Material Flow Analysis: An Integrated Tool for Stormwater Runoff Management (A Case Study of Copper in stormwater runoff)

Analyse de débit de matière : un outil intégré pour la gestion de l'écoulement d'eau de pluie (l'exemple du cuivre présent dans l'écoulement d'eau de pluie)

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RESUME

L'analyse du flux de cuivre issu de l'écoulement d'eau de pluie dans le bassin versant de la rivière Parramatta est effectuée pour démontrer l'importance de la pollution due aux eaux de pluie. Les principales origines du cuivre dans ce genre d'écoulement sont liées à la circulation automobile et à l'utilisation de fertilisants à base de cuivre. Un système de traitement d'eau de pluie a été modélisé a partir de travaux expérimentaux pour évaluer l'efficacité du compost comme agent d'abattement. Les résultats indiquent que ce traitement peut éliminer le cuivre de l'eau de précipitation et ainsi protéger les eaux de rivière de possible contamination. Cette analyse effectuée dans le bassin versant permet de valider l'utilisation de ce traitement pour diminuer le flux de cuivre à travers l'anthroposphère jusqu'au milieu récepteur, et en particulier la rivière Parramatta.

ABSTRACT

Material Flow Analysis (MFA) of copper associated with the stormwater runoff pathway in the Upper Parramatta River Catchment is evaluated to show the significance of stormwater pollution, a non-point source, in the contamination of the River. The major sources of copper in this pathway are traffic and copper trace element application. A stormwater treatment system is modelled from experimental work to demonstrate the performance of compost, for copper removal. The results indicate that stormwater treatment has the potential to remove copper and protect the receiving water from contamination. The MFA of copper in the catchment enables this treatment to be seen in the context of the total flow of copper through the anthroposphere to the receiving environment, particularly the Parramatta River.

KEYWORDS

Compost, Copper, Material Flow Analysis, SIMBOX, Stormwater.

1 INTRODUCTION

Stormwater quality can have considerable impact on receiving water bodies. In the water cycle, the amount of precipitation diverted into stormwater runoff depends on the type of surface. With urban growth and associated impervious surfaces, urban stormwater represents a significant component of precipitation, constituting a significant underutilised resource at this time, while also potentially impacting adversely on the water quality and ecology of regional receiving waterways. Advances in wastewater treatment technologies, and the economies of scale available in point source based treatment, have resulted in the non-point source discharges now representing the major source of pollutants impacting on the health of streams and their environmental and human use values. However, in older urban areas a proportion of these pollutants may originate from traditional sources such as industry and the sewerage system[1], but their delivery to receiving waters is now via the stormwater system in the form of illegal stormwater connections and resulting overflows during wet weather. Wash-off from catchment surfaces represents the remainder of the diffuse pollutant sources.

Heavy metals in stormwater affect aquatic organisms in receiving waters (Makepeace *et al*., 1995 and Largos, 1997), and the soluble form which is not removed by traditional inert media filtration treatment systems, is the most toxic. Compost from recycled organic materials derived from waste can be employed in stormwater treatment because of its ability to remove dissolved heavy metals and retain particulate contaminants (Seelsaen *et al*., 2006). Material Flow Analysis (MFA), or Substance Flow Analysis (SFA), originally developed by Baccini and Brunner (1991) is an analytical tool that can be used in regional environmental management. It can provide a holistic picture of physical flows of resource use and loss through a given region in a specific year, and examines all material/substance inflows, outflows, and stocks through each process in the economy. It has been extensively applied for numerous cases (Brunner and Rechberger, 2004), and the results can be used for policy development and analysis.

SIMBOX is a computer program used for modelling and simulation of Material/Substance Flows in environmental management. The program has been developed at the Swiss Federal Institute for Environmental Science and Technology (EAWAG), Zürich, Switzerland. The concept, methodology and mathematical expression for the modelling and simulation included in SIMBOX have been described in detail in Baccini and Bader (1996).

In this paper, a stationary model of SIMBOX for evaluating the Substance Flow Analysis (SFA) is applied to a case study of copper associated with stormwater runoff in an urban catchment. This shows the significance of sources of copper in goods in different economic processes, which lead to emission to the stormwater. Compost derived from garden waste, itself containing copper from the use of copper goods, will be used as an alternative stormwater filtration medium.

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[1] Sydney has a separate sewerage system for sewage, and stormwater pipe/drain system for rainwater runoff.

2 CASE STUDY DESCRIPTION

Substance Flow Analysis of copper, with an emphasis on the stormwater runoff pathway in the Upper Parramatta River Catchment, Sydney, Australia has been conducted as a case study.

