STORM WATER: POLLUTANT CHARACTERISATION AND TREATMENT PRACTICES

D.Ekanayake
Dept of Civil and Environmental Engineering
University of Technolohy Sydney
Sydney, Australia

P. Loganathan
Dept of Civil and Environmental Engineering
University of Technolohy Sydney
Sydney, Australia
Paripurnanda.Loganathan@uts.edu.au

Jaya Kandasamy
Dept of Civil and Environmental Engineering
University of Technolohy Sydney
Sydney, Australia
Jaya.Kandasamy@uts.edu.au line

Saravanamuthu Vigneswaran
Dept of Civil and Environmental Engineering
University of Technolohy Sydney
Sydney, Australia
Saravanamuth.Vigneswaran@uts.edu.au

***Abstract*— Stormwater quantity and quality can vary widely depending on the landscape of the area and amount and intensity of precipitation. Stormwater is a good source of water which can reduce the demand on potable water supply. Treated stormwater can also be employed for non-potable uses which account more than 40% of household domestic water demand. Wetlands, bio-retention, and permeable pavements are widely used in stormwater management. Current bio-retention systems used in Australia for stormwater pollution control seldom provide the water quality necessary for water recycling due to their varies removal efficiency for a range of inflow conditions and pollutants. Stormwater discharge in certain periods is relatively large, and therefore, it needs to be treated intensively at high rates. There is a large gap of research data available on improving bio-retention media for effective stormwater treatment.**

Keywords—Stormwater, characterization, treatment

I.INTRODUCTION

Stormwater originates from precipitation such as rain, hail, and snow. Stormwater quantity and quality can vary widely depending on the landscape of the area and amount and intensity of precipitation. When precipitation occurs through natural landscapes, majority of the precipitation is absorbed into the soil, whereas in an urban landscape, stormwater falls mostly onto impervious surfaces such as roads, sidewalks, rooftops, or parking lots and is not soaked up by the ground. Because of this, the falling water is swept across these surfaces as runoff to the nearby water bodies. As a result, stormwater transport large quantity of pollutants and nutrients from the land to the surface water bodies in the neighboring surroundings. When stormwater drains too much water at once, it can cause landslides and localized flooding due to erosion and sedimentation.

Stormwater is also an important water-reuse resource as the demand for water grows with the increase of human population and industries, particularly in arid and drought-prone climates. The runoff in Australian cities generally exceeds the volume of water that the cities draw from their catchments and groundwater sources, which is estimated to an annual total of 2100 gigalitres, when the annual Australia's urban areas produce around 3000 gigalitres of average annual runoff (Commonwealth of Australia 2015). Fig. 1 shows that each city has a high potential on saving the potable water resource by investing on stormwater harvesting. Stormwater harvesting techniques and purification could potentially make some urban environments self-sustaining in terms of water requirement.

ISBN: 978-624-6150-05-1

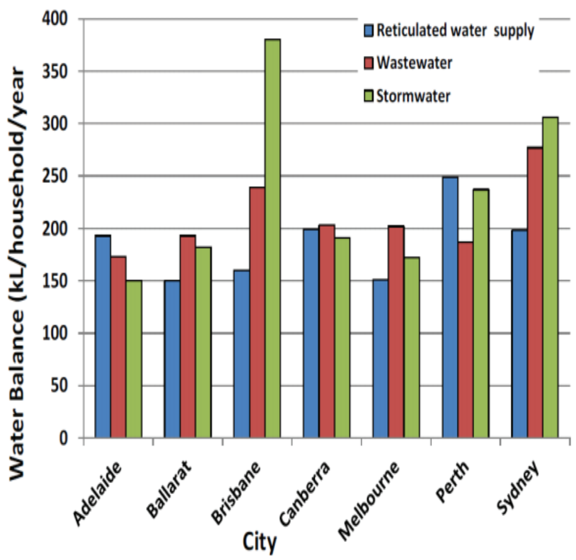

Fig. 1. Average annual water balances from households in various Australian cities (Commonwealth of Australia 2015)

In Australia, within cities, only about 4% of rainwater and stormwater is recycled, while less than 1% of reclaimed wastewater is reused within urban areas (Dillon & Ellis 2004). The average annual volume of urban stormwater runoff in Australian cities is almost equal to the average annual urban water usage, of which at least 50% is for non-potable use. Stormwater is the best source for reuse when compared to grey water and industrial waste water (Mitchell, Mein & McMahon 2002).

