Chapter 13 in "*Water Sensitive Communities" edited by Carol Howe and Cynthia Mitchell, IWA Publishing, 2011*

Water Centric Cities of the Future – Towards Macro Scale Assessment of Sustainability

Vladimir Novotny* and Eric V. Novotny**

* Professor, Northeastern University, Boston 02115, MA (USA) and Managing Partner, AquaNova LLC, Newton, MA (USA)
**Water Resources Specialist, Barr Engineering, Minneapolis, MN
MN (USA)

Abstract The developments of several current and future ecocities have been comparatively assessed as to their environmental benefits of preservation or restoration of the ecological and hydrological (water reuse) functionality of their surface water bodies and social benefits such as carbon emissions reduction, recreation, and resource recovery. These evaluation categories are, in addition to economic assessment, the key components of the Triple Bottom Line assessment of sustainability. They are based on the urban metabolism concept. The assessed urban water developments include downtown San Antonio (TX, USA), Treasure Island in San Francisco and Sonoma Mountain Village (CA, USA); Hammarby Sjöstad (Sweden); Tianjin, Qingdao and Dongtan (China); and Masdar (UAE). Because of their frugality with respect to energy and water requirements, the "new cities" can be built in "hostile" environments such as arid areas with poor soils or decontaminated brownfields. The analysis revealed some problems with the lack of macroscale measures, models, and indices for some key components of the triple bottom line assessment that should be investigated and solved by research such as what is the limit of recycle to prevent accumulation of some harmful pollutants within the system, what are the thresholds, and what is the best distributed/hybrid configuration of the water/stormwater/used water management in the Cities of the Future, considering general and local aspects.

Keywords Ecocity, Ecoblock, Sustainable development, Urban metabolism, Sustainability footprints, Triple bottom assessment, LEED criteria, One Planet Living criteria, Water reuse, Recycle, Global warming

INTRODUCTION

The concepts of the new paradigm of sustainable water centric ecocities have been emerging for the last fifteen years in environmental research and landscape design laboratories in several countries, including Europe (Sweden, Germany, United Kingdom, The Netherlands), Asia (Singapore, China, Japan and Korea), Australia, United Arab Emirates (Masdar), USA (Chicago, Portland, Seattle, Philadelphia, San Francisco) and Canada (British Columbia). This paradigm is based on the premise that urban waters are the lifeline of cities and focus of the movement towards more sustainable cities. The evolution of the new paradigm of urbanization ranges from microscale "green" buildings, subdivisions or "ecoblock" to macroscale ecocities and ecologically reengineered urban watersheds and incorporating also transportation, food production and consumption and neighborhood urban living (Novotny, 2008). Many concepts developed by landscape architects incorporate surface water bodies as a focus. At the same time, environmental engineers and urban planners are developing water/stormwater/wastewater management concepts based on switching from the linear once through water management (minimum reuse) to a closed loop hydrological cycle system that maximizes reuse and recycling. Reduction of green house gas (GHG) emissions and application of green technologies have become a major goal in the last five years.

Water centric sustainable urban developments recognize the ecological value of surface water resources. In this approach the ecological integrity of the water resources and the riparian and flood zones is preserved or restored, using integrated resource management while also considering the impact on GHG emissions. Sustainability implies intergenerational preservation of natural resource assets so that future generations are not adversely impacted by present (and near past) development and economic utilization of resources; it considers the impacts of population increases, occurring mostly in the cities, and effects of global warming.

An *ecocity* is a city or a part thereof that balances social, economic and environmental factors (triple bottom line) to achieve sustainable development (Figure 1). Its definition was coined by Register (1987) as "a **sustainable city**, or **eco-city** is a city designed with consideration of environmental impact, inhabited by people dedicated to minimisation of required inputs of energy, water and food, and waste output of heat, air pollution - CO_2, methane, and water pollution". Hence, the water centric ecocity will combine and protect the hydrological and ecological value of the urban landscape with sustainable development. Integrated resources management (IRM) of the water centric cities of the future will consider; (1) Water conservation (green development); (2) Distributed stormwater management using best management practices of rainwater harvesting, infiltration and storage of excess flows, and mostly or fully surface drainage; (3) Distributed wastewater treatment generating water for reuse in buildings, landscape irrigation and ecological flow of existing or restored water bodies; (4) Using landscape and landscape components (e.g., ponds, wetlands, grass filters, etc.) for attenuation of diffuse pollution and post treatment of effluents recovered for reuse; (5) Heat and energy recovery; (6) Nutrient recovery; (7) Biogas recovery and, in the future, hydrogen generation from biogas and wastewater in fuel cells; and (8) Extent of use of alternate renewable energy sources.

