Performance Evaluation of an In-Line Litter Separator

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Master of Engineering

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PERFORMANCE EVALUATION OF AN IN-LINE LITTER SEPARATOR

Thesis submitted for the degree of
Master of Engineering

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ABSTRACT

In recent years, much more work has been done on understanding the nature, characteristics and problems associated with litter and gross pollutants in waterways. Gross pollutants consist of litter, debris and sediments. Litter is the most visible of all stormwater pollution. Shorelines of beaches, waterways and wetlands polluted with litter are unsightly, unpleasant and a serious health hazard; with sharp items such as glass, syringe needles and other metal fragments posing a risk to personal injury.

With the advent of non-biodegradable plastic, and its widespread use, this problem has been exacerbated in recent years. Most litter originates from shopping centres and fast food outlets and is blown or washed into the urban drainage system during storm events and ultimately discharge into waterways and bays.

Victorian State Government agencies have responded to community concerns about litter in our environment by providing financial support for the installation of gross pollutant traps (GPT). There are many gross pollutant traps but most are either inefficient in trapping litter, or labour or capital intensive. EcoRecycle Victoria funded the development of an innovative type of gross pollutant trap known as the In-Line Litter Separator (ILLS), invented by Dr. D.I. Phillips within the School of Engineering and Science at Swinburne University.

The ILLS provided a unique method of trapping gross pollutants, oils and greases, as well as sediments, and allows easy installation and on-going maintenance. EcoRecycle Victoria allocated a grant of $100,000 to Swinburne University for the installation and testing of ten ILLS prototype units within Melbourne and the metropolitan area.

This research program fulfilled the testing requirements and objectives of the grant and included monitoring of the installed prototypes and determination of litter trapping efficiencies for sample litter items. Further analysis of the data enabled the number of untagged (natural) sample litter items during the monitoring periods to be deduced for each of the prototype urban catchments of the study.

I would also like to thank helpful and friendly staff at Melbourne Water and the Bureau of Meteorology for their assistance, especially with the supply of rainfall data.

Incredible thanks must go to Belinda McKenzie, my dearest friend and partner throughout most of this thesis write up, for her tremendous encouragement, support, patience and joy.

Many thanks also goes to my parents and sisters Maree, Amanda, and Tanya. Also, my sister Marees' husband Ewan and his family, my friends, work colleagues, and Belinda's family who gave me tremendous encouragement and support during the long (and sometimes difficult) road of writing up and completing this thesis. I'm sure that everybody has heard and learnt enough about litter and its management, drainage, stormwater and waterway management in general to last them a lifetime, but this may well be just the beginning!

PREFACE / DISCLAIMER

This thesis, to the author's knowledge, contains no previously written material, unless due reference is made in the text, is therefore original work, and has not been submitted for any award at any University. The length of this thesis is less than 100,000 words.

Stephen Woods.

Stephen J WOODS

29/6/2005.

LIST OF ABBREVIATIONS

COMMON ABBREVIATIONS

ARI	Average Recurrence Interval (Years)
BMP	Best Management Practice
DRN	Dimensional Rating Number
EPA	Environment Protection Authority
GPT	Gross Pollutant Trap
ILLS	In-line Litter Separator (manufactured by Humes as Humegard^{TM})
MWC	Melbourne Water Corporation (Victoria)
MRN	Melbourne Rating Number (ILLS)
SEP (and SEPT)	Side Entry Pit (and Side Entry Pit Trap)
SEPP	State Environment Protection Policy
SWMP	Storm Water Management Plan (Municipal)
TFR	Treatment Flow Rate (Design Flow)

THESIS ABBREVIATIONS

SLI	Sample litter item (Test litter item) (refer to Appendix B)
RE (%)	Removal (capture) efficiency per SLI for a single period (= sum of tagged SLIs retrieved (from prototype) over single period divided by sum of tagged SLIs introduced into catchment)*100
Drop total	Denotes number of SLIs introduced in ILLS catchments over entire study period
Retrieved total	Denotes number of SLIs retrieved from ILLS prototype across all clean-outs
TRE (%)	Total removal efficiency for entire study per SLI (= sum of tagged SLIs retrieved (from prototype) divided by sum of tagged SLIs introduced into catchment)*100
STDVP	Denotes 'standard deviation' ('n' biased method)
UTP	Frequency of untagged (natural) SLIs trapped in each prototype over entire study period for each SLIs
EUP (= UTP/TRE)	Estimated frequency of untagged SLIs exporting catchment for study period for each SLIs.

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1 INTRODUCTION

1.1 BACKGROUND

Human derived (anthropogenic) litter is a major problem throughout the world with long-term persisting consequences for our environment. The appearance of discarded plastics and other litter degrade our urban wetlands, streams and rivers, as well as the marine environment, and can harm or injure aquatic life (Wade, 1996). Litter may also carry viruses and bacteria, and pose a health risk with such items as discarded needles.

Anthropogenic litter, in the form of non-biodegradable plastics, is aesthetically offensive and has the potential to have significant recreational and economic implications (Edyvane, 1996; USEPA, 1996). Some litter items are extremely persistent in the environment and may exist for long periods of time (possibly thousands of years) before finally breaking down or decomposing, if at all. Unfortunately, effective litter clean-up operations are highly expensive (KAB, 1996).

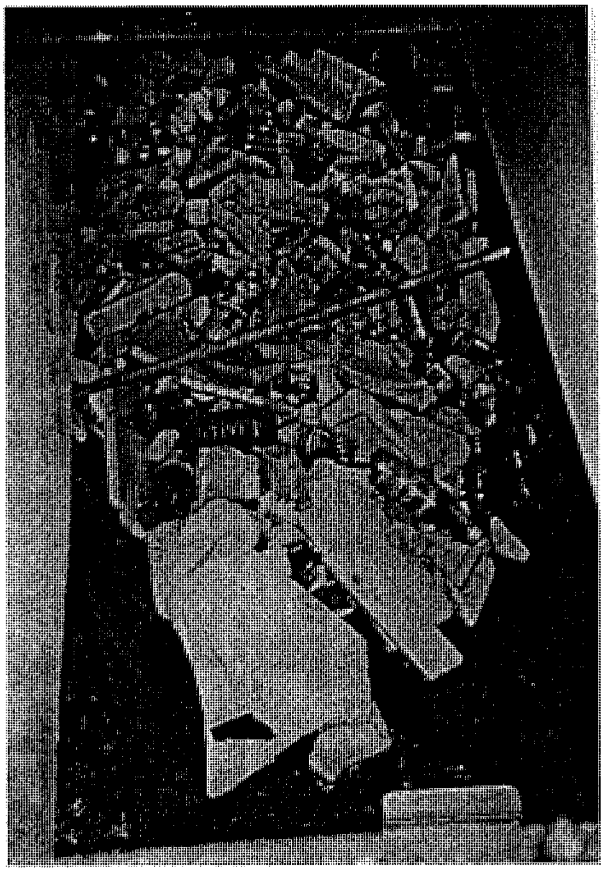
Most litter in the public domain is discarded in industrial, commercial and business areas (Allison, 1997; Armitage et al., 1998). When there is sufficient wind, rainfall and runoff, litter, along with various other pollutants, is blown and washed from impervious surfaces into the urban stormwater drainage system to be carried to receiving waters.

As litter law enforcement, awareness and education grows, changing attitudes will most likely lead to reduced littering. However, to date these strategies have failed to substantially reduce the estimated 1,800 million litter items (Allison, 1997) transported through the Melbourne and metropolitan urban stormwater system annually. Governments are now taking more direct action in controlling litter in stormwater runoff as a result of growing political pressure (eg. Victorian Stormwater Committee, 1999).

The need to prevent litter from reaching receiving waters has led to more effective structural controls within the urban stormwater system. Improved management practices to reduce the quantities of urban litter currently washed onto our favourite beaches are required. The result has been the evolution and evolution of more promising and innovative structural control techniques.

Many stormwater drainage litter control techniques are thought to have limited hydraulic application or cost effectiveness, being capital and/or maintenance intensive, and/or lacking in capture performance. A litter trap featuring a floating boom, known as the In-Line Litter Separator (ILLS, now manufactured as the Humegard^{TM}) was developed by Dr. D. Phillips within the School of Engineering and Science, Swinburne University of Technology, to provide a suitable best management practice alternative. The ILLS has the potential of providing a low-maintenance and more cost-effective stormwater management tool suitable for a range of hydraulic operating conditions. Plate 1.1 shows the inside of a commercial Humegard^{TM} unit. Based on the theoretical developments and observations, the ILLS is a promising litter control device with scope for wide application. There was however an identified need for field performance monitoring and evaluation of the ILLS.

Plate 1.1. Photograph of the inside of an In-Line Litter Separator, Roxburgh Park, City of Hume (Authors photograph, 1999).



1.2 THESIS OBJECTIVES

This thesis examines the following:

- An overview of the ILLS and its development
- The development of a field-testing methodology that includes monitoring and performance evaluation of installed prototypes, including an additional commercial ILLS unit installed in the City of Greater Bendigo, to examine the following;
    - Total removal efficiencies for introduced 'tagged' sample litter items (SLIs)
    - Syringes total removal efficiencies as a priority SLI
    - Natural (untagged) SLI frequency observations and estimates of total frequency from prototype catchments over the study periods (EUP)
    - Additional analysis of the Youth Road prototype to assess litter composition, including floating proportion of captured litter
    - Comments towards prototype component characteristics, such as the boom, comb and weir characteristics with field monitoring results
    - ILLS maintenance requirements.

2 LITERATURE REVIEW

2.1 INTRODUCTION

This chapter presents findings of an extensive literature review relating to the field evaluation of an In-Line Litter Separator (ILLS). The first five sections present the following, viz:

- The context, problems associated with, persistence and impacts of litter;
- Urban stormwater management and gross pollutant and litter characteristics;
- Government intervention and strategies to manage litter in waterways, including stormwater management planning;
- Urban stormwater structural control measures, including the treatment train and role and development of gross pollutant traps (GPTs).

The remaining three sections of the literature review focuses on GPT design and performance, best practice structural control measures, and the ILLS. The literature review also presents a summary of findings in the conclusion.

The GPT design and performance section presents an overview of factors including: site planning, identification, and the ideal GPT; a detailed section on design sizing and performance considerations; and litter trapping decision support. The design sizing and performance considerations provided include:

- hydrologic and hydraulic considerations, including energy losses, storage and outlet characteristics;
- pollutant capture and retention, including hydraulic efficiency and screening; and
- life cycle costs, including capital and maintenance cost considerations.

An overview of the various existing best practice structural litter trapping techniques are also presented, along with a discussion of each types' components, operation, performance, and maintenance. A relevant background to the ILLS is also provided in this literature review prior to the thesis study method, case studies, results, discussion, and conclusion.

2.2 LITTER IN CONTEXT

2.2.1 What is litter?

Litter is pollution (Judd, 1997). Litter is the most visible symbol of water pollution (MWC, 1993; Allison and Seymour, 1998; EPA Victoria, 2003a). The public rate litter as one of the most important environmental problems in urban areas (YarraCare Working Group, 1996) and 94% of people feel that litter is an important environmental issue (CCC, 2001). "One of the most persistent and frustrating environmental problems of cities, towns, and communities across the world is litter" (KAB Inc., 1996; ICNZT, 1996). Litter scored the highest problem ranking in a customer survey on the values of our streams (Seymour, 1993; Effendi, 2004) and is the public's main concern in regard to urban waterway health (Allison, 1997).

Litter is defined as a man-made, misplaced solid waste (KABV, 1997). Litter comprises any solid or liquid, domestic or commercial waste, refuse, debris or rubbish and includes any glass, metal, plastic, paper, wood, food, garden remnant and clippings, soil, sand, concrete, or rock and any other material which affects the place where it is deposited (Victorian Government, 1997). Clean and Green (1995) present litter products according to design, use and responsibility.

Studies have been undertaken to understand the composition of street litter. KAB litter studies conducted at random at various locations of differing land use have reported on litter item counts (KAB, 1996; Rako, 1998; Ecorecycle Victoria, 1999). The litter stream is reported by KAB (1996) to comprise 150 separate items that can be classified into five categories. Table 2.1 presents material compositions (by category) recorded in a Victorian frequency survey (KAB, 1996).

Murfitt and Le Couteur (1997) listed the following 'common' litter items: cigarette butts, "other paper", "other plastic", confectionery wrappers, plastic bags/sacks and sheeting, straws, styrene, bottle and can tops, and tickets. Murfitt and Le Couteur (1997) reported on street sweeping analysis data for litter, which did not include volume data (shown in Table 2.2).

Table 2.1 Street sweeping analysis material compositions (by category)

Category	**Composition**
Paper (11 sub-categories)	41.5 %
Plastic (13 sub-categories)	42.1 %
Glass (5 sub-categories)	2.9 %
Cans (6 sub-categories)	1.7 %
Miscellaneous (12 sub-categories)	11.8 %
TOTAL:	**100%**

Table 2.2 Street sweeping litter survey data analysis for material compositions

Category	**By weight**	**By count**
Plastics (excluding bottles)	18.7 %	46.1 %
Plastic bottles	12.4 %	3.0 %
Metals	8.1 %	21.0 %
Other	60.8 %	29.9 %

Table 2.3 presents data for plastic composition from the same study by Murfitt and Le Couteur (1997).

Table 2.3 Survey plastic compositions (by category)

Plastic Category	**By weight**	**By count**
Plastic bags	20.5 %	6.3 %
Straws	3.0 %	12.0 %
Take-away food wrap	8.0 %	14.8 %
Confectionary:	9.1 %	23.4 %
Styrofoam	1.1 %	5.8 %
Other	58.3 %	37.7 %

Table 2.4 presents data from a visual frequency survey in 1998 (Ecorecycle Victoria, 1999) of 216 sites across Victoria.

Table 2.4 Victorian litter survey count data (1998)

Category	By count
Cigarette butts	33 %
Paper	28 %
Plastic	26 %
Miscellaneous (7 other categories)	< 5 % each (range: 0.5 to 4.23 %)

Table 2.5 presents litter categories and counts data by Clean Up Australia Ltd. (2003).

Table 2.5 Litter analysis material compositions (by category)

Category	Composition
Plastic	36 %
Paper	18 %
Metals/ Aluminium	15 %
Polystyrene	3 %
Glass	12 %
Wood	2 %
Rubber	1 %
Miscellaneous	13 %
TOTAL	**100%**

Clean and Green Victoria (1995) identifies that existing data collection, which concentrates on litter material types, needs to be complemented by particular product information in the litter stream. The literature shows that various methods of data collection have been used, and as reported by Syrek in 1985 (Curnow et al., 1995), 'A single building block is surely not as visually offensive as its weight equivalent of 40 cardboard cartons strewn along a road side'.