In Australia, most of the recycled urban stormwater is used for field irrigation such as watering of public parks, gardens, and ovals. Even though the recycling of stormwater is still not fully functioning in Australia, several investigations suggested that recycled stormwater is one of the economical options for potable water and this would also successfully help to reduce the environment damage from stormwater. Hence, there is a demand for developing techniques for the collection, treatment, and storage of stormwater. Existing stormwater recycling practices are not efficient, and novel compared to those practiced in recycling other water resources.

Stormwater is a good source of water which can reduce the demand on potable water supply. Treated stormwater can also be employed for non-potable uses which account more than 40% of household domestic water demand. Stormwater treatment can be less expensive and more acceptable to the public compared with wastewater recycling. Treated stormwater can be used for agricultural irrigation, toilet flushing, gardening, car washing, and for residential purposes. It can also be used to irrigate public places such as golf courses and gardens and for aesthetic purposes. Stormwater harvesting and reuse is somewhat a novel technique but popular among local governments. However, there are potential limitations of stormwater harvesting because the process totally depends on climatic changes and rainfall patterns, and relative cost of stormwater treatment, although these do not hamper the multiple benefits of stormwater.

I. CHARACTERISATION OF STORMWATER

Stormwater runoff gets polluted from non-point and point sources. Point sources are easy to detect and control such as illegal spilling from industries and mining. Non-point sources are identified as one of the major causative agent for the stormwater deterioration. Due to the complex nature of the non-point sources such as atmospheric deposition, road dust and soil erosion, stormwater is difficult to characterise and quantify. Increased industrialization and rapid urbanisation create more impervious areas contributing to nonpoint sources. Pollution load of stormwater depends on land use pattern, geography, and the atmospheric depositions in the catchment area.

There are many organic and inorganic pollutants in urban stormwater (Hvitved-Jacobsen, Vollertsen & Nielsen 2010). The major categories of these pollutants are: (i) total suspended solids (TSS), (ii) heavy metals, (iii) micro pollutants such as polycyclic aromatic hydrocarbons (PAHs), (iv) nutrients (v) oxygen demanding substances and pathogens. Heavy metals such as lead (Pb), mercury, cadmium (Cd) and metalloids such as arsenic (As) are in the top six hazardous chemicals listed by a US agency for toxic substances and disease registry (ATSDR 2014). These contaminants go through various physico-chemical processes before they impact on the aquatic community.

Fine particles are often carried as suspended materials by stormwater runoff. The total load of these suspended materials is called total suspended solids (TSS). There are many sources of TSS in stormwater such as soil erosion, siltation, sewer outflow systems, dust particles and asphalt etc. As a result of increased impervious areas, TSS load in the stormwater can be increased and receiving water becomes more turbid and poorer in quality.

ISBN: 978-624-6150-05-1

Excessive TSS levels present in the water bodies can hinder the growth of aquatic plants and animals. On the other hand, other pollutants such as metals and organic pollutants are bonded to these particles and get transported along with the runoff and settle in the river bottoms which is a serious environmental concern (Nguyen et al. 2014). Hence reducing the contents of particles in stormwater is an important part of the stormwater management. TSS in stormwater can be reduced by infiltration, filtration and detention facilities. Most of these structural techniques are effective in removing TSS from stormwater (Smirnova 2011).

II. Current stormwater treatment practices in Australia

Fig. 2. presents the typically used treatment methods in stormwater pollution control in Australia. Of these methods, advanced treatments (23%) are the most popular with litter and sediments traps (21%) and infiltration systems (20%) taking the second and third places, respectively. Usually litter and sediments traps are installed at the beginning of the treatment train and advanced treatments are at the end of the treatment train.

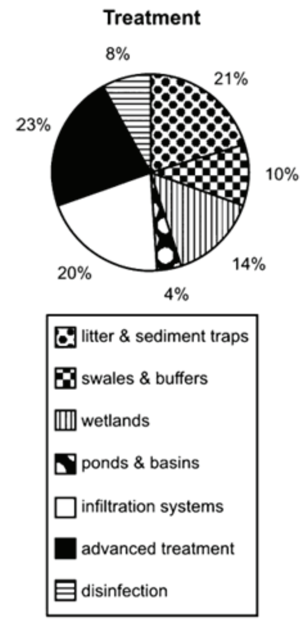

Fig. 2. Distribution of stormwater treatment methods used in Australia (adopted from (Hatt, Deletic & Fletcher 2006)

A. *Infiltration methods*

Infiltration systems are porous and permeable pavements, infiltration basins and trenches, sand filters and biologically engineered soils which can be accompanied by certain types of plant species. In this method, stormwater infiltrates through the pavement surface and there is a temporarily storage of water in the pavement structure before it follows by further infiltration methods to underlying soils or is removed by a subsurface drain. In this process, pollutants get trapped and filtered in the structure and runoff volume gets reduced. Streets runoff and run off from parking areas can be infiltrated and penetrated through the soil to accumulate into groundwater recharge. Sand filtration is another popular method and effective in removing suspended solids, nutrients, pathogens, oil and grease from urban runoff (Kandasamy, Beecham & Dunphy 2008).