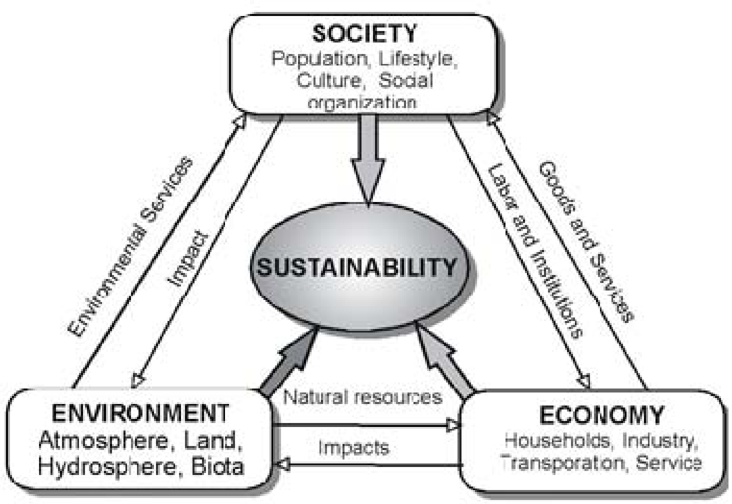

Figure 1 Triple bottom assessment and interactions of sustainable developments

Generically, urban planning and its relation to water can range from (A) Cities that develop their water resources to provide visual enjoyment and attraction of surface water bodies with less or even no emphasis of ecological and hydrological functionality of the surface water bodies and less or no reduction of GHG emissions such as, e.g., San Antonio (Texas) or partially Gent (Belgium), to (B) Sustainable developments, retrofits and ecocities that result in enhancement of the ecological integrity of their receiving surface water bodies, restore the hydrologic function of the watershed, and significantly reduce their carbon footprint. Category (A) developments are mostly spurred by the desire of the cities to bring Venice type attractiveness to the city, including restaurants, boat rides and gondolas, to attract resident population and tourists. This was facilitated by the cleanup of surface waters mandated by the water quality regulations such as the Clean Water Act in the US and Water Framework Directive of the European Community. Category (B) cities, among other resource restoration and management measures and in addition to aesthetic improvements, recreate ecology of existing or daylighted surface waters currently buried in sewers or culverts and incorporate into their landscape ponds for storage and treatment of urban runoff and/or wetlands used for post treatment of effluents and stormwater.

Category A urban developments may not be fully sustainable because the triple bottom line assessment benefits are not balanced, the benefits are mostly economical (tourism, employment in hotels and restaurants), less social (aesthetic, attractiveness of river front development, and noncontact recreation) and not fully environmental (Figure 2).

Figure 1 San Antonio River (TX) is a beautifully landscaped and restored urban river that brought great economic and social benefits to the city. However, in 2007 the river in the city was a concrete channel with almost no habitat and relatively poor water quality. This type of development does not reduce GHG footprint (photo V. Novotny).

ASSESSMENT OF SUSTAINABITY

Microscale assessment indices and metrics

Several rating systems and performance criteria for assessment of green/sustainable developments have become popular in the last five years. They are a mix of numeric performance metrics with narrative criteria. In general, they focus on individual buildings, limited scale development (for example, a shopping mall or a treatment plant) or a subdivision. The most popular are:

LEED Criteria. The US Green Building Council has proposed LEED (Leadership in Energy and Environmental Design) standards for "green" buildings and neighborhoods (USGBC 2005; 2007) that are becoming a yardstick for building and development. The problem with LEED standards is that only about 15% of points obtained in the certification are related to water, water quality and ecology. The LEED standards address:

- *"Green" certification* formulated for homes, neighborhood development and commercial interiors;

- *Smart location & linkage* which include, among others, required indices of proximity to water and wastewater infrastructure, flood plain avoidance, endangered species protection, wetland and water body conservation, and agricultural land conservation;
- *Neighborhood pattern and design* such as compact development, diversity and affordability of housing, walkable streets, transit facilities, access to public spaces, or local food production;
- *Green construction & technology;* and
- *Innovation & design process.*

Low Impact Developments. LID concepts are used in and restricted to subdivisions or small size developments practicing mostly on site stormwater containment, storage, infiltration and conveyance. In the US, a "subdivision" is a settlement of tens or hundreds mostly single family homes developed by a single developer who acquires land and installs infrastructure such as roads, drainage, sewers, and, in most cases, water supplies where private wells are not feasible. Some developers also build the homes in the development. The governance of the subdivision is usually by an association the homeowners are required to establish. The goal of LID is to mimic the predevelopment hydrololgy by minimizing and attenuating urban runoff by implementing green roofs, raingardens, infiltration ponds and wetlands, pervious pavements and other best management practices that control volume and pollution by urban runoff (Prince George's County, 1999). LID low density developments are often situated in rural settings with very high open/built space ratios, which could imply long distance travel and urban sprawl.