2.2.2 Where does litter come from?

Many people who litter believe that they are not creating a problem or having much of an impact. This is correct only to a point, as a single item does impact only slightly, but when multiplied, this attitude leads to many people discarding vast amounts of litter. Litter attracts litter, is caused by people's behaviour, and is an individual decision and responsibility (KAB, 1996). Littering behaviour is complex and may be attributed to many practices, including (Clean and Green Victoria, 1995; CCC, 2002):

- Anti-social behaviour of individuals;
- Imposition of unwanted packaging on unwilling customers;
- Failure of street cleaning regimes;
- Insufficient disposal facilities;
- Failure to enforce fines or penalties; and
- Penalties which are too low.

Litter reduction behaviour studies have reported that on 24% of littering occasions people were just too lazy to properly dispose of their litter (CCC, 2001).

The source of litter may be attributed to both people and places, occurring almost anywhere, be it shopping centres, river banks, beaches, local streets, main roads on highways (Clean and Green Victoria, 1995; Clean Up Australia Ltd, 2003). A litter frequency (count) survey by Ecorecycle Victoria (1999) found the percentage of litter by site classification, as shown in Table 2.6.

Table 2.6 Litter material compositions (% count by land use)

Land Use	**% (by count)**
Landfill	66 %
School, industrial, and commercial	Range: 33 to 36 %
Parkland, public building, and waterfront	Range: 23 to 30 %
Residential	8 %

Plates 2.1 and 2.2 show litter found on a major road along side a strip shopping centre and in a car park at a Melbourne shopping centre respectively. Litter that accumulates in urban areas is washed into urban stormwater drainage systems during rainfall events. This will be discussed in section 2.3.2.

Plate 2.1 Litter found in major road shopping centre (Author's photograph, 1998).

Plate 2.2 Litter found in shopping centre car park (Author's photograph, 2003).

2.2.3 The impacts of litter

Litter is a risk to our environment (DNRE, 2002b) with implications for human health, ecology, flooding (hydraulic), the economy and aesthetics.

2.2.3.1 Human health impacts

There are direct hazards to human health associated with sharps (such as inappropriately disposed needles and syringes) found in litter (Clean and Green Victoria, 1995; KAB, 1996; Lewis, 2002), as shown in Plate 2.3 below. The 'Syringes on Victorian Beaches' taskforce (SVBT, 2000) highlighted the concern regarding presence of hypodermic needles (syringes) found in beach litter, following much media attention on a needle-stick injury incident. Litter also attracts vermin and provides an ideal breeding ground for bacteria (KAB, 1996). Risks to human health associated with litter may present complex legal issues.

Plate 2.3 Syringes found at a Melbourne wetland (photograph: L. Correia, 2004).

2.2.3.2 Ecological impacts

Litter remains a serious environmental issue (KAB, 1996). Litter is hazardous to animals (Chester and Gibbons, 1996). Litter constitutes a key environmental risk to the aquatic ecosystem (KAB, 1996), such as for seabirds and turtles (Battelle Ocean Sciences, 1992; Wade, 1996; Wade et al., 1996). Rubbish was identified among 'Serious management issues', affecting habitat of native water rats (Williams and Serena, 2004; Quinn et al., 2004). Litter also attracts pest animals (EPA Victoria, 2003a) and is reported to affect water quality (Riley and Abood, 1995).

2.2.3.3 Flooding (hydraulic) impacts

Litter may also accumulate and block drainage entrances creating localised flooding (Beecham and Sablatnig, 1994; Hussainey, 1995; IMEAV, c.1995; Allison and Seymour, 1998; Lewis, 2002; Akan and Houghtalen, 2003). Entry structures to the underground drainage network, whilst restricting the transport of larger litter items as intended, cause flooding if full coverage occurs throughout storm events, or if maintenance is inadequate (Phillips, 1987).

2.2.3.4 Economic impacts

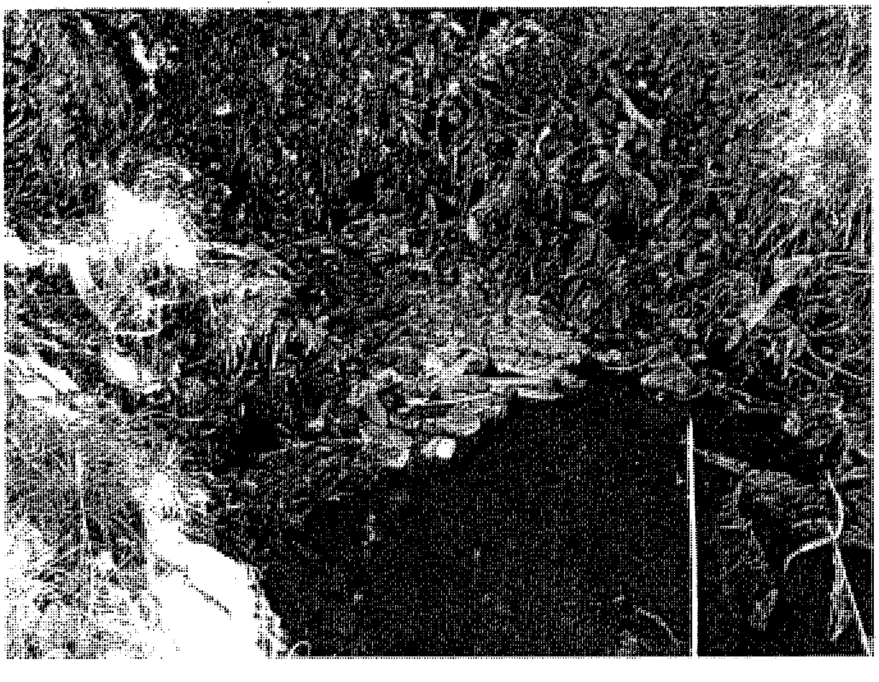
Litter imposes significant community cost (YarraCare Working Group, 1996). Melbourne bayside councils spend $2 million removing litter from beaches annually (Fisher, 2004) and Melbourne Water Corporation allocates $1 million annually to litter management and reduction (MWC, 1993). It has been estimated that it costs as much as $80,000 per year (on average) for local governments, and is equivalent to hundreds of millions of dollars being taken annually from the Australian economy (KAB, 1996). A Victorian government survey estimated that at least $50 million was spent on controlling litter annually (Clean and Green Victoria, 1995; EPAV, 1996). The impacts of floating debris on the Long Island economy in America in the summer of 1988 was estimated to be in the order of $1 to $2 billion (USEPA, 1996). KAB (1996) reports that litter affects tourism.

2.2.3.5 Aesthetic impacts

The impact of litter on aesthetics and landscape amenity of beaches and waterways is well documented (Molinari and Carleton, 1987; Nielson and Carleton, 1989; MMBW, 1989; Brown and Wong, 1995; Golder Associates, 1995; Edyvane, 1996; YarraCare Working Group, 1996; Breen and Lawrence, 2003), as shown in Plates 2.4 to 2.7.

Plate 2.4 Floating litter and debris on Yarra River (Heidelberg) following rainfall event (Author's photograph, c. 1992).

Plate 2.5 Litter and debris in an urban stream (Bungalook Creek, North Bayswater) (Author's photograph, 2004).



Accumulated litter despoils the natural environment and landscapes (Clean and Green Victoria, 1995; KAB, 1996; Edyvane, 1996; Winstanley, 1996).

Plate 2.6 Litter and debris bank of the Yarra River (Port Melbourne - opposite Newport with Williamstown in background) (Author's photograph, 1999).

Plate 2.7 Litter and debris on St Kilda beach (Author's photograph, 2000).

Litter is a hindrance to watercourse development for recreation (Mills et al., 1983). Affordable solutions delivering long-term satisfaction to catchment and coastal managers need to be found and highlighted to ensure cost-effective environmental protection from litter threats.

2.2.4 The persistence of litter

How long will litter persist? Prior to the invention of plastic, many household and industrial items were made of materials that readily degraded in the aquatic environment (MWC, 1993). The following persistence times have been presented on the web site of Zion National Park (Zion National Park, 1998); although the information source is not listed.

• Cigarette butts	1-5 years
• Plastic-coated paper	5 years
• Plastic bags	10-20 years
• Plastic film containers	20-30 years
• Nylon fabric	30-40 years
• Leather and tin cans	up to 50 years
• Plastic six-pack holders	100 years
• Aluminium cans and caps	500 years
• Glass bottles	1,000 years
• Plastic bottles and styrofoam	**Indefinitely.**

It is clear from the above that litter is extremely persistent, with plastic being the worst culprit. However, little knowledge is yet available about some of these materials, and as such, some of the above figures may be speculative.

Litter creates an on-going risk to the environment because of its persistence (MMBW, 1989; Allison et al., 1994; YarraCare Working Group, 1996).

2.3 URBAN STORMWATER MANAGEMENT

2.3.1 General

Not all developed countries have separate sewer and stormwater drainage systems as in Australia. Some countries utilise combined systems, which treat most of the combined flows through a single system of conveyance and treatment infrastructure (ASCE, 1992; Akan and Houghtalen, 2003). Whilst separate systems provide adequate design service for sewage flows, including treatment, the separated stormwater drainage systems have been traditionally designed to adequately and safely convey floodwater, with little consideration to pollutant separation and retention (Argue, 1986; Allison et al., 1994; Mills and O'Loughlin, 1998).

Traditional urban stormwater drainage systems have incorporated a minor and major systems approach, where minor system flows are typically conveyed underground through pipes, and major systems are typically above ground (Argue, 1986; Mills and O'Loughlin, 1998; IEAust, 1987). This traditional drainage approach, involving the connection of impervious surfaces to receiving waters, has led to hydrological disruption and rise to physical and ecological impacts on streams (Chester and Gibbons, 1996; Walsh et al., 2004). General concern regarding impacts of urban stormwater quality on receiving waters is well documented (Cullen et al., 1988; Commonwealth of Australia, 1996; Collett et al., 1993; Tourbier, 1994; Akan and Houghtalen, 2003; Walsh et al., 2004).

In urban areas, around 90% of rainfall is reported as converting to stormwater runoff during severe storms (CEPA, 1993), with an increase in peak flows from those of the original undeveloped catchment of up to 20 times (Dasika et al., 1995; Allison, 1997; Mein and Goyen, 1988). The quantity of flow is characterised by the amount, frequency, intensity, duration and pattern of precipitation indicative of spatial and temporal fluctuations (Chadwick and Morfett, 1986; Wanielista, 1978). Physical characteristics, such as the extent to which surfaces are drainage connected, ie. effective imperviousness, also influence flow quantity (USEPA, 1999; Walsh et al., 2004).

Dramatic change in catchment hydrology through urbanisation also results in large increases of stormwater pollutants, such as litter, sediments, nutrients, toxicants, and pathogens being carried to receiving waters through drainage systems (Wanielista, 1978; Loh, 1988; Joliffe, 1989; ASCE, 1992; Collett et al, 1993; Tourbier, 1994; Cullen et al, 1995; Watkins, 1995; Wade, 1996; Chiew et al, 1997; Lawrence and Breen, 1998; Pettigrove, 1998; ABM, 2004). The three pollutant groups of particular interest in small urban catchments are sediments, nutrients and litter (Brown and Wong, 1995).

As will be discussed shortly, the terms 'gross pollutants' or 'gross pollution' are also used in much of the literature (Allison, 1997; Victorian Stormwater Committee, 1999; Wong et al., 2000).

2.3.2 Pollutant mobilisation and transport

The process of stormwater contamination has been reported to occur in two phases – buildup and washoff (Chiew et al., 1997). Buildup is the process through which dry deposition of pollutants accumulate on impervious surfaces and is influenced by land use type, pollutant type, length of dry period, and removal by washoff, redistribution or management practices, such as street sweeping (Chiew et al., 1997; Mudgway et al., 1997). Washoff is the removal of pollutants, whether in dissolved or particulate form, created by flow energy and turbulence of rainfall and runoff (Chiew et al., 1997). Pollutant buildup and washoff processes from impervious surfaces, relevant to litter transport, may be described using empirical equations, and include calculating pollutographs and loadographs, with various methods presented for calculating loads, eg. annual load estimates and mean annual loads (Wanielista, 1978; Akan et al., 2003). However, Mudgway et. al. (1997) indicate that there is no consensus as to the actual process and driving force behind washoff.

It is reported (Chadwick and Morfett, 1986) that mobilisation of particles by a moving fluid along an erodible boundary is very complex and relates to the natural particle resistance to movement and the acting shear forces. The concept of a 'first flush' is reported to occur in some of the literature (Sansalone et al., 1998; Cristina and Sansalone, 2003), however, other studies reported that a 'first flush' was 'not observed' (Deletic and Maksomovic, 1998). Once the 'threshold of motion' has been overcome, particles are swept into the fluid and become part of the suspended load (Chadwick and Morfett, 1986). Therefore, once resisting forces have been overcome, unless intercepted and retained, particles are otherwise transported into the drainage system and eventually receiving waters. Chiew et. al. (1997) note that the rate of pollutant transport depends on water velocity, depth and degree of turbulence.

Factors influencing pollutant loads in urban stormwater include the following (Clean and Green, 1995; Allison, 1997; Ball and Luk, 1998; Victorian Stormwater Committee, 1999; Fernandez et al., 1999):

- Land-use type (eg. residential, commercial, light industrial, parks);
- Rainfall event characteristics such as intensity and duration, and temporal, seasonal and spatial variation and resulting runoff volume and discharges;
- Population (permanent and transient);
- Best management practices (BMPs) (eg. street sweeping, availability of collection bins and regularity of emptying, and recycling programs);
- Education and awareness programs;
- Time since the last runoff event;
- Size and geometry of inlets and pipe networks;
- Physical catchment characteristics (such as size, slope, surface characteristics, drainage entrance types, vegetation); and
- Wind intensity and direction.

Additionally, pollutant properties are relevant in the export of litter loads. Pollutant transport (excluding dissolved matter) following washoff is generally categorised as concentrated flows according to vertical positions within the flow stream, such as: floating (flotsam), suspended or bed load fractions (Mudgway et al., 1997; Chadwick and Morfett, 1986). However, these are somewhat arbitrary and will vary greatly, depending on many factors, such as stream power and the pollutant types and properties. Material properties may vary, as explained in section 2.2.1, from those being extremely buoyant to those that are highly settleable, and also vary over time (Armitage et al., 1998).

