The removal of urban litter from stormwater conduits and streams: Paper 1 - The quantities involved and catchment litter management options

Neil Armitage[1]* and Albert Rooseboom[2]

[1] *Department of Civil Engineering, University of Cape Town, Private Bag Rondebosch, 7701, South Africa*

[2] *Department of Civil Engineering, University of Stellenbosch, Private Bag X1 Matieland, 7602, South Africa*

Abstract

A large quantity of urban litter is finding its way into the drainage systems from where it is potentially able to travel via the stormwater conduits, streams, rivers, lakes and estuaries until it eventually reaches the open sea. Along the way items are entangled amongst the vegetation along the banks or strewn along the beaches to become an eyesore and a potential health hazard. The potential annual cost of cleaning South Africa's waterways of urban litter assuming current practices is conservatively estimated to be in the order of R2 bn. at current prices. The main factors influencing the quantity of litter finding its way into the waterways are identified, and suggestions are made for reducing this quantity through catchment litter management. Data from Australia and New Zealand are also reported to illustrate the potential for major reductions in the quantity of litter entering South Africa's waterways. On the assumption that it will take a while for effective catchment litter management to be implemented, some South African data on current urban litter loading rates related to land use, vegetation, the level of street cleaning and the type of rainfall are presented. The influence of these factors is then summarised in the form of simple equations to assist designers in the sizing of litter traps.

Introduction

In years to come, archaeologists sifting through the remains of late 20th century civilisation might well come to identify this period of history as one of waste - "the throw-away society". In South Africa this is most clearly demonstrated by the large quantities of urban litter (alternatively called trash, debris, flotsam, jetsam, rubbish or solid waste) that is so often to be seen strewn about in public places.

The litter, consisting mainly of manufactured materials such as bottles, cans, plastic and paper wrappings, newspapers, shopping bags, and cigarette packets - but also including items such as used car parts, rubble from construction sites, and old mattresses - accumulates in the vicinity of shopping centres, car parks, fast food outlets, railway and bus stations, roads, schools, public parks and gardens, garbage bins, landfill sites and recycling depots. There it remains until it is either removed by the local authority, or it is transported by the wind and/or stormwater runoff into the drainage system.

Once in the drainage system, the litter is potentially able to travel via the stormwater conduits, streams, rivers, lakes and estuaries until it eventually reaches the open sea. Along the way, however, items are frequently entangled amongst the vegetation along the banks of the streams, rivers or lakes, or strewn along the beaches. Some of this debris is picked up - often at great expense. Most of it is probably buried in the river, lake or beach sediments (Hall, 1996).

The existence of such litter in the waterways and on the beaches has a number of impacts:

- Litter is aesthetically unattractive.
- There is a potential health hazard to humans associated with, for example, the putrefying contents of bottles and tins, or pathogenic organisms attached to discarded hypodermic needles.
- Aquatic fauna are at risk of becoming entangled in, or suffocating from, litter ingested in the course of their search for food.
- Pathogenic organisms or toxins, for example heavy metals, may be taken into the food chain poisoning aquatic life and possibly later impacting on humans.
- significant costs are incurred by local authorities in conducting clean-up operations.

According to a President's Council Report of 1991, South Africa was at that stage producing some 40 m. t of solid waste annually - mostly of domestic origin. A large portion of this amount was street litter, much of it packing material (President's Council Report, 1991).

Nearly all solid waste pollution in the river systems of South Africa is derived from the urban areas although they comprise only 5.6% (6 m. ha) of the land area (President's Council Report, 1991). According to the CSIR (1991), some 780 000 t of waste was then entering the drainage system every year, of which about 195 000 t reached the sea. By way of comparison, at the time of above studies, the recycling of glass, paper and tins only accounted for 23 000 t. Fortunately this amount is increasing.

Armitage et al. (1998) has shown that, even with the most efficient litter traps, it typically costs between R1 500 and R2 500/t at 1997 prices to trap and remove litter from the aquatic environment. Therefore, unless steps are taken to reduce the amount of litter entering the drainage system, **the potential cost of keeping South Africa's waterways clean is in the order of R2bn. (R2 000 m.) per year.**

South Africa is not the only country with this sort of problem.

* To whom all correspondence should be addressed.

☎(021) 650-2584; fax: (021) 689-7471; e-mail: civil@eng.uct.ac.za

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Local governments in Texas, for example, spend upwards of US$14m./yr to clean their beaches (Baur and Iudicello, 1990). Allison (1997) recently estimated that 230 000 m^3 or 1.8 bn. items of litter (approximately 60 000 t of wet material) annually enters the waterways of greater Melbourne in Australia.

