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The Use of GIS to Determine a Strategy for the Removal of Urban Litter

Upper Lotus and Lower Salt River Catchments, Cape Town

Christopher Wise and Neil Armitage

Urban litter pollution is a persistent problem in rivers, canals and drainage pipelines throughout South Africa. Part of an integrated approach to achieve a reduction of litter pollution in the stormwater systems involves the development of optimized strategies for the removal of litter from the pipelines and canals. This can only be achieved by developing a clearer understanding of the volume, source and distribution of litter within South African stormwater systems.

This chapter presents a study in which a litter generation model was developed to estimate the source and quantities of litter in the upper reaches of the Lotus River and lower reaches of the Salt River catchments. Using GIS modeling techniques, the litter generation model integrated land-use data sets with litter wash-off rates for various land-use types to determine the quantity of litter generated from discrete sub-catchments within the study area.

This model was then used as an aid in selecting the most appropriate litter removal devices in optimal locations within the study area to achieve the greatest litter removal at the lowest cost. A practical phased implementation program was thus developed for the City of Cape Town that could potentially remove 65% of the litter from the rivers and canals in the study area.

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24.1 Introduction

Urban litter pollution of urban stormwater systems is of increasing concern for local authorities in South Africa and a cost-effective strategy for the removal of this litter is required. To develop this strategy, however, an understanding of the source, distribution and volume of the litter within the stormwater systems is required. This information then needs to be linked to the selection of appropriate litter removal devices placed in suitable locations.

Geographical information systems (GIS) is a computer-based tool that assembles, manipulates and displays database information spatially on geographically referenced maps by relating database information to its spatial position. It is a very useful tool for establishing spatial patterns of database information and is thus ideally suited to assist in developing an understanding of the source, distribution and volume of litter in urban stormwater systems.

This chapter presents a case study to demonstrate how GIS can be used to develop an optimized strategy for the removal of litter from stormwater systems.

The study was limited to investigating the removal of litter in the open channels and rivers. For the purpose of the study, litter was defined as human generated solid waste and excluded silt and vegetation.

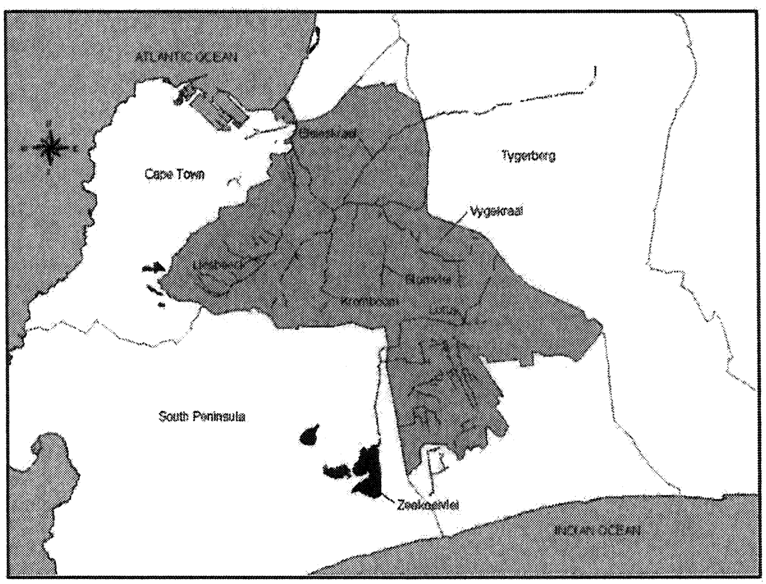

Figure 24.1 Study area showing the major rivers (underground conduits not shown).

The study area (shown as the shaded area in Figure 24.1) is located roughly in the centre of the Cape Metropolitan Area and has a total gross area of 147 km^2. It comprises the lower reaches of the Salt River and the upper reaches of the Lotus River and excludesthe reaches of the catchments that fell outside of the Cape Town Administration boundary. Figure 24.1 depicts the boundaries of the local administrations and the open channel waterways in the study area. Where discontinuities are shown, the flow is conveyed underground. The land-uses across the study area include agriculture, residential, commercial and industrial.