Need for macroscale criteria and assessment
The development of the cities of the future, the ecocities, requires a comprehensive and hierarchical macroscale approach to the microscale and often fragmented piecemeal transformation (Hill, 2007) of the current unsustainable urbanization to the new ecology friendly and sustainable urban areas and finally entire cities. The macroscale goals of the new paradigm for water centric ecocity communities are (Novotny, Ahern and Brown, 2010; Novotny and Brown, 2006):

- Developing an urban watershed and its landscape that is sustainable and resilient over a long run and preserves or mimics but not necessarily reproduces the hydrologic processes and ecological structures present in the predevelopment natural system;
- Protection of the natural systems and restoration of natural drainage (daylighting);
- Mimicking predevelopment ecology and hydrology, relying on reduction of imperviousness, increased infiltration, surface storage and use of plants that retain water (e.g., coniferous trees);
- Developing or restoring interconnected green ecotones (green areas bordering the streams that connect nature with the built human habitat), especially those connected to water bodies, that provide habitat to flora and fauna, while providing storage and infiltration of excess flows and buffering pollutant loads from the surrounding inhabited, commercialized, and traffic urban areas;
- Adaptation to the trends of global warming and stresses caused by increasing population. It is not enough to keep emissions at the present level; the new development must dramatically reduce carbon emissions and increase resources to accommodate anticipated urban population increases; and
- Retrofitting and reconnecting old underground systems interlinked with the daylighted or existing surface streams.

The development of macroscale criteria of urban sustainability is a work in progress by several associations, governmental agencies (for example, in Australia) and research groups. A subcommittee of The International Steering Committee for the Cities of the Future of the International Water Association is developing concepts of macroscale sustainability criteria for the (Novotny, 2010). Sustainability of the cities, pollution, social qualities and other attributes and amenities are related to "urban metabolism" (Kennedy, Cuddihi, and Engel-Yan, 2007) which is a mass balance concept that relates inputs into the city (materials, chemicals, water, energy, and food) to the outputs. Outputs are numerous and the examples of undesirable environmental outputs are

(a) *liquid sewage, industrial wastewater and combined sewer overflows* (point sources of pollution);
(b) *polluted urban, construction sites and highway runoff* (diffuse sources);
(c) *air pollution emissions,* including greenhouse gases (GHG);
(d) *rubbish and other solid waste; and*
(e) contaminated land (brownfields) and shallow groundwater.

Urban metabolism can be linear, cyclic or hybrid. Daigger (2009), Novotny (2008) and others agree the current "linear" approach, sometimes called the *take, make, waste* approach in the sustainability literature, when applied more broadly to natural resources use and global climatic change, has become increasingly unsustainable. If every city on earth would strive to achieve the same consumption of inputs as the North American cities today, the productive land needed to provide food, raw materials, assimilation of waste and emissions, and produce energy would be three times of all available productive land and resources on the earth. Scientists, the informed public and politicians agree that the system must change along the three R's – *reduce (conserve), reclaim, and reuse* which is a foundation of the cyclic/hybrid system.

The footprints for which the sustainability criteria should be developed are based on the Triple Bottom Line (TBL) – Life Cycle Assessment, i.e., they should cover economic, social and environmental/ecological aspects (Figure 1) in the intergenerational sustainability context. One Planet Living criteria listed below are an example of large scale criteria of urban sustainability. Currently, the major large scale ("giant") footprints suggested in the literature are (Hoekstra and Chapagain, 2008):

- *Ecological footprint* is a measure of the use of bio-productive space (e.g., hectares of productive land needed to support life of one person in the cities)
- *Carbon footprint* is a measure of the impact that human activities have on the environment in terms of the amount of GHG emissions measured in units of carbon dioxide in tons/person-year
- *Water footprint* measures the total water use on site and also virtual water in liters/person-day.

The One Planet Living (OPL) Criteria introduced by The World Wild Life Fund (WWF, 2008) promote implementation of principles that include social, environmental and technological TBL metrics as follows:

- net zero carbon emissions with 100% of the energy coming from renewable resources;
- zero solid waste with the diversion of 99% of the solid waste from landfills;
- sustainable transportation with zero carbon emission from transportation inside of the city;
- local and sustainable materials used throughout the construction;
- sustainable foods with retail outlets providing organic and or fair trade products;
- sustainable water with a 50% reduction in water use from the national average;
- natural habitat and wildlife protection and preservation;

- preservation of local culture and heritage with architecture to integrate local values;
- equity and fair trade with wages and working conditions following the international labor standards; and
- health and happiness with facilities and events for every demographic group.

Some ecocity developments are now aiming at receiving OPL certification. These macroscale criteria for ecocities are more broad and stringent than LEED or LID Criteria. However, there are some equity problems between the developed and undeveloped nations when applying these criteria. For example, the water use criterion is extremely easy to achieve in the US and Canada which have a very high water use (~ 500 Liters/person-day) while it may be difficult in developing nations where per capita water use may be less than 100 Liters/capita-day or Japan or Europe where typical water use is around 150 Liters/person-day. The OPL criteria do not *a priori* promote urban and suburban agriculture that is important for reusing used water and recovered fertilizer thus reducing the high *virtual* water use to produce imported food for the city.

SEVEN ECOCITIES CASE STUDY

The authors in Novotny and Novotny (2009) (see also Novotny, Ahern and Brown, 2010) analyzed seven cities/urban developments that are striving to become the "ecocities" and looked at common features of the key macroscale parameters such as population density, energy use and carbon imprint, water use and reuse, and cost. None of the analyzed cities have been fully built. We looked at whether the water system is linear and centralized or closed and decentralized. The results are summarized in Table 1.

Hammarby Sjőstad (Sweden).