As the first steps towards addressing the problem, this paper seeks to:

- define what is meant by urban litter;
- identify the main sources of urban litter;
- list the main factors influencing the quantity of urban litter finding its way into the waterways;
- suggest some ways of preventing urban litter from getting into the drainage system;
- present data on litter loadings in different catchments; and
- present simple equations enabling designers to estimate the amount of urban litter they can expect to wash off different types of catchment.

Definition of urban litter

Many different types of litter have been identified by researchers e.g. Allison and Chiew (1995), Island Care New Zealand Trust (1996), or Armitage et al. (1998). A simplified classification system is proposed below:

Plastics: e.g. shopping bags, wrapping, containers, bottles, crates, straws, polystyrene blocks, straps, ropes, nets, music cassettes, syringes, eating utensils.
Paper: e.g. wrappers, newspapers, advertising flyers, ATM dockets, bus tickets, food and drink containers, cardboard.
Metals: e.g. foil, cans, bottle tops, number plates.
Glass: e.g. bottles, broken pieces.
Vegetation: e.g. branches, leaves, rotten fruit and vegetables.
Animals: e.g. dead dogs and cats, sundry skeletons.
Construction material: e.g. shutters, planks, timber props, broken bricks, lumps of concrete.
Miscellaneous: e.g. old clothing, shoes, rags, sponges, balls, pens and pencils, balloons, oil filters, cigarette butts, tyres.

Following the classification suggested by Neville Jones et al. (1996), this could be categorised as "primary" pollution. Under this system, sediment and nutrient loads are categorised as "secondary" pollution, whilst faecal coliforms and pathogens are categorised as "tertiary" pollution.

The reduction of secondary pollution - primarily through the trapping and removal of silts washed off urban catchments - will not be considered here. Nevertheless, the removal of these silts from the natural environment is of great concern in many parts of the world as they can contain potentially dangerous concentrations of heavy metals, nutrients or pesticides of human origin. The sediments are usually dried and taken to a hazardous-waste landfill.

In South Africa, very little attention has been paid to the environmental problems posed by the pollutants bound up in urban sediments. This is possibly because the problem of litter removal is far more obvious and pressing. Indeed, if maintenance and operation costs are to be at a sustainable level, designers in South Africa may be forced to choose litter removal structures that minimise the trapping of sediment.

Although South Africa is a world leader in wastewater treatment and most residential and industrial wastewater is conveyed to appropriately designed wastewater treatment plants, very little attention is currently being paid to the removal of nutrients and pathogenic organisms outside of the sewage systems. An exception to this is the trap on the Robinson Canal in Johannesburg which does divert the heavily polluted low flows into the nearby Klipspruit outfall sewer for treatment (Armitage et al., 1998). Given the existing financial restraints, the removal of this type of pollution is unlikely to be affordable in South Africa for the foreseeable future.

Given the emphasis in South Africa on the removal of the larger pollution elements, the focus of this paper will be on addressing the problem of primary pollution i.e. urban litter (henceforth called simply "litter") which will be defined as visible solid waste emanating from the urban environment.

The main sources of litter

Hall (1996) suggests that the most common sources of litter are the following:

- The anti-social behaviour of individuals in dropping litter on footpaths, throwing it from vehicles, and dumping household wastes.
- Excessive packaging.
- The failure of street sweeping services to rid pavements and public areas of litter.
- Inadequate disposal facilities, including a breakdown in litter collection practices or the provision of inappropriate bins. Open bins and collection vehicles may provide an opportunity for litter to be blown into the public domain.
- The failure by the authorities to enforce effective penalties to act as a deterrent to offenders.

It is obvious that litter is a problem associated with human habitation. It is also obvious that, to a point, the problem rapidly increases with population density and level of development. As a rule, traditional African villages do not have a litter problem. The inhabitants do not have access to many of the accoutrements of modern civilisation, and those they do have, they look after. Also, much of what they have is biodegradable.

Even the cities of so-called "less developed" countries are often cleaner than those of "more developed" countries. The perception of the authors is that litter is less evident in the streets of Harare and Bulawayo than in those of Johannesburg and Durban. This is probably because brown paper packets are used in place of polyethylene shopping bags, beverages are supplied in returnable glass bottles instead of disposable polyethylene sachets or bottles, and food is bought fresh instead of in tins. Unfortunately, as Zimbabwe becomes more developed, its streets are likely to become as polluted as those in South Africa.