24.2 Methodology

Armitage and Rooseboom (2000) identified a number of trapping mechanisms for the removal of litter from stormwater systems, mostly involving litter traps of some form. The first stage of this study involved identifying which of these litter traps was most suitable for the conditions in the study area. It was recognized from the outset of the project that the traps would be fairly large structures removing litter form the main watercourses rather that many small kerb inlets. This decision was based on considerations of both cost and practicability - much material is deposited directly into the water courses.

Once suitable trapping locations had been identified, a GIS-based litter generation model was used to predict the volume and distribution of litter associated with each potential trapping location within the study area. Once this information had been linked to the estimated cost of the structure, it was possible to identify those locations that would allow the removal of the maximum volume of litter at the minimum cost. The methodology for the development of this removal strategy is given in Figure 24.2. A hydrological model was undertaken separately to the litter generation modeling exercise to determine the optimal hydraulic capacity of traps. Further information on this process can be obtained from Armitage and Rooseboom 2000.

24.3 Data Collection

Typically, three categories of data were required for the litter generation model namely, spatial information in GIS format (e.g. erven, census, land-use and stormwater reticulation data), litter generation rates, and visual assessments of waste prevalence.

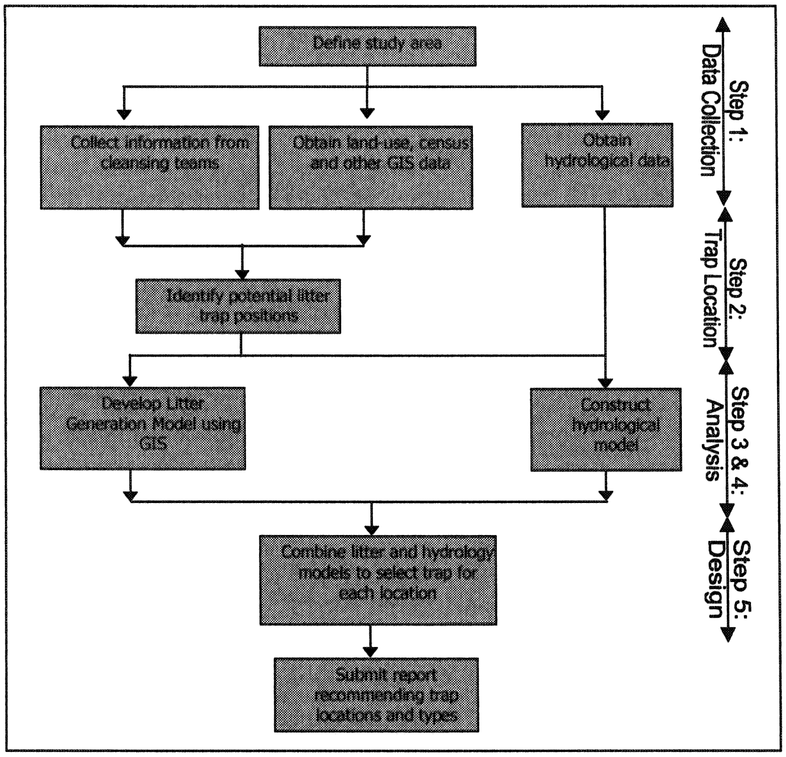

Figure 24.2 Methodology for the strategy development.

Interviews were conducted with City of Cape Town (CCT) personnel to assess the general trends in the distribution of litter in the rivers, as well as to help determine the major sources of litter within the study area.

The necessary baseline GIS data was obtained directly from the CCT. The litter generation rates for certain land-uses (in kg/ha.y) were obtained from Armitage (2001) and modified slightly in the light of the interviews with the CCT personal combined with visual assessments. The derivation of the litter generation rates will be published in a separate paper.

24.4 Determining Potential Litter Trap Locations

Potential trap locations were identified with the assistance of CCT personnel. These were assessed in terms of their technical suitability and their position in relation to reaches deemed to be environmentally sensitive by the City of Cape Town. These reaches were to be protected from litter pollution for a variety of different reasons, which are not essential to the theme of this chapter. (Figure 24.3).

