ASSESSMENT METHODOLOGIES FOR WATER REUSE SCHEME AND TECHNOLOGY

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Summary

This chapter illustrates the most basis assessment methodologies as decision support system and assessment framework for water reuse scheme and technology evaluation. It includes the analyses of life cycle, material flow, ecological footprint, health risk, energy consumption and economic and social impact in order to form rational concepts and approaches towards a comprehensive assessment method for water reuse.

1. Introduction

Water reuse has developed from a basic method of disposing wastewater without any treatment to currently highly engineered wastewater treatment techniques. Due to the limited water resources, typically water stressed countries in dry climates like Australia, Israel and the State of California have developed wastewater reuse strategies and programs acknowledging the beneficial role wastewater reuse can play in integrated water management (Rubin, 2001; D of WR, 2003; MacDonald, 2004).

Wastewater reuse has progressively developed from a traditional method of wastewater collection and disposal without any treatment to an advanced highly engineered treatment, upgrading technologies, wastewater management and augmentation of water resources (Hochstrat et al., 2005).

One of the major challenges faced by the water industry when examining water reuse services is lack of comprehensive assessment method, a defined set of sustainability assessment criteria and definitive measurable indicators that can embrace the principles of sustainability such as consideration of economic, social and environmental issues of water service provision, considered as an integrated life cycle, multi-criteria approach, technology, public health risk (Holz, et al, 2004).

There are several methodologies in which the principal water reuse schemes can be assessed. Integrated assessments methodologies are more broadly targeted than discipline-specific assessments. They attempt to pull together dissimilar types of information into a cohesive and comprehensible format. Such integrated assessments could be conducted for several alternative treatment systems, thus resulting in a comparative integrated assessment (Jones et. al., 2000).

Integrated assessment is commonly thought of as a model or better defined as a process for bringing various disciplines together to derive information and insights that would not otherwise be possible. The assessment methodologies for water reuse generally include: (i) space (e.g., across a watershed), (ii) time (e.g., across the life of a system), (iii) sources of risk (e.g., other activities in a watershed), (iv) results (e.g., direct effects causing indirect effects), and (v) multiple endpoints (e.g. engineering costs and social impacts) (John et al., 2000).

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Wastewater reuse, resource conservation and pollution prevention requires consideration of the processes in terms of the product extraction - refining - manufacturing - distribution - consumption - disposal scheme based on decision making techniques (Carnegie Mellon University, 2003).

The wastewater recycling and reuse generates a certain degree of risk for humans and the environment, such risk could be assessed and appropriately managed. (AQUAREC, 2006). Quality assurance model, defined as the procedural and operational framework and assessment methodology has potential to address a number of complex, usually multidisciplinary processes associated with water reuse.

Consequently, a certain modeling work has been developed, aiming at supporting the assessment process. Modeling for water management has significantly changed from mono-disciplinary models to describe relatively simple problems in the areas of hydrodynamics, groundwater, surface water quality or ecology, to more multidisciplinary and complex approaches to solving water management problem including socio-economic impact assessments.

Model-based decision support requires the expertise from various domains and would typically be performed by teams consisting of persons with a variety of disciplinary backgrounds (Scholten et al., 2006).

The most basic methodologies used for assessment of water reuse are as follows:

- Life Cycle Analysis
- Material Flow Analysis
- Ecological Footprint Analysis
- Health Risk Analysis
- Energy Consumption and Economic Analysis
- Social Impact Analysis

2. Assessment Methodologies

2.1 Life Cycle Analysis

Life cycle assessment (Figure 1) can be described as a methodology, which allows for the estimation and calculation of environmental impacts that occur during the life cycle of a product (Rebitzer, et al, 2004). The immediate precursors of life cycle analysis and assessment (LCAs) were the global modelling studies and energy audits of the late 1960s and early 1970s.

These attempted to assess the resource cost and environmental implications of different patterns of human behaviour (Rubin, 2001). Life-cycle approach is a way of addressing environmental issues and opportunities from a system or holistic perspective and evaluating a product or service system with the goal of reducing potential environmental impacts over its entire life-cycle (Blumenfeld et. al., 2003).

