Water and Energy Framework and Footprints for Sustainable Communities

Vladimir Novotny, Vicky Elmer, Hiroaki Furumai, Steven Kenway, and Owen Phills

Abstract The framework for sustainability of urban areas is tied to the patterns of urban metabolism in which resources (water, food, energy, materials and chemicals) are delivered to an urban area, metabolized and changed to outputs. Under the current linear concept, water, energy and other inputs generate waste and pollution. Furthermore, lack of conservation and waste within the city leads to shortages and, in the near future, to exhaustion of resources. There is a need to change the current linear metabolism to one that would reuse and recycle and in which used water and solids would become a resource. This would involve a paradigm change of how cities are retrofitted and built.

The footprints are quantitative measures of sustainability and metabolism. Footprints covered in this article are water, energy/greenhouse emissions, and ecology. When the footprints are defined, development of sustainability criteria should follow. The footprints may be global, regional or local and can be hierarchically interconnected.

Keywords Urban metabolism, Urban footprints, Water reuse, Recycle, Global warming, Resources availability, Water shortages, Sustainable development, Cities of the Future

INTRODUCTION

The impetus to develop sustainable cities (Cities Of The Future - COTF) has emerged because of the realization of anticipated consequences of business as usual progression of cities under the major stresses of (1) population increases and migration; (2) threats of adverse impacts of global climatic changes; (3) increasing water shortages in many highly populated regions of the world; (4) cities that are frugal with their water; and other resources are also more economically efficient. It has also become evident the worldwide goals of adequate water supply and sanitation, of the last decade of the twentieth century, have not been met in many cities of developing countries. Also the problem of poor public health and inadequate water supply may be worsening as populations increase.

There is now an almost uniform agreement among professionals in many disciplines (environmental engineering and science, urban planning, architecture, urban and suburban ecology) that in most cases, the current infrastructure and urban planning paradigm relying on fast surface and underground conveyance of water and wastewater, regional water and wastewater management systems, energy overuse for sustaining living processes, commerce, transportation and use of other resources in the cities have become impediments to achieving sustainable urban development and living including addressing the impacts of global climatic change. A paradigm shift from the current unsustainable urban development and living to a more sustainable city is needed. The idea of the sustainable city has a rich history, dating from concerns about the negative impacts of the industrial revolution back in the 1850's to the present. Late 19th century social reformers called for a balance between the city and country side to mitigate the unhealthy conditions in urban areas. Today, most ideas about sustainability revolve around the balance between the environment, equity and economy, although there is considerable debate about their relative importance. Indeed, there are many definitions of various aspects of the the sustainable cities in today's publications. Most, agree however, that the concept involves the necessity of including environmental factors when planning our future cities—the City of the Future. An environmentally focused City of the Future is the EcoCity concept proposed by Richard Register in the mid 1980's. (See Box).

The idea of the City of the Future represents a major paradigm shift in the way new cities will be built or older ones retrofitted to achieve a change from the current unsustainable status to sustainability. At its core this shift involves mimic-ing the natural cycle when making development and operational decisions about water, energy and other material flows in and out of the city. This represents a radical change from the linear approach that has characterized the industrial and post-industrial effort to the present. To assist decision-makers and professionals in this area, a conceptual framework is needed to serve as a support and a guide for developing and building the integrated infrastructure of the City of the Future.

This paper represents an effort to assist in the development of that framework with a particular emphasis on what this might mean for water professionals and local officials (?). It begins by examining the concept of urban metabolism for guidance in the development of principles for the CoF. It then turns to ways in which we can characterize the material flows of the CoF in a quantitative manner, so that we can evaluate the performance of current and alternative urban systems. Sustainability indicators are discussed in general including the notion of an ecological footprint, water footprints and other indicators. Efforts by national, state and local governments to develop sustainability indicators with an emphasis on water and energy are reviewed before drawing conclusions for the water professional and other development officials.

Definition: *An ecocity is a city or a part thereof that balances social, economic and environmental factors (triple bottom line) to achieve sustainable development. It is a city designed with consideration of environmental impact, inhabited by people dedicated to minimization of required inputs of energy, water and food, and waste output of heat, air pollution - CO_2, methane, and water pollution and protecting public health. Ideally, a sustainable city powers itself with renewable sources of energy, creates the smallest possible ecological footprint, and produces the lowest quantity of pollution possible. It also efficiently uses land and recycles or converts waste to energy. If such practices are adapted, overall contribution of the city to climate change will be minimal and below the resiliency threshold. Urban (green) infrastructure; resilient and hydrologically and ecologically functioning landscape and water resources will constitute one system.*

Adapted from Register (1987) and Novotny et al. (2010)

URBAN METABOLISM

Concepts

Sustainability of the cities, pollution, social qualities and other attributes and amenities are related to "urban metabolism" (Wolman, 1965; Kennedy, Cuddihi, and Engel-Yan, 2007). Wolman in his pioneering article compared the overall fluxes of energy, water, materials, and wastes in a hypothetical urban community of one million. He used the concept to address "evident shortages of water and pollution of water and air" (Pamminger and Kenway, 2008) and was concerned, forty five years ago, about the deteriorating state of the urban environment, high pollution, and overuse of resources. Wolman was the first to define urban metabolism, also stating that it must be sustainable (Hermanowitz and Asano, 1999) and identified water as comprising over 96% of the total mass flow through the cities.

Cities and interconnected surroundings are complex systems consisting of nonliving infrastructure, machinery, roads and ecosystems with living organisms. Humans are part of the ecosystem. The urban system receives inputs which are accumulated and grow, cycled, attenuated and transformed within the system, and produces outputs (Figure1). Urban metabolism can be defined as the "sum of the technical and socio – economic processes that occur within the cities, resulting in growth, production of energy, and elimination of waste" (Kennedy et al., 2007). The balance or imbalance between the inputs, accumulation and growth, and waste resulting in emissions of undesirable pollutants determine the sustainability or unsustainability of the city.

The goal of sustainable development, in the context of the future ecocity, is to meet the water and energy needs of the current and future generations in ways that would (1) be equitable, but still result in economic development, (2) protect the environment, even under the scenario of diminishing nonrenewable resources (e.g., fossil fuel), and (3) benefit society. Because resources are finite, the equity goal of sustainability, i.e., the urban population in less developed countries should enjoy the same consumption of resources as people in developed countries under the current paradigms of water and resources management of the last century, cannot be achieved without severe curtailment of society's demands on these resources. This could result in inconveniences and even hardship. Unlike people living in rural communities, urban people purchase food, other merchandise, and energy, all of which produce trash, waste, polluted water, and emissions of air pollution, including carbon at elevated levels. This is a linear process of transport of mass and energy from the resource to pollution and other waste emissions and discharges (Figure 1A). The objective of the pollution controls of the last century was to minimize the effects of pollution and the throwaway practices of society in both developing and developed countries. It is significant to note that, under the hardship of poverty, the poorest segments of the population in the megalopolises of developing countries have become "recyclers" who depend on unsanitary landfills for their subsistence and income, where entire families spend their days searching for throwaway food and trash and sometimes uses untreated sewage for crop irrigation in urban and suburban agriculture. (Novotny,Ahern, and Brown, 2010).

The linear system has also other drawbacks and adverse environmental impacts. Because water use in the linear system withdraws excessive volumes of water from the surface and groundwater resources, the urban streams for long distances, including the urban sections, have insufficient or no flow. The effluent flow from large regional treatment plants is added at a long distance downstream, converting the receiving water body into an effluent dominated stream (Novotny, 2007). This natural low flow deficiency of urban streams is exasperated by the modified hydrology of the cities that greatly increases urban surface runoff and minimizes infiltration.

Generally, the inputs can be categorized into five groups

Materials (raw materials for buildings and production of goods and services within the city)

Food (homegrown and imported)

Water (potable and nonpotable from the grid, harvested rainwater, groundwater and surface)

Energy (coal, natural gas, gasoline, electricity from renewable and fossil fuel sources)

Chemicals (industrial fertilizers, pesticides, road and highway deicing chemicals, pharmaceutical products and other drugs, household and commercial cleaners and solvents)

Societies have realized the throwaway polluting practices of the last century cannot continue at the current increasing pace. Water resources have been severely polluted or even lost, there is no more landfill space available, and global warming is accelerating. Ideas of recycling and reuse are again attracting attention as the main methods for achieving sustainability.