Figure 3 Hammarby Sjöstad (Stockholm) with surface drainage (Photo credit Malena Karlsson, GlashusEtt, Hammarby Sjöstad). The surface drainage collects all clean water flows (rain, groundwater, cooling).

Hammarby Sjostad, located on Lake Hammarby Sjö in Stockholm, is an ongoing development that shaped the project's infrastructure, planning and design of the buildings into a modern mixed-use sustainable and environmentally friendly urban space. The scheme has attracted international acclaim for the quality of habitat it created and convinced many that carbon neutral development does not require lifestyle changes. The development concept successfully connects the historic landscape with aquatic areas which act as storm water drainage, encourages biodiversity, creation of new habitats, informal amenity areas and formal areas of public open space (Figure 3). Sustainability is also enhanced through the use of green roofs, solar panels, and eco-friendly construction products. The use of glass as a core material maximizes sunlight and views of the water and green spaces. The city has a fully integrated underground sanitary (separated) waste collection system conveying wastewater to the local district treatment and heat and nutrient recovery plant. Methane is recovered from digested sludge and organic solid waste is incinerated in a municipal incinerator that recovers energy. Passive energy savings and solar panels, both thermal and photovoltaic are installed throughout the city to save energy. The development has its own ecosystem, known as the Hammarby Model. In spite of the fact that the ecocity is still based on the linear model and water reclamation and water reuse is not included to a great extent, Hammarby Sjöstad is the first city built on ecological principles that broke the barrier toward sustainable urban development.

Dongtan (China)
Dongtan was planned to be at the eastern tip of Chongming Island at the mouth of the Yangtze River in the middle of a designated nature reserve with outstanding biodiversity about 40 km north of downtown Shanghai. The approach to the design of the city by the architectural firm Arup was different from other designs submitted by various other firms in the mode of "low impact" spread out subdivisions. Arup envisioned Dongtan to be a vibrant city with green 'corridors' of public space ensuring a high quality of life for residents. The city was designed to attract employment locally across all social and economic demographics in the hope that people will choose to live and work there. This pioneering approach initiated the new paradigm of ecocity building that was then adopted by other ecocity developers. The city design is exceedingly water centric with canals and lagoons within the development for aesthetics, recreation and transportation and also water for reuse (Figure 4). Energy would be produced by incinerating rice husks and organic solids as well as by renewable solar panels and wind energy production throughout the city.

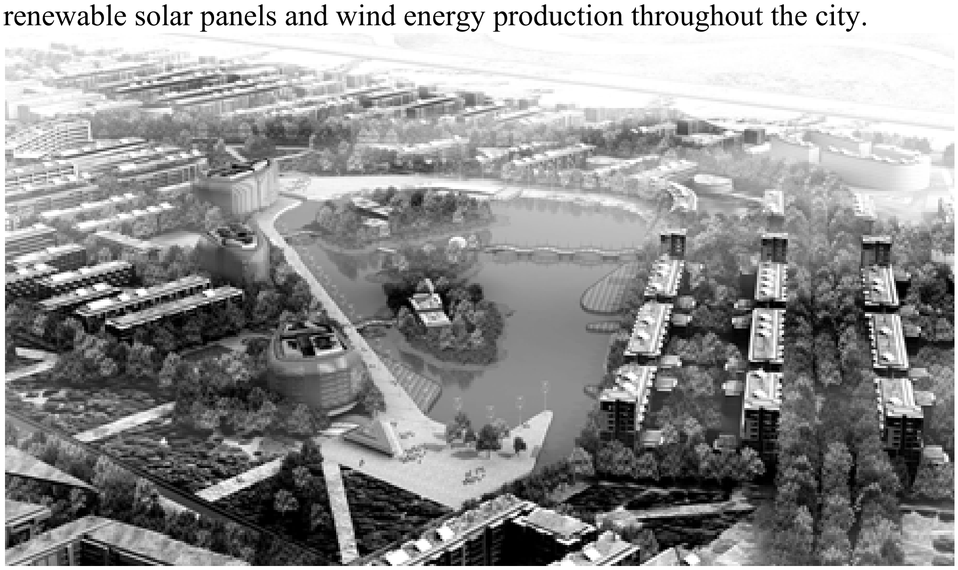

Figure 4 Architect's rendering of the East Village and Lake in Dongtan. Note solar panels on the roofs of the buildings and wind turbines surrounding the lake (Source and courtesy Arup).

The development of Dongtan was supposed to have its first 5000 inhabitants moved in during the 2010 World Exhibition in Shanghai but the project realization was indefinitely postponed because of political reasons.

Qingdao (China) Ecoblock and Ecocity

The ecoblock concepts were developed by the team of Professor Harrison Fraker of the University of California Berkeley College of Environmental Design specifically for urban developments in China but could be used anywhere in the world, especially in the countries with rapid population increase. An e*coblock* is self sustained and semi-independent with its water and energy needs. It generates its own energy from renewable sources and used water, harvests rainwater, and processes and reclaims its used water.

