The removal of urban litter from stormwater conduits and streams

Neil Armitage, Albert Rooseboom,
Christo Nel & Peter Townshend

Report to the
Water Research Commission
by
The University of Stellenbosch
in association with
The University of Cape Town,
Stormwater Cleaning Systems (Pty) Ltd,
and
Urban Water

WRC Report No TT 95/98
July 1998

Obtainable from:

Water Research Commission
PO Box 824
Pretoria
0001

The publication of this report emanates from a project entitled: *The Removal of Floating and Suspended Materials from Springs* (WRC Project No. 691)

ISBN 1 86845 367 7

Printed in the Republic of South Africa

Beria Printers

Contents

Appendices:

List of Figures

List of Tables

List of Abbreviations

BGPT = Baramy® Gross Pollutant Trap

CBD = Central Business District

CDS = Continuous Deflective Separation (device)

CCC = Cape Town City Council

Fr = Froude number

GPT = Gross Pollutant Trap

ILLS = In-line Litter Separator

LCD = (North Sydney) Litter Control Device

MAP = Mean Annual Precipitation

OGS = Oil-grit separator

RI = Recurrence Interval

SCS = Stormwater Cleaning Systems (structure)

SECT = Side-entry catchpit trap

TWL = Top Water Level

UCT = University of Cape Town

US = University of Stellenbosch

UTS = University of Technology, Sydney

UWEM = Urban Water Environmental Management (concept)

WL = Water Level

Executive Summary

In years to come, archaeologists sifting through the remains of late twentieth 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 litter (alternatively called trash, debris, flotsam, jetsam, rubbish or solid waste) that is so often to be seen strewn about public places. There it remains until it is either removed by the local authority or until it is transported by the wind and stormwater run-off into the drainage system.

The purpose of this document is to discuss the most appropriate and cost-effective methods of removing litter from the drainage system. It should be emphasised that the findings are still somewhat tentative in view of the limited operational experience of many of the structures described herein.

The report points out that the strategy for the removal of litter from the stormwater system will have to be two-pronged, aiming to reduce the quantity that finds its way into the system in the first place, as well as removing the balance as efficiently as possible. **Whilst the report suggests some ways of reducing the rate of litter deposition in the catchment, large amounts of litter are likely to escape into the drains for the foreseeable future, and for this reason, the bulk of the report focuses on litter removal structures.**

It is important for designers to be able to estimate the amount of litter that is currently washed off urban catchments because that will determine the volume of material that the trap must hold, together with the frequency of cleaning. However, it appears that each catchment has a unique litter "footprint" which is indicative of the state of the catchment at the time of measurement. Moreover, studies carried out in South Africa, Australia and New Zealand appear to indicate that litter wash-off rates vary by up to two orders of magnitude (ie. 100 times), with the problem being much worse in South Africa than it is in either Australia or New Zealand. This is probably because of the poor levels of service in many areas of South Africa, combined with the lack of a national environmental ethic. Plastics seem to be by far the biggest single litter problem everywhere. In spite of the uncertainty that surrounds the estimation of the litter load, **the report makes some suggestions for the estimation of litter loads for design purposes**.

The biggest challenge facing the designers of litter traps is that litter can be just about anything - any size, any shape, any density, any hardness. Furthermore, the behaviour of a single item often changes as it moves through the drainage system. Another challenge is that the flow rate in channels changes continuously. A structure might work well at a low flow rate, but not at a high flow rate, or vice versa. **The report discusses the large quantity of research that has been carried out in South Africa, Australia and elsewhere into the problem of the removal of litter from the aquatic system.** This included an extensive series of model tests in the hydraulics laboratories at the Universities of Stellenbosch and Cape Town.

As a result of this research, **seven devices are identified as showing the greatest promise**, namely:

1. Side-entry catchpit traps (SECTs);
2. The North Sydney Litter Control Device (LCD);
3. The In-line Litter Separator (ILLS);
4. The Continuous Deflective Separation (CDS) device;
5. The Baramy® Gross Pollutant Trap (BGPT);
6. The Stormwater Cleaning Systems (SCS) structure; and
7. The Urban Water Environmental Management (UWEM) concept

Fences, nets, booms or baffles may also be successfully used to intercept litter in streams provided the peak flow velocities are not too high.

The main criteria governing the choice of trap at any particular location are the maximum flow rate, the allowable head loss, the relative size of the structure, the efficiency of litter removal, the reliability of the device in removing litter without increasing flood risk, its ease of cleaning and maintenance, and its cost effectiveness. The report evaluates the more promising trapping structures in terms of these criteria. **The report then recommends a standard procedure for the selection of the trapping system.**

The removal of litter from stormwater conduits and urban streams is costly and should always be carried out as part of a proper catchment management plan. It is better to prevent littering than to remove the litter from the drainage system once it is there.

The report concludes by recommending further research into the removal of urban litter from stormwater conduits and streams - in particular into:

- identifying the source, type and amount of urban litter coming from different types of urban catchments,
- the efficacy of various catchment management techniques in the reduction of urban litter reaching the drainage systems;
- the optimisation of declined screens; and
- new trapping structures.

In addition to the above, research is required into the control and removal of other pollutants from stormwater conduits and streams, in particular: heavy metals, excessive nutrient loads, and pathogenic organisms.

Acknowledgements

A report of this magnitude requires input from many people. As project leader and principal author it is incumbent on me to thank the following people and organisations who have provided a major input:

i) The Water Research Commission for supporting the project. In particular, special thanks is due to Mr Dawid van der Merwe, Deputy Executive Director of the WRC for his positive and able leadership.

ii) The Project Steering Committee who provided constructive and enthusiastic support throughout. The complete committee was as follows:

Mr DS van der Merwe	-	Water Research Commission (Chairperson)
Mr DJM Huyser	-	Water Research Commission (Secretary)
Ms CM Smit	-	Water Research Commission (Secretary)
Mr HC Chapman	-	formerly Water Research Commission
Mr J Bhagwan	-	Water Research Commission
Prof PW van der Walt	-	University of Stellenbosch
Prof A Rooseboom	-	University of Stellenbosch (Project Manager)
Mr NP Armitage	-	University of Cape Town (Project Leader)
Dr JM Jordaan	-	formerly Dept. of Water Affairs and Forestry
Mr FPJ van der Merwe	-	Dept. of Water Affairs and Forestry
Mr RW Arnold	-	Cape Town City Council
Mr KA Barnett	-	Durban City Council (PESU)
Mr M Braune	-	SRK Consulting Engineers
Mr BL Kisch	-	Silk Kisch Peralta cc, Consulting Engineers
Mr C Nel	-	Stormwater Cleaning Systems (Pty) Ltd
Mr PD Townshend	-	Urban Water

iii) My fellow authors: Mr Christo Nel who provided much of the data on litter loads in South Africa and the material on the Stormwater Cleaning Services (SCS) device; Mr Peter Townshend who provided the material on the Urban Water Environmental Management (UWEM) concept and hydraulically actuated sluice gates; and especially Prof Albert Rooseboom who managed the project and continually provided valuable advice.

iv) The Universities of Stellenbosch and Cape Town who made students and laboratory resources available and allowed Prof Albert Rooseboom and myself to spend considerable time on the project. University of Cape Town further funded my attendance at the 1st International Conference on Sewer Solids, Dundee, UK, 1995 which helped the team to redirect and focus the research effort.

v) The many students of both universities who carried out many of the laboratory studies. Particular thanks must go to Mr Cobus Compion who covered a lot of ground in the course of his MIng thesis at the University of Stellenbosch. A complete list of students who provided input into the project is as follows:

Mr C Compion	University of Stellenbosch
Ms C Visagie	ditto
Mr LJ Uys	ditto
Mr JA Wilsenach	ditto
Mr LC Louw	ditto
Messrs Burger & Beeslaar	ditto
Mr W Furlong	University of Cape Town
Mr D Watson	ditto
Mr A Lawson	ditto

vi) Ms Gael Arnold, Director of Island Care New Zealand Trust, who provided valuable information on New Zealand experience and opened the door to the work being carried out in Melbourne. Her enthusiasm for litter reduction lives on in the Marine Litter Network founded by her in Cape Town during the time she was working with the University of Cape Town.

vii) Dr Robin Allison, former PhD student at the University of Melbourne, played a major part in the advancement of this project. Not only did his thesis *"Effective Gross Pollutant Removal from Urban Waterways"* provide much valuable Australian data, but he also helped to organise my very successful field trip to Australia in 1996 and he provided a lot of helpful comments on the draft reports

viii) The large number of Australians working in the field who so generously assisted me on my field trip there in 1996. They included:

Dr R Allison	formerly University of Melbourne
Dr D Fabian	Monash University
Dr D Phillips	Swinburne University of Technology
Mr M Hall	PG student, Swinburne University of Technology
Mr D Vallance	Melbourne Parks & Waterways, Waterways Division
Mr GR Rooney	Melbourne Water Corporation
Mr S Seymour	Melbourne Water Corporation
Mr Tony Welsh	Bandalong Engineering
Mr P Blanche	CDS Technologies Pty. Ltd
Mr S Crompton	CDS Technologies Pty. Ltd
Mr S Thomas	Banyule City Council
Mr C Rose	Banyule City Council
Mr K Cloos	ACT Department of Urban Services - Stormwater
Mr M Al-Hajjiri	ACT Department of Urban Services - Stormwater
Mr P Bennett	Baramy Engineering Pty. Ltd
Mr D Dunkerley	Sidney Water, Stormwater Systems Management
Dr BC Phillips	Willing & Partners
Mr R Brownlee	North Sydney Council
Ms J Hocking	North Sydney Council
Dr S Beecham	University of Technology, Sydney

Neil Armitage PrEng, CEng
Principal Author, University of Cape Town, May 1998

1. Introduction

1.1 Background

In years to come, archaeologists sifting through the remains of late twentieth 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 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 surrounds 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 stormwater run-off 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; and
- Significant costs are incurred by local authorities in conducting clean-up operations.

The purpose of this document is to discuss the most appropriate and cost-effective methods of removing the litter from the drainage system. It should be emphasised that the findings are still somewhat tentative in view of the limited operational experience of many of the structures described herein.

1.2 Definition of litter

Many different types of litter have been identified by researchers eg. Allison et al, 1996, Island Care New Zealand Trust, 1996, or Nel, 1996. A simplified classification system is proposed below:

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

Following the classification suggested by the Neville Jones - Willing & Partners Consulting Group, 1996, we could categorise this 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 - is only addressed in passing in this report. The removal of these silts from the natural environment is of great concern in some parts of the world as they may contain potentially dangerous concentrations of heavy metals, nutrients and pesticides of human origin. Much of the enormous capital investment made, for example, in Australia into so-called Gross Pollutant Traps - GPTs, has actually been with a view to trapping these sediments. These sediments are then dried and removed to hazardous waste land-fill.

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 chose litter removal structures that minimise the trapping of sediment. This difference in approach must be remembered when some of the Australian technology is considered later on in this report.

Although South Africa is a world leader in waste water treatment and most residential and industrial waste water is conveyed to an appropriately designed waste water treatment plant, 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. Given the existing financial restraints, this situation is unlikely to change in the foreseeable future.

Given the emphasis in South Africa on the removal of the larger pollution elements, the focus of this report will be on addressing the problem of primary pollution - litter. In the context of this report, **litter** is defined as **visible solid waste**.

1.3 The South African litter problem

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;
- the imposition of unwanted packaging on unwilling consumers;
- 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;
- a 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. Litter is less evident in the streets of Harare and Bulawayo than those of Johannesburg and Durban. In general, this is 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 of 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. As its population grows and becomes more urbanised, **the problem is likely to get worse before it gets better**.

1.4 The scope of the problem

According to the President's Council Report, 1991, South Africa at that stage was producing some 40 million tonnes of solid waste annually - mostly of domestic origin. A large portion of this amount was street litter, much of it packing material.

Nearly all solid waste pollution in our river systems is derived from the urban areas although they comprise only 5,6% (± 6 000 000 ha) of the land area of South Africa (President's Council Report, 1991). According to the CSIR, 1991, some 780 000 tonnes of waste was then entering the drainage system every year, of which about 195 000 tonnes reached the sea. The amount of waste being generated in South Africa is almost certainly increasing. The exact breakdown of the waste by category is not known - nor is its impact on the environment.

By way of comparison, at the time of above studies, the recycling of glass, paper and tins only accounted for 23 000 tonnes, although this amount is also on the increase.

South Africa is not the only country with this sort of problem. Local governments in Texas, for example, spend upwards of US$14 million per annum to clean their beaches (Baur and Iudicello, 1990). Allison, 1997 recently estimated that 230 000 cubic metres or 1,8 billion items of litter (approximately 60 000 tonnes of wet material) annually enters the waterways of greater Melbourne.

Legislation alone is insufficient to control littering (Knoetze & McDonald, 1991). There are insufficient resources available to enforce the law, and the majority of offenders cannot be traced. The situation is particularly bad in the sub-economic communities where solid waste services are often not functioning properly and the inhabitants are more concerned with survival than environmental protection.

It is therefore clear that the **strategy** for the removal of litter from the stormwater system will have to be two-pronged, **aiming to reduce the quantity that finds its way into the system** in the first place, as well as **removing the balance as efficiently as possible.** This report focuses mainly on the latter.

It should be emphasised that the report only describes the current "state of the art". It comprises a survey of some of the approaches that have been adopted around the world - particularly in Australia and South Africa - and describes extensive physical modelling undertaken at the Universities of Stellenbosch and Cape Town. From this research, it has become apparent that there are no cheap or easy solutions to the problem of litter removal. The most satisfactory way of reducing the amount of litter in the environment is to reduce it at source.

In addition to discussing the implications of research carried out locally and abroad, the report describes a number of litter removal structures - some successful, others less so. Most of the more successful structures have been patented and are available only from approved suppliers. Mention of a trade name does not indicate that the Water Research Commission or the authors necessarily support the product in question. They are described in this document in an attempt to show designers the sort of features to look out for in litter removal structures, and to indicate some of the better options currently available "off the shelf". There may of course be other structures, not described in this document, that might remove litter from drainage systems more efficiently and effectively than those described herein.

1.5 The format of this report

This report has been structured in the following way:

Section 2 presents measurements and estimates made in South Africa and Australia into the quantity and types of litter being carried by stormwater systems in those two countries.

Section 3 focuses on some ways of preventing litter from getting into the drainage system in the first place, then goes onto to describe the ideal litter trap and some of the difficulties experienced in the trapping of litter.

Section 4 describes some of the model studies carried out at the Universities of Stellenbosch and Cape Town into the optimum design of litter traps.

Section 5 outlines the search for a self-cleaning screen including additional work carried out at the Universities of Stellenbosch and Cape Town.

Section 6 looks at some of the problems associated with in-line screens, and describes some of the more successful designs.

Section 7 deals with the use of booms and baffles to deflect and trap litter with reference to a few examples.

Section 8 raises the possibility of using detention / retention ponds and wetlands as an opportunity to remove litter

Section 9 looks at problems associated with vortex devices and describes one of the more promising designs.

Section 10 summarises the outcome of the research and describes the current best available technologies.

Section 11 proposes a method of selecting and locating litter trapping systems

Section 12 discusses future research needs.

The following information is contained in the Appendices.

Appendix A lists the available information on some of the more promising 'Off-the-shelf'' devices for the removal of litter

Appendix B shows how trap selection might be performed on an hypothetical catchment

Appendix C provides some background information on the operation of hydraulically operated sluice gates

2. The amount of litter coming off urban catchments

2.1 Introduction

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 the trap must hold together with the 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, ie. 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, ie. does the rain come in one season only or all the 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 majority of "litter" collected in traps. Some species of trees cause more problems than others eg. 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 don't, for example, sweep or flush the street litter into the stormwater drains as so often happens in South Africa;

the level of environmental concern in the community - leading to, for example, reduction in the use of certain products, and the recycling of others;

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 Figure 2-1:

(a) Mixed commercial / residential site

(b) Residential site

(c) Light Industrial Site

(d) Downstream site

Figure 2-1 : Composition of collected gross pollutants by dry mass from different catchments in Coburg (after Allison & Chiew, 1995)

Often, a single shop or factory eg. 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**.

2.2 The Springs study

Probably the most comprehensive measurement of the types and quantities of litter coming off South African catchments was that carried out over a period of four months starting from 1 December 1990 and ending 31 March 1991 for the Central Business District (CBD) of Springs (Nel, 1996).

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 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. This structure will be described in greater detail in Section 5.5.

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 volumes were adjusted to a standard density of 95 kg/m^3.

Estimates of the runoff from each storm were calculated by multiplying the area of the catchment by the depth of rainfall measured by the City Council of Springs multiplied by a runoff factor of 0,4. The town has a mean annual precipitation (MAP) of about 750 mm and falls within the summer rainfall region of South Africa.

The volumes of solid waste trapped by the structure are detailed in Table 2-1.

In addition to the above, fourteen samples of litter trapped in the structure were removed and analysed. A typical analysis of the litter in the samples expressed in terms of the average number per cubic metre, the percentage of volume, the average number per storm, the maximum number per cubic metre, and the minimum number per cubic metre is given in Table 2-2.

Some more unusual items trapped by the structure included items of clothing, hand bags, stockings, tyres, car number plates, dead dogs and cats, oil cans, and oil filters.

Figure 2-2 shows the breakdown in types of litter in the form of a pie-chart. 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.

Date	Day No.	Rainfall (mm)	Volume removed (m^3)	Volume runoff (x 1 000 m^3)	Volume removed per storm (m^3)
1/12/90	1				
3/12/90	3	2		2	
4/12/90	4	2		2	
5/12/90	5		4		2
6/12/90	6	26		31	
7/12/90	7	16		19	
10/12/90	10		5		2,5
12/12/90	12	14	4	17	4
13/12/90	13	7	3	8	3
14/12/90	14	28		34	
17/12/90	17	25		30	
18/12/90	18		4		2
24/12/90	24	3		4	
30/12/90	30	5	5	6	2,5
1/1/91	32	5		6	
3/1/91	34	4	11	5	5
7/1/91	38	14		17	
8/1/91	39	10		12	
9/1/91	40		6		3
10/1/91	41	16		19	
15/1/91	46	24	10	29	5
17/1/91	48	2		2	
24/1/91	55	14		17	
28/1/91	59		5		5
30/1/91	61	14		17	
31/1/91	62	109		131	
1/2/91	63	10	8	12	2,7
4/2/91	66	10		12	
7/2/91	69		4		4
8/2/91	70	7		8	
11/2/91	73	13		16	
12/2/91	74		3		1,5
18/2/91	80	88		106	
21/2/91	83		12		12
25/2/91	87	7		8	
27/2/91	89		4		4
4/3/91	95	65		78	
5/3/91	96		8		8
6/3/91	97	9		11	
7/3/91	98	18		22	
11/3/91	102	6		7	
14/3/91	105		6		2
17/3/91	108	40		48	
18/3/91	109	55		66	
19/3/91	110		4		2
31/3/91	122				
Total	122	668	106	802	

Table 2-1 : Volumes of solid waste from the Springs CBD Catchment trapped over the period 1 December 1990 to 31 March 1991 (after Nel, 1996)

Item No.	Description	No. per m^3	% of volume	No. per storm	Max. no. per m^3	Min. no. per m^3
1	Tin cans	267	9,7	890	383	106
2	Glass bottles	14,8	2,1	49	60	0
3	Plastic bags	1 660	47,3	5 533	2 333	660
4	Plastic containers	10,2	10,2	34	27	0
5	Plastic bottles	99	5,1	332	143	0
6	Straws	153	negl.	512	203	50
7	Paper	1 227	7	424	403	33
8	Cartons	95	3	317	300	0
9	Matches	8,8	negl.	29	40	0
10	Polystyrene blocks	196	10,8	655	423	33
11	Stalks	11	negl.	37	37	0
12	Plastic nets / straps	7,1	negl.	11	37	0
13	String / rope	1,4	negl.	5	7	0
14	Pens / pencils	4,8	negl.	16	60	0
15	Bottle tops	21	negl.	70	47	7
16	Sponges	5,5	negl.	18	23	0
17	Music cassettes	negl.	negl.	2	2	0
18	Blocks of wood	6,4	negl.	21	27	0
19	Bones / skeletons	3,6	negl.	12	12	0
20	Tennis balls	2,1	negl.	7	7	0
21	Tissue boxes	2,4	negl.	8	10	0
22	Plastic utensils	6,7	negl.	22	27	0
23	Spray cans	3,3	negl.	8	10	0
24	Other		4,8			
	Total	2 709	100	8 982		

Table 2-2 : Analysis of litter commonly found trapped in the Springs structure, measured by volume (after Nel, 1996)

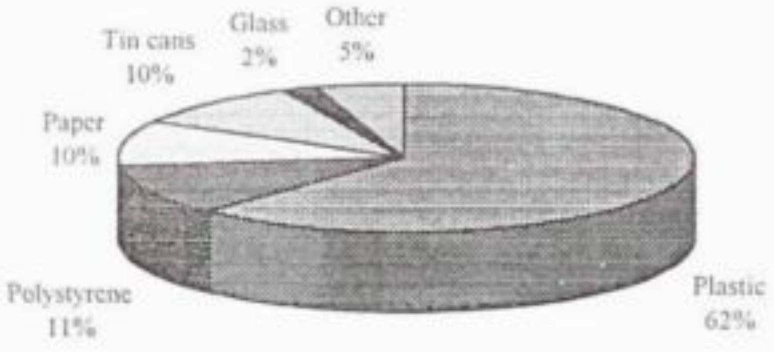


Figure 2-2 : The types of litter trapped by the Springs structure (after Nel, 1996)

A total of 106 cubic metres of litter, transported by 32 separate storm events, was removed from the structure over the 122 day 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 per year (3,3 m^3 per 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 per year (at a density of 95 kg/m^3) currently finds its way past the structure into the Blesbokspruit.

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

Springs is in a summer rainfall area. An average litter volume of 12 m^3 per 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 comprises 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 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 per year (at a density of 95 kg/m^3, ie. about 550 kg/ha per year) in the commercial / industrial area of Springs. 1,0 m^3/ha per year (at a density of 95 kg/m^3, ie. about 95 kg/ha per year) is washed into the stormwater system. If we add back the residential area, then the rate of deposition is 4,9 m^3/ha per year (470 kg/ha per year) with 0,86 m^3/ha per year (82 kg/ha per year) ending up in the canal.

2.3 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, Orphiton 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, capable of handling a flow of 15 m^3/s before partial bypassing commenced, 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%. It is described in greater detail in Section 6.6.

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 rains. Typically 70 to 100 bags were collected from ongoing storms, the larger amount being associated with longer periods between storms (more than 10 days).

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 are 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 ie. 95 kg/m^3, and there are also about 56 storms a year, then this implies that approximately 0,50 m^3/ha per year (ie. about 48 kg/ha per year) is washed into the stormwater system from this part of Johannesburg.

2.4 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 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 per year (31 kg/ha per year assuming a density of 95 kg/m^3). The efficiency of the structure is unknown, but is undoubtedly less than 50%. If we assume a trap efficiency of 50%, then 0,66 m^3/ha per year (63 kg/ha per year assuming a density of 95 kg/m^3) is washed off the catchment.

Including the residential component in the calculation reduces the wash-off rate to 0,28 m^3/ha per year (26 kg/m^3 per year).

2.5 Australian and New Zealand 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 ie. sewage and stormwater are mixed together and transported directly to the waste water treatment works in all except severe storms.

Some work into aquatic litter removal has been conducted in the UK, USA and Canada, but by far the greatest research effort to date, relevant to South African conditions, seems to have been carried out by the Australians, and to a lesser extent the New Zealanders (generally using Australian technology). Australian technology has particular relevance to South Africa because the climates are similar and the Australians also use "separate" systems ie. 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.

2.5.1 The Merri Creek study, Melbourne

Late in 1986, the Merri Creek Co-ordinating Committee (a joint community and local government group) approached the Board of Works, Melbourne and the Victorian Environmental Protection Authority to request support for an investigation into the litter problem on the Merri Creek. Merri Creek is a major tributary of the Yarra River and flows through the northern suburbs of Melbourne.

A working group was established with representatives from the three bodies, and one of the eight local municipalities (Coburg) agreed to provide logistical support for the project. The resultant study is detailed in the publication "Litter Control in Urban Waterways" (Board of Works, Melbourne et. al., 1989), which was a land-mark study in Australia. The study involved the identification of litter types and sources, assessment of a variety of simple litter trap devices and the development of recommendations arising from these investigations and associated observations.

The area selected for the study comprised the catchments of three underground drains discharging into Merri Creek. In addition to trapping litter from these underground drains, a floating litter boom was installed on Coburg Lake, a small water feature on Merri Creek (Senior, 1992).

Although the trapping devices were crude and generally inefficient, and although monitoring took place over fairly limited time periods, it was possible to establish that there is a strong correlation between the land-use and the type of material being trapped. Altogether, 2 231 items of litter were collected and separated into paper, plastic, aluminium cans, glass and miscellaneous. Plastic based products comprised 66% (by item count) of the total litter collected. Paper items comprised 21% of the total litter count.

The report concluded that a significant component of plastic-based litter in waterways is due to poor handling and disposal techniques in industrial and commercial areas Pedestrians and motorists were also identified as being the "most probable" major source of litter (Board of Works, 1989)

The Merri Creek study has proved to be a landmark in pollution identification and control as it suggested methods of pollution mitigation which have been taken up in further studies. Some of the recommendations will be discussed further in Section 3.2.

2.5.2 The Coburg study

The Merri Creek study also laid the groundwork for an in-depth study of litter deposition and removal in the Coburg catchment as part of a PhD thesis (Allison, 1997). The study was almost certainly the most comprehensive to date carried out by anyone anywhere. It has already been alluded to in Section 2.1 above.

The location for the field experiments was a 50 hectare catchment encompassing some 35% commercial (shopping centre, library and fast food outlets) and 65% residential (middle income single storey dwelling units at a density of about 10 units per hectare) land-uses Side-entry catchpit traps (see Section 6.2) were placed in all 192 road entrances to the drainage system (some privately owned outlets - mainly carrying discharges from roofs - were not trapped). A CDS device (see Section 5.9) was installed on the single 1 220 mm diameter outlet to the catchment site

Field trials on the CDS device indicated that almost 100% of all material larger than 4,7 mm (the aperture size of the separation screen) was trapped, and a considerable percentage of material much smaller than this.

Data from the study appeared to indicate that an average of approximately 30 kg/ha per year dry (100 kg/ha per year wet) or some 0,4 m^3/ha litter per year is washed off Melbourne urban catchments This amounts to a total of 230 000 cubic metres or 60 000 tonnes (wet) per year. However, as much as 80% of this material is leaf matter Ignoring the leaf matter would give a loading rate of 6 kg/ha per year dry, 20 kg/ha per year wet, or 0,08 m^3/ha per year See Figure 2-1 for the breakdown of types of material by catchment type.

2.5.3 The North Sydney Council Litter Control Device programme

Commencement of the North Sydney Council Litter Control Device programme began in May 1992 after strong pressure from the community to address the problem of "polluting stormwater drains". By 1995, nine litter control devices accounting for a total catchment area of 322,5 ha had been installed. The catchment is highly urbanised and includes commercial, residential and industrial components (Brownlee, 1995).

The devices (see Section 6.5) were designed to trap particles with a minimum dimension of greater than 20 mm. A litter data collection programme was implemented to enable the Council to determine their effectiveness and efficiency. Initially the traps were emptied every 4-6 weeks or after a storm event. The litter was then sorted into three distinct categories: floatables, organics and sediment. The 'floatable" category corresponds most closely to our definition of litter.

Over the period February 1993 to February 1995, the traps only caught an average of 109,3 m^3 of material of which only 6,2 m^3 was classified as 'floatable". This represents a litter wash-off rate of 0,019 m^3/ha per year (1,8 kg/ha per year at an assumed density of 95 kg/m^3). By way of comparison, the volume of organics, mainly leaves and grass clippings, amounted to 35,6 m^3, whilst the sediment, which was bound up in the other two components, amounted to 67,5 m^3.

Between February and June 1996 however, one of the traps (Smoothey Park) was cleaned more frequently to ensure that it was as empty as possible before the commencement of the next storm. This increased the volumes of material trapped by the device by 192% (Hocking, 1996)! This illustrates the unreliability of much of the data on litter wash-off rates.

The relative proportions of the three different components trapped by the Smoothey Park device was not reported.

2.5.4 The Auckland Study

This study was intended to provide information concerning discharges of litter from the Auckland stormwater drainage system into the Hauraki Gulf. The programme included sampling from commercial, industrial and residential catchments on the assumption that there would be differences in the composition of debris discharged from stormwater networks draining areas of differing land use (Cornelius et. al., 1994).

Nine outfalls were sampled, three each from the basic land use types. The litter traps were constructed of 22 gauge welded wire mesh with a mesh size of 19 mm. They were connected to the stormwater outfalls in December 1992 and were cleared at approximately weekly intervals through to the end of November 1993.

Converted to annual figures and assuming a density of 95 kg/m^3, the results of the study indicated the following litter loading rates:

commercial = 1,35 kg/ha per year (0,014 m^3/ha per year)
industrial = 0,88 kg/ha per year (0,009 m^3/ha per year)
residential = 0,53 kg/ha per year (0,006 m^3/ha per year)

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.

Also of significance is the dramatically lower loading rates for Auckland compared with South African data.

2.6 Conclusions

In Section 2.1, it was mentioned that the amount and type of litter coming off urban catchments is extremely variable and depends on a large number of independent factors. This is borne out by what little data is available. If the data presented in Sections 2.2 - 2.5 above is reliable, **litter wash-off rates appear to vary from about 0,53 kg/ha per year for the residential areas in Auckland, to about 96 kg/ha per year for the CBD of Springs**.

In reality, none of the trapping devices used to obtain the data in Sections 2.2 - 2.5 above are 100% effective, and many may be less than 50% efficient in the trapping of litter. The efficiency may also vary 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 (ie. 100 times) worse. This is presumably a combination of many factors, but is probably mostly as a result of **the lack of proper 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 local exceptions to this.

Plastics are by far the biggest single problem.

2.7 Recommendations

There is likely to be a much greater benefit in trying to **reduce the production of litter than by trying to trap it all once it has got into the drainage system**. A survey of municipal street cleaning methods among 54 councils in the metropolitan area of Melbourne by the Board of Works, Melbourne in 1990 showed that 67% of municipalities then 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 (Senior, 1992). In other words, the cleansing departments of many municipalities are part of the problem rather than being part of the solution! Nevertheless, some litter will always escape into the drains, and for this reason, **litter removal structures will always be required in and around urban areas**.

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 (Nel, 1996) and Robinson Canal data, is tentatively suggested for South Africa until such time that better data is available:

$$T = \Sigma f_{sci}.(V_i + B_i).A_i \qquad \textbf{(Equation 2-1)}$$

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

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 per year for poorly
vegetated areas to about 0,5 m^3/ha per year for
densely vegetated areas)

B_i = basic litter load for each land use
(commercial = 1,2 m^3/ha per year
industrial = 0,8 m^3/ha per year
residential = 0,01 m^3/ha per year)

A_i = area of each land use (ha)

The data from Coburg, Australia suggests 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 suggests 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 (Nel, 1996) and Robinson Canal data, is tentatively suggested for South Africa until such time that better data is available:

$$S = f_s.T/\sum f_{si} \qquad \textbf{(Equation 2-2)}$$

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)

$\sum f_{si}$ = 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)

3. Alternative approaches to the removal of litter

3.1 Introduction

In the previous section, the huge variability in the types and amounts of litter coming off different catchments was presented. For example, if the figures are to believed, South African catchments produce from ten to one hundred times as much litter per hectare as do Australian and New Zealand catchments. If the Australian and New Zealand public are concerned about litter along their waterways and on their beaches - and they are extremely concerned - how much greater should be the concern in South Africa?

What is the solution?

It was pointed out in Section 1 that litter is a problem associated with human habitation. Section 2 concluded with the following points:

1. There isn't a proper environmental ethic in South Africa;
2. The level of litter removal service offered by many local authorities is poor;
3. Plastics are by far the biggest problem;
4. There is likely to be a much greater benefit by trying to reduce the production of litter than by trying to trap it all once it has got into the drainage system;
5. Some litter will always escape into the drains, and for this reason, litter removal structures will always be required in and around urban areas.

Although it would undoubtedly be preferable to prevent littering altogether, this will be an unachievable goal in South Africa for the foreseeable future. Much, however, can and should be done to reduce the quantity of litter that finds its way into the stormwater drainage. In consequence, although it falls outside the strictly defined purpose of this report, some attention will first be given to preventing the litter from entering the stormwater system. Then, acknowledging that some litter will always escape into the drains, attention will be focused on the ideal trapping structure and some of the difficulties experienced in the capture of litter.

The section is set out as follows:

3.2 Some ways of preventing litter from getting into the drainage system.

3.3 The ideal litter trap.

3.4 Some of the difficulties experienced in the trapping of litter.

Some candidate trapping methods are described in later sections of this report.

3.2 Some ways of preventing litter from getting into the drainage system

3.2.1 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, local authorities in South Africa almost always allow some form of unrestricted overflow even when grids are provided. This is seen most clearly on the standard designs of kerb inlets used in this country. 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 shanty towns 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).

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. Traps may then be placed on the reduced number of open entrances.

3.2.2 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 et. al., 1993; Hall, 1996; Allison, 1996) 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 catch-pits. **Use the evidence provided by litter trapped in the catch-pits to identify the polluters who may then 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 pathway 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).

  Use the results of similar evaluations to develop guidelines and recommendations which would minimise the amount of litter entering the stormwater drainage system;

- **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 before and after polystyrene and plastic items - that is unused, and recovered from river litter traps, respectively. Also prominent among a number of large litter photographs was an enlarged close-up of a litter boom which illustrated many recognisable items. This was provocatively captioned "Do you really want your product advertised in this way?" (Senior, 1992).

- **Try to 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** eg. 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 unemployed 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**.

At present it is very difficult for the Government to institute effective control measures (Davies 1991). A basic requirement for the success of any new environment management system is the support of the majority of citizens.

Unless South Africans adopt a new credo with respect to nature, no new policy or programme, no matter how good, will succeed in protecting our natural heritage (President's Council Report, 1991).

3.3 The ideal litter trap

Since, at this stage anyhow, litter cannot be eliminated from the drainage system, attention must now be focused on the possibility of placing traps in the waterways in such a way that the litter is efficiently trapped and removed. According to Nel, 1996, the ideal trap should have the following features:

- it should be economical to construct and operate;

- it should have a simple operation;

- it should have no moving parts;

- it should not require an external power source;

- it should be robust;

- it should be able to handle widely varying flow-rates;
- it should have a high removal efficiency;
- it should never block;
- it should be reliable;
- it should be safe eg. for children playing in the vicinity;
- it should not constitute a health hazard eg. by providing a breeding spot for mosquitoes and flies;
- it should not increase the flood hazard in the vicinity of the structure ie. it must not cause substantial damming of the water;
- it should only require minimal maintenance;
- it should require minimal water head ie. it can be used in association with flat gradients;
- it should be easy to clean, eg. by collecting all the litter in a central point for removal by the local authority; and
- it should be unattractive to vandals.

Nothing fulfilling all these criteria currently exists. All known structures represent some sort of compromise. It is the designer's task to choose the most appropriate structure to fit the circumstances. Ideally this should fit into a total litter removal strategy which takes into account a number of actions in line with those suggested in 3.2 above.

3.4 Some of the difficulties experienced in the trapping of litter

The biggest problem faced by anyone trying to design a structure to trap litter is that litter can be just about anything - any size, any shape, any density, any hardness. Furthermore, the characteristics of a single item often change as it moves through the drainage system.

Consider, for example, the behaviour of plastic shopping bag, probably the biggest contributor to the pollution of our waterways. When discarded by its owner - or displaced from a rubbish bin - it is generally more or less rectangular and full of air. Therefore it is readily blown by the wind or washed away into the stormwater system.

Once in the drain, the turbulence along its passage causes the air to be displaced and partly replaced by water. In consequence, the bag starts to float lower and lower and on more and more occasions is dragged below the surface. It starts to deform in such a way as to present the most streamlined profile to the ever-changing fluid flow. Interaction with other objects might also tear it into shreds, or weigh it down so that in calmer waters it is deposited temporarily on the bottom of the channel.

By the time it reaches the trapping device, it can have virtually any shape, and its effective density can vary over a wide range. It is capable of flattening itself over several bars causing considerable blockage or "blinding". Alternatively it may wind itself around one bar - or distort itself into the form of a streamer and slip between the bars.

Similar sorts of patterns are exhibited by other litter elements. Bottles may be full of air, full of water, or broken. Aluminium cans may change their shape as they are knocked around. Branches of trees break up and so forth....

For convenience, litter moving down an open channel is often considered as belonging to one of three fractions:

- **Bed-load** - ie. rolling or sliding along the floor of the channel,
- **Suspended material** - ie. drifting somewhere in-between the floor of the channel and the surface of the stream, and
- **Flotsam** - ie. material floating on the surface.

This division is somewhat arbitrary, as it can be shown (eg. Rooseboom, 1992) that solids carried in a water matrix can adopt just about any position depending on the power applied by the stream. In simpler terms, at any particular moment a piece of litter is either more or less dense than water so it will either tend to sink or float respectively. However, the turbulence that is always present in running water tends to force everything into suspension. If it is also remembered that many forms of litter continuously change their effective densities as they are transported through the drainage system, virtually any combination of the above fractions is possible.

It therefore appears that the division of material into bed-load, suspended material and flotsam is not a particularly helpful classification. Although metallic objects generally move along the bottom, and pieces of polystyrene generally float, virtually everything else can be anywhere in the water column depending on the applied stream-power.

Three more useful characteristics are size, density and settling velocity.

- The **size** of a particular type of litter eg. an aluminium can, plastic bottle, or plastic shopping bag - is reasonably constant except, of course, when it is broken.

- Although the **density** of a particular item of litter often changes as it moves down the drainage system, it generally tends asymptotically to some reasonably constant value which will determine whether, in slow moving water, it will either float to the surface or sink to the bottom.

- **Settling velocity** is a function of size, density and shape factor (which is a measure of how streamlined a particular object is), electrical charge, viscosity and concentration (see for example Raudkivi, 1990). The higher the settling velocity, the more likely the object under consideration is to be found near the bottom of the water column. The more negative it is, the more likely it is to be found near the surface. Although settling velocity is clearly highly variable, it is probably the single parameter that is the most useful and easiest to measure.

It is the high degree of variability that makes it extremely difficult for the designer to design a structure that will cater for every eventuality. Many structures work extremely well in low flows, but not in high - or vice versa - or work well with certain types of litter, but not others. Some pose major maintenance problems. Most structures constructed in South Africa to date have achieved limited success.

Attention is now turned to candidate trapping devices.

4. Some model studies

4.1 Introduction

This series of model studies into the optimum design of litter traps was conducted at the Universities of Stellenbosch and Cape Town between 1994 and 1997. Seven are discussed here under the following section headings:

4.2 Visagie, 1994 (US - BIng thesis)

4.3 Uys, 1994 (US - BIng thesis)

4.4 Wilsenach, 1994 (US - BIng thesis)

4.5 Furlong, 1995 (UCT - BSc(Eng) thesis)

4.6 Louw, 1995 (US - BIng thesis)

4.7 Burger and Beeslaar, 1996 (US - BIng thesis)

4.8 Compion, 1997 (Part 1) (US - MIng thesis)

Three others will be discussed under the topic of self-cleaning screens in Section 5.

4.2 Visagie, 1994

The motivation for this entire report was originally as a consequence of problems that the Cape Town City Council (CCC) had had with a litter trap that they had built on the Vygekraal Canal in Athlone Park.

The structure was originally conceived by Arnold and Walker of CCC Drainage and Sewerage Branch. The concept was taken up by Obree of CCC who discussed it with Rooseboom of Stellenbosch University in August / September 1991. Rooseboom then arranged for some basic model testing of the concept as part of an undergraduate project by Geldenhuys. The test results were sufficiently encouraging for CCC to embark on larger scale modelling, which was carried out by Drainage and Sewerage branch staff at the Athlone Treatment Works in May 1992.

The concept called for the litter in the flow to be directed towards one wall of the canal by means of a grating positioned at a slight angle to the flow direction. An opening in the wall would allow the passage of the litter into a specially constructed sump alongside the canal.

As a result of the large scale tests, it was decided that the deflector grating should be broken up into a series of smaller overlapping screens (effectively horizontal rods) of similar proportions, each with free ends. This obviated the need to use supporting fixtures (which could snag passing debris) in view of the length of the deflector grating required. The free end concept had already been developed and successfully applied in Springs (see Section 5.5). The tests also provided the basic information required for full scale design, such as the angle of deflection needed to avoid sticking of debris, and showed that under steady flow conditions and with the type of litter tested the system worked well.

A full size installation was then designed for use upstream of the recently built Athlone Park Detention pond on the Vygekraal Canal. The work involved the installation of 36 m of horizontal screens and the construction of a 10 m diameter litter accumulation sump, and was completed in June 1993. The structure was called an "Enviroscreen" for simplicity and for public relations reasons. See Figure 4-1

Figure 4-1 : View of the Vygekraal Canal "Enviroscreen"

At the same time, Consulting Engineers Silk Kisch Peralta designed a second "Enviroscreen" for the Durban City Council for installation on the Mullet Stream just prior to its discharge into Durban Bay. This design was carried out in early 1993, construction followed, and by September the installation was complete. Cleaning of the Mullet Stream sump was to be effected by the installation of a specially designed "fishing net" attached to a lifting ring (see Figure 4-2).

Figure 4-2 : View of the Mullet Stream "Enviroscreen" showing the net and lifting ring provided to remove the litter from the sump

Although both "Enviroscreens" satisfactorily prevented the transportation of litter downstream, litter tended to stick onto the screens rather than be deflected into the sumps as intended - particularly at low flows. The screen only deflected litter at high flows if there was no initial accumulation on the screens. Once deposition on the screens began, the flow direction was affected and the deposits rapidly increased.