There are many outputs. The examples of undesirable environmental outputs are:

> *liquid sewage, industrial wastewater and combined sewer overflows* (point sources) containing suspended solids, organics, nutrients, oxic compounds and pathogens that impairs the integrity of the receiving waters, often far downstream from the city;
>
> *polluted urban construction sites and highway runoff* (diffuse sources) also contain solids, toxic compounds and pathogens. Because of the changed hydrology of the cities, peak flows and volume of urban runoff increases flooding and enlarges floodplains. The response of city planners (an undesirable output) was to channelize the streams or convert them to underground sewers and culverts (Novotny, Ahern, and Brown, 2010);

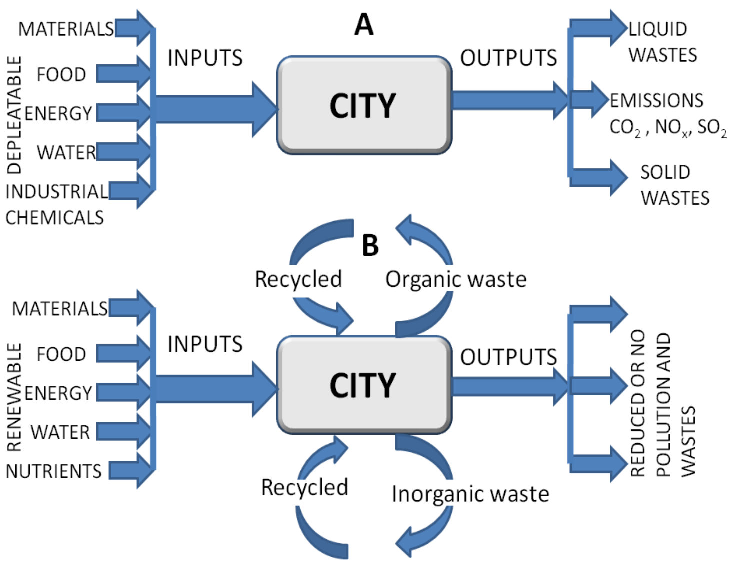

Figure 1 Linear (A) and circular (B) urban metabolism systems

> *air pollution emissions* with local, regional and global impacts (including regional and global green house gases (GHG), ozone layer destroying chemicals (fluorocarbons), polychlorinated bi-phenyls that contaminate fish and can be detected as far away as in Greenland and Antarctic glaciers, and acid forming oxides of sulfur and nitric oxides from power production and traffic; and
>
> *rubbish and other solid waste* such as demolition and construction materials, newspapers, packaging solids, woodchips and other landscaping solids, discarded TVs, computers, etc.

"Urban metabolism" does not only consider mass and energy. People are a part of the urban system as their well being and behavior are strongly affected by the mass and energy balances and the consequences (pollution, water shortages, warmer, hot and catastrophically turbulent weather). Other undesirable inputs of unbalanced urban metabolism in the past were famine, diseases or malnutrition of disadvantaged population, loss of jobs after catastrophic pollution discharges and water shortages, increased flooding, and deteriorating neighborhoods.

Food and water are often delivered from sources far from the urban area where additional energy and water demand are imposed on the production and transport to the city. Concurrently, large urban areas and industrial conglomerates have pollution impacts that can extend far from the urban source areas (acid rainfall, nutrient effects on hypoxia in seas), some impacts are global (climatic changes, some conservative toxins impact the ozone layer and accumulate in marine organisms). In political-economic literature these impacts and effects of physical transport of pollution by air and water currents from sources to distant areas of impact are defined as economic externalities (Meade, 1973; Mankiw, 2008). Pollution is a classic example of a negative externality but externalities can also be positive such as investment into urban renewal or restoration and/or clean-up of an urban water body where benefits are not limited only to people and commerce in the vicinity.

Mass balance approaches

The concept of urban metabolism is derived from the more general concept of the ecosystem analysis. In the ecosystem, production of organic matter begins with photosynthesis which converts inorganic mass (carbon dioxide, water and nutrients) into organic living organisms that are at the bottom of the food web. The output of one organism is the input to other species, organic matter provides energy and elements of growth, and in the final outcome the matter is broken (decomposed) to its original mineral forms and organic residues (e.g., humus). In ecological metabolism, organic and inorganic mass and energy undergoes several cycles.

Urban metabolism is essentially a large scale mass balance of inputs entering the city, their use, losses and transformation within the urban area, and, finally, resulting in outputs. The most obvious is water balance whereby inputs are precipitation, surface and groundwater fluxes, long distance transfer and water in food and raw materials (Kenway, Gregory, and McMahoh, 2010). In the more general mass balance, food input is converted into waste containing organic and inorganic pollutants and nutrients, materials are converted into new construction which may result also in demolition refuse, and so forth. The basic mass balance equation is

$$\frac{dM}{dt} = input - output - attenuation + growth + internal\ sources$$

One can stipulate that an output is proportional to the accumulated mass. For energy balance, attenuation is replaced by use and conversion of used energy used into waste heat and GHG emissions as undesirable outputs. From the law of mass/energy conservation each attenuation results into another growth (emission) form of mass/energy in and out of the system. Input to the system is from external sources.

An equation by Mitchell et al. (2003) describes the water balance of urban catchments as:

$$\Delta S = (P + I) - (E_a + R_s + R_w)$$

where ΔS is change in catchment storage including water held in the soil profile, groundwater aquifers and natural and constructed surface water storages; P is precipitation; I is imported water; E_a is actual evapotranspiration; R_s is stormwater runoff; and R_w is wastewater discharge.

Mass balance can be completed at a wide range of spatial and temporal scales, from a flower patch receiving water and nutrients to a city and entire region, which would also include virtual water transfers. Several methods of life cycle assessment and models for urban metabolism and footprinting were outlined by Berger and Finkbeiner (2010). Realistically, a family building or apartment is the smallest system. Several buildings are organized in a block or a neighborhood (a loose organization) or a more organized clusters or ecoblocks. A larger apartment, hotel, resort area building, office complex could be a cluster. Novotny, Ahern and Brown (2010) defined a cluster as a semiautonomous water management/drainage unit that receives water, implements water conservation inside the structural components of the cluster and throughout the cluster, reclaims sewage for reuse, such as flushing, irrigation and providing ecological flow to restored existing or dayligthted streams, recovers heat energy from used water, and possibly recovers biogas from organic solids. Using the term "ecoblock" is for the same purpose but the preposition "eco" may give a small degree of ambiguity because it could mean either an emphasis on economic management or management focusing on ecology. Without recovery, many components such as organic carbon and nutrients would become pollution. Standard traditional wastewater treatment in a linear regional system demands energy and also emits GHGs. This also includes constructed treatment wetlands that emit methane, nitrous oxides and carbon dioxide. A region of impact may extend beyond the regions administered by the urban sewerage agency, causing economic externality effects. As shown on Figure 2, urban systems are also hierarchically divided according to their scale. In the holistic hierarchical analysis, output from a system with a lower hierarchy becomes an input into the higher level system, often in another form. For example, the water cycle in the city combined with food increases nutrient emissions into used (waste) water at the local level which then affects the regional surface water bodies by increasing photosynthetic primary productivity of algae followed by an adverse impact on water quality in a downstream region. The mass transfers between the larger region scale and the smaller scale units are physical as well as virtual.

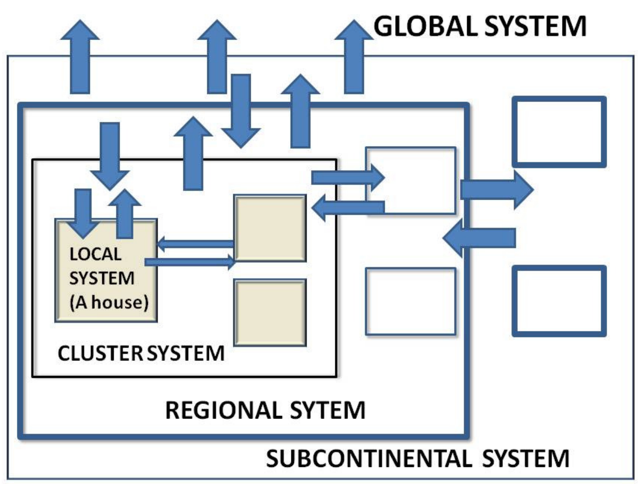

Figure 2
Hierarchical concept of urban metabolism

Figure 2 indicates that the assessment indices/footprints of urban metabolism and its impact on resources and environment can be both large scale ("giant") and regional/local.

Linear and cyclic metabolism

As stated in the preceding section, current urban systems have been mostly linear. 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. The most obvious causes and effects are increasing demands for energy, food and water by increased population and living standards which then results in pollution, shortages and overuse of resources throughout the world. The major concerns are the ecological status of the water bodies impacted by urban development, food, materials and other resource consumption. The dispersion of nutrients may result in severe algal blooms, and GHG emissions lead to adverse global climatic changes. A linear system relies on an unrestricted availability of resources and energy and, without strong regulations and enforcement, disregards the adverse impacts of waste and GHG emissions on the environment and society. In the prevailing current linear water system, water is taken from upstream sources, delivered to the urban area by underground conduits, used and polluted, then delivered by underground conduits to a regional wastewater treatment facility many kilometers downstream from the points of potential reuse, and finally overwhelming the receiving water body by the effluent discharge, creating often an effluent dominated water body. Traditional simple economic cost analysis for water systems based on economy of scale dogma was leading planners to build large regional facilities and (in the 1970s after the passage of the Clean Water Act in the US and elsewhere) to abandoning smaller community based treatment plants that were deemed uneconomical and inefficient.