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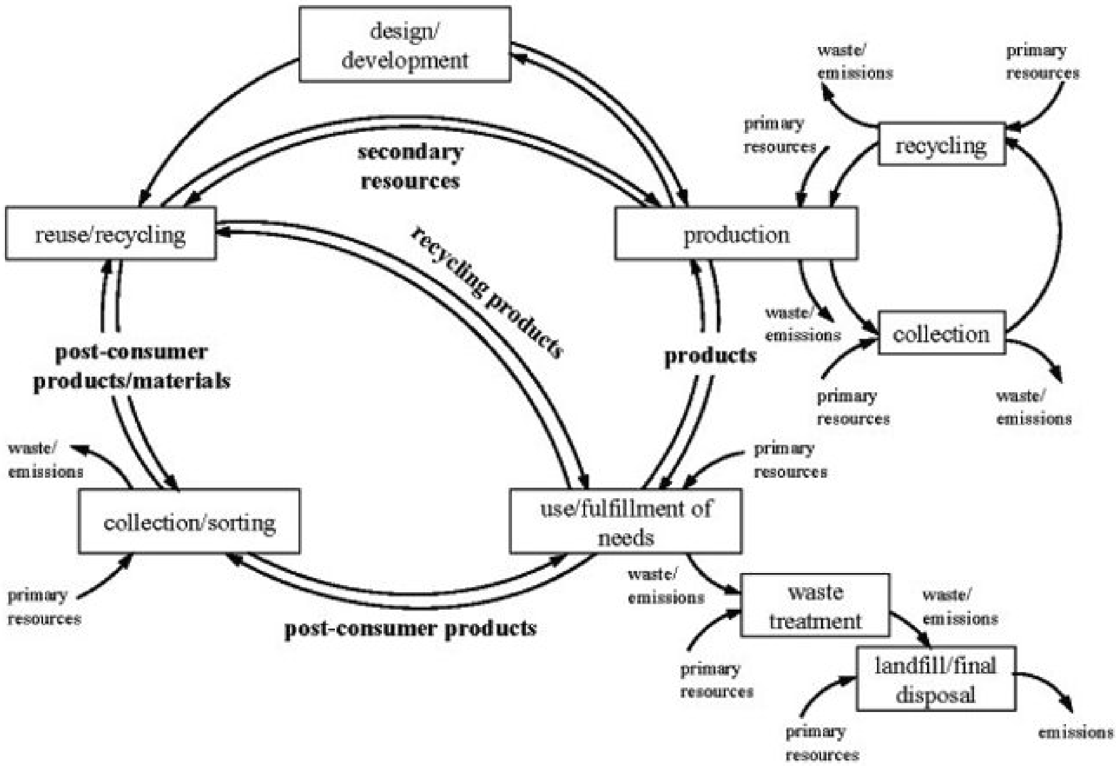

Figure 1 Holistic Life-cycle approach represents a simplified product life cycle concept, which includes loops between the several life phases

Life Cycle Analysis (LCA) is a technique used to assess the environmental impacts of a product over its entire life cycle. Figure 2 depicts the stages in a product life cycle (AQUAREC, 2006). At each of the five sections the inputs include materials, energy and natural resources and the output is waste products. Through each of these five sections the inventory analysis calculates the amount of energy and materials going in, as well as analyzing the outputs exiting, including intended products, by- products and energy released (Rubin, 2001).