Primary factors determining the position of a particle/object in a flow stream are physical characteristics in variation (comparison) from that of water, such as size, density, and settling velocity, where the last relates to the first two and the following: shape factor, electrical charge, viscosity, and concentration (Armitage et al., 1998). Armitage et. al. (1998) also noted that the biggest problem with litter found in urban stormwater is that it can be just about any size, any shape, any density, any hardness, and can change properties as it moves in the water column, such as a plastic bag that becomes less buoyant with time when flow turbulence gradually replaces air with water. This is consistent with Selinger (1991) who reported that litter items have varying properties, depending on the material, such as mass, dimensions and thickness, volume, and specific gravity, hardness, strength, and permeability.

McKay and Marshall (1993) reported that a proportion of transported litter is retained in waterway riparian vegetation, and that much of the litter that ends up on Melbourne's bayside beaches is believed to come directly from the drainage network. Hussainy (1995) reports that as much as 95% of litter polluting Port Phillip Bay and its beaches, is believed to have been transported through the extensive drainage system serving the entire area of greater Melbourne.

Variables associated with measuring litter export within urban stormwater runoff include (Mein and Goyen, 1988; Allison, 1997):

- The 'flashy' nature of catchments, ie. they respond quickly to rainfall;
- The amount of debris creating blockages of flow control structures;
- Monitoring during changing urbanisation;
- Aerial variability of rainfall creates a need for a greater density of gauges;
- The need for special instruments;
- Vandalism; and
- The great range of flows encountered.

Litter is by no means the only urban stormwater problem but has priority for reasons of public health, ecology, flooding, economy and aesthetics, as discussed earlier in this chapter.

2.3.3 Characterising gross pollutants and litter transported in urban stormwater

2.3.3.1 General

This section presents data from various studies on quantities and composition of gross pollutants and litter found in urban stormwater, including categories used to define litter. Much of the early data was obtained from early types of litter control structures, such as floating booms, trash racks and 'gross pollutant' traps (GPTs).

2.3.3.2 Gross pollutants in urban stormwater

Gross pollution is defined as the matter found transported in urban stormwater drainage systems with a size of greater than 5 mm (Allison, 1997; Allison et al., 1997a). Gross pollution describes the solid material found transported in stormwater runoff, consisting mostly of organic material, but with large quantities of inorganic litter and coarse sediments also present (Allison et al., 1997a; Knox City Council, 2002). While organic component, made up of grass clippings, leaves and twigs, is biodegradable it should be incorporated into any trapping system evaluation or design (Allison et al., 1997a). Although the full impact of gross pollutants may not be clearly understood, it is recognised that persistent non-biodegradable anthropogenic litter, and other gross pollutant material, remains an on-going issue for waterway managers, as discussed earlier in this chapter.

2.3.3.2.1 Quantities of gross pollutants in urban stormwater

Allison (1997) found that highest concentrations of gross pollutants in urban stormwater occur early in runoff events and generally peak before the hydrograph. However, the highest load is transported during peak discharges throughout a runoff event. Results of an analysis of data collected by Allison (1997), found that:

- Mixed commercial and residential catchments deliver the most gross pollutants to the stormwater system (and suggests that these areas should be the first to be considered in reduction strategies);
- Despite best practices, urban areas contribute approximately 30 kilograms per hectare per year (230,000 m^3/year) of dry gross pollutants (0.4 m^3/ha per year wet) to the stormwater system;
- Where much of the gross pollutant load is organic, the litter alone was estimated to have a loading rate of 6 kg/ha per year (dry), ie. 0.08 m^3/ha per year.

Wong et. al. (2000) report that loads of 0.4 m^3/ha/year and 1.6 m^3/ha/year for gross solids and sediment export respectively should be used in design sizing. Wong and Walker (2002), in a New South Wales EPA study, report on total wet (gross pollutant) loads trapped by various GPTs, however, volume or frequency data is not presented.

2.3.3.2.2 The composition of gross pollutants in urban stormwater

Early studies of material collected from two trash interception devices in the Cooks River catchment in New South Wales found the composition of gross pollutants by volume as shown in Table 2.7 (Molinari and Carleton, 1987).

Table 2.7 Composition of gross pollutants by volume (Cooks River)

Material category	**% (by Volume)**
Vegetative matter (such as leaves and branches)	50 %
Plastic bottles	20 %
Aluminium drink cans	5 %
Plastic bags/containers	5 %
Fast food containers	5 %
Other: such as tyres, toys, and household trash	15 %
TOTAL:	100 %

These results were consistent with those of Nielson and Carleton (1989), who quantified gross pollutant composition using volumetric measurements. Their results indicated that the bulk of material was also found to be of organic (mostly garden refuse – leaves and twigs) or plastic origin, along with high amounts of paper. A later study by O'Brien (1994) of litter and organics by dry weight in a study of the contents of GPTs (located at Bondi in New South Wales) found the materials breakdown as shown in Table 2.8.

Table 2.8 Composition of gross pollutants by volume (Bondi)

Material category	**% (by Volume)**
Leaf litter	60 %
Plastics	6 to 13 %
Paper	7.5 to 10 %
Wood	7 to 10 %
Other: such as foam, rubber, and food	< 7 %
TOTAL:	100 %

Monitoring of floating litter booms on the Yarra River in Melbourne, by Melbourne Parks and Waterways between January and October 1995, collected approximately 500 cubic metres of litter, debris and organic matter (EPA Victoria, 1996). Allison and Chiew (1995) found considerable differences in the composition of gross pollutants depending on land use type, as shown in Table 2.9.

Table 2.9 Quantities of gross pollutant in urban stormwater by land use type

	Mixed commercial/ residential site	Residential site	Light industrial site
Garden debris	67	85	36
Plastic	11	9	29
Paper	19	4	35
Metal	3	1	0
Other	0	1	0
TOTAL	100	100	100

2.3.3.3 Litter in urban stormwater

2.3.3.3.1 Quantities of litter in urban stormwater

McKay and Marshall (1993) reported four to five million items of floating litter enter Melbourne's urban waterways each year via the underground drainage network. More detailed monitoring by Allison (1997) found that a total of 1,800 million items of litter are transported through Melbourne's stormwater system annually, varying by 360 times (higher) from that of McKay and Marshall (1993), who only examined floatable materials. A North Sydney Council litter control device program found a litter washoff rate of 0.019 m^3/ha/year from a varied land use catchment (Armitage et al., 1998).

In South Africa, the Springs study reported that, assuming a litter density of 95 kg/m^3, a total of 5.8 m^3/ha/year (95 kg/ha/year) is deposited in commercial and industrial areas with approximately 1.0 m^3/ha of this being washed into the stormwater system (Armitage et al., 1998). In the Capel Sloot culvert study, Cape Town, the overall litter washoff rate, including residential areas, was found to be 0.28 m^3/ha (Armitage et al., 1998). The amounts obviously vary considerably depending on the catchment. An Auckland study, in New Zealand found litter loading rates from a catchment of varied land use as shown in Table 2.10 (Armitage et al., 1998).

Table 2.10 Litter load in urban stormwater by land use type

Land use	Litter load (kg/ha/year)	Litter load (m^3/ha/year)
Commercial	1.35	0.014
Industrial	0.88	0.009
Residential	0.53	0.006

Hall and Phillips (1998) monitored the contents of side entry pit traps (SEPTs), capturing litter from two catchments (located in Carnegie and McKinnon in Melbourne, both with a majority of commercial land use), and found that the litter load per unit catchment area varied from 0.858 to 0.867 kg/ha/month (dry weight). Seymour (1993) reported that large proportions of litter are generated at and around regional and strip-shopping centres, corner stores, and industrial and developing areas, which is consistent with other reports (Ecorecycle Victoria, 1999). Wong and Walker (2002), in a New South Wales EPA study, also present data on the litter fraction component of total wet (gross pollutant) loads trapped by various GPTs. Once again, large variations exist in litter generation loads between various studies. It may be observed that various estimates on quantities of litter passing through urban stormwater systems and waterways have been reported. This may be due to the large variations of quantities between drainage systems and sub-catchments, cultural differences and study methods.

2.3.3.3.2 The composition of litter in urban stormwater

Nielson and Carleton (1989) found high proportions of cans, plastic bottles, polystyrene (greater than 50 mm), paper cartons, and confectionary wrappers, consistent with other literature. A study in New Zealand categorised stormwater litter as biotic, and abiotic which includes the following (ICNZT, 1996): plastics: hard, foam; sheeting/fibres; cigarette materials; sanitary items; glass; aluminium; tin/steel; paper; confectionary/ice-cream wrappers; fastfood/take-away; and other (such as timber).

Allison (1997) adopted the following seven categories in order to monitor gross pollutants in urban stormwater;

- Plastics (personal);
- Plastics (commercial);
- Paper (personal);
- Paper (commercial);
- Metals: foil and cans (appears to be mostly aluminium);
- Organic debris (such as timber, wood, and leaves); and
- Other (such as glass and cloth).

Classifications above provided by Allison (1997) provide a differing approach to that used by Molinari and Carleton (1987).

Hall and Phillips (1998) in their study of SEPTs in two catchments in Melbourne also reported the following range of compositions of litter (by item count):

- Paper: 55 to 58%
- Plastic: 25 to 26%
- Metals: 12 to 13%
- Polystyrene: 2 to 4%
- Glass: 1%
- Miscellaneous: 1 to 2%.

Floatable litter has been reported as creating the greatest community comment and concern (Golder Associates, 1995).

Riley and Abood (1995) examined effects of gross pollutants on water quality and based the representative litter sample on work done by Nielson and Carleton (1989) utilising the following non-biodegradable rubbish (40% by volume): aluminium cans; food containers; PET bottles; glass bottles; cigarette foil; plastic drink lids; plastic shopping bags; pieces of packing foam; drinking straws; and confectionery wrappers.

Allison (1997) in a study of the contents trapped in SEPTs over 27 days, found that the most numerous litter items found in the stormwater system were cigarette butts (2,500), pieces of paper (2,400), plastic food wrappers (1,200), paper food containers (1,150), plastic cigarette wrappers (950), polystyrene pieces (approximately 300), foil (approximately 900), and other plastics (approximately 700).

Allison (1997) reported that over 90% of litter items are greater than 20 mm in size and that floating litter represents approximately 20% of litter load. However, a point to note is that Allison's study examined the floating proportion at the time of clean-out, which may not allow for materials becoming waterlogged and settling following storm events, and therefore may greatly underestimates the true proportion of floating litter (at the time of capture).

Armitage et al. (1998) reported, in a study in Springs (South Africa), that plastics comprised approximately 62% of all litter and polystyrene 11% of all litter. Lewis (2002) reported that plastics account for 51% of the volume of litter items trapped in SEPTs in urban catchments in Melbourne (St Kilda and Frankston). Studies in the Merri Creek catchment have shown that 66% of items counted comprised plastic-based products (McKay and Marshall, 1993; Murfitt & Le Couteur, 1997).

Data reported in this section relating to composition of litter within urban stormwater is vastly different from data reported by KAB (1996) in land-based studies (section 2.2.2). Although the literature identified many litter materials that are commonly found in urban stormwater systems, litter was not identified by product type or brand name or manufacturer, such as McDonalds.

2.4 GOVERNMENT INTERVENTION AND STRATEGY

2.4.1 General

In response to the urban stormwater problem, governments throughout Australia are attempting to manage pollutants such as litter through many initiatives that encourage responsible management of pollutants and wastes (Molinari and Carleton, 1987; Waste Management Council Victoria, 1996; KABV, 1998; DNRE, 1999; Queensland Government, 1998; DNRE, 2002a). However, littering continues, and a study in Melbourne reported that nearly 26% of people were observed littering (Williams et al., 1997). With urban stormwater litter management; 'one of the biggest problems is that governments and the community don't cooperate in a coordinated fashion to solve the problems' (Commonwealth of Australia, 1993b).

2.4.2 Litter reduction strategies and studies

Littering has been reported across all Australian States (CCC, 2002). The Australian government National Packaging Covenant has also established litter management as important (CCC, 2002). National studies have now taken over 40,000 observations as part of developing a littering behaviour database (CCC, 2003a). A national benchmarking study across Australia provides information on progress with littering using a Disposal Behaviour Index (DBI) (CCC, 2002; CCC, 2003A). It is intended that (in time) this litter count data will be able to be used in reporting on the effectiveness of management practices. The literature examined did not attempt to compare the usefulness or cost effectiveness of this work against structural measures, such as GPTs, which are discussed later in this document. Although litter count studies would appear to provide a sound methodology, their usefulness may be questionable, unless they can be linked with other critical variables that affect litter washoff (export), such as rainfall and runoff data, as will be reported later.

State governments are supporting litter count surveys (Ecorecycle Victoria, 1999). Anti-littering initiatives are implemented in New South Wales each year and include street litter signage, litter bins and recycling facilities, all of which can reduce litter to some degree (CCC, 1999). Curnow et. al. (2003) have developed a pilot test and benchmarks using the clean communities assessment tool for the development of a Victorian litter monitoring protocol. As discussed in section 2.2.3.1, the Victorian government made syringes a priority through the Syringes on Victorian Beaches Taskforce (SVBT, 2000).

The Victorian Litter Reduction Strategy (VLRS) (Clean and Green Victoria, 1995) was developed to set directions for litter reduction and management. The strategy proposes analytical and strategic frameworks, priorities, tools, and covers many litter issues. The VLRS draws into consideration the shortage of available information and the many influences on litter. Particular attention is placed on the following areas: research and data collection, people, places, products, and stakeholders (or players) (Clean & Green Victoria, 1995). The VLRS notes that stakeholders involved in the litter problem include: industry, governments, non-government organisations, and individuals alike.

Littering is illegal and government agencies are authorised to take action against offenders. EPA Victoria (2003c) issued a staggering record number of fines (13,722) in 2002/03. EPA Victoria provides the public means for reporting litter offenders (EPA Victoria, 2003b) and public officials may take action against offenders with 'on the spot' fines, and sometimes in court, with fines including those shown in Table 2.11.

Table 2.11 Victorian litter fine details (EPA Victoria, 2004)

Offence	On the Spot	In Court
Placing advertising material on vehicles	$205	$1023
Having an unsecured load	$205	$1023
Depositing burning litter	$205	$4090
Depositing household or business rubbish in a litter bin	$205	$4090
General littering on or into land or water	$205	$4090
Depositing small item of litter	$102	$4090
Throwing litter from vehicles	$205	$4090
Aggravated littering – ie. causing harm.	--	$6135

The Victorian Government has established a discussion paper; 'The statutory framework for litter in Victoria', as well as a task force involving many organizations and stakeholders that provide a strategic approach to litter management through all levels of Government (DNRE, 1999; Melbourne Water, 1999; EPA Victoria, 2001; Frankston City Council, 2004; VLAA, 2002; VLAA, 2004). Local government also has a commitment to managing litter, as part of waste and stormwater management activities, with strategies, plans and actions involving litter education, surveys, and installation of litter traps (Ku-ring-gai Council, 1993; Shire of Yarra Ranges, 1997; Spagnoli, 1999; KABV, 2000; Knox City Council, 2002; EPA Victoria, 2002; Kellogg, Brown and Root, 2003; Chrispijn, 2004; Frankston City Council, 2004).