A typical standardized ecoblock (Figure 5) has 600 units on 3.5 hectares and houses 1500 - 1800 residents. The proposal for the Qingdao ecocity included 16 ecoblocks. Similarly to Dongtan, the Qingdao ecocity's development has been postponed but the ecoblocks and their concepts have been incorporated into the design of Tianjin. In 2011, the governments of China and Germany signed an agreement on the joint development of an Ecocity in Qingdao.

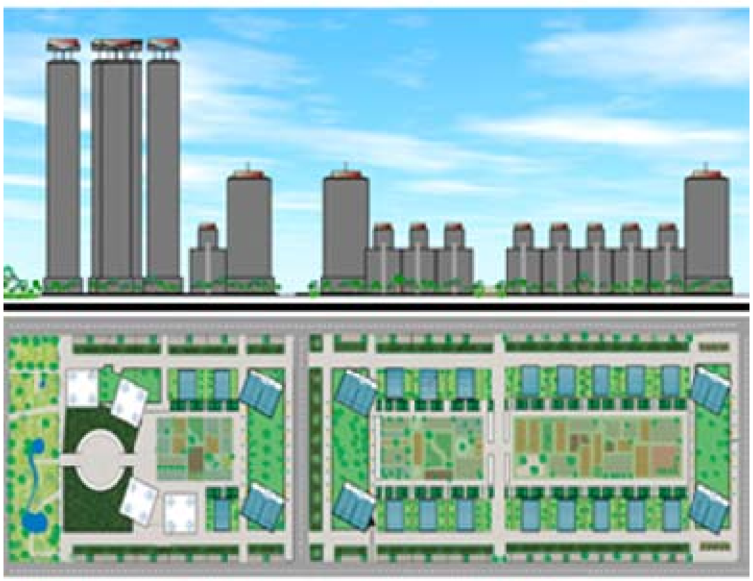

Figure 5 Plan and view of the Ecoblock module (Courtesy Prof. H. Fraker, University of California, Berkeley). The treatment wetland is to the left of the ecoblock.

Tianjin (China)

The site of the new city development is about 150 kilometer southeast of Beijing and 40 km from the historic Tianjin City (population about 12 million) which is the regional center and the largest port city in northeast China. The city will be a part of a huge regional development of the Tianjin – Binhai New Area. The ecocity is a joint venture project of China and Singapore.

The city is divided into (eco) blocks. The smallest block unit has an area of 400 x 400 meters (16 ha). Professor Harrison Fraker (University of California-Berkeley) confirmed that Tianjin would also include the Quindao ecoblocks. The city is water centric and features an "Eco-valley" which is the main north –south green connector in the city which will retain a large ecological wetland set aside as a habitat for bird migration, and preserves former watercourses.

The primary sources of water for the new Tianjin ecocity are desalinated water and rainwater which constitute more than 50% of water used in the city. An extensive system of rainfall collection and sewage reuse will be established relying heavily on the landscape for collection and infiltration of rainwater. The city will have centralized sewage and wastewater treatment and recycling and will develop and utilize non-conventional water resources such as recycled storm and rain water and desalinated seawater in a water supply infrastructure that will reduce the need for conventional water resources. Treated used water will be used for landscape irrigation and as flow in the lake and created surface channels.

Masdar (UAE)
Masdar in United Arab Emirates is being built and has been designed to follow the "One Planet Living" (OPL) ten principles. When the city is completed it will be home to 50,000 residents and 40,000 people are expected to commute to work in the city. Water used inside the city will be provided by a desalinization plant run by solar power which also provides most of energy to the city. The plant will produce two types of high quality water: one fit for drinking and the other fit for personal uses such as showering and washing dishes.

Masdar city will use a plethora of water management principles in order to treat all parts of the water cycle and use them as a water source. As many as nine water conveyance systems will be used in 12 different ways and treated at three treatment levels. The variety of water sources to be used includes groundwater, seawater, surface runoff, rainwater harvesting, dew/fog capture, grey and black water reuse and resource recovery from urine streams. The city will employ extensively passive energy savings by shading, narrow shaded streets, wind exposure for cooling, and solar power plants. Nutrients are recovered and some used in a algae growing farm.

Treasure Island (San Francisco, California, USA)
Treasure Island is a manmade island built by dredging sediments from the San Francisco Bay. Currently, it as a partially abandoned navy base with brownfield problems which are being remedied. The city is embarking on developing the island into a sustainable residential/commercial community with suburban agriculture. The planned water/wastewater system will be linear with some reuse after treatment in a central WWTP for irrigation. 75% of the effluent will be discharged into the bay. Potable water will be imported from the San Francisco municipal grid. Stormwater management will center on xeriscape, permeable surfaces and pavements, green roofs and routing excess runoff to be treated in a wetland. Once the excess runoff is collected it will be routed to a constructed treatment wetland and water reused for irrigation and other nonpotable uses.