The location of the Upper Parramatta River catchment in relation to the Sydney region is shown in Figure 1. The catchment's area of 9,317 ha includes the suburbs of Bulkham Hills Shire (36%), Parramatta (23%), Blacktown (22%) and Holroyd (19%). The resident population of the catchment is 220,500 with approximately 80,000 properties.

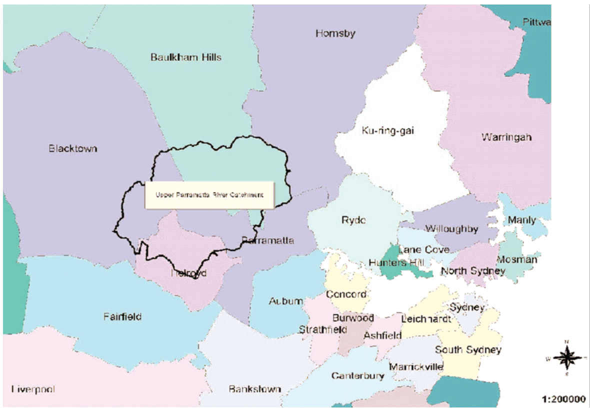

Figure 1: Regional context of The Upper Parramatta River Catchment (Upper Parramatta River Stormwater Management Plan, 2002)

The catchment is a part of Sydney Harbour and Parramatta River Catchment. It drains into the tidal estuaries of the Parramatta River, and eventually into Port Jackson estuary (Sydney Harbour) and the Tasman Sea as shown in Figure 2.

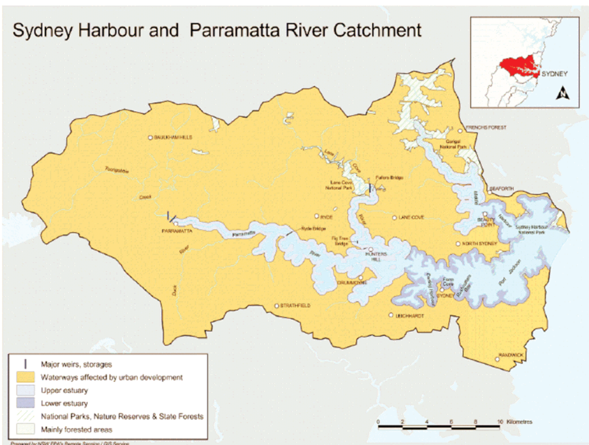

Figure 2 The regional context of Sydney Harbour and Parramatta River Catchment (http://www.environment.nsw.gov.au)

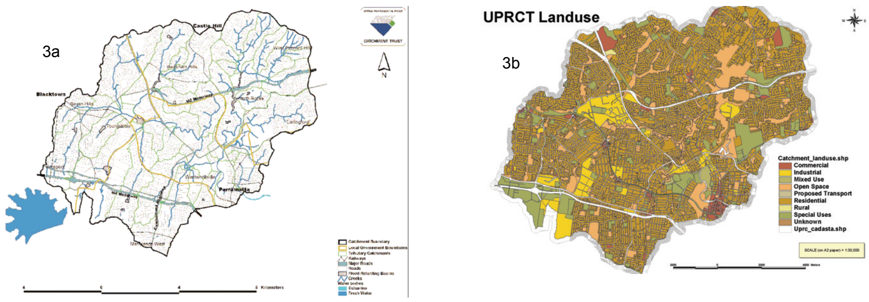

Figure 3a and 3b The Upper Parramatta River Catchment
(Upper Parramatta River Stormwater Management Plan, 2002)

From Figure 3a, the main waterways in the catchment are the Parramatta River, and its tributaries Toongabbie Creek and Darling Mills Creek. The Toongabbie Creek and its tributaries drain the southwest area of the catchment. The Darling Mills Creek sub-catchment is located in the northeast section of the catchment, with the majority of the creeks remaining in a natural or semi-natural state. The downstream boundary of the catchment is a weir located in the Parramatta River at the end of Charles St., Parramatta. Figure 3b demonstrates that the majority of land use within the catchment is urban (94%); 72% being residential, 10% commercial and industrial zoning, and 12% infrastructure 5% of the catchment is open space and bushland, and the remaining 1% is zoned rural. Major transport corridors cross the catchment including the M2 and M4 motorways, the Great Western Highway, James Ruse Drive, Cumberland Highway and Windsor Road. Industrial areas are located at Seven Hills, Girraween and North Rocks.

The main pollutant sources in the outflow from the catchment to the Parramatta River are diffuse pollution from stormwater and sewage overflows discharging into the upper parts of many harbour embayments locating as shown in Figure 4a (Birch and Taylor, 1999). This suggested that stormwater and atmospheric deposition were major sources of heavy metals to Port Jackson estuary. Figure 4b show possible sources of heavy metals. This study reported heavy metals inventories in the Port Jackson area, where copper was 1900 tonnes.