2.4.3 Protection of the aquatic environment

As discussed previously in this chapter, historical urban stormwater management and impacts of pollutants such as litter has led to some considerable changes, including government attitudes, viz (Ellis, 1995):

- *"The objectives of floodwater and pollution control are now being supplemented with aesthetic, recreational, ecological, and economic objectives."* and;
- *"Strategic principles for sustainable development now include precautionary principle, polluter pays, and ecosystem carrying capacity."*

These have noticeably changed the management of urban stormwater and it is reported: "More scientific knowledge, community involvement and engineering expertise is needed to plan cost effective strategies for better stormwater management" (CEPA, 1993). McGuckin (2000) identifies that direct rubbish dumping has been reported as a major problem in some waterways.

The Commonwealth of Australia has acted to protect beneficial uses of aquatic environments, with specific guidelines for urban stormwater, freshwater and marine waters, including litter management (Commonwealth of Australia, 1996; Commonwealth of Australia, 2000).

In Victoria, publicly agreed State environment protection policies (SEPPs) provide objectives for water quality of receiving waters and have been set around a statutory framework allowing legal enforcement to protect beneficial uses (EPA Victoria, 1997). The Victorian Government has shown leadership in combating stormwater contamination and the litter problem, by developing best practice environmental management guidelines for urban stormwater (Victorian Stormwater Committee, 1999). The Victorian Stormwater Committee (1999) sets out the following best practice performance objective for litter reduction:

- *"70% reduction of typical urban annual load".*

What is not provided is the definition of typical, as limited research has been conducted on litter loads, as will be discussed later in this chapter. The Victorian Stormwater Committee (1999) also sets out reduction targets for total suspended solids (TSS), total nitrogen (TN), and total phosphorus (TP) as 80%, 45% and 45% reductions respectively, as well as flow management targets for protecting receiving waters, which must also be considered during stormwater planning and management.

Many government initiatives aimed at addressing litter and other stormwater threats to waterways may be found in the literature (Yarra Care Working Group, 1996; Melbourne Water, 1997, DNRE, 2000b; Melbourne Water, 2000; DSE, 2004; PPWPCMA, 2004; Melbourne Water, 2004a; Melbourne Water, 2004b; Melbourne Water, 2004c). It has been estimated, based on low-level screening, that the cost of retrofitting Melbourne Water's area of jurisdiction (5,000 drains at $60,000 each) will be in the order of $300 million (EPA Victoria, 1995).

The Victorian Government reacted to the Syringes on Victorian Beaches Taskforce report (SVBT, 2000) with funding support to assist in reducing the incidence of hypodermic needles found in beach litter. This funding included immediate action, including: increased beach cleaning (up $300,000 to $1.3 million), litter trap installations in priority areas ($200,000), and securing the allocation of $22.5 million for the 'Urban Stormwater Initiative' over three years between 2000 and 2003 (SVBT, 2000; EPA Victoria, 2002). Funding for the later through part of the Victorian government's "Greener Cities" policy, allowed for the Victorian Stormwater Action Program (VSAP). VSAP assisted the development and implementation of local Government Stormwater Management Plans (EPA Victoria, 2002). A $10 million Victorian government 'Stormwater and urban water conservation fund' (DSE, 2004) adds to government commitment towards improving management of stormwater, including infrastructure projects to protect receiving waters from pollutants, eg. litter.

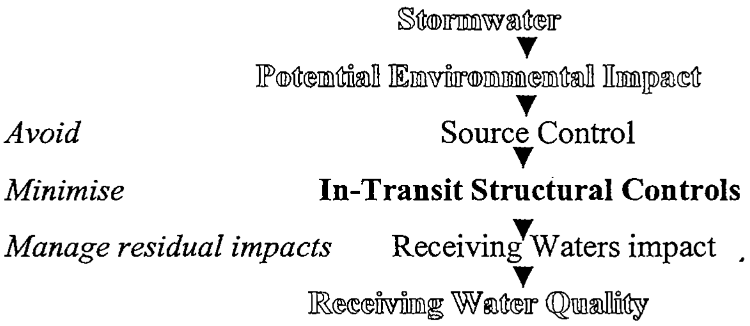
2.4.4 Stormwater management planning

Municipal stormwater management plans are encouraged or required by governments and include an assessment of risks relating to values and threats, and include the following (adapted by author from Allison, 1997; Victorian Stormwater Committee, 1999; Phillips, 2002; Kellogg, Brown & Root, 2003):

- Threat (including scale or severity and likelihood of frequency) of impact:
    - Catchment runoff litter characteristics and loads;
    - Effectiveness of non-structural control measures and management practices;
    - Performance and maintenance of structural control measures;
- Value (including sensitivity and significance) of receiving water environment;
- Stormwater management objectives;
- Stormwater management issues of concern and causes; and
- Management intervention and actions.

The flow chart in Figure 2.1 provides a simplified framework for stormwater management and provides guidance about the role of structural control mechanisms.

Figure 2.1 Stormwater management framework (Victorian Stormwater Committee, 1999).



Tools available for the management of litter include stormwater 'best management practices' (BMPs) and the following (Clean and Green Victoria, 1995):

- Investigation and monitoring;
- Information and education;
- Enforcement action;
- Guidelines for product packaging;
- Infrastructure provision; and
- Codes of practice.

This thesis will shortly focus on the provision of infrastructure (second last dot point above) associated with urban stormwater management. Installation of litter traps in priority areas has been documented as a key action in the Victorian Litter Reduction Strategy (Clean and Green Victoria, 1995). However, a large number of non-structural and structural control measures exist which may be applied in an integrated approach in any urban catchment to control non-point source pollutants, such as litter (Southcott, 1995; Thomas et al., 1997; Brown and Ball, 1999; Victorian Stormwater Committee, 1999; USEPA, 1999; Lloyd et al., 2002). Tools (BMPs) referred to above may also be defined as 'control measures' in the literature. Table 2.12 lists some typical control measures used in urban stormwater management (Thomas et al., 1997).

Table 2.12 Urban stormwater management control measures

Structural	Non-structural
Source Controls	*Source Controls*
• on-site detention • in-situ re-use • permeable surfaces • infiltration trenches/swales • infiltration basins • sand filters • extended detention ponds • biological control wetlands • multiple pond systems • wetland retrofits • illicit connection controls	• zoning • subdivision regulations • water-sensitive design guidelines • restrictive covenants • buffers and setbacks • source pollution prevention • spill control programs • road maintenance programs • public education • pet control • drain labelling • EIS • permitting • water circulation planning models • inundation models • design storm models • adaptive management
In-line controls	
• inlet design • in-line storages • overflow/bypass design • radar/real-time control • CSO management • litter booms • gross pollutant traps • sediment traps • geotextile filters • hydrodynamic separators • oil/grit separators • chlorination/dechlorination • coagulation/flocculation • lamellar decantation	

Non-structural BMPs generally do not require engineering design and include: pollution prevention methods, illicit discharge detection and elimination procedures, and public education (Thiering et al., 1988; Akan et al., 2003; Taylor and Wong, 2003). Lawrence (1989) discussed the socio-political context of urban development with the bio-physical context in relation to pollution control infrastructure, considering technical, planning, institutional, management, along with economic, environmental and social objectives. Coles (2004) argues the importance and need for greater action in litter prevention. As Young (2000) explains, 'because management of stormwater is as much about the social sciences as about engineering considerations, the involvement of the community and other stakeholders such as community groups, councils and the land development industry is essential'.

It is generally acknowledged that no single option will suit every situation and objectives need to be considered with costs and limitations for each technique, as well as their benefits and advantages. As previously discussed, other BMP options or tools are also able to be integrated into stormwater management planning, and allows planners and designers to consider the achievement of stormwater quality and quantity objectives, such as pollution reduction through increased education. Hussainey (1995) presented that effective litter management includes the following:

1. Prevention of littering at source, through education, publicity and enforcement;
2. Containment and collection of litter on land, by street sweeping or manual collection, before it enters the stormwater drainage system;
3. Containment of litter at source, in the underground drainage system or open waterways by the installation of pollution control devices, without undue interference to the hydraulics;
4. Remedial clean-up measures to remove the litter deposited on stream banks and bay beaches, or litter that has settled to the bottom of rivers and bays. This is labour intensive and costly.

Sample et. al. (2003) conclude that an overall system evaluation should include non-structural and structural BMPs, and that benefits of stormwater quality controls are elusive. This discussion regarding comparison of all BMPs is outside the scope of this thesis, but consideration towards the third dot point above will be provided.

2.5 URBAN STORMWATER STRUCTURAL CONTROL MEASURES

2.5.1 The treatment train

'Treatment train' is the term used in the literature to describe the series of BMP treatment measures constructed along a drainage line, and may be conveniently classified according to the stage of the water cycle (Livingston et al., 1997; Victorian Stormwater Committee, 1999; Lloyd et al., 2002; Mouritz et al., 2003). The 'treatment train' approach recommends a system that controls all target pollutants to an acceptable level within financial constraints (Victorian Stormwater Committee, 1999). Many types of BMPs employed in the treatment of urban stormwater are known to exist (Victorian Stormwater Committee, 1999; USEPA, 1999; ASCE/EPA, 2002). Wong and Walker (2002) report on the cost effectiveness of various GPTs in terms of a capture index and capital cost, which is discussed more in section 2.6.4.

Individual methods alone cannot be expected to meet all of the stormwater management objectives and a treatment train approach is necessary (Wong and Eadie, 2000). Common problems have often arisen from inappropriate utilisation of BMPs; their positioning within the treatment train; prioritisation in their implementation in a staged program and lack of maintenance (Wong and Eadie, 2000). Much literature argues that more effort needs to be devoted to trapping litter closer to the generating source (Pitrans, 1993; Seymour, 1993; Woollard, 1996; Livingston et al., 1997). Seymour (1993) continues, reporting strong preference for higher efficiency source or near source control, and small sub-catchment control structures compared to in-stream structures.

The traditional approach to treatment was by wet and dry storage (Mudgway et al., 1997). Other types include infiltration (sub-surface filtration), surface vegetated practices (swales and wetlands), and filtration practices such as sand filters, also exist (Livingston et al., 1997; Auckland Regional Council, 2003; Akan et al., 2003). Many type of structural source controls, such as porous pavements, grass buffer strips, swales and infiltration/bioretention systems, are now being adopted as part of Australian land development practice (Water sensitive urban design - WSUD), and are very promising in term of water quality improvement (Tourbier, 1994; Commonwealth of Australia, 1993a; McAlister, 2000; Mouritz, 2000; TNRCC, 1999; Coomes et al., 2000; Wong and Eadie, 2000; Mouritz et al., 2003; Melbourne Water, 2004a; ABM, 2004).

WSUD measures may be utilised as tools in achieving a range of stormwater best practice quality objectives as they intercept stormwater draining from impervious surfaces. Lloyd et. al. (2002) report that WSUD measures can prevent litter from being conveyed to receiving waters by keeping it above ground, where it may be easily picked up, and also provide flow control benefits. Fisher et. al. (2003) warn that 'a large volume of water entering a basin has the potential to deliver a substantial mass of contaminants to the water table, even when the infiltration rate is low'. Teng and Sansalone (2004) conclude in reference to infiltration-exfiltration BMPs that: 'have the potential to be effective controls for in situ particle separation if properly designed, however, effective performance and avoidance of failure will require regular maintenance and monitoring'.

Recent advances in water cycle management research include development of engineering design procedures for urban stormwater best management practices for WSUD measures (Knox City Council, 2002; Lloyd et. al. 2002; Mouritz et al., 2003; ABM, 2004; Melbourne Water, 2004a). However, care may need to be taken to manage risks, eg. infiltration in close proximity to other engineered structures and the maintenance requirements (Bayetto, 1993; Livingston et al., 1997). Long-term performance and life cycle costs are also a consideration given limited data availability (Mudgway et al., 1997; Lloyd et al., 2001). Lloyd et. al. (2002) report that: 'to date no well established procedures exist that enable alternative approaches .... to be assessed in terms of life cycle costs and associated downstream benefits'.

Thurston et. al. (2003) discuss the concept of a market based 'tradeable allowance system' for stormwater runoff management and propose that a de-centralised approach is more cost-effective than the traditional 'command and control' approach. The concept framework lists features such as institutional mechanisms and regulations, pollutant sources, control strategies, special scales, and asset location. Thurston et. al. (2003) mention that detailed property information is required and argue that the application with GIS technology is 'fairly' inexpensive. However, they conclude that many issues need to be explored before considering policy, viz:

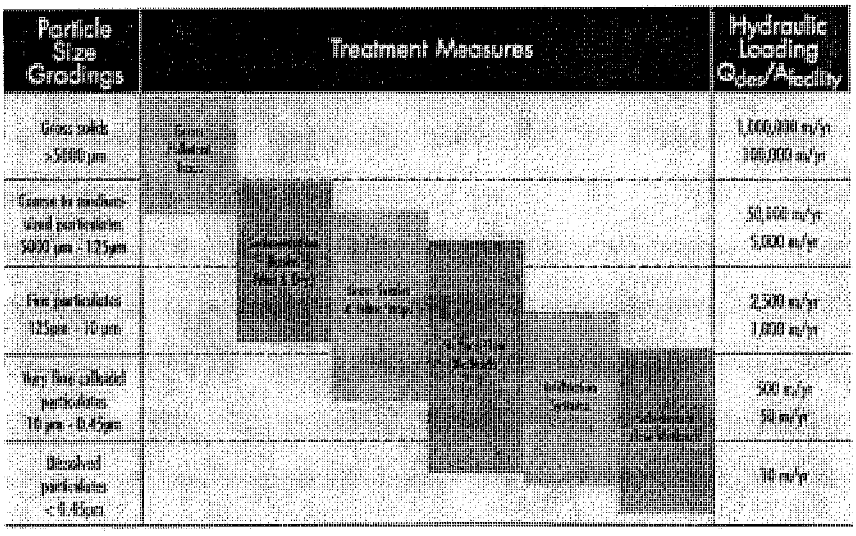
- Determination of opportunity cost of land devoted to BMPs;
- Institutional and market structure could guide dispersed investments;
- Extent to which trading ratios are needed to satisfy local ecological constraints;
- Estimation of the public and private transactions costs; and
- Analysis of the properties of such a market.

Considerations for planners and designers in the selection or design of structural control measures (eg. GPTs), as with expected performance (hydraulic and pollutant capture) benefits and costs, will be discussed later in this chapter.