On the input side of the mass balance linear systems require more resource input that the system that reuse and recycle and will have greater footprint. On the output side linear system produce more pollution that requires resources (water, air, soil and landscape) for dilution and safe assimilation of residuals.

The current problems with the linear urban systems, including water, food and materials shortages, and waste of organic and inorganic compounds, nutrients and toxic chemicals, will get worse in the future. The reasons are population increase, depletion of cheap energy (oil), increased living standards and pressure on resources by the emerging economic giants (China, India, Brazil, etc.), global climatic change which is upsetting the hydrologic water cycle and the effects of rapid urbanization. Switching from concepts described by the terms "waste" and "wastewater" to those characterized as "resource recovery" or "used water reclamation" cannot be done under the typical prevailing linear system scenario even when the utility name is changed from wastewater treatment to water reclamation.

In order to achieve more sustainable urban water/stormwater/use water management the urban metabolism system should be partially closed. A 100 % reuse/recycle system is not physically possible even on the international space laboratory because of inherent necessary "waste" generation in the system such as reject water in the reverse osmosis or water in sludge that cannot be or is difficult to recycle. These water losses must be replaced by make-up flows of fresh water.

Based on the concepts by Allan (1998), in a regional context water is divided into green, blue and grey waters. Blue water use is the volume of ground and surface water that evaporates during production. Green water is evapotranspiration of rain and groundwater (including irrigation) for agricultural production, and grey water is water used for dilution of the used water until it reaches commonly agreed quality standards. It should also include minimum ecologic flow (after withdrawals) to maintain healthy aquatic life. In the local water management domain; however, urban water flows are divided into blue (clean rain, surface and groundwaters); white (relatively clean runoff); grey (water from bathroom sinks, showers, bathtubs, washers that does not contain toilets flushing); and black water (toilets and kitchen sinks). Black water can be separated into yellow (urine) and brown (containing feces) flows.

The four processes of resource recovery and conservation of diminishing resources are:

1. Water conservation and reclamation and reuse of used water
2. Energy use savings and reclamation from various sources, such as heat, electricity, methane recovery from wastewater and organic wastes, and renewable wind, solar, and geothermal power sources
3. Recycling of organic solid waste for power generation by incineration or methane biogas production, or cardboard or paper production
4. Recycling of inorganic waste from metal, asphalt, glass, insulation, construction materials, and other products

URBAN SUSTAINABILITY INDICATORS

As noted in the introduction, the both the concept and implementation of urban sustainability is in the process of being developed. This is particularly true of the environmental portion of urban sustainability, where lively contributions by a variety of authors have sought to influence the direction of sustainable development through studies of individual environmental aspects. Social and economic statistics have been available for over a century in most countries. Over time, consensus has emerged about indicators to measure progress towards goals for economic and social well being, such as GDP, unemployment rates, poverty levels and so on.

This same process has only been underway for environmental indicators since 1992 when the Earth Summit focused attention on this sector. Therefore it is necessary to briefly review the context for all kinds of indicators, before drilling down to sustainable urban indicators, and then water indicators.

The Context for Indicators

National statistical indicators have arisen in response to the needs and excesses of the industrial economy, beginning early in the 19th century in the United States and Europe. Economic indicators were some of the first (besides population in the US Census) to be produced at a national level, and today the GDP is a recognized indicator of economic well being. The concept of social indicators was furthered in 1933 in the US with the publication of a series of monographs on social concerns, but it wasn't until the 1960's that social indicators became mainstream. In the United States today, a core set of regularly reported indicators on social and economic conditions exist, with many of them disaggregated geographically to a fine level (Innes, 1985).

Generally, the process for developing these indicators first involved special studies by academics, foundations, and blue ribbon government task forces and agencies. This included debate about the meanings and importance of the data and the indicators. Finally, these indicators and the underlying data collection mechanisms became institutionalized and today most people recognize (Innes, 1985)

At the same time that national indicators grew in importance, the reinventing government movement, or "managing for results" movement, resulted in many national, state and local governments developing a set of internal indicators to measure the effectiveness and efficiency of their operations. The intent was to develop a management system that would improve budget and operational decision-making that would ultimately be reflected in an improved quality of life for citizens. Key to this concept is the development of a strategic plan for the agency, deploying resources to achieve goals and objectives, developing performance indicators to measure progress towards the goal, reporting on progress, and making changes as needed to stay on course.

Performance indicators under this system were conceived of as a hierarchy: input indicators tracked staff and dollars allocated to a particular activity or program undertaken by the government. Output indicators measure the tangible products of the program, while impact or outcome indicators are related to ultimate quality of life goals. A key element of performance indicators is the development of a logic model that relates dollars and staff time, to program activities, thence to program outputs, and finally to a quality of life or higher outcome (Hatry, 2005). The outcome measures are often the same ones measured beyond the geographic boundary of the organization, and are not always under the control of the organization or agency so frequently these were developed by third party agencies to track the overall quality of life in various sectors.

Sustainability Indicators

A similar process is being following today for the development of sustainability indicators, including those for urban water management. Although the term "sustainable development" and the need to report on progress towards sustainability was first seen in 1972 in *Limits to Growth*, it wasn't until the late 1980's and 1990's in response to the same pressures that led to the 1992 Rio Conference (Earth Summit), that sustainability indicators, their programs and goals began to gain currency. The Rio Summit also gave rise to Agenda 21, which was a sustainable development plan for the 21st century. Part of the plan was a proposal by ICLEI International Council for Local Environmental Initiatives—now called International Cities for Sustainability) to assist local governments in developing local campaigns. One of the elements was to set up indicators to inform the community of the impact of local activities upon the sustainable development of the community. (Roseland, 2005).

Furumai et al (2009) identifies five major characteristic for sustainability indicators related to water quality and environmental and social sustainablity:

1. *Natural State*

The footprint assessment should evaluate the extent to which the aquatic and riparian environment maitais its original natural state. Urban water and its surrounding areas (riparian zones) and the watersheds itself should retain or restore as much as possible the natural status of the aquatic ecosystem. Human interventions such as channelization, conversion to underground conduits and sewers, and modification of hydrology (increase4d flood flows and lack of base flow) and excessive flow withdrawals should be considered.

2. *Biological diversity*

This assessment includes eveluattion of biological diversity and living habitats in the riparian zones littoral zones

3. *Use of water*

This assessment evaluates water quality in terms of attaining its designated uses (aquatic life, recreation, water supply, etc.)

4. Relation to people – people's amenities

Evaluations should include assessment of intangible values of the water body and surrounding ecotones to people such as aesthetics, recreation values, landscape beauty on one side and signs of deterioration and disregard (trash, weeds and barren unsightly land) on the other side.

5. Regional water culture

In many regions natural water bodies have special cultural, recreational and even religious values. Hence accessibility values, availability of picnic areas and character of the surroundings should be assessed.

National Sustainable Indicators

At the national level, the most complete system for a sustainable plan and indicator system is in Holland, where the Dutch have connected its plan and indicators to benchmarks with a system of "covenants" with key actors. The Dutch were among the first to establish a sustainable development plan, called the National Environmental Policy Plan, which has national goals and indicators tracked at both the national and the province level. The goals are developed by sector, and businesses, academia, and local governments are involved. Initially passed by Parliament in 1989, it is updated every four years and score cards of results published every 2 years.

Other national efforts that arose after the Rio Summit have broad scopes but no benchmarks or targets. They range from simple data collection at the national scale to more complicated efforts with indicators at various scales of aggregation. The United Nations Commission on Sustainable Development developed a system in 1995 of reporting on indicators of environmental, social, economic and institutional health at the national level with minimal aggregation (United Nations, 2009) . The United Kingdom has evolved a reporting system that includes local, regional, 147 national and 15 key 'headline' indicators of sustainable development. Norway has been a long-time state of the environment reporter. Its focus is on environment rather than sustainability reporting. Sweden also adopted 16 environmental benchmarks in 1999 that were to be achieved by 2020. South Africa also has an indicator system that deals not only with the traditional physical environmental conditions, but includes social, economic and political environments, making it more of a sustainability report.

In the United States, the President's Committee on Sustainable Development established a sustainable indicators project in 1995 which brought together both public and private groups to develop a set of national indicators for six sectors of the environment. The outcome was a report entitled the "State of the Nation's Ecosystems" which reported on 32 different indicators. This group morphed into the SDI group (Sustainable Development Indicators) in 2000. Increasingly there was concern about the duplication of environmental data collection and production as well as inconsistencies since data was drawn from 17 different federal agencies. Accordingly, in 2004, the federal resource and environmental agencies began efforts to build an environmental information framework (Guldin, 2010). In 2008, both EPA and the Heinz Center (a non-profit) produced reports on the environment that used a variety of indicators. In that same year, OMB formed an interagency task force to develop the National Environmental Status and Trends (NEST) Indicators project, beginning with a pilot project on water. (Discussed further below) Similar indicators will later be developed for oceans, freshwater/estuarine, air, forests, rangelands, agricultural lands and urban areas.