According to Armitage and Rooseboom (2000), the most effective litter traps are generally those with declined screens, as they are self-cleaning e.g Stormwater Cleaning System (SCS) or Baramy®. These traps however require locations with sufficient fall to provide the water head needed to operate the declined screen, and owing to the relatively flat nature of the study area, these were difficult to find. This turned out to be a major technical constraint that limited the number of potential litter trap sites. The selection of the type of litter for the potential trap location is outside the scope of this chapter.

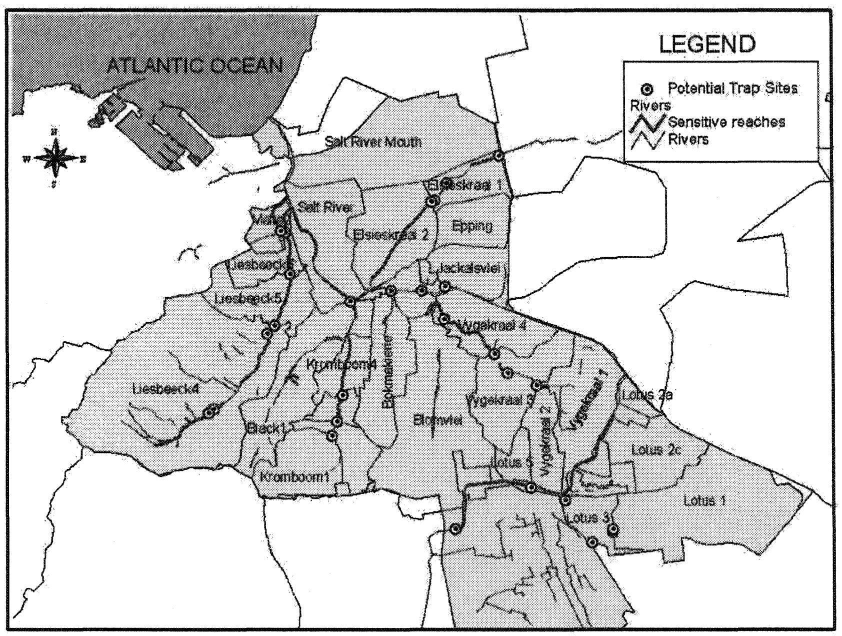

Figure 24.3 Potential litter trap sites in relation to sensitive reaches (underground conduits not shown).

The details of a potential litter trap position, on the Vygekraal River are given in Figure 24.4. The information shown on the table indicates the criteria used to assess the technical feasibility of the trap location.