Sonoma Mountain Village
Sonoma Mountain Village in California is in the initial phases of the development. When finished in 2020 it will have 5000 inhabitants, hence, it will be the smallest of the seven ecocities (Figure 6). The developer has applied for and received OPL certification. The goal for water used within the village is a reduction in water consumption by 60% from a general norm for single family homes in the region. This will be accomplished through water reduction devises, education, rainwater harvesting and reuse of water. The municipal drinking water supply will be used inside of all buildings and for irrigation in private backyards. Reclaimed water will be used for irrigation of all public parks, medians, and street trees along with high efficiency (sub-drip) irrigation of all common areas, private front yards and for use in firefighting. Stormwater reuse will be used for habitat maintenance, groundwater recharge and as a supplemental irrigation supply for all landscape areas. There will be habitat protected bioswales acting as wetlands connected to an underground reservoir from which water will be recycled for irrigation purposes. Most electricity will be produced by on site photovoltaic power plant and solar panels to achieve net zero GHG emissions goal.

Other "ecocities" have been proposed and are being developed throughout the world. The first phase of the Dockside Greens in Victoria (British Columbia, Canada) has been essentially completed. It is a hybrid water centric community that has received "platinum" LEED certification. It reuses water for providing ecological flow to recreated streams and irrigation and recovers energy from methane from sludge and organic solids digestion and syngas (mostly carbon monoxide) from organic solid waste (O'Riordan et al., 2008). New developments are in the planning stages in Portugal, United Kingdom (2010 Olympic sites), Canada, Turkey and other countries.

Figure 6 Architect's rendering of the main square in the Sonoma Mountain Village (Source and courtesy Sonoma Mountain Village - SOMO)

SYNTHESIS

We have summarized the basic parameters of the analyzed ecocities and the synthesis is presented in Table 1.

Population Density. With the exceptions of the Qingdao ecoblock which is the development with the highest population density, the densities of the remaining six developments varied between 60 to 170 people/ha. From the presentations and literature findings it was evident that all design teams used some kind of a proprietary model which balanced the population and its energy use based on probability of walking and biking instead of driving, energy insulation of buildings and exposure to sun, renewable energy sources and other determinants for GHG emissions from urban areas. The fact of medium design density development being the most optimal refutes, to some degree, the utility of the "low impact" LID subdivisions which in most cases have an objective of minimizing stormwater impacts and discharges and generally results in low density developments but with a relatively high energy use and reliance on automobiles.

Green House Gas Emissions (carbon footprint). Table 1 shows the energy savings and production of energy from local renewable sources (solar, wind) reducing the GHG emissions. For example, Qingdao, Masdar and Sonoma Mountain Village designs are proving ecocities could fulfill the OPL criterion of net zero GHG emissions from infrastructure heating and cooling and electricity consumption. All three developments also reduce energy by restricting traffic inside the city and in

Masdar and Tianjin to vehicles powered by electricity produced by renewable sources. Hence, 100% energy savings and renewable energy use implies the net zero OPL criterion is met.

City	Population Total	Population Density #/ha	Water use L/cap-day*	% water recycle	Water System	% Energy savings and renewable energy production	Green area m^2/cap	Cost US$/unit**
Hammarby Sjőstad	30,000	133	100	0	Linear	50	40	200,000
Dongtan	500,000 (80,000)++	160	200	43	Mostly Linear	100	100	~40,000
Qingdao	1500-1800+	430 – 515	160	85	Closed loop	100	~15	?
Tianjin	350,000 (50,000)++	117	160	60	Partially closed	15	15	60,000 – 70,000
Masdar	50,000	135	160	80	Closed loop	100	<10	1 million
Treasure Island	13,500	170	264	25	Mostly Linear	60	75	550,000
Sonoma Mountain V.	5,000	62	185	22	Mostly Linear	100	20	525,000

* Indoor and outdoor domestic water use ** Based on average 2.5 members per household unit
\+ Qingdao ecoblock ++ Phase I

Table 1 Synthesis of the main parameters of the seven investigated ecocity developments (Novotny and Novotny, 2009)

Water Reclamation and Reuse. All cities use the latest technology for in-house water savings such as low flush toilets, showers, etc. Hammarby Sjöstad is almost a 100 % linear system with recovery of phosphorus. The Stockholm metropolitan area, where the ecocity is located, is water rich and there is apparently no need for recycle, yet, they expect to reduce the per capita water use to the limit of 100 L/capita-day which is apparently the lowest limit for a well functioning linear urban system (Falkermark and Widstrand, 1992) that can be reached by water conservation. Other cities use various degrees of water reclamation and reuse but start with a higher per capita water use reduced by reclamation of used water and stormwater.

A high density Qingdao ecoblock with 430-515 people/ha appears to be an anomaly which should be further researched as to the feasibility and sustainability of the concept regarding the used water reclamation. Qingdao's treatment of black water consists of "sequential batch reactors" described in a promotional video (Green Dragon, 2008) as septic tanks, followed by wetland. Putting a surface flow wetland treating black water, even after pretreatment, in a densely populated ecoblock is not possible from health reasons in the US and other advanced countries. Based on the WEF (2001) a detached fenced off wetland would have to have a fully submerged flow. Based on the WEF (2001) manual the minimum area of the wetland serving 1500-1800 people will have to have an area of about ½ hectare or one football field. Also such wetland will have a relatively large evapotranspiration during dry summer days period. Wetlands also emit methane and nitrous oxides.