Non-governmental sustainable indicators and related studies also proliferated during this period. The indicators in these studies are usually aggregate measures designed to document the problem (ie, carbon emissions by country; virtual water use by country and so on), and to raise the consciousness of the general public. Many of these indicators are used to model different action scenarios. The most well-known of these in the environmental area are the ecological footprint, the carbon and water footprints discussed below.

Local Sustainable Indicators

Until very recently, most local sustainable indicator efforts were developed by non-profit groups or third party agencies. For example, in the mid-1990's a group of citizens in Seattle produced an urban sustainability report for that city containing 20 sustainability indicators and an evaluation of where Seattle was against those rankings. This was a powerful tool to induce decision-makers to establish local sustainability efforts. In 1991, the State of Oregon issued its first benchmarking report which evaluates progress in the state against 272 indicators of environmental, social and economic well-being. Other cities and states in North America began developing sustainability plans and using indicators to measure progress (Willapa Bay, Washington, Minnesota) and today many local communities have substantial experience with sustainability programs and indicators that assess the state of their community and also track local program and activities. Several land use plans in the United States, such as Marin County, California, calculate the ecological footprint for its geographic area before going on to set goals and objectives for development.

A parallel effort of green indicators for development projects also emerged at this time. These indicators were part of certification systems designed to influence local development decisions. These generally involve the use of outside evaluators to rank various attributes such as of a proposed development against a rating system. The most well known of these is LEED (Leadership in energy and Environmental Design) run by the U.S. Green Building Council, a non-profit organization (USGBC, 2005;2007). Founded in 1993, USGBC began with a rating system for new construction commercial buildings, and over the years added various other types of buildings, including residential. Most recently, a system for evaluating the neighborhood was added (Yudelson, 2008). Many state and local governments now offer development incentives for buildings that rank high on these scales, and California recently made a variation of these mandatory for all new construction. In the US, these systems however, concentrate primarily on energy use and alternate transportation systems. The LEED system for example, has only 4 "indicators" out of 169 for new construction focused on water (USGBC, 2005. 2007).

There are a variety of outside ranking systems for sustainable cities usually developed by a magazine. SustainLane is one example but they abound. Two years ago, ICLEI-USA began a broadbased effort to come up a more rigorous system for measuring the sustainability of cities. Called the Star System, it would be patterned after the LEED ranking system. Other efforts include that by the World Wild Life Fund (WWF, 2008) which has developed and is promoting the principles that include social and technological metrics under the name of *One Planet Living (Community)*. Some ecocity developments are now aiming at OPL certification (e.g., Masdar in UAE and Sonoma Mountain Village in California). These criteria for ecocities are far more broad and stringent than LEED or LID criteria. OPL criteria are as follows:

- 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 emissions coming 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;
- health and happiness with facilities and events for every demographic group.

FOOTPRINTS: Ecological, Carbon and Water

A "footprint" is a quantitative measure showing the appropriation of natural resources by human beings (Hoekstra and Chapagain, 2007). Three major categories of footprints have been developed to evaluate sustainability and are discussed below in greater detail.

- *The ecological footprint* is a measure of the use of bio-productive space (e.g., hectares of productive land needed to support life in the cities)
- *The 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
- *The water footprint* measures the total water use on site and also virtual water

A fourth foot print, the *resilience footprint* was proposed by Jiang and Beck (2007) which specifies the frequency and intensity of disturbance such as floods, pollution emergencies, in a city and evaluates its ability to bounce back. This will not be discussed below.

Ecological footprints

Ecological footprinting is widely used around the world as an indicator of sustainability, at the global level, but also the regional, and city level. This concept was developed by Rees and his students and coinvestigators (Girardet, 1996; Rees, 1996; 1997; Wackernagel and Rees, 1996). The ecological footprint was defined as the total area of productive land and water required to produce, on a continuous basis, all the resources consumed and to assimilate all the wastes produced by that population, wherever on earth the land may be located (Rees, 1996; 1997). The ecological footprint of a city is proportional to the population of that city, its population density and per capita material (plus food and water) consumption.

In 1995 with the earth population of less than 6 billion, the unit area of productive land was 1.5 ha/person. In contrast, megalopoli (cities with more than five million people) in the developing world have an ecological footprint well below 1 ha/person. With the expected population to grow by 2040 to 10 billion and reduction of productive land area by urbanization, deforestation, etc., the available productive area will be less than 1 ha/person. Rees (1997) and Wackernagel and Rees (1996) calculated the ecological footprint of Vancouver (BC) called then a "typical North American city" as being 4.8 ha/person, which will be 3 to 4 times the available productive land on earth.

The ecological footprint is obviously not the same even in the cities of the developing world. Rees (1997) estimated the ecological footprint of some other cities in the developed countries as

Countries with 2- 3 ha/capita footprint
 Japan and Republic of Korea
Countries with 3 – 4 ha/capita footprint
 Austria, Belgium, United Kingdom, Denmark, France, Germany, Netherlands, Switzerland
Countries with 4-5 ha/capita footprint
 Australia, Canada, and USA

Even though the difference between the US and Japan is almost 50 %, all developed countries are running an ecological deficit, i.e., the footprint is much greater than the fair share of global productive land. Large cities in developed countries have an ecological footprint in productive land use hundreds times greater than the city area. The dilemma the world is facing is the resource and productive land availability for future population growth and increased living standards that, if things go as usual, would exhaust the productive land long before the living standards in developing countries would reach levels comparable to that in the developed countries. If every person on earth living in the future cities (more than 60% of the total earth population according to forecasts) desires to achieve the current living standard of Vancouver, the ecological footprint (i.e., the demand on resources for production and assimilation of emissions) would be more than three times the available productive land on earth. Hence, to achieve a sustainable future for all there is no other choice than to abandon linear urban systems, switch to a conservation and reuse circular system and reduce substantially the footprint. Increasing densities lead to lower land requirements, less transportation by private automobiles and generally to less energy use (Novotny and Novotny, 2010).

In spite of the fact that the University of British Columbia and various NGO provide "footprint calculators (http://www.footprintstandards.org) the application of this concept is more appropriate to agriculture, nonurban land management, food people eat (what and how much) than to urban water management. It is clear that the giant ecological footprint is related to living standard of the country or of the city. It is also clear that the amount of waste is greater in countries with higher living standard and consumption than in the poorer countries. On the other hand, the levels of abatement (wastewater treatment, safe disposal of refuse, air pollution emission controls) are high in developed countries. The footprint based on the estimates of the productive lands needed to support living and production process in the cities may indicate the seriousness of the overall problem of the lack of resources for food, materials, etc. and land, air and water for assimilation of pollution emissions but it is difficult for using it to make quantitative assessments of the impacts of water management on thus type of indicator or develop a meaningful index that would provide a guidance for remediation and correction of the problems. Water, soil and air availability and quality should be an important part of the measurement of the ecological footprint; however, such measurements and assessment indices in a hierarchical context may be more local than "giant", i.e., global. Furumai et al (2009) outlined the following considerations that have to be taken into account in developing a water footprint (paraphrased):

1. Psychological quality of life and perception of water quality as they may be difference between the nations with different economic status and resource availability;
2. Overall conditions of the watersheds and their water cycles;
3. The index should be consistent, easy to apply and understandable;
4. The metrics and indices should be accepted by the governments, NGOs, stakeholdes and a majority of the population.

Pollution export – virtual pollution and externalities
Similarly to virtual water, import of goods to a large city from distant areas and countries that have lax pollution laws and abatement creates virtual pollution export from the city to areas where the goods are produced. Examples are many and the most obvious ones are imports of inexpensive goods from some developing countries that would be more costly to produce in the US and other developed countries with stringent and enforced environmental laws. Hence, the pollution that would have occurred in the area receiving the goods, if production occurred in the city, is exported to the country that produces the goods which also includes GHG emissions.

Pollution externality is an example of virtual effects. Pollution externality or external diseconomics (Meade, 1973; Novotny, 2003; Mankiw, 2008) occurs when pollution created by a city or industry is transferred by a physical conduit (e.g., river) downstream to another user of the water body who incurs additional costs due to more treatment or loss of the resource and the sufferer has no economic recourse to recover the cost from the upstream polluter. Externalities are regional and often transboundary. Externalities also apply to air pollution (e.g., acid rainfall effect, GHG emissions). For example, in Europe upstream countries discharge nutrients into the Danube River (the second largest river in Europe after the Volga River in Russia) creating severe anoxia in the Black Sea that causes loss of fishing and problems with recreation in the nations surrounding the sea. As pointed out previously, externalities can be both negative and positive.

In the context of footprints pollution externalities reduce the assimilation capacity of the environment, damage water resources and in doing so diminish productive water and land resources.