Paradoxically, the streets of many developed countries are noticeably cleaner than those of Johannesburg and Durban. One reason for this could be a greater environmental ethic in those countries. Public pressure is rapidly brought to bear on the more obvious polluters and they are soon brought into line. An example from Australia graphically illustrates what a strong environmental lobby can do. Here in South Africa, a well-known international fast food company supplies its hamburgers in polystyrene containers. In Australia, public pressure forced the same company to replace the polystyrene with cardboard (Allison, 1996).

It seems therefore that the problem of litter in the stormwater drainage system is relatively speaking at its worst in countries which are developed enough to have the sophistication of modern technologies, such as the plastics industry, but not so developed that there is a strong environmental lobby in place to police the waste. South Africa falls into this category. Furthermore, as its population grows and becomes more urbanised, the problem is likely to get worse before it gets better.

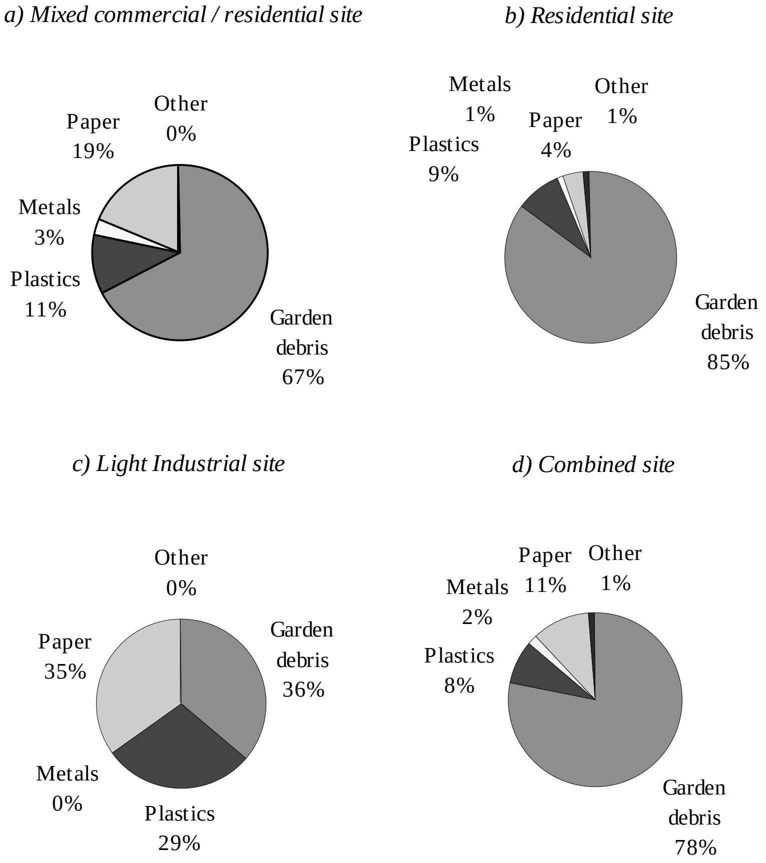

Figure 1
Composition of collected gross pollutants by dry mass from different catchments in Coburg (after Allison and Chiew, 1995)

The main factors influencing the quantity of litter finding its way into the waterways

It is important for designers to be able to estimate the amount of litter coming off urban catchments because that will determine the volume of material that litter traps must hold and the required frequency of cleaning. However, the rate of litter production is highly variable - depending on a large number of independent factors including:

- The type of development, i.e. commercial, industrial, residential.
- The density of development.
- The income level of the community - poor people in poor countries don't have access to many products, hence are not in a position to waste them or their containers.
- The type of industry - some industries tend to produce more pollutants than others.
- The rainfall patterns, i.e. does the rain come in one season only or year-round? Litter will build up in the catchment until it is either picked up by refuse removal, or is swept into the drains by a downpour. Long dry spells give greater opportunity to the local authority to pick up the litter, but also tend to result in heavy concentrations of accumulated rubbish being brought down the channels with the first rains of the season - the so-called "first flush".
- The type of vegetation in the catchment - in Australia for example, leaves form the major proportion of "litter" collected in traps. Some species of trees cause more problems than others e.g. London Plane trees have relatively large leaves which are slow to decompose and are mostly shed over a very short period in autumn;
- The efficiency and effectiveness of refuse removal by the local authority - it is important that the local authority not only clean the streets and bins regularly, but also that sweepers do not, for example, sweep or flush the street litter into the stormwater drains as often happens in South Africa;
- The level of environmental concern in the community - leading to, for example, the reduction in the use of certain products, and the recycling of others; and
- The extent of legislation prohibiting or reducing waste, with which is associated the effectiveness of the policing of the legislation, and the level of the fines.

