The Use of Material Flow Analysis for Supporting Enhanced Water Policy

Abstract

The use of environmental and resource accounting tools have proliferated and are widely used both as messaging tools for the public to communicate impacts of consumption patterns and also as valuable indicator for supporting environmental policy-making. These include ecological foot-printing, water foot-printing and material flow analysis among others. Of these, material flow analysis (MFA) offers great potential to link with economic and social processes and therefore policy interventions. However, there is little consensus on how to use these tools at multiple spatial scales and what indicators to employ to assess sustainability and performance of the ecosystem. In addition to this, a greater understanding of how to apply tools such as MFA to have salience with policy-makers is needed. The paper explores the use of MFA in supporting better water management policies at the urban-regional level. This is a novel application of an increasingly important method of assessment for determining the resilience of urban regions to water scarcity.

Keywords: *material flow analysis, water scarcity, resilience, environmental policy*

Introduction

Countries face ever-increasing water challenges that contribute to the global water crises. Populations living in cities are especially vulnerable because of the patterns of migration, poorly integrated water management policies due to the lack of institutional capacity to manage water resources, compartmentalized water management (Mitchell, 2005;UN-Habitat, 2003) and competing and over-lapping jurisdictions for water management. Other common drivers of environmental change include social attitudes towards water use, economic development and climate change (Grimm et.al, 2008; Millennium Ecosystem Assessment, 2005; Muller, 2007; Uitto and Biswas, 2000). These trends have adversely affected the security of water supply which includes the delivery of a safe, affordable, equitable and consistent water supply to cities. Urban areas function as important ecosystems, providing valuable ecosystem services, such as water supply, food, and cultural services (Alberti and Marzluff, 2004; Bolund, 1999; MEA, 2005; Sprin, 1980). Conventional approaches to water management and the delivery of these ecosystem services has been based on sectoral management which has failed to adequately anticipate and manage water supply challenges. Increasingly, integrated rather than sectoral approaches and policies to water management are being sough, however these are fraught with difficulties to implement.

In order to mitigate and adapt to ever changing and increasing water security challenges, appropriate water management approaches and tools need to be implemented. This paper is an exploratory discussion of integrated urban water management, particularly of the analytical tools of Material Flow Analysis and Ecological and Water Footprinting, two commonly used tools that could provide scientific basis for policy development and implementation for this integrated approach. Given the assumption that cities function as open and integrated ecosystems, this paper will discuss how the concept of urban water metabolism, can contribute effectively to the analysis of urban water issues using material flow analysis. These efforts will support sound policy and decision-making under the changing water management and ecosystem management regimes of urban areas globally.

I. Integrated approaches to water management

One of the key water management paradigms in the last decade is Integrated Water Resources Management (IWRM), an ecosystem-based approach to natural resource management (Falkenmark and Rockstrom, 2004; GWP, 2000). The ecosystem approach is a strategy for integrated management of land, water, and living resources that promotes sustainable use in an equitable way (Christensen, 1996; Gleick, 2000; Slocombe, 1998; Timmerman and White, 1997; Waltner-Towes and Kay, 2005). The Global Water Partnership provides a definition of IWRM as " a process which promotes the co-coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems" (GWP, 2000). Integrated Water Resources Management is based on a set of principles which seek to maximize efficiency, both in cost and allocation, through stakeholder participation and managing water at the lowest hydrological unit, the watershed, and in the process ensure water security. The essence of IWRM reflects a paradigm shift from managing the hydrological cycle to managing the hydro-social cycle (the human use of water) (Merret, 1997;Thomas and Durham, 2003). Much of the literature has focused exclusively on IWRM planning and management at river basin levels while neglecting the application of IWRM to the urban context, even though the principles are applicable at urban levels given the emphasis on sectoral integration, equity, and efficiency (Rees, 2006). It is clear that a more thorough concept of IWRM is needed, especially given the spatial relationship of the city to its watershed.

Fundamental problems exist with implementing an IWRM approach. First, there are no clear guidelines for implementation, as it is difficult to assess, quantify, and report the success of implementation given the diversity in plans and geographic context (Biswas, 2004). Second, there is a lack of coherent polices, such as economic instruments to support the IWRM process outlined above (GWP, 2000). Developing policies to enhance the resilience of urban areas to future water scarcity is dependant on assessing and reporting the state of water resources through accurate data. In essence, as water management regimens shift to endeavor to be more integrated, so too must the scientific information and analytical frameworks that policy and management decisions are based on.