Carbon Footprints
It is now generally accepted that we are undergoing a long period of global climatic changes, indentified also as global warming, caused by excessive emissions of GHG that include carbon dioxide (CO_2), methane (CH_4), nitrous oxides (N_2O) and fluorinated gases. GHG emissions are natural (including living processes by humans and biota) and without them the earth would be too cold to live in. Excessive anthropogenic CO_2 and other GHG emissions from power plants, traffic, industrial operations, home heating, etc., after the onset of the industrial revolution, trap heat in the atmosphere and cause global warming.

Carbon footprints are used to evaluate the sustainability of nations, regions and cities. Until recently the US was the largest emitter of GHG gases but was overtaken by China. If statistics are presented in emissions per person (Table 3), the Middle East states are the largest emitters. Dodman (2009) found large cities emit per capita less GHG than the national average. For example, London’s emissions (6.2 tons/capita/year) are 50% less than the national average (9.4 tons/capita/year).

A new paradigm shift in the COTF urbanisms can be observed in *the push for carbon neutrality* which could be considered as self - preservation of the global society from wide spread worldwide effects of predicted climatic changes if nothing or little is done to reduce emissions of GHG. Global warming solutions cut across all the major systems of the city: energy provision for buildings; energy use by transportation systems and the "discovery" by transportation engineers that land use and urban form decisions can reduce mileage (kilometers) traveled by cars and other traffic, a major contributor to transportation carbon emissions; and the dual relationship of water and energy. Energy is needed by the water/wastewater industry (highest energy cost is for transporting water and used water) and water is needed by the energy industry, particularly for nuclear power plants. Global warming solutions are also assisted by taking a more eco-friendly approach to development. Today pressing news about the deleterious effects of increasing concentrations of CO_2 and other GHG's give added impetus for the need to make our cities more sustainable.

Water and energy nexus is also a premise of global sustainability. In the area of water management, achieving the global goal of reducing GHG emissions implies water (energy) conservation, reuse of used water and use of stormwater, development and use of renewable energy, reduction in energy use in urban and suburban transportation and building infrastructure, and reliance on local and sustainable agriculture. Figure 3 shows possible paths towards achieving the net zero GHG emissions and thereby reduce the social/energy footprint of our cities.

Table 3 Per capita CO_2 emissions statistics

Top ten countries in GHG (CO_2 equivalent) emissions in tons/person/year in 2006[1]									
Qatar	UAE	Kuwait	Bahrain	Aruba	Luxembourg	USA	Australia	Canada	Saudi Arabia
56.2	32.8	31.8	28.8	23.3	22.4	19.1	18.8	17.4	15.8
Selected world cities total emissions of CO_2 equivalent in tons/person/year[2]									
Washington *DC	Glasgow UK	Toronto CA	Shanghai China	New York City	Beijing China	London UK	Tokyo Japan	Seoul Korea	Barcelor Spain
19.7	8.4	8.2	8.1	7.1	6.9	6.2	4.8	3.8	3.4
Selected US cities domestic emissions of CO_2 equivalent in tons/person/year[3]									
San Diego CA	San Francisco	Boston MA	Portland OR	Chicago IL	Tampa FL	Atlanta GA	Tulsa OK	Austin TX	Memphi TN
7.2	4.5	8.7	8.9	9.3	9.3	10.4	9.9	12.6	11.06
[1]Wikipedia (2009); [2] Dodman (2009) ; [3]Gleaser and Kahn (2008)									
[2,3] Values include transportation, heating, and electricity									

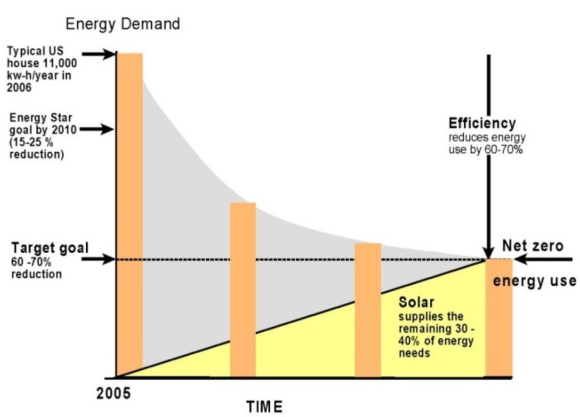

Figure 3 Water and energy nexus of ecocities with reduced water use and resource recovery can achieve net zero GHG emissions. Source NSTC (2008).

Similarly to water, the carbon footprint concept can be extended to include virtual energy use. For example, Geick and Cooley (2008) estimated total energy use for producing 1 liter of bottled water being on average 1.5 – 2.8 kW-hr which is 2000 times the energy cost for producing tap water.

The parameters that can affect the energy/carbon footprint are:

- Living standard (automobile and electric appliance ownership)
- Population density (Fig. 4)

- Percent inclusion of renewable energy (solar, wind, geothermal) into electricity production and on site generation (e.g., solar panels on the roofs)
- Use of passive energy savings on houses (LEED certification)
- Public transportation availability and use
- Geographical location
- Per capita water use (water – energy nexus)
- Degree and type of water reuse (e.g., reusing rain/stormwater vs. recycling highly treated effluents).

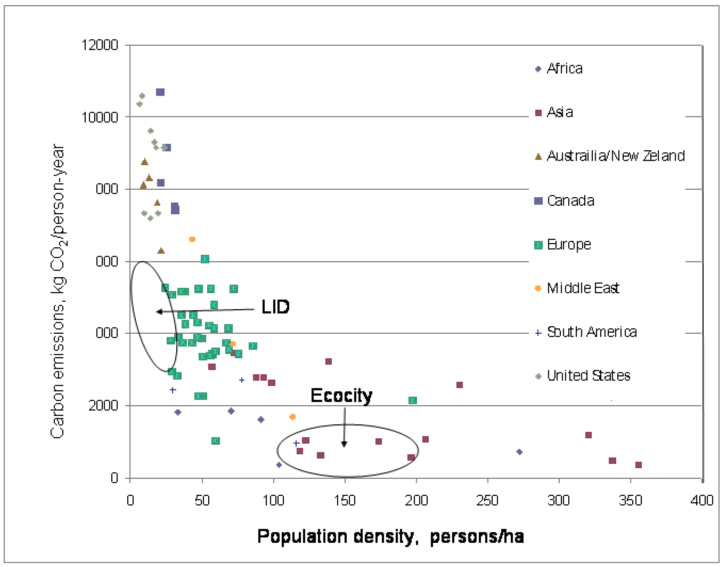

Figure 4

Relation of the carbon footprint to population density. From Novotny and Novotny, 2009, 2010)

Water Footprint – Direct use of water

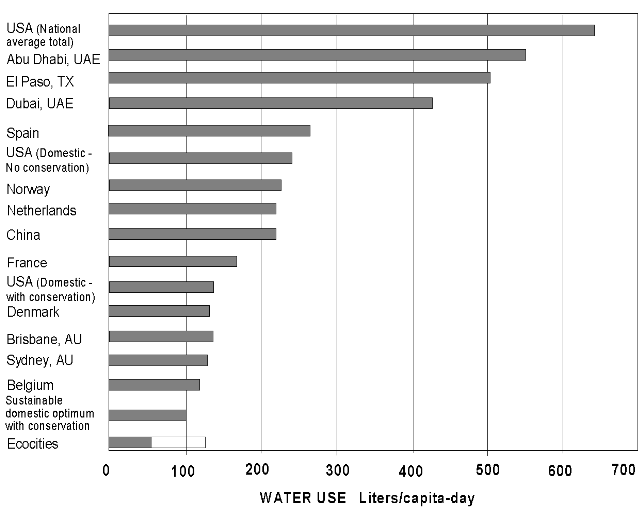

Figure 5 Per capita water use in selected urban areas and countries compiled in Novotny (2010) and Novotny et al. (2010)

Figure 5 shows the per capita water uses in several cities and countries. The per capita water use in the cities is a local footprint which usually has regional significance. In the US, domestic indoor water use is relatively constant among the major urban areas (Heaney et al., 2000), averaging 242 Liters/capita/day for a household without water conservation and 136 Liters/capita/day for a household practicing water conservation, respectively. However, the total per capita water use is magnified by outdoor irrigation (using potable water), pipeline leaks, or swimming pools and in the

US reaches almost 650 Liters/capita/day. The water demand in the US is the highest in the world and, because of the high demand in the dry regions of the arid US southwest, severe water shortages have been common in many southwest US communities.

Many people—especially in developing countries, developed parts of China, and even the US southwest, live in areas that anticipate severe water shortages, which will be exacerbated by population increases and migration, and also by global warming. The World Bank (2001) has estimated that, during this century, available water must increase by 25–60% to meet the basic needs of the population, but most of it will have to come from water conservation and reuse. In many communities that have already reached the limit of the availability of freshwater, water reclamation, in addition to desalination (in coastal communities), has already become a viable option for providing additional water for their increasing population. However, the high cost, energy use and discharges of high salinity reject water into the environment are the major drawbacks of desalination. Water reclamation and reuse also create opportunities to build new sustainable cities in areas that would be unsuitable for urban development under the current linear paradigm, such as the desert coastal areas in the Middle East.