The variability in the nature of the litter coming off different catchments has been identified by a number of researchers, for example, Allison and Chiew (1995) who showed that for a fully urbanised catchment at Coburg, which is situated about 10 km north of Melbourne's CBD, "garden debris" made up 85% of the litter collected from a residential site, but only 36% from a light industrial site; whilst "paper" and "plastics" made up 64% of the litter from the light industrial site, but only 13% from the residential site. Similar profiles have been obtained for Auckland (Cornelius et al., 1994; Island Care New Zealand Trust, 1996) (see Fig. 1).

Often, a single shop or factory e.g. a fast food outlet, a bank, or a plastic recycling factory, is responsible for a large percentage of the litter collected in the drains, and the amount of litter can be substantially reduced once the situation has been brought to the attention of the offending company (Island Care New Zealand Trust, 1996; Allison, 1996).

There is an infinite variety in the types and quantities of litter washed off a catchment. In fact, **each catchment has a unique litter "footprint" which is indicative of the state of the catchment at the time of measurement**.

Some ways of preventing litter from getting into the drainage system

Much can and should be done to reduce the quantity of litter that finds its way into the stormwater drainage system.

The use of grids over catchpit entrances

The most obvious method of preventing litter from getting into the drainage system is to ensure that as many entrances as possible are covered by some form of grid. This is the norm in the more developed countries - for example in Europe. In less developed countries, however, this is not always a satisfactory solution. High litter loads together with high rainfall intensities and unreliable maintenance programmes frequently lead to blockages and the associated risk of flooding. The question of who is liable for damages in the event of flooding associated with such an eventuality is unclear, but the local authority is likely to be a focus of attention. For this reason, most local authorities in South Africa allow some form of unrestricted overflow even when grids are provided. Where unrestricted overflows exist, litter will certainly be found in the drains.

Paradoxically, grids may be the most viable solution in the very high-density, low income informal urban settlements surrounding all the major South African cities, for the simple reason that if the residents can see the grids blocking, and if there is a risk that their own homes will be affected by the consequent flooding, they are likely to take the appropriate action to keep them clear. If the litter trap is hidden away, or if local drainage is unaffected by moderate litter loads, it is unlikely that the residents will intervene, leaving it to the local authority to take full responsibility for maintenance. This has been observed in Khayelitsha near Cape Town (Compion, 1998). There is of course a risk of serious flooding if a major storm occurs at night.

An alternative approach is to place grids over the entrances to high-lying drains, whilst placing litter traps into lower-lying drains. In this situation, the additional flood risk may be limited as stormwater can bypass blocked grids to enter the drains at another point. This will reduce the number of traps required to cover a catchment.

Reducing the litter load

A more desirable solution to the problem of litter in the drainage system is to reduce the total litter load. Some of the various options that are available to local authorities are listed below. Many of these suggestions come from the pioneering work being carried out in Melbourne (Senior, 1992; Melbourne Water, 1993; Hall, 1996; Allison, 1997) supplemented by some more recent work carried out in Auckland (Island Care New Zealand Trust, 1996).

The following actions are suggested:

