changes, such as odour containment. However, activist associations and a sympathetic ear from government legislators soon led to increased regulatory requirements for odour emission control. The Province of Ontario has led the way in emission control regulations that often call for limits of one dilution to threshold for odour at property boundaries through conditions of permit.

The need for odour control in wastewater treatment plants is now well established. Most plant expansions or new plant installations have been subject to odour control for the last decade or more with the endorsement of municipal administration. However, the physical design of odour-control systems has had to adapt to the constraints of available plant space. Urbanization has not only necessitated odour control, but it has influenced its technology and architecture.

Conventional odour control technologies at the turn of the century included chemical scrubbers and activated carbon. Each of these technologies exhibits comparatively low capital cost and requires only a small footprint. Increased restrictions on hauling of hazardous chemicals within urban areas and the associated safety and operating cost of hazardous chemical use have been factors in decreased use of chemical scrubbers for odour control. Activated carbon use is limited to applications that have low levels of contaminant to avoid rapid exhaustion of carbon beds.

Biofilters have been used for odour control on a selected basis for more than 30 years. They are an attractive technology because of low operating cost and low carbon footprint. However, early design parameters included long residence times, which created sprawling systems that took up valuable space. In cities of the future, space will continue to

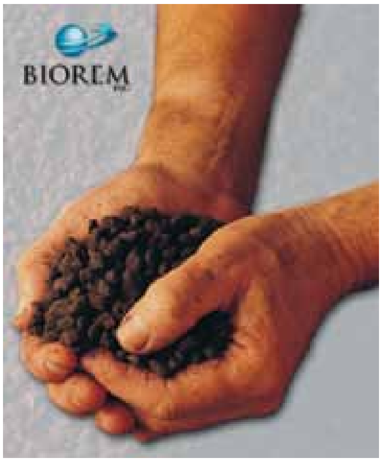

Figure 1: Biosorbens inorganic media

Figure 2: Odour control system at the Peel Region compost facility, ON

become an even more precious commodity. Another limitation of conventional biofilter design is the short lifespan of the media itself, which degrades over time and typically requires replacement every three to five years.

Technology development of biofilters for odour control, driven by urbanization, has been directed at both space reduction and extended media life that eliminates the need for frequent replacement, including transport and disposal. Technology advancements included the development of a new, more efficient media that is permanent and has robust physical characteristics. This has been achieved with products such as Biosorbens® and XLD® by Biorem. Significantly, these products can provide superior, 95% odour removal at reduced empty bed residence times and are warranted for 10 years of operation (Figure 1). Because of the physical structure and pressure-loss characteristics, this form of media can be used in bed depths of greater than two metres. The footprint of a conventional wood-based biofilter system in the 1990s was was large, typically operating at 60 cubic metres per hour (cu m/hr) of airflow per square metre (sq m) of surface area. Modern media has doubled the bed depths and halved the empty bed retention time so the footprint has been further decreased with designs exceeding 240 cu m/hr per sq m now in operation (Figure 2).

Taking the compact design concept one step further has led to the development of horizontal flow systems that enable even taller vessels. Vessels six metres tall provide design capacities greater than 1000 cu m/hr of airflow per sq m of surface area (Figure 3).

Another driving force of urbanization is a need for aesthetic considerations incorporated into plant construction. Modern architecture is incorporated into plant design to make them visually appealing (Figure 4). As an alternative to tall structures that may be inappropriate for the location, biofilters can be located below grade and have no visual impact at all (Figure 5).

Evolution of the modern city has not only caused the necessity of stringent odour management, it has driven the development of advanced technologies for odour control and will continue to do so in the 21st century. ♦

Figure 3: High-profile horizontal flow demonstration plant at Ashbridges Bay, Toronto

Figure 4: Town of Tillsonburg, ON

Figure 5: Zero-profile, below-grade biofilter in sensitive area, Loudon County, VA

An increased role for distributed water infrastructure in meeting future energy, nutrient, and environmental goals

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In Canada's urban centres, water and wastewater infrastructure is largely effective at meeting the historical goals of eliminating water-borne disease and preventing gross contamination of waterways, but what are appropriate goals looking ahead to the coming decades? The protection of human health and surface and groundwater will remain paramount. We can expand our set of goals, however, to address energy use, recycling of nutrients and organic matter, and maintaining healthy watersheds.

Advances in small-scale water and wastewater technology, not just in treatment and storage equipment, but also in monitoring and management systems, promise a future where a reliable central system supplying base flow is complemented by a fabric of distributed water infrastructure contributing toward peak capacity and meeting incremental new capacity needs. Outside of centrally located service areas, management of compact on-site systems alongside cluster systems with small-diameter piping can reduce the overall cost of water services and reduce land requirements.