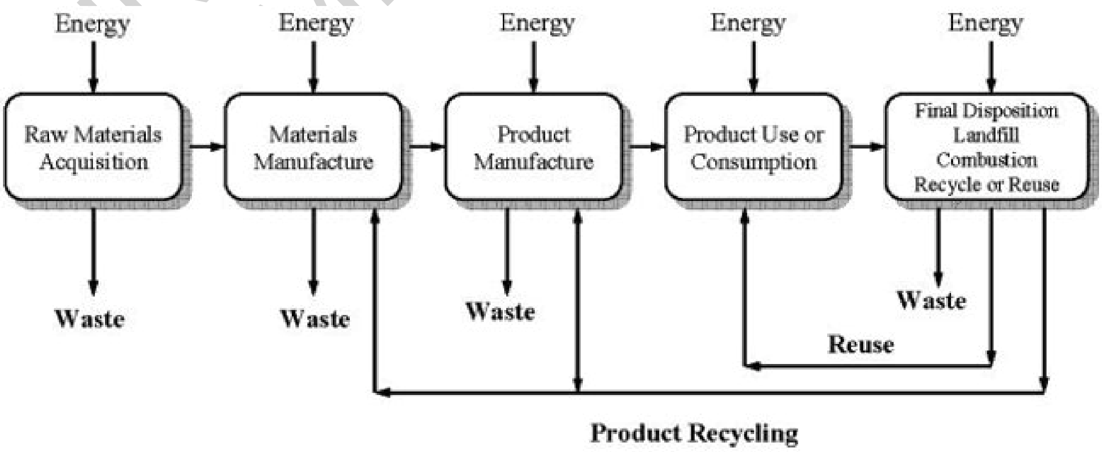

Figure 2 General materials flow for "cradle-to-grave" analysis of a product system

LCAs are used to evaluate the environmental impacts of products at every stage from material extraction to disposal of the used product. A unique feature of the life cycle assessment process is the investigation of a product or processes impacts from 'the cradle to the grave' (Harding, 2002). A life cycle assessment process looks specifically at the inputs, such as the raw materials and outputs, such as waste products (AS/ NZS ISO 14040, 1998). Currently, the applications of life cycle assessments are diverse and include waste management, policy making and strategic planning (Fatta and Moll, 2003) and could be used to evaluate different environmental loads with different technical resolutions (Lundin, *et a*l, 2000).

LCA could be determined by the input and output parameters that also recognize and clearly define functional system boundaries. There are some advantages and disadvantages associated with the use of life cycle assessments compared with other environmental tools. One advantage is the formal nature of the life cycle assessment, meaning that it is possible to come to a rational decision when trying to determine which alternative is environmentally better (Fatta and Moll, 2003). For instance, in determining which is environmentally better between wastewater treatment and ocean outfall a life cycle assessment could be used to find the best option. Life cycle assessment also has the ability to predict potential environmental impacts before they occur, which can assist decision makers.

The two major analyses of LCA are as follows:

2.1.1 Life Cycle Inventory Analysis

The general concept of inventory analysis is to complete list of all inputs and outputs that occur during a system process at each stage (Figure 3). This process quantifies the energy and raw materials that go into each stage, including transportation and outputs of products as well as all environmental releases (Ciambrone, 1997). The stages of LCA inventory are:

- Definition of system and system boundaries
- List of raw materials, their sources, energy involved in extraction, wastes and effluents produced
- Steps of processing the raw materials, stages involving combination of raw materials and manufacturing process
- Possibilities for recycling materials during processing and manufacture
- Accounting of energy and effluents from each of these steps
- Distribution and Transportation needed for the product to reach the consumer
- Energy used and material waste and effluents produced during use and maintenance
- Possibilities of reuse of whole product or parts
- Possibilities of recycling of materials and the energy expenditure and effluent production in the recycling process.