2.5.2 The role of GPTs

The general range of structural treatment measures employed to improve stormwater may be grouped into a number of categories. GPTs are in-line structural controls, and are a type of primary treatment measure that employ a wet sump to collect not only litter, but as the name suggests, gross pollutants, as well as other fine material such as sediment. Figure 2.2 helps define the role of GPTs by defining the pollutant physical sizing range as greater than 5 mm and the hydraulic loading rate, discussed more in Section 2.6.3 (Victorian Stormwater Committee, 1999; Lloyd et. al. 2002).

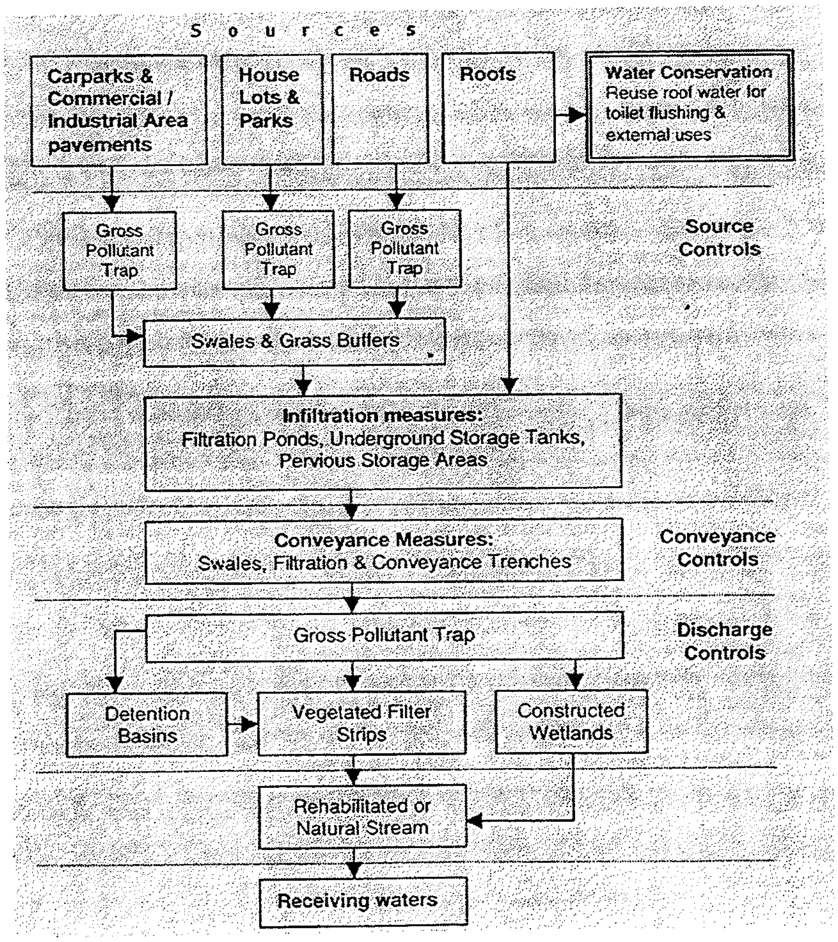
Figure 2.2 Best management practices, their target particle size range and operating hydraulic range (Lloyd et al., 2002 – from Wong, 2000)



GPTs allow gross pollutants (including litter) to travel as far as the control itself (what is caught and retained), and are preferably placed as close to the source of litter as practically possible, litter generation areas, such as shopping centres and fast food outlets (Seymour, 1993; Woollard, 1996). Wong and Eadie (2000) explain that drainage retrofitting opportunities are confined to the application of methods for removal of gross pollutants. GPTs are also considered a key component of wetland design (MWC, 2003). BMPs, such as wetlands, provide water quality improvement as well as flood control, ecological values (habitat), passive recreation, amenity and aesthetic enjoyment and landscape values for the community (Wong et al., 1998; Melbourne Water, 2003).

Figure 2.3 provides another example of defining the application of GPTs as a tool (or BMP – Best Management Practice) in WSUD.

Figure 2.3 Relationship between WSUD elements (Knox City Council, 2002 – adapted from Coomes et al., 2000)



The need for controlling litter with GPTs was identified in much of the literature reviewed (Cullen et al., 1988; Loh, 1988; Joliffe, 1989; Perrens et al., 1991; Boyden, 1996; Thomas et al., 1997; Lawrence and Breen, 1998; DNRE, 1999; WBM, 1999; Knox City Council, 2002; Melbourne Water, 2003; Auckland Regional Council, 2003; PPWPCMA, 2004; ABM, 2004) and they are typically installed where there is a need to:

- Limit deposition rates in engineered and natural waterways to levels that grass can sustain, without prejudicing the effectiveness of channel stability;
- Maintain a high aesthetic quality along sections of engineered and natural waterways identified as pedestrian/cycleway corridors, and as open space;
- Protect aesthetic and environmental quality of small on-line ponds by limiting the rate of sediment aggradation and intercepting debris and trash to maintain a high visual quality; and
- Protect macrophytes and fauna habitats at the upper end of pollution control ponds and lakes by limiting the rate of coarse sediment aggradation.

(Goyen et al., 1988; Phillips et al., 1989; Commonwealth of Australia, 1993a).

2.5.3 The historical development of GPTs

The previous chapter discussed the need for GPTs as primary measures in a treatment train. Early GPTs evolved in the late 1970s out of difficulties associated with maintenance of sediment ponds (Goyen et. al, 1988). An ever increasing number of complaints regarding the impact litter has on passive and active enjoyment of urban waterways reporting back to the mid 1980s led to more pressure to meet water quality standards and evolution of structural solutions (Molinari and Carleton, 1987; Thiering et al., 1988; Effendi, 2004).

Early endeavours to reduce litter included infrastructure such as floating booms and adoption of trash racks within major GPTs (Molinari and Carleton, 1987). A more at source-control approach soon evolved with the introduction of minor GPTs on branch stormwater drains (Goyen et. al, 1988). Experience in Canberra in the 1980s recommended the following design criteria for GPTs (Joliffe, 1989):

- Should trap 375 ml drink cans;
- Should operate up to a 1-year ARI (refer to section 4.4.2.1) flow;
- Should be stable under overtopping flows;

- Provisions should be made to bypass base flows;
- Access for mechanical cleaning;
- Wash down facilities for major traps;
- The liquid content should be discharged to sewer; and
- 1-year ARI water surface level inlet pipes should not be exceeded in minor traps.

Since the 1980s, an ever increasing number of structural control techniques have been developed, providing planners and designers greater design flexibility and choice in managing stormwater and litter. These have included side entry pit baskets, self cleaning screens, net basket systems, and proprietary products that provide treatment to a design flow proportion of runoff in urban drainage systems. Structural control techniques that were discovered in the literature now available in controlling litter are presented in section 2.7.

2.6 GROSS POLLUTANT TRAP DESIGN AND PERFORMANCE

2.6.1 General

The need for employment of GPTs in trapping litter (and gross pollutants) to protect aquatic environments was highlighted in the previous section. Catchment characteristics were established as important considerations influencing GPT design in terms of the in-flow characteristics: flow rates, volumes and pollutant loads. In deciding a GPT design suitability for a particular application, issues such as: design sizing, expected performance and costs must also be taken into consideration (Wong and Wootton, 1998). As highlighted in the previous sections, priorities for trapping are also important and take into consideration pollutant types and compositions, such as by litter item type or category (floating, suspended, and bed/settling load).

The 'Victorian Stormwater Committee' (1999) presents an overview of primary treatment measures, including GPTs, and provides brief descriptions and claims relating to the following factors relevant in design:

- typical catchment area;
- head requirements;
- advantages and limitations;
- trapping performance for a range of pollutant types;
- costs (installation and maintenance); and
- maintenance considerations - including recommended cleaning frequency.

An overview of general GPT site planning, design and cost considerations are provided in this section, with factors influencing design capture performance also discussed in more detail. In addition, current research and the application of decision support systems and computer modelling are also discussed later in this section.

An overview of the various structural litter control techniques currently employed will be presented in the next section (section 2.7), providing information on both designed and 'off the shelf' type proprietary products.

2.6.2 Overview of GPT site planning, identification and the ideal GPT

2.6.2.1 Site planning and identification

Locating GPTs is of prime importance and the following considerations are provided in the literature (ACTPA, 1992; Allison 1997; Victorian Stormwater Committee, 1999; Wong et al., 2000; Lloyd et al., 2002; Allison and Pezzaniti, 2003; AAV, 2004).

- Catchment planning and BMP 'treatment train' context:
  - catchment characteristics: land use and pollutant types and loads;
  - drainage systems, hydrology and hydraulics;
  - litter trapping and other objectives (stormwater management planning);
  - subdivision and site layout, availability, topography and terrain;
  - life cycle cost analysis of BMP options: 'source' and 'outlet' types.
- Site features, opportunities and constraints:
  - geology, soil types and groundwater;
  - flora and fauna significance;
  - other physical assets and services;
- Site area and depth requirements:
  - preliminary GPT area 'footprint' and sizing requirements;
  - maintenance access and disposal, including land requirements.
- Social-political planning considerations:
  - Occupational Health and Safety (OH&S): exposure, access and general safety;
  - aesthetic/visual impact and landscape considerations; eg. design compatible with waterway geometry, screening the structure from major use areas;
  - adjacent current and future land use and public open space, type and location of recreational or other activity and the dominant directions of viewer focus;
  - cultural heritage and archaeological considerations;
  - stakeholder consultation and educational opportunities; and
  - other nuisances - vermin, insects, noise and odour.

The physical control of litter may be introduced at nearly any point within the stormwater system. However, a distributed source control approach is preferred in terms of staging works, cost effectiveness, improved litter removal efficiencies, level of downstream protection and distributed risk (Victorian Stormwater Committee, 1999).

2.6.2.2 The ideal GPT design

The ideal GPT features that designers seek are (modified from: Armitage et al., 1998):

- structurally robust;
- able to handle widely varying flow-rates;
- able to operate under minimal water 'head' (acceptable energy loss);
- generally safe (OH&S);
- easy to clean;
- unattractive to vandals; and
- economical to construct and operate.

The ideal GPT should have (modified from Armitage et al., 1998):

- simple operation with reliability;
- minimal maintenance requirements; and
- high pollutant capture efficiency.

The ideal GPT should not (modified from Armitage et al., 1998):

- block or clog up, or reduce system capacity at peak flows;
- contain moving parts;
- constitute a health hazard (eg. attracts flies and mosquitoes); and
- require an external power source.

Quin et al. (1999) also report that 'the existence of ... litter traps potentially pose a significant barrier to the upstream movement of native fish species', and should be considered in design where applicable. It must also be kept in mind that each catchment, drainage system and site-trapping opportunity may inherit particular design characteristics and limitations. Therefore, no single litter trap or GPT is likely to be able to satisfy all of the above and some compromise will be required in terms of design.

2.6.3 Design sizing and performance

2.6.3.1 General

GPT considerations relating to site planning, identification and costs, includeing catchment characteristics (litter, gross pollutant and sediment loads, types and compositions), trapping objectives, available space, and social-political considerations, have already been presented. Once these considerations have been evaluated, a more detailed GPT design, including a balance between the following, is required (Armitage et al., 1998; Wong et al., 2000):

- Hydrologic and hydraulic considerations;
- Trapping efficiency; and
- Capital and maintenance costs.

The above considerations will assist in evaluating the expected trapping cost effectiveness. However, pollutant capture and retention performance is difficult to quantify, as many factors are interrelated. As explained in the literature, a great many variables may be used in the consideration of structural BMP design (Urbonas, 1995; Strecker et al., 2001), some of which are relevant to GPTs, and are presented later in this section.

2.6.3.2 Hydrologic and hydraulic considerations

Hydrologic and hydraulic considerations in GPT design require a balance between the following (Armitage et al., 1998; Wong et al., 2000):

- System allowable 'head' (energy) loss;
- Unit storage volume and outlet characteristics; and
- Design treatment flow.

2.6.3.2.1 System allowable 'head' (energy) loss

As discussed in section 2.3.1, urban drainage design is based on providing adequate levels of service for both minor and major drainage systems. These systems are designed to provide service in terms of catering for flows of a chosen design - Average Recurrence Interval (ARI) in years (Argue, 1986; IEAust, 1987). This relates to probability and is the average interval of time within which an event will be equaled or exceeded (Wanielista, 1978; Chadwick and Morfett, 1986). The rational method, partial

area effects, runoff coefficients, including the Hughes frequency factor (Fy), and equivalent impervious areas are used to estimate design system flows for urbanised catchments and are discussed in the literature (Bergen, 1985; IEAust, 1987).

GPT operating performance both at and above design flow-rates must be considered, with the potential for either system blockage or excessive 'head' losses as key considerations (Armitage et al., 1998; Wong et al., 2000). A blockage or excessive head loss when a system is operating under design capacity may cause system flows to change from supercritical flow to subcritical flow, consistent with hydraulic principles explained in hydraulic texts (Chadwick and Morphett, 1986; Hamill, 1995). This may result in property damage, due to local overflows, or upstream backwater flooding. The type of GPT structure to be used in litter capture, including the design treatment flow-rate (design flow), is therefore governed by the allowable energy loss under maximum design flow conditions.

Energy losses associated with hydraulic structures are commonly referred to as shock losses, and are a function of the pipe flow velocity. Shock losses, h_s, are calculated using the following relationship (IEAust, 1987; Mills and O'Loughlin, 1998; Akan and Houghtalen, 2003):

h_s = head loss at structure (total) = $K*V_o^2/2g$ **Equation 2.1**

Where: V_o = downstream velocity (m/s);

K = shock loss coefficient (K value); and

g = gravitational constant = 9.81 m/s^2

Shock loss (K value) coefficients vary depending on the type of hydraulic structure, and local head losses associated with common situations are provided, such as with general bends, entry, exit and pit losses, and can be referenced in the literature (Black and Pigott, 1983; deGroot and Boyd, 1983; Chadwick and Morfett, 1986; Johnston et al., 1988; Mills and O'Loughlin, 1998; ASCE, 1992; Akan and Houghtalen, 2003).

2.6.3.2.2 Storage volume and outlet (flow control) characteristics

Most GPT designs utilise a storage volume and outlet characteristics that allow a flow detention period, velocity reduction, and/or physical barriers (such as screens or nets) to assist pollutant capture or separation and retention. Storage volume will act according to hydraulic principles, such as with reservoir routing, and will operate depending on in-flow, stage (height) and corresponding storage volume, and outlet flow control characteristics (Mills et al., 1983; Chadwick and Morfett, 1986; Wong et al. 2000). As presented in section 2.7, some GPT designs also contain a wet sump storage volume as a permanent pool to increase pollutant capture and retention. Wong and Breen (1998) report that the permanent pool can significantly influence detention time and provides sedimentation.