Wastewater is a dilute suspension of what is essentially unused food, to which we apply energy to convert most of the transported matter to carbon dioxide gas. Agriculture, where the food originates, is reliant on natural gas to produce nitrogen fertilizer, transports phosphate and potassium fertilizers from distant and finite sources, and is losing organic topsoil through erosion. The energy used to pump water and blow air into wastewater generates greenhouse gases. The transporting of water long distances may also disrupt the water regime within the watershed.

Optimizing water infrastructure can be accomplished in a synergistic manner with climate, watershed, and agricultural objectives. Where do we want to be in 50 years? The first step is to define a set of goals for that time frame. These goals would include:

- providing drinking water to meet potable demand;
- providing appropriate quality water for non-potable demand and irrigation;
- maintaining a natural water regime in the watershed in terms of timing, location, and water quality;
- minimizing the dilution of extractable resources in wastewater and recovering resources to close the loop with agriculture;
- minimizing the habitat impact of water infrastructure, both in terms of the land area used and the nature of the interface with natural soil and water systems; and
- minimizing the generation of greenhouse gases and pollution related to the energy used to treat and deliver water and wastewater.

Some of these goals can be met with incremental improvements to the existing model, but others, like closing the loop with agriculture, need a shift in servicing approach and a greater economic value put on these resources. For the near future, we will be reliant on water to transport solids in wastewater, but this makes plant nutrients (nitrogen and phosphorus) very dilute, with the physical-chemical processes for extraction being correspondingly inefficient. Companies such as 3XR and Ostara apply their nitrogen and phosphorus capture technologies to high concentration streams such as from organic digesters, but this captures only a fraction of potential nutrients excreted by humans. At a building level, these approaches could be efficient if grey water is excluded and they operate with wastewater from low-flush toilets and urinals. Ultimately, a central water-borne system with enough nitrogen and phosphorus to ensure proper biodegradation of carbon could operate in parallel with a decentralized collection system for dry urinal, urine-diverting toilet, and dry toilet products with further processing to ensure a pathogen-free and stabilized amendment for agricultural use. The resources in wastewater, e.g., collected urine, organic matter and nutrient matrix and water, are bulky and heavy and suggest that closing the loop with agriculture also requires food production to be more local.

In assessing the role of distributed water systems, it is instructive to use distributed energy as an analogy. Both water and electricity lose capacity to do work as they are transported over long distances: water loses pressure and leaks, and electricity loses potential by heating up the wires. For both water and electricity, peak demand factors are high, which challenges the ability of large central plants to adjust output quickly and forces central assets to be oversized compared with the base load. Distributed energy generation minimizes line losses by generating electricity where it is consumed. It is also faster and generally cheaper to build a small generator to meet incremental new demand rather than to build a new central plant. Electricity has a spot-market price, which is high on a summer afternoon when air conditioning use is high. There is no spot-market price for water, yet the cost of supplying peak water demand and treating peak wastewater flow is very real: pipe and sewer diameters, water towers, pumps, blowers, and tanks all need to be large enough to handle that peak capacity.

Toronto has about 5,500 km of trunk and distribution water mains and up to 133 m of vertical rise to the highest point of land. Toronto Water uses 33% of the electricity and produces 10% of the

Distributed energy and distributed water both complement central supply.

Above: rooftop photovoltaic
Left: rainwater cistern

greenhouse gases generated by the City of Toronto as a corporation to deliver and treat water and wastewater or $45 million in electricity and 130,000 tonnes (t) CO_2e emitted *(RiverSides, 2010)*. The amount of energy used in water and wastewater servicing, mostly electricity, is approximately 2 kWh/m^3 for a centralized municipal system *(Arpke, 2005, Sala, 2004)*. Compared with that figure, Toronto's 537,000,000 kWh to treat about 480,000,000 m^3 of water (from drinking through wastewater treatment) is relatively energy efficient at 1.1 kWh/m^3. It would take 0.2 kWh to provide the 200 L/d that a Torontonian might use domestically. For a household of 3.5 people, water use consumes 290 kWh/y or 3% of the electricity used for lighting, appliances, and air conditioning of 8,000 kWh/y in Ontario *(ICF Consulting, 2005)*. Implementing distributed water infrastructure to save greenhouse gases must compare the benefit of not pumping from the central facility against the energy cost to pressurize the local supply network.