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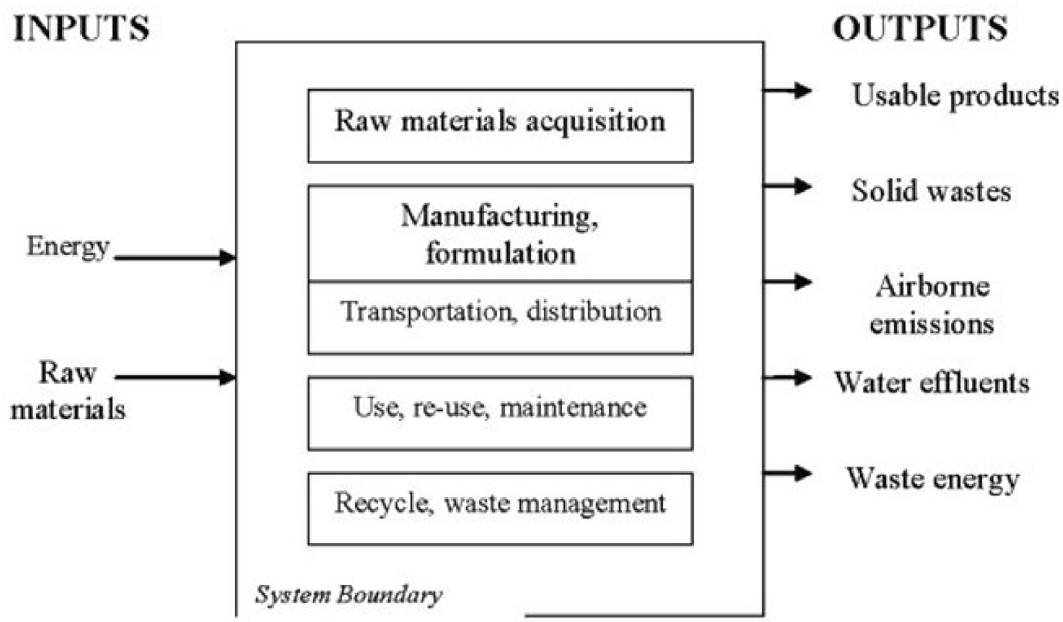

Figure 3. Life cycle inventory

2.1.2 Life Cycle Impact Analysis

After the inventory analysis is finalized, the next stage is to document the impacts. These analyses characterize the environmental loading and assess what ecological and human health impacts each loading would cause. In assessing impacts, it would be required to list and prioritise the impacts of concern such land loss, water pollution, global climate change, deforestation, and human or ecological health hazards etc. As well as the above limitations, there are also difficulties mainly related the large volume of data required and the time and cost associate with gathering it. Due to these problems, a full life cycle assessment is often considered to be an unfeasible option for smaller designers and manufactures (Yencken and Wilkinson, 2000).

Additionally, Life Cycle Improvement Analysis is another tool in LCA to systematically assess how the environmental loading and impacts could be reduced without losing the quality of the product (Frosh et al., 2003).

2.2 Material Flow Analysis

Material flow analyses are analytical environmental tools, which can be defined as ‘a systematic assessment of the flows and stocks of material within a system defined in space and time’ (Brunner and Rechberger, 2004). Material flow analysis has a long history, with the concept of material flow analysis dating back to the Greek philosophers 2000 years ago. Since then material flow analysis has been used in a range of fields including medicine, chemistry and economics, but it was first used as an environmental tool in the 1970’s. Material flow analysis differs from other environmental tools, such as the life cycle assessment, as material flow analysis only follows the flow of material for a set period of time, while the life cycle assessment follows the product from ‘cradle to grave’ (Barrett, 2001). In the context of recycled

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products, such as water, material flow analysis can be used to trace the product through the economy in order to determine the best recycling system in terms of economic sustainability (Yencken and Wilkinson, 2000).

Like other environmental tools, material flow analysis looks at inputs and outputs into a system. In general the input parameters are considered to be flows entering the system, while the output parameters are flows leaving the system. Using the example of a sewage treatment plant the main input can be seen as wastewater, while the main outputs included treated wastewater and sewage sludge, with other minor outputs such as off- gas and sediment (Brunner and Rechberger, 2004). The flows of wastewater and treated water are recorded as they enter and leave the plant, and the flow of sewage sludge is recorded by total volume removed from the treatment plant. The result of this is a material flow diagram similar to Figure 4.