Southcott (1995) reported the need to reduce turbulence in design. The hydraulic design of an outlet structure has a direct effect on the hydrodynamic behaviour and storage detention period (Wong and Breen, 1998). The storage volume design will also be dependant on the design flow and internal control structure characteristics, flow path layout and positioning of flow control structures, such as the inlets and outlets. A greater emphasis on design of the storage volume, outlet characteristics and internal treatment process is presented soon.

2.6.3.2.3 Design flow and hydrologic effectiveness

The design flow (or treatment flow-rate) is an important term used to describe the maximum or ideal design flow-rate under which a GPT is to have optimum performance, and above which, performance may be compromised (Armitage et al., 1998; Wong, 1998; Victorian Stormwater Committee, 1999; Wong et al., 2000). Selecting a design flow is a trade-off between size and cost of a GPT and volume of untreated stormwater bypassing (Victorian Stormwater Committee, 1999). This design balance involves the allowable system head loss and the design flow optimisation (as a percentage of the maximum system design flow capacity). GPT designs employing either a fixed diversion weir, and/or screening rack (or similar), to divert and/or directly capture pollutants, will impact on the system flow regime and energy 'head' losses in the system according to hydraulic principles already discussed.

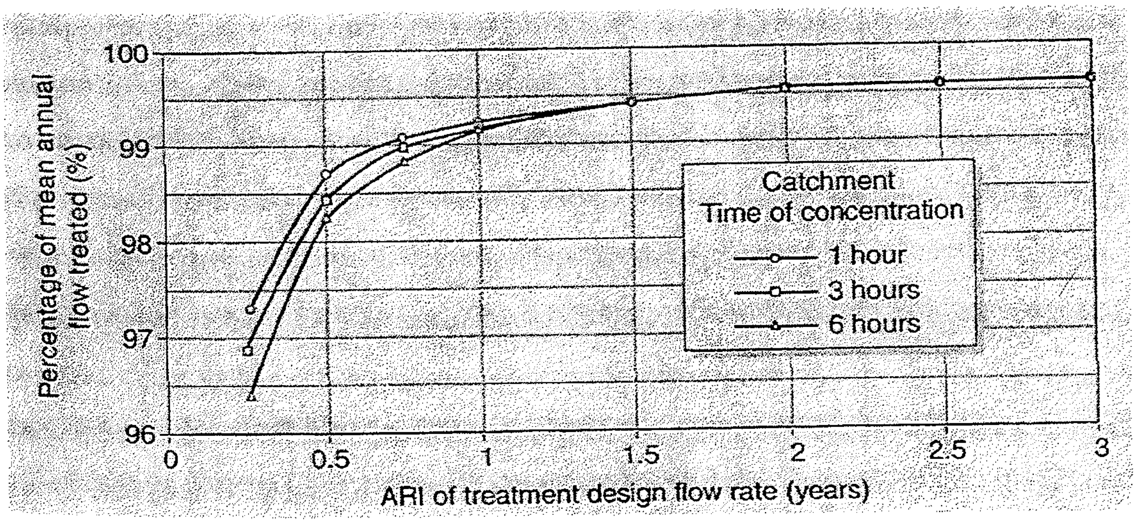
Strecker et al. (2001) define BMP effectiveness as follows: 'a measure of how well a BMP system meets its goals for all stormwater flows reaching the BMP site, including flow bypasses'. Hydrologic effectiveness, as a term commonly used to describe the proportion of runoff entering a treatment system, relates to the following factors (Wong et al., 1998; Wong et al., 1999; Wong et al., 2000), viz:

- In-flow characteristics;
- Storage volume; and
- Detention period.

The principles of this theory may also be applicable to GPT design and performance. Downstream water level controls, such as tidal influences, may also influence the hydrologic effectiveness consistent with hydraulic principles.

Figure 2.4 shows the treatment design flow rate ARI (years) versus percentage of mean annual flow treated, indicating that a relationship between hydrologic effectiveness and the treatment flow-rate exists. Curves in figure 2.4 are affected by the catchment time of concentration (please refer to hydraulic texts). It is also noted with figure 2.4 that with catchments of significantly smaller times of concentration, as with small urbanised catchments, for a typical design flow of 4 in 1 Year (3 month) ARI, that the proportion of runoff treated may be greater. However, no reference was discovered as part of the literature review presenting data for catchments with smaller times of concentrations and may be the subject of future investigation. The relationship for hydrologic effectiveness may vary depending on unique characteristics of each GPT.

Figure 2.4. Treatment design flow rate (ARI) versus percentage mean annual flow treated for Melbourne (Victorian Stormwater Committee, 1999)



Melbourne Water (2003) requires that capture for all litter items of size greater than 20 mm for design flow rates up to a 4 in 1 Year (3 month) ARI be provided. Tighter restrictions may apply where the receiving water is of high recreational or environmental value, and a requirement for trapping all material greater than 5 mm in size up to a 2 in 1 Year (6 month) ARI flow may be applicable (Melbourne Water, 2003). However, a requirement for a larger GPT design flow (eg. 2 in 1 Year ARI), is likely to require a much larger diversion structure, and consistent with hydraulic principles, may incur unacceptable head losses.

2.6.3.3 Trapping performance

2.6.3.3.1 General

This section presents an overview of design trapping (capture) performance considerations, including design flow, internal treatment-process hydraulic loading, efficiency, and technologies such as screening. Maintenance considerations are also important and are discussed later in section 2.6.3.4. As will be presented in section 2.7, GPTs provide for sedimentation and floatation to occur where wet sumps are a feature and primarily rely on coarse filtering to retain separated materials.

2.6.3.3.2 Total capture performance

2.6.3.3.3.1 General

The importance of GPTs in a 'treatment train' has already been discussed and litter capture (trapping) performance objectives will establish what parameters should be used in design and sizing. Benefits from high levels of treatment, along with the capture and retention of non-priority pollutants, may also be carefully considered. The literature provided many examples of urban stormwater treatment objectives, viz (Mudgway et al., 1997; Ecosol™ product information, 1999; Wong et al., 1998):

- Volumetric runoff, eg. 25 mm of rainfall to be treated;
- Volumetric runoff with discharge criteria, eg. 25 mm of rainfall to be treated and discharged over a certain time interval;
- Storage area as percentage of catchment area;
- Percentage of Mean Annual Runoff (MAR); and
- Percentage of rain events, eg. 90% of events.

Mudgway et al. (1997) report on recommendations for water quality treatment for less than 'first flush' 0.3 year ARI events, as follows: "*capture and detain 75 to 90% of runoff events = volume to accommodate 60 mm from impervious area*". Key variables relating to pollutant removal of ponds are noted by Chiew et al. (1997), viz:

- In-flow concentrations;
- Up-flow rate (annual runoff, storage area and catchment area).
- Design index (such as storage shape and depth).

Chiew et al. (1997) also note that some pollutants are more influenced by the first and third points above, whilst the second point relates more to dissolved pollutant removal. TARP (2003) present an example of a stormwater BMP performance claim, viz:

> *"The model X system can capture and treat the first 15mm, 24 hour storm for a 40 Hectare runoff area. Under these conditions, a total suspended solids (TSS) removal rate of 85% +/- 5% (at 95% confidence level) can be achieved with inflow TSS concentrations greater than 100 mg/l".*

However, no reference to gross pollutants or litter is provided in this literature.

Performance, as defined by Strecker et al. (2001), is 'a measure of how well a BMP meets it's goals for stormwater that flows through, or is processed by it'. The literature reports that total pollutant removal is related to the volume of stormwater available for treatment (capture) and the removal performance of the treatment (Mudgway et al., 1997; Victorian Stormwater Committee, 1999). Equation 2.2 presents that the total capture efficiency is a function of the treated flow volume (η_f) (or hydrologic effectiveness), and the efficiency (η_s), viz (Armitage et al., 1998):

Equation 2.2

$$\eta_0 = \eta_f \cdot \eta_s$$

Where: η_0 = GPT capture efficiency (fraction);

η_f = treated flow volume expressed as a fraction of the total flow; and

η_s = published efficiency of the structure (fraction).

The effectiveness of in-line hydraulic controls can be measured by monitoring flow rates and pollutant inputs and outputs (Aitken, 1995; Thomas et al., 1997). However, Strecker et al. (2001) report that effectiveness and efficiency estimations are not straightforward and a wide variety of methods has been employed. The following methods are reported in the literature for evaluating stormwater BMP efficiency, including that the effect of bypass flow should also be quantified (ASCE/EPA, 1999; Wong et al., 2003; Strecker et al., 2001; TARP, 2003), viz:

- Efficiency ratio;
- Summation of loads;
- Regression of loads;
- Mean concentration;
- Efficiency of individual storm loads;
- Irreducible concentration (C*) or achievable efficiency;
- First order kinetic (k-C*) model;
- Multi-variate and non-linear models; and
- Effluent probability.

ASCE/EPA (1999) also highlight that the last method should be accepted as a standard and used as a 'rating curve'. Additional theory relating to removal efficiency, including internal design factors, will be presented in section 2.6.3.3.3.

The most common of the above methods reported in the literature, sometimes expressed in terms of concentrations (also event mean concentrations) and volumes, is the efficiency ratio (Urbonas, 1995; Chiew et. al, 1997; ASCE/EPA, 1999; Wong et al., 2000; Raju et al., 1999; TARP, 2003; Sansalone and Teng, 2004):

$$RE = [(M_{in}-M_{out})/M_{in}].100 \qquad \textbf{Equation 2.3}$$

Where: RE = removal efficiency (%)

M_{in} = influent mass (mg)

M_{out} = effluent mass (mg)

TARP (2003) report that the 'efficiency ratio' method is preferred and the 'summation of loads' method should also be used where feasible.

The Victorian Stormwater Committee (1999) presented the objectives for litter trapping as: '70% reduction in average annual litter load'. Capture (trapping) performance may therefore be generally defined in terms of a GPT's overall ability to trap litter, that is, an overall reduction in litter load transported to a GPT. However, GPT design may also consider capture performance objectives relevant to previous discussion, viz:

- total balance of mass frequency counts and/or volumes;

- litter category or types, such as those that are highly visible;
- specific targeted 'problem' litter items, such as syringes; and
- other pollutant types, such as sediments and attached pollutants.

Mudgway et al. (1997) note that performance characteristics of a GPT are unique in that capture performance is likely to either remain constant regardless of in-flow load, or decrease with increasing load, in contrast to other types of pollutants for other BMPs. The Victorian Stormwater Committee (1999) also presented capture (retention or removal) efficiency claims for other pollutants, for a range of BMPs, however, notes that refinement of design parameters can be expected over time.

Harwood and Saul (1999) report on removal efficiency in terms of a controlled study involving particle frequencies, viz:

$$RE = \frac{\text{Total number of particles retained within the system}}{\text{Total number of particles introduced}} \times 100 \quad \textbf{Equation 2.4}$$

This approach may be considered as a suitable method for evaluating GPT performance, as intensive event monitoring is not required, and is therefore used as the basis for the methodology in this thesis using a controlled litter sample.

2.6.3.3.3 Internal treatment process

2.6.3.3.3.1 Design sizing and hydraulic loading

As previously discussed, a key consideration in terms of treatment is hydraulic loading, which is a ratio of GPT design flow to the effective surface area. Hydraulic loading will depend on the GPT design and whether it is located on-line (in-line) or off-line. The design flow of a GPT located on-line will have to endure all flow conditions, including high flows and velocities. If a GPT is located off-line, with the provision of a high flow bypass, the design flow will determine hydrologic effectiveness.

Removal of suspended solids is directly influenced by detention period and characteristics of the solids, such as particle size distribution and specific gravity (Wong and Breen, 1998). The settling velocity of a target particle is defined under ideal flow conditions as the 'overflow' (or 'surface loading' or 'hydraulic loading') rate, and is expressed as follows (Victorian Stormwater Committee, 1999):

$$v = Q_d/A_b$$ **Equation 2.5**

Where: v = particle settling velocity (m/s)

A_b = surface area of basin (m^2)

Q_d = GPT design flow rate (m^3/s)

The percentage of sediment deposited (P) may be expressed, after Willing and Partners in 1989 (previously Einstein in 1965 and Pemberton and Lara in 1971), as follows (Armitage et al., 1998; Wong et al., 2000):

$$P = 100\,[1 - e^{x}]$$ **Equation 2.6**

Where: $x = (-1.0548.A_b.v/\,Q_d)$ **Equation 2.7**

Settling velocities for various particle size fractions and diameters under ideal conditions may be obtained from the literature (Urbonas, 1995; Victorian Stormwater Committee, 1999; Wong et al., 2000; Melbourne Water, 2004). In practice however, ideal settling conditions rarely occur due to variability in concentration, shape, size, density, turbulence, and flocculation and coagulation (Melbourne Water, 2004).

Harwood and Saul (1999) report, for a chamber storage type treatment facility, that the level of pollutant removal is related to particle settling velocity, particle drag coefficient, and inlet mean fluid velocity. The settling velocity of a particle with a diameter (d) greater than 0.08mm is given by Rubey's formula when the Reynolds number (R_e) is greater than 0.1 (Lawrence and Breen, 1998; Wong et al., 2003):

$$v = 1/d[\sqrt{(}10.79d^3 + 36\nu^2) - 6\nu]$$ **Equation 2.8**

Where: R_e = Reynolds number = $v.d/\nu$

v = particle settling velocity (m/s)

d = diameter of particle (mm)

$\nu\ (=\mu/\rho)$ = kinematic viscosity (m^2/s)

μ = dynamic viscosity (kg/(m.s))

ρ = density (kg/m^3)

The kinematic viscosity (ν) may be referenced in hydraulic texts (Chadwick and Morfett, 1986; Hamill, 1995). Stokes law applies when the Reynolds number is less than 0.1, but this is not as relevant to GPTs given this applies for particles with a diameter less than 0.08 mm, which are not considered a trapping priority.

Various theoretical principles and models for particle transport and separation, including bed, suspended and total load, have been developed. These approaches are outside the scope of this thesis but may be examined in the literature (Chadwick and Morfett, 1986; ACTPA, 1992; Swamee and Tyagi, 1996; Lawrence and Breen, 1998; Armitage et al., 1998; Raju et al., 1999), viz:

- particle size distribution curves;
- flow, geometry, and roughness;
- Shields entrainment function (F_s) as a function of the Reynolds number;
- self weight and maximum fall velocity of a particle;
- sedimentation tank or basin removal efficiency and design;
- tractive force ('Du Boys type') equation relating transport to shear stress;
- Probabilistic theory, such as Einstein and Einstein-Brown formulae;
- Energy (stream power) formulae; and
- Ackers and White formulae (1972).