- Better placement of rubbish bins.
- Place litter traps inside strategically located catchpits. Use the evidence provided by litter trapped in the catchpits to identify the polluters who may then be pressurised into changing their ways.
- Organise volunteer litter clean-up days for cleaning the banks of urban streams and lakes. This also helps to raise public awareness of the problem.
- Organise a public education campaign to highlight the source of litter in urban waterways, its pathways and environmental hazards. During 1990 a number of small informal public awareness surveys were conducted in offices and schools in Melbourne. It was readily apparent that a majority of children and adults in that city either did not appreciate that there are separate stormwater and sewerage systems, or did not understand that catch-pits in streets and surface grates in private properties connect to the drainage and stream systems. Even after an extensive radio and poster campaign, a more comprehensive market survey undertaken in 1991 revealed that at least a third of the population in Melbourne were still ignorant of the drainage systems role and its connection to waterways. Subsequent to this, a television advertising campaign was prepared, whilst kits were put together to educate school children (Senior, 1992).
- Encourage the formation of public interest / action groups to brain-storm new ideas and to act as environmental watch-dogs.
- Force businesses to become responsible for the proper reduction and disposal of litter generated on their premises.
- Evaluate street sweeping and street flushing operations currently undertaken by metropolitan authorities. A survey carried out by the Board of Works, Melbourne in 1990 revealed that 67% of 54 councils in the metropolitan area used street flushing to some extent. Of these about half regularly and extensively used flushing equipment or street hydrants to clean shopping centres and similar litter accumulation areas. The Board then commenced discussions with a representative number of councils to review methods, equipment and programmes (Senior, 1992).
- Study the behaviour of litter in the stormwater drainage system through the tracking of tagged litter items. Information from this study could be used to devise better ways of controlling litter in waterways as well as raising public awareness of the pathway of litter.
- Encourage commerce and industry to move to more environmentally friendly packaging. In 1991, the Board of Works, Melbourne staged a small exhibit as part of the Plastic Institute's Annual Conference in Melbourne. The display featured a number of polystyrene and plastic items - both unused and recovered from river litter traps. Also prominent was an enlarged photograph of the material trapped behind a litter boom which illustrated many recognisable items. This was provocatively captioned: "Do you really want your product advertised in this way?" (Senior, 1992).
- Prevent businesses from imposing unwanted packaging or advertising on unwilling consumers.
- Set up proper solid-waste collection services in those urban areas which do not yet have such a service.
- Ensure that there is no loss of litter once it has been collected e.g. from inadequate disposal facilities or open collection vehicles.
- Force shops to institute a deposit on all containers.
- Place an "environment tax" on plastic shopping bags. Encourage the move back to large reusable bags provided by the customer.
- Employ the jobless to collect rubbish from more remote areas;
- Institute and enforce effective penalties to act as a deterrent to offenders.
- Encourage the formation of interest groups that will adopt areas/reaches of streams etc. and help keep them free of litter.

Measured litter loadings

Although it would undoubtedly be preferable to prevent littering altogether, this will be an unachievable goal in South Africa for the foreseeable future. Data on existing litter loadings are therefore required for design purposes.

The Springs study

Probably the most comprehensive measurement of the types and quantities of litter coming off South African catchments was that carried out under the leadership of Mr Christo Nel over a period of four months, starting from 1 December 1990 and ending 31 March 1991, for the Central Business District (CBD) of Springs (Armitage et al., 1998). The town has a mean annual precipitation (MAP) of about 750 mm and falls within the summer rainfall region of South Africa.

The size of the catchment area considered in the study was about 299 ha and had a commercial / industrial component of about 254 ha (85%) and a residential component of about 45 ha (15%). The entire catchment drains to a single point from where it flows via an open canal to the Blesbokspruit.

A single structure, capable of handling a flow of 7.5 m^3/s before

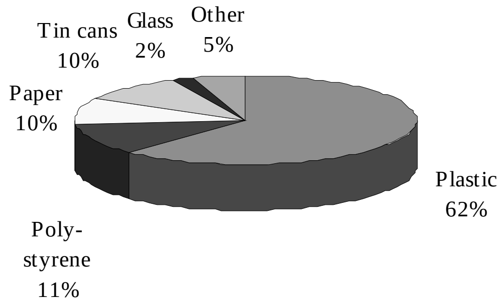

Figure 2
The types of litter trapped by the Springs structure (Armitage et al., 1998)

partial bypassing commenced, was used to screen out all particles with a minimum dimension larger than about 20 mm. Bypassing occurred only for short periods during approximately 60% of storms.

In an attempt to standardise the method of reporting, measurements were made of the density of litter collected from various sources including streets (35 kg/m^3), the Blesbokspruit (95 kg/m^3), refuse vehicles (150 kg/m^3), and the structure itself (95 kg/m^3). In the end, all loads were adjusted to a standard density of 95 kg/m^3.

In addition to measurements of the total quantities of litter collected within the catchment and in the trapping structure, 14 samples of litter trapped in the structure were removed and analysed. Some more unusual items included items of clothing, handbags, stockings, tyres, car number plates, dead dogs and cats, oil cans, and oil filters.

Figure 2 shows a breakdown in the dominant types of litter trapped by the Springs structure. It should be noted that the quantity of vegetation trapped by the structure formed a negligible portion of the total amount and was not measured.

A total of 106 m^3 of litter, transported by 32 separate storm events, was removed from the structure over the 122 d measuring period. Records kept by the Springs City Council show that there had been an average of 56 storm events per year over the previous three years giving an effective removal rate of about 106 m^3 x 56/32 = 186 m^3 litter/yr (3.3 m^3/storm) at a density of 95 kg/m^3. The structure was estimated to be about 72% effective in the removal of litter, indicating that some 71 m^3/yr (at a density of 95 kg/m^3) found its way past the structure into the Blesbokspruit.