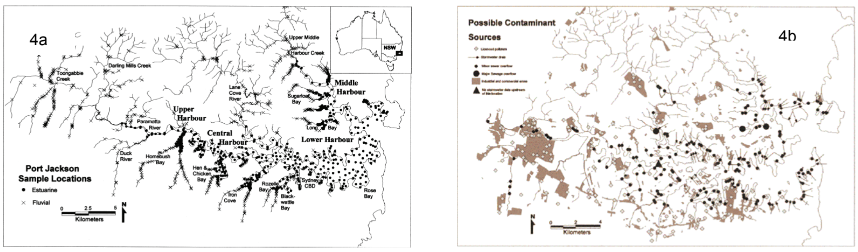

Figure 4a and 4b The Sydney Harbour catchment and possible sources of heavy metals to the waterway (Birch and Taylor, 1999).

Specific investigations in the Upper Parramatta River Catchment carried out by Birch (undated) on fluvial sediments, indicated high levels of contamination of zinc, lead, and copper adjacent to industrial areas (Figure 4b), with the highest levels adjacent to the Seven Hills and Girraween industrial areas. Organochlorine pesticide concentrations closely followed the trends seen with heavy metals near the industrial areas. Pendle Creek and Finlaysons Creek also contained high levels of heavy metals.

The original diversity of aquatic flora and fauna has been reduced significantly as a result of urbanisation in the catchment. The aquatic flora is freshwater macrophytes and phytoplankton (floating algae). Native fish that occur, or are expected to occur in the catchment, are recreational fish and other large species such as Australian Bass (*Macquaria novemaculeata*), Freshwater Mullet (*Myxus petardi*), Long-finned Eel (*Anguilla reinhardtii*), and Striped Mullet (*Mugil cephalis*).Small species include Common Jollytails (*Galaxias maculatus*), Striped Gudgeon (*Gobiomorphus australis*), Empire Gudgeon (*Hypseleotris compressa*), Australian Smelt (*Retropinna semoni*), Flathead Gudgeon (*Philypnodon grandiceps*), and Cox's Gudgeon (*Gobiomorphus coxii*). Alien species that are found in the catchment are European Carp (*Cyprinus carpio*), Goldfish (*Carassius auratus*) and Mosquitofish (*Gambusia holbrooki*).

3 METHODOLOGY

This study of copper flow in the Upper Parramatta River Catchment in the year of 2004/2005 used the Substance Flow Analysis (SFA) method (Baccini and Brunner, 1991). SFA modelling and SIMBOX (a stationary Input-Output MFA-Model) were applied to model the flow of copper within the system boundary. The calculation of copper flows based on area, amount of rainfall, and concentration of copper in goods.

Australian web-based searchable databases provided most of the data, as follows: the Upper Parramatta River Catchment Trust (http://www.uprct.nsw.gov.au); the Catchment Authority (http://www.catchment.crc.org.au); Australian Runoff Quality (ARQ), Cooperative Research Council of Catchment Hydrology (CRCCH), the Bureau of Meteorology (http://www.bom.gov.au); Department of Environment and Heritage (http://www.deh.gov.au); Department of Local Government (http://www.dlg.gov.au) and National Pollutant Inventory (http://www.npi.gov.au). Published papers also provided data in order to calculate the copper flow in the system. References from the US and Europe were used where Australian data was missing. Key Australian and overseas references were Hewitt and Rashed (1990), Duncan (1995), Chiew et al. (1997), Boller (1997), Boulay and Edwards (2000), Sansalone (2001), and Duncan (2005). Interviews with Sydney Water and home hardware stores also provided realistic data for the use of some goods containing copper such as root killer which can affect stormwater runoff quality.

4 RESULTS AND DISCUSSIONS

In the system boundary, processes were classified according to landuse categories (Figure 3b). Major goods containing copper and affecting the stormwater pathway are rainfall, fertiliser, copper trace element, root killer, water supply, and brake pad wearing from traffic. SIMBOX model ran a stationary Input-Output MFA-Model for the basic scenario to illustrate the overall copper load in stormwater runoff from the catchment, as shown the diagram in Figure 5.