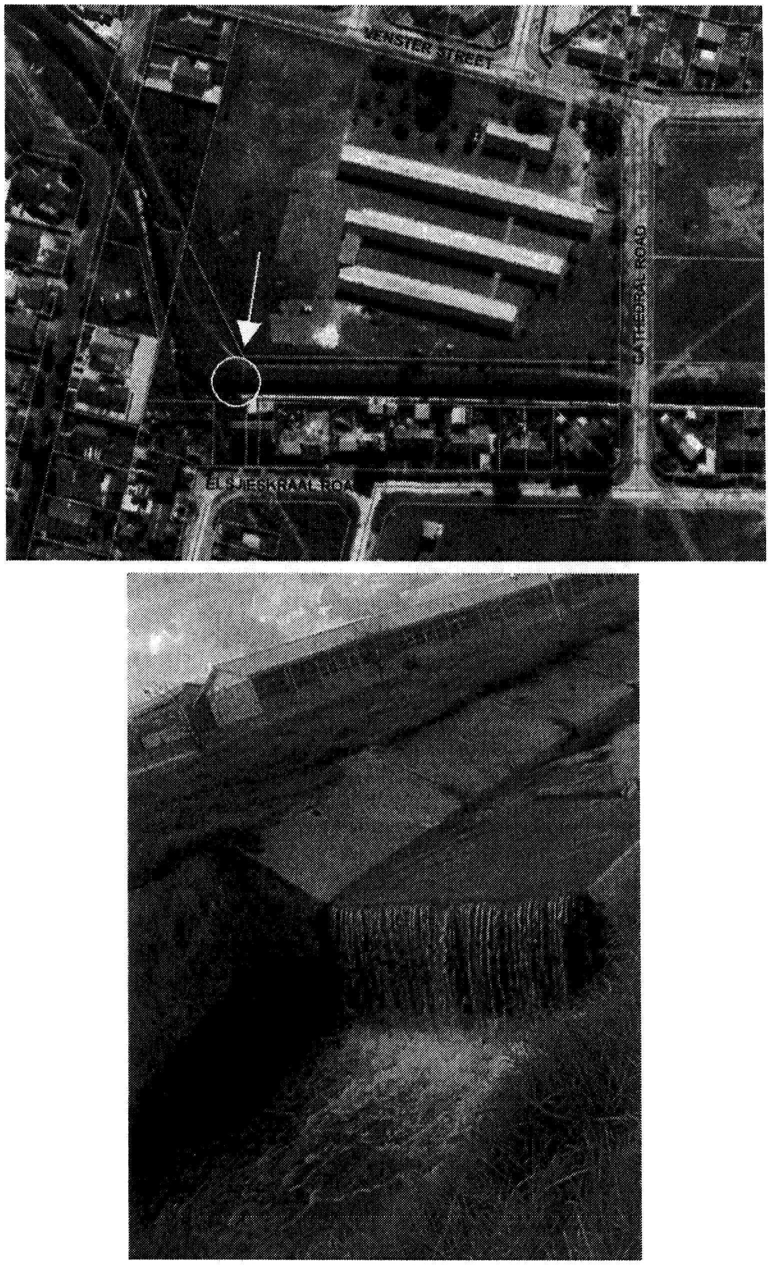

Figure 24.4 A potential litter trap location on the Vygekraal canal.

24.5 Litter Generation Modeling

24.5.1 Catchment Sub-division

Once the most feasible trap locations were identified, the hydraulic catchments of each location, based on the stormwater pipe network, were demarcated on the GIS (see also Figure 24.3). Each of these sub-catchments thus made up discrete model elements that were treated as individual units. The litter generation modeling exercise thus involved approximating the volume of litter entering the stormwater system from each of these discrete sub-catchments.

24.5.2 Land-Use

Each plot (called erf (pl: erven) in South Africa) in these sub-catchments was assigned a general land-use type based on GIS land-use base data. The following eleven broad land-use types were used in the study.

- manufacturing,
- retail,
- offices,
- halls, stadiums and entertainment facilities,
- taxi ranks and transport interchange facilities,
- education facilities,
- hospital & clinics,
- low density residential,
- medium density residential,
- high density residential, and
- informal settlements.

In defining the residential area densities, the following criteria, based on normal South African town planning principles were used.

- low density: 0.5 to 50 persons/ha;
- medium density: 50 to 175 persons/ha; and
- high density: > 175 persons/ha.

The income group was assumed to be linked to the population density, which is typical for the South African context. In practice the litter generation from the low and medium density residential erven was very small and thus had very little impact of the results from the model.

The litter generated from land-use types such as farming and parks were deemed to be negligible and ignored in the calculations. A correction factor was applied to the land-use data to make an allowance for the road reserve areas.

24.5.3 Litter Generation Rates

The litter generation rates, defined as the mass of litter entering the stormwater system per unit area for a specific land-use in one year used in the model for each of the land-uses is given in Table 24.1. The values are best estimates and could be subject to a 50% uncertainty. It is envisaged that the traps installed under the first phase of the scheme will be used to collect further data and calibrate the model.

Table 24.1 Litter generation rates for identified land-uses (based on Armitage 2001).

Land-use Type	Litter Generation Rate
	kg/ha.y
Informal Settlements (on the banks of rivers)	6000
Low Density Residential	1
Medium Density Residential	15
High Density Residential	150
Manufacture/Industrial	75
Retail	2500
Offices	50
Halls, Stadiums & Entertainment Facilities	300
Taxi Ranks etc.	6000
Schools	100
Hospitals	50

24.5.4 1.1 Street Sweeping

The litter generation rates indicated in Table 24.1 assume that no litter is removed via street sweeping. The effect of street sweeping was accounted for in the model by reducing the volume of litter entering the stormwater system by a factor based on the frequency of street sweeping. This was carried out using the approach taken from Armitage (2001) where the ratio of number of days between street sweeping to the average number of days between critical rain storms gives an indication of the maximum likely efficiency of litter removal by street sweeping. For the rainfall data applicable to the study area, the removal efficiency of the street sweeping as a function of the frequency of the street sweeping is shown in Figure 24.5.