II. Frameworks to support implementation of IWRM through Urban Water Metabolism

Conceptual frameworks guide the assessment of the biophysical environment and therefore structure the discourse around integrating environmental with social and economic information. They also facilitate government accountability with the public, and in choosing valuable policy-support tools that help policy makers make informed judgments about socio-economic and environmental management plans, among other attributes (Marin et.al, 2007; Pollard et.al, 2004; Sing and Maldon, 2002). How information is collected and what indicators are used to drive policy decisions, are rooted in the conceptual view of the urban environment and subsequently affect how it is governed (Hammond et.al, 1995; Weichselgartner, 2001; Zhang et.al, 2006).

Urban Metabolism (UM) is a concept that is borrowed from biology used to quantify the overall fluxes of water, materials, energy, and waste into and out of an urban region that can also serve as a conceptual framework for policy development (Fung and Kennedy, 2005; Huang and Chen, 2005; Huang et.al, 2006). It provides a powerful analogy to analyze and understand the urban environment since urban areas function as ecosystems. In addition to this, given that systems-based conceptual methods are needed to effectively support the implementation of IWRM, it warrants using frameworks that incorporate both human and environmental drivers of environmental change, as well as quantify and assess the nature of those relationships within an urban ecosystem (Jewitt, 2002; Pickett et.al, 2001).

The metabolism analogy, as it relates to the urban water cycle, is Urban Water Metabolism (UWM). It facilitates an understanding of the water cycle of use and to anticipate some of the problems that might arise in the urban system as a result of that use. The metabolism concept is not without limitations. Douglas (1983) noted that this analogy doesn't necessarily aid in understanding urban change, but it is useful in that it reminds us that cities are biologically parasites in the sense that they use of resources in metabolism. It has been argued that this approach does not give a truly integrated view of Urban Metabolism, since the functions of cities are so complex that they defy quantification (White, 1998; 2004). While both of these points are valid, the application of Urban Metabolism is not meant to quantify every interaction within the urban environment, but to highlight the key interactions based on a preliminary assessment of the key drivers of change in the urban ecosystem. The approach is a useful concept because it allows for an integrated view of the urban ecosystem that will benefit more integrated policy development and implementation (Haberl 2006; Huang et.al, 2006). The Urban Metabolism framework allows for an understanding of the total physical processes in cities or regions (including hidden flows from outside the system), which are spatially defined and can be correlated with sectors, as well as social and economic processes through time (Brunner, 2001; 2004; 2007; Huang, 1998; Strayer, 2003). The potential to use a temporal comparison is an important feature of this framework that allows for elucidation of trends over time. Therefore while the application of Urban Water Metabolism can help use draw parallels between the built and natural ecosystems in relation to the water cycle, the ultimate application of this concept is that it provides a comprehensive framework to analyze the urban environment in an integrated manner as a counterpart to certain policy approaches.

The use of a UWM framework has many advantages by including:

- the provision of new indicators that contribute to state of the environment reports and other assessments (Kennedy et al., 2007);
- assess resource use and waste production by different sectors, at different spatial scales, and governance levels (Haberl, 2006);
- the potential for multiple analyses, including time series, to elucidate trends (Hendricks et al., 2000);
- make use of geo-referenced indicators through application of Geographic Information Systems (GIS) correlated to resource use and consumption (Pickett et.al, 2001); and
- take into account "rucksucks" which are areas that are outside of the system but contribute to overall inputs in the system (Udo de Haes, 2006).

III. Tools to support the metabolic view of the urban environment

Many tools exist for quantifying and assessing environmental impacts and the state of the environment. These tools can be used at multiple spatial scales and governance levels, such as Ecological Footprinting (EF), Water Footprinting and Material Flow Analysis (MFA). Consensus has not been reached with respect to which analytical tools are appropriate to evaluate Urban Water Metabolism processes and ultimately provide a sound scientific basis for policy-support and development (Finnvedon and Moberg, 2005; Huang and Hsu, 2003; Udo de Haes, 2006; Ny et.al, 2006).