If the litter had been deflected into the sump, not only would its removal have been easier, but maintenance intervals would have been controlled by the volume of the sump - which could be designed to accommodate litter from several storms. The reality was however that the continued effectiveness of the structure relied on the removal of accumulated litter after every storm event, which imposed a heavy maintenance burden. Fortunately, the enormous surface area of the screens meant that fairly large volumes of litter were trapped before the screens were blinded and overtopped (Obree, 1993).

CCC then approached the University of Stellenbosch with a request that the university carry out the appropriate experiments to examine the possible causes of the problems identified in the prototype, and identify possible solutions. The small-scale model that was constructed at the University of Stellenbosch is shown in Figure 4-3.

Figure 4-3 : View of the "Enviroscreen" model

The study clearly showed that the performance of the structure could be improved by the construction of a low weir a short distance downstream of the screen. The effect of this weir was to reduce the average flow velocity through the screen - particularly at low flows. This reduced the head loss across the screen, which in turn reduced the tendency for litter to be pinned against it giving more opportunity for the litter to drift into the sump. The higher the weir the better as this reduced the average flow velocity still further, but of course this also increased the danger of upstream flooding. The shape of the weir was also shown to be important. Better results were obtained when the flow was concentrated down the centre of the canal by means of a central drop-section.

The structure was shown to be particularly vulnerable to large concentrations of litter coming down the canal. In this instance the litter tended to clump together against the screen, or between the downstream end of the screen and the canal wall.

4.3 Uys, 1994

Concerns over problems caused by the blocking of screens prompted a series of exploratory investigations into structures that did not use them at all. Attempts were instead made to reduce the average flow velocity to a point where the suspended material divided into flotsam and bed-load material which could be separated by means of suspended baffle walls and weirs respectively. This was the basis of model studies by Uys, 1994 and Wilsenach, 1994 (see Section 4.4).

In an attempt to save as much space as possible, Uys split the flow in two around the separation structure, and then turned the two streams inwards through almost 90° to pass under a long baffle wall. A low weir in the downstream channel ensured that the opening under the baffle-wall was always under water.

Although the structure seemed to show considerable promise whilst the flow rate was reasonably low, as soon as the flow rate increased above a certain critical value the increased turbulence re-entrained the scaled litter particles and passed them through the trap and into the downstream canal. Some improvement in retention was achieved by the addition of a second baffle-wall and an intermediate weir on either side, but in general the concept was a failure. Figure 4-4 shows a view of the improved model. Figure 4-5 shows a cross-section through it.

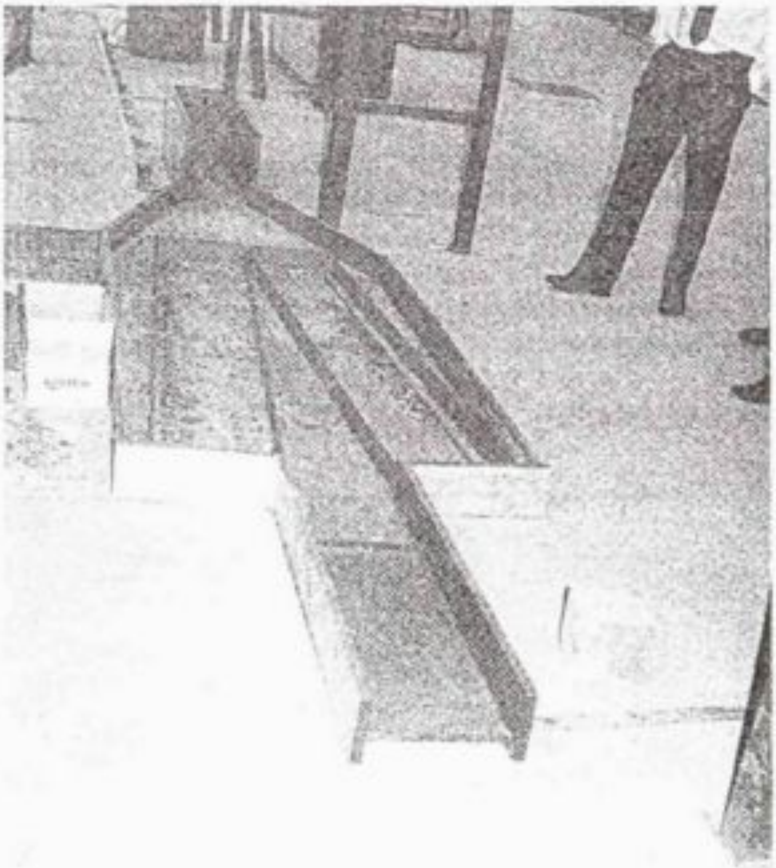


Figure 4-4 : View of the improved Uys model (flow from top to bottom)

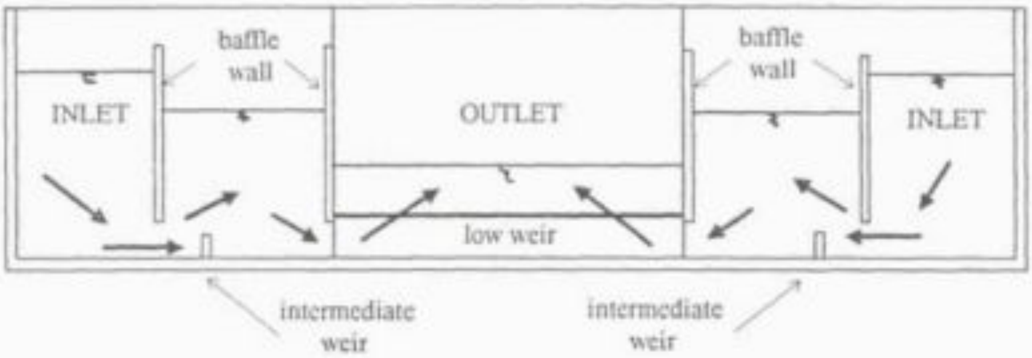


Figure 4-5 : Cross-section through the improved Uys structure

4.4 Wilsenach, 1994

In the Wilsenach structure, longitudinal slots were located at approximately mid-height along both walls of the inflow channel. This channel ended with a blank wall. The hope was that the bed-load and flotsam would be desegregated as a result of the reducing velocity in the central channel and be trapped there. The slots would allow the relatively litter-free mid-depth water out of the inflow channel into outflow channels constructed on either side of, and parallel to the inflow section. A downstream weir would keep the water depth in the inflow channel within narrow limits.

Problems were immediately encountered with turbulence in the inflow section as a result of the torturous path the water had to follow through the slots and into the side-channels. The turbulence was particularly severe in the vicinity of the stop-end, The addition of flow deflectors, flow straighteners, and a second weir parallel to the flow direction helped to improve the performance of the trap, but the result was an extremely complicated structure (see Figures 4-6 and 4-7). Once again the concept was considered a failure.

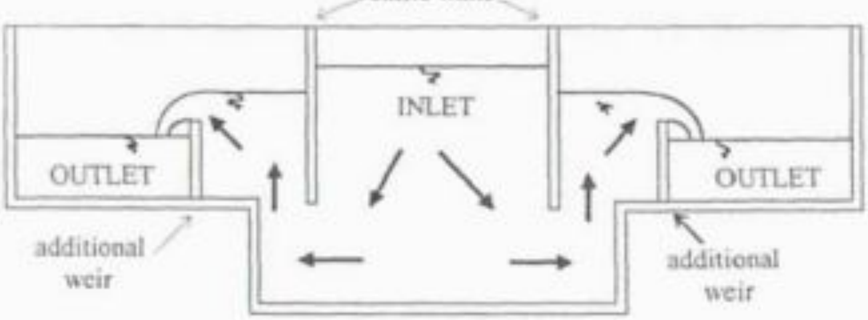


Figure 4-6 : Cross-section through the improved Wilsenach structure (deflectors not shown)

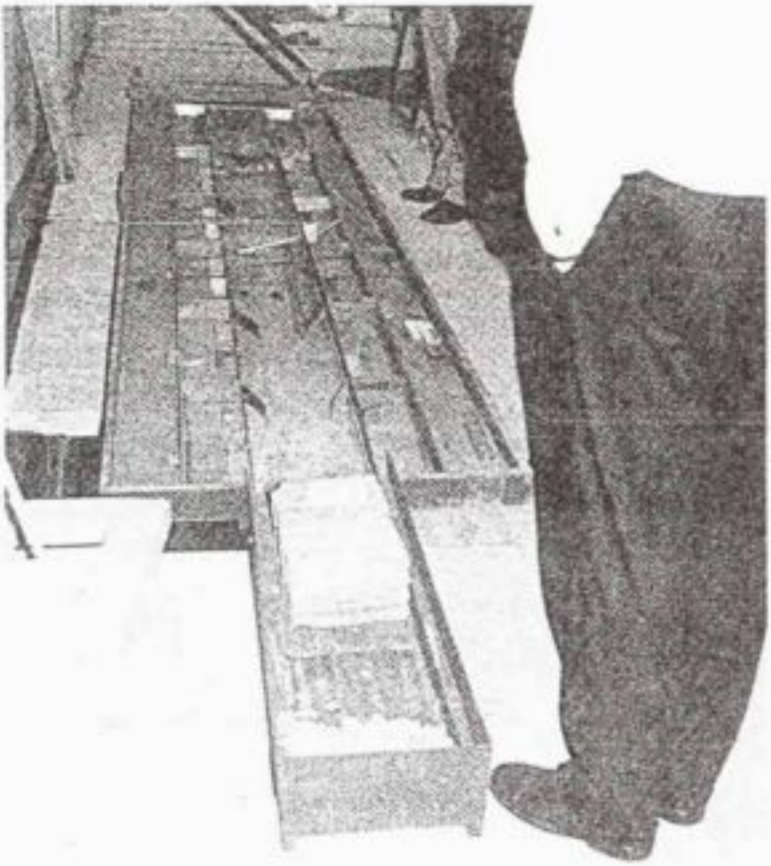


Figure 4-7 : View of the Wilsenach model (flow from bottom to top)

4.5 Furlong, 1995

The failure of the Uys, 1994 and Wilsenach, 1994 investigations now prompted some fundamental research into the limitations of suspended baffle walls as a method of stripping flotsam. A series of very simple experiments were conducted in a 300 mm wide, glass-sided flume using the downstream tail-gate on the flume control the water depth.

The experiments, depicted in Figures 4-8 and 4-9, were as follows:

1. A single suspended baffle wall (Figure 4-8a);
2. Double suspended baffle walls (Figure 4-8b);
3. A single suspended baffle wall in conjunction with a horizontal screen suspended above the bottom of the channel (Figure 4-8c);
4. The suspended baffle wall in 3. above replaced by a screen (Figure 4-8d); and
5. A suspended, inclined screen (Figure 4-9).

(a) Single baffle wall

(b) Double baffle wall

(c) Single baffle wall and horizontal screen

(d) Vertical and horizontal screens

Figure 4-8 : The Furlong suspended barrier experiments

Cut pieces of polyethylene shopping bags were used to represent litter as they were considered to be the hardest particles to trap. The trapping efficiency was generally expressed in terms of the percentage of particles trapped, and this was measured for a wide range of flow rates, water depths, and opening heights.

The results were extremely enlightening. The use of a single suspended baffle wall was shown to be almost completely ineffective at trapping flotsam. Except at extremely low flow rates, almost all the litter followed the streamlines (indicated by the addition of vegetable dye) and was pulled under the baffle wall. Frequently, more litter was trapped in the vortex downstream of the baffle wall than was trapped upstream of the sluice!

The use of the double suspended baffle walls was an attempt to exploit the apparent efficiency of the downstream vortex in trapping litter as well as investigate what effect the second baffle wall might have on the first. However, it was readily shown that the double baffle walls either acted as though they were one (if they were close together), or like two separate baffle walls (if they were further apart). There did not appear to be any benefit in using double baffle walls.

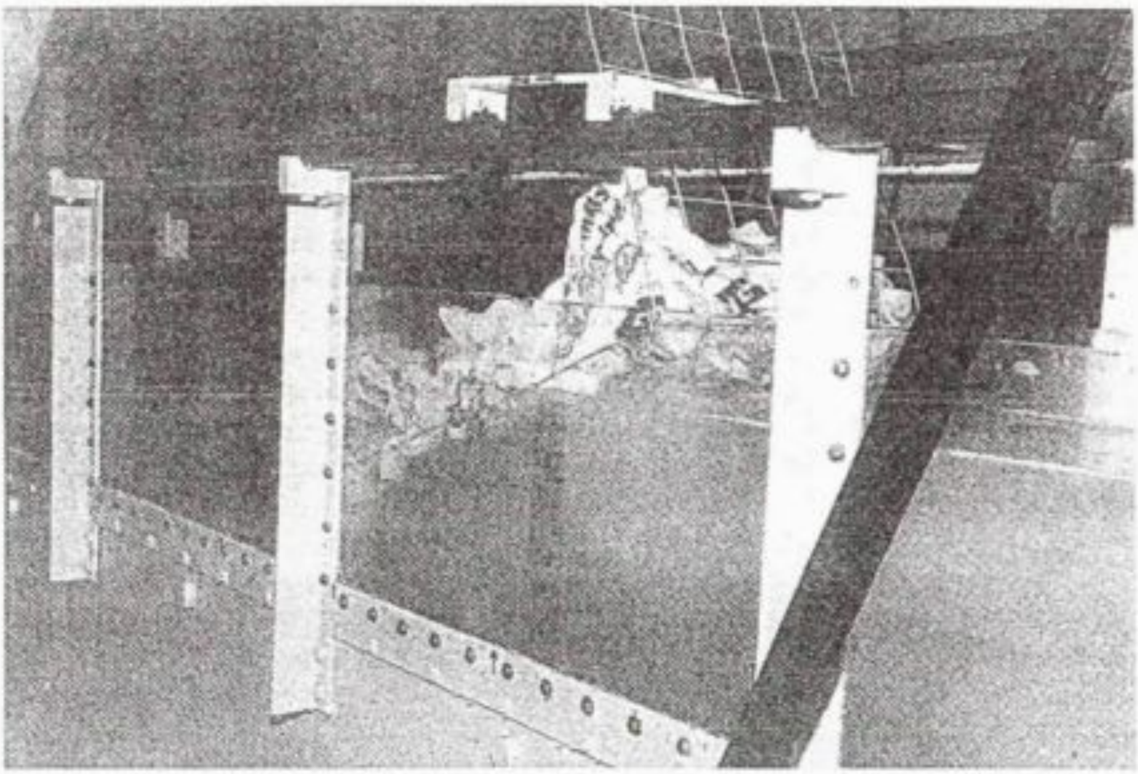


Figure 4-9 : View of Furlong's suspended, inclined screen in the flume

The use of a single suspended baffle wall in conjunction with a horizontal screen suspended above the bottom of the channel grew out of an experiment with a horizontal "shelf" attached to the bottom edge of the baffle wall on the upstream side. Whilst the use of a solid "shelf" showed no advantage - the combined structure behaved almost exactly as though the "shelf" was not there, replacing the solid "shelf" with a screen in the same position showed an immediate improvement. Provided the litter particles were floating above the line of the screen immediately upstream of the trap, they were generally caught. Very good packing was achieved in the area above the screen, the capacity of which appeared to be only limited by its length. It appeared that there was almost always sufficient draught through the previously deposited litter to ensure that later deposits were overlaid in an efficient manner.

The biggest shortcoming with the above structure appeared to be the fact that if there was intensive turbulence upstream of the trap, the litter particles tended to move closer to the bottom of the flume and consequently pass underneath.

Replacing the suspended baffle wall with a screen section (now L-shaped) showed a slight improvement.

Replacing the L-shaped suspended screen with an inclined screen gave much the same results except that the energy loss across the structure was reduced slightly whilst half the storage capacity was lost.

4.6 Louw, 1995

The purpose of this investigation was to explore the possibility of using a suspended screen in association with a long length of weir to trap the flotsam and bed-load respectively.

The average flow velocity was reduced partly by expanding the canal section and partly through the damming effect of the weir. This, it was hoped, would induce the necessary desegregation. To reduce the size of the structure, the weir was constructed in the form of a 'V', with the apex pointing upstream. At the same time, the expanded section was brought uniformly back to that of the original canal over the length of the weir. The uniformly reducing section coupled with the relatively uniform overflow rate over the weir guaranteed that the "forward" velocity was also more or less constant. The long overflow length guaranteed that the normal velocity was fairly small and also more or less constant. See Figure 4-10:

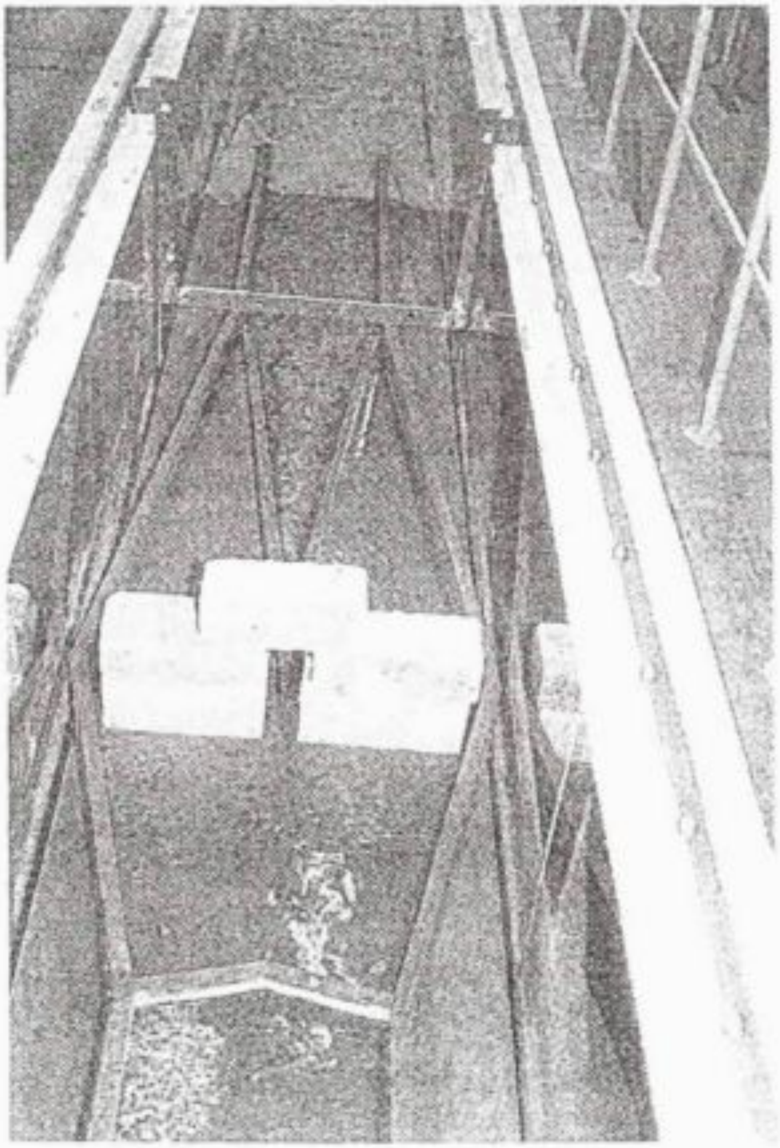


Figure 4-10 : View of the Louw model (flow from bottom to top)

No attempt was made, with the small scale model that was used, to study the effect of the addition of the suspended, inclined screen. The attraction of using such a screen is that upstream flooding can be limited as there is always an opening under the screen. The model did however appear to show considerable potential for the trapping of bed-load.

Once again, upstream turbulence, particularly that resulting from the expansion in the canal section, did have considerable impact on the trapping efficiency of the structure. In the model, this was solved by the installation of flow-straighteners in the expanded section.

4.7 Burger and Beeslaar, 1996

A key to the success of the Louw structure would be the efficiency of the suspended, inclined screen in trapping the majority of the flotsam and suspended material. This was now assessed in a series of experiments carried out in a 600 mm wide hydraulic flume.

Measurements were carried out with a screen inclined at an angle of 1:5 (vertical : horizontal), and for effective screen openings a/w, where a is the height of the opening and w is the height of a folded plate weir downstream, of 0,5, 0,6 and 0,7. Plastic squares, 40 mm x 40 mm in size, were used to represent plastic bags floating in the water column. The ratio E_0/E_1, where $E = y + V^2/2g$ = specific energy, gave an indication of the energy loss across the screen, which in turn was related to its blockage. See Figure 4-11.

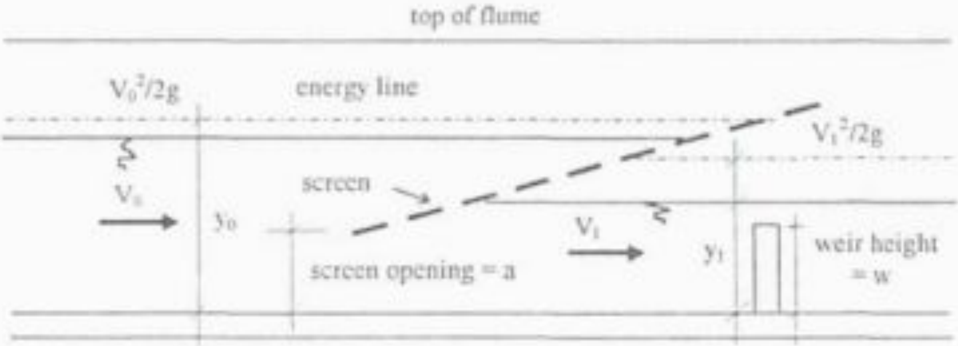


Figure 4-11 : Definition sketch of the apparatus used to measure the efficiency of suspended, inclined screens

The results, depicted in Figure 4-12, clearly show that:

- for a particular energy ratio (E_0/E_1), the trapping efficiency (% Trapped) for the effective screen opening (a/w) of 0,5 was markedly higher than for the effective screen openings of 0,6 and 0,7.
- for any particular trapping efficiency less than about 77%, the energy ratio was much less for the larger effective screen openings.

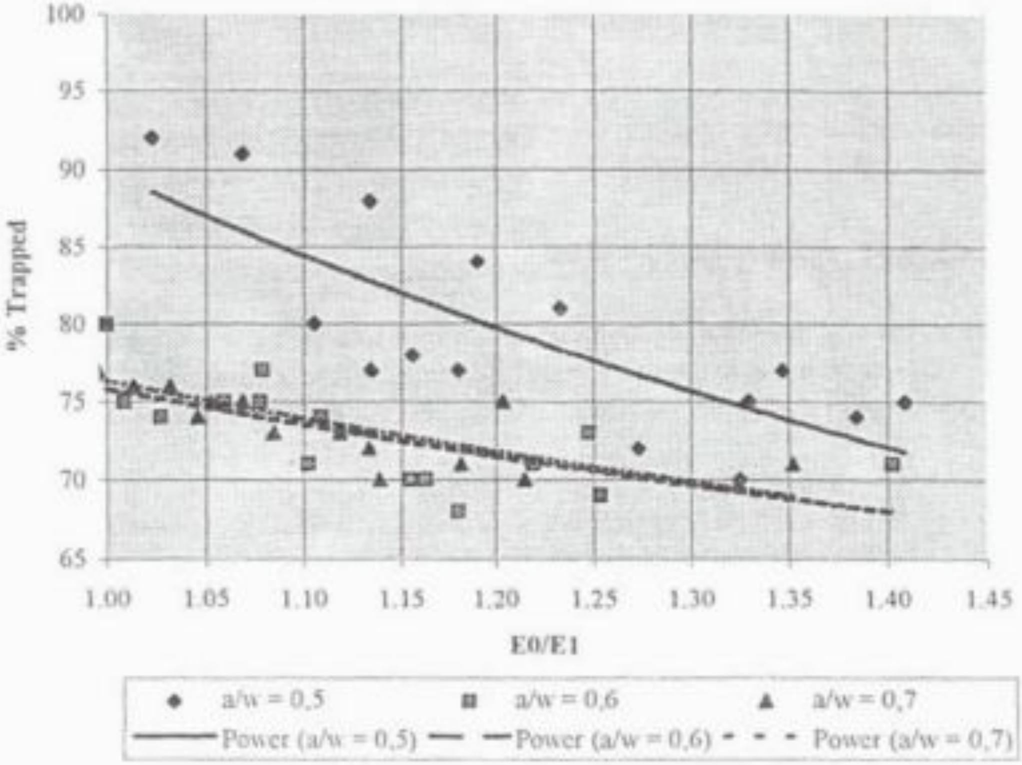


Figure 4-12 : Plot of percentage trapped versus relative specific energies for different effective overlaps of a suspended, inclined screen

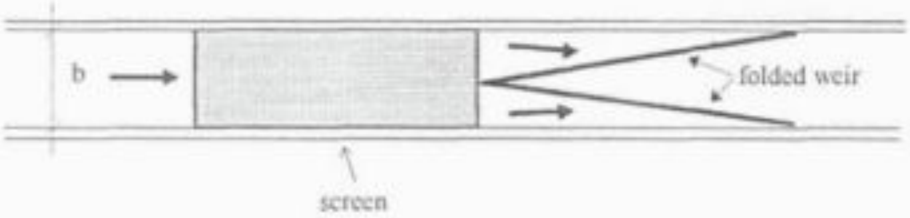
An effective screen opening less than 0,5 would, of course, have greatly increased the trapping efficiency, but at the cost of high energy losses in the blocked condition. This would have defeated the purpose of the partial screen, which was to reduce upstream flooding.

4.8 Compion, 1997 (Part 1)

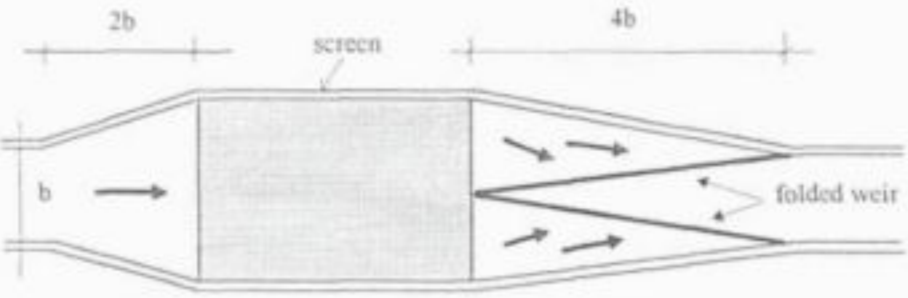
The relative success of the Louw structure (see Section 4.6) prompted an in-depth investigation at a larger scale. This time, the tests were also carried out with an inclined screen installed (at an angle of 1:5 vertical : horizontal). The angle of the screen allowed for partial head recovery in the case where the screen was completely blocked (simulated by replacing the screen with a blank board).

Tests were carried out for a variety of flow rates and weir heights for a uniform channel without expansion, and a channel expanded to twice its normal width. Tests were also carried out with the apex of the folded weir pointing both upstream and downstream, and finally, in the case of the expanded channel, with weirs having both single and double folds. Figure 4-13 shows the plans and long-section of the experimental layout. Figure 4-14 shows the various layouts of the weirs. Figures 4-15 shows a view of the expanded channel.

(a) Plan : uniform channel



(b) Plan : expanded channel



(c) Section

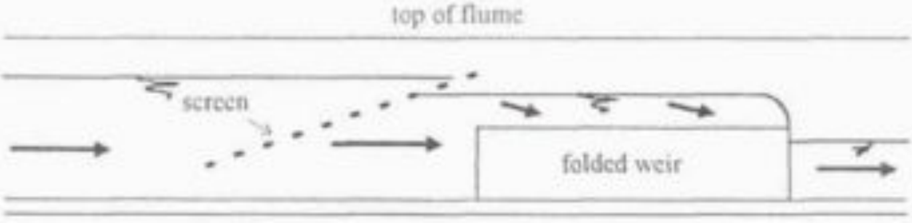
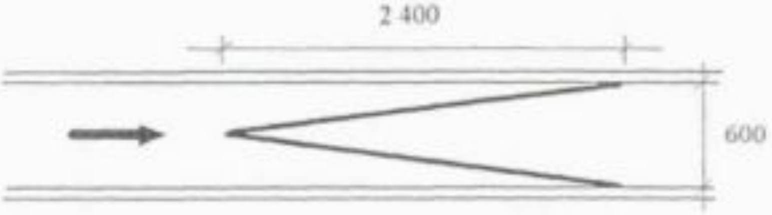
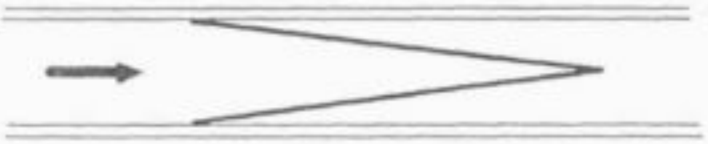


Figure 4-13 : Plans and long-section of the layouts used in the first series of investigations by Compion, 1997

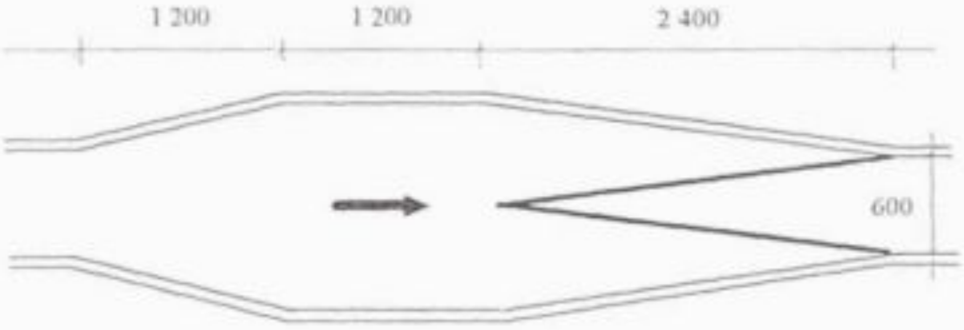
(a) Folded weir pointing upstream in a uniform channel



(b) Folded weir pointing downstream in a uniform channel



(c) Folded weir pointing upstream in an expanded channel



(d) Double folded weir pointing upstream in an expanded channel

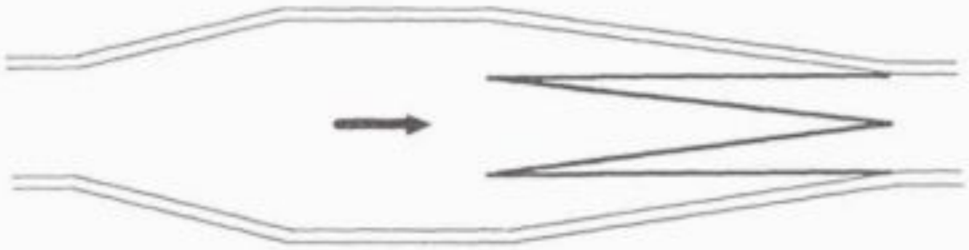


Figure 4-14 : Layouts of the weirs used in the first series of investigations by Compion, 1997

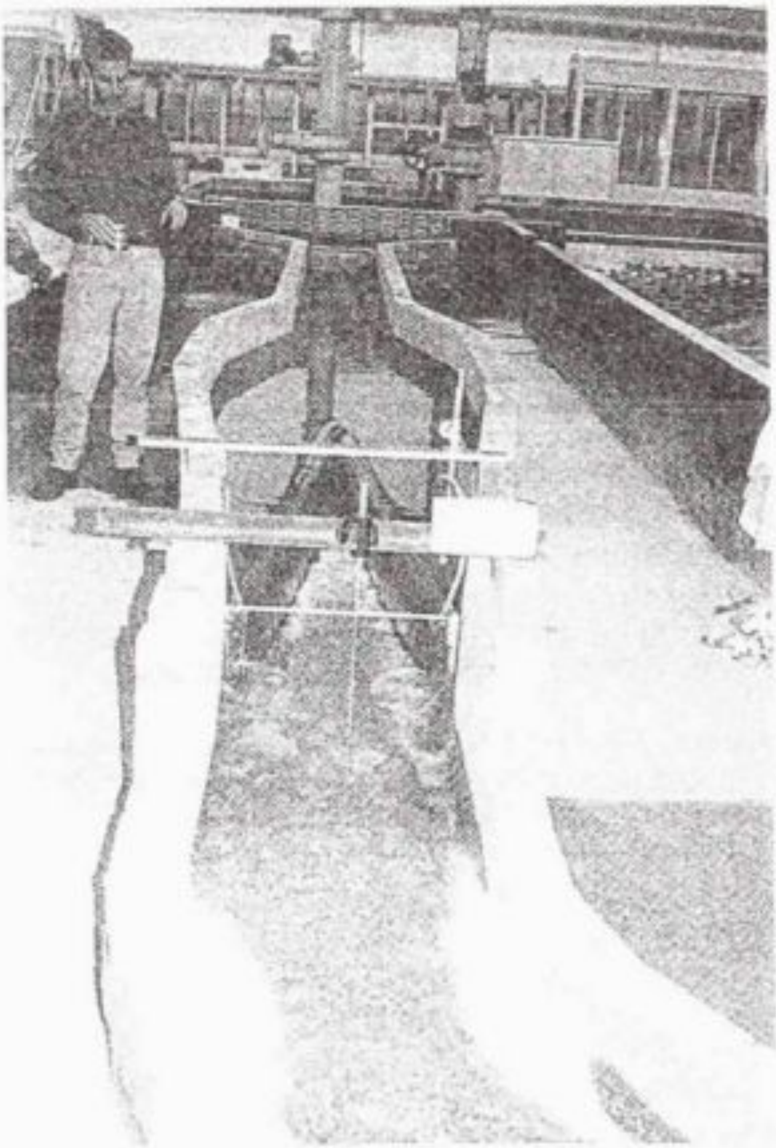


Figure 4-15 : View of the expanded channel used in the first series of investigations by Compion, 1997 (flow from top to bottom)

As discussed in Section 3.4, litter may be found in almost infinite size, density and shape, but for the sake of the model tests, some standardisation was required. The settling velocities and densities of typical items of litter were therefore determined and modelling laws were then used to identify representative scale particles. Gum rubber particles (settling velocity = 27 mm/s) were chosen as the most convenient indicator of the traps' performance with respect to objects with a positive settling velocity. The complete settling velocity test results are depicted in Table 4-1.

Tests were first carried out for a single folded weir pointing upstream in a uniform channel without a screen in position. A plot of Froude number (Fr) against % Trapped (Figure 4-16) for particles with a settling velocity of 27 mm/s shows that the performance of this trap was almost independent of the channel breadth to weir height ratio (b/w). Complete trapping with this type of particle was only achieved when Fr dropped below about 0,05. Once Fr was above 0,3, no particles were trapped.

Typical litter in urban stormwater		Candidate particles to simulate litter		
Type	Settling velocity (m/s)	Type	Settling velocity (m/s)	Density (kg/m)
Glass	0,533	Gum rubber	0,027	1 010
Tin can	0,266	Silicon rubber	0,102	1 067
Paper	0,031	Natural rubber	0,176	1 389
Plastic container	-0,040	Latex rubber	-0,095	885
Plastic bag	-0,010*	Polystyrene	0,029	1 043
Polystyrene (amorph.	-0,367	Polyethylene	-0,060	938

* The settling velocity of plastic bags cannot be accurately determined owing to the difficulty in removing all the air bubbles attached to the surface

Table 4-1 : Typical settling velocities of litter and the settling velocities and densities of candidate particles to simulate litter in the Compion experiments

Turning the weir around resulted in a decline in trapping performance.

Expanding the channel to twice its initial width was expected to improve the trapping performance since the average velocity would be approximately halved. However this was not found to be the case with the model dimensions indicated in Figure 4-14.

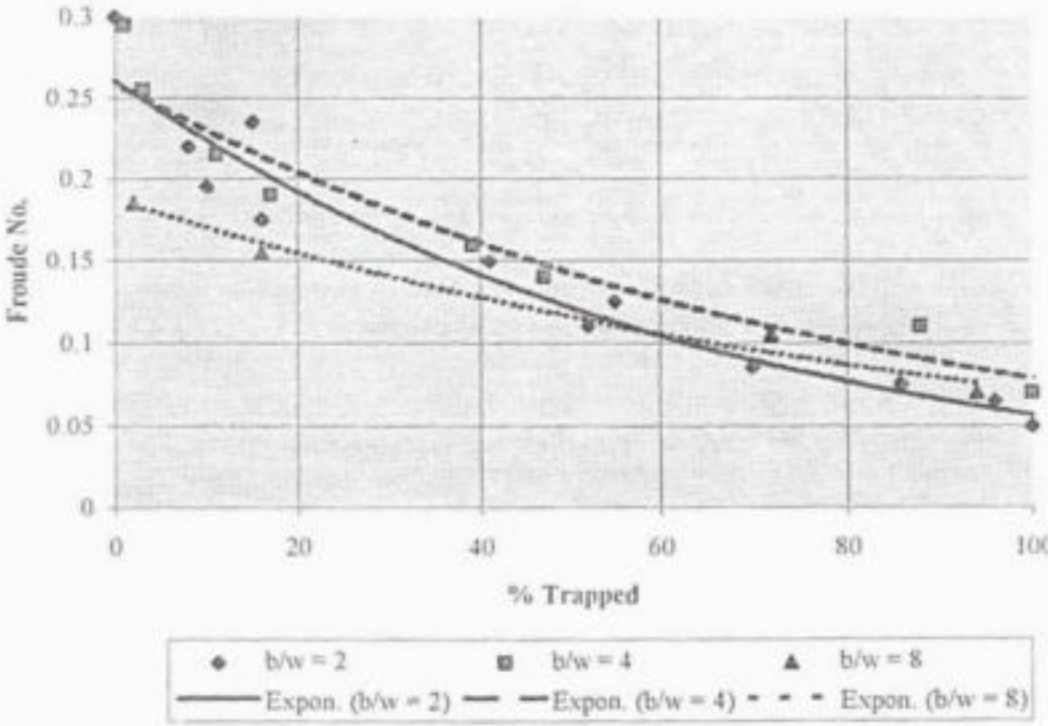


Figure 4-16 : Froude Number vs % Trapped for a particle having a settling velocity of 27 mm/s and with a single folded weir pointing upstream in a uniform channel without any screen in position

The reason for the poor performance of the expanded channel was indicated by the presence of large vortices generated at the diverging section. These vortices greatly increased the power dissipation per unit volume in the trap, which in turn ensured that a considerable number of particles were kept suspended by the flow and washed over the weir. When flow directors, in the form of 250 mm long by 50 mm diameter uPVC pipes, were installed directly downstream of the diverging channel section, much of the additional vorticity was eliminated resulting in a major improvement in the performance of the trap.

When the screen was installed, there was a major deterioration in the performance of all the above layouts. It had now become obvious that any obstruction such as an expansion, sluice or screen would result in considerable turbulence causing a greater power dissipation in the flow with consequent suspension and carry over of particles. If partially penetrating screens were to be used in conjunction with weirs, they would have to be kept a substantial distance upstream of the weir since the use of flow straighteners, which had proven to be effective, was not considered a practicable option in the stormwater environment.

5. The search for a self-cleaning screen

5.1 Introduction

Screens are extremely susceptible to blockage by litter and other debris. A single plastic bag or large leaf is capable of sealing a substantial area of screen. The change in the flow regime effected by the resulting partial blockage then directs the next plastic bag or leaf in such a way as to make blockage of an adjacent open area very likely. It therefore doesn't take many plastic bags or leaves to block the largest of screens. This makes the common practice of placing a screen normal, or near normal, to the flow direction an extremely inefficient method of trapping litter. It will require frequent cleaning or else blockage and upstream flooding, will result.

There appear to be two alternatives. Either dispense with screens altogether, or else make the screens self-cleaning. The Enviroscreen, described in Section 4.2 was an attempt to make the screens self-cleaning. Unfortunately, it was not successful.

As demonstrated in the previous section, suspended baffle walls or weirs are only effective with low Froude numbers. Low Froude numbers are achieved by increasing the cross-sectional area of the flow - typically by passing the flow through some sort of pond. The space to accommodate a pond may not however be available, and even when it is, this may be too expensive a solution.

Another alternative - self-cleaning screens - will now be discussed by reference to the work carried out by a number of investigators including three from the University of Stellenbosch / University of Cape Town programme:

5.2 Bondurant and Kemper, 1985

5.3 Bouvard, 1992

5.4 Beecham and Sablatnig, 1994

5.5 Nel, 1996 and the Stormwater Cleaning Systems (SCS) structure

5.6 Compion, 1997 (Part 2) (US - MIng thesis)

5.7 Watson, 1996 (UCT - BSc(Eng) thesis)

5.8 The Baramy® Gross Pollutant Trap

5.9 Lawson, 1997 (UCT - BSc(Eng) thesis)

5.10 The Continuous Deflective Separation (CDS) approach

5.11 Conclusions

5.2 Bondurant and Kemper, 1985

Bondurant and Kemper were concerned about the removal of litter in irrigation water supplies. When irrigators used earth distribution ditches and sod cut-outs, they seldom had problems with litter. When increasing use was made of siphon tubes and gated pipes and their associated small entrances, litter started to become a major problem.

Bondurant and Kemper experimented with various litter removal devices, mostly horizontal screens, in an attempt to come up with a low-cost self-cleaning trap. The device showing the greatest promise comprised a low weir plate discharging water onto a horizontal screen situated some 200 mm below the lip of the weir. The turbulence of the water splashing on the screen tended to displace litter from the impact zone and thus keep it clear. The performance of this device was greatly enhanced by installing a metal bar across the flow immediately upstream of the nappe (see Figure 5-1), or by installing a second slightly lower weir a short distance downstream of the first (thereby slightly submerging the screen). In both instances, the additional turbulence helped to keep the screen clear for longer periods.