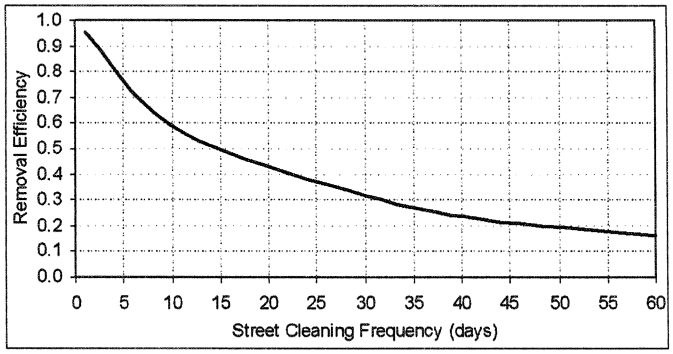

Figure 24.5 Litter removal efficiency in relation to the street cleaning frequency.

Street sweeping can be seen to have a significant effect on the volume of litter entering the stormwater systems. Daily street sweeping can prevent up to 95% of the litter from entering the stormwater system.

24.5.5 Calculation of Litter Generation for Sub-catchments

The total mass of litter entering the stormwater system from each land-use in each of the discrete sub-catchments was calculated by adjusting the litter generation rate for each land-use (TL) for street sweeping, and multiplying it by the area. This is then divided by a factor that takes into account the road reserves (not generally included in the raw land-use data):

$$T_L = (1 - \eta_{removal}) \cdot L_G \cdot \frac{A_E}{f_{EG}} \tag{24.1}$$

where:

- L = litter entering stormwater system (kg/ y),
- $\eta_{removal}$ = litter removal efficiency by street sweeping,
- L_G = litter generation per gross area for the specific land-use (kg/ha. y),
- A_E = total net area of the specific land-use (ha), and
- f_{EG} = fraction of the gross area that is erven only (the baseline data was given in terms of erf areas only. This had to be adjusted to take into account the additional area of the road reserves).

The litter generated by each land-use type was then summed to obtain the total mass of litter entering the stormwater system from each of the sub-catchments.

24.6 Litter Generation Modeling Results

The litter generation figures were plotted on colour maps, which showed the distribution and magnitude of litter generation. The mass of litter entering the stormwater system per hectare per year, termed the *litter generation density*, is plotted in Figure 24.6 for each sub-catchment. The darker areas show a greater density of litter entering the stormwater system.

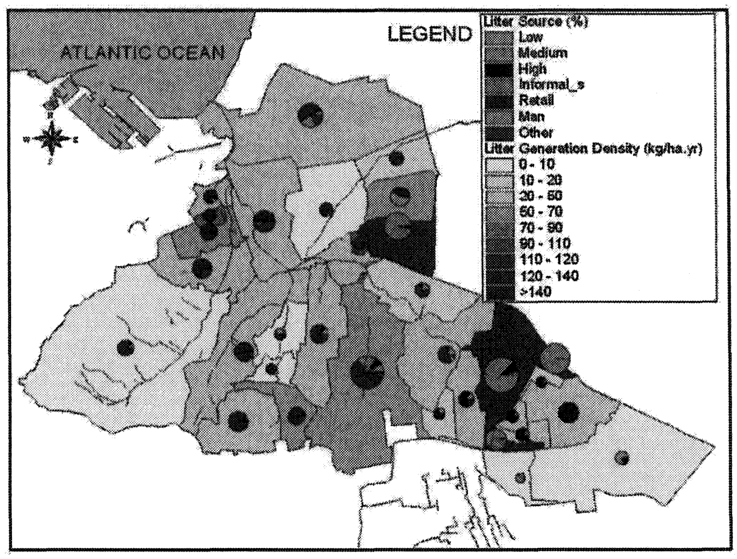

Figure 24.6 Litter generation density in study area (underground conduits not shown).