B. *Biofilters*

Biofilters normally composed of vegetated soil filter medium and contains a porous collection pipe to transport treated water for end use. Best example of a biofilter is wetland which utilise physical and biological process simultaneously. This method is much popular in Australia and many researchers have worked on evaluating the adoptability, functionality and the enhancement of the process. They have used different types of bio filter for their experiments. According to their findings, total P (TP), suspended solids and heavy metals were removed effectively by gravel bio filters but not total nitrogen (TN). Read et al. (2008) reported that certain plant species can be used to enhance the performances and significantly improve the removal of TN and TP. A column study conducted by Bratieres et al. (2008) in Melbourne, Australia showed that up to 70% nitrogen, 85% phosphorus, and >95% suspended solids was removed from stormwater by biofilters.

Constructed wetlands are widely used to recover urban stormwater runoffs and as a tertiary treatment for industrial wastewater (Deletic et al. 2014). Wetlands are more attractive due its passive operation and creating more habitats by enhancing the ecological balance and aesthetic values within the urban landscapes. However, wetlands for stormwater remediation require a large open-spaces which is extremely limited in urban areas. Also, continuous base flow or a high water table to support vegetation is difficult to achieve in dry seasons (Headley & Tanner 2012).

Wetland systems with horizontal subsurface flow are commonly used for wastewater treatments. Applications of wetlands are limited for stormwater treatment whenever there are high flow

ISBN: 978-624-6150-05-1

velocities which causes hydraulic limitations of the substrate. Another limitation is that the vegetation in the constructed wetlands can tolerate only relatively shallow water depths of 30-50 cm and are susceptible to chronic die-back if inundated beyond these depths too frequently or for extensive periods (Jenkins & Greenway 2007).

C. Bio-retention system

A bio-retention system is usually composed of several layers of filter media, certain types of plants in the top layers, and an over- flow outlet. Bio-retention systems are designed based on the natural hydrologic cycle by retaining runoff to decrease flow rates and volumes. Bio-retention systems help to enhance the aesthetic value of the area by preserving habitat for prevention of soil erosion and also support groundwater recharge by enhancing the quality of surface water flows. Vegetation planted in the top layer of the bio-retention system uptake water and nutrients from the media. Once the media is saturated mainly by particles of incoming water the performance of the system will get drastically reduced. When this happen, the incoming water will overflow from the system.

Main constituents of the bio-retention media are sand, soil, and organic mixture. Water professionals prefer to add gravels or mulch to the top layer, grow various species of vegetation which are easy to maintain as well as capable of taking up some nutrients and pollutants from the incoming water. Vegetation layer helps to slow down the infiltration velocity of water which allows sufficient time for the chemical, biological, and physical processes in the water to take place and withdraw pollutants from the influent water. Because of a bioretention system, peak flows of the urban stormwater runoff, as well as the volume, and pollutant loads, are reduced. Media depth is an important parameter of a bio retention system which determines its hydrologic performances.

Removal of nitrogen species in bio-retention system includes several processes such as ammonification, volatilization, nitrification, denitrification, and vegetative uptake (Liu et al. 2014). Breaking organic N compounds into ammonium is known as ammonification and ammonia can be released from the ammonium as a gas which is known as volatilization (Liu et al. 2014). Certain bacteria are capable of oxidising ammonium to nitrite and nitrate species (NO_2^- and NO_3^-) by a process called nitrification (Hunt et al. 2008). These nitrogen species are removed from the system mostly by plant uptake. Hunt et al. (2015) conducted a field investigation and discovered high annual NO_3^- mass removal rates by plants varying between 13% and 75%.

As in the case of N species, there are several processes operate to remove P species from the bio-retention system such as precipitation, adsorption, filtration, and vegetation uptake. P ions can be adsorbed readily by many soil constituents through the process of ion exchange or ligand exchange. P removal by adsorption process is one of the important process of bio-retention media. Most of the soluble P forms can be removed by plant uptake. Soil temperature and soil pH are important influential factors in this process.

Heavy metals are one of the pollutants which draw much attention due to its persistence and toxicity. Studies have stressed that the surface vegetative layer is a major contributor to removal of heavy metals from the incoming waters. Field and laboratory scale experiments have proved that bio-retention media are capable of removing certain types of metals from the stormwater by adsorption process (Hatt, Deletic & Fletcher 2006).