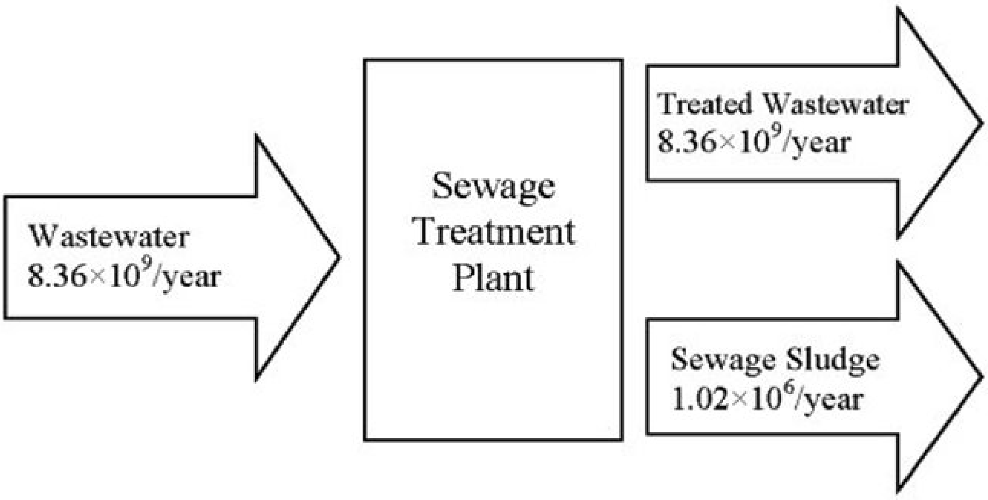

Figure 4 A simple material flow analysis for a sewage treatment plant

The most obvious benefit associated with material flow analysis is related to its ability to track of flows and stocks within a system. Without this understanding the process could be costly, in both time and money, as it would be difficult to focus on priority pathway, which can now be found by monitoring the flows. However, it needs to be kept in mind that when investigating the treatment of wastewater material flow analysis would probably look at the whole water cycle, instead of considering the sewage and water systems separately. Another benefit of material flow analysis is it can be used as a decision support tool, which is because it takes into account all the material flows within a system. An important benefit that material flow analysis has above other environmental tools is its transparency, as it details the input and output of the materials (Robèrt, et al, 2002).

A disadvantage of material flow analysis is that it is not alone an adequate environmental tool to measure or maintain engineering or management processes. This is because the interpretation of the material flow analysis is subjective, as it is based on political and social factors. Material flow analysis could be undertaken as a static assessment of the flows within a system. The information required to calculate the material flow analysis of a water recycling system is controlled by the inputs and

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outputs. In water recycling facilities the typical material input is wastewater and the typical output product is recycled water, as well as a by- product of sludge (Brunner and Rechberger, 2004).

One way to calculate the material flow analysis for a water recycling system is by using the ORWARE model. ORWARE or Organic Waste Research model is specifically designed to evaluate material flows in wastewater systems (Ramírez, et al, 2000).

This model in particular is considering waste management and recycling from a systems viewpoint. However, ORWARE is primarily used for research, rather than used by local authorities, as originally planned as it is not a user friendly model (Eriksson, et al, 2002).

Natural resources are materials that are found in nature in their basic form rather than being manufactured (e.g., water, minerals, petroleum and wood). Renewable (or flow) resources, which are those that can be regenerated, are typically biotic resources (e.g., forest products, other plants or animals) and water.

Nonrenewable (or stock) resources are abiotic, such as mineral ore or fossil fuels. Both of these natural resource impacts are calculated using the loading approach (University of Tennessee, 2002).

Renewable and nonrenewable resource consumption impacts use direct consumption values (i.e., material mass) from the inventory. Renewable resource impact scores are based on the following process inputs in the LCI: primary, ancillary, water, and fuel inputs of renewable materials.

The model considers waste management and recycling from a systems viewpoint. ORWARE model is primarily used for research purposes, rather than used by plant operators (Eriksson, *et al*, 2002).

According to principle of life cycle assessment; materials, products, production process and the generation of pollutants should be examined from the following perspective:

- *toxicity* -- we should not use the materials which are harmful to environment.
- *ecology influence* -- we should aim to increase the ecological efficiency
- *the character of regeneration* -- we should use the materials which are regenerative.
- *the intensity of energy* -- we should aim to use the material which are lower intensity of energy including the consumption of energy in the obtaining these energy materials.
- *reusability* -- we should aim to use the material which can be reused.
- *increase life of products* – we should aim to use products over longer period of time
- *pollutant generation* - *w*e should consider the total quantity of wastewater generation, because it can reflect the level of management and technology. We must also consider the concentration of the wastewater, so the target of wastewater generation made up of the quantity of wastewater generation and the main pollutants in water to produce one product (Gao, 2006).