Severe and critical water shortages and poor quality of available water have to be vigorously addressed in many developing countries but also in many developed countries anticipating severe drought conditions (e.g., Australia, southwest US, Israel, Middle East). During the 1990's the goal for adequate water supply and sanitation for all was established by the United Nations. This goal has not been fully met in many developing countries where it is exasperated by critical water shortages, missing or inadequate infrastructure to deliver water, poor sanitation and drainage, uncontrolled population migration to cities, and by water contamination. There are many cases throughout the world where the situation with urban water supply is critical and cities are looking for increasingly more expensive ways to provide water to citizens. Australia has been facing severe drought for more than a decade and millions of urban dwellers are coping with severe shortages. In 2008 the two largest cities, Brisbane and Adelaine with a total population of three million, were running out of water. In China, the China Daily news agency reported (24th of November 2007) serious water shortages in two thirds of the 641 largest cities in the country, based on the information provided by the Ministry of Water Resources. Millions of the world poorest subside on fewer than 20 liters per person per day and more than 46% of people do not have access to a nearby running drinking water tap.

Minimum water use criteria. In suggesting water conservation and sometimes outright drastic restrictions, in water shortage emergencies, it is necessary to know the minimum water use criteria. Globally, most water withdrawn from surface and groundwater sources is used in agriculture for irrigation, resulting in large consumptive losses. Agriculture worldwide accounts for 69% of annual water withdrawals (Anon., 1998). However, this varies among countries and even continents. In Europe, most water is used for industries.

A range of 20 to 40 Liters/capita-day is generally considered as the lowest limit to meet basic water supply and sanitation needs in developing countries (Gleick, 1996). Gleick further proposed "an overall basic water requirement of 50 Liters/person-day" as a minimum standard to meet four basic needs: drinking, sanitation, bathing, and cooking. Falkermark and Widstrand (1992) used 100 Liters/person-day as a rough estimate of a minimally acceptable water availability standard for people living in developing countries, excluding uses for agriculture and industry. These estimates have been widely accepted in many hydrological studies (Anon, 1998). These low values do not consider water reclamation and reuse.

Water Footprint—"Virtual water" or Indirect Use of Water

The virtual water concept was introduced by Allan in the early 1990s (Allan, 1993: 1995) when studying the option of importing virtual water (as opposed to real water) to solve the problems of water scarcity in the Middle East. Virtual water transfers and trading refer to the water use outside of the city area that is used to produce food, materials and other goods to satisfy the needs of the people living in the city. Such production water demanding activities outside of the city include agriculture, production of electricity, construction materials, paper, and, today, biofuel from corn or sugar cane or oil derived from tar sands. It is a regional to global footprint which describes water use and losses in the regions providing these commodities to urban populations. For example, the water use of an average US citizen for direct household use is 242 Liters/capita/day but the water use for producing food for the same citizen, including irrigation and livestock, will require 1,928 Liters/capita/day of which 61% is consumptive use, i.e., water lost by evaporation and transpiration. Producing electricity requires 1780 Liters/capita/day, mostly for cooling. The consumptive loss from cooling water is about 3 to 4 %, hence, the virtual water demand for producing electricity is about 53 to 73 Liters/capita/day (McMahon, 2008; Gleick et al., 2008).

Hoekstra and Chapagain (2007; 2008) divided virtual water into

- The volume of fresh water that is lost by evapotranspiration to produce the goods and services consumed by the individual or community
- Volume of water needed to dilute pollutants generated and discharged in the production process

The flow of virtual water to the city is shown on Figure 6. A water footprint can be estimated for an individual, city or unit of the product (Tables 1 and 2).

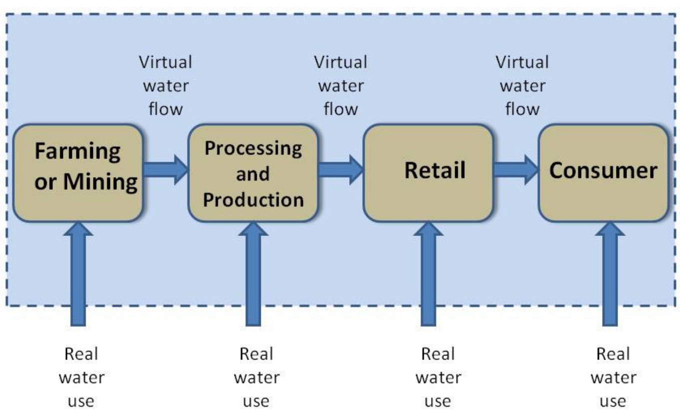

Figure 6
Virtual water flow and export (from Hoekstra, 2008)

The concept of virtual water was originally proposed by Allan (1998) and has been extensively studied by the Pacific Institute (Gleick et al., 2008; Hoekstra and Hung, 2002; Chapagain and Hoekstra, 2008; Hoekstra and Chapagain, 2007; Aldaya et al., 2010; Kenwey, Gregory, Berger and Finkbeiner, 2010; and McMahon, 2010) who point out the overall water footprint, and by the same reasoning the energy footprint, are related to virtual water. As pointed out by Hoekstra and Hung (2002) when assessing the water footprint of a city (or a country), it is essential to quantify the flows of virtual water leaving and entering the city (country). Similar estimates can be made for building materials, fruit, vegetables and other products delivered from distant areas, some of them on the other side of the globe. While international trade is not discouraged, the philosophy of ecocities emphasizes local (organic) fruit and vegetables, recycled and local building materials.

Table 1 The water footprint (virtual water) of different foot items (based on Hoekstra, 2008)

Item	Unit	Average water footprint (litres)
Banana	1 kg	860
Beef	1 kg	15,500
Bread	1 kg	1,300
Cheese	1 kg	5,000
Chicken	1 kg	3,900
Lettuce	1 kg	130
Corn	1 kg	900
Mango	1 kg	1,600
Milk	1 litre	1,000
Peach or nectarine	1 kg	1,200
Pork	1 kg	4,800
Potato	1 kg	250
Rice	1 kg	3,400
Wine	1 litre	960

Table 2 Examples of the water footprint (virtual water) of items other than food (based on Hoekstra, 2008 and Ellis and Dillich, 2010)

Item	Unit of product	Average water footprint (m^3) per unit of product
Energy Nonrenewable		
Natural gas	1 Kw-hr	0.0004
Coal		0.0006
Crude oil		0.0038
Energy Renewable		
Wind	1 Kw-hr	0
Solar thermal		0.0792
Biomass		0.252
Pulp and paper		
Newsprint paper	1 ton	43.3
Bleached market kraft pulp	1 ton	93.2
Petroleum		
Crude oil	1 barrel	0.83 – 037
Textile		
Wool	ton	283
Carpet	ton	46.6
Knit	ton	83.3
Cotton bedsheet	1 sheet	10.6
Blue jeans	1 pair	11.0
1 Kw-hr = 3.6 MJ	1 barrel of oil = 159 litres	

T*he urban parameters that can affect the water footprint* are numerous and could include:

- Population density
- Percent imperviousness

- Percent irrigated area per household
- Living standard
- Irrigated area per dwelling unit
- Water needs for street flushing, irrigation of public parks, and fire fighting
- Geographical location and meteorological conditions (arid vs. humid; warm vs. temperate)
- Food consumption and type (virtual water)
- Virtual water in other products (e.g., bottled water, textiles, paper, automobiles, etc.)

INDICATORS AT THE LOCAL LEVEL

As stated in the preceding section the "giant" ecological footprint has not been a particularly useful tool for the water sector because it does not take into account upstream or downstream effects, nor biodiversity. Consequently in a city context the water sector has relatively little direct influence over it. However, it is a good city and national-scale measure and its simplicity helps with communication of the seriousness and inequity to stakeholders and the public. The local footprints specified below have more utility and are more traditional in the water sector.

Local ecological footprints are different than global footprints focusing on sustainability of resources to provide viability to the city. The local and subregional footprints focus on sustainability of resources and ecology within the city and the region of ecological influence that is much smaller than that identified by the Rees' and Girardet's "giant footprint". The global virtual water, ecology and carbon footprints, in contrast, deal with the load and demand of the city on the earth's ecological resources and assimilation of pollution and waste. As pointed out by Rees (1997) "the ecological location of human settlements no longer coincides with their geographic location". This may not be true with the local/subregional ecological footprints. Healthy ecology in and near cities is paramount for healthy living and, with the exception of mammoth water transfer from long distances, cities are connected physically with the water resources that provide drinking water, recreation, residual pollution assimilation, and happiness. Furthermore, the excessive pollution impacts in most cases are most severe in or near the city that is responsible for them.