Solid particles in the stormwater are important pollutant as it can contribute to the shelf life of the bio-retention system. Clogging of the media can greatly reduce the infiltration velocity and finally the system can become inefficient due to reduced hydraulic flow through the system. However, total suspended solids can be easily trapped by the top vegetation as well as the media. A study conducted at Maryland, USA has shown 54 - 59% mass removals of TSS in a bio-retention system. Aged bioretention can hold more particles hence filtration and sedimentation of TSS results in improved TSS removal efficacy (Liu et al. 2014).

To study the significance of first flush Stormwater runoff, samples were collected during 16 rainfall events covering three years (2016-2018) from the Blacktown International Sports park, Sydney and analysed for water quality with an aim to identify the relationships among the measured pollutants and the method to quantify the first flush runoff volume. Mostly all events showed a first flush effect irrespective of the preceding dry weather period. This indicates that the first flush after a dry period carried the dissolved constituents, which had accumulated during the dry period, with the stormwater and increased the pollutant concentration (Ekanayake et al. 2019).

The UV spectroscopy measurements on the stormwater samples revealed changes in the spectrum over time during runoff.

Another study was conducted at the Ku-ring-gai city council area of Sydney where stormwater was collected from 15 sites including roads, parks, subsoil drains, hard surfaces, and roof tops of shops. The collected water was subjected to various treatments before they are used for irrigation of agricultural lands, landscaped areas, and green roof, or flushing public toilets. The treatments were:

- Gross pollutant litter basket, Sand filter
- Gross pollutant trap, stormwater storage dam on golf course
- Biofilter alone
- Bio filter/sand filter + subsurface drainage from the field
- Disc filters, UV disinfection
- Runoff from hard surfaces + subsoil drainage from the field
- Gross pollutant traps + wetland and sub soil drainage from the field
- Gross pollutant litter separation, bio filter, UV disinfection

The quality of the treated stormwaters was assessed by analysing water samples collected eight times during 2015-2017. Concentrations of pollutants that can affect crops when stormwater is used for short-term (up to 20 years) and long-term irrigation (20-100 years) were used to evaluate the quality of the treated stormwater. The concentration of pollutants at all sampling sites for all sampling dates were lower than the limits for short-term irrigation. In the case of long-term irrigation scenario, at few sites, for some sampling dates, some pollutants exceeded the safety limits. For example, of the heavy metals tested, Cu exceeded the safety limit at one site where the stormwater was collected from roofs of shops (Cu might have originated from the roof materials containing these metals), whereas Cr, Pb, Ni, and Zn were much below the safety level. Fe concentration was higher than the safety level for long-term irrigation at many sites. The electrical conductivity of treated stormwater from the site with only Disc filters/UV disinfection treatment was very high (500-1700 μS/cm) and therefore the water was not suitable for irrigating salt-sensitive crops. Biofilters or wetlands used in other sites can be implemented to reduce the excess salts at this site.

III. Conclusions

Stormwater quantity and quality can vary widely depending on the landscape of the area and amount and intensity of precipitation. Untreated stormwater runoff can cause environmental pollution from the many pollutants it carries from the land surfaces. Australia suffers severely from water scarcity. According to the current urban water demand, alternative sources of water are required to reduce the pressure on existing potable water sources. As stormwater harvesting in urban environment is a relatively new strategy for supplying water, treatment techniques have so far been based on either stormwater treatment for environmental protection, or on treatments designed for conventional water supply or industrial applications. The quantification of the pollutants is necessary for stormwater harvesting and reuse as well as to design treatment systems.

In wet weather events, most of the pollutants are washed off during an early stage (of runoff) giving rise to the first flush phenomena. Being high in pollutants concentration, this stage often carries a large proportion of pollutants load for that event. Identifying the first flush and characterising pollutants in it is a key priority in terms of pollution control and management. There are number of pollutants of concern in the first flush due to its association with human and environmental health associated risks. The most commonly concerned pollutants are conductivity, turbidity, suspended solids, heavy metals, sodium, nitrate, and phosphate. Because the pollutants co-exist in nature, they may play a synergistic or an antagonistic role on the health of humans and aquatic organisms. These interactions may also have impact on their remediation. The limitation on knowledge and understanding of the pollutants is due to its complexity and to their dynamic inter relationships during wash-off. Understanding the relationships between the concentrations of pollutants and developing onsite testing are vital for the management of stormwater runoff.