Approximately 1 210 m^3/yr (at a density of 95 kg/m^3) was then being removed from the catchment area by various street cleaning services. Thus the total quantity of litter that found its way onto the streets was approximately 1 467 m^3/yr (or 139 t), of which some 18% (or 24 t) found its way into the stormwater drainage system.

An average litter volume of 12 m^3/storm was trapped by the structure during the first storm after winter over the period 1991 - 1993. This was some 3.6 times the average. This phenomenon, where an unusually large quantity of litter is transported through the drainage system following a long dry period, is often termed a "first flush", and the load consists largely of material that has been accumulating in the drains. Although the litter load is much higher than the average, the accumulation rate of litter in the system prior to the first storm is much lower. Presumably street cleaning is more efficient during the dry season when the cleansing department can generally get to the litter before wind and/or rainfall can carry it into the catch-pits.

If the contribution by the residential area to the total is ignored, then litter is currently deposited at a rate of about 5.8 m^3/ha·yr (at a density of 95 kg/m^3, i.e. about 550 kg/ha·yr) in the commercial / industrial area of Springs. 1.0 m^3/ha·yr (at a density of 95 kg/m^3, i.e. about 95 kg/ha·yr) is washed into the stormwater system. If the residential area is added in, then the rate of deposition is 4.9 m^3/ha·yr (470 kg/ha·yr) with 0.86 m^3/ha·yr (82 kg/ha·yr) ending up in the canal.

The Robinson Canal trap, Johannesburg

The Robinson Canal is situated in the Central Metropolitan Council District of Johannesburg. The canal drains approximately 8 km^2 (800 ha) of highly developed urban area, and flows southwards from the Braamfontein ridge through the areas of Selby, Ophirton and Booysens to join with the headwaters of the Klipspruit. The catchment area includes a mix of residential, commercial, industrial and informal trading areas. Johannesburg has a similar climate to Springs.

A single structure, designed by Mr Peter Townshend, capable of handling a flow of 15 m^3/s before partial bypassing commences, was used to screen out all particles with a minimum dimension larger than about 20 mm. This structure is believed to have an efficiency of about 70% (Armitage et al., 1998).

The first rains of the season carry the most debris. In the 1995/6 rainy season, more than 150 garbage bags were collected from the first flush. Typically 70 to 100 bags were collected from ongoing storms, the larger amount being associated with longer periods between storms (more than 10 d).

The trapped material consisted of roughly equal amounts of "sediment", "suspended debris" and flotsam. The "sediment" consisted mostly of coarse objects such as tyres, stones, and bricks, grading down to silty sands. The "suspended debris" comprised about 80% plastic bags. The flotsam was mostly polystyrene fast-food containers, floating tins and bottles. Some large objects such as tractor tyres were also occasionally trapped. A particular health hazard was the number of carcasses that were carried down the canal and deposited in the trap. These had to be disposed of immediately as they rapidly decomposed in the heat.

Each garbage bag holds about 0.06 m^3, and if the density of material in each bag is assumed to be the same as for the Springs structure i.e. 95 kg/m^3, and there are also about 56 storms a year, then this implies that approximately 0.50 m^3/ha·yr (i.e. about 48 kg/ha·yr) is washed into the stormwater system from this part of Johannesburg.

The Capel Sloot culverts, Cape Town

The Capel Sloot culverts drain an area of about 1 092 ha of Cape Town into Duncan Docks. The catchment includes an undeveloped portion of Table Mountain (60.4%), a residential component (18.3%), park land (8.0%), an industrial component (4.2%), a commercial component (7.1%), and railway land (2.0%) (Arnold, 1996).

The mouths of the culverts are closed by fishing nets with square openings of approximately 75 mm a side.

Portnet, the harbour authority, have not kept accurate records, but they estimate that they empty the nets about four times a year, each time removing approximately 12 m^3. Once again, a lot of litter comes down the culverts with the first rains of the wet season (Coetzee, 1996).

Bearing in mind that many particles with a minimum dimension smaller than 75 mm will escape the nets, and considering only the industrial, commercial and railway areas, this amounts to about 0.33 m^3/ha·yr (31 kg/ha·yr assuming a density of 95 kg/m^3). The efficiency of the structure is unknown, but is undoubtedly less than 50%. If a trap efficiency of 50% is assumed, then 0.66 m^3/ha·yr (63 kg/ha·yr assuming a density of 95 kg/m^3) is washed off the catchment.

Including the residential component in the calculation reduces the mean wash-off rate to 0.28 m^3/ha·yr (26 kg/m^3·yr).