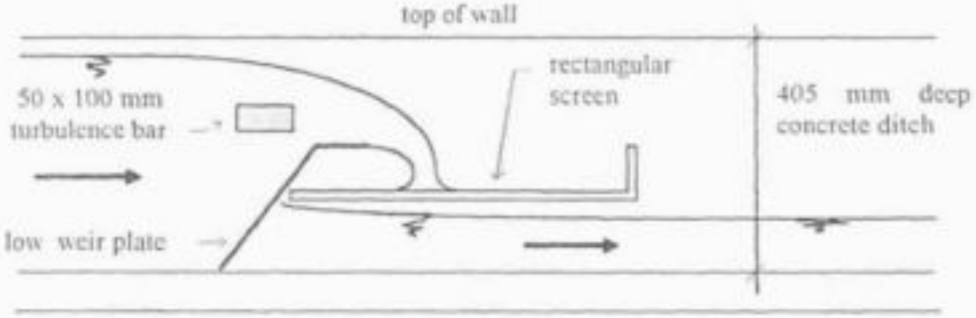


Figure 5-1 : Long-section through the Bondurant and Kemper self-cleaning litter screen

5.3 Bouvard, 1992

Bouvard's book 'Mobile barrages and intakes on sediment transporting rivers", part of the IAHR Monograph Series, provides a wealth of information on sediment exclusion devices. The problem with the book is that most of the structures described therein are designed for large dams and barrages, or else are intakes designed to accommodate a portion of the flow only (the remaining flow can then be used to help keep the screens clean). The book does however describe some stream-bed intake structures constructed in France which have incorporated self-cleaning litter screens.

One such structure on the River Pradin, originally constructed in 1947 but considerably modified since, combines an uncontrolled spillway and a streambed intake. The intake is protected by a trashrack comprised of parallel bars sloped at an angle of 40% (21,8°) below the horizontal in the direction of flow, with 30 mm wide openings. It can be dried out by opening a nearby bypass - which is normally closed with stoplogs. Figure 5-2 shows a section through the trashrack.

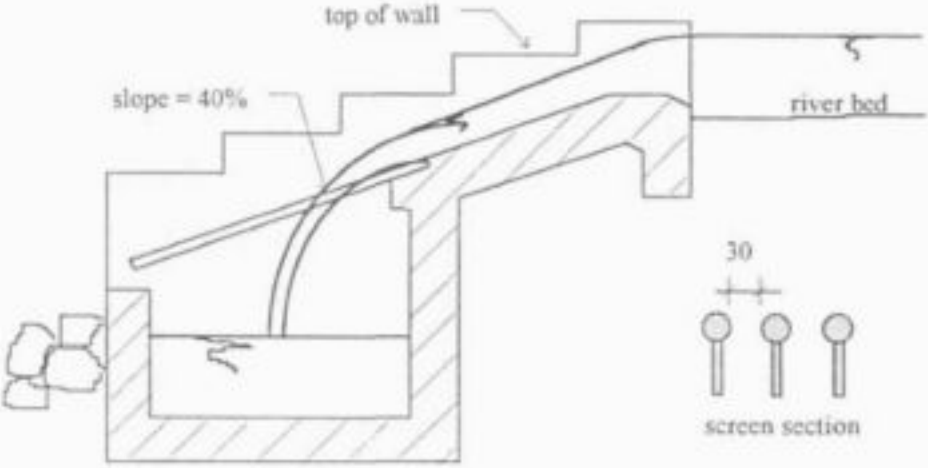


Figure 5-2 : Section through the trashrack installed on the River Pradin, France

French experience with self-cleaning trashracks (in rivers) indicates that the shape of the bars is extremely important. The bars should be sufficiently rigid to prevent current-induced vibration and bar deformation and are thus are normally strengthened with spacers, generally welded to the under-side of the bars. Care should be taken to ensure that the spacers do not jeopardise the entry and withdrawal of the teeth of litter-rack rakes. Tapered bar shapes which are thicker at the upstream end of the screen offer considerable advantages. The taper increases the rigidity of the bars which makes it more difficult for material to jam between them and facilitates cleaning. Material which gets through the narrower clearance upstream are freed as the flow forces it into the wider clearance beyond. Unfortunately, tapered bars are not readily available off-the-shelf, and the cost of having them made individually to the designer's specification is usually prohibitive.

The bars should also preferably have a tapered cross-section to prevent sediment from jamming them. See Figure 5-3. Trapezoidal bars however, are more difficult to assemble than round-ended bars. Moreover many sections have square corners at the top making them scarcely more effective than ordinary flat bars. Round bars usually lack rigidity.

The slope of the trashracks is also important. The steeper the racks, the lower the probability of blockages but the greater the effective rack area required and the bigger the drop across the section. In France, steeply sloping racks are increasingly prevalent. Slopes used to be about 10 - 20% (6 - 12°), but now 30 - 60% (17 - 31°) seems to be the norm.

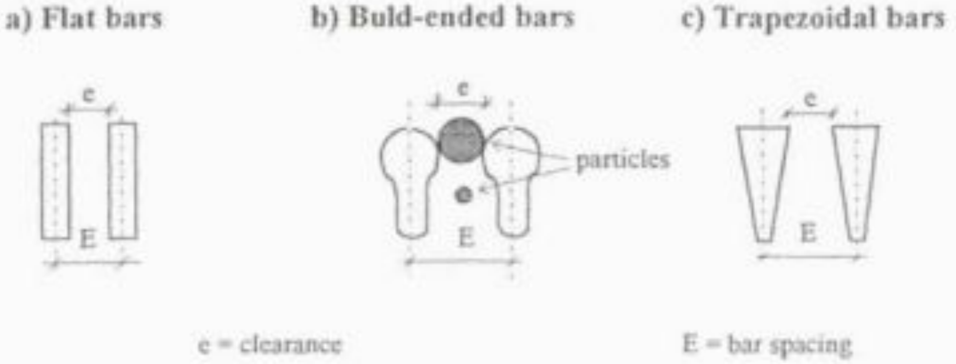


Figure 5-3 : Typical rack bar sections used in France

5.4 Beecham and Sablatnig, 1994

In an attempt to improve the self-cleaning and rubbish removal characteristics in trashrack design, hydraulic model tests were performed on twenty-three trashrack configurations at the Sydney Water Board's Manly Vale Hydraulics Laboratory - although admittedly some of the configurations merely entailed a small modification to a basic arrangement.

The configurations can be subdivided into "on-line" and "off-line" arrangements where "on-line" refers to an arrangement that would be built solely within the confines of the existing channel. This would suit situations where land was either expensive or unavailable. "Off-line" refers to an arrangement which has a side-channel or collection area. These arrangements would require larger areas of land:

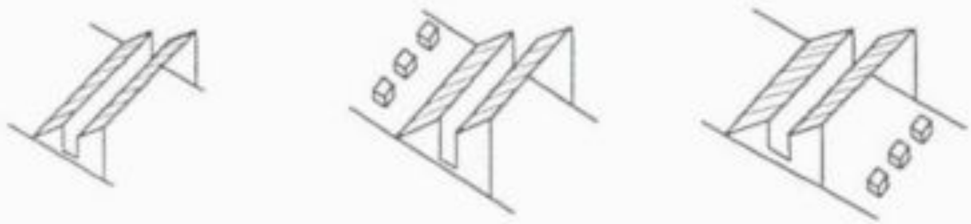
Group A : "On-line" arrangements

1. Basic trashrack constructed with vertical bars.
2. Inclined trashrack (45° downstream).
3. Declined trashrack (45° upstream).
4. Twin racks and bin structure (45° downstream).
5. Twin rack structure with upstream blocks.
6. Twin rack structure with downstream blocks.
7. Twin rack structure with rack blocks.
8. Twin rack structure with declined upper rack (45° upstream).
9. Twin angled racks and bin structure - the racks constructed with horizontal bars and angled across the flow at 30° towards a small bin.
10. Twin angled racks and bin structure with horizontal weirs.
11. Twin angled racks and bin structure with tapered weirs.
12. Twin angled racks and bin structure with tapered weirs and extended bin.
13. Bin and rack drop structure.
14. Bin and rack drop structure with declined rack (45° upstream).
15. Sloping screen and bin structure.

These are illustrated in Figure 5-4.

(a) Arrangement 1 (b) Arrangement 2 (c) Arrangement 3

(d) Arrangement 4 (e) Arrangement 5 (f) Arrangement 6



(g) Arrangement 7 (h) Arrangement 8 (i) Arrangement 9

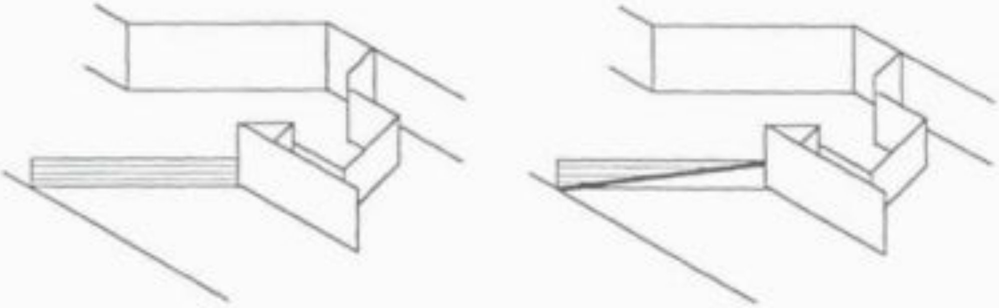
(j) Arrangement 10 (k) Arrangement 11 (l) Arrangement 12

(m) Arrangement 13 (n) Arrangement 14 (o) Arrangement 15

Figure 5-4 : Model trashrack configurations evaluated in the Beecham and Sablatnig tests : On-line Arrangements

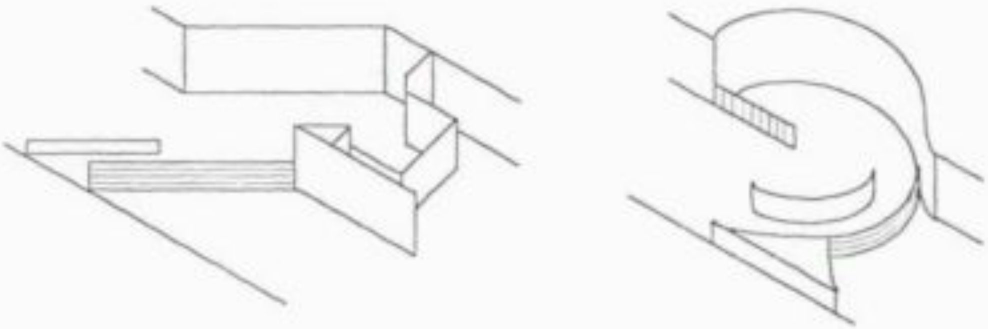
(a) Arrangement 16

(b) Arrangement 17



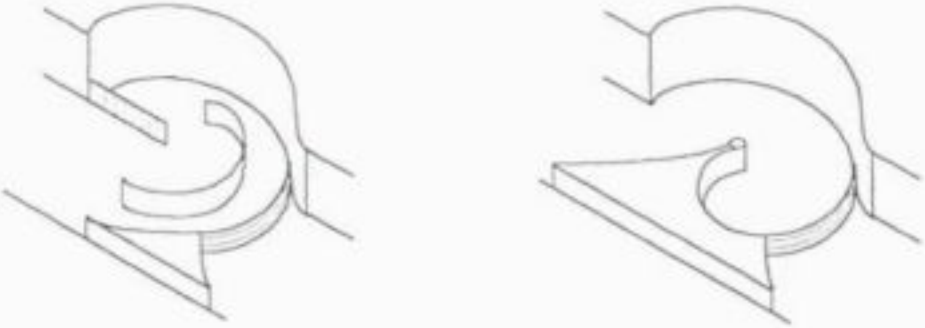
(c) Arrangement 18

(d) Arrangement 19



(e) Arrangement 20

(f) Arrangement 21



(g) Arrangement 22

(h) Arrangement 23

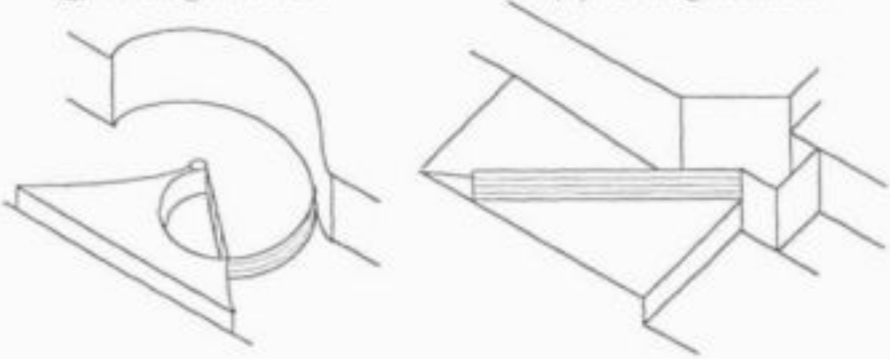


Figure 5-5 : Model trashrack configurations evaluated in the Beecham and Sablatnig tests : Off-line Arrangements

Group B : "Off-line" arrangements

16. Angled rack (horizontal bars at 45°) and side bin.
17. Angled rack with sloping weir and side bin.
18. Angled rack and side bin with an upstream triangular weir.
19. Offset swirl chamber and rack with a quarter circle baffle wall and slatted rack.
20. Offset swirl chamber and curved rack with a half circle baffle wall and slatted rack.
21. "S"- shaped channel and curved rack.
22. "S"- shaped channel and curved rack with slatted rack.
23. Angled rack (45°) and side bin with a vertical drop and sloping cross channel.

These are illustrated in Figure 5-5.

The configurations could also be further categorised into those for use in channels with a "gradual slope", ie. a channel with a small vertical change in elevation along its length, and a "steep slope", ie. a channel with a large vertical change in elevation that could easily accommodate the construction of a vertical drop without interfering with the overall fall of the channel.

The testing procedure was made as representative as possible of the typical conditions pertaining in real channels within the constraints of the reasonably small scale (1 200 mm x 1 200 mm x 500 mm) of the models. The results were strictly qualitative.

The configurations that appeared to perform the best were 12, 13, 14, 15, 17 and 23.

The study came to the following conclusions:

1. Trashracks with horizontal bars had better self-cleaning potential than racks with vertical bars;

2. The installation of a bin structure would make cleaning and rubbish removal far easier and probably cheaper;

3. The inclusion of a vertical drop within the arrangement would greatly reduce the likelihood of the flow backing-up; and

4. Off-line litter storage would provide a much larger storage area, create less disturbance to the channel flow, and provide much better access for cleaning and general maintenance.

Each of the six preferred arrangements had features designed to accommodate at least some of these points. Arrangement 23, with a combination of off-line storage and vertical drop, proved the most effective.

5.5 Nel, 1996 and the Stormwater Cleaning Systems (SCS) structure

Nel, 1996 also investigated the self-cleaning potential of a screen angled downwards in the direction of the flow (cf. the River Pradin structure in section 5.3 and configuration 15 in the Beecham and Sablatnig tests in section 5.4).

His approach, patented in South Africa under Patent No. 92/4759, was to force the flow over a low weir and through a screen angled at approximately 45° below the horizontal. The litter was intercepted by the screen and forced down it by a combination of the momentum of the water and gravity, until it comes to rest in a bin ready for removal. The resulting structure was called the Stormwater Cleaning Systems (SCS) structure.

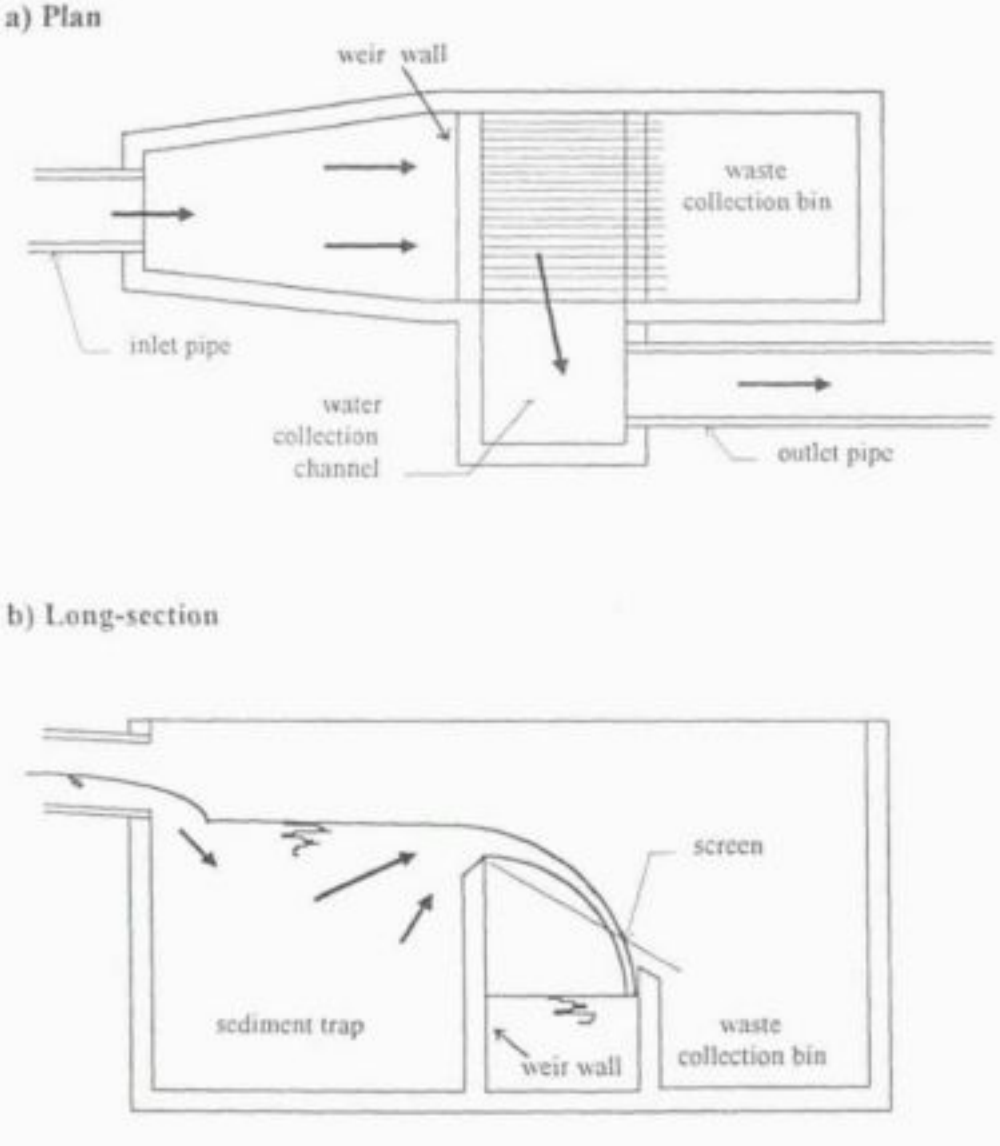
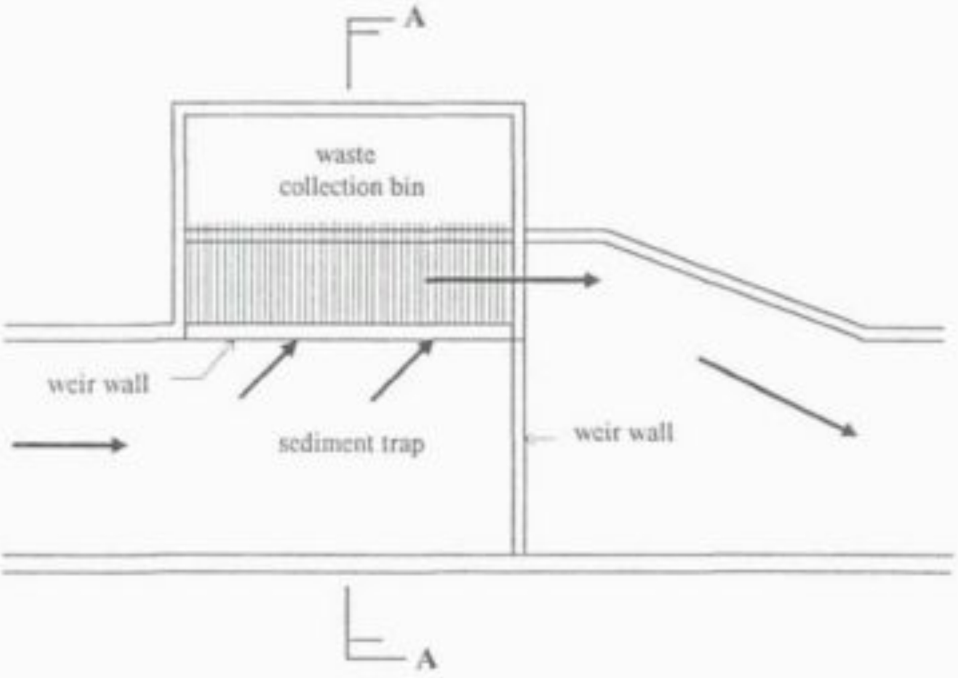


Figure 5-6 : Plan of and long-section through Nel's proposal for a self-cleaning screen for removing litter from pipes

a) Plan



b) Section A-A

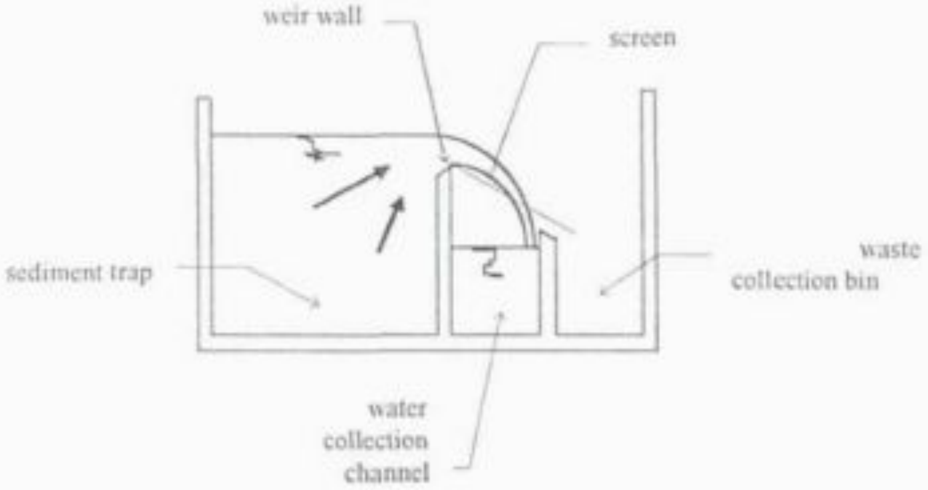


Figure 5-7 : Plan of and long-section through Nel's proposal for a self-cleaning screen for removing litter from canals

Two alternative layouts were envisaged:

1. with the weir directly in the path of flow for small flows emanating from, say, a pipe (see Figure 5-6); and

2. with the weir lying tangential to the initial flow direction for the larger flows in canals (see Figure 5-7).

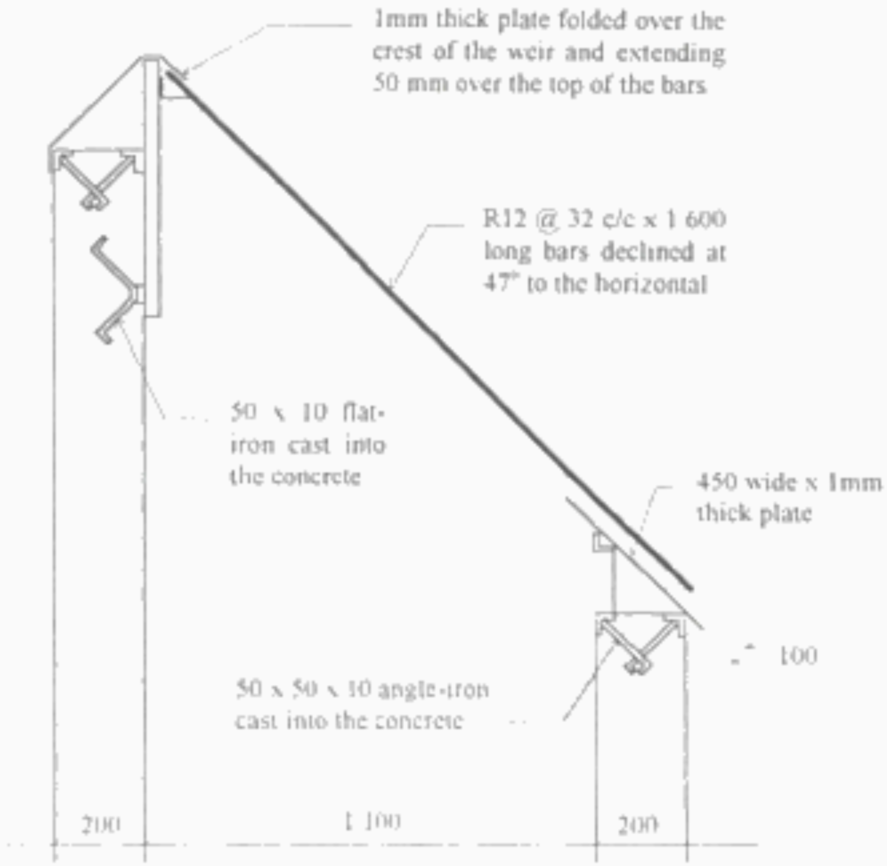


Figure 5-8 : Typical cross-section through a screen on a SCS structure

A settling basin can be provided upstream of the weirs to trap the bed-load separately if required.

Numerous tests were carried out on hydraulic models to optimise the layout of the structures and the choice of screen. The tests revealed that the self-cleaning ability of the screen was adversely affected by a flow direction that deviated more than about 5° away from the line of the bars making up the screen, or by eddies in the horizontal plane of the approaching flow caused, for example, by a sudden change in direction. The influence of other forms of turbulence could be eliminated by ensuring that the Froude number was less than 0,15.

The tests also indicated that the most appropriate design of the crest of the weir incorporated a 45° bevel on the upstream side with a capping piece directing the flow over the edge of the screens. This is illustrated in Figure 5-8.

Nel examined various alternatives for the screens including 25 x 5 mm flat bars, 25 x 25 x 3 mm angle iron, and 10 mm and 12 mm diameter round bars (in both mild steel and 3CR12). The gap was varied between 12 and 25 mm, and the angle of declination was also varied. He concluded that the optimum screen design incorporated 12 mm diameter mild steel round bars with a 20 mm gap at an angle of about 47°. A more expensive alternative incorporated 10 mm diameter 3CR12 bars at an angle of about 43°.

Once the choice of screen angle had been made, further experimentation indicated that a maximum overflow depth of 225 mm (approximately 230 litres per second per metre length of weir) could reasonably be accommodated. Lower overflow depths (and hence unit flow rates) would be used in circumstances where the available head was limited. The minimum practicable head loss was in the order of 400 mm.

A further refinement to the design of the screen was to support it a minimum distance of 100 mm away from the wall of the bin to ensure that litter did not catch on it.

Figure 5-8 shows a typical cross-section through a screen on a SCS structure.

A prototype structure was constructed in Springs to accommodate a flow of 7,5 m^3/s (see Section 2.2). A plan and cross-section of the structure is shown in Figure 5-9. Figure 5-10 shows a view of the empty structure being cleaned and repaired with the screens clearly visible. The return flow is via a row of culverts underneath the sediment trap and back into the canal off the picture to the right. The screens would normally cover the entire central area. The waste collection bin is clearly visible on the left of the photograph. The layout was optimised by model tests before construction began.

For flow rates up to 7,5 m^3/s the flow path is as follows:

1. Water is deflected by means of a low weir into a secondary channel lying parallel and next to the canal;

2. Once in the secondary channel, it is turned through 90° so as to flow up and over the trapping weir;

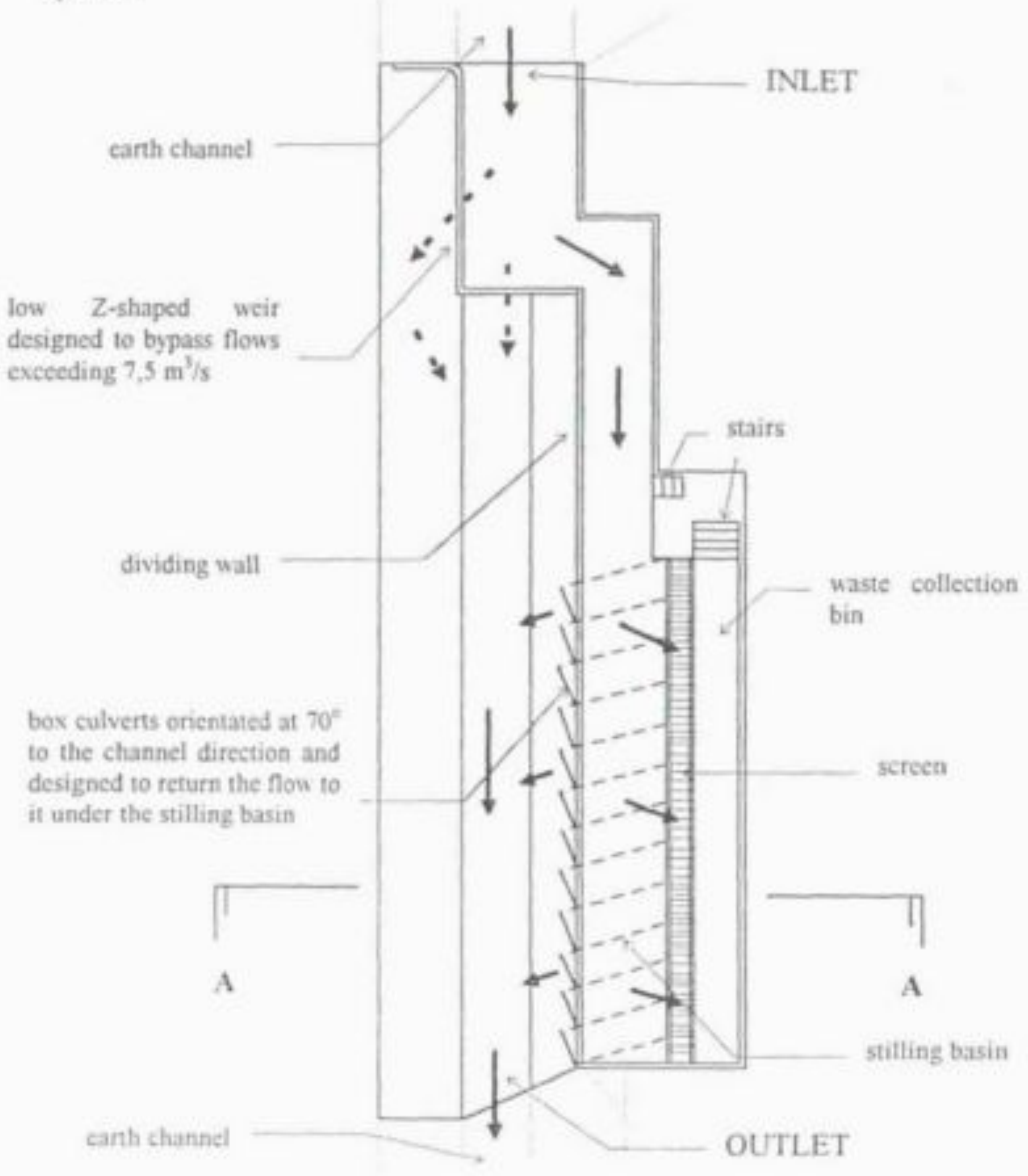
3. It then passes through the screen where the litter is stripped off and deposited into a bin for collection by the municipality;

4. The litter-stripped water lands in a collection box from where it returns to the canal via box culverts located under the secondary channel.

Flows in excess of 7,5 m/s cause over-topping of the low weir and consequent by-passing.

The SCS structure has proven itself to be a relatively efficient structure that is easy to construct and maintain. It is a good option providing there is sufficient space available for its installation. Even in situations where there is a not a lot of fall, the minimum head requirement of at least 400 mm (approximately 1 m is desirable) can often be met via the installation of an hydraulically actuated sluice gate (see Appendix C). More information on the SCS structure is to found in Section 2.2 and Appendices A.6 and B.6.

a) Plan



b) Cross-section A-A (at a larger scale)

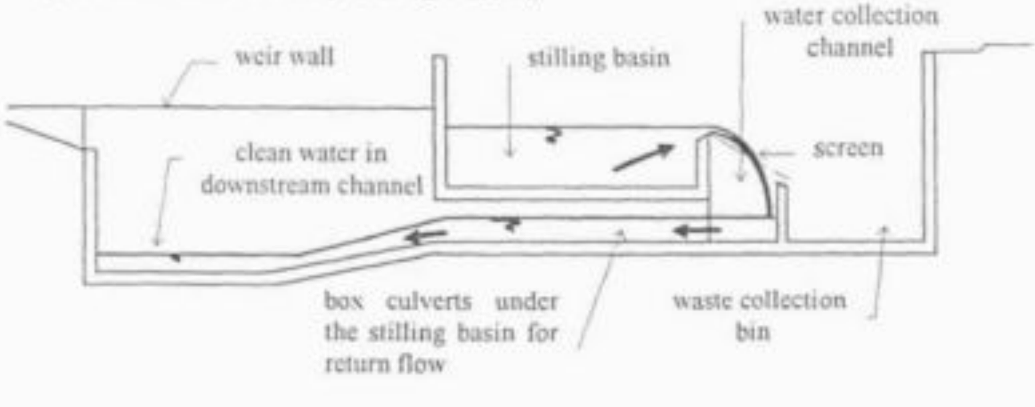


Figure 5-9 : Plan and cross-section of the SCS structure constructed in Springs

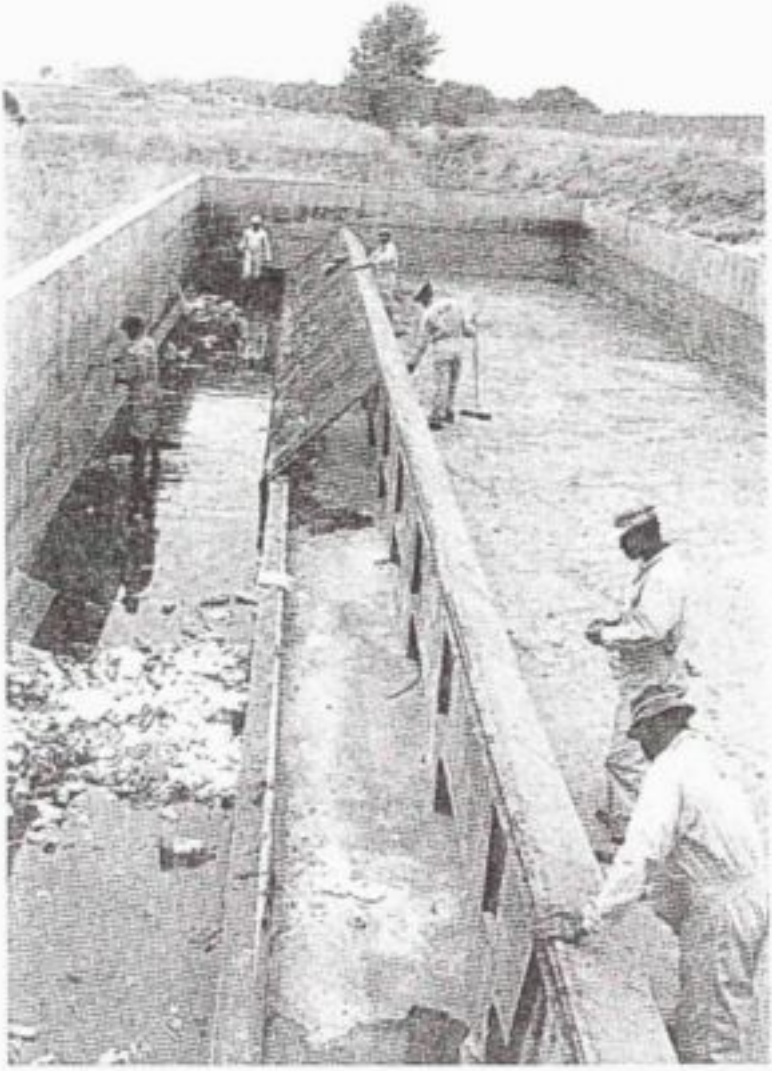


Figure 5-10 : View of the SCS structure at Springs being cleaned and repaired (flow is from right to centre and down. The bin is on the left)

5.6 Compion, 1997 (Part 2)

Mention was made in Section 4.8 of the work of Compion (Compion, 1997). Compion also attempted the development of an in-line, horizontal, self-cleaning screen capable of removing all the litter from the flow with minimum loss of head. Tests were carried out in two types of channels:

1. a 600 mm wide channel that was abruptly expanded to twice its original width (1 200 mm), and
2. in a channel of 300 mm uniform width.

Figure 5-11 shows a view of the first of the two test sections. A plan and long-section of this test section is depicted in Figure 5-12.

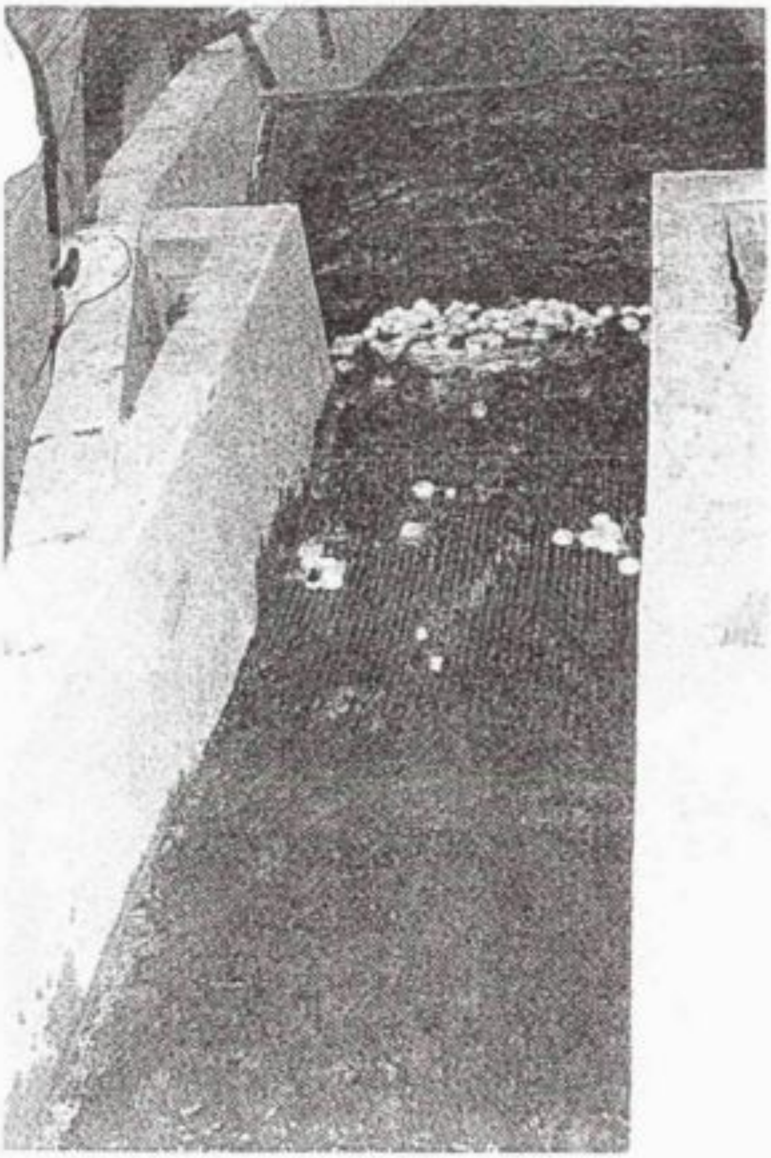


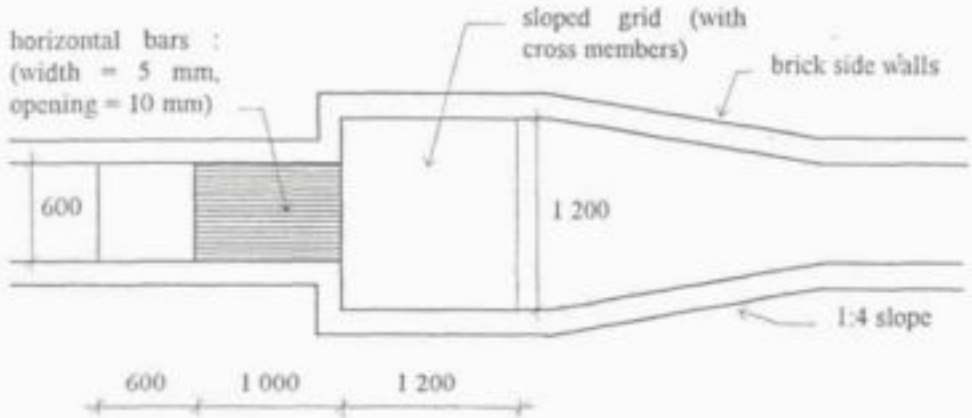
Figure 5-11 : View of the expanded channel used in the second series of investigations by Compion, 1997 (flow from bottom to top)

The theory behind the design of the expanded channel was as follows:

1. Flow in the 600 mm channel would be forced through critical depth over a 100 mm high step in the form of a broad-crested weir;

2. Once over the weir, the flow would be directed down a spillway section consisting of a ramp at a uniform 1:10 slope. A horizontal screen, comprising of 5 mm wide bars with 10 mm openings orientated in the downstream direction, was placed at the same level as the top of the weir, and connected to it. The idea was that litter would be separated from the flow by the screen whilst the momentum of the water flow would continually push the litter along the bars and out of the way (similar to the Bondurant and Kemper concept discussed in Section 5.2). The ramp was intended to fulfil two purposes - to maintain a large momentum component in the plane of the horizontal screen (approximately 99,5% of the total at the angle chosen), and help to minimise local head losses;

a) Plan



b) Long-section

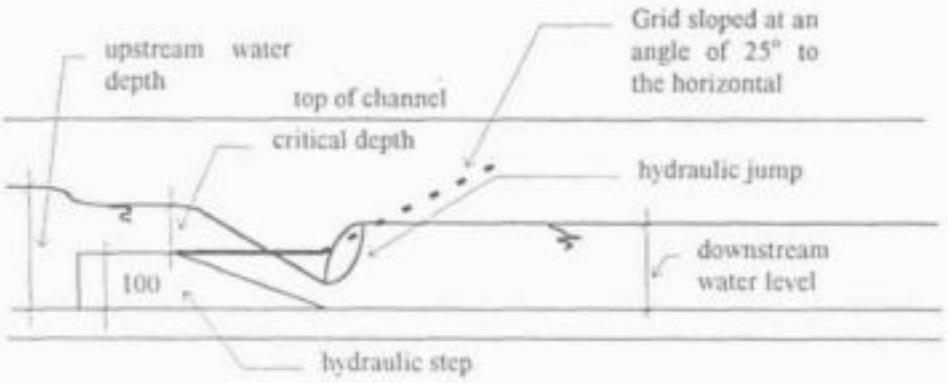


Figure 5-12 : Plan of and long-section through the Compion structure (expanded channel)

3. At the toe of the ramp, the section was abruptly expanded to twice its original width. At the same time, the horizontal bar screen gave way to a grid sloped at an angle of 25° over the full expanded width of the channel. The expanded section forced the occurrence of an hydraulic jump, which at high flows encompassed the lower portion of the sloped grid. Part of the turbulence generated by the hydraulic jump was thus available to redistribute incoming litter over the full face of the sloped grid;

4. Downstream of the sloped grid, the walls of the channel were tapered at 1:4 so as to redirect the flow back into the original channel section with minimum head loss.