Distribution and collection system assets comprise 72% and treatment assets 28% of the total public wastewater infrastructure assets in Ontario *(Water Strategy Expert Panel, 2005)*. For areas of lower density, the cost of conventional sewers can be 80% or more of the total cost of sewers and treatment *(Crites, 1998)*. When considering rural servicing, this suggests that it is cheaper for a municipality to manage a large number of private on-site systems than to connect them to a central facility. Traditionally, municipalities have been reluctant to manage private assets, but Ontario is implementing mandatory re-inspections of on-site sewage systems. We have a growing number of case studies of this model from the US, and sampling, monitoring, and telemetry equipment is increasing our knowledge and management capabilities. A hybrid approach is of benefit even in a communally serviced area. Clearford Industries supplies an on-site tank in which organics are digested passively, peak flow is attenuated, and even methane can be captured. With solids removed and peaks dampened, the sewer can be much smaller in diameter and set at a shallower slope, which may avoid lift pumps, is less disruptive to install, and tends to be more watertight. The central treatment plant is smaller because it is not digesting all the solids and does not have to handle such a high peak flow.

On-site treatment technology has moved beyond the septic tank, as much as large scale technology has moved beyond lagoons. Package treatment systems using approaches such as compact trickle filters, attached growth media with aeration and membranes can be located on the grounds or within large buildings to supply reuse water, with solids ejected into the central sewer *(Water Environment Research Foundation)*. For on-site disposal systems, reuse can reduce the size of the property required to assimilate effluent both in terms of the quantity of effluent and the amount of nitrogen released (to the extent that recirculation of nitrate from an aerobic process to an anoxic tank denitrifies).

Calculating equivalent CO_2

Equivalent CO_2 (CO_2e) is the concentration of CO_2 that would cause the same level of radiative forcing as a given type and concentration of greenhouse gas (GHG).

The radiative force of a given GHG is the mass of the gas times its global warming potential (GWP). For example, the GWP of methane (CH_4) is 21. Therefore, 1 kg CH_4 is equivalent to 21 kg carbon dioxide or 21 kg CO_2e. In other words, a methane emission is 21 times worse than a carbon dioxide emission of the same mass.

A greenhouse gas inventory is constructed by (1) estimating the mass of each greenhouse gas emitted, (2) converting each emission to a carbon dioxide equivalent using the GHG's GWP, and (3) summing all the carbon dioxide equivalents. This is equivalent to reporting your income in Canadian dollars by summing up your income in each currency, converting each income to Canadian dollars using an exchange rate, and then summing the total.

On the drinking water side, approximately 20% of the initial water supply is lost as leaks *(Federation of Canadian Municipalities, 2005)*. Since leaks are proportional to water pressure and pipe length, it follows that urban densification is one solution to water efficiency as it decreases the length of trunk water mains per user. We can fit more users per pipe with distributed water infrastructure.

Rainwater harvesting with storage in cisterns provides a reservoir from which to supply peak demand and decreases the demand on stormwater services. Reuse of treated wastewater, however, could prove to be more reliable than rainwater harvesting in that the supply always matches the demand, whereas the supply of precipitation is variable. Dual water supply involves two sets of water supply piping, but the cost is not necessarily double. Water reuse ready streets would lay the two pipes in the same trench. Water reuse ready houses would run labelled and coloured non-potable piping to the appropriate fixtures with a central switchover point where non-potable supply is connected once available. Potable water can be stored within a building so that only a trickle feed is required from the central system, and pressure can be conserved by elevating the tank within the building.

Fire fighting water supply often determines the pressure and diameter of water supply pipe required, which could render any possible reduction in capacity from water efficiency and reuse efforts irrelevant. In some areas, dry ponds or tanks could be used with truck-mounted pumps instead of sizing the drinking water supply to the fire fighting requirements.

To the extent that storage and reuse flatten peak demand and reduce base flow, capacity is freed up in the central system to serve more customers or to delay costly system expansions. The cost of a reuse water supply, which is generally somewhat higher than the current water rate, could be justified based on peak water cost, just as paying a higher price for electricity for rooftop solar photovoltaics is reasonable in that they produce power when air conditioning raises the cost of electricity *(Brooks, 2009)*. The concept of a 'smart grid' for electricity where distributed generation assets and end-user demand can be managed, e.g., switches on air conditioners controlled by Toronto Hydro, can be extended to a smart water grid where neighbourhood or building level potable and non-potable storage tanks and pumps could be activated by the municipality to maintain pressure during peak periods.

Future water infrastructure will move in a similar direction to computing, where large centralized computers work together with many small embedded computers in a distributed communication and computational network. Water infrastructure will move from reliance on large treatment plants to a hybrid, interdependent system of central and distributed technologies. Management will also adapt to monitor a greater number of smaller assets. It will result in a more diverse, energy-efficient, and resilient infrastructure, with tighter connections to the watershed and to agriculture. ♦

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