Responsibility for urban water management is usually fragmented between a variety of entities: the water utility, the local general purpose government and various other agencies with responsibility for storm water management, local levees, sewers, water and wastewater treatment. Effective and comprehensive outcome indicators for water at the local level are not the norm at this point. Water utility best practices for sustainable indicators may track some regional outcome measures such as per capita water use; the amount of water recycled and so on, but generally their performance indicators follow the "performance for results" model described earlier (Kenway, et al, 2007). In the past two decades many local governments have begun carbon counting, and calculating the carbon footprint of various programs. Indeed, the State of California has mandated carbon emission reduction planning and reporting at the regional level that is linked to land use planning as a condition of receiving federal transportation dollars.

However, similar efforts at the city wide level are nascent for water. The Nature Conservancy attempted several years ago to develop urban water indicators but the project did not come to fruition. In the United States, the NEST project will be developing a consistent set of data on the following questions:

- How much water do we have?
- How much water do we use?
- What is the condition of aquatic ecological communities?
- What is the physical and chemical quality of our water?
- Is the water we have suitable for human use and contact?

The goal of NEST is "to regularly report on current environmental conditions and recent trends, to assess the outcomes of federal policies and programs and to help decision makers at the regional, state and local levels." To the extent this data will be available over the next decade at the small area level (as is employment and social data), this would enable local and regional communities to develop a more sophisticated set of indicators to assess local conditions and programs as well as evaluate alternative water programs. For example, using existing data, one research group calculated the total flow of water in and out of four metropolitan areas in Australia in 2004-05, including rainwater, stormwater, accounting for evaporation, drinking and wastewater. They came up with four indicators of water sustainability in the developed city:

1) water use per capita;
2) Percent of household and centralized water supply that could be met by rainwater harvesting;
3) Same as 2 but by wastewater recycling;
4) same as 2 but by stormwater recycling.

The four metropolitan areas were found to vary from 26% to 86% in their potential to meet total water use with wastewater recycling; and from 47 to 104% by recycling storm water (Kenway et al, 2010).

Other analytical tools are being developed at the local level to make investment decisions by private companies and developers. CH2MHill's (2009) Global water tool has water data sets and the modeling capability to help companies calculate water footprints, determine efficiencies, and to minimize external risks. A tool called the Green Values calculator has been developed by a non-profit organization to compare the hydraulics and life cycle costs of six Best Management Practices to reduce storm water runoff in a project to conventional practices. The user enters data on the location such as the area, number of lots, roofsize, number of trees on the lot, driveway and so on. It can be used by a Greenfield developer or for a retrofit development (Kennedy et al., 2009)

An ideal framework for local indicators which focuses on livability of cities and restoration and preservation of urban ecology could consist of information regarding (a) urban waterways and impoundments, (b) water corridors and urban open green space; and (c) urban hydrology, including surface and subsurface water resources and drainage.

Urban waterways and impoundments are the most dominant component of the local ecological footprint of the COTF. Current environmental regulation in advanced countries calls for "attaining, maintaining and preserving the integrity" of the receiving waters (US Clean Water Act of 1972) or achieving "good ecologic status" (Water Framework Directive of the EU countries). These narrative goals have been converted by regulation into standards and criteria. Similar statutory requirements have been incorporated also in other countries. Wagner et al (2002) and Furumai et al (2009) have outlined the basic features of the water body (including surrounding lands and watershed) and groups of parameters and formulated indices to be included in an overall index of watershed sustainability. They were organized in five categories (see the discussion on Ecological Footprints): (1) Indicators of natural sate; (2) Biological diversity; (3) Designated water use; (4) Amenity to people; and (5) Regional culture of water.

Previous practice put urban streams underground as sewers or out of sight culverts because of severe pollution decades or a century ago. In the COTF, water conservation and treatment will provide ecological flow to surface water bodies that today lack it because of overuse. Current and future used water reclamation technologies can bring water quality to levels that would support aquatic life, water supply and recreation.

Responsible nutrient management. Many water bodies, not just urban, are severely affected by eutrophication which in some cases has led to a hypertrophic status characterized by massive algal blooms of cyanobacteria. These resilient microorganisms greatly impair beneficial uses of water bodies such as fish and wildlife propagation, recreation, and water supply. The problems are caused by excessive nutrient (nitrogen and phosphorus) inputs both from urban and rural point and nonpoint sources. To make the matter worse, the world is running out of phosphorus needed to grow crops. In some countries (e.g., China, Czech Republic) hypertrophic conditions of the impoundments are decommissioning water supplies during the conditions of cyanobacteria algal blooms, leading to severe problems with providing safe water from the infested sources to millions of people. Efficient and responsible nutrient management and phosphorus recovery is a COTF goal and a measurable footprint.

Water quality assessment evaluates compliance with established criteria and standards. Hence a degree of compliance with standards and integrity (ecological status) goals are the measures of the ecological footprint. In general, the quality of streams, estuaries and impoundments is evaluated using four types of assessments that have been included in numerous countrywide guidelines and regulations:

1) Chemical integrity that involves statistical evaluation of measured chemical parameters with established standards and includes many parameters such as turbidity, dissolved oxygen, biodegradable organics, nutrients, temperature and priority (toxic) pollutants.
2) Physical integrity of the water body that evaluates the quality of the habitat to support a healthy life and includes parameters such as bank stability, riparian habitat quality, substrate texture and quality, sinuosity, riffle and pool sequence, and channelization.
3) Biological integrity that assesses the composition, diversity and health of aquatic organisms such as fish, benthic macroinvertebrates, or periphyton. It also should include the quality of surrounding ecotones (riparian zones) and assess the presence and health of water fowl, amphibians, aquatic and shoreline plant growth.
4) Algae (phytoplankton) density and composition is a measure of nutrient management and load. This footprint could also include measurements of presence or absence of algal toxins to assess a potential or reality of severe infestation of the water body by cyanobacteria with adverse impacts on water supply, recreation, public health and other uses of the urban surface water resources.

Ecological corridors and open space. Urban ecology consisting of green areas, water bodies and ecotones that separate nature from built habitat has to provide connectivity and passage to the urban biota and people. The opposite of connectivity is fragmentation that impedes healthy ecology and survival during the time of stress. Ecological corridors along urban surface water bodies also provide resiliency to extreme meteorological events such as floods.

The parameters characterizing ecological corridors are

1) Degree of fragmentation of ecological corridor (freeways that transect natural areas which prevent wildlife crossing) and aquatic water bodies (presence of culverts and dams that prevent passage of aquatic organisms)
2) Riparian zone width and ecological quality (presence, diversity and numbers of healthy water fowl, amphibians and animals).
3) Ratio of green area per person
4) Degree of preservation of natural lands

Furumai et al. (2009) also propose to assess the urban landscape that is include or surrounds the ecological corridors which should include the assessment of the surrounding landscape (industrial zones vs low density residential); relation of the surrounding environment to shoreline development; visual amenities such as the amount of garbage; availability or lack of access to the water bodies; conditions of the water and the river bed; quality or objectionability of odors, and surrounding sounds.

Urban hydrology. Past urbanization has dramatically changed the hydrology of our cities by reducing infiltration, groundwater recharge and increasing flooding. This led not only to water shortages but also to dangerous subsidence in many communities, including Venice (Italy), Mexico City, Philadelphia, and Boston by increasing vulnerability to catastrophic flooding. Unrestricted development and climatic changes will also increase the portions of urban areas in floodplains. Restoring hydrology as close to the natural water cycle should be a goal and also one that measures the progress towards sustainability.

The parameters characterizing the hydrological footprint and integrity are:

1) Percent imperviousness and percent of directly connected impervious area to receiving waters and channels
2) Groundwater table changes as compared to predevelopment, groundwater recharge
3) The degree of deviation of the urban hydrological cycle from the natural cycle (assessed by hydrologic modeling)
4) Loss of base flow and increase of high flows
5) Floodplain extent and development in the floodplain
6) Resiliency to extreme events to be increased by global warming

THRESHOLDS OF CHANGE

Users of indices must realize that the relationship of the overall sustainability and ecological status of urban waters is not linearly related to the individual parameters of any index. Index may represent a status but many systems are resilient to the change in both directions. Thresholds are the triggers of change and should be established by scientific research. The present state of the art does not allow yet to fully understand the thresholds of change.

SUMMARY
Water, ecological, carbon/energy and economical footprints are linked to and are expressions of the urban metabolism which can be linear or cyclic. Linear urban water and energy management exert high demand on resources and inputs (water, energy, food, chemicals, and materials) which is not sustainable. Urban metabolism and the need for change is also driven by the adverse effects of ongoing and future global warming caused by emissions of GHG into the atmosphere and future population increases. As countries currently developing at a fast pace will try to catch up with the currently developed countries, there will not be enough resources to sustain the growth and the existing resources, including water, would be rapidly exhausted.