The Upper reaches of the Lotus River and the upper reaches of the Vygekraal River, were the largest contributors of litter pollution in the study area, followed by the Jakkalsvlei and the Blomvlei sub-catchments.

The pie charts plotted on Figure 24.6 show the source of the litter in each sub-catchment as a percentage from each land-use. From this it was established that the major litter contributor in the Vygekraal and Jakkalsvlei catchments was direct dumping from the informal settlement along the river banks. Comments from the river cleaning team during the initial interviews verified this.

The results from the litter generation modeling are summarised for each of the sub-catchments in the table below. The results show that the total litter load from the Vygekraal, Jakkalsvlei, Blomvlei, Bokmakierie and Langa canals is approximately 71% of the total litter entering the Salt River Catchment.

Table 24.2 Litter in each tributary

Salt River

	Area	Loading	% of	
	ha	kg/y	Total	
Vygekraal	2838	96053	29.8%	
Jakkalsvlei	286	39253	12.2%	
Blomvlei	1090	63925	19.8%	71.1%
Bokmakierie	421	12603	3.9%	
Langa	24	17501	5.4%	
Elsieskraal	1005	7726	2.4%	
Black	1502	43807	13.6%	
Liesbeeck	2465	33896	10.5%	
Malta	133	7903	2.4%	
Total	9764	322667		

Lotus River

	Area	Loading	% of Total
	ha	Kg/y	
Upper Lotus	670	93091	94.9%
Browns Farm/Phillipi Area	1189	3556	3.6%
Lower reaches	214	1456	1.5%
Total	2073	98103	

The majority of the litter in the Lotus River appeared to originate in the upper reaches of the river, owing mainly to the informal settlements and high density residential areas close to the open canal. Although there are large informal settlements in the Browns Farm and Phillipi areas, these are not connected to the stormwater system and thus do not contribute a significant amount to the litter in the Lotus River.

24.7 Development of the Removal Strategy

Using the results for the model, the mass of litter that would be intercepted by each of the potential litter trap locations shown in Figure 24.3 could be calculated. This is shown in Table 24.3 for the Salt and Lotus River catchments.

Table 24.3 Litter intercepted by potential litter trap locations.

Salt River Catchment

Proposed Location	Contributing Catchments	Area ha	tonnes/y	% of Salt River Total
V1	Vygekraal 1	484	72.5	22.5%
V2	Vygekraal 2 & Vygekraal 3	704	18.6	5.8%
J1	Jakkalsvlei	286	39.3	12.2%
Blomvlei	Blomvlei	1090	63.9	19.8%
Bo1	Bokmakierie	421	12.6	3.9%
E3	Elsieskraal 1	225	3.7	1.2%
K1	Kromboom 1	367	15.7	4.9%
L5	Liesbeeck 4 & Liesbeeck 5	517	23.7	7.3%
M1	Malta 1	39	3.4	1.1%
	Total	4133	253.4	78.70%
	Salt River Total		322.7	tonnes/y

Lotus River Catchment

Proposed Location	Contributing Catchments	Area ha	tonnes/y	% of Lotus River Total
Lo4	Lotus 1	1013	3.3	3.4%
Lo2	Lotus 3	177	0.2	0.2%
Upper Reaches	Lotus 2	670	93.1	94.9%
Lo1	Lotus 2, Lotus 4& Lotus5	883	94.5	96.4%
	Lotus River Total	2743	98.1	tonnes/y

It was clear from the above that priority should be given to trap sites such as Vygekraal 1, Blomvlei and Lotus 2 as these have the potential of intercepting the greatest volumes of litter. The preferred trap locations could therefore be prioritised according to their effective impact on litter reduction in the catchment. A phased strategy was then developed by selecting the traps that are expected to remove the greatest volume of litter for the initial phases and then selecting the traps that remove less litter in the later phases. This strategy is summarized in Figure 24.7.