Surface Drainage for Runoff and Clean Water. All ecocities use surface drainage for collecting urban runoff and clean water inputs (see Figure 3). All cities will use extensively best management practices for urban runoff such as pervious pavements for infiltration, capture and storage in underground basins, and its reuse for various purposes such as irrigation, fire protection, and some plan to tap into the groundwater resources for reclaimed water for nonpotable water supply. Use of green roofs has not been planned on a large scale with the exception of Hammarby Sjöstad.

Cost Per Unit. The cost per unit has been estimated by dividing the capital costs of the development by the number of dwelling units or by the population in the city divided by 2.5. The cost is only approximate and varies based on the standard of living of the country and a type of the buildings which determines population density. The lowest cost is for an apartment in the Qingdao ecoblock which consists of several high rises and buildings ranging from six to twenty four stories. The highest cost is in Masdar which has the highest degree of recycle, very high cost of desalination, and proposes a futuristic public transportation system. The affordability and standard of living also determines the cost. For example, the development of Sonoma Mountain Village was slowed down by the housing financing crisis in the US and that of Masdar is affected by the global financial crisis. A true convertibility between Chinese currency and US $ has not yet been established but the data for Tianjin are based on information from Singapore which is a major partner of the development. The Tianjin ecocity is located in the large Tianjin – Binhai new development area and the cost of the housing is commensurate with the middle class incomes of people living and working in this giant development which will contain an airplane (Airbus) manufacturing facility, research centers, universities, large port facility and many other industries located in "green" environments.

Water Centric Development Opportunities. Hammarby Sjőstad, Dongtan, and Tianjin are clearly water centric whereby open water and canals are the architectural centerpieces of the development and will have an aesthetic role, provide recreation and local transportation. By locating their advanced wastewater treatment plant at the fringe of the city and directly discharging the used treated wastewater into the Hammarby Lake connected to the Stockholm Bay without water reclamation, the city has missed its opportunity for water reuse. Dongtan and Tianjin in China considered using the water bodies inside the city for discharge and additional treatment of reclaimed water. The desert city Masdar will apparently create small artificial streams transecting the city. Masdar also has sophisticated underground potable water, reclaimed water and used water conveyance systems (Hartman et al., 2010). Qingdao, Sonoma Mountain Village, and Treasure Island will not have permanent streams, natural or artificial, planned within the ecocity boundary. Sonoma Valley Village is planning to create habitat bioswales with wetlands for stormwater conveyance transecting the village and connected to a storage basin from which water will be reused. Qingdao created two conveyance systems for reuse: one for the reclaimed black water via a chain of wetlands, the other for stormwater both ending in an underground storage facility, followed by reuse. The architectural rendering of the Qingdao ecoblock does not show any surface stormwater conveyance to the central storage basin.

Lack of Macroscale Assessment

The analysis has revealed some problems with the lack of macroscale of some key components of the triple bottom line assessment. The literature data and personal inquiries revealed that the major companies providing engineering designs of the ecocities have or are developing models by which they calculate energy or water use by the city. However, a comprehensive environmental assessment model is not yet available. Such model or models are needed to test the following hypotheses:

- There is a quantifiable limit to water reuse at the macro, i.e., city scale. Sustainable urban water systems are characterized by a significant amount of recycling, supplemented by rainwater and/or make-up water import. This water import (and consequently export) required for flushing out conservative or poorly degradable contaminants within the system, constitutes a key macro-scale design parameter for the good health of people and aquatic biotic integrity. Quantification of the amount of import is critical for the design of these systems, including assessing the needs for ecologic flow to sustain viable aquatic life of the water bodies.

- Reuse may lead to accumulation and exceedance of thresholds for good water quality for several key water quality accumulative parameters in the surface streams, canals and lakes of the water centric ecocities such as nutrients (nitrogen and phosphorus) to prevent highly eutrophic and hypertrophic conditions. The hypertrophic status is characterized by dense blooms of toxins producing cyanobacteria and algae. This could happen in situations where the surrounding water bodies are already near such thresholds as might be the case of the Chinese ecocities of Tianjin and Dongtan.
- During the previous paradigm of building the underground urban water/wastewater conveyance, and treatment and disposal infrastructures based on the minimum capital and OMR costs, water reuse and energy recovery from used water and organic solids was not economical because it would have required another pipeline system and pumping to bring water and reclaimed energy back to the city. If the systems were broken into a number of semi-autonomous (with respect to water/stormwater/used water management) clusters (ecoblocks), water and energy reclamation and reuse would become socially attractive. Then there would be no need for large underground interceptors and pipelines; potable water would not be used for irrigation and providing ecologic flow to flow deficient urban streams or even recharging groundwater zones to prevent subsidence of historic buildings (e.g. in Boston). However, the optimal size of the cluster is not known and most likely there may be none as documented in Table 1 where the ecocity communities ranged from 5,000 to 500,000 inhabitants. Is the Qingdao ecoblock with 1800 people the most economical, efficient, and sustainable cluster? Or, is it the 50,000 people Masdar city/cluster or 500,000 Tianjin subdivided into clusters? The cluster size, population density within the cluster, ratio of green and built areas, quantity of water reused and renewable energy produced are examples of decision variables but there is no limit on the size as long as the hybrid distributed system is proposed (Novotny, Ahern and Brown, 2010). The future eco-communities may range from a cluster of houses, a large resort, a highrise building with hundreds to thousands of tenants, to large cities with partially or fully distributed water/stromwater/used water system.