The structure was extremely effective in high flows, in rapidly fluctuating flows, or in situations where, for whatever reason, the downstream water levels increased (reducing the velocities through both screens) . Problems however arose after long periods of low flows. Particles would be deposited on the upstream side of the horizontal section to form a temporary weir. If sufficient particles were deposited in this way, they would not readily be moved and would eventually cause blockage of the section.

The tests on the uniform section were not nearly as successful as the test on the expanded section. Without the expansion, control of the hydraulic jump was lost. Without the turbulence generated by the hydraulic jump to redistribute particles on the sloped screen, both screens soon blocked.

The capacity of the structure was, of course, still limited by the area of the sloped screen, although the tumbling action of the hydraulic jump generally helped to increase the depth of deposit before blockage.

5.7 Watson, 1996

Watson attempted to improve the performance of the self-cleaning screen designed by Compion (see Section 5.6), particularly with respect to the prevention and removal of blockages caused by long low-flow sequences.

Various alternatives were tried out on a scale model (half the scale of the model used in the Compion experiments). The only alternative that showed real promise involved the installation of an inclined suspended baffle wall upstream of the horizontal screen (see Figure 5-13).

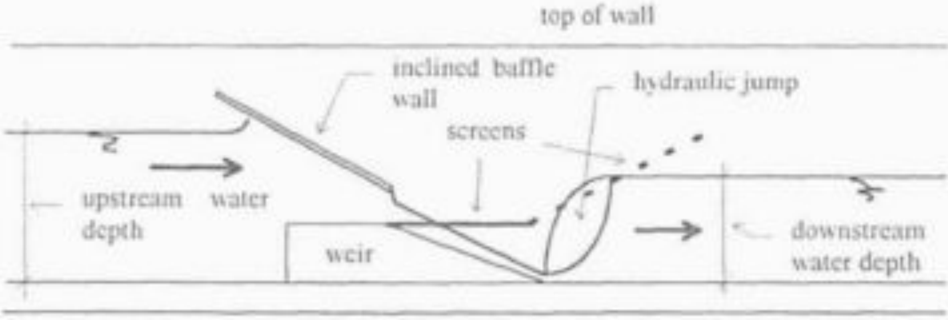


Figure 5-13 : Long-section through the Compion structure showing the inclined suspended baffle wall

The baffle wall was designed in such a way that it remained clear of the water surface except at very high flows or until such time as the horizontal screen began to block. Once blockage commenced, water levels upstream were raised forcing an increasing percentage of the flow over blockage on the horizontal screen, under the baffle wall, and through the relatively large open area of the inclined screen (provided of course that this screen wasn't already blocked by the prior deposition of large quantities of material). The acceleration of the water through the gap between the sluice and the screen increased the shear on the deposited material to a point which was usually sufficient to induce it to move. The baffle wall also appeared to help with the packing of material on the inclined screen by increasing downstream turbulence.

5.8 The Baramy® Gross Pollutant Trap (BGPT)

Working independently of the South African investigations, Baramy Engineering Pty Ltd of Katoomba, NSW, Australia has developed a simple litter removal structure that bears strong resemblance to the River Pradin intake (see Section 5.3), Configuration 15 of the Beecham and Sablatnig experiments (see Section 5.4), the SCS device (see Section 5.5) and the Compion / Watson structure (see Sections 5.6 & 7).

At the heart of the structure is a screen declined at an angle of about 20° which leads onto a collection shelf for the litter. The water flows through the screen and either goes under the collection shelf (Direct Flow version, see Figure 5-14), or around it (Low Profile version, see Figure 5-15). Retention of the litter on the collection shelf is improved by the installation of wire mesh panels on the downstream side. The litter is readily removed by a skid-steer loader (Bobcat or similar) which gains access down a concrete ramp.

The performance of the pipe outlet devices is enhanced by the installation of a deflector plate at the upstream end of the screen - reminiscent of the inclined sluice in the Watson experiments (see Section 5.7).

By September 1997, three prototypes of the structure had been constructed and these units appeared to be working in accordance with expectations. Further tests carried out at the New South Wales, Manly Hydraulics Laboratory in Sydney (Manly Hydraulics Laboratory, 1997) also confirm that the structures work under a wide range of flows and litter loads. As a result of the drop across the structures, upstream flood levels are not generally affected by the traps except at very high flows. The above-mentioned tests also show that, within reason, the structure also performs well even when the outlet channel is being drowned by downstream water levels. Of particular interest is the standing wave that is formed on the collection shelf at higher flows. This helps to redistribute litter and reduce blockages.

According to Baramy Engineering, the units have been designed for rapid construction from pre-cast reinforced concrete panels and prefabricated screens and to handle flows up to 30 m^3/s from either pipe or channel sections in either the Direct Flow (DF) or Low Profile (LP) formats. The biggest drawback of the unit is the relatively large drop that is required in the floor of the channel - usually between 700 and 1 500 mm.

Currently, Baramy Engineering are using screens constructed from 10 mm thick by 50 mm deep steel plate with 15 mm wide openings orientated in the direction of the flow.

Baramy Engineering Pty Ltd has Australian and Overseas patents on the device (Baramy).

More information on the Baramy® Gross Pollutant Trap may be found in Appendix A.5.

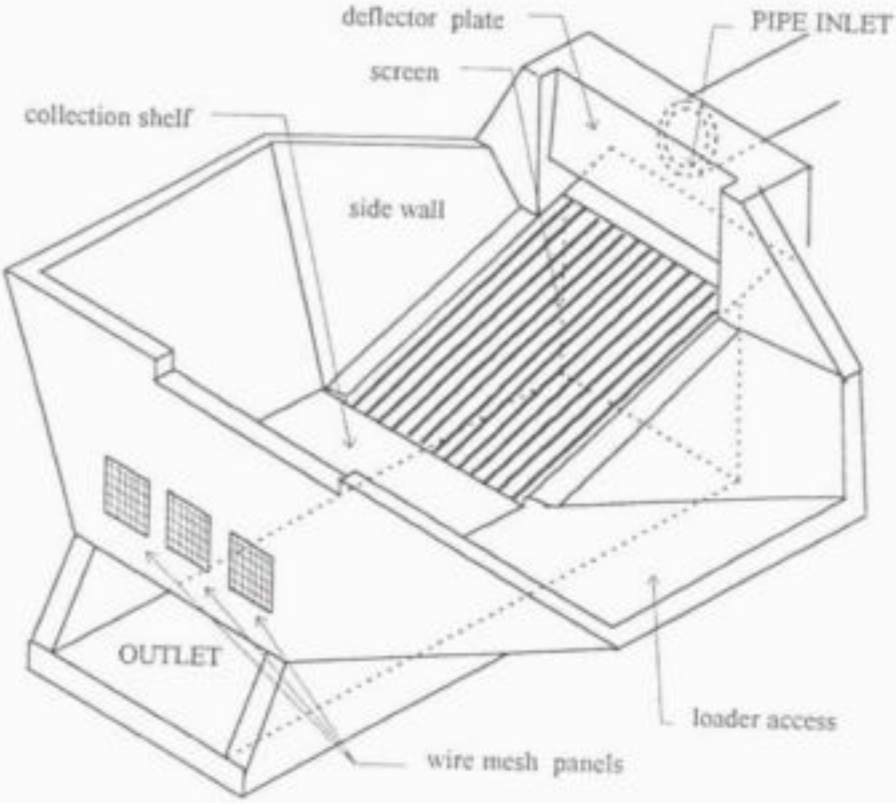


Figure 5-14 : Baramy® Gross Pollutant Trap - Typical Direct Flow version

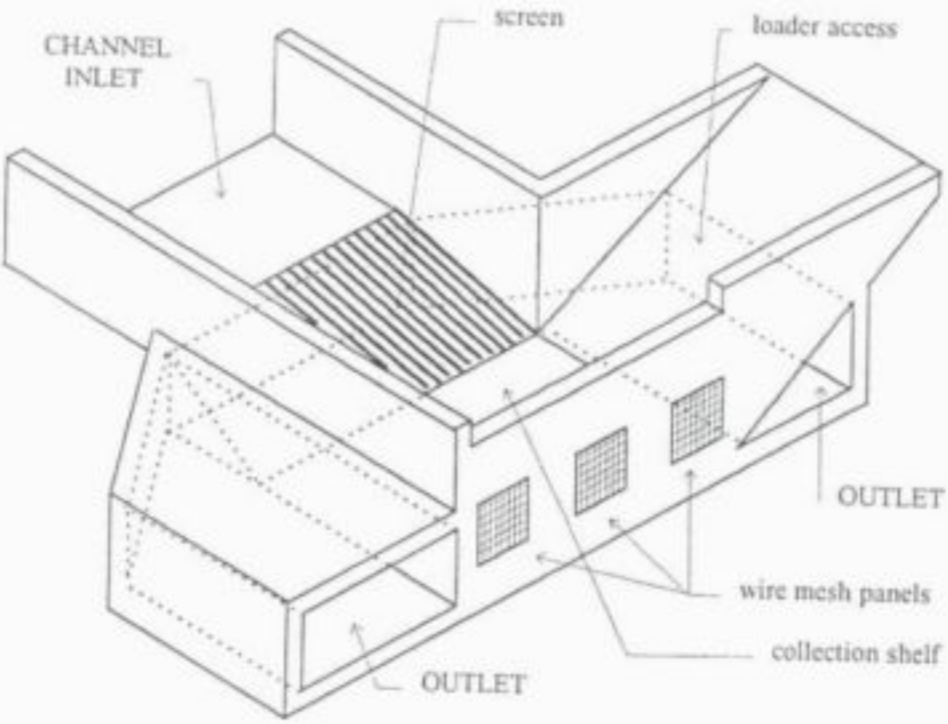


Figure 5-15 : Baramy® Gross Pollutant Trap - Typical Low Profile version

5.9 The optimisation of declined screens (Lawson, 1997)

It will have been noted that self-cleaning declined screens were used on the River Pradin intake (see Section 5.3), by Beecham and Sablatnig (Configuration 15 - see Section 5.4), by Nel (the SCS device - see Section 5.5) and by Baramy Engineering (see Section 5.8). There was however a range of bar designs and declination angles. In an attempt to optimise the design of declined screens, Lawson carried out a series of full scale tests on screens assembled from round bars (R12), rectangular bars (10 mm wide by 30 mm deep) and a tee section (fabricated by welding together two 5 x 15 mm plates). The clearance between each bar was kept constant at 15 mm, whilst the angle of declination was varied between 0° and 45°.

A very small declination angle resulted in the accumulation of litter on the screen and eventual blockage. If the angle of declination was increased to a certain critical minimum (different for each bar section), litter would accumulate on the screen until a combination of hydrostatic and hydrodynamic forces would induce it to slide a little so as to open a flow path through the screen upstream of the blockage. Additional material deposition and / or a change in flow rate would cause a commensurate movement of the litter along the screen until an equilibrium position was reached where litter would drop off the end of the screen at much the same rate as it was being deposited (see Figure 5-16). Increasing the angle of declination further eventually resulted in the litter tumbling off the end of the screen without requiring additional deposition.

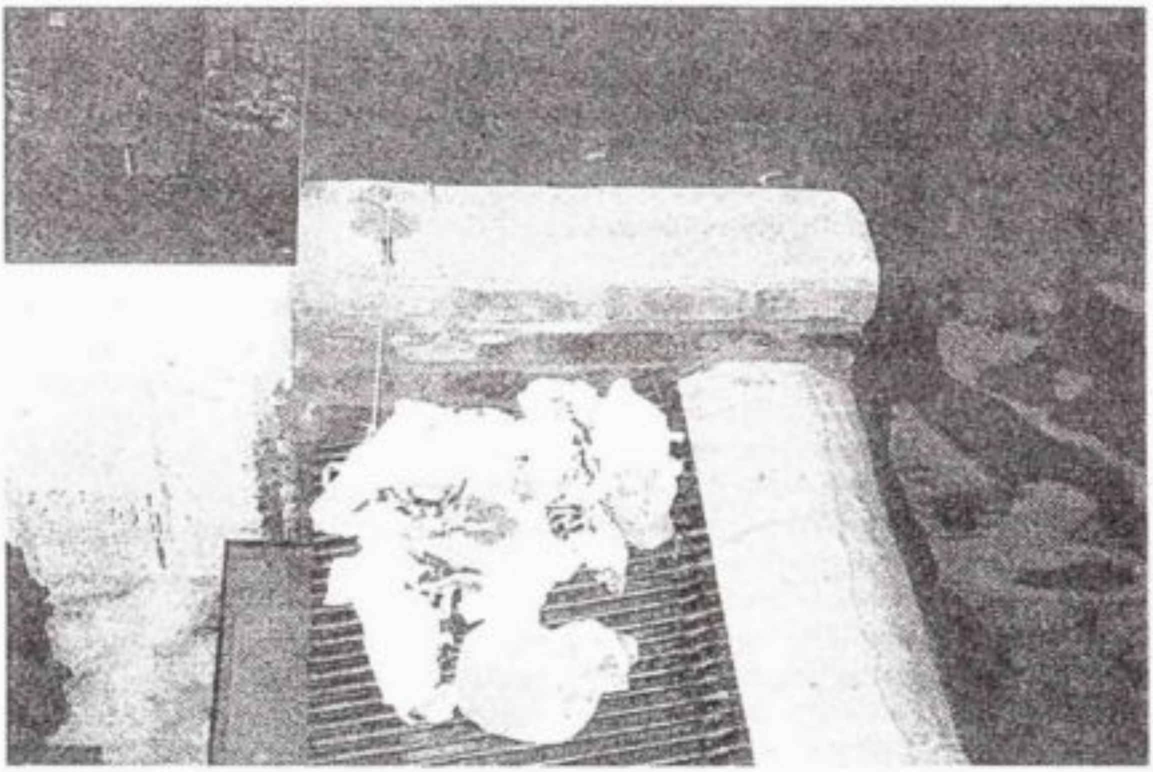


Figure 5-16 : View of the Lawson apparatus showing litter moving down a declined screen installed at the critical angle

Within the experimental limits of the apparatus (screen 900 mm wide x 650 mm long, a maximum flow of 60 litres per second, and the litter selected - mainly full sized polyethylene shopping bags), the critical angle of declination to ensure self-cleaning was 18° for the tee section, 20° for the round section and 22° for the rectangular section. On the other hand, the hydraulic performance - the discharge per unit length of screen - at the critical angle was significantly better for the round and rectangular sections than for the tee section at the flow rates measured. Overall, the optimum screen design (maximum flow capacity for minimum screen size and head loss) appeared to be a round bar section at about a 20° declination angle, but final design would have to be based on experimental data gathered from higher unit flow rates and a more realistic spread of litter type.

The investigation indicated that the River Pradin and Baramy® structures rely on a combination of gravity and fluid forces for self-cleaning whilst the SCS structure relies on gravity alone.

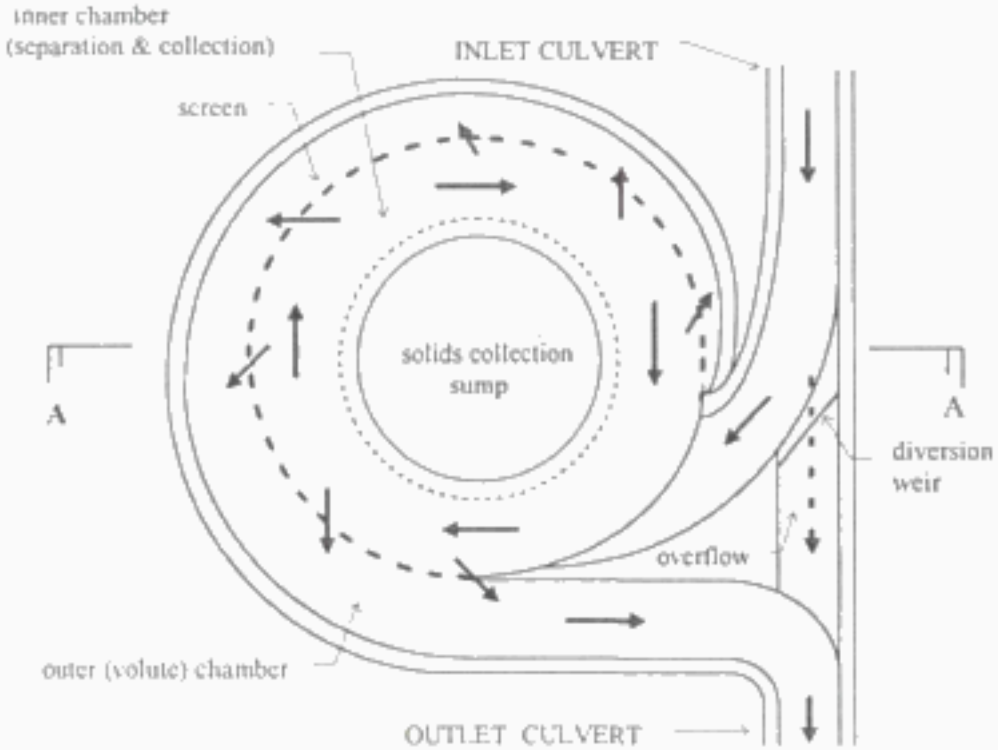
5.10 The Continuous Deflective Separation (CDS) approach

From the foregoing, it is evident that self-cleaning screens work because there are large velocity, velocity gradient and/or gravitational components in the plane of the screen providing the necessary forces to prevent the deposition of particles. Frequently the gravitational force ie. head, is at a premium and consequently the self-cleansing action must rely solely on velocity and the velocity gradient (which induce shear and drag forces). In a linear system, this can only be achieved for short periods of time, because, unless the screen is infinitely long, blockage will commence from the downstream stop-end.

Making the screen circular, on the other hand, is equivalent to making it infinitely long, and provided that the flow moves continuously over the entire screen surface, it is theoretically possible for it to be permanently non-clogging. This is the basis of the Continuous Deflective Separation (CDS) approach devised and refined by CDS Technologies Pty Ltd, with further testing in the hydraulics laboratories of Monash University in Melbourne, Australia to establish the overall performance.

The CDS device is designed as an on-line unit for separating and retaining gross pollutants in a stormwater drainage pipe with possible applications to other similar pipe conveyance systems for industrial and sewerage effluent. The mechanism by which the unit separates and retains gross pollutants (which includes sediments as well as litter) is by deflecting the flow and associated pollutants away from the main flow stream of the pipe into a pollutant separation and containment chamber. Gross pollutants are separated within the upper separation portion of the inner chamber with the aid of a perforated plate screen which allows the filtered water to pass through to a volute return system and hence back to the outlet pipe. The water and associated pollutant contained within the inner chamber are kept in continuous motion by the vortex action generated by the incoming flow. This has the effect of keeping the gross pollutant in the containment chamber from blocking the perforated plate screen. The heavier pollutants ultimately settle into the lower solids collection sump, whilst the flotsam floats on the surface of the containment chamber (Wong and Wootton, 1995). See Figure 5-17.

a) Horizontal section



b) Vertical section A-A

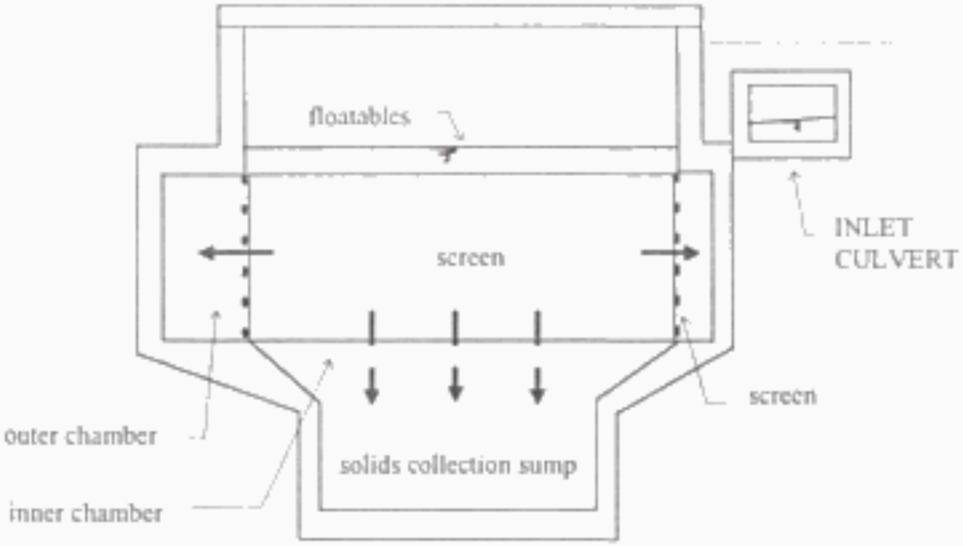


Figure 5-17 : Horizontal and vertical sections through the CDS device

The design of the screen varies a little depending on the type of material that must be trapped. For the removal of litter from stormwater, a pressed metal screen with perforated openings of about 10 mm is used. The perforations are orientated in such a way that the openings are facing away from the direction of flow. This helps to further reduce the risk of blocking (Blanche and Crompton, 1996).

The screen surface area is dependent on the water level in the inner chamber, but is of the order of 40 - 45 times the pipe inlet area. The orifice area of the perforations in the direction perpendicular to the screen is approximately 20% of the total screen area. The maximum orifice flow area available (looking at an angle against the direction of flow) is approximately 40% of the screen area. The average radial flow velocity through the screen is thus at least an order of magnitude less than the pipe inlet velocity.

The tangential flow velocities in the inner separation chamber decrease along the screen with increasing distance from the inlet. They also decrease with depth and the distance from the screen towards the centre of the chamber. At the same time, the radial flow velocities through the screen also decrease along the screen with increasing distance from the inlet. The net result is that there is some sort of balance between the significantly higher shearing forces along the screen compared to the relatively low pressure and centrifugal forces acting outwards across it, thereby ensuring that litter is kept in continuous motion and does not stick to the screen.

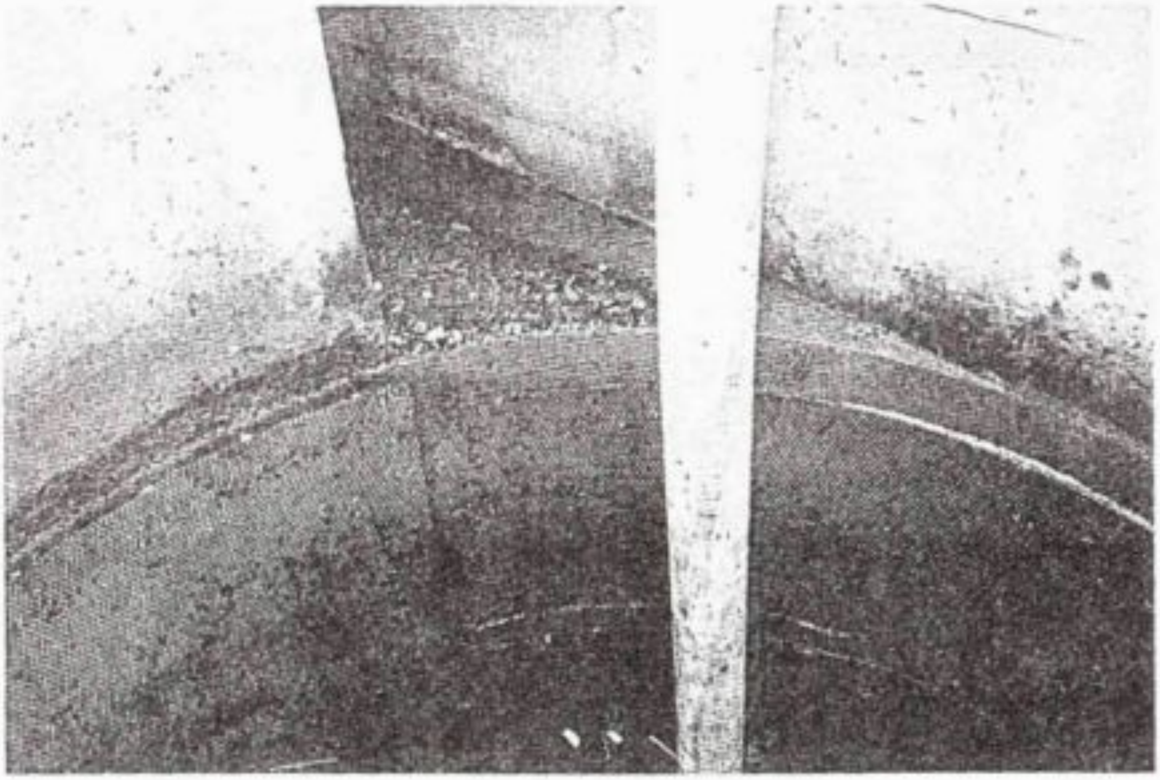


Figure 5-18 : View of the inside of the CDS device installed at Coburg, Australia. The unit is being drained for cleaning. The inlet culvert and the screen are clearly visible.

The flow direction in the outer volute chamber is opposite to that of the separation and containment chamber. The difference in head on either side of the screen (which determines the rate of orifice flow) is thus largest near the inlet and decreases with increasing distance along the screen from the inlet and this explains the variation in the rate of flow through the screen.

A number of different materials have been employed to test the efficiency of the screening mechanism including sand, grass clippings, leaves, twigs and samples of litter. None of the materials were found to produce any significant blockage or interfere with the continuous operation of the device (Wong and Wootton, 1995).

Head loss measurements, carried out in the laboratory, indicate that, as the flow increases, the head loss coefficient trends to about 1,3 times the velocity head of the inlet pipe assuming pipe-full conditions ($V^2/2g$ where V is the average velocity across the entire section), depending on the height of the diversion weir (surplus flow by-passes the device) (Wong et al, 1996).

The trapping efficiency for material less than the mesh size is unclear, although laboratory studies by Wong et al, 1996 indicate a high percentage (near 95%) of captured sediment of sizes down to 50% of the separation screen aperture size. The field data from a field study in Coburg near Melbourne, indicates that 70% of the sediment collected from the unit was less than the mesh size thus suggesting that it efficiently traps finer sediments (Allison et al, 1996).

Major drawbacks with the device are its relatively large size (and hence cost - see Appendices A.4 and B.4) and the difficulties associated with the cleaning of the unit. The CDS unit that was constructed in the Coburg, Australia catchment was only capable of treating 550 litres per second before bypassing commenced, yet had gross dimensions of approximately 6 x 6 x 4 m. During the field trials, this unit was cleaned by hand. This required 36 hours of dry weather (to ensure low inflows), removing the floating material with a swimming pool leaf-scoop, pumping out the water from inside the two chambers (approximately 45 m^3), and then manually removing the sump materials using a rope and bucket. All personnel entering the unit were required to have completed a course in confined space entry. On all occasions the cleaning process involved at least three people and took between two and three hours (Allison, 1997). Figure 5-18 shows a view of the Coburg unit being drained for hand cleaning. The inlet culvert and the screen are clearly visible.

According to CDS Technologies, 1997, modifications have recently been made to produce a larger flow capacity using a more compact precast concrete design which is cheaper to construct, together with a larger sump (about 9 m^3) to reduce the frequency of cleaning. The new P3030 precast unit has a footprint of 5 x 5 m (excluding the weir chamber on the pipeline) and a flow capacity of 1,75 m^3/s. It can be cleaned in about 3,5 hours using a truck mounted telescoping grab which does not require the unit to be dewatered.

Alternative methods of cleaning the CDS units is by pumping them using a powerful pump and a minimum 150 mm diameter hose into a specially designed eductor truck, or by installing a woven "basket" in the sump which is periodically lifted by an externally located crane and drained into waiting trucks (Blanche and Crompton, 1996 and Allison, 1997). A reasonably large crane would be required to lift the weight of the basket, which in the case of the Coburg unit would be in the order of seven tonnes.

Cleaning the Coburg trap after a two and a half month period resulted in collection of four tonnes of wet material - much of it sediment (Allison, 1997). In South Africa, the current high litter loads carried by the stormwater drainage system (see Section 2) may very well lead to an unacceptably high cleaning frequency.

The device has been patented.

More information on the CDS device may be found in Appendices A.4 and B.4.

5.11 Conclusions

Consider a piece of litter near a screen. Only the following forces can be present:

1. gravity (vertical);
2. pressure (normal to the particle surface);
3. shear (tangential to the particle surface); and
4. inertia (in the direction of movement).

The pressure forces are as a result of:

- a) flow separation from the surface of the particle which prevents pressure recovery in accordance with the Bernoulli principle,
- b) hydrostatic variation, and
- c) local variations caused, for example, by flow acceleration through the gaps in a screen.

Shear forces are effected by way of skin friction on the particle as a result of the velocity gradient at the surface. This velocity gradient is determined by the shape of the boundary layer around the particle, which in turn is influenced by:

- a) the shape of the boundary layer in the vicinity of the screen (or the sides of the channel, or other particles etc.), and
- b) eddies resulting from in-stream turbulence and / or flow separation.

The inertia force is not normally very large unless the object is moving as a substantially different velocity to the fluid.

The forces combine to cause drag (in the direction of flow), lift (normal to the direction of flow), and rotation. Rotation can be around some axis within the particle or around an axis somewhere in the fluid.

If the particle gets to touch the screen (or any other solid boundary), then two other forces may come into operation:

5. the reaction of the boundary (normal to the contact surface); and
6. friction (static or kinetic) resulting from the contact (tangential to the contact surface).

If trapping and consequent blockage is to be prevented, the forces acting to free the particle must be capable of overcoming the forces acting to trap it. This is illustrated in Figure 5-19.

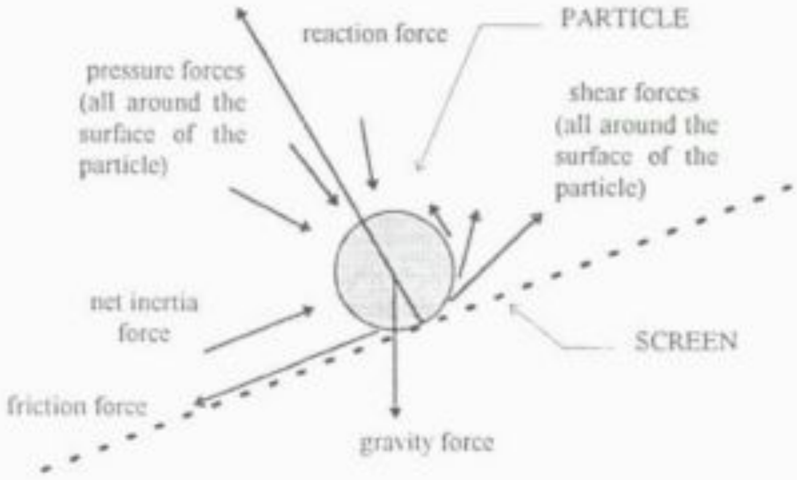


Figure 5-19 : The forces acting on a particle in contact with a self-cleaning screen

Pressure and shear are both directly related to the velocity and velocity gradient of the flow. The reaction of the boundary and the friction resulting from contact are related to the gravity and velocity components normal to the boundary. Surging (as a result of vortex shedding generated around an obstacle in the flow path or by rapid variations in the flow rate) helps to keep the screen clean by momentarily changing the velocity and velocity gradient vectors.

From this it is clear that the design of a self-cleaning screen comes down to the use of:

1. velocity;
2. velocity gradient; and
3. gravity.

The optimum self-cleaning structure would be expected to have a thin sheet of high velocity flow directed down a steeply declined screen with a relatively small velocity component through it, and would be made subject to some form of surging flow. The design of the screen is also important. Screens should offer as little resistance as possible to litter sliding along their surfaces, and litter that does penetrate the openings should not catch the bars.

The problem with such a device, is that it requires considerable head for its operation, and head is frequently in short supply. Hence compromises are required.

It is now possible to explain the self-cleaning mechanisms of the different structures described previously.

The Bondurant and Kemper device (Section 5.2) relies on the high velocities and surging created by "dropping" the flow onto a horizontal screen, enhanced if necessary by vortex shedding around a metal bar installed upstream of nappe.

The River Pradin (Section 5.3), SCS (Section 5.5) and Baramy® (Section 5.8) devices all use a combination of high velocities and gravity created by spilling the flow over a declined screen.

The Compion device (Section 5.6) relies on a combination of high velocity and surging. The flow is forced through critical velocity over a horizontal screen with the spillway so shaped that the component of velocity in the plane of the screen greatly exceeds that normal to it. The flow is then forced back through critical velocity to form an hydraulic jump that impacts on the downstream, inclined section of the screen. Watson (Section 5.7) showed that the horizontal screen remained self-cleaning over a wider range of flows if the flow velocity is increased locally by means of a sloping baffle wall.

The CDS device (Section 5.10) relies on a high velocity jet directed along the inside surface of a continuous, circular screen. The area of the openings through the screen is large compared with the effective flow area within the inner chamber thus keeping the angle between the velocity vector and the tangent to the screen small.

Closer examination of the more successful models tested by Beecham and Sablatnig (Section 5.4) shows that the key in every instance was a high velocity flow directed at a very small angle to the plane of bars. The bars were generally orientated in the direction of flow once blocking commenced.

It can also be seen that the "Enviroscreen" (Section 4.2) failed as a self-cleaning screen because when it started to block there was nowhere for the water to go but over the top of the blockage. There was no outlet to the sump, so no net force propelling the litter bearing water there. The movement of litter into the sump relied purely on a force component generated by the angle of the bars, which in general was inadequate to overcome the forces causing the blockage.

6. In-line screens

6.1 Introduction

In-line screens are the most common form of litter removal device. They usually consist of metal bars mounted on the floor of the channel (or on a low weir lying on the floor of the channel) and raked at some angle between 25° and 90° to the invert of the channel in the direction of flow. Figure 6-1 shows a typical example of such a device.

They may also comprise nets around the outlets of stormwater pipes (for example on the Capel Sloot culverts, Cape Town - see Section 2.4) or steel baskets (for example North Sydney Litter Control Device described in Section 6.5 below). In fact, there have been numerous "ingenious" ideas for cheap, maintenance friendly in-line screens.

Figure 6-1 : View of a typical in-line screen

In-line screens do not have a good record in South Africa for several reasons:

- They are easily blocked;
- Unless they are carefully located in an area with considerable fall, they represent an upstream flood hazard;
- They are easily damaged (a log moving at, say, 3 m/s down a channel can do considerable damage to a screen that is in its path);
- They are often hard to maintain (so are frequently not maintained at all!); and
- They have a relatively limited storage capacity.

All of these failings are illustrated by the structure depicted in Figure 6-1. Since there is little flow in the channel for much of the time, the litter load is trapped over a small area at the bottom of the screen to form a sharp crested weir. The presence of this sharp crested weir accelerates the flow through critical depth. Additional items of litter carried by the flow now rapidly block the screen on the crest of the informal weir. The screen thus blocks from the bottom upwards. Meantime, the water level in the channel upstream of the structure increases with the increasing height of the informal weir. In times of flood, any remaining screen area is quickly blinded out by the litter and the water is forced to go over or around the structure.

In the structure illustrated above, the municipality concerned showed considerable ingenuity in providing several rows of mild-steel, vertical "prongs" projecting some 300 mm above the ground across the flood-plain. These prongs strain out the litter that by-passes the structure - until they too block. A coarse grid was also placed across the upper section of the canal immediately upstream of the structure to reduce damage by large flotsam during floods, but even so the screen shows considerable evidence of impact damage.

Maintenance is difficult, so rarely carried out properly. Long rakes, which are seldom available on the maintenance vehicles, are required to dislodge the litter that has collected on the bars. The prongs also take some time to clean properly, whilst silt deposited on the flood-plain provides an excellent growing medium for the grass that was supposed to protect the banks from scour! Soon, the prongs disappear under silt and grass, and the floodwaters must find an alternative route - with unknown consequences.

To make matters worse, the municipality is continually caught between the desire to use a coarse screen to reduce blockage and hence upstream flooding, and the demand of downstream users for them to use a fine screen to reduce the amount of litter escaping through the bars.

Nevertheless, in-line screens can be made to work if they are appropriately designed. The remainder of this section is devoted to five examples of in-line structures that have been used with some degree of success. These are:

6.2 Side-entry catchpit traps (SECTs);

6.3 Fences or nets straining slow flowing streams;

6.4 The Canberra Gross Pollutant Trap (GPT);

6.5 The North Sydney Litter Control Device (LCD); and

6.6 The Urban Water Environmental Management (UWEM) concept.

6.2 Side-entry catchpit traps (SECTs)

Numerous side-entry catchpit traps have been designed - and patented - by various organisations (see for example Melbourne Water Waterways and Drainage Group, 1995).

In its most basic form, a wire mesh or plastic perforated tray is mounted on metal supports embedded in the catchpit side walls next to, and immediately underneath, the catchpit opening. Stormwater either flows through the perforations (which are typically between 5 and 20 mm in diameter) leaving the litter behind, or, if the perforations are blocked and / or the tray full, the stormwater flows over the back wall of the tray. To remove the litter, the basket is either manually cleaned, or it is vacuum educted ("sucked" clean) and washed with water under high pressure. See Figures 6-2 and 6-3.

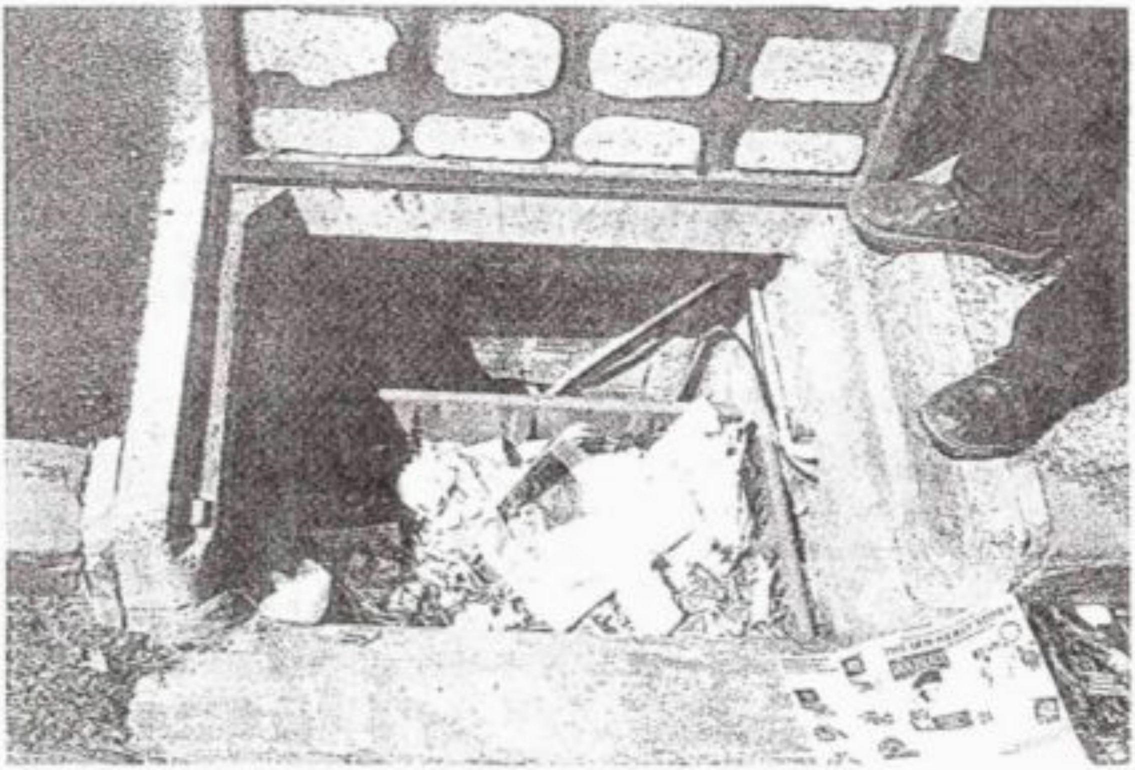


Figure 6-2 : View of a typical side-entry catchpit trap

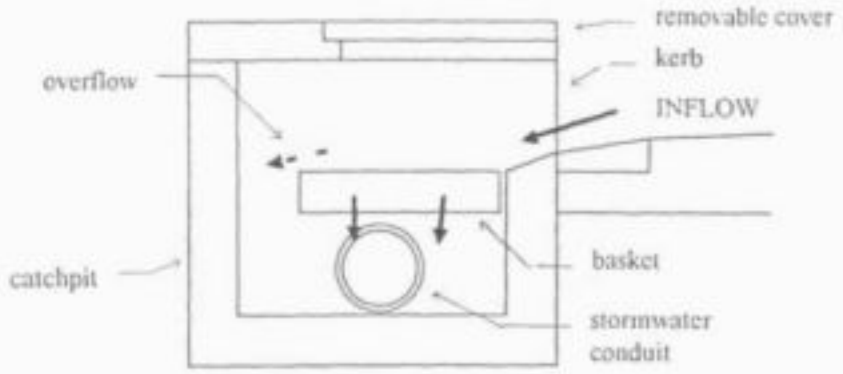


Figure 6-3 : Cross-section through a typical side-entry catchpit trap

Although, at first glance, the installation and maintenance of such a device looks to be extremely tedious and costly, there are potential advantages. Work carried out by the City of Banyule, a suburb of Melbourne, Australia (City of Banyule, 1994) and the University of Melbourne (Allison, 1996(a) and Allison, 1997) show that frequently, a large percentage of the litter comes from relatively few sources. If these sources can be identified, not only can this large percentage be removed relatively cheaply, but pressure can be brought onto the culprits to do something to reduce its generation. The City of Banyule operates a fleet of eductor trucks that clean the thousand or so catchpits under their jurisdiction at a frequency determined by information gleaned from a data-base they continuously update as they clean. See Appendices A.1 and B.1 for more information.