Hydraulic loading is also related to pollutant detention period and the concept of a Probabilistic Residence Time Distribution (PRTD) (Wong et al., 2000; Wong et al., 2003). The PRTD is influenced by internal and external factors, such as inflow characteristics, hydrograph shape, storage volume, and outlet type (Wong et al., 2000). The 'k-C*' model, a pollutant treatment processes model, utilises the hydraulic loading (q), as well as the rate (k) in which pollutant concentrations move towards an equilibrium or 'background' concentration (C*) (Wong et al., 2003; Fletcher, 2004). The type of outlet structures will influence 'k' values.

Lawrence (2002) recommends that GPTs be sized to trap only the coarse particles as a means of limiting the amounts of fine particles intercepted and mobilisation of associated adsorbed pollutant and organic materials. The maximum velocity recommended under GPT design flow conditions is 0.5 m/s, assuming the GPT is half full with previously trapped materials (Wong et al., 2000). Minimum storage sizing for maintenance requirements must also be considered in the evaluation of trapping techniques to ensure GPT suitability (Allison and Pezzaniti, 2003). This is discussed in more detail in section 2.6.3.4.

In design sizing of trapping systems for particle removal and retention, other factors relating to shape, layout, and location of the flow inlet and outlets must be considered relevant to the particle settling velocity (**v**), and are now discussed.

2.6.3.3.3.2 Design layout and hydraulic efficiency

After considering design size and storage, hydraulic loading and outlet structures, the internal layout must also be considered to 'ensure that the design detention period can be consistently achieved for the full range of flow conditions' (Wong and Breen, 1998). The literature also points out the importance of locating in-flows away from outflows to avoid short circuiting, and the importance of the outlet structure design for allowing a water level control and slow flow release (Cullen et al., 1988; Spotts, 1998).

Performance 'efficiency' is defined as 'a measure of how well a BMP (or system) removes pollutants' (Strecker et al., 2001). Hydraulic efficiency is a major design consideration in the level of pollutant retention once design flows have been separated from the stormwater system into a GPT (Nielson and Carleton, 1989). Hydraulic efficiency is described as the extent to which plug flow conditions are approximated and the proportion of the volume utilised in movement of in-flows through the storage (Wong et al., 1998). Hydraulic efficiency is also strongly influenced by storage volume shape and depth, as well as the location and characteristics of internal hydraulic structures, fixtures and components, such as inlet and outlet arrangements, baffles, and screens (Urbonas, 1995; Spotts, 1998; Koskiaho, 2003). An explanation of hydraulic efficiency (λ) can be found in the literature and relates to the volume utilisation and the number of 'continuously stirred tank reactors' (N) (Wong and Breen, 1998; Wong et al., 2001; Wong et al., 2003; Melbourne Water, 2004), viz:

$$\text{Hydraulic efficiency} = \lambda = 1 - (1/N) \qquad \textbf{Equation 2.9}$$

where values for λ are reported as follows:

- Good: $\lambda => 0.75$
- Satisfactory: $0.5 < \lambda < 0.75$
- Poor: $\lambda <= 0.5$

Fair and Geyer reported on the sediment fraction that can be removed in a pool of water under dynamic conditions (Urbonas, 1995; Melbourne Water, 2004). However, this is applicable for systems with no permanent pool, and when a permanent pool does exist, the following theory using 'N' is recommended (Melbourne Water, 2004):

$$R = 1 - [1+\{(v(d_e+d_p))/(NQ_d/A_b(d_e+d^*))\}]^{-N} \qquad \textbf{Equation 2.10}$$

Where: R = fraction of solids removed

v = particle settling velocity (m/s)

Q_d/A_b = hydraulic loading (m/year)

N = turbulence factor [$= 1/(1-\lambda)$]

d_e = extended detention depth (m) above the permanent pool volume

d_p = permanent pool depth (m)

d^* = depth below permanent pool level to retain target sediment (m)

Equation 2.10 reduces to Equation 2.11 as a system performs better and 'N' approaches infinity (Urbonas, 1995):

$$R = 1.0 - e^{-kt} \qquad \textbf{Equation 2.11}$$

Where: $k = v/h$ (sedimentation rate coefficient) [(/time) units]

Where: v = particle settling velocity (m/s) and h = average pond depth (m)

$t = V/Q_d$ = residence time in pond (hours)

Where: V = pond volume (m^3) and Q_d = design flow (m^3/s)

As explained in the literature, care needs to be taken in the hydraulic design to ensure that an elongated narrow cross-section flow path does not create resuspension and remobilisation of materials (Asano, 1995; Swamee and Tyagi, 1996; Wong and Breen, 1998; Wong et al. 2000; Wu and Chow, 2003). This requires the designer to balance the expected maximum flow velocity with the desired particle retention. Wong et al. (2000) present data on critical scour velocities for various particle sizes. However, as explained by the Victorian Stormwater Committee (1999), there are many limitations with current design techniques for sediment basin sizing, mainly because of non-ideal settling characteristics and dynamic flow conditions, which may also be true for GPTs.

2.6.3.3.3.3 Design flow control technologies for improved capture performance

As will be presented in section 2.7, structures that are typically used in GPT design for improving flow control and trapping performance include baffles, weirs, orifices, screens, bars (combs) and net bags. These flow control structures influence treatment process, as already discussed, and can provide pollutant interception, distribution of flows, velocity reduction, and can improve hydraulic performance, litter capture and retention. Weirs are employed in GPT design where in-flow interception, diversion, flow ponding and outlet control are required. The literature also reports on the use of baffles within wet sumps to capture both floatable and settleable pollutants (Urbonas, 1995; Armitage et al., 1998). Armitage et al. (1998) note the importance of screens and baffles in trapping performance.

Many screen technologies (eg. screens, bars, combs, and net bags) are available to designers (Blackwood and Sons Ltd., 1997; Environmental and Civil Pty. Ltd., 1997; Environmental Solutions (Aust) Pty. Ltd., 2003). They may be employed directly or indirectly in trapping. They may be introduced directly into the path of the main flow stream to intercept and capture litter through the allowance of filtration by many openings. Off-line systems may also include GPTs featuring a permanent wet sump with internal screening technologies that act to retain suspended material with a specific gravity of approximately unity, such as with sheet plastic or organic material. Materials in suspension once settled may also be prone to re-suspension, therefore, screening technologies may be useful in trapping materials entrained in the design flow that would otherwise be carried through or resuspended to an outlet.

Screen design may also influence litter capture performance depending on the size of the bars' centre to centre spacing, individual open areas and the total open area. Screen design requires a balance with design flow to ensure that excessive velocities do not occur. Smaller openings, although providing capture of smaller materials, will reduce the flow area through the screen, therefore increasing design flow velocities, head losses and risks associated with reduced hydrologic effectiveness and even upstream flooding consistent with hydraulic theory (Chadwick and Morfett, 1986).

Various screening technology approaches have been developed and employed with some claimed as being self cleaning or non-blocking (CDS Pty. Ltd. – product information, 1997; Armitage et al., 1998). Some technologies are reporting to significantly improve the retention of materials, however, are also reported as being susceptible to blockage (Armitage et al., 1998). Armitage et al. (1998) outline that litter in contact with an interface experiences the following forces:

- Gravity (vertical);
- Pressure (Bernoulli principle, hydrostatic variation, and local variation);
- Shear (shape of boundary layer near screen and turbulence eddies);
- Inertia (usually not large);
- The reaction of the boundary (normal to the contact surface); and
- Friction (static or kinetic) resulting from contact (tangential to contact surface).

This theory is considered beyond the scope of this thesis.

2.6.3.4 Capital and maintenance costs

2.6.3.4.1 General

Life cycle costs associated with GPTs are classified as follows (Victorian Stormwater Committee, 1999; Lloyd et. al, 2002; Lloyd and Wong, 2003; Zhen et al., 2004):

- Capital costs - design and construction, or manufacture and installation.
- Maintenance costs - inspections, monitoring, cleaning, and pollutant disposal; and
- Externality costs - associated with additional benefits, such as enhanced recreational values of receiving waters.

Armitage et al. (1998) report that the total annual cost of a GPT is obtained by adding the annual maintenance cost to the annual capital recovery cost, where the latter is calculated using the capital cost, interest rate, and the repayment period. Therefore, the unit cost of litter removal is the total annual cost divided by the estimated annual load that will be trapped (Armitage et al.; 1998). However, Armitage et al. (1998) do not account for externality costs in their evaluation.

2.6.3.4.2 Capital costs

Capital costs are primarily set by catchment area, the site terrain, design discharge, and the above-design and non-ideal flow conditions (Wong et al., 2000; Lloyd et al., 2002). Although not directly reported by Wong et al. (2000), the design discharge may be expected to influence the capital cost through the design sizing and internal components of the trap. The general considerations already listed in section 2.6.2.1 also have the potential to affect the feasibility and capital cost. Structural considerations influencing the capital cost include (but are not restricted to) the following (ACTPA, 1992; Southcott, 1995; Victorian Stormwater Committee, 1999; Allison and Pezzaniti, 2003):

- Ease of construction – installation;
- Structural integrity/durability of components in wet conditions;
- The introduction of a sump draw-down allowance; and

Lloyd and Wong (2003) present data that indicates capital costs may range from as low as approximately $1,000 per hectare to as high as approximately $40,000 per hectare.

2.6.3.4.3 Maintenance costs

Maintenance costs relate to trapping efficiency, expected pollutant loading, minimum dimensions (sizing) of the trap and the clean-out frequency (Wong et al., 2000). Other maintenance cost considerations include (but are not restricted to) the following (Livingston et al., 1997; Victorian Stormwater Committee, 1999; Lawrence, 2002; CSR Humes Ltd., 2001; Allison and Pezzaniti, 2003):

- Water quality deterioration from residual water in sump;
- Other upstream BMPs that reduce maintenance;
- Management of trapped materials, such as retrieval methods and pollutant disposal; and
- Economies of scale.

Lloyd and Wong (2003) report that the annual costs to remove accumulated materials to be $310 per m^3, but may vary significantly from approximately $30 to $1,000 per m^3.

GPT maintenance considerations are important in design trapping performance (Molinari and Carleton, 1987; Southcott, 1995; Mudgway et al., 1997; Allison and Pezzaniti, 2003). ACTPA (1992) reported that the on-going cost of cleaning out a GPT generally represents a much higher proportion of the total life cost of the structure compared with other elements of the stormwater system. Regular cleaning out of accumulated pollutants will ensure optimum design treatment capacity and capture performance (Wong and Wootton, 1998; Loizeaux-Bennett, 1999). As previously discussed, appropriate sizing of the GPT (to accommodate expected capture loads) will assist satisfactory cleaning frequencies.

Several key considerations relating to the maintenance of GPTs are now discussed, viz:

- Access;
- Methods;
- Cleaning frequency;
- Waste management and disposal; and
- Maintenance planning and programming.

However, these are offered as a guide only as too few data are currently available.

2.6.3.4.3.1 Access

Maintenance access requirements will depend on the method required or employed. Access to the facility should allow for machinery and vehicle types expected, with implications on access track and ramp widths, grades, loading (hard stand) and turning considerations (Melbourne Water, 2003). GPT access requirements should also consider the cover and opening arrangements and considerations towards lifting requirements (OH&S and machinery) (Allison and Pezzanati, 2003).

2.6.3.4.3.2 Maintenance methods for GPT pollutant recovery

Manual handling of gross pollutants is to be avoided. Existing mechanical methods that limit contact with gross pollutants during the recovery and removal processes when cleaning GPTs may be preferred, and include (Goyen et al., 1988; CDS, 2002; Allison and Pezzaniti, 2003):

- Street sweeper vacuum trucks;
- Eductor trucks;
- Scoop and grab type systems; and
- Net and bag type systems (often requiring cranes).

Time and ease of cleaning and servicing, as well as the potential need for sump dewatering, are important considerations that relate to the methods of recovery (as given above), and may vary greatly.

2.6.3.4.3.3 Cleaning frequency

Design sizing should include a 'storage volume' determined by proposed cleaning frequency of the 'treatment volume'. If a GPT is undersized, then it will be limited in holding capacity, require intensive maintenance and potentially a greater life cycle cost over its design life. Wong et al. (2000) report loads of 0.4 m^3/ha/year and 1.6 m^3/ha/year for gross solids and sediment export respectively in design sizing. However, section 2.3.3.2 discussed that urban runoff gross pollutant characteristics and loads are affected by many factors and vary greatly between catchments. Therefore, cleaning frequencies will need to be determined based on individual monitoring and experience.

The expected cleaning frequency may be considered in terms of the expected load to be trapped by the structure and the design capacity of the structure before a clean is required (Wong et al., 1998): $F_c = L / V_{sc}$ **Equation 2.12**

Where:

F_c = frequency of cleaning (per year);
L = load trapped by the structure (m^3 per year); and
V_{sc} = design storage capacity before a clean is required.

Armitage et al. (1998) present the following equation for estimating load trapped by the structure each year, L (m^3/Year), viz:

$L = T.\eta_o$ **Equation 2.13**

Where:

T = Total pollutant load volume export (m^3/Year)
η_o = GPT capture efficiency (from Equation 2.2)

The total pollutant volumetric load (T) may be considered in terms of the catchment area and the litter export load rate (m^3/ha/Year), and may consider the land use types, as presented in section 2.3.3. The design storage capacity (V_{sc}) may be determined in terms of the GPT area and the effective design depth before a clean-out is required.

Wong et al. (2000) recommend cleaning be undertaken when the GPT is half full and it should be sized to reduce cleaning frequency to a maximum of six times annually. Melbourne Water (2003) recommends that GPT cleaning frequencies be no more than four times per year. However, recommendations that pollutants be removed between twelve and four times per annum (as a minimum) have been made (Woollard, 1996). This large variation may have significant life cycle cost implications and may be attributed to several factors (Wong and Wootton, 1998; Allison and Pezzaniti, 2003):

- retained solids are prone to breakdown and decomposition under anaerobic conditions, and may release particulates and pollutants in other forms; and
- an excessive accumulation of gross solids may lead to poor trap performance, and loss of further incoming materials.

The effect that cleaning frequency of a GPT has on water quality, both within the sump and downstream receiving water, was not reported in the literature. However, the literature (Lawrence and Breen, 1998; Wong and Breen, 1998; Lawrence, 2002) reports that permanent pools in wetlands can release soluble pollutants previously trapped as particulates during low dissolved oxygen conditions. Lawrence (2002) recommends that frequent cleaning be undertaken to limit the detention period following interception. Riley and Abood (1995) report that gross pollutants cannot be considered neutral materials as the non-biodegradable materials may be of influence.