Dissolved organic matter (DOM) is one of the key parameters determining stormwater quality. It can also be used as an indicator parameter for other pollutants such as nutrients, heavy meals and organic micro pollutants from the catchment. Optical techniques such as UV and fluorescence spectroscopies can provide useful information on the characteristics of a wide range of DOM in stormwater.

ISBN: 978-624-6150-05-1

Wetlands, bio-retention, and permeable pavements are widely used in stormwater management. Current bio-retention systems used in Australia for stormwater pollution control seldom provide the water quality necessary for water recycling due to their varies removal efficiency for a range of inflow conditions and pollutants. Stormwater discharge in certain periods is relatively large, and therefore, it needs to be treated intensively at high rates. There is a large gap of research data available on improving bio-retention media for effective stormwater treatment. Incorporating adsorbents having contrasting properties into the bio-retention media to target pollutants with different chemical characteristics is an attractive option.

References

Commonwealth of Australia, C.o. 2015, 'Stormwater management in Australia', *Senate Standing Committees on Environment and Communications*, p. 3.

Bratieres, K., Fletcher, T.D., Deletic, A. & Zinger, Y. 2008, 'Nutrient and sediment removal by stormwater biofilters: A large-scale design optimisation study', *Water research*, vol. 42, no. 14, pp. 3930-40.

Deletic, A., McCarthy, D., Chandresena, G., Li, Y., Hatt, B., Payne, E., Zhang, K., Henry, R., Kolotelo, P. & Randjelovic, A. 2014, 'Biofilters and wetlands for stormwater treatment and harvesting', *Cooperative Research Centre for Water Sensitive Cities, Monash University, Melbourne*, p. 67.

Dillon, P. & Ellis, D. 2004, 'Australian water conservation and reuse research program', *Water(Australia)*, vol. 31, no. 1, pp. 36-9.

Ekanayake, D., Aryal, R., Johir, M.A.H., Loganathan, P., Bush, C., Kandasamy, J. & Vigneswaran, S. 2019, 'Interrelationship among the pollutants in stormwater in an urban catchment and first flush identification using UV spectroscopy', *Chemosphere*, vol. 233, pp. 245-51.

Hatt, B.E., Deletic, A. & Fletcher, T.D. 2006, 'Integrated treatment and recycling of stormwater: a review of Australian practice', *Journal of environmental management*, vol. 79, no. 1, pp. 102-13.

Headley, T. & Tanner, C.C. 2012, 'Constructed wetlands with floating emergent macrophytes: an innovative stormwater treatment technology', *Critical Reviews in Environmental Science and Technology*, vol. 42, no. 21, pp. 2261-310.

Hunt, W., Smith, J., Jadlocki, S., Hathaway, J. & Eubanks, P. 2008, 'Pollutant removal and peak flow mitigation by a bioretention cell in urban Charlotte, NC', *Journal of Environmental Engineering*, vol. 134, no. 5, pp. 403-8.

Hunt, W.F., Lord, B., Loh, B. & Sia, A. 2015, *Plant selection for bioretention systems and stormwater treatment practices*, Springer Nature.

Hvitved-Jacobsen, T., Vollertsen, J. & Nielsen, A.H. 2010, *Urban and highway stormwater pollution: concepts and engineering*, CRC press.

Jenkins, G.A. & Greenway, M. 2007, 'Restoration of a constructed stormwater wetland to improve its ecological and hydrological performance', *Water Science and Technology*, vol. 56, no. 11, pp. 109-16.

Kandasamy, J., Beecham, S. & Dunphy, A. 2008, 'Stormwater sand filters in water-sensitive urban design'.

Liu, J., Sample, D.J., Bell, C. & Guan, Y. 2014, 'Review and research needs of bioretention used for the treatment of urban stormwater', *Water*, vol. 6, no. 4, pp. 1069-99.

Mitchell, V.G., Mein, R.G. & McMahon, T.A. 2002, 'Utilising stormwater and wastewater resources in urban areas', *Australasian Journal of Water Resources*, vol. 6, no. 1, pp. 31-43.

Mostofa, K.M., Wu, F., Liu, C.-Q., Vione, D., Yoshioka, T., Sakugawa, H. & Tanoue, E. 2011, 'Photochemical, microbial and metal complexation behavior of fluorescent dissolved organic matter in the aquatic environments', *Geochemical Journal*, vol. 45, no. 3, pp. 235-54.

Read, J., Wevill, T., Fletcher, T. & Deletic, A. 2008, 'Variation among plant species in pollutant removal from stormwater in biofiltration systems', *Water research*, vol. 42, no. 4-5, pp. 893-902.

Smirnova, A. 2011, 'Use of numerical symbols by birds', *Zoologichesky Zhurnal*, vol. 90, no. 7, pp. 803-10.