6.3 Fences or nets straining slow flowing streams

If a channel is generally drowned - for example where it flows into a lake or the sea - average velocities are reduced and the litter load starts segregating into flotsam and bed-load. A porous barrier, such as a fence or net, placed in the path of the litter will therefore readily intercept it. Figures 6-4 (the fences across the mouth of the Lotus River into Zeekoeivlei near Cape Town), and 6-5 (the nets over the mouth of the Capel Sloot culverts in the Duncan Docks in Table Bay) illustrate two typical arrangements.

There are several points to bear in mind:

1. The velocities through such devices must remain reasonably low at all times (maximum velocity less than, say, 0,3 m/s and Froude No. less than 0,1) to ensure reasonable segregation and to prevent compaction of the material against the barrier;

2. Care must be taken to ensure that if the screen does block, flood-waters can get through, over or around. Obviously, considerable volumes of accumulated litter is likely to be lost in such an event;

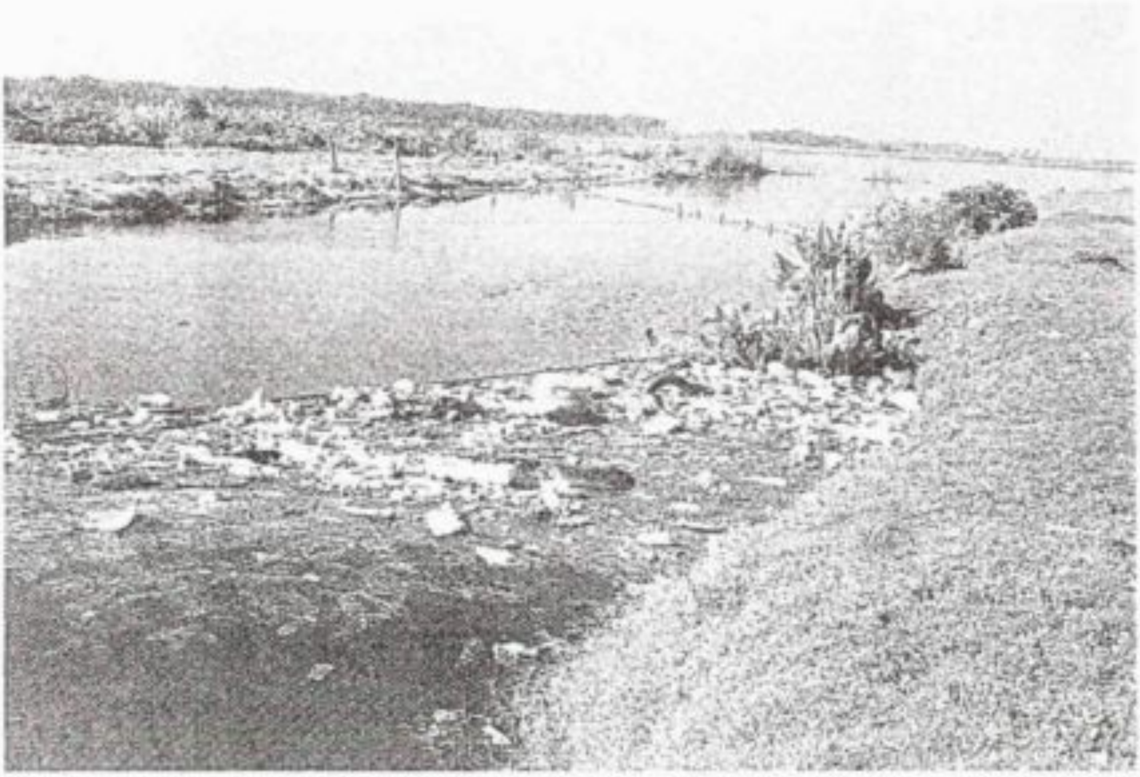


Figure 6-4 : View of the fences across the mouth of the Lotus River into Zeekoeivlei near Cape Town

3. The devices must be easy to clean. In the case of nets, this might mean allowing a portion of the net to lie along the upstream bed of the channel to catch the bulk of the bed load, and then cleaning it by pulling the entire net out of channel with a crane. In the case of a fence, angling the fence can help to bring flotsam to the bank where it can be fished out with scoops - particularly if this bank is generally on the down-wind side of the channel. Getting the bed-load out of channels can however pose a considerable problem unless the channel can be drained - which is not normally feasible. The channel may have to be dredged from time to time - an expensive process.

The key to the success of this type of device is a low flow velocity . Once the average velocity in the channel starts to build up to 1 m/s or more, the openings will block, there will be upstream flooding, and in all probability the structure will eventually wash away.

6.4 The Canberra Gross Pollutant Traps (GPT)

These devices (which are found in many other places apart from Canberra, eg. Sydney) consist of a concrete-lined sedimentation basin dammed by a wide low weir surmounted by a screen The screen is typically made from 10 mm thick vertical bars at a spacing of about 60 mm and ranges in height from 300 mm to 900 mm. Provision is generally made for the basin to be drained for the maintenance and cleaning of the trap (Willing & Partners, 1989).

Figure 6-5 : View of the nets over the mouth of the Capel Sloot culverts in the Duncan Docks in Table Bay, Cape Town

The structures come in two main configurations. Major Gross Pollutant Traps (Major GPTs) are located on major floodways and drains to intercept medium to high stormwater flows from large catchments. Figure 6-4 shows a typical Major GPT. Minor GPTs are located at the head of major floodways, locations where stormwater pipes discharge laterally into floodways, or on the shores of ponds and lakes where stormwater discharges directly into these water bodies. In the case of Minor GPTs, the sedimentation basin is much smaller and the screen is often orientated parallel to the incoming flow.

The design of these structures is primarily orientated towards the capture of silts. Silts which are washed off roads in densely populated urban areas frequently contain high concentrations of heavy metals which are toxic to plant and animal life, particularly if they are deposited in thick banks in bays and estuaries. The silts may also carry nutrients - which cause eutrophication of downstream water bodies - and pesticides.

Figure 6-6 : View of a typical Canberra type Gross Pollutant Trap (GPT) looking upstream from below the screen

Although the design of the sedimentation basin is beyond the scope of this report, the design of the screen is of some interest.

No attempt is made to make the screen self-cleaning. The low-level weir on which the screen is mounted forces the flow through critical depth on the line of the screen. Litter accumulates from the bottom and effectively raises the crest of the weir until the screen is blocked over its full height. The vertical height of the screen is therefore governed primarily by the need to minimise adverse effects in the upstream drainage system if the screen becomes completely blocked. As a general rule, the screen height does not exceed one half of the height of the pipe or drain. Before the screen height is selected, the upstream drainage system is investigated to determine whether raised water levels are likely to cause surcharging on properties adjacent to the drain.

Once a suitable screen height has been selected, its length is determined by ensuring that the one year recurrence interval discharge can pass through it without overtopping when it is 50% blocked. The effective flow width of the screen is usually taken to be 85% of its total width.

The bars of the screen are mounted vertically rather than horizontally because vertical bars are much easier to clean. When the basin is drained, the litter tends to fall off the vertical screens.

In general, these structures are not appropriate for South African conditions. They work in the Australian environment because of the large area of the screen and the relatively small litter load in the stormwater (see Section 2.5). They are also extremely expensive - the larger structures costing several millions of rands. However, by the end of 1996, sixty-four examples of this type of structure had been constructed in Canberra alone (ACT, 1996).

6.5 The North Sydney Litter Control Device (LCD)

The North Sydney Litter Control Device programme has already been described in Section 2.5.3.

The device was developed jointly by the University of Technology Sydney (UTS) and North Sydney Council. Each trap consists of a pre-cast or in-situ concrete pit located downstream of a stormwater drainage pipe or culvert. A drop is provided in the pit between the invert of the inlet and the floor of the outlet structure. This drop is in the order of a metre, which caters for the 635 - 850 mm deep removable baskets and a 150 - 300 mm gap below the outlet structure. Above the removable litter basket is an inclined trash rack with vertical bars spaced every 50 mm. This trash rack is inclined towards the litter baskets to prevent the inflow from scouring out previously deposited litter. It is hinged so that it can be pushed back to enable easy removal of the litter baskets (Brownlee, 1994). See Figures 6-7 and 6-8.

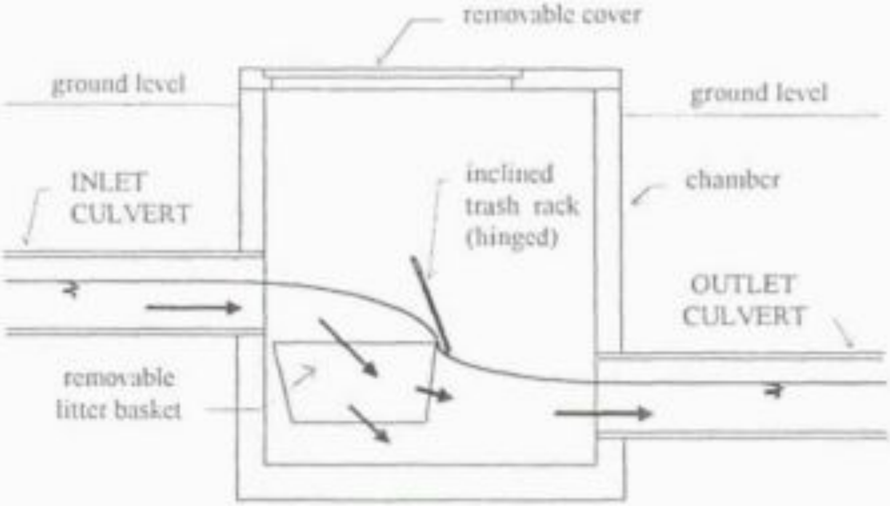


Figure 6-7 : Section through a typical North Sydney Litter Control Device (LCD) (after Brownlee, 1995 and Hocking, 1996)

Different styles of litter baskets have been used. Typically, they are made from 5 mm thick punched sheet metal with staggered 30 mm diameter holes at 45 mm centres and supported on a galvanised steel frame (Hocking, 1996).

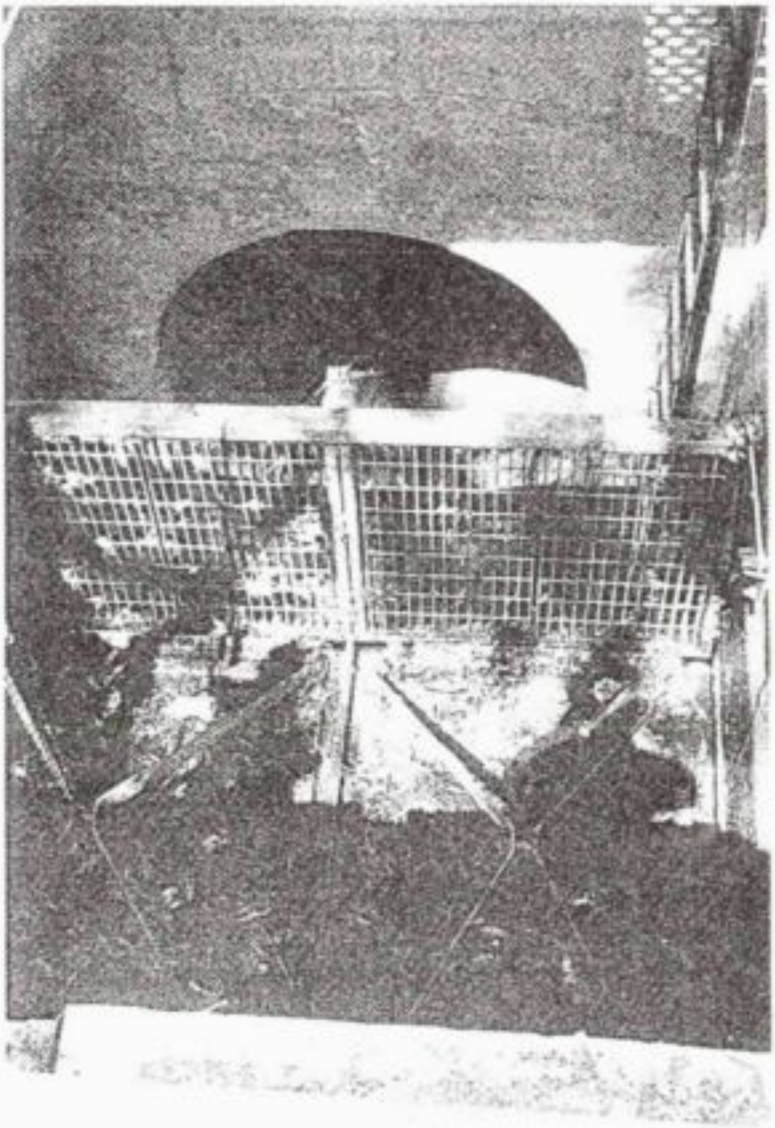


Figure 6-8 : View inside the North Sydney Litter Control Device (LCD)

The UTS model studies, carried out by Beecham and Sablatnig, 1994, confirmed that the drop in floor elevation provides sufficient energy to force the flow through the mesh and out through the bottom and sides of the baskets without substantially increasing flood levels upstream. When the litter eventually blocks the flow of stormwater through the basket and litter rack, the trash rack is over-topped and becomes a sharp-crested weir.

The chief advantage of the device is the relative ease of maintenance. The lid of the pit is removed, the litter rack is rotated into the upright position, and a small crane mounted on the back of a truck is used to lift out the basket and empty it into the back of the vehicle.

The chief disadvantages of the structure are its poor efficiency (estimated to be in the order of 25%), the limited capacity of the baskets, and the substantial drop in elevation required for the structure to operate. See Appendices A.2 and B.2 for more information.

6.6 The Urban Water Environmental Management (UWEM) Concept

The essence of the Urban Water Environmental Management (UWEM) Concept is that an hydraulically controlled sluice gate is used to create the necessary head required to force the stormwater through a series of screens, under a suspended baffle wall and over a weir. In the event of a major flood coming down the channel, the sluice gate automatically lifts to pass the peak and prevent upstream flood levels from being raised higher than they would have been had there been no structure at all.

The flexibility of this approach is probably demonstrated best by reference to the Robinson Canal Pollution Control Works in Johannesburg (see also Section 2.3).

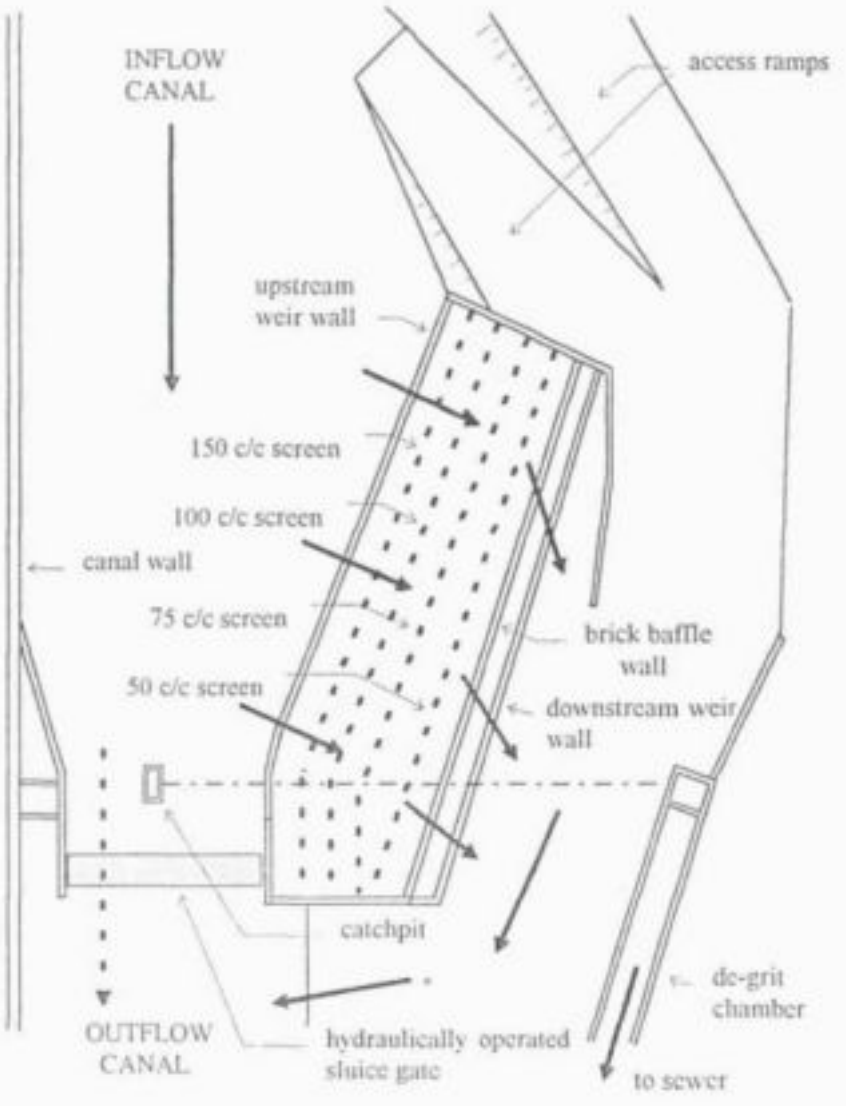
The Robinson Canal is situated in the central Metropolitan Council District, Johannesburg. It drains approximately 8 km^2 of highly developed urban area and flows southwards from the Braamfontein ridge through the areas of Selby, Orphiton and Booysens to join with the headwaters of the Klipspruit. The catchment area includes a mix of land uses including residential, commercial, industrial, and a portion of the central business district including the market and informal trading areas.

The Robinson Canal also transports sewage which enters the stormwater system as a result of collapsed or blocked drains. Because of the high level of pollution in the canal, the then City Council of Johannesburg wanted the low flow polluted water to be diverted into the nearby Klipspruit outfall sewer.

Urban Water Environmental Management (UWEM) proposed a scheme which would both divert the low flow sewage into the outfall sewer and trap most of the urban litter and flotsam which emanates from the catchment. See Figures 6-9 and 6-10. The system, designed and patented by UWEM, comprises the following:

- a catchpit in the canal to divert the low flow polluted water out of the canal;
- a de-grit channel to deposit the sediment from this low flow;
- an automatic diaphragm valve to pass low discharges of polluted water into the Klipspruit outfall sewer;
- a series of screens placed at an angle to the main water way to entrap suspended materials carried by slightly higher flows;
- a baffle wall downstream of the screens to trap oils and flotsam that escape the screens;
- a low weir downstream of the baffle wall to maintain a minimum water level (and low flow velocities) through the screen area; and

a) Plan



b) Section through the screens

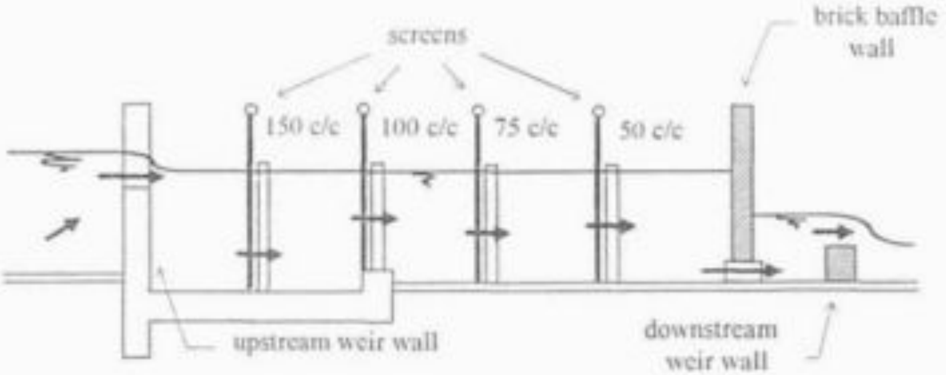


Figure 6-9 : Plan of and section through the screens at the UWEM Pollution Control Works on the Robinson Canal, Johannesburg

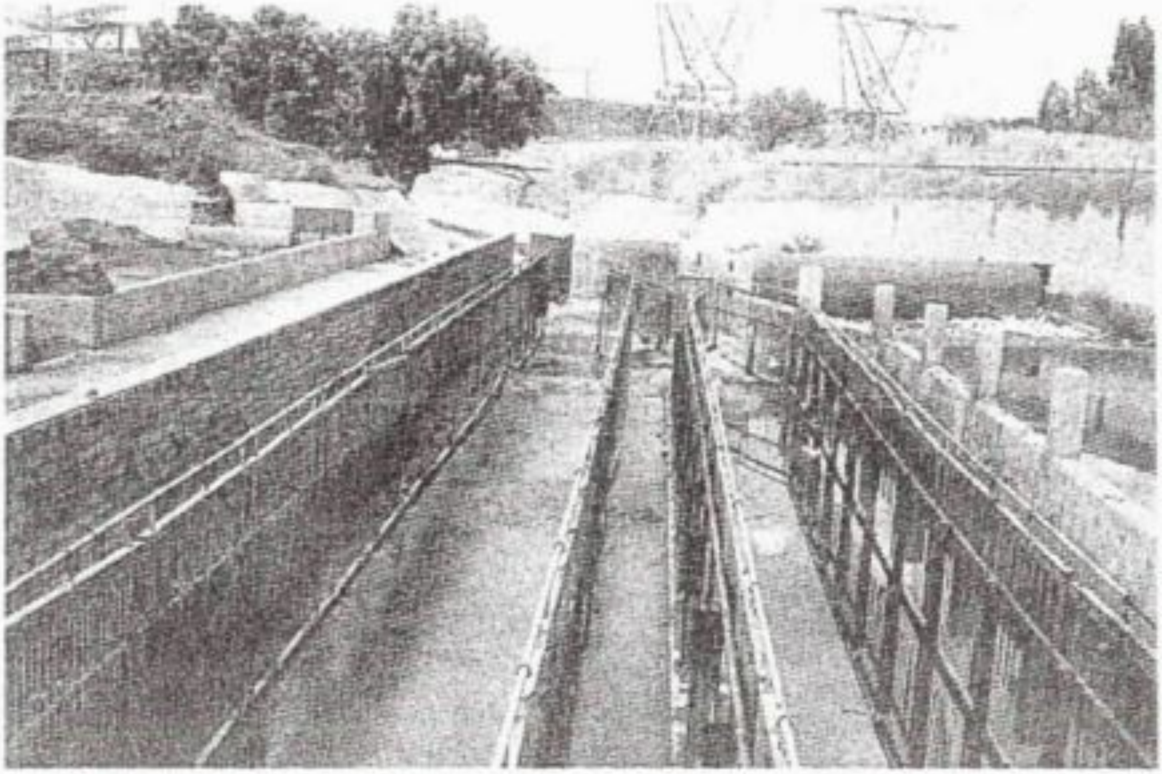


Figure 6-10 : View of the Robinson Canal screens after cleaning. The hydraulically operated sluice gate is clearly visible on the right hand side of the picture.

- an hydraulically actuated flood control gate which is designed to divert all flows less than 15 m^3/s into the catchpit or through the screens. See Appendix C for more details on hydraulically actuated flood control gates.

The structure operates in the following manner:

1. With low flows of under approximately 120 litres per second, the polluted water flows into the catchpit in the canal, and through a pipe into the de-grit channel where the sand settles out. It then flows through the diaphragm valve and down a vertical shaft into the main outfall sewer.

2. When the water in the canal rises above 120 litres per second, the control system for the diaphragm valve is activated and the valve automatically closes to prevent the sewer from being surcharged with stormwater.

3. The flood control gate remains closed as the water level rises further. The flood waters are diverted over the upstream weir wall and through a series of screens ranging from the course screens spaced at 150 mm centre to centre, and fining down through three more rows spaced at 100 mm, 75 mm, and 50mm respectively, before exiting under the suspended baffle wall and over the downstream weir wall.

4. If the flood waters rise further as a result of very large downpours, the flood control gate opens in order to maintain a constant upstream water level and limit the flow through the screens to its maximum capacity.

5. When the flood waters recede, the flood control gate first closes, then the water ceases to flow over the weir wall into the screen basin, and finally the diaphragm valve opens and starts discharging water into the sewer as per 1. above. The screen basin is drained by a 400mm diameter pipe.

The trapped litter needs to be cleaned out after every storm event. The screens can be cleaned by one person in less than three days or alternatively by a team within a day. After the water has receded from the litter basin, the cleaners may enter the area through a gate. The screens are comprised of vertical rods welded to a top frame. To clean the screens, the frame is raised and the litter either falls, or is raked, onto the floor of the basin. Here it is easily collected into bags for disposal. Sufficient isle width has been left between the rows of screens to afford the cleaners comfortable access.

The sediment in the canal requires removal approximately every three months during the wet season. It is cleaned out with a front end loader.

The structure passes a flow of 15 m^3/s, or approximately 85 percentile of all flows, before the flood control gate starts to open. As the gate starts opening, some bottom transported debris is passed downstream under the gate, but flotsam is still trapped by the gate and diverted towards the screens. The structure can retain litter up to approximately the 1:2 year recurrence interval flood (56 m^3/s) which represents approximately 99% of all flows. Once the 1:2 year flow rate is exceeded, the trap is over-topped and the litter lost downstream. The gate opens fully to pass a combined flow of 82 m^3/s, which is nearly the 1:10 year flood, with very little increase in the upstream flood levels. This type of structure is therefore very useful for urban areas where upstream flooding must be prevented or minimised.

The flow velocities through the screens and in the canal are generally less than 0,5 m/s.

In addition to the cleaning of the structure, the following maintenance is required:

- the flood gate and sewer diversion valve need to be inspected and cleaned once a year;
- the low flow de-grit channel needs to be agitated once a week to break up the scum that forms there; and
- during the rainy season, the de-grit channel needs to be cleaned out by a back-actor once a month.

The regular cleaning of the structure during the rainy season also ensures that:

- carcasses are removed before they decay and become a health hazard;

- spills of oils or toxic materials are immediately referred for further action by the pollution control officers;
- litter is collected before it dries up and blows away; and
- abnormalities or damages are promptly reported.

Possible improvements to the structure could include:

- the addition of a flotsam chamber at the ends of the baffle wall to collect the flotsam for easy removal and prevent complete loss in the event of a large storm.
- an additional row of screening (100 mm centre to centre) to increase the litter storage
- an increase in the width of the isles to accommodate a skid-steer loader (Bobcat or similar).
- the covering of the structure with shade cloth to make it more aesthetically acceptable to local residents and prevent litter being blown away by the wind.

The chief advantage of the UWEM approach is that is can be applied in areas with flat gradients, such as along the coast, as the head that is required to operate the trap is generated by a sluice gate which lifts us out of the way in the event of a major flood.

See Appendices A.7 and B.7 for more information.

7. Booms and baffles

7.1 Introduction

As was shown in Section 4, bed-load will be trapped behind a weir, and flotsam will be trapped behind a boom or suspended baffle wall, provided the flow velocities are low enough to:

1. allow desegregation; and
2. prevent wash-over / wash-under

and provided further that there is no hydraulic interference between the different structural elements increasing the vorticity.

The following devices will be discussed in this section:

7.2 the Sydney Harbour Litter Booms;

7.3 other floating boom installations; and

7.4 the In-line Litter Separator (ILLS)

Further applications of booms and baffles will be discussed in Section 8 in conjunction with detention / retention ponds and wetlands.

7.2 The Sydney Harbour Litter Booms

In 1990, the Sydney Water Board (now called Sydney Water) installed pollution control booms at the outlets of four stormwater channels: Hawthorne Canal, Dobroyd Canal, Rushcutters Bay and Blackwattle Bay. These locations are all on Sydney Harbour and are subject to tidal movement. The objectives of the boom installation (Sydney Water Board, 1993) were:

1. interception of floating litter and other debris in the stormwater canals before it entered the receiving waters; and
2. to raise community awareness of litter in the urban waterways as an environmental problem.

The booms consist of buoyant segments which float on top of the water, with an attached skirt or curtain, made from a solid PVC type material, hanging below. The booms are attached at their ends to stainless steel rings which are free to slide up and down a stainless steel rod. This allows the segment strings free movement in response to changes in the water level (see Figure 7-1).

Figure 7-1 : View of a typical floating boom (Rushcutters Bay)

A performance assessment of the booms carried out by Gamtron Pty. Ltd for the Sydney Water Board (Gamtron, 1992) revealed inter alia:

- It was extremely important that the design of the end connections ensured that the ends of the booms were always lying along the surface, as any catching of the ends would suspend the booms allowing litter to escape on falling flood levels;
- When the tide started to come in, stormwater tended to roll over the top of both the boom and the denser incoming salt water. This sometimes caused a temporary sinking of the boom to just under the water surface. This also made free movement at the end connections imperative;
- Apart from organic material (mostly leaves) which comprised 71% of all rubbish caught in the traps, plastic items were the most prevalent item of litter captured (13%), followed by paper (7%), glass (2%) and metal items (1%). It was observed that this type of trap could not be expected to catch items which do not generally float;
- The booms were prone to vandalism: a rowing club had unfastened one boom to paddle through; the same boom on another occasion was weighed down with bricks; shackles were stolen off another, and someone had damaged a flotation chamber by running over a boom in a power boat. The recommendation was that signs be provided indicating that power boats cannot pass through the booms, but rowing boats may actually row over the top of the booms without harm to them;

- The turbidity of the water appeared to reduce markedly between the inside and the outside of the booms;
- The booms required periodic removal for repair and maintenance - in particular because of barnacle growths which tended to weigh down the booms. The problem of barnacle growth might be solved by painting the booms with anti-fouling paint such as that used on the bottom of boats;
- The functioning of the booms was severely disrupted by high flows. Possible improvements to the booms could include: increasing the strength of the side anchorage; increasing the depth and weight of the skirt; and increasing the skirt gauge to reduce resistance against flow.

Gamtron concluded that there are a number of considerations that need to be kept in mind when considering the installation of booms:

- The booms should be kept floating at all times;
- They are only suitable for trapping small light-weight floatable objects such as leaves and lunch packaging;
- They should not be installed in channels or near outlets which are frequently subjected to high velocity flows;
- Special attention should be paid to the end connections which should be strong enough to withstand the flow forces, and have sufficient side slack to allow the booms to move up and down with changes in water level;
- There needs to be boat access for cleaning and maintenance; and
- Ideally the channel should be orientated parallel to the direction of the prevailing winds (to ensure that the litter travels down the channel to the booms).

7.3 Other floating boom installations

A review of other floating boom installations reveals similar experiences.

On the River Tame in Britain, there is a structure comprising of four rigid floating steel booms arranged in a "V" configuration with sloping front faces designed in such a way that flotsam is swept along the face into collection zones adjacent to access ramps. The structure appears to work well at low river flows, but the restraint system had to be redesigned after the booms were partially washed away at a higher flow. The modified booms were reported to operate satisfactorily up to a stream flow of approximately 75 m^3/s (a 1 in 10 year recurrence interval event). It is not certain from the description by Keiller and Ackers, 1982 whether the point in the River Tame where the boom was installed was tidal.

Molinari and Carleton, 1987 compared the advantages and disadvantages of the standard type of in-line screens with booms, using information from previous literature and field trials in the Cooks River catchment in Sydney. They found booms to be the more appropriate of the two structures where an existing urban area drains to an estuary, harbour or lake.

Neilson and Carleton, 1989 examined a boom at Muddy Creek and two conventional in-line screens in the Cooks River catchment to determine the composition of litter collected. They concluded that the boom and screens differed in their ability to collect different components of litter and consequently the choice of the most suitable litter interception device should be governed by the litter composition at a particular site. The booms appeared to be effective in retaining smaller floating and partially submerged objects eg. garden refuse and small bits of polystyrene, whereas the screens captured larger portions of fully or partially submerged objects such as bags and sheets of paper. The rubbish retaining performance of the boom was however reduced at high flows due to litter being forced under and over the boom.

A number of somewhat unusual floating debris collection traps designed by Bandalong Engineering of Melbourne in conjunction with Melbourne Parks and Waterways have reportedly reduced the amount of floating debris in the Yarra River (Vallance, 1996). The trap is comprised of two polyethylene pontoons which give buoyancy to the structure, whilst adjustable boom arms on the upstream side helps direct litter and debris into the trap via a swinging gate. The rear of the trap contains a drop gate enabling easy removal of the litter by boat. A special feature of the trap is its ability to perform in tidal reaches of a river system so that entrapped litter does not escape once the tide turns. This is achieved through the aluminium swing gate which is counterweighted to react to a reversal in the stream-flow direction and 'lock in" entrapped litter (Bandalong Engineering). A vertical skirt 150 mm in depth lies below the storage compartment to prevent buoyant items escaping underneath the pontoons. Strategically placed on bends in the river where the prevailing winds and surface currents tend to direct the flotsam, the device is surprisingly effective in reducing visual pollution in the river. It is unknown as to how much bed-load and suspended material escapes the trap.

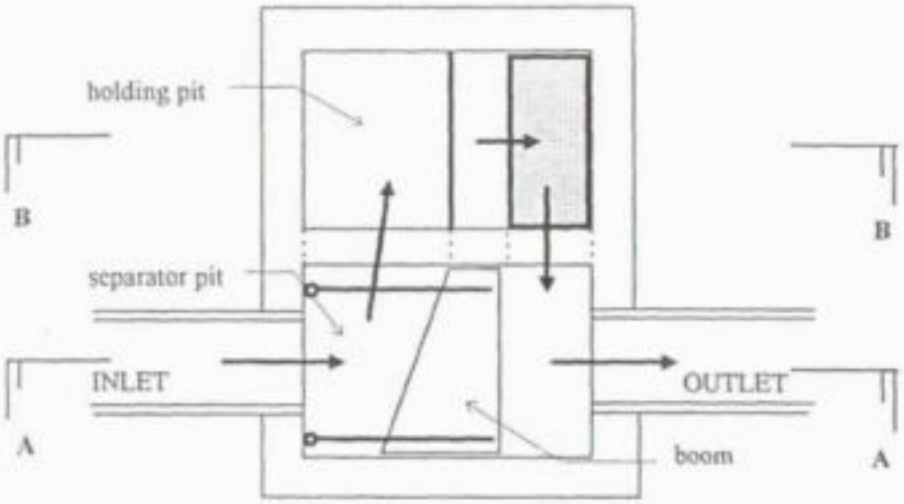
Probably the most appropriate use for booms is for containing and absorbing oil slicks but this is beyond the scope of this report.

7.4 The In-line Litter Separator (ILLS)

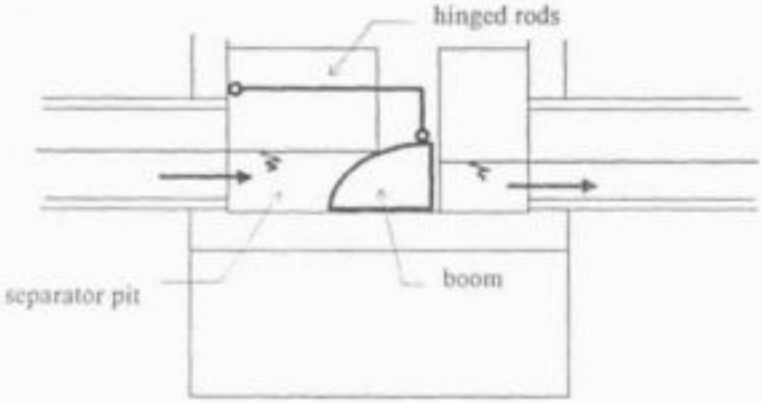
The In-line Litter Separator (ILLS) is designed for the removal of litter from underground stormwater conduits up to a diameter of about 750 mm with minimal loss of head.

It comprises a separator pit and a variable sized holding pit. A carefully shaped boom situated in the separator pit deflects the flow into the holding pit. Once in the holding pit, the flow is forced down under a suspended baffle wall and up over a weir before being returned to the separator pit downstream of the boom. The relatively large plan area of the holding pit ensures that the average vertical flow velocities are low enough to prevent carry-through of those objects, such as plastic bags, that have a negligible settling velocity (positive or negative).

a) Plan



b) Section A-A



b) Section B-B

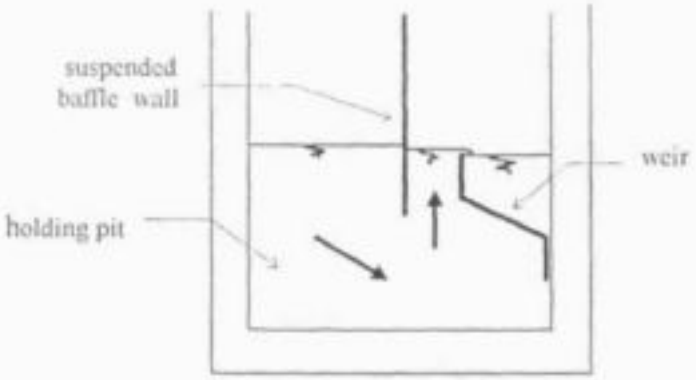


Figure 7-2 : Plan of and cross-sections through the In-line Litter Separator (ILLS)

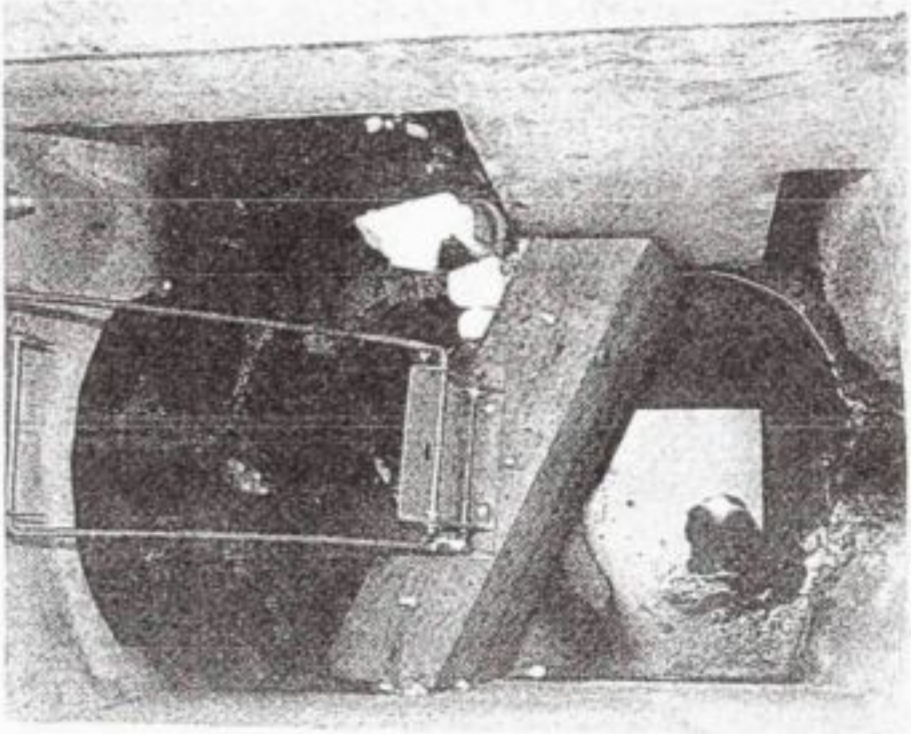


Figure 7-3 : View of the In-line Litter Separator (ILLS) (Flow from left to right)

In the event of particularly high flows through the stormwater conduit, the increased water levels on both sides of the boom causes it to float out of the way, ensuring that upstream flood levels are not affected by the structure, and the litter already trapped in the holding pit is not washed out. The boom is restrained by rods, which are attached to its upper surface and the walls of the chamber above the pipe inlet, in such a way that the boom is free to rotate about a hinge at the wall. See Figures 7-2 and 7-3.

For pipes up to 450 mm diameter, a 600 x 900 mm separator pit is used, while for pipes from 525 to 750 mm, a 900 x 900 mm pit is needed. The holding pit may comprise 600 x 900 mm, 900 x 900 mm, 900 x 1200 mm or even 1200 x 1200 mm pits of varying depth. The size of the holding pit depends on many factors including the area served, the nature of the businesses in that area, the frequency of street sweeping, and the frequency of litter removal (Swinburne University of Technology, 1996).

In many ways, the ILLS is similar to the UWEM concept described in Section 6.6 above, except in this case the flow velocities are reduced to the point that there is no longer any need for screens. Clearly, use of the ILLS is limited to pipes, whilst the UWEM approach is more appropriate for canals. A potential weakness of the ILLS is the possibility of litter fouling the hinge mechanism and thereby preventing the boom from lifting (or dropping) in the event of high flows.

More information may be found in Appendices A.3 and A.4.

8. Detention / Retention ponds and wetlands

Urban development tends to reduce the rate at which rainwater percolates into the soil, whilst at the same time, the harder, smoother surfaces tend to increase overland flow velocities. As a result, flood flows may be substantially increased over that which pertained prior to the development. This in turn increases downstream flood levels and average channel velocities. Natural channels may now have inadequate conveyance and erosion may result, or alternatively larger pipes or canals may be required to prevent flooding.

In consequence of the above, detention and retention ponds are frequently constructed along urban drainage systems to provide temporary storage for upstream stormwater peak flows, thereby reducing the downstream peaks. Definitions vary from country to country, but in South Africa a "detention pond" generally refers to a pond that is dry between flood events, whilst a "retention pond" generally refers to a pond that always has some water in it. Clearly a lake, whether natural or man-made, is a form of retention pond. Detention ponds often have a secondary role eg. as sports fields or parking areas.