Ecological Footprints/ Water Footprints

Eugene Odum (1981; 1983) outlined the concept of production ecology in an urban and regional context. This concept was an early predecessor to the idea of Ecological Footprint that was proposed by Wackernagel and Rees (1996), as an environmental impact measure that correlated the impacts of consumption patterns on the amount of land-resources needed. The Ecological Footprint is a spatial measurement of Urban Metabolism since it expresses the amount of land that a city has appropriated to meet its metabolic needs to sustain the individual or population (Haberl et.al, 2004; McDonald and Patterson, Melbourne Atlas, 2005; 2007; Sahely et al., 2003; Wackernagel and Rees, 1996). The Ecological Footprint has been used at multiple spatial scales and levels (Rees, 1996). London, England's footprint, for example, is estimated to be 216 times its spatial size. The Ecological Footprint has mainly been used as a public-awareness tool to communicate the patterns of over-consumption of a population or individual (Haberl et. al., 2004; Brunner, 2001).

The concept of the Water Footprint (WF) was recently developed in 2004 in order to have an indicator of water-use in relation to consumption by people (Chapagain and

Hoekstra, 2004; Hoekstra and Chapagain, 2006; Jenerette, 2006). The Water Footprint is analogous to the Ecological Footprint, in that the values are expressed as the annual water volume required to sustain a population (Chapagain and Hoekstra, 2004). Water footprint's have consumption-based indicators of water-use that could provide useful information, in addition to the traditional production-sector based indicators of water usage. The Water Footprint's emphasis is on water-use by the domestic, agricultural, and industrial sectors. Footprinting analysis, in general, is a useful measure of impact of consumption patterns, and is a valuable communication tool. Footprinting tools are widely recognized and accepted by governments, industry and the public. However, it has some limitations:

- the footprint does not account for external flows, which includes water imported from other countries, other river basins, etc; (Pickett et al., 2001)
- it does not account for water used by nature, water loss through leakage or the hydrological cycle;
- it is simply a measure of the current impact, as the tool does not lend itself to temporal comparison (e.g.: time series analysis) and is not anticipatory;
- the focus of the tool is on measures of impact, not an assessment or stock-taking of resources to forecast future problems;
- cannot disaggregate impact of activities by spatially relevant sectors. For example, a Water Footprint of a city will not yield information about where inefficiencies of each sector lie in the urban ecosystem;
- takes a systems view, but not an integrated systems view, and therefore is not indicative of the inter-relationships among and between the different sectors or users; and
- the data yielded is based on a series of scientific assumptions, such as the use of fixed values for consumption (e.g. doesn't allow the inclusion of variation between individual behaviors or use of different types of potentially water saving technologies, among other factors) (Brunner, 2001).

Material Flow Analysis

Material Flow Analysis (MFA) is an analytical tool that examines the material stocks and flows coming into and out of a given system, and the resulting outputs from the system (Baccini and Brunner, 1991; Brunner, 2004; Douglas, 1983; Hashimoto and Moriguchi, 2004). Material Flow Analysis is useful to examine the relationship between a region or city and its corresponding hinterland, making it a particularly useful tool for studying Urban Water Metabolism (Burstroem, 1999; Harremoes, 1998; Hendricks et al., 2000; Obernosterer et al., 1998; Suh, 2005; Ness et al., 2006). Material Flow Analysis also allows global, regional, or urban processes and activities to be linked (Niza and Ferrao, 2006; Wernick and Irwin, 2005). Other features of this tool include the capacity for inclusion of social and economic indicators by using extended MFA analysis (Bartelmus, 2000; 2002; Balat, 2004). This extended analysis allows for human drivers of environmental change to be factored into an analysis of the biogeochemical cycles (Hobbes et. al, 2007; Kytzia et.al, 2004). Material Flow Analysis are anticipatory in their nature that are spatially and temporally defined (Bringezu and Moriguchi, 2003; Bringezu et.al, 2003; Brunner, 2001; Decker, 2000; 2006;Udo de Haes et al., 2004;

OECD, 1998). Hendricks et.al (2000) noted that MFA allows for a precautionary approach through early recognition of environmental problems without relying on signals of environmental stress. Material Flow Analysis has some weaknesses in that:

- the tool is currently used mainly by industrial ecologists and engineers, and not water resource managers (Binder, 2007; Cortner et al., 1998). Raising awareness and building technical capacity among water managers for use of this tool and policy-makers will be needed;
- it is heavily reliant on up-to-date and complete data sets, many of which are uncertain (Douglas and Larson, 1998); and
- ecosystem boundaries must be consistently defined in studies to quantify the flows into and out of the system.