Overseas experience

Although litter in the aquatic environment is a universal problem, surprisingly little has been done to address it. In Europe and some parts of North America, relatively low rainfall intensities and a greater environmental consciousness makes it relatively easy to exclude the majority of the litter from the stormwater system through the use of grids over the catchpits. Also, many of the stormwater systems are so-called "combined" systems i.e. sewage and stormwater are mixed together and transported directly to the wastewater treatment works in all except severe storms.

The research effort that is the most relevant to South Africa, appears to have been that carried out by the Australians and to a lesser extent the New Zealanders. The Australian data are of particular interest to South Africa because the climates are similar and the Australians also use "separate" systems i.e. sewage and stormwater are reticulated in separate networks - although, of course, the socio-economic situations are totally different. In consequence, considerable effort was made to research Australian and New Zealand experience.

Data from a study carried out in Coburg, Melbourne (Allison, 1997) appears to indicate that an average of approximately 30 kg/ha·yr of dry material (100 kg/ha·yr of wet material) or some 0.4 m^3/ha litter/yr is washed off Melbourne urban catchments. This amounts to a total of 230 000 m^3 or 60 000t (wet)/yr. However, as much as 80% of this material is leaf matter. Ignoring the leaf matter would give a loading rate of 6 kg/ha·yr dry, 20 kg/ha·yr wet, or 0.08 m^3/ha·yr.

A study carried out in Auckland (Cornelius et al., 1994) indicated the following litter loading rates:

- *commercial* : 1.35 kg/ha·yr (0.014 m^3/ha·yr)
- *industrial* : 0.88 kg/ha·yr (0.009 m^3/ha·yr)
- *residential* : 0.53 kg/ha·yr (0.006 m^3/ha·yr)

It is interesting to note that although the commercial and industrial areas produced higher litter loading rates than the residential areas, the residential areas, because they cover a much larger percentage of the city, contribute more litter than all the other areas put together.

Of significance are the dramatically lower loading rates for Melbourne and Auckland compared with South African data.

The estimation of litter loadings

From the foregoing, it can be seen that the amount and type of litter coming off urban catchments is extremely variable and depend on a large number of independent factors. According to the available data, litter wash-off rates appear to vary from about 0.53 kg/ha·yr for the residential areas in Auckland, to about 96 kg/ha·yr for the CBD of Springs.

In reality, none of the trapping devices used to obtain the data above were 100% efficient, and at least one - over the mouth of the Capel Sloot culvert - was probably much less than 50% efficient in the trapping of litter. The efficiency of the devices might also have varied depending on the type of litter being trapped. It is easier to trap tin cans and polystyrene blocks than plastic bags and pieces of paper. This leads to great uncertainties in the determination of the quantities of litter reaching the streams. The Auckland study seems to support the proposition that commercial and industrial areas produce a higher litter loading rate than do residential areas, but this may not hold in South Africa where services to many sub-economic residential areas have completely collapsed. It is also important to note that even in Auckland**,** residential areas, by virtue of their much greater area, contribute a greater total of litter to the Hauraki Gulf than the commercial and industrial areas combined.

One thing is clear, the litter problem is much worse in South Africa than it is in either Australia or New Zealand - the figures seem to indicate up to about two orders of magnitude (i.e. 100 times) worse. This is presumably a combination of many factors, but is probably mostly as a result of the lack of a widespread environmental ethic in South Africa, coupled with poor levels of service in certain areas.

Vegetation does not seem to cause the problems in South Africa that it causes in Australia, but there may be local exceptions to this.

Plastics are by far the biggest single problem.

Without data from the specific catchment, estimates of the amount of litter that comes from it are likely to be highly conjectural. As a **preliminary guide to design** however, the following formula, derived largely from the Springs and Robinson Canal data (Armitage et al., 1998), is tentatively suggested for South Africa until such time that better data are available:

$$T = \Sigma f_{sci}.(V_i + B_i).A_i \qquad (1)$$

where:

T = total litter load in the waterways (m^3/yr)

f_{sci} = street cleaning factor for each land use (varies from 1.0 for regular street cleaning to about 6.0 for non-existent street cleaning / complete collapse of services)

V_i = vegetation load for each land use (varies from 0.0 m^3/ha·yr for poorly vegetated areas to about 0.5 m^3/ha·yr for densely vegetated areas)

B_i = basic litter load for each land use (commercial = 1.2 m^3/ha·yr; industrial = 0.8 m^3/ha·yr; residential = 0.01 m^3/ha·yr)

A_i = area of each land use (ha)

The data from Coburg, Australia suggest that the basic litter load can easily be reduced by at least 90% with a little public awareness and co-operation. The data from Auckland suggest that much greater reductions are in fact achievable.