"Wetlands" are also a type of "retention pond", except in this case the implication is generally that aquatic plants are allowed to grow across a major portion of the surface. These plants, particularly those of the reed family, play an extremely important role in trapping sediments, taking up excess nutrients, and holding back flood flows. They are also very efficient litter traps. Although in the past, most wetlands developed naturally, there are increasing moves to construct "artificial" wetlands to reduce pollution loads in streams or even to "polish" the effluent from waste water treatment works.

The design of detention / retention ponds and wetlands will not be discussed here. There are many texts available that deal with this, and it falls outside the scope of this report. What should be obvious however, is that these structures provide excellent opportunities for litter removal. The large flow sections generally reduce the average flow velocities to a point where the litter will segregate almost completely into bed-load and flotsam. The bed-load settles out, whilst the flotsam is easily trapped behind virtually any type of screen.

The biggest problem with using a pond system as a litter trap is usually the removal of the litter material. Litter (and silt) deposited on the floor of detention ponds can be extremely unsightly, and can interfere with alternative usage of the land if not promptly removed. Furthermore, because of the large plan area associated with detention ponds, the litter (and silt) tends to be spread out and removal takes some effort.

The same goes for retention ponds and wetlands where the removal process is complicated by the presence of water. Clearly it is a help if the ponds can be drained for cleaning. This is the principle of the Canberra type Gross Pollutant Traps (see Section 6.4). In these structures, the floor of the sedimentation basins are concrete-lined. When the structures are cleaned, the basins are drained and flotsam falls off, or is raked off, the vertical screen onto the floor. It is removed from here at the same time as the sediment deposits in the basin by a front-end loader or similar.

The minimum area of basin required, from the point of view of bed-load removal, depends on the settling velocities of particles required to be removed. For the design of the Canberra GPTs, Willing & Partners, 1989(a) used the method of Pemberton and Lara, 1971, which in turn was based on the work of Einstein, 1965, and is summarised by Equation 8-1:

$$P = 100\left(1 - e^{y}\right)$$ **Equation 8-1**

where

$$y = \frac{-1{,}0548.L.u_{ss}}{q}$$

and where: P = percentage of sediment deposited over total basin length (%),
L = basin length (m),
u_{ss} = settling velocity of the design particle (m/s).
q = basin discharge ($m^3/s/m$), and

The daily runoff and sediment export predicted by a rainfall / runoff model and sediment export model is computed on an hourly basis in proportion to the rainfall falling in any one hour on a given day. The deposition of individual size fractions of a designated grading curve in a GPT of known dimensions on an hourly basis is then calculated from Equation 8-1.

9. Vortex devices

It is well known that when a fluid is forced to flow in a circular arc, secondary currents are set up that tend to move denser objects towards the floor on the inside of the bend, whilst floatables tend to move towards the surface on the outside of the bend. This has been extensively exploited in the past for sediment removal (see for example: Salakhov, 1975, Cecen and Bayazit, 1975, Ogihara and Sakaguchi, 1984, Mashauri, 1986, Paul et. al., 1991, Weiss and Michelbach, 1995, Konicek et. al., 1995, and Evance et. al., 1995). Most of these devices, however, require that the sediment is continuously withdrawn, and are more suitable for the separation of sediments from sewage than for the removal of litter from stormwater.

Some vortex devices suitable for the treatment of stormwater have been designed and constructed in the USA and have proven effective in the removal of sand and other dense objects with a relatively high settling velocity. Most of these devices are however relatively ineffective in the removal of plastics for the simple reason that objects such as polyethylene shopping bags have a density close to that of water and tend to follow the streamlines, particularly in conditions of high turbulence (Pisano, 1995).

It is evident that vortex type devices will only be effective in the trapping of litter if used in conjunction with some form of screen or baffle to ensure that suspended material does not get carried through the structure with the stormwater.

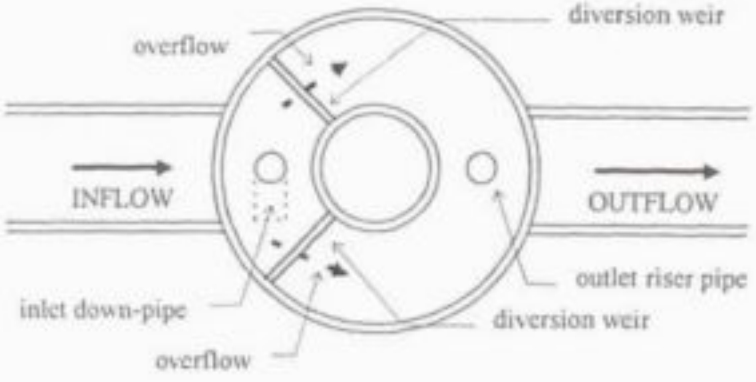
In a sense, this is the principle of the Continuous Deflective Separation (CDS) unit which has already been described in Section 5.10. However, although the CDS unit looks like a vortex separation device, the main separation element is a self-cleaning screen rather than the secondary currents induced by the vortex. Here the vortex performs two functions - it provides the shear velocity needed to keep the screen clear, and helps to collect the sediment in the sump ready for removal (Wong and Wootton, 1995).

A more promising example of a vortex device for use with stormwater is the Stormceptor® device which has recently been developed in Canada.

The Stormceptor® is really a type of oil-grit separator (OGS), designed to protect drainage systems from the ingress and oil and grit arising from potentially highly polluting areas such as service stations, parking areas and industrial developments. The device is cylindrical in shape, and is divided into an upper diversion chamber and a lower treatment chamber. See Figure 9-1.

Water is directed by a diversion weir into an inlet down-pipe which discharges into the lower treatment chamber through a 90° bend orientated so as to spin the contents of the chamber. Water exits the treatment chamber through an outlet riser pipe. The inlet and outlet pipes are set to the same elevation, thus providing for oil storage volume above the inlet / outlet elevation, and sedimentation volume below. The sediment and oil may be removed through an access hole provided through the centre of the diversion structure.

a) Plan



b) Section

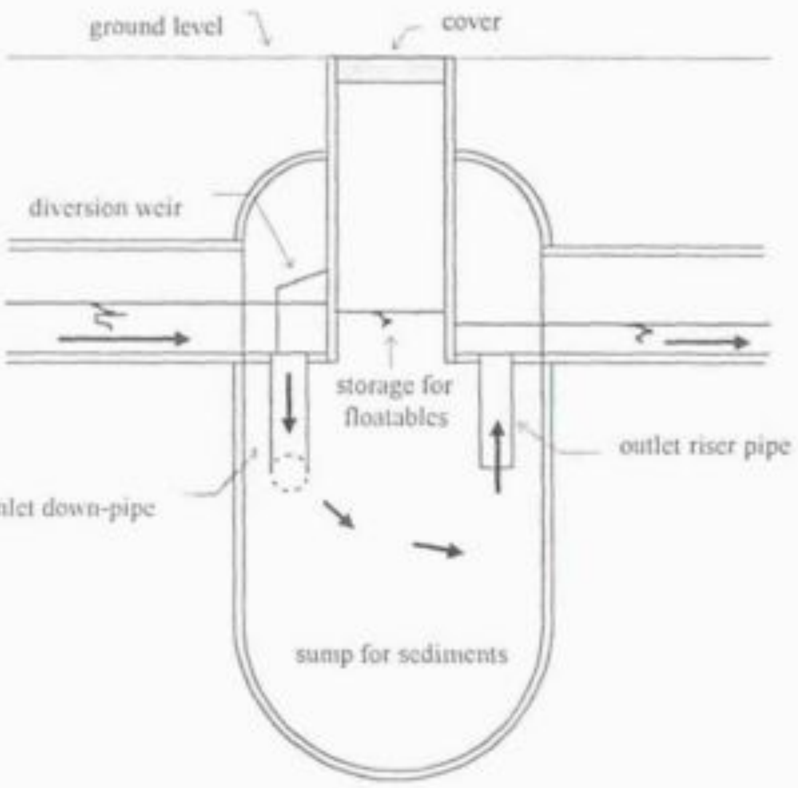


Figure 9-1 : Stormceptor® plan and section

The Stormceptor® comes in different sizes and may be constructed entirely out of fibreglass, or with the body out of concrete and the diversion structure out of a fibreglass insert.

The system operates in two modes depending on the flow into the system. At low to medium flows, all of the flow, along with the sediment and oil, is diverted to the treatment chamber by the diversion weir. Oil rises above the exit elevation and sediment settles to the bottom During higher flows, a proportion of the flow overflows the weir and bypasses the treatment chamber.

The flow diversion proportion is governed by the height of the weir. Up to the level of the weir, 100% of the flow is diverted to the treatment chamber. As flow increases, the weir is over-topped. At the same time, the head over the inlet down-pipe is increased which would normally result in continued increase in flow However, in the Stormceptor® design, the increased flow over the weir also results in an increased head over the outlet riser pipe. As a consequence, as the flow increases, the flow diverted to the treatment chamber increases by only an additional 10% before decreasing with further increases in flow. This feature prevents the resuspension and scouring of trapped sediments.

Head losses for the system measured in the laboratory showed that the head loss depended on the weir setting and varied between 1,83 and 2,5 of the velocity head ($V^2/2g$), with the higher values for higher weir configurations (Weatherbe et. al, 1995).

The performance of the Stormceptor® with respect to the removal of litter is not reported, but it is probable that it would quickly block if there is a high proportion of litter in the flow

10. The current "best available technologies"

10.1 Introduction

The biggest challenge facing the designer of a litter removal system is that litter can be just about anything - any size, any shape, any density, any hardness. Furthermore, the behaviour of a single item often changes as it moves through the drainage system (see Section 3.4). To make matters worse, the flow rate in channels changes continuously. A structure might work well at a low flow rate, but not at a high flow rate, or vice versa. Once in the drainage system, litter is not easily removed. It is partly for this reason that as much as possible should be done to prevent litter from entering the drainage system in the first place (see Section 3.2).

The ideal trap has, inter alia, the following features (see Section 3.3):

- is economical to construct and operate;
- has no moving parts;
- does not require an external power source;
- has a high removal efficiency;
- is self-cleaning; and
- does not increase flood levels in the vicinity of the structure.

No existing structure satisfies all these requirements perfectly. They are all better in some situations than others. The objective of this section is to summarise and compare the existing technologies to help the designer match the correct technology to the situation.

Some options are summarised in Sections 10.2 - 10.4, and in Appendices A and B. They are briefly compared in Section 10.5. Most of the more successful structures have been patented and are available only from approved suppliers. Mention of a trade name does not indicate that the Water Research Commission or the authors necessarily support the product in question. They are described in this document in an attempt to show designers the sort of features to look out for in litter removal structures, and to indicate some of the better options currently available 'off the shelf'. There may of course be other structures, not described in this document, that might remove litter from drainage systems more efficiently and effectively than those described herein.

10.2 Self-cleaning screens

A lot of work has gone into the development of self-cleaning screens. They rely on the control of the flow velocity, the velocity gradient, and gravity to create the self-cleaning action. Three designs show considerable promise:

- The Stormwater Cleaning Systems (SCS) structure (Sections 2.2 and 5.5, and Appendices A.6 and B.6);
- The Baramy® Gross Pollutant Trap (BGPT) (Section 5.8, and Appendices A.5 and B.5); and
- The Continuous Deflective Separation (CDS) device (Section 5.10, and Appendices A.4 and B.4).

The **Stormwater Cleaning Systems (SCS) structure** directs flow over a weir and through a steeply declined screen (in the order of -45°). The self-cleaning action arises from a combination of the momentum of the flow and the considerable gravitational force component down the screen. The main advantage of the structure is that it places the litter into a conveniently located self-draining bin ready for easy removal. Its disadvantages are that the maximum upstream Froude number of 0,15 and the maximum overflow rate of 230 litres per second per metre length of weir make it an extremely large structure, whilst the steep angle of declination of the screen inevitably means that there is a considerable drop in water level across the structure - translating into head loss.

The **Baramy® device (BGPT)** is similar to the SCS device, but the screen declination is less and consequently the structure relies less on gravity and more on the momentum of the water for its self-cleaning properties. This is achieved by placing the screen directly on the flow path. The performance of the structure is not impacted by high inflow velocities (unlike the SCS structure). Long periods of low flows could, however, potentially cause blockages. It is generally smaller, and therefore potentially cheaper, than the equivalent SCS device, but has a similar head loss. It also places the litter in a conveniently located self-draining bin.

In the **Continuous Deflective Separation (CDS) device**, the flow is also directed across the face of a screen, but in this case, the screen is orientated vertically and gravity plays no role in the self-cleaning mechanism. Instead, a vortex generated within a circular screen keeps water moving rapidly over the surface of the screen and prevents it from blocking. It is the most efficient of the three units both in terms of the low head requirement (approximately 1,3 x the velocity head of the flow in the in-flow conduit), and trap efficiency, but it is an expensive structure to build and maintain because of its complex geometry and great depth.

10.3 In-line screens

In-line screens are the most common form of litter removal device. They usually consist of metal bars raked at some angle between 25° and 90° to the invert of the channel (in the direction of flow). They are usually mounted on the floor of the channel or on the top of a low weir wall.

They do not have a good record in South Africa for several reasons:

- They are easily blocked;
- Unless they are carefully located in an area with considerable fall, they represent an upstream flood hazard;
- They are easily damaged (a log moving, say, 3 m/s down a channel can do considerable damage to a screen that is in its path);
- They are often hard to maintain (so are frequently not maintained at all!); and
- They have a relatively limited storage capacity.

Nevertheless, in-line screen can be made to work if they are appropriately designed (see Section 6.). Some of the more successful designs are:

- Side-entry catchpit traps (SECT) (Section 6.2 and Appendices A.1 and B.1);
- Fences or nets straining slow flowing streams (Section 6.3);
- The Canberra Gross Pollutant Trap (GPT) (Section 6.4);
- The North Sydney Litter Control Device (LCD) (Section 6.5 and Appendices A.2 and B.2); and
- The Urban Water Environmental Management (UWEM) concept (Section 6.6 and Appendices A.7 and B.7).

Side-entry catchpit traps (SECTs) offer great potential as a trapping device. They are cheap and easy to construct and install, have a high trapping efficiency, and are a useful catchment management tool as they trap litter close to its source. Their biggest drawbacks are that literally thousands of them are required to cover a whole catchment, and they require an efficient and reliable cleaning programme. Strategically placed, though, they can provide a cost-effective trapping mechanism. Although they require a considerable drop for operation, that drop is usually already provided within the catch-pits.

Fences or nets may be used to **strain slow flowing streams** and thus provide an extremely cheap and effective method of trapping litter providing that they are well located. A particular advantage is that drowned channels frequently imply low velocities and consequently low head losses. Maintenance however is frequently a problem as ideally the channel needs to be drained for the maintenance crew to access the bed-load deposition. This is not usually possible.

The **Canberra type Gross Pollutant Traps (GPTs)** are currently not appropriate for South African conditions unless the prime consideration is sediment removal. The screening principle can be used in conjunction with detention / retention ponds or wetlands, provided that those structures can be drained. GPTs are generally very large, expensive structures that impose a large head loss (1 - 2 m).

The **North Sydney Litter Control Device (LCD)** is easy to maintain, but relatively large and consequently expensive structures will be required to cater for the volume of litter that comes from South African catchments. Other drawbacks are that it can only treat relatively low flows, it has a low trapping efficiency, and it requires a high head (1 - 2 m) for its operation. It may have some application on small commercial or industrial catchments.

In the case of the **Urban Water Environmental Management (UWEM)** approach, head is "generated" by an hydraulically operated sluice gate which forces the flow through rows of suspended screens, under a suspended baffle wall and over a weir. The structure can be drained and the screens lifted for cleaning. The sluice gate opens in the event of a flood to prevent upstream flooding. This is particularly attractive for large canals in areas where gradient is a premium. The fact that the device has a very large screen area makes it possible for the structure to trap enormous volumes of litter.

In every case, the key to the success of an in-line screen is a large screen area. Unless the screen areas are large, head losses will be high and there is a risk of upstream flooding.

10.4 Booms, baffles and ponds

Booms and baffles may be used to deflect and trap litter provided the flow velocities are low enough to:

1. allow desegregation of the litter into bed-load and flotsam; and
2. prevent wash-over / wash-under

and also provided that there is no hydraulic interference between the different structural elements thereby increasing the vorticity of the flow.

This method of trapping is used, inter alia, by:

- The Sydney Harbour Litter Booms (Section 7.2); and
- The In-line Litter Separator (ILLS) (Section 7.4 and Appendices A.3 and B.3).

Litter booms are only capable of removing flotsam - the suspended load and bed-load must be trapped some other way, generally by settling it behind a low weir. The **In-line Litter Separator (ILLS)** shows potential for trapping litter in pipe conduit systems where head is at a premium. Its main disadvantages are that it is a relatively large and therefore expensive structure, and there is always a danger that the rotating boom might get stuck at a crucial moment causing upstream flooding or litter loss.

Detention / retention ponds and wetlands are convenient trapping points because they provide the large flow area that decreases the velocity to levels suitable for booms, baffles and in-line screens (Section 8.).

Work carried out by Furlong, 1995 (Section 4.5) from the University of Cape Town, Burger and Beeslaar, 1996 (Section 4.7) and Compion, 1996 (Section 4.8) all from the University of Stellenbosch, seems to indicate that the practical upper limit for trapping litter behind a weir or suspended screen is a Froude number of about 0,07. This equates to a maximum velocity that varies from about 0,15 m/s for a 500 mm deep channel to about 0,3 m/s for a 2 m deep channel. Once again, this implies large flow areas - from 10 to 20 times that of a typical conduit.

One advantage of using **booms or baffles** is that the structures are simple and there is minimal head loss. The main disadvantages are the difficulty of accessing the large areas for cleaning and maintenance, and the potentially high capital costs of such large structures.

No vortex device suitable for the removal of suspended litter from stormwater has been developed (see Section 9).

10.5 Comparing the structures

The main features of the more promising devices are summarised in Table 10-1. Further information about them, in particular the patent holders or suppliers and typical costs, is to be found in Appendices A and B. Regrettably, very little detailed design information is available as the structures are nearly all protected by patents and design information is jealously guarded by the patent holders.

Device	Typical catchment area (hectares)	Typical cleaning frequency	Head require-ment	Maximum efficiency (%)	Comments on performance
SECT	0,1 - 1	Monthly or after every major storm	Low (effectively)	59 - 76 (50 - 100% coverage respect-ively)	Need to be able to target the catchpits with the highest loads. The efficiency of the unit is strongly affected by the number of untrapped catchpits and the cleaning frequency.
LCD	20 - 150	Monthly or after every major storm	High	25	Inefficient in high flows but collects most material at low to medium flows. Likely to be a relatively expensive option. Relatively easy to clean.
ILLS	5 - 25	Monthly or after every major storm	Low	25	Little data available. Likely to be a relatively expensive option. Moving parts may cause problems.
CDS	10 - 200	4 times a year	Low	99	Very efficient trapping device, but very expensive to install and tedious to clean.
Baramy®	10 - 500	4 times a year	High	95	Little prototype data available, but shows considerable promise. Compact. Easy to clean.
SCS	>1	Monthly or after every major storm	High	95	Works well providing the head is available. Easy to clean.
UWEM	>400	After every major storm	Low (effectively - the head is generated by a sluice gate)	90	The concept of generating head in-situ via a hydraulically actuated sluice shows considerable promise for use with other structures eg. Baramy® , SCS.
Fences, nets, weirs, booms or baffles used to intercept litter moving down slow-flowing streams	>400	Depends on structure and location. Could vary from weekly to annually.	Low	Varies. Could approach 100% with very low peak velocities.	Efficiency unpredictable - depends on structure and location. Generally the cheapest solution.

Table 10-1 : Summary of litter trapping devices (adapted from Allison, 1997)

In general, **based on the data supplied in Appendix A**, it appears that:

- the Baramy®, SCS and UWEM devices have a much higher economic efficiency than the remaining four structures;
- the CDS unit offers a very high removal efficiency, but at a heavy cost. Unit costs may however be brought down if high bypass ratios are used;
- SECTs offer the advantage of being a potential catchment management tool as they show where the bulk of the litter is being generated. They might also be a little cheaper to install and clean in South Africa than the Australian data indicates - owing to the lower cost of labour;
- the ILLS and LCD structures appear on the surface to be costly, but have the advantage they are small and can be installed under streets in confined spaces. The ILLS has the additional advantage that it requires very little head.
- Fences, nets, weirs, booms or baffles may be the most cost effective structures of all, provided a suitable slow-flowing stream (which includes flows through detention / retention ponds and wetlands) is available. A major problem with these devices is cleaning and maintenance. Ideally it should be possible for the channel to be periodically drained for cleaning and maintenance purposes.

Another avenue to explore is a mix of technologies. For example, the hydraulically actuated sluice gate that is used in the UWEM approach could be used to generate the required head to run a Baramy® device or a SCS structure.

The final decision of a trapping structure will be site specific. Lack of head may rule out the Baramy® and SCS devices. Lack of space may rule out the UWEM approach. The desire for a catchment management tool may favour the choice of SECTs. A requirement for exceptionally high removal efficiency may prompt the installation of a CDS unit. A small catchment may be best served by an ILLS or LCD.

Conditions vary from site to site, but most sites in South Africa would probably be best served by SECTs installed in key catchpits around the CBD, and a Baramy®, SCS or UWEM unit installed on the main outlet conduit to the catchment with head provided by a hydraulically actuated sluice if required. Fences or nets will probably be the most cost effective solution in very flat areas where the stormwater is discharging into large bodies of water eg. a lake or the sea.

The recommended selection procedure is described in Section 11. More details on the seven most promising structures are given in Appendix A. A worked example of an hypothetical selection is given in Appendix B.

11. The selection of the trapping system

11.1 Introduction

The selection of the trapping system should form part of an overall catchment management plan (see Section 3.2). It will always be more cost effective and aesthetically more acceptable to reduce littering than to attempt to remove all the litter from the environment once it has got there. However, accepting that some litter will always escape into the drains, litter removal structures will always be required in and around urban areas. This section deals with the location and selection of these litter removal structures.

11.2 The location of the traps

The choice of trapping structure is site specific. The location of the traps is therefore the key decision. Clearly, the closer to the source a trap is located, the smaller the flow and therefore the smaller the structure required. On the other hand, many more of these structures will be required to cover the entire catchment. The construction and maintenance of large numbers of smaller traps might well be greater than the construction and maintenance of one or two larger traps situated at the mouth of the main canal or the stream draining the entire catchment.

Trapping points and the typical associated structures may be loosely categorised as follows:

1. **Entry:** SECT.

2. **In-pipe (flow rates up to about 1 m^3/s):** CDS, ILLS, LCD.

3. **End-of-pipe:** LCD, CDS, SCS, Baramy®.

4. **Canal / stream:** Baramy®, SCS, UWEM, fences, nets, booms or baffles installed across slow flowing streams (or ponds).

It should be remembered that no trap is 100% effective. In fact, it is often more cost effective to aim for a trap efficiency of, say, 70% and look to trap the balance at another point in the system. In consequence, many traps are only designed to handle peak flow rates in the region of 1:1 month recurrence interval (ie. the structure is bypassed twelve times a year on average) to 1:2 years (which is the capacity of many conduits). The surplus flow - with its associated litter - is bypassed. Consideration should therefore be given to providing at least two lines of traps eg. side-entry catchpits at key locations together with a number of in-pipe or end-of-pipe traps downstream.

Another important issue is access for cleaning and maintenance - particularly for the larger structures. Ease of maintenance is crucial. Trapping efficiency will rapidly fall to zero if the traps are not properly cleaned and maintained. In some instances, the cost of providing adequate access may be more than the structure itself.

11.3 The suitability of particular traps

Once suitable trapping points have been identified, the main criteria determining the suitability of a particular trap in that location are:

- flow rate,
- allowable head loss,
- size,
- efficiency,
- reliability,
- ease of maintenance, and
- cost effectiveness.

The first three items on this list are site constraints, whilst the balance depend on the structure under consideration.

Considering only the site constraints, the available structures may be roughly divided into:

- "low flow" or "high flow";
- "low head" or "high head"; and
- "small", "medium" or "large"

where the division between "low" and "high" flow may be taken to be roughly 1 m^3/s, the division between "low" and "high" head may be taken to be roughly 0,5 m; and structures may be described as "small" if they are contained wholly within the channel, "medium" if they are only slightly larger than the channel, and "large" if they require considerable extra space or if the channel must be widened.

We may loosely categorise the better available technologies as follows:

1. **Low flow, low head structures:**
   - **Small** - Side-entry catchpit traps (SECTs),
   - **Medium** - ILLS.
   - **Large** - CDS.

2. **Low flow, high head structures:**
   - **Medium** - LCD.
   - **Large** - Baramy®, SCS (pipe option).

3. **High flow, low head structures:**
   - **Small** - Fences, nets, booms or baffles installed across wide drowned channels (or ponds),
   - **Large** - UWEM, CDS (with high bypass ratio).

4. **High flow, high head structures:**

   - **Medium** - Baramy®.
   - **Large** - SCS (side-channel spillway option).

11.4 The recommended selection procedure

Once the designer has some idea of the potential trapping point and associated structures, the recommended selection procedure is as follows:

1. Identify each catchment with its associated drainage system / waterways. It may be necessary to divide the catchments into sub-catchments depending on the number, type and location of structures envisaged;

2. Identify and measure the area of each land use (A_i) within each catchment (the main categories being commercial, industrial and residential);

3. Estimate the total litter load (T) in each catchment area. In the unlikely event that there are existing litter traps of known efficiency already operating in the catchment/s, information gleaned from these traps would be used to estimate the total litter load/s. Otherwise, estimate the street cleaning service factor (f_{sci}), the vegetation load (V_i) and the basic litter load (Bi) for each land use in each catchment or sub-catchment, and apply Equation 2-1 (see Section 2.6):

$$\mathbf{T = \Sigma f_{sci}.(V_i + B_i).A_i} \qquad \textbf{(Equation 2-1)}$$

   where T = total litter load in the waterways (m^3/year)
   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 per year for poorly vegetated areas to about 0,5 m^3/ha per year for densely vegetated areas)
   B_i = basic litter load for each land use
   (commercial = 1,2 m^3/ha per year
   industrial = 0,8 m^3/ha per year
   residential = 0,01 m^3/ha per year)
   A_i = area of each land use (ha)

4. For each potential trap site, carry out an hydrological assessment of the flood peak versus frequency curve and the treated flow volume versus the design capacity of the structure curve. These curves are shown schematically in Figure 11-1.

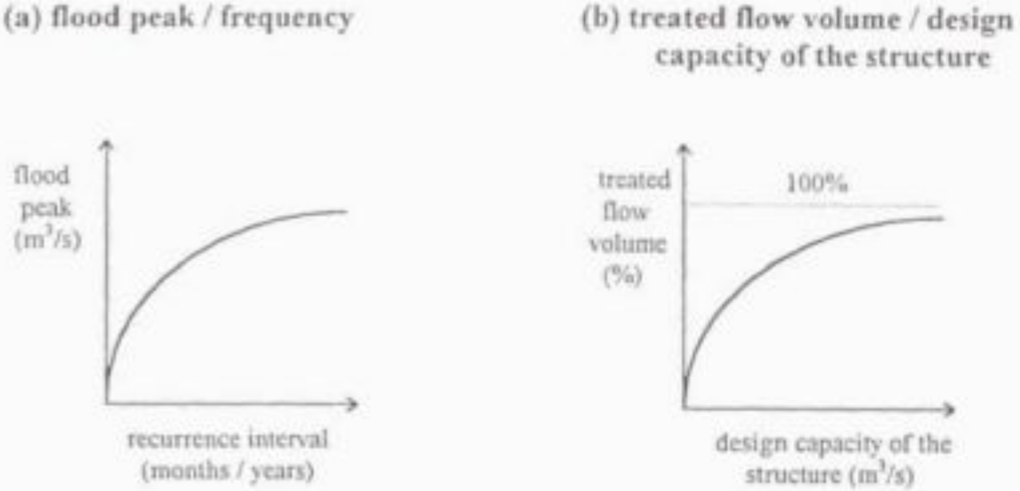


Figure 11-1 : **Schematic flood peak / frequency and treated flow volume / design capacity of structure curves**

The flood peak / frequency curve is well known. It is a plot of the flood peak in cubic metres per second (or litres per second) versus the inverse of the probability of excedence expressed in months or years and called the recurrence interval (R.I.). If a flow of, say, 1 m^3/s has a R.I. of 2 years, then it means that a flow of 1 m^3/s will only be exceeded once every two years on average. Alternatively there is a 50% probability of a flow of 1 m^3/s being exceeded in any one year.

The treated flow volume / design capacity of the structure curve expresses the percentage of the total flow volume intercepted by a structure versus its design capacity. The calculation is shown schematically in Figure 11-2. Its significance lies in the fact that trapping structures are seldom designed to handle the maximum expected flood peak. Usually they are designed to handle a much lower flow - typically with a R.I. in the order of a few months - on the assumption that the total flow volume bypassing the structure will be a relatively small percentage of the total. If we make the assumption (usually conservative) that the concentration of litter is constant (it usually decreases with high flows), then the overall trapping efficiency of the structure at any design capacity can be calculated from a knowledge of proportion of flow through the structure. Once this is known, considerable cost savings can often be made at the expense of a minimal drop in efficiency by selecting a smaller structure with a slightly higher bypass ratio.

The hydrological assessment would typically be carried out with the assistance of one of the numerous urban hydrology computer packages (eg. ILLUDAS, SWMM, WITWAT, CIVIL DESIGNER etc). Alternatively, a rough estimate may be obtained with the assistance of the well-known rational formula and assuming triangular shaped hydrographs with flood durations of three times the time of concentration. Care must be taken to ensure that the capacities of any conduits are taken into account. The reader is referred to any of the standard texts on urban hydrology for further information.

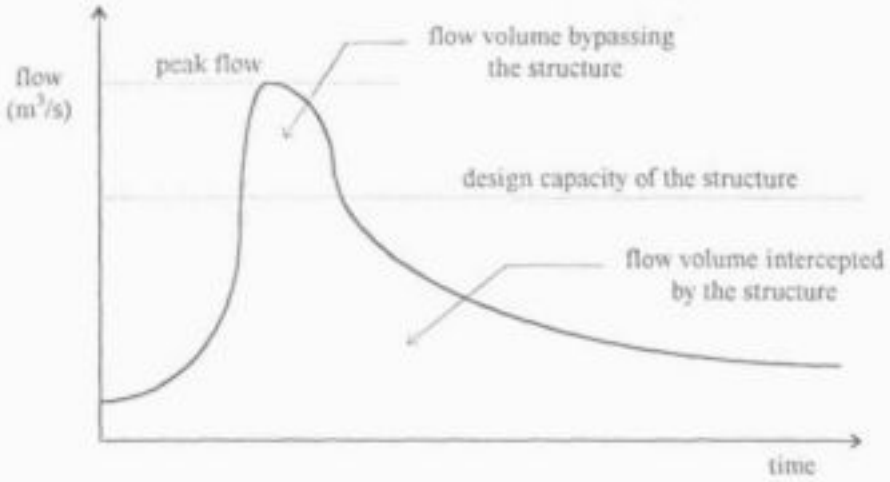


Figure 11-2 : Typical flood hydrograph indicating the relative volumes intercepted by, and bypassing the structure

5. Consideration is now given to the candidate trapping structures. Some preliminary information on the better structures currently available on the market is to be found in Section 10 and Appendix A. Once a preliminary selection has been made, the patent holders / suppliers should be contacted for more up to date information on design and cost.

6. The approximate minimum storage capacity of each trap may be determined from the maximum storm load estimated from Equation 2-2 (see Section 2.6):

$$S = f_s.T/\Sigma f_{si} \qquad \textbf{(Equation 2-2)}$$

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)
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)

7. The cost effectiveness of the candidate structures may now be determined by means of an economic analysis. There are many ways of carrying out this economic analysis, but the simplest is described below:

g) For each particular structure, consider several design capacities with R.I.s varying between, say, 1:1 month (the structure is bypassed twelve times a year) to 1:2 years (which is the capacity of many pipe conduits). For each design capacity, obtain an estimate of the overall efficiency of the trap by multiplying the published trap efficiency by the percentage of flow volume treated by the structure, as previously determined in step 4 above, using Equation 11-1 (N.B. published SECT data gives overall efficiency directly):

$$\eta_o = \eta_s . \eta_f \qquad \textbf{Equation 11-1}$$

where η_o = overall efficiency of the installation (fraction)
η_s = published efficiency of the structure (fraction)
η_f = treated flow volume expressed as a fraction of the total flow

b) The storage capacity can be calculated by multiplying the proposed average cleaning frequency by the average estimated storm load (determined with the aid of Equation 2-2 above) and by the overall efficiency of the installation, and dividing this product by the average storm frequency during the wet season determined from municipal records. The storage capacity must be more than the minimum determined in step 6 above. The calculation is shown in Equation 11-2:

$$V_t = F_c . \eta_o . S_{av} / F_s \qquad \textbf{Equation 11-2}$$

where V_t = proposed trap storage (m)
F_c = average cleaning frequency (days)
η_o = overall efficiency of the installation (fraction)
S_{av} = average estimated storm load (m)
F_s = average storm frequency (days)

c) For each particular type and size of structure, decide on the repayment period, and estimate the capital cost and the real interest rate (a good approximation is to simply subtract the average inflation rate from the average nominal interest rates). The capital recovery amount may then be determined from Equation 11-3:

$$A = P.i(1+i)^n/((1+i)^n-1) \qquad \textbf{Equation 11-3}$$

where A = capital recovery amount (R/year)
P = capital cost of the structure (R)
i = interest rate (expressed as a fraction)
n = repayment period (years)

The effect of inflation is simply to make the initial payments higher, and the later payments lower (in real terms), but this will not change the overall picture.

d) The total volume of litter that the trap is likely to intercept at each design capacity is obtained by multiplying the total litter load determined in Step 3 above by η_o using Equation 11-4:

$$L = T.\eta_o \qquad \textbf{Equation 11-4}$$

where L = load trapped by the structure (m^3/year)
T = total litter load (m^3/year)
η_o = overall efficiency of the installation

e) The total annual cost of the structure is obtained by adding the annual capital recovery amount to the annual cost of cleaning and maintaining the structure using Equation 11-5:

$$C_t = A + C_c \qquad \textbf{Equation 11-5}$$

where C_t = total annual cost of the structure (R/year)
A = capital recovery amount (R/year)
C_c = annual cost of cleaning and maintaining the structure (R/year)

f) The unit cost of litter removal for any particular structure and design capacity is obtained by dividing the total annual cost of the structure by the estimated annual load that will be trapped by the structure as expressed in Equation 11-6:

$$C = C_t / L \qquad \textbf{Equation 11-6}$$

where C = unit cost of litter removal (R/m^3)
C_t = total annual cost of the structure (R/year)
L = load trapped by the structure (m^3/ha/year)

Unit costs in terms of R/kg or R/ha may be obtained by dividing the unit cost of litter removal by the standardised density of 95 kg/m^3, or by dividing the total annual cost of the structure by the catchment area respectively.

8 In theory, the trapping system may now be optimised to give the lowest overall unit cost of removal. In reality, a balance must be struck between the desire to achieve the lowest overall unit cost of removal, and the overall objective of removing as much litter from the aquatic system as is reasonably possible - in other words, achieving the maximum efficiency. This is a political decision which requires input from all the role players concerned with the removal of litter from the environment, including engineers, hydrologists, aquatic scientists, environmental interest groups, ratepayers and local government. One further caution: data on trapping structures is site specific and highly variable. Costs and efficiencies may vary considerably from site to site.

The litter removal process is summarised in Figure 11-3. The trap selection procedure is summarised in Figure 11-4. An example of an hypothetical trap selection is given in Appendix B.

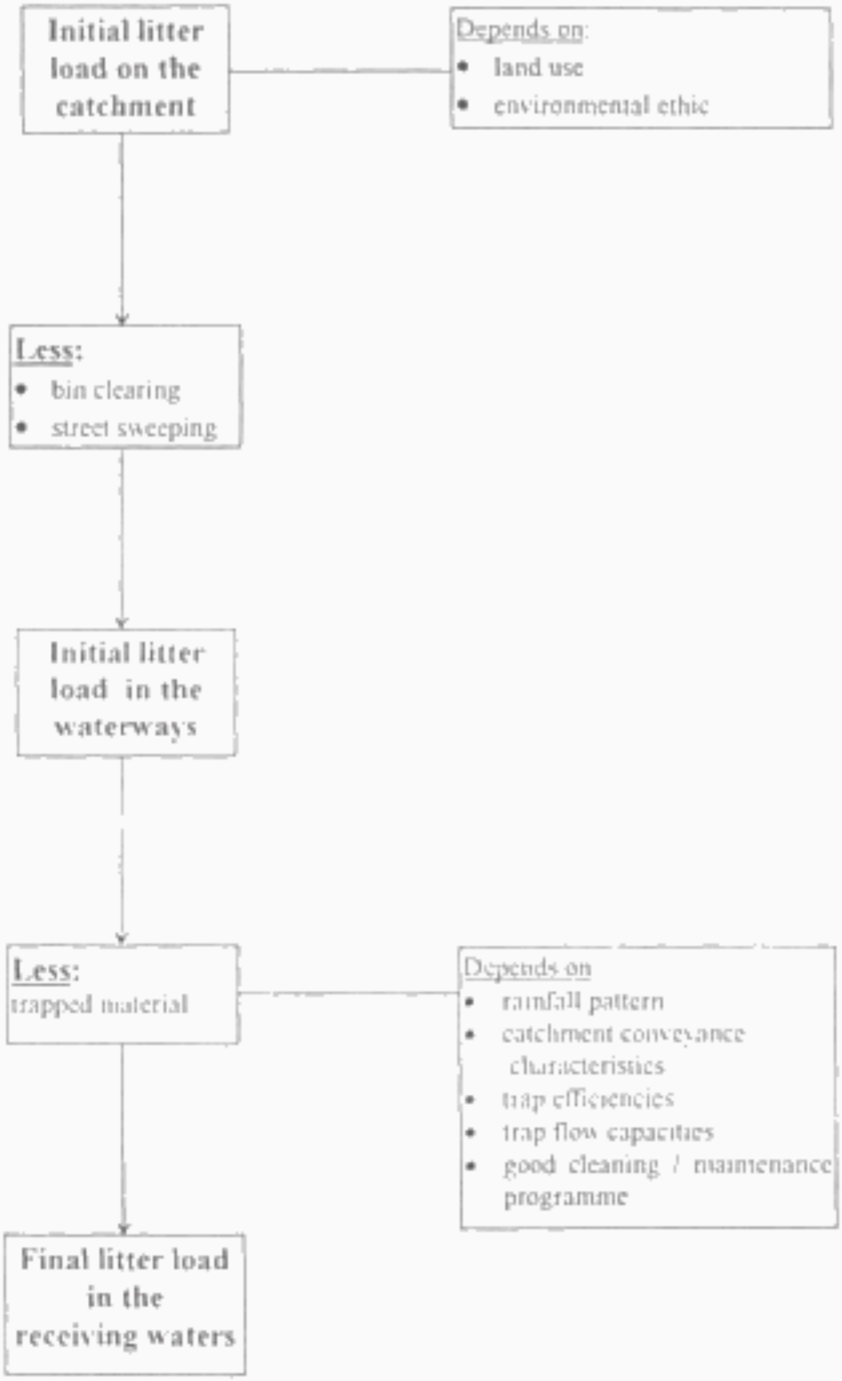


Figure 11-3 : The litter removal process

Figure 11-4 : Summary of the trap selection procedure

12. Proposals for future research

It is quite clear that there is a need for further research into the removal of urban litter from stormwater conduits and streams - in particular into:

- the source, type and amount of urban litter coming from different types of urban catchments (which is linked to land use and the level of environmental awareness). This knowledge will assist the appropriate allocation of resources for litter removal;
- the efficacy of various catchment management techniques in the reduction of urban litter reaching the drainage systems. Such knowledge would enable local authorities to develop sustainable integrated catchment management techniques that will, inter alia, drastically reduce the urban litter pollution in streams whilst realising considerable cost savings;
- the optimisation of declined screens, as these screens currently show the greatest potential as self-cleaning litter trapping devices; and
- new trapping structures.

In addition to the above, research is required into the control and removal of other pollutants from stormwater conduits and streams (see Section 1.2), in particular:

- heavy metals (often bound up in the sediments washing off urban catchments);
- excessive nutrient loads; and
- pathogenic organisms.

References

ACT, 1996: Personal communication with Mr K. Cloos of the Roads & Maintenance Branch of the Australian Capital Territory (ACT) Government Service, Canberra.

Allison, R.A. and Chiew, F.H.S., 1995: *"Monitoring of stormwater pollution from various landuses in an urban catchment"*. The Second International Symposium on Urban Stormwater Management, Melbourne, pp 551-516.

Allison, R.A., Wong, T.H.F. and McMahon, T.A., 1996: *"Field trials of the Pollutec Stormwater Pollution Trap"*. Draft paper to be submitted to Water - the magazine of the AWWA, Universities of Melbourne and Monash, Melbourne.

Allison, R.A., 1996: Personal communication with Mr R.A. Allison, PhD student, Department of Civil and Environmental Engineering, University of Melbourne.

Allison, R.A., 1997: *"Effective Gross Pollutant Removal from Urban Waterways"*. PhD thesis, University of Melbourne.

Arnold, R.W., 1996: Personal communication with Mr R.W. Arnold, Drainage and Sewerage Branch, Cape Town City Engineer's Department.

Bandalong Engineering: Undated promotional literature.

Baramy: Undated promotional literature, Baramy Engineering Pty. Ltd., Katoomba, New South Wales, Australia.

Baramy, 1997: Private correspondence coupled with promotional literature, Baramy Engineering Pty. Ltd., Katoomba, New South Wales, Australia.

Baur, D.C. and Iudicello, S., 1990: *"Stemming the tide of marine debris pollution: Putting domestic and international control authorities to work"*. Ecology Law Quarterly, Vol. 17, pp71-142.

Beecham, S.C. and Sablatnig S.J., 1994: *"Hydraulic Modelling of Stormwater Trashracks"*. Hydraulics in Civil Engineering Conference, University of Queensland, Brisbane.