V. The use of MFA for water policy support

As previously indicated, some of the problems associated with implementing an IWRM approach are the lack of clear guidelines on what aspects of water management should be integrated, how to set priorities and the lack of clear, coherent and synthesized information that can be used to provide policy-support for a particular management goal. Material Flow Analysis can facilitate the implementation of IWRM at the urban level since it identifies where the inefficiencies in the urban system lie and therefore set priorities for water management.

It is clear that Material Flow Analysis holds potential for a more integrated analysis of the urban environment. However, Decker et.al (2000) noted the paucity of information on material flows of water at urban level despite water comprising up to 90% of all materials entering the urban ecosystem. There is also a lack of analysis of urban water fluxes which is necessary given that data could be used to support water policy decision-making and therefore improve urban environmental governance. What MFA's provide are indicators of environmental change related to water supply and use that can be evaluated over time using baseline measures. Given that the data and resulting indicators can be disaggregated by sector and also integrate social and economic data, the analysis is very relevant to support integrated urban water management policy. As policies endeavor to become increasingly integrated so too must the data sets and assessments that provide the science-policy linkages.

Substantial research has been undertaken modeling the urban water balance resulting from rainfall and runoff relationship and considerably less research has been undertaken on the overall water balance of water supply and use which reflects the traditional sectoral driven approaches to water management (Stephenson, 2003). While some urban metabolism studies have included measures of water, the information is sporadic and limited to a few indicators, namely overall urban water supply, leakage and wastewater discharge. Specific information regarding efficiency of water use by sector is largely absent, however in some instances though estimates of water use by user have been obtained namely in Sydney, Hong Kong, Mexico City and Toronto (Douglas, 1983; Sahely et.al, 2003; Oke, 1999; Warren-Rhodes and Koeing, 2001). Most of these studies have correlated the increasing or decreasing urban water metabolism to particular drivers of water supply and use change such as industrial development, urbanization or lifestyle. For example, in Toronto water use decreased since the 1990's mainly because of the shift in industries in the city over time, namely the decline in industrial water consumption (Kennedy, et.al, 2007).

Despite holding great potential to influence policy, urban metabolism studies using MFAs have not been well utilized on a systems wide basis, engineers have long used this analysis for analyzing flows of substances though (Sahely et.al, 2003). This is a result of MFA's not being mainstreamed into the toolbox of the policy-maker. The exception is Material Flow Accounts which analyze material flows on an economy wide scale however this is not the focus of the paper (Lange, 2003). Material Flow Analysis has been used to identify trends in material and energy flows between three settlements in Australia (Lennox and Turner, 2005). In addition to this, a recent study of the MFA and Ecological Footprint of the City of York (UK) was carried out, the first of its kind in the UK. The City of Melbourne's sustainability plan, *Melbourne 2030* outlined the use of metabolism studies using MFA and ecological footprints as important measures of progress towards urban sustainability. These Governments are recognizing the value of establishing systematic benchmarking studies using these tools to monitor progress of their programs and policies and inform the public using State of the Environment reports (Francis et.al, 2005; Healy, 1987; ICS, 2002; Lyons, 1997; Ward, 2007). The use of water related indicators in all urban metabolism studies remain limited and in some instances sporadic though, again highlighting the need for a more comprehensive framework for Urban Water Metabolism. A more comprehensive and consistent framework will certainly enable more accurate and coherent monitoring and reporting, which are important mechanisms for linking scientific information to policy development.

IV. Conclusions and next steps

The choice of tool, either Material Flow Analysis or Water Footprinting is determined by the ultimate management goal (Bringezu and Moriguchi, 2003). For many urban-regional areas, this is to facilitate the implementation of integrated urban water management for sustainable water use. In order to do this effectively, environmental problems, such as future water scarcity, either through human or natural drivers, need to be mitigated to ensure water security. Because specific indicators can be drawn from Material Flow Analysis, particular policy instruments can be used more effectively, namely initiating tailor-made water service cost-recovery programs through use of targeted economic instruments. Traditional environmental and sectoral indicators are difficult to attribute to a social and economic process, making the environmental and resource accounting indicators derived from MFA particularly valuable for policy-making. Material Flow Analysis and Water Footprinting can serve complementary roles in the context of enhanced integrated urban water management, in that the Water Footprinting data raises awareness among the general public, government and stakeholders as to the environmental impact of societal activities, and MFA can elucidate where some of the inefficiencies of water-use are in the system (Chen, 2006). This makes Material Flow Analysis ultimately more useful for actual policy-support and impact.

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