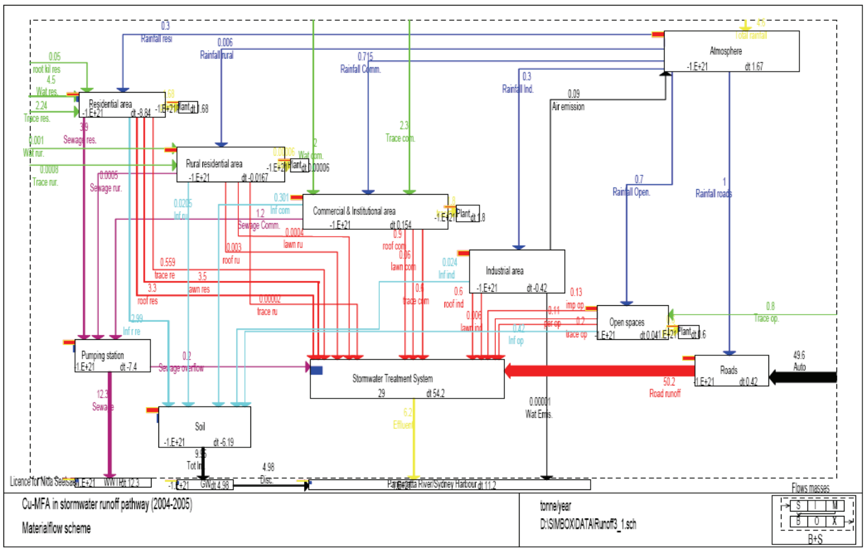

Figure 5 Cu-MFA in stormwater runoff pathway (2004-2005)

From Figure 5, the thickness of the arrows indicate the major copper good causing the copper flows was traffic, mainly from the M2 and M4 highways. Impervious runoff, such as roof runoff, and sewage overflows containing dissolved copper from pumping station and pipe corrosion are considered as sources of copper. The roads are the main source of copper into stormwater pathway, arising from the use of fuel where copper is an additive (http://www.npi.gov.au), and from engine oil and break pads (Sansalone, 2001 and Hewitt and Rashed, 1990). Copper in trace elements is another significant source applied in agriculture, gardening and backyard cropping. For plants, copper plays an important role in their metabolic processes, and copper sulphate is added to heavily leached Australian soils to overcome copper deficiency in crops (http://www.incitecpivot.com.au). The total flow of copper in stormwater runoff is 61 tonnes/year which is considerably high compared to copper load in the effluent from the North Head Primary Sewage Treatment Plant (13 tonnes/year, http://www.npi.gov.au).

The small red/blue boxes adjacent to the processes represent depletion/accumulation of copper in the process. Most of the processes have only stock depletion according to this model based on a one year period, whereas compost in the stormwater treatment system has an increasing copper stock. These components also illustrate the stock changing rate per year, which can be used to design the stormwater treatment system.

From our previous studies, compost from source-separated garden organics contains a low 51 - 57 mg Cu/kg compost (dry matter) which is lower than that of the compost criteria for unrestricted use, 100 mg Cu/kg dry matter (Standard Australia, 1999). Compost from mechanical biological treatment of residual waste to disposal contains 150 - 230 mg Cu/kg compost (dry matter). This is 3 – 4 times that of source separated garden waste compost and is also greater than that of natural soil

(2 – 100 mg Cu/kg dry matter) (http://www.ephc.gov.au). However, it is still less than the maximum level of copper allowed in manure and fertiliser (400 mg Cu/kg dry matter) (http://www.deh.gov.au). Leaching of this copper with deionised water having a similar pH to rainwater was shown to be only 10% of total copper. The garden compost used as a filtration medium in experimental columns for stormwater treatment, has the capability to remove dissolved copper up to 1330 g Cu/kg compost (dry matter). In addition, compost and sand are able to retain copper bound on particulate matter; so that the removal efficiency of the treatment of 90% of the total copper in stormwater can be achieved.

5 CONCLUSIONS

Copper in stormwater runoff can potentially have an adverse impact on aquatic organisms in the receiving water of the Sydney Harbour. Stormwater treatment using compost combined with inert material, such as sand, can remove the majority of dissolved and particulate copper in stormwater. Policy planners can make use of this diagram with prioritisation on source control. The overall load of copper from stormwater runoff was compared to other waste streams (sewage sludge from the sewage treatment plant) to demonstrate the significance of stormwater runoff, confirming it as a major source of pollutant.

Design guidelines for stormwater treatment using compost/inert media filter are now being developed from the experimental performance data referred to above. SIMBOX modelling and MFA provide the overview for the proper design period and capacity of a stormwater treatment system in the catchment. Treatment and disposal of the spent filtration media from both garden compost and residual waste to disposal compost, is now being investigated, with the aim of preventing the copper going to an environmental sink that may have detrimental impacts. Ideally, the copper should be recovered and returned to economic goods to further conserve the non-renewable resource of copper ores.

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