Blanche, P. and Crompton, S., 1996: Personal communication with Messrs. P. Blanche and S. Crompton, Executive Directors, CDS Technologies Pty Ltd, Mornington, Victoria, Australia.

Bondurant, J.A. and Kemper, W.D., 1985: *"Self-Cleaning, Non-Powered Trash Screens for Small Irrigation Flows"*. Transactions of the American Society of Agricultural Engineers, pp 113-117.

Bouvard, M., 1992: *"Mobile barrages and intakes on sediment transporting rivers"*. IAHR Monograph Series. A.A. Balkema, Rotterdam.

Brownlee, R.P., 1995: *"Evaluation of Effectiveness and Efficiency of North Sydney Council Litter Control Device Program"*. The Second International Symposium on Urban Stormwater Management, Melbourne, Australia.

Board of Works, Melbourne (now called Melbourne Water) et. al., 1989: *"Litter Control in Urban Waterways"*. Melbourne.

Burger, L. and Beeslaar, A., 1996: *"'n ondersoek van 'n skuins rooster as oplossing vir die probleme in stormwaterkanale"*. Unpublished BIng thesis, University of Stellenbosch.

CDS Technologies, 1997: Personal communication per fax from Mr S Crompton, Technical Director, CDS Pty Ltd, Mornington, Victoria, Australia.

Cecen, K. and Bayazit, M., 1975: *"Some laboratory studies of sediment controlling structures"*. Proceedings of the Ninth Congress of the ICID, Moscow, pp 107-111.

City of Banyule, 1994: *"Litta-trap (Jeniton Corporation). An effective litter control program"*. Video produced for City of Banyule, Victoria, Australia.

Coetzee, F., 1996: Personal communication with Mr F. Coetzee, Portnet, Cape Town.

Compion, J.K., 1997: *"The trapping of litter in waterways by means of flow retardation and screens"*. Unpublished MIng thesis, University of Stellenbosch.

Compion, J.K., 1998: Personal communication with Mr J. K. Compion, 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 Department of Environment Affairs by the CSIR Programme for the Environment. Pretoria.

Davies, P., 1991: Major seminar on Waste Management. Municipal Engineer 22(10), South Africa.

Einstein, H.A., 1965: *"Final Report Spawning Grounds"*. University of California, Hydraulic Engineering Laboratory.

Evance, J.G., Deamer, A.P. and Andoh, R.Y.G., 1995: *"Swirl-Flo™ and Lamella Separators - A Comparison"*. International Conference on Sewer Solids, University of Abertay Dundee, Scotland, pp 298-307

Furlong, W., 1995: *"The design of debris traps in stormwater canals"*. Unpublished BSc (Eng) thesis, University of Cape Town.

Gamtron, 1992: *"Performance assessment of four rubbish interception booms"*. Report prepared for Water Board, Southern Region Stormwater Management, Sydney by Gamtron Pty. Ltd, West Ryde, NSW, Australia.

Hall, M., 1996: *"Litter traps in the stormwater drainage system"*. Unpublished MEng paper, Swinburne University of Technology, Melbourne.

Hocking, J., 1996: *"Evaluation of Effectiveness and Efficiency of Smoothey Park Litter Control Device"*. Soil and Water Management for Urban Development, 4th Annual Conference, Australia.

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.

Keiller, D.C. and Ackers, P., 1982: *"A mathematical model of a floating boom"*. Proceedings of the International Conference on Hydraulic Modelling of Civil Engineering Structures, UK.

Knoetze, M., & McDonald, M., 1991: *"Study indicates the need for stormwater policy"*. Technobrief, 1(5), CSIR. Pretoria.

Konicek, Z., Pryl, K. and Suchanek, M., 1995: *"Practical Applications of Vortex Flow Separators in the Czech Republic"*. International Conference on Sewer Solids, University of Abertay Dundee, Scotland, pp 280-289.

Lawson, A., 1997: *"The design of self-cleaning screens"*. Unpublished BSc(Eng) thesis, University of Cape Town.

Louw, L.C., 1995: *"Verwydering van partikels uit stormwater"*. Unpublished BIng thesis, University of Stellenbosch.

Manly Hydraulics Laboratory, 1997: *"Baramy Low Profile Gross Pollutant Trap, Physical Model Testing"*. Report MHL781, July 1997, New South Wales Department of Public Works and Services, Australia.

Mashauri, D.A., 1986: *"Modelling of a vortex settling basin for primary clarification of water"*. Thesis presented to the Tampere University of Technology, Finland in partial fulfilment of the requirements for the degree of Doctor of Technology.

Melbourne Water and Melbourne Parks & Waterways, 1993: *"Backyard to bay Program"*. Melbourne, Australia.

Melbourne Water Waterways and Drainage Group, 1995: *"A guide to current technology for removing litter and sediments from drains and waterways"*. Melbourne Water, Australia.

Molinari, S. and Carleton, M., 1987: *"Interception and Collection of Litter in Urban Waterways"*. Proceedings Seminar on Urban Runoff Water Quality, Sydney.

Neilsen, J.S. and Carleton, M., 1989: *"A Study of Trash and Trash Interception Devices on the Cooks River Catchment, Sydney"*. Australian Water and Wastewater Association 13th Federal Convention.

Nel, C., 1996: *"Die ontwikkeling van 'n struktuur vir die verwydering van vaste besoedeling uit stormwateraflope"*. Unpublished DTechEng thesis, Technikon Pretoria.

Neville Jones - Willing & Partners Consulting Group, 1996: *"Catchment D37 Stormwater Management Study"*. Report to Redcliffe City Council, Springwood, Queensland.

Obree, M.R., 1993: *"Report on research and development on trash removal from stormwater conduits"*. Cape Town City Council.

Ogihara, K. and Sakaguchi, S., 1984: *"New systems to separate the sediments from the water flow by using the rotating flow"*. Proceedings of the Fourth Congress of the Asian and Pacific Division, IAHR, Chiang Mai, Thailand, pp 753-766.

Paul, T.C., Sayal, S.K., Sakhuja, V.S. and Dhillon, G.S.: *"Vortex-Settling Basin Design Considerations"*. ASCE Journal of Hydraulic Engineering, Vol. 117, No 2, pp 172-189.

Pemberton, E.L. and Lara, J.M., 1971: *"A Procedure to Determine Sediment Deposition in a Settling Basin"*. Sediment Investigations Technical Guide Series, Section E, Part 2, USDI, Bureau of Reclamation, August.

Pisano, W.C., 1995: Personal communication with Dr. W.C. Pisano of Montgomery Watson, US.

Presidentsraad, Republiek van Suid-Afrika, 1991: *"Verslag van die Komitees van die Presidentsraad oor 'n Nasionale Omgewingsbestuurstelsel"*. Staatsdrukker. Kaapstad.

Raudkivi, A.J., 1990: *"Loose Boundary Hydraulics, 3rd Edition"*. Pergamon Press, Oxford, UK.

Rooseboom, A., 1992: *"Sediment transport in rivers and reservoirs - A Southern African perspective"*. Water Research Commission (South Africa) Report No. 297/1/92.

Salakhov, F.S., 1975: *"Rotational designs and methods of hydraulic calculation of load-controlling water intake structures for mountain rivers"*. Proceedings of the Ninth Congress of the ICID, Moscow, pp 151-161.

Senior, J.C., 1992: *"Litter Control in Urban Waterways"*. International Symposium on Urban Stormwater Management, Sydney.

Swinburne University of Technology, 1996: In-line Litter Separator Research and Development Project 1996/8, Waste Management Council of Victoria, Australia.

Sydney Water Board, 1993: *"Iron Cove User Questionnaire, Preliminary Report on User Response"*.

Uys, L.J., 1994: *"Vangstruktuur vir rommel in stormwaterkanale"*. Unpublished BIng thesis, University of Stellenbosch.

Vallance, D, 1996: Personal communication with Mr D. Vallance of Melbourne Parks & Waterways, Waterways Division, Australia.

Visagie, C., 1994: *"Verbetering van die werking van 'n rommelvangput in 'n stormwaterkanaal"*. Unpublished BIng thesis, University of Stellenbosch.

Watson, D., 1996: *"The design of self-cleaning screens in stormwater canals"*. Unpublished BSc(Eng) thesis, University of Cape Town.

Weatherbe, D.G., Bryant, G. and Snodgrass, W., 1995: *"Performance of the Stormceptor Water Quality Inlet"*. Water Environment Federation Speciality Conference: New and Emerging Technologies and Products, Toronto, Ontario.

Weiss, G.J. and Michelbach, S., 1995: *"Vortex Separator: Dimensionless Properties and Calculation of Annual Separation Efficiencies"*. International Conference on Sewer Solids, University of Abertay Dundee, Scotland, pp 272-279.

Willing & Partners, 1989(a): *"City of Lake Macquarie, Cross Pollutant Traps - Design Guidelines"*. Australia.

Willing & Partners, 1989(b): *"Survey of the effectiveness of Diffuse Source Pollution Control Measures, Draft Report"*. State Pollution Control Commission, Sydney.

Wilsenach, J.A., 1994: *"Die ontwerp van 'n vangstruktuur om rommel in kanale to onderskep"*. Unpublished BIng thesis, University of Stellenbosch.

Wong, T.H.F. and Wootton, R.M., 1995: *"An Innovative Gross Pollutant Trap for Stormwater Treatment"*. The Second International Symposium on Urban Stormwater Management, Australia.

Wong, T.H.F., Wootton, R.M. and Fabian, D., 1996: *"A Solid Separator using a Continuous Deflective System"*. Paper accepted for the 7th International Conference on Urban Stormwater Drainage, Hanover, Germany.

Appendices

A : "Off-the-shelf" devices for the removal of litter

As explained in Section 10.5, very little detailed design information is available on many of the more effective structures as they are nearly all protected by patents, and design information is jealously guarded by the patent holders. The information that was publicly available in 1997 of the suppliers / patent holders and typical costs is supplied below. Some general information on the application, trap efficiency, method of cleaning, advantages and disadvantages of each structure is also given.

Where relevant, the source of the data is indicated in the text. Much of the cost data comes from the suppliers / patent holders and should thus be treated with some caution. Site works (ie. the cost of providing access, re-routing services, or re-establishing road surfaces over the finished structures) have been excluded unless otherwise indicated. **It is the responsibility of the designer to check all data with the suppliers / patent holders prior to the selection of a trapping system. Neither the Water Research Commission nor the authors can be held responsible for any costs that might be incurred through the use of data supplied in this report.**

Since many of the structures are Australian, most of the costs are in Australian dollars (A$). The exchange rate between Australian dollars and South African Rand (R) varied between A$1,00 = R3,30 and A$1,00 = R3,80 over the period September 1996 to September 1997. In view of the fact that labour is much cheaper in South Africa than Australia, an approximate exchange rate of A$1,00 = R3,00 in 1997 is probably realistic for the purposes of comparison.

Information is supplied on the following devices:

A.1 Side-entry catchpit traps (SECTs);

A.2 The North Sydney Litter Control Device (LCD);

A.3 The In-line Litter Separator (ILLS);

A.4 The Continuous Deflective Separation (CDS) device;

A.5 The Baramy® Gross Pollutant Trap (BGPT);

A.6 The Stormwater Cleaning Systems (SCS) structure: and

A.7 The Urban Water Environmental Management (UWEM) concept.

It should be noted that neither the Water Research Commission nor the authors are necessarily in favour of any of the products listed here. They are described here in an attempt to indicate some of the better options currently available 'off the shelf'. There may of course be other structures, not described in this document, that might remove litter from drainage systems more efficiently and effectively than these.

A.1 Side-entry catchpit traps (SECTs)

1. **Operation :** A suspended basket inside a side-entry catchpit intercepts the litter. See Section 6.2.

2. **Application :** Side-entry catchpits. SECTs can be custom made to suit virtually any side-entry catchpit.

3. **Patent holder :** Various different Australian designers and / or patent holders including the following:

   - Banyule City Council
     275 Upper Heidelberg Road
     Ivanhoe, Victoria
     AUSTRALIA

     Phone: [++61] (3) 9490 4222

   - Pitclear Industries
     38 McGlynn Avenue
     South Morang, Victoria, 3752
     AUSTRALIA.

   - Dencal Industries
     24 Halcyon Way
     Narre Warren South, Victoria, 3805
     AUSTRALIA

4. **Installation costs :** A$60 - 150 per catchpit (Allison, 1997).

5. **Cleaning costs :** A$5 - 10 per catchpit per clean (Allison, 1997). Typically a catchpit would be cleaned at monthly intervals or after every major storm.

6. **Head requirement :** A minimum of 500 mm (includes the depth of the basket and diameter of the stormwater conduit) - but this is generally already available within the side-entry catchpit.

7. **Size :** Fits within almost all existing side-entry catchpits.

8. **Trap efficiency :** The basket mesh size varies between 5 and 20 mm. Particles smaller than this are often trapped as a result of the "filter" that starts to form on the basket following deposition. If the baskets are not cleaned often enough, litter will pass over the overflow. According to Allison, 1997 the maximum trap efficiency is about 76%. If not all catchpits are fitted with baskets, the overall efficiency will obviously drop. Allison, 1997 showed that for Coburg, if the engineer correctly selected the catchpits carrying the higher loads, the net efficiency could be predicted from:

$$E = 1{,}18 \times 10^{-4} \, . \, T^3 - 2{,}58 \times 10^{-2} \, . \, T^2 + 2{,}184 \, . \, T \qquad (R^2 = 0{,}91)$$

where E = net trap efficiency (%)
T = trap coverage (%)

9. **Method of cleaning :** By hand or with a vacuum eductor (truck fitted with a suction hose). The basket is then washed with water under high pressure.

10. **Advantages** (after Melbourne Water Waterways and Drainage Group, 1995) **:**

- Quick and easy to install.
- Collection of litter is easily integrated into catchpit maintenance programme.
- Prevents transfer of kerb-side litter into drains and waterways.
- Litter trap basket can be easily removed for maintenance purposes.
- Litter trap basket has been designed to capture debris while still allowing water to pass into the drainage system.
- Can be used to identify the main sources of litter as part of a catchment management programme.

11. **Disadvantages** (after Melbourne Water Waterways and Drainage Group, 1995) **:**

- High cost of acquiring a special vacuum track for litter collection.
- The catchpit covers are heavy and need to be removed using safe lifting techniques.
- A large number of units are required in litter prone areas.

12. **Comments :** Only cost-effective in high litter producing areas such as in the CBD. Additional traps might be required downstream to catch bypass material. Most effective when used in conjunction with a catchment management programme.

A.2 The North Sydney Litter Control Device (LCD)

1. **Operation :** Conduit flow is dropped through a basket guided, if necessary, by a inclined trash rack on the downstream end of the basket which acts as a deflector plate. The litter is retained in the basket allowing the water to continue downstream. When the basket is full, or the flow rate exceeds the drainage capacity of the basket, surplus water is allowed to overflow the deflector rack. See Section 6.5.

2. **Application :** On conduits up to about 1 500 mm diameter.

3. **Patent holder :**

Attention : Mr Ray Brownlee
North Sydney Council
200 Miller Street
North Sydney, New South Wales, 2060
AUSTRALIA

Phone [++61] (2) 9936 8231
Fax [++61] (2) 9936 8203

4. **Installation costs :** The existing data is given in Table A-1:

Location	Cost (A$)	Catchment Area (Ha)
Willoughby Street	100 000	8,92
Walker Street	120 000	16,76
Smoothey Park	120 000	16,48
Waverton Park	120 000	30,01
Crows Nest Road	120 000	25,27
Ellamang Street	50 000	1,71
Honda Road	100 000	40,20
Grafton Road	130 000	144,74
Hayes Street	80 000	38,40
TOTAL	**940 000**	**322,50**

Table A-1 : Capital Costs of Litter Control Devices (Brownlee, 1995)

The average installation cost is A$2 900 per hectare.

5. **Cleaning costs :** The average cleaning costs are estimated to be in the order of A$2,67 per hectare per clean (Allison, 1997).

6. **Head requirement :** 650 - 1 000 mm.

7. **Size :** A LCD typically has external dimensions in the order of 3,5 x 3 x 3 m deep.

8. **Trap efficiency :** The baskets are generally constructed from 5 mm thick punched sheet metal with staggered 30 mm diameter holes (Hocking, 1996). Sometimes 20 mm holes are used (Brownlee, 1995). Studies have shown that finer material than this is often bound up in the matrix of coarse material that is soon trapped by the baskets. Trap efficiency is however strongly related to cleaning frequency. Increasing the cleaning frequency from monthly to after every storm (approximately weekly), increased the quantity of litter trapped at the Smoothey Park LCD by 192% (Hocking, 1996). The device is considered to be generally less than 30% efficient with monthly cleaning (Allison, 1997).

9. **Method of cleaning :** The litter is retrieved by lifting the baskets out of the LCD and depositing the litter into the rear of a 6 tonne haulage unit. This takes a two person maintenance crew approximately 35 minutes (Hocking, 1996).

10. **Advantages :**

- Simple operation.
- May be installed under road surfaces
- Relatively easy to clean.

11. **Disadvantages :**

- Expensive
- Inefficient.
- Requires a relatively high head for operation.

12. **Comments :** Only likely to find application in high density commercial areas where there is insufficient room to install a more efficient device. Although the LCD is probably the least efficient of the "off the shelf" devices described here, it is considerably better than many other similar devices which are currently on the market. This illustrates the difficulties facing the designers of litter control devices.

A.3 The In-line Litter Separator (ILLS)

1. **Operation :** Conduit flow is deflected by a hinged boom into a rectangular holding pit with a cross-sectional area considerably greater than that of the incoming pipe. The flow is forced underneath a suspended baffle wall, over a weir and then returns to the conduit downstream of the boom. The reduction in velocity through the holding pit causes the litter to desegregate into floatables and sinkables which are (theoretically) unable to follow the torturous path followed by the flow and are therefore trapped in the chamber. During high flows, the hinged boom floats out of the way allowing the flows to bypass the holding pit without disturbing previously trapped litter. See Section 7.4.

2. **Application :** On conduits up to about 900 mm in diameter.

3. **Supplier :** Marketed under the name "Litterguard" and supplied by:

   CSR Humes
   122a Doherty's Road
   Laverton North, Victoria
   AUSTRALIA

   Phone : [++61] (3) 9360 3888
   Fax : [++61] (3) 9360 3887

4. **Installation costs :** A$4 000 - A$8 000 depending on the pit size, depth of pipe and type of pit cover required.

5. **Cleaning costs :** No information available. Will probably be in the order of R50 per unit per clean. The unit would probably have to be cleaned monthly or after every major storm.

6. **Head requirement :** Less than 200 mm.

7. **Size :** Whilst considerably smaller than the CDS unit, the ILLS never-the-less extends from one and a half to two metres from one wall of the pipe.

8. **Trap efficiency :** Little information is available. Likely to be a very inefficient with polyethylene sheeting - for example in the form of shopping bags. This is problematical as shopping bags make up a large percentage of water-borne litter. By-passing also commences at a fairly low flow rate to keep the head requirement to a minimum. As considerable quantities of litter are carried in high flows, the overall efficiency of the device is likely to be low.

9. **Method of cleaning :** Hand-held scoop or vacuum eduction.

10. **Advantages :**

- Fairly easily retro-fitted to existing stormwater systems.
- Very low head requirement means that it has great flexibility.
- Can also trap oils and grease.
- Retains previously trapped litter during periods of bypass.
- Relatively easy to clean.

11. **Disadvantages :**

- Unreliable trapping performance.
- Boom might be damaged by fast moving heavy objects.
- Boom hinging mechanism might be damaged causing flooding during periods of high flow, or loss of litter once flows have dropped.
- Lack of field data.

12. **Comments :** The ILLS is probably only viable as a retro-fit system in situations where flat gradients and lack of space preclude other options

A.4 The Continuous Deflective Separation (CDS) device

1. **Operation :** Conduit flow is diverted into a circular chamber by means of a low weir. A circular screen allows litter-free water to return to the conduit downstream of the weir. The continuous motion across the surface of the circular screen keeps it from blocking whilst litter collects in the inner chamber. Material more dense than water sinks into a sump. Material less dense than water rises to the surface. See Section 5.10.

2. **Application :** Typically on conduits greater than one metre in diameter. They can be installed on open channels carrying flows up to about 50 m^3/s provided a high bypass ratio (during floods) is acceptable.

3. **Patent holder :**

   CDS Technologies Pty Ltd
   1140 Nepean Highway
   Mornington, Victoria, 3931
   AUSTRALIA.

   Phone : [++61] (3) 5977 0305
   Fax : [++61] (3) 5977 0302
   Email : info@cdstech.com.au
   Internet : http://www.cdstech.com.au

4. **Installation costs :** Little data currently exists. The three metre diameter unit constructed in Coburg (see Sections 2.5.2 and 5.9), which is capable of treating 550 litres per second, cost A$230 000, but this including many extra costs associated with construction including realignment of power, water, telephone and gas lines, and strengthening of the covers to allow the passage of large trucks. The cost of the unit excluding site works was about A$100 000 (Allison, 1997). CDS Technologies have recently installed units treating from 0,8 - 1,75 m^3/s for costs in the range A$140 000 - 160 000. These prices might be reduced by 15 - 20% once precast units become available (CDS Technologies, 1997). Further information regarding costs should be obtained from CDS Technologies Pty Ltd.

5. **Cleaning costs :** Little data currently exists. The Coburg unit costs about A$1 000 per clean. In Australia, these units are cleaned about four times a year (Allison, 1997). In South Africa, with much higher litter loads, cleaning might be required more frequently.

6. **Head requirement :** Approximately 400 mm at commencement of bypass flow (Allison, 1997).

7. **Size :** A large off-channel structure. The Coburg unit required a 6 x 6 x 4 m excavation. The unit may however be installed underneath road surfaces (Allison, 1997).

8. **Trap efficiency :** A typical screen has a 5 mm opening. Studies by Wong et al. (1995) indicate that approximately 95% of material down to 50% of the separation screen aperture size is also trapped. Litter loss is predominantly as a result of bypass during high flows. The litter already trapped in the unit is unaffected by bypass.

9. **Method of cleaning :** CDS Technologies Pty. Ltd have designed a "basket" that fits within the sump of the unit. This basket can be raised by means of an external crane, and the contents deposited into waiting trucks (Blanche and Crompton, 1996). In Melbourne, the CDS Technologies have invested in a truck mounted telescoping grab to achieve fast and cost effective mechanical without dewatering (CDS Technologies, 1997). Alternatively the unit can be pumped dry using a specially designed eductor truck that strips the litter off and returns the liquid to the conduit downstream of the bypass weir. If the unit is cleaned manually, special training and equipment is required - but this method of cleaning is not recommended (Allison, 1997).

10. **Advantages** (after Melbourne Water Waterways and Drainage Group, 1995) **:**

- High percentage removal of all litter.
- Will not block (except if the unit is completely full of litter).
- Minimal maintenance.
- Can be located anywhere in the drainage system.
- Effective even in high flows - a bypass operates if the system is overloaded.

11. **Disadvantages** (after Melbourne Water Waterways and Drainage Group, 1995) **:**

- Very high capital cost.
- High cost of acquiring a special truck designed for litter collection from the unit.
- May require annual eduction of sediments from the sump.
- Trapped material might ferment to produce toxic substances.

12. **Comments :** Although an extremely efficient device from an hydraulic point of view, the high installation and cleaning costs make this unit suitable only for high value land where there is limited space for alternatives.

A.5 The Baramy® Gross Pollutant Trap (BGPT)

1. **Operation :** Conduit flow is dropped over a declined trash-rack. The momentum of the flow combined with gravity propels the litter into a holding shelf ready for collection. The litter-free water either flows under the collection shelf (direct flow version) or around it (low profile version). See Section 5.8.

2. **Application :** On pipes or channels from 300 mm diameter upwards. The direct flow version has no particular upper flow limit as long as there is sufficient space and drop available (as much as 4,5 m is required in some instances). It is unlikely that a BGPT would ever be installed on a channel with a maximum flow in excess of 50 m^3/s.

3. **Patent holder :** Baramy Engineering Pty. Ltd
P O Box 357
Katoomba, New South Wales, 2780
AUSTRALIA

Phone : [++61] (47) 82 5741
Fax : [++61] (47) 82 3430
Email : Baramy@Lisp.com.au

4. **Installation costs :** Depends on size and layout. The estimated costs of the basic units (they are usually prefabricated and delivered to site for installation) is given in Table A-2:

Pipe diameter (mm)	Installation Cost (A$)
300 - 450	6 000 - 8 000
525 - 900	12 000 - 16 000
1 000 - 1 500	20 000 - 24 000
Multiple pipes	From 34 000
Flows in excess of 30 cumec	From 40 000

Table A-2 : The basic installation cost of Baramy® Gross Pollutant Traps

To the above must be added site costs which would be site specific and could double the cost of the installation (Baramy, 1997).

5. **Cleaning costs :** Little data currently exists. Seeing that the device is cleaned in much the same way as the SCS structure (see Section A.6 below), the cleaning costs are probably of the same order of magnitude ie. R35/m^3 litter.

6. **Head requirement :** Typically between 700 mm and 1,5 m (Baramy, 1997). However, some units require as little as 350 mm, whilst others require as much as 4,5 m (Baramy).

7. **Size :** The relative size of the structure varies from installation to installation. The smallest units for installation on pipes are about 3 m wide including the access ramp. The larger units are typically three times the width of the channel. Installations on very wide channels may only be 50% wider than the channel.

8. **Trap efficiency :** The screen opening is typically 15 mm and, since the trap is usually designed to intercept the entire flow range, the trap would thus be expected to catch virtually all material with a minimum dimension larger than this. If a bypass is provided, litter carried over the bypass would naturally be lost.

9. **Method of cleaning :** Generally by skid steer loader (Bobcat or similar). The units are also easily cleaned by hand using ordinary shovels and buckets / barrows.

10. **Advantages :**

    - Generally designed to remove litter over the entire flow range.
    - Can handle relatively high flows (up to say 30 m^3/s) with ease.
    - Negligible maintenance.
    - Easy to clean.
    - Little risk of toxic fermentation.
    - Relatively safe for public and workers.

11. **Disadvantages :**

    - High head requirement.
    - Requires a large amount of ground that must generally be fenced off to prevent the public from coming into contact with trapped litter.

12. **Comments :** If it was not for its high head requirement, this device would be the first choice in most situations. Head may however be created by means of an hydraulically actuated sluice gate as with the UWEM concept. In some instances, the drop in trapping efficiency occasioned by the use of a sluice gate may be more than compensated for by the hydraulic efficiency of the structure.

A.6 The Stormwater Cleaning Systems (SCS) Structure

1. **Operation :** In a typical layout, a weir deflects water from a channel into another channel parallel to, but higher than, the original. The flow is then turned through 90° over a side-channel spillway, through a declined screen, and returned to the original channel downstream of the weir. The litter carried by the flow is stripped off by the screen and deposited, ready for removal, into a self-draining basin that runs parallel to the two channels. High flow peaks are allowed to bypass the structure over the weir (See Section 5.5). An alternative sees the screen rotated into line with the channel when the SCS structure, to all intents and purposes, becomes identical to the Baramy® structure. Another alternative replaces the weir with an hydraulically operated sluice gate as with the UWEM approach (See Appendix A.7)

2. **Application :** Although the SCS principle can be applied to any flow rate and situation, the typical application described in 1. above would generally be most suitable for channel flows with peak flow rates in the range 1 - 30 cumecs.

3. **Patent holder :**

Mr Christo Nel
Stormwater Cleaning Systems Pty. Ltd.
P O Box 7210
Ulundi, KwaZulu-Natal, 3838
SOUTH AFRICA

Phone : [++27] (358) 70 3196
Fax : [++27] (358) 70 3197
Phone & Fax : [++27] (358) 70 3301

4. **Installation costs :** The Springs structure, which is capable of treating 7,5 cumecs, cost R127 500 in 1990 - equivalent to about R250 000 in 1997. However this included the model studies (R46 000) and application for patents (R7 000). On the other hand, the structure was constructed "in house" by the municipality under the direct supervision of the designer who was an employee of the municipality at the time. This might mean that construction by a contractor would be more expensive. The estimated 1996 costs for various alternatives for installation on the Jukskei River in Alexandria near Johannesburg, which included hydraulically actuated sluice gates were as listed in Table A-3:

5. **Cleaning costs :** Estimated to be about R35/m^3 at Springs (Nel, 1996).

6. **Head requirement :** At least 400 mm, but generally in the order of 1 300 mm. This head is usually created by means of a low weir or hydraulically actuated weir. The weir is cheaper but will however raise upstream flood levels.

7. **Size :** Depends on the application. The Springs structure extends for over 70 m and is some 13 m wide at its widest point. The channel it is installed on is only some 6 m wide at the same place. A more space efficient structure than this has however recently been installed in Port Elizabeth.

Size (m^3/s)	Cost (R)
10	250 000
20	550 000
30	800 000
40	1 010 000
50	1 220 000
60	1 420 000
70	1 600 000
80	1 760 000

Table A-3 : Estimated 1996 costs of an SCS structure across the Jukskei River in Alexandria (Nel, 1996)

8. **Trap efficiency :** A 20 mm opening was used at Springs (Nel, 1996), and therefore the structure would be expected to capture all material with a minimum dimension greater than this. The opening could of course be reduced, but this would tend to affect the hydraulic performance of the structure. In Springs, flood peaks greater than 7,5 m^3/s are allowed to bypass the structure and this is the greatest source of litter loss. As a result of bypassing, the Springs structure is estimated to be about 72% efficient. Efficiencies up to about 95% could easily be obtained, but at considerable extra cost.

9. **Method of cleaning :** By skid steer loader (Bobcat or similar) or by hand using ordinary shovels and buckets / barrows.

10. **Advantages :**

    - Can handle relatively high flows (up to 80 m^3/s or more if necessary) with ease.
    - Negligible maintenance.
    - Easy to clean.
    - Little risk of toxic fermentation.
    - Relatively safe for public and workers.

11. **Disadvantages :**

    - High head requirement.
    - Requires a large amount of ground that must generally be fenced off to prevent the public from coming into contact with trapped litter.

12. **Comments :** Like the Baramy® device (see Appendix A.5), the SCS device would be a popular choice in many situations if it were not for the high head requirement. Head may however be created without substantially increasing the upstream flood risk by means of an hydraulically actuated sluice gate as with the UWEM concept (see Appendix A.7).

A.7 The Urban Water Environmental Management (UWEM) concept

1. **Operation :** An hydraulically actuated sluice gate provides a relatively constant upstream head sufficient to divert channel flow through a series of suspended screens whose clearance systematically decreases in such a way as to provide an in-depth filter. A suspended baffle wall followed by a low weir ensure that the flow depth and consequently the flow area in the vicinity of the screens is kept large throughout the flow range. This in turn ensures that the flow velocity through the screens is kept low to reduce the risk of blockage. In the event of blockage of the screens and / or very high flood peaks, the hydraulically actuated sluice gate opens from the bottom in such a way as to keep upstream flood levels constant until such a point that the sluice gate is effectively out of the main channel and the flood peak can pass the structure with negligible increase in flood risk. The sluice gate automatically closes once the flood peak has passed.

2. **Application :** Although the UWEM concept can theoretically be applied to any flow rate and situation, practical difficulties associated with the cleaning of the structure tend to limit its application in the form described above to the use in open channels handling flows in excess of 15 m^3/s. The use of an hydraulically actuated sluice gate as a method of providing temporary head can be used in conjunction with both the Baramy® and SCS traps (see Appendices A.4 and A.6).

3. **Patent holder :**

Urban Water Environment Management
P O Box 2673
Pinegowrie, Gauteng, 2123
SOUTH AFRICA

Phone : [++27] (11) 789 6257
Fax : [++27] (11) 789 6499

4. **Installation costs :** Site specific - the Robinson canal structure, which has a design capacity of 15 m^3/s, cost approximately R600 000 in 1994 (equivalent to about R800 000 in 1997), but this included a considerable amount for the low-flow sewer connection. A more recent structure designed to treat 40 m^3/s had an estimated capital cost of R450 000. The hydraulically actuated control gates (for further information see Appendix C) typically cost about R2 500 per cumec of full design capacity. For preliminary costing, assume that the basic 15 m/s unit would normally cost about R300 000.

5. **Cleaning costs :** R15 - 35 per cubic metre of trapped litter depending on the size and location of the structure. As the size of the structure increases, the unit rate drops due to economies of scale.

6. **Head requirement :** 1,5 - 2 m - but this is provided in-situ by the hydraulically actuated gate. The UWEM concept can be applied to near horizontal channels.

7. **Size :** Large. The Robinson Canal structure (see Sections 2.3 and 6.6), which is capable of treating 15 cumec before bypassing commences, has a gross plan area of approximately 50 x 25 m excluding the de-grit channel for the low-flow sewer line. The plan area of the (off-channel) screens alone is approximately 30 x 10 m. At that point, the Robinson Canal is approximately 9 m wide.

8. **Trap efficiency :** This is strongly dependent on the mesh size and the capacity of the structure relative the flood peaks. In the case of the Robinson Canal, the screens fined down to 50 mm centre to centre giving a clearance of about 40 mm. However, as debris starts to pile up on the screens, the effective clearance decreases thereby improving the trap efficiency of the structure. On the other hand, the 15 m^3/s capacity of the trap is only sufficient for 85 percentile of all flows and consequently litter will be lost when peaks in excess of this pass under the sluice gate. It was not considered to be cost effective to attempt to treat the entire flow range - the annual flood flow peak is approximately 56 m^3/s, and the 10 year recurrence interval flow peak is approximately 92 m^3/s. The Robinson Canal structure is probably in the order of 70% efficient.

9. **Method of cleaning :** Generally by skid steer loader (Bobcat or similar). The units are also easily cleaned by hand using ordinary shovels and buckets / barrows

10. **Advantages :**

- Can be used in channels with very flat gradients
- Suitable for treating very high flows (0,8 m^3/s per metre length of trap)
- Can be easily adapted to trap other gross pollutants eg. oils, low flow sewage spills, sediments.
- Minimal maintenance.
- Relatively easy to clean.
- Relatively safe for public and workers.
- Cost effective for very large structures.

11. **Disadvantages :**

- Requires a large amount of ground that must generally be fenced off to prevent the public from coming into contact with trapped litter
- There is a slight risk that the sluice gate might fail to open at the critical moment causing upstream flooding and consequent damage claims
- Harder to clean than the Baramy® and SCS devices

12. **Comments :** Eminently suitable for very large flows eg. equal to or greater than 15 m^3/s. For flows a little less than this, the Baramy® and SCS devices are likely to be easier to clean and hence more cost effective in the long run. The ILLS is effectively a miniaturised version of the UWEM device without the screens, but, as discussed in Appendix A.3 above, is not likely to be cost-effective in most situations. There is considerable potential for the use of hydraulically operated sluice gates with the Baramy® and SCS devices.

B : Hypothetical trap selection

(N.B. This Appendix was written by the principal author without input from any of the co-authors having a vested interest in the results of the analysis)

To illustrate the trap selection procedure described in Section 11.4, consider the following hypothetical catchment:

- CBD of a medium sized town (50% commercial, 30% industrial, 20% residential);
- Area = 100 hectares (1 square kilometre);
- Situated in the summer rainfall area of South Africa with a MAP = 850 mm;
- Topography and layout permits the installation of any of the seven 'Off-the-shelf' devices described in Appendix A;
- Underground drainage system designed for 1:2 year recurrence interval (R.I.);
- 400 catchpits (a density of 4/ha);
- Regular street cleaning;
- No vegetation load;
- Runoff coefficient of 0,7 (70% of the storm rainfall is transported by the drainage system during the storm);
- Time of concentration of the rainfall (the time theoretically taken for a rain drop falling on the most remote point of the catchment to reach the trap) is 30 minutes;
- 50 significant rainfall events (more than 1 mm rainfall) a year concentrated in the summer rainfall season;
- Only recurrence intervals of 1:1 month and 1:2 years to be considered. Assume that the associated critical rainfall intensities are 21 and 51 mm/hour respectively;
- Litter density standardised to 95 kg / m^3;
- Economic analysis to be carried out assuming a repayment period of 20 years and a real interest rate (after taking inflation into account) of 6%.
- Effective exchange rate is A$1,00 = R3,00.

Solution:

1. Assume that the data for all sub-catchments is in the ratio of their areas.

2. According to the data supplied:
   commercial = 50 ha
   industrial = 30 ha
   residential = 20 ha

3. To estimate the total litter load, apply Equation 2-1:

$$T = \Sigma f_{sci}.(V_i + B_i).A_i \qquad \text{(Equation 2-1)}$$

$\Rightarrow$ T = 1,0 x 1,20 x 50 = 60,0 m^3 per year (commercial)
+ 1,0 x 0,80 x 30 = 24,0 m^3 per year (industrial)
+ 1,0 x 0,01 x 20 = 0,20 m^3 per year (residential)

$\Rightarrow$ T = 84,2 m^3 per year.

4. The well known Rational Formula is:

$$Q_P = C.I.A / 3,6$$

where
Q_p = peak flow (m^3/s)
C = runoff coefficient (fraction)
I = critical rainfall intensity (mm/hour)
A = catchment area (km^2)

Applying the Rational Method to the hypothetical catchment gives a 1:1 month peak flow of approximately 4,0 m^3/s, and a 1:2 year peak flow of approximately 10 m^3/s.

Assume further that a structure designed for the 1:1 month peak flow will treat only 90% of the total flow whilst a structure designed for the 1:2 year peak flow will effectively treat all of the flow.

5. All seven structures described in Appendix A will be costed.

6. The minimum storage capacity of the traps is determined from Equation 2-2:

$$S = f_s.T/\Sigma f_{si} \qquad \text{(Equation 2-2)}$$

$\Rightarrow$ S = 4,0 x 84,2 / (1,1 x 50) = 6,1 m^3

7. The cost effectiveness of the structures are determined in B.1 to B.7 below with any structure specific assumptions stated where relevant.

8. B.8 contains a summary of the calculations and makes some comments.

B.1 Side-entry catchpit traps (SECTs)

B.1.1 100% coverage

Assume that every catchpit is fitted with a SECT to give a total of 400 SECTs.

a) **Efficiency :** The efficiency of SECTs may be estimated from Allison, 1997:

$$E = 1{,}18 \times 10^{-4} \,.\, T^3 - 2{,}58 \times 10^{-2} \,.\, T^2 + 2{,}184 \,.\, T \qquad (R^2 = 0{,}91)$$

$$\Rightarrow E = 1{,}18 \times 10^{-4} \times 100^3 - 2{,}58 \times 10^{-2} \times 100^2 + 2{,}184 \times 100 = 78\%$$

Since this is the system efficiency, $\eta_e = 78 / 100 = 0{,}78$

b) **Storage capacity :** Assume a cleaning frequency of 14 days and an average storm frequency of 4 days during the wet season. The average storm load (after the first storm of the season) is estimated to be about 1,5 m^3 from Equation 2-2. The required storage capacity is then given by Equation 11-2:

$$V_t = F_c . \eta_e . S_{av} / F_s \qquad \text{Equation 11-2}$$

$$\Rightarrow V_t = 14 \times 0{,}78 \times 1{,}5 / 4 = 4{,}1 \text{ m}^3$$

Since this is not greater than the minimum calculated in Step 4 above = 6,1 m^3, the minimum storage capacity per trap = 6,1 m^3 / 400 traps = 0,015 m^3.

c) **Capital recovery amount :** Assume an average installation cost of R300 each to give 400 traps x R300 / trap = R120 000. The capital recovery amount is then calculated from Equation 11-3:

$$A = P.i(1+i)^n/((1+i)^n-1) \qquad \text{Equation 11-3}$$

$$\Rightarrow A = 120\,000 \times 0{,}06 \times (1 + 0{,}06)^{20} / ((1 + 0{,}06)^{20} - 1) = \text{R10 462 / year}$$

d) **Total volume of litter trapped :** is calculated from Equation 11-4:

$$L = T.\eta_e \qquad \text{Equation 11-4}$$

$$\Rightarrow L = 84{,}2 \times 0{,}78 = 65{,}7 \text{ m}^3 \text{ / year}$$

e) **Annual cost of the structure :** If the wet season is approximately 30 weeks long, the traps will have to be cleaned 15 times a year on average. Assume an average cost of R20 per catchpit per clean to make the annual cost of cleaning = 400 traps x 15 cleans / year x R20 / trap per clean = R120 000 / year. This assumes the requisite equipment is available. In not, add for the additional cost of the eductor truck etc.

The total annual cost is then calculated from Equation 11-5:

$$C_t = A + C_c \qquad \text{Equation 11-5}$$

$\Rightarrow C_t = 10\ 462 + 120\ 000 = \text{R}130\ 462$ / year

f) **Unit cost of litter removal :** is calculated from Equation 11-6:

$$C = C_t / L \qquad \text{Equation 11-6}$$

$\Rightarrow C = 130\ 462 / 65{,}7 = \text{R}1\ 986 / \text{m}^3$
$= \text{R}20{,}90$ / kg (dividing by the density = 95 kg/m^3)
$= \text{R}1\ 305$ / ha (dividing the cost by the area)

B.1.2 50% coverage

Assume that the 50% of catchpits trapping the highest load can be correctly identified in advance to give a total of 200 SECTs.

a) **Efficiency :** The efficiency of SECTs may be estimated from Allison, 1997:

$$E = 1{,}18 \times 10^{-4} \,.\, T^3 - 2{,}58 \times 10^{-2} \,.\, T^2 + 2{,}184 \,.\, T \qquad (R^2 = 0{,}91)$$

$\Rightarrow E = 1{,}18 \times 10^{-4} \times 50^3 - 2{,}58 \times 10^{-2} \times 50^2 + 2{,}184 \times 50 = 59\%$

Since this is the system efficiency, $\eta_o = 59 / 100 = 0{,}59$

b) **Storage capacity :** Assume the same as for 100% coverage = 0,015 m^3 / trap

c) **Capital recovery amount :** Half of that for 100% coverage or R5 231 / year

d) **Total volume of litter trapped :** is calculated from Equation 11-4:

$$L = T \,.\, \eta_o \qquad \text{Equation 11-4}$$

$\Rightarrow L = 84{,}2 \times 0{,}59 = 49{,}7 \text{ m}^3$ / year

e) **Annual cost of the structure :** Assuming that cost of cleaning is proportional to the loads captured, the annual cost of cleaning is given by R120 000 / year (the cost for 100% coverage) x 59 / 78 (the ratio of the efficiencies) = R90 769 / year.