SUMMARY

Currently, there are dozens of urban developments throughout the world claiming to become "an ecocity". A few, with various degrees of success, are striving to become certified as "One Planet Living" community. In our analysis we have compared only a fraction of the most publicized developments. Because of their frugality with respect of energy and water requirements, the "new cities" can be built in "hostile" environments such as arid areas with poor soils (Tianjin, Masdar) or decontaminated brownfields (Hammarby Sjöstad in Sweden, Dockside Greens in British Columbia, 2021 Olympic sites in London, Treasure Island in San Francisco). This may relieve the pressure on valuable agricultural lands, wetlands and forests even in countries still undergoing excessive population growth. Building new cities in fragile natural environments such as a desert should still take into account the natural systems that need to be protected.

Masdar is an unusual case that will be a test ground for the Cities of the Future research and development. It is showing that the state of the art of building cities has reached a point where there are almost no limits but at a cost which still may be prohibitive elsewhere. The main source of water in Masdar is evaporation/condensation desalination, powered by abundant solar energy, of Gulf of Persia (Arabia) water which has high salinity.

In developed countries, the direction will be more towards retrofitting the existing cities and reducing or even reversing urban sprawl by bringing people back from distant energy gobbling low density suburbs to the retrofitted and water and energy efficient cites. Unfortunately, in old municipalities, bringing new sustainable concepts into rebuilding and retrofitting may be running into resistance and obstacles caused by existing regulations and traditions.

Acknowledgement. Partial support for the work described in the article was provided by contracts from US EPA and WERF (Steve Moddemeyer) and from CDM, Inc. which is greatly appreciated. The views expressed in the article are solely those of the authors.

References

Daigger, G. (2009) Evolving urban water and residuals management paradigms: Water reclamation and reuse, decentralization, resource recovery, *Water Environment Research* **81**(8):809-823

Falkermark, M. and C. Widstrand (1992) "Population and water resources – A delicate balance," *Population Bulletin* 47(3):1–36

Green Dragon (2008) www.greendragonfilm.com/qingdao_ecoblock_project.html

Hartman, M., M.B. Knell, and J.W. Witherspoon (2010) Masdar City's integrated approach to sustainability, Proc. Cities of the Future 2010 Conference, March 7-10, Cambridge, MA. Pp. 104-117

Hill, K. (2007) Urban ecological design and urban ecology: an assessment of the state of current knowledge and a suggested research agenda, in *Cities of the Future: Towards integrated sustainable water and landscape management* (V. Novotny and P. Brown, eds), IWA Publishing, London, UK

Hoekstra, A. Y. & A. K. Chapagain (2008), Globalization of Water: Sharing the Planet's Freshwater Resources. Oxford: Blackwell Publishing

Kennedy, C., J. Cuddihy, and J. Engel – Yan (2007) The changing metabolism of cities, *Journal of Industrial Ecology,* **11**(2):43-59

Novotny, V. (2008) Sustainable urban water management, In *Water & Urban Development Paradigms (J. Feyen, K. Shannon, and M. Neville, eds.)* pp. 19-31, CRC Press, Bocca Raton, FL

Novotny, V. (2010) Water and energy footprints of the Cities of the Future, Invited key note presentation at the 2010 Singapore International Water Week June 28-July 2, published in *Water Policy and Technology* **4**(5)

Novotny, V., and E.V. Novotny (2009) Ecocity – Evaluation and Synthesis, www.aquanovallc.com

Novotny, V., J.F.Ahern, and P.R. Brown (2010) Water-Centric Sustainable Communities: Designing, Building and Retrofitting the Next Urban Environments, J. Wiley & Sons, Hoboken, NJ

O'Riordan, J., W.P. Luccey, C.L. Barraclough, and C.C. Corps (2008) Resources from waste: An integrated approach to managing municipal wate and waste systems, *Industrial Biotechnology* **4**(33):238-245

Prince George's County (1999) *Low-Impact Development Design Strategies: An Integrated Design Approach,* http://www.epa.gov/owow/nps/lid/lidnatl.pdf (accessed September 2010)

Register, R. (1987) *Ecocity Berkeley: building cities for a healthy future*, North Atlantic Books. ISBN 1556430094

USGBC (2005) *Green Building Rating System for new Construction & Major Renovations Version 2.2,* US Green Building Council, Washington, DC. , http://www.usgbc.org

USGBC (2007) *LEED for Neighborhood Development Rating System, Pilot Version,* US Green Building Council, Washington, DC. , http://www.usgbc.org

Water Environment Federation (2001) *Natural Systems for Wastewater Treatment*. Manual of Practice FD-16, Alexandria, VA

WWF (2008) One planet living, http://www.oneplanetliving.org/index.html