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Biographical Sketches

Mr. Andrzej Listowski is the Senior Manager, Water and Energy with Sydney Olympic Park Authority. He is responsible for design, development, implementation and operation of the Water Reclamation and Management Scheme (WRAMS), the first integrated urban water recycling scheme in Australia and one of the first in the world. He is also responsible for selection; undertaking and management of number of scientific research projects associated with treatment processes for recycled water, plant operations efficiency and recycled water quality. The most recent study include: (i) hollow fibre membrane, (ii) autopsy study involving characteristics of MF operational environment, water quantity and quality, identification of causes of MF fouling; (iii) use of recycled water i.e. laundry washing, playing fields irrigation, ornamental fountains, air-conditioning cooling towers etc. He was also involved in a wide range of recycled water research and investigations across Australia and overseas including collaboration with Prime Minister Science, Engineering and Innovation Council and Aquarec project for the European Commission under the 5th Framework Program.

Dr. Huu Hao Ngo is an academic and senior environmental research engineer with more than twenty five years' professional experience in Australia and in Asian countries. He is now working as Associate Professor of Environmental Engineering and Manager, in-charge of Environmental Engineering R & D Laboratory, School of Civil and Environmental Engineering at University of Technology, Sydney (UTS). He is also serving as a core member (Team Leader of advanced water and wastewater treatment materials based technology group and Project Investigation of membrane based technology in the theme of Urban Water Management) of the Institute of Water and Environmental Resource Management at UTS. Assoc. Prof. Ngo is internationally known for his activities in the development of innovative water, wastewater treatment and recycling technologies, and is a recognized authority on the flocculation and filtration process, biofiltration and membrane hybrid technology. He has been involved in more than 50 research projects and published more than 200 technical papers including two books and several book chapters. He is also a reviewer for more than 20 international journals.

Dr. Wenshan Guo is working as UTS Chancellor's Postdoctoral Research Fellow and her research focus is on the innovative water and wastewater treatment and reuse technologies. Her expertise and practical experience cover the areas of water and wastewater engineering such as membrane technologies (e.g. membrane bioreactor, microfiltration, membrane hybrid system, and PAC-submerged membrane bioreactor etc.), advanced biological wastewater treatment technologies (e.g. suspended growth reactors and attached growth reactors), and physical/chemical separation technologies as pre-treatment or post-treatment (e.g. adsorption, column, and flocculation). She also has strong ability to work in solid waste management, life cycle assessment, and desalination.

Dr S. Vigneswaran has been working on water and wastewater treatment and reuse related research since 1976. During the last twenty years, he has made significant contributions in physico-chemical water treatment related processes such as filtration, flocculation, membrane-filtration and adsorption. His research activities both on new processes development and mathematical modelling are well documented in reputed international journals such as Water Research, American Institute of Chemical Engineers Journal, Chemical Engineering Science, Journal of American Society of Civil Engineers, and Journal of Membrane Science. He has also been involved in a number of consulting activities in this field in Australia, Indonesia, France, Korea, and Thailand through various national and international agencies. He has authored two books in this field at the invitation of CRC press, USA, and has published more than

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230 papers in journals and conference's proceedings. Currently a Professor of the Environmental Engineering Group at the University of Technology, Sydney, he was the founding Head of and the founding Co-ordinator of the University Key Research Strength Program in Water and Waste Management. He is coordinating the Urban Water Cycle and Water and Environmental Management of the newly established Research Institutes on Water and Environmental Resources Management and Nano-scale Technology respectively.

Dr. Carolyn Gay Palmer is working as Professor and Director of Institute of Water and Environmental Resource and Management (IWERM), University of Technology, Sydney**.** The most significant contributions to her research fields are Ecotoxicology/Environmental Water Quality and Water Resource Management. She was also the leader of the team that developed the methods for environmental water quality assessments as part of the Reserve process – which prescribes the water available for allocation to water users in South Africa. Prof. Palmer has published more than 30 papers, 3 book chapters, 2 handbooks and over 20 peer-refereed reports. Prof Palmer played an important role in developing the new Water Law in South Africa and she was awarded the Silver Medal of the South African Society of Aquatic Scientists and the Women in Water Award from the Minister of Water Affairs and Forestry.

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