The total annual cost is then calculated from Equation 11-5:

$$C_t = A + C_c \qquad \text{Equation 11-5}$$

$\Rightarrow C_t = 5\ 231 + 90\ 769 = \text{R}96\ 000$ / year

f) **Unit cost of litter removal :** is calculated from Equation 11-6:

$$C = C_t / L \qquad \text{Equation 11-6}$$

$\Rightarrow C = 96\ 000 / 49{,}7 = R1\ 932 / m^3$
$= R20{,}33 / kg$ (dividing by the density $= 95\ kg/m^3$)
$= R960 / ha$ (dividing the cost by the area)

B.2 The North Sydney Litter Control Device (LCD)

Assume the installation of as many as is required (costs are given on an area basis).

a) **Efficiency :** Assume a system efficiency of 25%, ie. $\eta_e = 25 / 100 = 0{,}25$

b) **Storage capacity :** Assume a cleaning frequency of 30 days and an average storm frequency of 4 days during the wet season. The average storm load (after the first storm of the season) is estimated to be about 1,5 m^3 from Equation 2-2. The required storage capacity is then given by Equation 11-2:

$$V_t = F_c . \eta_e . S_{av} / F_s \qquad \text{Equation 11-2}$$

$\Rightarrow V_t = 30 \times 0{,}25 \times 1{,}5 / 4 = 2{,}8\ m^3$

Since this is not greater than the minimum calculated in Step 4 above = 6,1 m^3, the minimum storage capacity = 6,1 m^3 distributed over all the traps.

c) **Capital recovery amount :** Assume an average installation cost of R8 700 / ha to give a total installation cost of R8 700 / ha x 100 ha = R870 000. The capital recovery amount is then calculated from Equation 11-3:

$$A = P.i(1+i)^n/((1+i)^n-1) \qquad \text{Equation 11-3}$$

$\Rightarrow A = 870\ 000 \times 0{,}06 \times (1 + 0{,}06)^{20} / ((1 + 0{,}06)^{20} - 1) = R75\ 851 / year$

d) **Total volume of litter trapped :** is calculated from Equation 11-4:

$$L = T . \eta_e \qquad \text{Equation 11-4}$$

$\Rightarrow L = 84{,}2 \times 0{,}25 = 21{,}1\ m^3 / year$

e) **Annual cost of the structure :** If the wet season is approximately 7 months long, the traps will have to be cleaned 7 times a year on average. Assume an average cost of R8 per hectare per clean to make the annual cost of cleaning = 100 ha x 7 cleans / year x R8 / ha per clean = R5 600 / year.

The total annual cost is then calculated from Equation 11-5:

$$C_t = A + C_c \qquad \text{Equation 11-5}$$

$\Rightarrow C_t = 75\ 851 + 5\ 600 = R81\ 451$ / year

f) **Unit cost of litter removal :** is calculated from Equation 11-6:

$$C = C_t / L \qquad \text{Equation 11-6}$$

$\Rightarrow C = 81\ 451 / 21{,}1 = R3\ 860 / m^3$
$= R40{,}63$ / kg (dividing by the density $= 95\ kg/m^3$)
$= R815$ / ha (dividing the cost by the area)

B.3 The In-line Litter Separator (ILLS)

Assume an average of 0,5 m^3/s per unit giving a total of 20.

a) **Efficiency :** Assume a system efficiency of 25%, ie. $\eta_o = 25 / 100 = 0{,}25$

b) **Storage capacity :** Assume a cleaning frequency of 14 days and an average storm frequency of 4 days during the wet season. The average storm load (after the first storm of the season) is estimated to be about 1,5 m^3 from Equation 2-2. The required storage capacity is then given by Equation 11-2:

$$V_t = F_c . \eta_o . S_{av} / F_s \qquad \text{Equation 11-2}$$

$\Rightarrow V_t = 14 \times 0{,}25 \times 1{,}5 / 4 = 1{,}3\ m^3$

Since this is not greater than the minimum calculated in Step 4 above = 6,1 m^3, the minimum storage capacity per trap = 6,1 m^3 / 20 traps = 0,31 m^3.

c) **Capital recovery amount :** Assume an average installation cost of R18 000 each to give R18 000 / trap x 20 traps = R360 000. The capital recovery amount is then calculated from Equation 11-3:

$$A = P.i(1+i)^n/((1+i)^n-1) \qquad \text{Equation 11-3}$$

$\Rightarrow A = 360\ 000 \times 0{,}06 \times (1 + 0{,}06)^{20} / ((1 + 0{,}06)^{20} - 1) = R31\ 386$ / year

d) **Total volume of litter trapped :** is calculated from Equation 11-4:

$$L = T.\eta_o \qquad \text{Equation 11-4}$$

$\Rightarrow L = 84{,}2 \times 0{,}25 = 21{,}1\ m^3$ / year

e) **Annual cost of the structure :** If the wet season is approximately 30 weeks long, the traps will have to be cleaned 15 times a year on average. Assume an average cost of R50 per trap per clean to make the annual cost of cleaning = 20 traps x 15 cleans / year x R50 / trap per clean = R15 000 / year. The total annual cost is then calculated from Equation 11-5:

$$C_t = A + C_c \qquad \text{Equation 11-5}$$

$\Rightarrow C_t = 31\ 386 + 15\ 000 = \text{R}46\ 386$ / year

f) **Unit cost of litter removal :** is calculated from Equation 11-6:

$$C = C_t / L \qquad \text{Equation 11-6}$$

$\Rightarrow C = 46\ 386 / 21{,}1 = \text{R}2\ 198 / \text{m}^3$
= R23,14 / kg (dividing by the density = 95 kg/m^3)
= R464 / ha (dividing the cost by the area)

B.4 The Continuous Deflective Separation (CDS) device

B.4.1 1:2 year R.I. design

Assume 6 units, each capable of treating about 1,67 m^3/s.

a) **Efficiency :** Assume that the units effectively treat all the flow. Assume that the units are 99% efficient. The overall efficiency of the installation is then given by Equation 11-1:

$$\eta_o = \eta_t . \eta_f \qquad \text{Equation 11-1}$$

$\Rightarrow \eta_o = 0{,}99 \times 1{,}00 = 0{,}99$

b) **Storage capacity :** Assume a cleaning frequency of 4 times a year or approximately once every 52 days during the wet season. Assume that the average storm frequency of 4 days during the wet season. The average storm load (after the first storm of the season) is estimated to be about 1,5 m^3 from Equation 2-2. The required storage capacity is then given by Equation 11-2:

$$V_t = F_c . \eta_o . S_{av} / F_s \qquad \text{Equation 11-2}$$

$\Rightarrow V_t = 52 \times 0{,}99 \times 1{,}5 / 4 = 19{,}3 \text{ m}^3$

Since this is greater than the minimum calculated in Step 4 above = 6,1 m^3, the minimum storage capacity per trap = 19.3 m^3 / 6 traps = 3,2 m^3.

c) **Capital recovery amount :** Assume an average installation cost of R480 000 each to give 6 traps x R480 000 / trap = R2 880 000. The capital recovery amount is then calculated from Equation 11-3:

$$A = P.i(1+i)^n/((1+i)^n-1) \qquad \text{Equation 11-3}$$

$\Rightarrow A = 2\ 880\ 000 \times 0{,}06 \times (1 + 0{,}06)^{20} / ((1 + 0{,}06)^{20} - 1) =$ R251 092 / year

d) **Total volume of litter trapped :** is calculated from Equation 11-4:

$$L = T.\eta_o \qquad \text{Equation 11-4}$$

$\Rightarrow L = 84{,}2 \times 0{,}99 = 83{,}4\ m^3$ / year

e) **Annual cost of the structure :** Assume an average cost of R3 000 per unit per clean to make the annual cost of cleaning = 6 traps x R3 000 / trap per clean x 4 cleans / year = R72 000 / year. The total annual cost is then calculated from Equation 11-5:

$$C_t = A + C_c \qquad \text{Equation 11-5}$$

$\Rightarrow C_t = 251\ 092 + 72\ 000 =$ R323 092 / year

f) **Unit cost of litter removal :** is calculated from Equation 11-6.

$$C = C_t / L \qquad \text{Equation 11-6}$$

$\Rightarrow C = 323\ 092 / 83{,}4 =$ R3 874 / m^3
= R40,78 / kg (dividing by the density = 95 kg/m^3)
= R3 231 / ha (dividing the cost by the area)

B.4.2 1:1 month R.I. design

Assume 3 units, each capable of treating about 1,33 m^3/s

a) **Efficiency :** Assume that the units effectively treat 90% of the flow. Assume that the units are 99% efficient. The overall efficiency of the installation is then given by Equation 11-1.

$$\eta_o = \eta_s.\eta_f \qquad \text{Equation 11-1}$$

$\Rightarrow \eta_o = 0{,}99 \times 0{,}90 = 0{,}89$

b) **Storage capacity :** Assume a cleaning frequency of 4 times a year or approximately once every 52 days during the wet season. Assume that the average storm frequency of 4 days during the wet season. The average storm load (after the first storm of the season) is estimated to be about 1,5 m^3 from Equation 2-2. The required storage capacity is then given by Equation 11-2:

$$V_t = F_c.\eta_o.S_{av} / F_s \qquad \text{Equation 11-2}$$

$\Rightarrow V_t = 52 \times 0{,}89 \times 1{,}5 / 4 = 17{,}4\ m^3$

Since this is greater than the minimum calculated in Step 4 above = 6,1 m^3, the minimum storage capacity per trap = 17,4 m^3 / 3 traps = 5,8 m^3.

c) **Capital recovery amount :** Assume an average installation cost of R480 000 each to give 3 traps x R480 000 / trap = R1 440 000. The capital recovery amount is then calculated from Equation 11-3:

$$A = P.i(1+i)^n/((1+i)^n-1) \qquad \text{Equation 11-3}$$

$\Rightarrow A = 1\ 440\ 000 \times 0{,}06 \times (1 + 0{,}06)^{20} / ((1 + 0{,}06)^{20} - 1) = R125\ 546$ / year

d) **Total volume of litter trapped :** is calculated from Equation 11-4:

$$L = T.\eta_o \qquad \text{Equation 11-4}$$

$\Rightarrow L = 84{,}2 \times 0{,}89 = 74{,}9\ m^3$ / year

e) **Annual cost of the structure :** Assume an average cost of R3 000 per unit per clean to make the annual cost of cleaning = 3 traps x R3 000 / trap per clean x 4 cleans / year = R36 000 / year. The total annual cost is then calculated from Equation 11-5:

$$C_t = A + C_c \qquad \text{Equation 11-5}$$

$\Rightarrow C_t = 125\ 546 + 36\ 000 = R161\ 546$ / year

f) **Unit cost of litter removal :** is calculated from Equation 11-6:

$$C = C_t / L \qquad \text{Equation 11-6}$$

$\Rightarrow C = 161\ 546 / 74{,}9 = R2\ 157 / m^3$
= R22,70 / kg (dividing by the density = 95 kg/m^3)
= R1 615 / ha (dividing the cost by the area)

B.5 The Baramy® Gross Pollutant Trap (BGPT)

B.5.1 1:2 year R.I. design

Assume 3 units, each capable of treating about 3,33 m^3/s.

a) **Efficiency :** Assume that the units effectively treat all the flow. Assume that the units are 95% efficient. The overall efficiency of the installation is then given by Equation 11-1:

$$\eta_o = \eta_s . \eta_f \qquad \text{Equation 11-1}$$

$\Rightarrow \eta_o = 0{,}95 \times 1{,}00 = 0{,}95$

b) **Storage capacity :** Assume a cleaning frequency of 14 days and an average storm frequency of 4 days during the wet season. The average storm load (after the first storm of the season) is estimated to be about 1,5 m^3 from Equation 2-2. The required storage capacity is then given by Equation 11-2:

$$V_t = F_c . \eta_o . S_{av} / F_s \qquad \text{Equation 11-2}$$

$\Rightarrow V_t = 14 \times 0{,}95 \times 1{,}5 / 4 = 5{,}0 \text{ m}^3$

Since this is less than the minimum calculated in Step 4 above = 6,1 m^3, the minimum storage capacity per trap = 6,1 m^3 / 3 traps = 2,0 m^3.

c) **Capital recovery amount :** Assume an average installation cost of R72 000 each to give 3 traps x R72 000 / trap = R216 000. The capital recovery amount is then calculated from Equation 11-3:

$$A = P.i(1+i)^n/((1+i)^n-1) \qquad \text{Equation 11-3}$$

$\Rightarrow A = 216\,000 \times 0{,}06 \times (1 + 0{,}06)^{20} / ((1 + 0{,}06)^{20} - 1) = \text{R18 832 / year}$

d) **Total volume of litter trapped :** is calculated from Equation 11-4:

$$L = T . \eta_o \qquad \text{Equation 11-4}$$

$\Rightarrow L = 84{,}2 \times 0{,}95 = 80{,}0 \text{ m}^3 / \text{year}$

e) **Annual cost of the structure :** Assume an average cleaning cost of R35 / m^3 to make the annual cost of cleaning = R35 / m^3 x 80,0 m^3 / year = R2 800 / year. The total annual cost is then calculated from Equation 11-5:

$$C_t = A + C_c \qquad \text{Equation 11-5}$$

$\Rightarrow C_t = 18\,832 + 2\,800 = \text{R21 632 / year}$

f) **Unit cost of litter removal :** is calculated from Equation 11-6:

$$C = C_t / L \qquad \text{Equation 11-6}$$

$\Rightarrow C = 21\,632 / 80{,}0 = R270 / m^3$
$= R2{,}85 / kg$ (dividing by the density $= 95\ kg/m^3$)
$\approx R216 / ha$ (dividing the cost by the area)

B.5.2 1:1 month R.I. design

Assume 1 unit capable of treating the entire 4 m^3/s.

a) **Efficiency :** Assume that the unit effectively treats 90% of the flow. Assume that the unit is 95% efficient. The overall efficiency of the installation is then given by Equation 11-1:

$$\eta_o = \eta_s . \eta_f \qquad \text{Equation 11-1}$$

$\Rightarrow \eta_o = 0{,}95 \times 0{,}90 = 0{,}86$

b) **Storage capacity :** Assume a cleaning frequency of 14 days and an average storm frequency of 4 days during the wet season. The average storm load (after the first storm of the season) is estimated to be about 1,5 m^3 from Equation 2-2. The required storage capacity is then given by Equation 11-2:

$$V_t = F_c . \eta_o . S_{av} / F_s \qquad \text{Equation 11-2}$$

$\Rightarrow V_t = 14 \times 0{,}86 \times 1{,}5 / 4 = 4{,}5\ m^3$

Since this is less than the minimum calculated in Step 4 above = 6,1 m^3, the minimum storage capacity = 6,1 m^3.

c) **Capital recovery amount :** Assume an installation cost of R85 000. The capital recovery amount is then calculated from Equation 11-3.

$$A = P.i(1+i)^n/((1+i)^n-1) \qquad \text{Equation 11-3}$$

$\Rightarrow A = 85\,000 \times 0{,}06 \times (1 + 0{,}06)^{20} / ((1 + 0{,}06)^{20} - 1) = R7\,411 / year$

d) **Total volume of litter trapped :** is calculated from Equation 11-4.

$$L = T.\eta_o \qquad \text{Equation 11-4}$$

$\Rightarrow L = 84{,}2 \times 0{,}86 = 72{,}4\ m^3 / year$

e) **Annual cost of the structure :** Assume an average cleaning cost of R35 / m^3 to make the annual cost of cleaning = R35 / m^3 x 72,4 m^3 / year = R2 534 / year. The total annual cost is then calculated from Equation 11-5:

$$C_t = A + C_c \qquad \text{Equation 11-5}$$

$\Rightarrow C_t = 7\,411 + 2\,534 =$ R9 945 / year

f) **Unit cost of litter removal :** is calculated from Equation 11-6:

$$C = C_t / L \qquad \text{Equation 11-6}$$

$\Rightarrow C = 9\,945 / 72{,}4 =$ R137 / m^3
= R1,45 / kg (dividing by the density = 95 kg/m^3)
= R99 / ha (dividing the cost by the area)

B.6 The Stormwater Cleaning Systems (SCS) Structure

B.6.1 1:2 year R.I. design

Assume 1 unit capable of treating the entire 10 m^3/s.

a) **Efficiency :** Assume that the unit effectively treats all the flow. Assume that the unit is 95% efficient. The overall efficiency of the installation is then given by Equation 11-1:

$$\eta_o = \eta_s . \eta_f \qquad \text{Equation 11-1}$$

$\Rightarrow \eta_o = 0{,}95 \times 1{,}00 = 0{,}95$

b) **Storage capacity :** Assume a cleaning frequency of 14 days and an average storm frequency of 4 days during the wet season. The average storm load (after the first storm of the season) is estimated to be about 1,5 m^3 from Equation 2-2. The required storage capacity is then given by Equation 11-2:

$$V_t = F_c . \eta_o . S_{av} / F_s \qquad \text{Equation 11-2}$$

$\Rightarrow V_t = 14 \times 0{,}95 \times 1{,}5 / 4 = 5{,}0\ m^3$

Since this is less than the minimum calculated in Step 4 above = 6,1 m^3, the minimum storage capacity = 6,1 m^3.

c) **Capital recovery amount :** Assume an installation cost of R250 000. The capital recovery amount is then calculated from Equation 11-3:

$$A = P.i(1+i)^n/((1+i)^n-1) \qquad \text{Equation 11-3}$$

$\Rightarrow A = 250\ 000 \times 0{,}06 \times (1 + 0{,}06)^{20} / ((1 + 0{,}06)^{20} - 1) = R21\ 796$ / year

d) **Total volume of litter trapped :** is calculated from Equation 11-4.

$$L = T.\eta_o \qquad \text{Equation 11-4}$$

$\Rightarrow L = 84{,}2 \times 0{,}95 = 80{,}0\ m^3$ / year

e) **Annual cost of the structure :** Assume an average cleaning cost of R35 / m^3 to make the annual cost of cleaning = R35 / m^3 x 80,0 m^3 / year = R2 800 / year. The total annual cost is then calculated from Equation 11-5:

$$C_t = A + C_c \qquad \text{Equation 11-5}$$

$\Rightarrow C_t = 21\ 796 + 2\ 800 = R24\ 596$ / year

f) **Unit cost of litter removal :** is calculated from Equation 11-6:

$$C = C_t / L \qquad \text{Equation 11-6}$$

$\Rightarrow C = 24\ 596 / 80{,}0 = R307 / m^3$
= R3,24 / kg (dividing by the density = 95 kg/m^3)
= R246 / ha (dividing the cost by the area)

B.6.2 1:1 month R.I. design

Assume 1 unit capable of treating the entire 4 m^3/s

a) **Efficiency :** Assume that the unit effectively treats 90% of the flow. Assume that the unit is 95% efficient. The overall efficiency of the installation is then given by Equation 11-1:

$$\eta_o = \eta_s.\eta_f \qquad \text{Equation 11-1}$$

$\Rightarrow \eta_o = 0{,}95 \times 0{,}90 = 0{,}86$

b) **Storage capacity :** Assume a cleaning frequency of 14 days and an average storm frequency of 4 days during the wet season. The average storm load (after the first storm of the season) is estimated to be about 1,5 m^3 from Equation 2-2. The required storage capacity is then given by Equation 11-2:

$$V_t = F_c\, \eta_o . S_{av} / F_s \qquad \text{Equation 11-2}$$

$\Rightarrow V_t = 14 \times 0{,}86 \times 1{,}5 / 4 \approx 4{,}5\ m^3$

Since this is less than the minimum calculated in Step 4 above = 6,1 m^3, the minimum storage capacity = 6,1 m^3.

c) **Capital recovery amount :** Assume an installation cost of R125 000. The capital recovery amount is then calculated from Equation 11-3:

$$A = P.i(1+i)^n/((1+i)^n-1) \qquad \text{Equation 11-3}$$

$\Rightarrow A = 125\ 000 \times 0{,}06 \times (1 + 0{,}06)^{20} / ((1 + 0{,}06)^{20} - 1) = R10\ 898$ / year

d) **Total volume of litter trapped :** is calculated from Equation 11-4:

$$L = T\, \eta_o \qquad \text{Equation 11-4}$$

$\Rightarrow L = 84{,}2 \times 0{,}86 = 72{,}4\ m^3$ / year

e) **Annual cost of the structure :** Assume an average cleaning cost of R35 / m^3 to make the annual cost of cleaning = R35 / m^3 x 72,4 m^3 / year = R2 534 / year. The total annual cost is then calculated from Equation 11-5:

$$C_t = A + C_c \qquad \text{Equation 11-5}$$

$\Rightarrow C_t = 10\ 898 + 2\ 534 = R13\ 432$ / year

Unit cost of litter removal : is calculated from Equation 11-6

$$C = C_t / L \qquad \text{Equation 11-6}$$

$\Rightarrow C = 13\ 432 / 72{,}4 = R185 / m^3$
= R1,95 / kg (dividing by the density = 95 kg/m^3)
= R134 / ha (dividing the cost by the area)

B.7 The Urban Water Environmental Management (UWEM) concept

B.7.1 1:2 year R.I. design

Assume 1 unit capable of treating the entire 10 m^3/s.

a) **Efficiency :** Assume that the unit effectively treats all the flow. Assume that the unit is 90% efficient. The overall efficiency of the installation is then given by Equation 11-1:

$$\eta_o = \eta_s . \eta_f \qquad \text{Equation 11-1}$$

$\Rightarrow \eta_o = 0,90 \times 1,00 = 0,90$

b) **Storage capacity :** Assume a cleaning frequency of 14 days and an average storm frequency of 4 days during the wet season. The average storm load (after the first storm of the season) is estimated to be about 1,5 m^3 from Equation 2-2. The required storage capacity is then given by Equation 11-2:

$$V_t = F_c . \eta_o . S_{av} / F_s \qquad \text{Equation 11-2}$$

$\Rightarrow V_t = 14 \times 0,90 \times 1,5 / 4 = 4,7\ m^3$

Since this is less than the minimum calculated in Step 4 above = 6,1 m^3, the minimum storage capacity = 6,1 m^3.

c) **Capital recovery amount :** Assume an installation cost of R250 000. The capital recovery amount is then calculated from Equation 11-3:

$$A = P.i(1+i)^n/((1+i)^n-1) \qquad \text{Equation 11-3}$$

$\Rightarrow A = 250\ 000 \times 0,06 \times (1 + 0,06)^{20} / ((1 + 0,06)^{20} - 1) =$ R21 796 / year

d) **Total volume of litter trapped :** is calculated from Equation 11-4:

$$L = T.\eta_o \qquad \text{Equation 11-4}$$

$\Rightarrow L = 84,2 \times 0,90 = 75,8\ m^3$ / year

e) **Annual cost of the structure :** Assume an average cleaning cost of R35 / m^3 to make the annual cost of cleaning = R35 / m^3 x 75,8 m^3 / year = R2 653 / year. The total annual cost is then calculated from Equation 11-5:

$$C_t = A + C_c \qquad \text{Equation 11-5}$$

$\Rightarrow C_t = 21\ 796 + 2\ 653 =$ R24 449 / year

f) **Unit cost of litter removal :** is calculated from Equation 11-6:

$$C = C_t / L \qquad \text{Equation 11-6}$$

$\Rightarrow C = 24\ 449 / 75{,}8 = R323 / m^3$
$= R3{,}40 / kg$ (dividing by the density = 95 kg/m^3)
$= R244 / ha$ (dividing the cost by the area)

B.7.2 1:1 month R.I. design

Assume 1 unit capable of treating the entire 4 m^3/s.

a) **Efficiency :** Assume that the unit effectively treats 90% of the flow. Assume that the unit is 90% efficient. The overall efficiency of the installation is then given by Equation 11-1:

$$\eta_o = \eta_s.\eta_f \qquad \text{Equation 11-1}$$

$\Rightarrow \eta_o = 0{,}90 \times 0{,}90 = 0{,}81$

b) **Storage capacity :** Assume a cleaning frequency of 14 days and an average storm frequency of 4 days during the wet season. The average storm load (after the first storm of the season) is estimated to be about 1,5 m^3 from Equation 2-2. The required storage capacity is then given by Equation 11-2:

$$V_t = F_c\ \eta_o.S_{av} / F_s \qquad \text{Equation 11-2}$$

$\Rightarrow V_t = 14 \times 0{,}81 \times 1{,}5 / 4 = 4{,}3\ m^3$

Since this is less than the minimum calculated in Step 4 above = 6,1 m^3, the minimum storage capacity = 6,1 m^3.

c) **Capital recovery amount :** Assume an installation cost of R150 000. The capital recovery amount is then calculated from Equation 11-3:

$$A = P.i(1+i)^n/((1+i)^n-1) \qquad \text{Equation 11-3}$$

$\Rightarrow A = 150\ 000 \times 0{,}06 \times (1 + 0{,}06)^{20} / ((1 + 0{,}06)^{20} - 1) = R13\ 078 / year$

d) **Total volume of litter trapped :** is calculated from Equation 11-4:

$$L = T.\eta_o \qquad \text{Equation 11-4}$$

$\Rightarrow L = 84{,}2 \times 0{,}81 = 68{,}2\ m^3 / year$

e) **Annual cost of the structure :** Assume an average cleaning cost of R35 / m^3 to make the annual cost of cleaning = R35 / m^3 x 68,2 m^3 / year = R2 387 / year. The total annual cost is then calculated from Equation 11-5:

$$C_t = A + C_c \qquad \text{Equation 11-5}$$

$\Rightarrow C_t = 13\ 078 + 2\ 387 = \text{R}15\ 465$ / year

f) **Unit cost of litter removal :** is calculated from Equation 11-6:

$$C = C_t / L \qquad \text{Equation 11-6}$$

$\Rightarrow C = 15\ 465 / 68{,}2 = \text{R}227 / \text{m}^3$
= R2,39 / kg (dividing by the density = 95 kg/m^3)
= R155 / ha (dividing the cost by the area)

B.8 Summary and conclusions

The results of the above analysis are summarised in Tables B-1 and Table B-2.

Assuming the validity of the data supplied in Appendix A, the above analysis clearly shows the much higher economic efficiency of the UWEM, Baramy® and SCS devices over the remaining four structures. SECTs might be a little more cost effective in South Africa than indicated in the analysis if they prove to be cheaper to install and clean than in Australia - owing to the lower cost of labour. In addition, they are also a potential catchment management tool as they show where the bulk of the litter is being generated. The CDS units offer very high removal efficiencies, but at a heavy cost. The ILLS and LCD structures appear on the surface to be costly, but have the advantage that they are small and can be installed under streets in confined spaces, and the ILLS has the additional advantage that it requires very little head.

The final decision of a trapping structure will be site specific. Lack of head may rule out the Baramy® and SCS devices. Lack of space may rule out the UWEM approach. The desire for a catchment management tool may favour the choice of SECTs. A requirement for exceptionally high removal efficiency may prompt the installation of a CDS unit. A small catchment may be best served by an ILLS or LCD. Local litter loadings and cost factors may also bias the analysis differently to that of the example.

The analysis shows that it is quite possible remove litter from stormwater conduits and urban streams for R150 - R350 / m^3 (1997 costs). By way of comparison, it cost the City Council of Springs approximately R680 / m^3 of litter in 1995 to remove litter from the streets and a further R900 / m^3 to remove what they could by hand out of the Blesbokspruit (Nel, 1996). This is approximately R810 / m^3 and R1 080 / m^3 respectively in 1997 terms.

Rank	Device	Traps	E(%)	R/m^3	R/kg	R/ha/y
1	Baramy® (1:1 month R.I.)	1	86	137	1,45	99
2	SCS (1:1 month R.I.)	1	86	185	1,95	134
3	UWEM (1:1 month R.I.)	1	81	227	2,39	155
4	Baramy® (1:2 year R.I.)	3	95	270	2,85	216
5	SCS (1:2 year R.I.)	1	95	307	3,24	246
6	UWEM (1:2 year R.I.)	1	90	323	3,40	244
7	SECTs (50% coverage)	200	59	1 932	20,33	960
8	SECTs (100% coverage)	400	78	1 986	20,90	1 305
9	CDS (1:1 month R.I.)	3	89	2 157	22,70	1 615
10	ILLS	20	25	2 198	23,14	464
11	LCD	-	25	3 860	40,63	815
12	CDS (1:2 year R.I.)	6	99	3 874	40,78	3 231

Table B-1 : Summary of the analysis ranked in terms of cost effectiveness

Rank	Device	Traps	E(%)	R/m^3	R/kg	R/ha
1	CDS (1:2 year R.I.)	6	99	3 874	40,78	3 231
2	Baramy® (1:2 year R.I.)	3	95	270	2,85	216
3	SCS (1:2 year R.I.)	1	95	307	3,24	246
4	UWEM (1:2 year R.I.)	1	90	323	3,40	244
5	CDS (1:1 month R.I.)	3	89	2 157	22,70	1 615
6	Baramy® (1:1 month R.I.)	1	86	137	1,45	99
7	SCS (1:1 month R.I.)	1	86	185	1,95	134
8	UWEM (1:1 month R.I.)	1	81	227	2,39	155
9	SECTs (100% coverage)	400	78	1 986	20,90	1 305
10	SECTs (50% coverage)	200	59	1 932	20,33	960
11	ILLS	20	25	2 198	23,14	464
12	LCD	-	25	3 860	40,63	815

Table B-2 : Summary of the analysis ranked in terms of removal efficiency

C : Hydraulically operated sluice gates

A major problem with many of the more cost effective litter removal technologies, is that they require considerable head - often up to 2 m - for their successful operation. This is seldom available. Most cities are built on relatively flat land.

A potential solution is to incorporate an hydraulically operated sluice gate which supplies the required head during low flow periods, and lifts out of the way to pass flood peaks without raising upstream flood levels. This approach was pioneered in the UWEM concept described in Section 6.6.

There are many patented designs of gate, each operating in a slightly different way. Two designs by Fluid Dynamics Systems are described here as examples.

C.1 Fluid Dynamics Systems Regulating Gate

A modified Fluid Dynamics Systems Regulating Gate was installed on the Robinson Canal trap (see Sections 2.3 and 6.6). It comprises a buoyancy tank (whose shape is determined from model testing) connected by two hollow radial arms to an axle unit, which is in turn attached a control chamber. An automatic level controlling valve installed in the control chamber allows water into and out of the buoyancy tank via the axle unit.

The gate operates as follows:

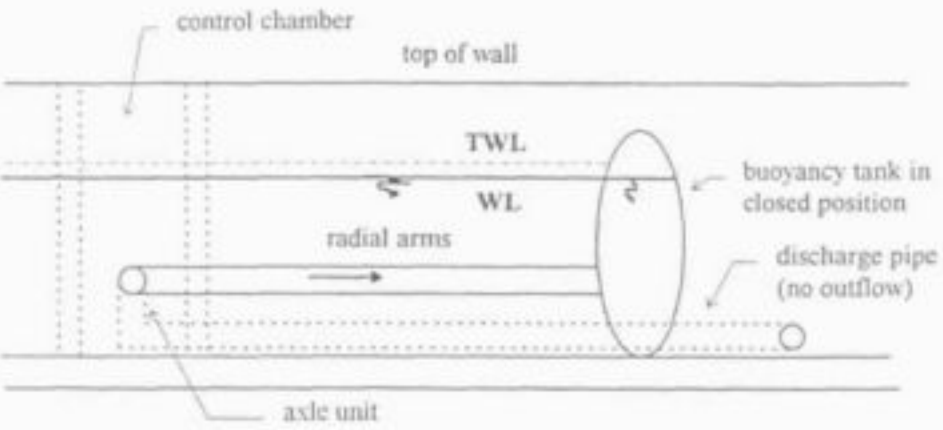
1. For all water levels (WLs) less than or equal to the required top water level (TWL), the control valve ensures that the buoyancy tank is kept full of water, and the thus the gate closed, by allowing water from the upstream channel to flow into it through the radial arms. The balance of the channel flow is thereby diverted through the screens so that the litter may be removed.

2. When the design flow is exceeded, the WL rises to above the required TWL. The control valve now stops the inflow into the buoyancy tank whilst simultaneously opening the discharge pipe. Water drains from the buoyancy tank thereby lightening it until a point is reached where the tank starts to float and the gate opens. Surplus flood waters are now released underneath the gate.

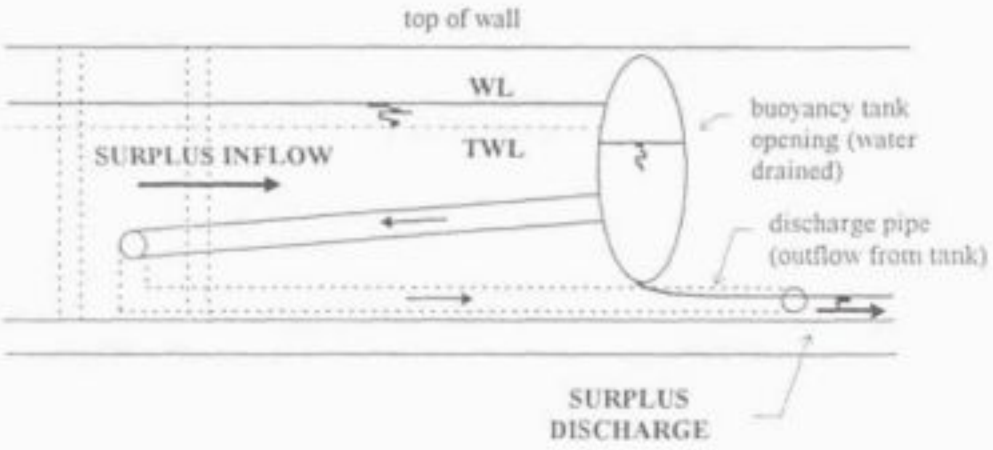
3. The gate continues to rise until water is being discharged at a slightly faster rate than the upstream flow. At this point, the WL starts to drop. As soon as it drops below the required TWL the control valve shuts off the discharge and opens up the inflow line into the buoyancy tank. As the buoyancy tank fills with water, it sinks thereby reducing the discharge. If the discharge drops below the upstream flow, the tank is drained a little to open the gate a bit more. In this manner the structure is able to maintain the upstream WL to within 50 mm of the required TWL. If the upstream flow drops below the design capacity of the litter removal structure, the gate closes completely.

The operation of the Fluid Dynamics Systems regulating gate is illustrated in Figure C-1.

(a) Closed position



(b) Opening



(c) Closing

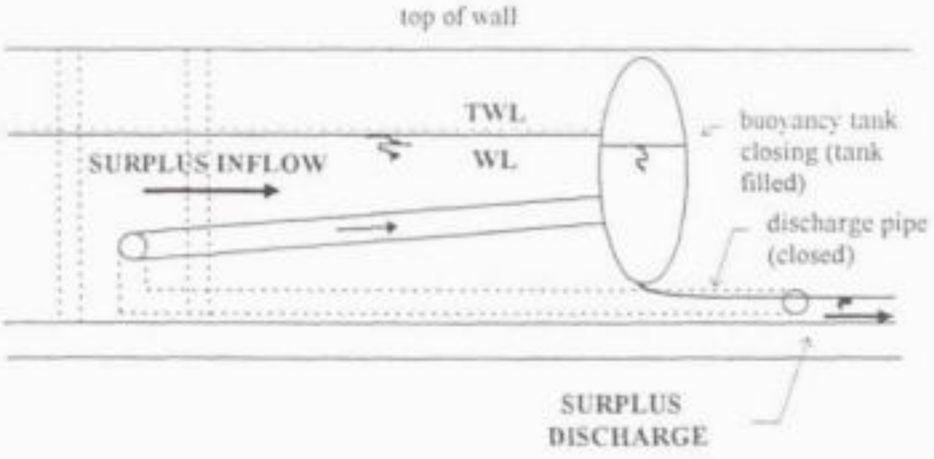


Figure C-1 : The operation of the Fluid Dynamics Systems Regulating Gate

C.2 Fluid Dynamics Systems Scour Gate

An alternative type of gate, the Fluid Dynamic Systems scour gate, is also suitable for level control, particularly in higher head schemes. It also comprises a buoyancy tank attached to radial arms and rotating on two axle units. In this design however, the buoyancy gate remains empty at all times, and is housed in a floatation chamber with a scour tunnel beneath. The floatation chamber is filled by an inlet pipe whose inlet is located in the upstream channel at the required TWL and is drained by an outlet pipe that is always open to the downstream channel. The scour tunnel is closed off by means of a leaf plate attached to the buoyancy tank.

The gate operates as follows:

1. Whilst WL ≤ TWL, no water flows into the floatation chamber, the chamber is dry, and the scour gate remains closed.

2. When the upstream WL rises above the required TWL, water starts to flow through the inlet pipe into the buoyancy chamber. Since the outlet pipe has a relatively small diameter compared with the inlet pipe, a condition is soon reached where the inflow exceeds the outflow and the buoyancy chamber begins to fill with water. As the water level in the chamber rises, the buoyancy tank and attached leaf gate also rise. Surplus flood waters are now released from beneath the gate.

3. The gate continues to rise until water is being discharged at a slightly faster rate than the upstream flow. At this point, the WL starts to drop. As soon as it drops to a point where the inflow into the floatation chamber is less than the discharge out of it, the chamber starts to drain and the buoyancy tank and attached gate are lowered. If the discharge drops below the upstream flow, the tank is filled a little to open the gate a bit more. In this manner the structure is able to maintain the upstream WL to within 50 mm of the required TWL. If the upstream flow drops below the design capacity of the litter removal structure, the gate closes completely.

The operation of the Fluid Dynamics Systems Scour Gate is illustrated in Figure C-2.

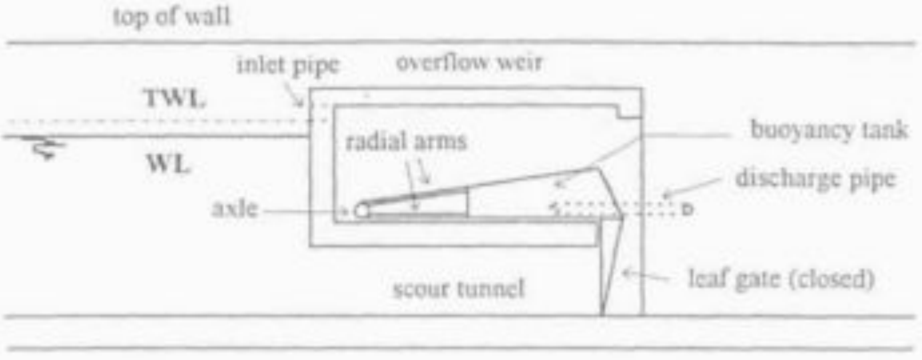
This type of gate is particularly suitable for large watercourses because it is able to pass large objects such as tree stumps, drums and bricks without damage.

Further information may be obtained from:

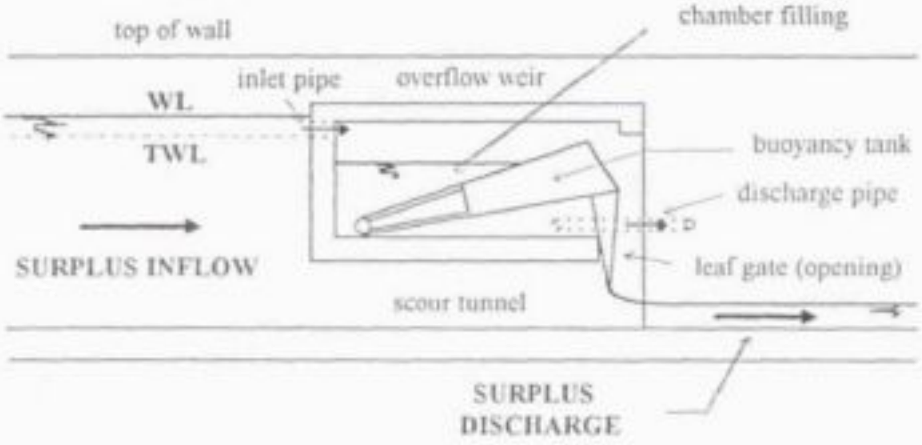
Attention : Mr P Townshend
Flowgate Projects
P O Box 3677
Randburg, Gauteng, 2125
SOUTH AFRICA

Phone : [++27] (11) 781 3910
Fax : [++27] (11) 781 3911

(a) Closed position



(b) Opening



(c) Closing

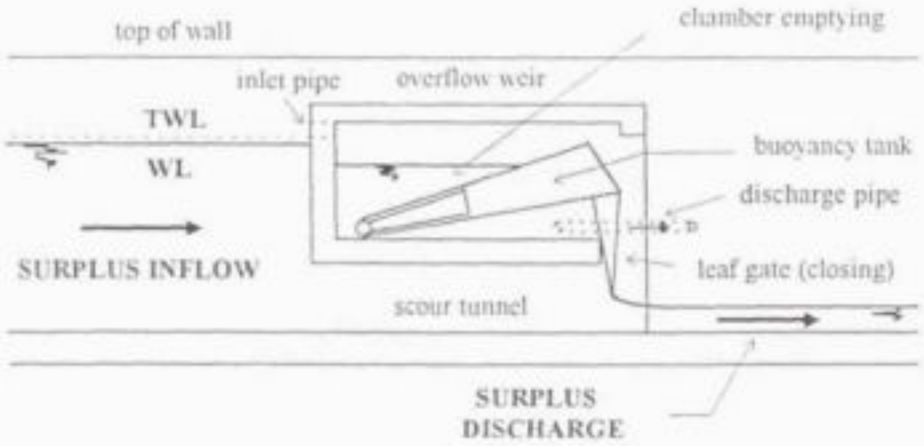


Figure C-2 : The operation of the Fluid Dynamics Systems Scour Gate