Changing towards sustainable urban development and retrofitting the current cities will require a great degree of water conservation and partially closing the urban metabolism cycle. For this purpose developing the measurable footprints and criteria based on the important footprints will be necessary. This requires a paradigm change of how cities are designed, built and retrofitted. The most current popular criteria and certifications are mostly local and most only loosely tied to the most important sustainability footprints.

There is a need to develop comprehensive metrics and indices of footprint measures along with better criteria defining sustainability and adherence to the Cities of the Future goals. Such indices and assessments would be used by residents (for example, high school students, local and regional NGO's); Local governments, as well as urban planners and consultants. The indices should be both qualitative and quantitative and amenable to easy graphical representations. Communities and citizens should be able to easily monitor the sustainability state of their of their water bodies and surrounding areas and put pressure on the authorities if the progress towards sustainability is slow or none. The planners should be able to delineate visually the areas of progress or problems. The developed indices should be tested using case studies.

Acknowledgement. The authors acknowledge and appreciate cooperation on this topic with the members of the Framework and Footprint subgroup of experts of the International Water Association Steering Committee for the Cities of the Future. Also graduate students of the Watershed Management class at Northeastern University have been diligently researching this important topic of the COTF framework and contributed to this article. The views expressed in the article are solely those of the authors. Special thanks are expressed to Peter van der Steen of UNESCO who reviewed the paper.

References

Anon. (1998) "Solutions for a Water-Short World," *Population Reports* 26 (1, September 1998), The Johns Hopkins University School of Public Health, Baltimore, MD, http://www.infoforhealth.org/pr/m14/m14chap7.shmtl

Allan, J.A. (1994) Overall perspectives on countries and regions. In: *Water in the Arab Worlds: Perspectives and Prognoses,*(P.A. Rogers and P. Lyndon, eds.), Harvard University Press, Cambridge, MA, pp 65-100

Allan, J.A. (1998) Virtual water: A strategic resource, global solution to regional deficits, *Ground Water* **36:**545-546

Allan, J.A. (2005) Water in the environmental/socio-economic development discourse: Sustainability, changing management and policy responses in a global system, *Government and Opposition Ltd. 2005,* Blackwell Publishing, Oxford (UK) and Malden (MA)

Aldaya, M.M., J.A. Allan, and A.Y. Hoekstra (2010) Strategic importance of green water in international crop trade, *Ecological Economics* **69:**887-894

Berger, M., and M. Finkbeiner (2010) Water Footprinting: How to address water use in life cycle assessment, *Sustainability, 2010(2):919-944,* Open access, ISSN 2071-1050, www.mdpi.com/journal/sustainabillity

Chapagain, A.K. and A. Y. Hoekstra (2008) The global component of freshwater demand and supply: as assessment of virtual water flows between nations as a result of trade in agricultural and industrial products, *Water International,* **33**(1):19-32

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

Dodman, D. (2009) Blaming cities for climate change? An analysis of urban greenhouse gas emissions inventories, *Environment and Urbanization,* **21**(1):185-2001

Ellis, M., and S. Dillich (2010) Industrial water use and its energy implications, accessed April 2010, http://www1.eere.energy.gov/industry/steel/pdfs/water_use_rpt.pdf

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

Fururmai, H., F. Kazama, H. Nagaoka, and Jun Nakajima (2009) Collaborative development of water environment quality index in Japan, in *Innovations in Collaborative Urban Regeneration (M. Horita and H. Koizumi, eds.),*Springer, Tokyo

Girarded, H. (1996) Giant footprints, *Our Planet,* June 1996, http://www.gdrc.org./uem/footprints/girarded.html

Gleaser, E.L. and M.E. Kahn (2008) *The Greenness of Cities: Carbon Dioxide Emissions and Urban Development,* Working Paper 14238, National Bureau of Economic Research, Cambridge, MA, http://www.nber.org/papers/w14238, accessed March 2009

Gleick, P. (1996) "Basic water requirements for human activities," *International Water* 21(2):83–92

Gleick, P.H. and H.S. Cooley (2009) Energy implications of bottled water, *Environ. Research Letters* **4** 014009 9 (6 pp)

Gleick, P., M. Palaniappan, M. Morikavwa, H. Cooley, and J. Morrison (2008) *The World Water,* Island Press, Washington, DC

Heaney, J.P, L.Wright, and D. Sample (2000) Sustainable urban water management, Chapter 3 in *Innovative Urban Wet-Weather Flow Management Systems (R. Field, J. P. Heaney, and R. Pitt, eds.)* TECHNOMIC Publ. Comp., Lancaster. PA

Hermanowitz, S.W. and T. Asano (1999) Abel Wolman's "The metabolism of cities revisited: A case for water recycling and reuse, *Water Sci. & Technol*., **40**(4-5):29-36

Hoekstra, A.Y. (2008) Water Neutral: Reducing and Offsetting the Impact of Water Footprints, Reuse Report Series 28, UNESCO-IHE, Delft, The Netherland

Hoekstra, A.Y., and A.K. Chapagain (2007) Water footprints of nations: water use by people as a function of their consumption pattern. *Water Resources Management* **21** (1), 35–48

Hoekstra, A.Y. and Hung, P.Q. (2002) Virtual water trade: a quantification of virtual water flows between nations in relation to international crop trade, Value of Water Research Report Series No.11, UNESCOIHE, Delft, the Netherlands.

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

Jiang, F., and M.B. Beck (2007) Cities and their water infrastructure: Forces for good in the watershed, Proc. Internatl. Symp. New Direction in Urban Water Management, UNESCO, September 2007, Paris. France

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

Kenway, S., A. Gregory, and J. McMahon (2008) Urban water mass balance analysis, submitted to *Journal of Industrial Ecology*

Kenway, Steven, Carol Howe and Shiroma Makeepala. 2007. Trip Bottom Line Reporting of Sustainable Water Utility Performance. Denver, CO: Awwa Research Foundation; and Black Mountain, Australia: CSIRO Land and Water.

Mankiw, N.G. (2008) *Principles of Economics,* Cengage Learning, Boston (Massachusetts)

McMahon, J.E. (2008) The energy-water nexus, Power point presentation at UC Berkeley, October 1, 2008

Mitchell, V.G., T.A. McMahon, and R.G. Mein (2003) Components of the total water balance of an urban catchment, *Environmental Management* **32**(6):735-746

Meade, J.E. (1973) *The Theory of Economic Externalities: The Control of Environmental Pollution and Similar Social Costs,* Brill, Leiden (The Netherlands) and Boston (Massachusetts)

National Science & Technology Council (2008) Federal Research and Development Agenda for Net-Zero Energy, High Performance Green Buildings, Committee on Technology, Office of the President of the United States, Washington, DC

Novotny, V. (2003) *Water Quality: Diffuse Pollution and Watershed Management*, J. Wiley and Sons, Hoboken, NJ

Novotny, V. (2007) Effluent dominated water bodies, their reclamation and reuse to achieve sustainability, Chapter 14 in *Cities of the Future – Toward Integrated Sustainable Water and Landscape Management (V. Novotny & P. Brown, eds.),* IWA Publishing, London

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) Urban water and energy use – From current US use to Cities of the Future, Proc. Cities of the Future Conference, Water Environment Federation, Cambridge (Massachusetts), March 7-10, pp. 118-140

Novotny, V., and E.V. Novotny (2009) Water centric ecocities – Towards macroscale assessment of sustainability, *Water Practice and Technology,* Vol. 4, No. 4, ISSN Online: 1751-231X

Novotny, V. J.F. Ahern, and P.R. Brown (2010) *Water-centric Sustainable Communities: Planning, Building and Retrofitting Future Urban Environments*, J.Wiley & Sons, Hoboken, NJ

Pamminger, F., and S. Kenway (2008) WATER – *Journal of the Australian Water Association, February Issue*, pp. 45-46

Rees, W. E. (1996) Revisiting carrying capacity: Area based indicators of sustainability. *Popul. Environ.* **17**:195-215

Rees, W. E. (1997) Urban ecosystems: the human dimension,, *Urban Ecosystems* **1**:63-75

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

Wackernagel, M. and W. Rees (1996) *Our Ecological Footprint: Reducing Human Impact on the Earth*, New Society Publishers, Gabriela Island, BC, Canada
Wagner, W., J. Gawel, H. Furumai, M.P. De Souza, D. Teixtera, L. Rios, S. Ohgaki,, A.J. B. Zehnder, and H.F. Hemond (2002) Sustainable waterdhed management, an international multi-watershed case study, *Ambio* **31**(1):2-13
Wikipedia (2009) List of countries by carbon dioxide emissions per capita, http://wikipedia.org/wiki/List_of_countries-by_carbon_dioxide_emissions_per_capita , accessed October 2009
Wolman, A. (1965) The metabolism of cities, *Scientific American* **213**(3):179-190
World Bank (2001) *Water and Sanitation Programs, 99-00 Report*, Water and Sanitation Program, Washington, DC
WWF (2008) One planet living, World Wildlife Fund, http://www.oneplanetliving.org/index.html