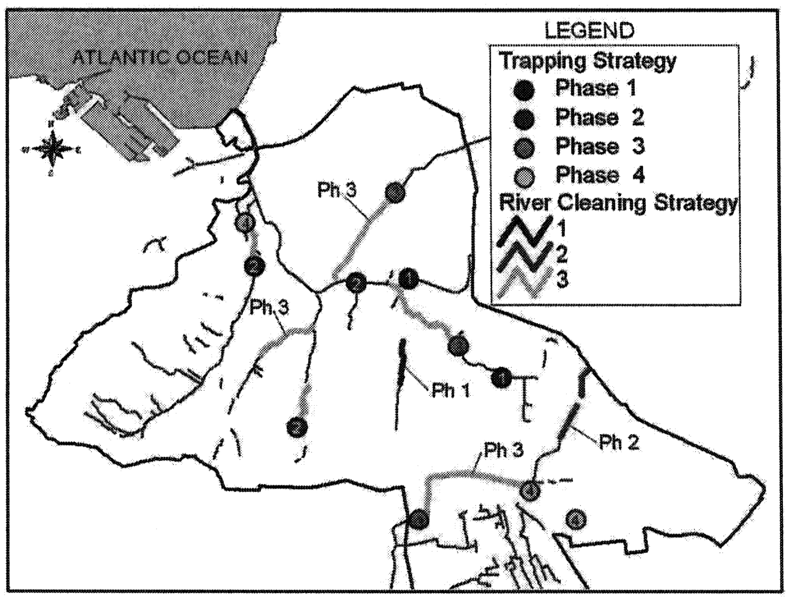

Figure 24.7 Proposed implementation phasing (underground conduits not shown).

Table 24.4 indicates the amount and percentage of the total volume of litter in the study area is projected to pass through each potential trap location in each phase.

Table 24.4 Amount of litter projected to pass each trap location in each phase.

	Estimated annual mass removal	% of total mass in waterways
Phase 1	176 tons	41.6%
Phase 2	145 tons	34.4%
Phase 3	40 tons	9.5%
Phase 4	7 tons	1.6%
	368 tons	87.1%

Assuming that the litter traps operate at a conservative 75% efficiency (Armitage and Rooseboom, 2000), the three traps proposed in Phase 1 are expected to remove a total of 31% of all the litter in the rivers. Eventually, 87% of the catchments in the study area would receive some form of litter removal resulting in an anticipated 65% reduction in the litter in the river and canals.

24.8 Conclusions

1. It is possible, using a land-use based GIS model, to simulate the volumes of litter generated in specific catchment areas of a river. This data can be displayed in graphical format to depict the patterns of litter generation.
2. Using this model, it is further possible to develop a strategy for litter removal in a river catchment that optimizes the location of the litter traps to remove the most amount of litter at the least cost with the greatest benefit to the environment.
3. The presence of informal settlements, with no basic services, immediately adjacent to the watercourses in the Salt and Lotus River Catchments appears to have contributed significantly to the litter loading within the watercourses.
4. The majority of the litter in the Salt River (approx. 62%) appears to originate from the Vygekraal, Jakkalsvlei and Blomvlei catchments.
5. The majority of the litter in the Lotus River (approx. 95%) appears to originate in the upper reaches of that river.
6. The implementation of Phase 1 of the removal strategy is expected to reduce the litter in the Salt River Catchment by approximately 31%. Ultimately, the entire litter removal strategy is expected to remove 65% of the litter discharged into the stormwater system.
7. Data gathered from the traps to be implemented under Phase 1 of strategy will be used to refine the litter generation model.

The implementation of Phase 1 was awaiting funding at the time this chapter was written.

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References

Armitage, Neil (2001) "The Removal of Urban Litter from Stormwater Drainage Systems". Ch. 19 in: Stormwater Collection Systems Design Handbook. L. W. Mays, Ed., McGraw-Hill Companies, Inc., New York.

Armitage, Neil & Albert Rooseboom (2000) "The Removal of urban litter from stormwater conduits and streams: Paper 3 - Selecting the most suitable trap". Water SA, Vol. 26, No. 2, pp 195-204, Pretoria, South Africa.