There is no consistent relationship between rainfall and transportation of litter, although the work carried out in Coburg suggests some correlation (Allison, 1997). What is certain is that very little litter is carried by the drainage system between major downpours, and an abnormally high "first flush" is frequently seen after long dry periods. To enable designers to calculate trap storage volumes and cleaning frequencies, it is suggested that the total litter load is assumed to be split between the significant downpours (with more than, say, 1 mm of rainfall) with the greater weighting given to those storms following long, dry periods. As a **preliminary guide to design**, the following formula, derived largely from the Springs and Robinson Canal data (Armitage et al., 1998), is tentatively suggested for South Africa:

$$S = f_s.T/ \Sigma f_{si} \quad (2)$$

where:

- S = storm load in the waterways (m^3/storm)
- f_s = storm factor (varies from 1.0 for storms occurring less than a week after a previous downpour; to about 1.5 for a storm occurring after a dry period of about three weeks; to about 4.0 for a storm occurring after a dry period of more than about three months)
- T = total litter load in the waterways (m^3/yr)
- Σf_{si} = the sum of all the storm factors for all of the storms in the year (since this information is generally not available, a suggested alternative is to count the average number of significant storms in a year and multiply by 1.1)

Conclusions

The following conclusions can be made concerning the amount of urban litter in waterways:

- Litter in the waterways is a major environmental problem that will cost a lot of money to address (estimated to be in the order of R2bn./yr in the absence of effective catchment litter management).
- It is a direct result of human behaviour.
- The amount and types of litter to be found at any one place are extremely variable as they depend on a large number of independent factors.
- Some form of catchment litter management might help to reduce the quantities of litter by large percentages.
- It is possible to make a preliminary estimate of the litter loads from South African catchments, but this can never take the place of data from the site in question.

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References

ALLISON RA and CHIEW FHS (1995) Monitoring of stormwater pollution from various land uses in an urban catchment. *Proc. of the 2nd Int. Symp. on Urban Stormwater Manage.* Melbourne. 551-516.

ALLISON RA (1996) Personal communication. Ph.D. student, Dept. of Civil and Environ. Eng., Univ. of Melbourne.

ALLISON RA (1997) Effective Gross Pollutant Removal from Urban Waterways. Ph.D. Thesis, Univ. of Melbourne.

ARMITAGE N, ROOSEBOOM A, NEL C and TOWNSHEND P (1998) The Removal of Urban Litter from Stormwater Conduits and Streams. WRC Report No. TT 95/98, Pretoria.

ARNOLD RW (1996) Personal communication. Drainage and Sewerage Branch, Cape Town City Engineer's Department.

BAUR DC and IUDICELLO S (1990) Stemming the tide of marine debris pollution: Putting domestic and international control authorities to work. *Ecol. Law Quarterly* **17** 71-142.

COETZEE F (1996) Personal communication. Portnet, Cape Town.

COMPION JK (1998) Personal communication. Liebenberg & Stander Western Cape (Pty) Ltd, Consulting Engineers, Cape Town.

CORNELIUS M, CLAYTON T, LEWIS G, ARNOLD G and CRAIG J (1994) *Litter Associated with Stormwater Discharge in Auckland City New Zealand*. Island Care New Zealand Trust, Auckland.

CSIR (1991) The Situation of Waste Management and Pollution Control in South Africa. Report CPE 1/91 to the Dept.of Environ. Affairs by the CSIR Programme for the Environment, Pretoria.

HALL M (1996) Litter Traps in the Stormwater Drainage System. Unpublished M.Eng. paper, Swinburne Univ. of Technol., Melbourne.

ISLAND CARE NEW ZEALAND TRUST (1996) *Reducing the Incidence of Stormwater Debris and Street Litter in the Marine Environment - A co-operative Community Approach*. Auckland.

MELBOURNE WATER AND MELBOURNE PARKS & WATERWAYS (1993) *Backyard to Bay Program*. Melbourne.

NEVILLE JONES - WILLING & PARTNERS CONSULTING GROUP (1996) Catchment D37 Stormwater Management Study. Report to Redcliffe City Council, Springwood, Queensland.

PRESIDENT'S COUNCIL REPORT (1991) *Report of the Committee of the President's Council Concerning a National Environment Management System.* State Press, Cape Town.

SENIOR JC (1992) Litter control in urban waterways. *Proc. Int. Symp. on Urban Stormwater Manage.*, Sydney. 234 - 239.