2.6.3.4.3.4 Waste management and disposal

Management of retrieved materials and pollutants will influence the disposal cost (Livingston et al., 1997; CSR Humes Ltd., 2001). Contamination and re-use; problems with classification, disposal, and recycling of materials retrieved from GPTs (issues relating to composition, eg. 'sharps') are all factors (Livingston et al., 1997). Provision of land for the purpose of dewatering and drying material retrieved from a GPT prior to disposal may also be a consideration for limiting disposal costs.

2.6.3.4.5 Maintenance planning and programming

The importance of maintenance planning is highlighted by Livingston et al. (1997), who also provide examples of maintenance schedules, including activities and frequencies. The importance of ownership and maintenance planning, including the agreement to responsibilities in planning and consultation, is also discussed in the literature (Livingston et al., 1997; Lloyd et al., 2002).

2.6.4 Litter trapping decision support

2.6.4.1 General

As identified in section 2.6.1, the best example of an easy to use decision support system for various trapping techniques discovered in the literature was a table (table 7.1) provided by the Victorian Stormwater Committee (1999), which includes the following:

- Catchment area;
- Trapping efficiency by pollutant types, including gross pollutants, but no separation for litter is provided;
- Cleaning frequencies;
- Head requirements;
- Installation costs; and
- Maintenance costs.

However, performance data on trapping systems are scarce (Southcott, 1995; Allison et al. 1997; Allison and Seymour, 1998). However, the literature reviewed included laboratory and field studies, a decision support system, computer modelling and discussion on a GPT monitoring protocol, and are now discussed below.

2.6.4.2 Measured performance of GPTs

2.6.4.2.1 Laboratory studies

Laboratory physical models have been used widely in civil engineering practice and provide an acceptable way to test and develop innovative ideas across a range of flow conditions prior to field testing (Keller, 1989; Evans, 1993; Perera and Keller, 1994; Hamill, 1995; Harwood and Saul, 1999). The testing of physical GPT scale models in a controlled laboratory environment allows a basic understanding of the hydraulic operation, including flow patterns, as well as pollutant capture characteristics (Wong and Wootton, 1998). A number of laboratory tests have been conducted to report on the development of GPTs (Edgtton et al., 1997; Wong et al., 1997; Phillips, 1998; Argue and Pezzaniti, 1998; University of Adelaide, 1998; Keller and Winston, 1999).

Many claims are provided in the literature about the general performance of proprietary products in terms of the Treatment Flow Rate (TFR), hydraulic head (energy) losses and overall pollutant removal, based predominantly on laboratory physical model studies (James Hardie Aust. Q-Guard^{TM} product information, 2002; Pezzaniti and Argue, 1998; Keller and Winston, 1999; Edgtton et.al., 1997; Ecosol Pty. Ltd. product information, 1999). However, performance claims are made from laboratory scale model test results, or no data, without adequate field testing (Allison and Seymour, 1998). Given the diverse composition of gross solids being transported through the urban stormwater system, it has been argued that due consideration of the duration of laboratory tests and pollutant loading rate is needed to allow any possible time dependent and load dependent deterioration of trapping efficiency to be determined (Wong and Wootton, 1998).

2.6.4.2.2 Field performance monitoring of GPTs

There has been only limited investigation into deployment and performance of devices designed to trap gross pollutants in urban stormwater drainage systems (Allison, 1997), highlighting the current lack of field data. Studies have only reported quantities (weight and/or volume assessment, some with only a visual assessment of content composition) of materials retained by trapping devices, but not the amount of gross pollutants bypassing the devices (Allison, 1997; Mudgway et al., 1997; Wong, 1998). The traditional visual assessment of GPT performance considered quantities caught, but failed to account for what was being transported to (or bypassing) the treatment device in terms of both composition and quantity, ie. mass balance (Wong and Wootton, 1998). As Wong (1998) explains, this situation did not allow for the historical determination of mass balance. However, these data were useful to a point in providing a very general assessment of performance, but fell short of being able to provide managers with any detailed field performance assessment between traps (Wong and Wootton, 1998).

GPT manufacturers generally claim many advantages with their products, as will be presented in the next section, such as cost-effectiveness, non-blocking, low maintenance, acceptable hydraulic performance, and highly efficient in the capture and retention of gross pollutants. Due to the lack of GPT field monitoring data, some information presented in the literature, including the supplier and manufacturer product information and the current Victorian Stormwater Committee guidelines (1999) is speculative, and has questionable validity. However, the Victorian Stormwater Committee (1999) present data relating to 'head' requirements associated with BMPs, and categorises losses according to low (< 0.5 m), medium (between 0.5 and 1.0 m), and high (> 1.0 m), but how these data have been sourced is unclear and may be speculative and not provide enough detail to designers.

As already discussed, the literature indicates that the actual field capture performance of those GPTs in the market place remains untested under field conditions, or unreported, and may require greater on-going monitoring and comparative research. This deficiency in field monitoring may be due to the expensive long term and tedious nature of field monitoring. Currently there are few data available to provide the designer with an adequate assessment of how various control measures will perform in the field, not only in terms of litter capture performance, but also in terms of hydraulic operating performance and energy 'head' losses. The literature review found few data for shock losses associated with current GPTs.

Normal measurements of pollutants in stormwater do not include gross pollutants, primarily because they do not fit into sample bottles (Mudgway et al., 1997), which has led to trapping techniques developed by Essery, as used by Allison (1997). Allison (1997; Allison et al., 1997b; Allison et al., 1998b) conducted valuable field research to evaluate the performance of SEPTs (litter baskets) using a large CDS as a downstream control (as discussed in sections 2.3.3 and 2.7.3). In this study, for all flow events passing through the downstream CDS control device (not bypassing), the performance of the upstream SEPTs could be determined. That is, performance evaluation of the SEPTs was not possible once the CDS diversion weir was bypassing, as there was no control, and may be seen as a severe limitation of the study.

The research conducted by Allison (1997) using a CDS device in Coburg, Melbourne, considered that the CDS has a capture performance (for all gross solids) of 98%. This was based on the theory that 100% of all gross solids are retained for the flow that passes through the device, where it is estimated that 98% of all pipe flows are diverted for treatment; ie. 98% hydrologic effectiveness. It was assumed in this short term study that the CDS captures all gross solids for all flows flowing through the device (treatment flows), as the internal screen has openings which are approximately the same size as that for the definition of gross solids (5 mm). However, this study does not account for litter transported past the CDS during high flows when the CDS is bypassing. Allison (1997) in the Coburg field studies found the energy losses associated with a large CDS™ (which has a fixed weir) were in the order of 250 mm for a flow depth of only 400 mm in a 1220 mm diameter pipe. These data indicate that shock losses can be significant where fixed diversion structures are employed, and cannot be ignored.

Lewis (2002) also conducted field performance monitoring of litter control devices, namely SEPTs (Ecosol RSF 100) and a Net-tech release net. Net bags with a 3 mm opening were placed downstream of the devices being tested to act as a downstream control, ie. to catch litter bypassing the devices being monitored. This procedure allowed capture performance to be evaluated for the upstream devices being tested whilst the bags were in place. However, the net bags used allowed release during high flow conditions to prevent flooding, rendering them ineffective, and performance data invalid during such conditions.

Wong and Walker (2002) in a GPT study for the NSW EPA report the following:

- The effectiveness of installed GPTs is made using a method that evaluates '*relative*' performance including modeled pollutant load and actual retrieved loads in clean-outs. This ratio provides a likely capture efficiency and is known as the '*capture index*';
- capture indices in this study could have been higher if traps were maintained and modeled pollutant loads may vary significantly from actual catchment loads;
- cost effectiveness of GPTs based on several methods, viz:
    - plotting unit area capital cost versus capture index; and
    - graphing a composite index [= capture index/unit area capital cost].

However, it is also reported that there are no data on loads bypassing the traps, and therefore no real assessment of performance, and no life cycle cost analysis is made.

Urbonas (1995) summarises, 'there is a great need for consistent reporting of various BMP parameters along with field testing data on their performance'. Various BMP studies in the USA were found to report on effectiveness, but not for gross pollutants, mostly sediments (Winker, 1997; Winker and Guswa, 2002). Chrispijn (2004), in a study in Hobart, also reports on field performance of various structural BMPs, however, once again, the percentage of load bypassing is not reported.

2.6.4.3 A decision support system (DSS) for structural litter control

A decision support system for gross pollutant trapping has also been created (Allison et al., 1998a). The DSS is intended to (Allison et al., 1998a):

- Aid catchment managers in choosing appropriate trapping strategies for gross pollutants; and
- Estimate the pollutant loads from different land-use catchments and the cost and performance of selected trapping systems.

The DSS considers the following (Allison et. al, 1998a):

- Seven main control techniques, namely street cleaning, SEPTs (side entry pit traps), trash racks, LCD (litter control device), CDS, GPTs (Canberra style), and FDT (floating debris trap); and
- Two primary aspects in evaluating the various techniques about trapping performances - the first is the system trapping efficiency, and the second is the maintenance requirements.

The DSS is intended to be used as a guide due-to the many input variables used (Allison et al., 1998a). In time, as more research data and results become available, additional data and new trapping techniques could be included into the DSS. The DSS assesses litter trapping combinations, based on litter capture performance data sets, as derived from previous research, such as Allison (1997).

2.6.4.4 Computer modelling

Many water quality models have now been developed to assist designers in evaluating stormwater treatment strategies, some of which have been referenced by Beecham (2002). Beecham (2002) explains that models vary greatly and include stochastic and deterministic models, and may be either spatially distributed or lumped, and may be in temporal terms either event or continuous. Newton and Jenkins (2002) highlight the importance of model calibration to ensure they adequately describe true behaviour. Computational fluid dynamics is also used in computer modelling to determine removal efficiency (Harwood and Saul, 1999).

A computer software program, MUSIC (model for urban stormwater improvement conceptualisation) has been developed to model urban runoff generation and pollutant load relationships, including data sets such as (Wong et al., 2003):

- Meteorological data;
- Catchment characteristics, such as percentage impervious and soils;
- Stormwater treatment measures, such as GPTs;
- Re-use; and
- Water quality objectives.

MUSIC is reported as suitable for catchments ranging in size from house lots to many square kilometers, and uses time steps ranging from 6 minutes to 24 hours to match specific scales (Wong et al., 2003). MUSIC models treatment measures based on a Universal Stormwater Treatment Model (USTM) that utilises the principles of hydraulic loading and pollutant behaviour (k-C*) and the hydraulic efficiency (λ), or 'N' (Wong et al., 2003), as identified in section 2.6.3.3.3.

GPTs are featured in MUSIC, with trap efficiency user-defined in terms of percentage load reduction and flow bypass (low and high), given that so many types of designs are available (Wong et al., 2003). However, it is noted that MUSIC is **not** a detailed design tool, and does **not** have any allowance for hydrologic routing for GPTs based on the assumption that they have a very small pool volume (Wong et al., 2003). Wong et al. (2003) report that future MUSIC versions will include life cycle costs.

2.6.4.5 Development of a GPT monitoring protocol

It is recognised that a standardised repeatable testing technique for GPTs is desired to create a 'level playing field' (SIA, 2002). SIA (2002) reports on a workshop agreement towards collecting GPT information on hydrologic/hydraulic operation and water quality data as a minimum, with more data only for selected GPTs.

Strecker et al. (2001) report that: 'inconsistent study methods, lack of associated design information, and reporting protocols make wide-scale assessments difficult, if not impossible'. Walker and Wootton (2000), in the development of a GPT monitoring procedure, report the following:

- determination of gross pollutant weight trapped does not adequately measure the effectiveness, as the pollutant load bypassing the system must also be collected and analysed;
- although the practice of trapping the bypassing load is important, it is also difficult and often not a practical or cost effective monitoring procedure, and consequently left out;
- measurement of discharge bypassing the unit was settled on as a substitute measurement to provide at least some indication of the potential pollutant load avoiding the system.

There is a need for a reliable, consistent and repeatable testing methodology for GPT performance evaluation. An approach using litter (item) capture performance (removal efficiency) for individual 'problem' or target items may be a suitable method for monitoring and assessing GPT performance in the field. This approach may also lead to future GPT testing and assessments that can be integrated into decision support systems. A methodology of field monitoring and evaluation of the ILLS GPT prototypes is presented in Chapter 3 of this thesis utilising a tagged litter study for litter capture performance evaluation.

2.7 BEST PRACTICE STRUCTURAL CONTROL MEASURES

2.7.1 General

There are many types of primary (pre-treatment) structural control devices that have been developed, and these may be categorised generally into the following, grouped according to their location within the stormwater system (Victorian Stormwater Committee, 1999):

1. Drainage entrance litter control:
    a) Grates and grilles;
    b) Baffled (gully) pits;
    c) Side entry pit traps (SEPTs); and
2. In-line litter control (within piped drainage systems):
    a) Diston™ trap;
    b) Canberra style minor 'GPT';
    c) Ecosol™ (RSF 4000, RSF 5000 & RSF 6000) solid pollutant filters;
    d) CDS Technologies™ Continuous Deflective Separation system;
    e) Cleansall™ weir diversion and basket retention system;
    f) Q-Guard™ stormwater treatment device;
    g) Q-Guard™ stormwater treatment device (Series X);
    h) Clevertek™ litter filtration system;
    i) Humegard™ (formerly In-line Litter Separator - ILLS) floating boom diversion and comb screening system; and
    j) BarRack™ collection GPT.
3. End of pipe litter control:
    a) Netting systems;
    b) Litter collection basket system;
    c) The Ski-Jump™ silt and litter trap;
    d) Circular fenced screen system;
    e) Self-cleaning inclined screens; and
    k) BarRack™ collection GPT.
4. Open channel and waterway litter control:
    a) Weirs and baffles;
    b) Netting and bag systems;
    c) Trash racks and screens;

d) Clevertek^{TM} litter filtration system;

e) Floating traps for open water;

f) Urban Water Environmental Management (UWEM) concept; and

l) BarRack^{TM} collection GPT (channel system).

The broad categories above (to be detailed in the remainder of this chapter) are a general guide only as the principles of some litter trapping systems can be modified to be fitted/constructed at almost any point in the drainage system. It must be noted that categories may also include other source control measures such as water sensitive urban design vegetated systems. Other vegetative systems may be examined in the literature and have been excluded for the purposes of this thesis in examining structural measures suitable for use in traditional drainage system design and retrofit situations. Vortex type devices have been primarily excluded, as Armitage et al. (1998) reports: 'Most of these devices require that the sediment is continuously withdrawn, and are suitable for the separation of sediments from sewage than for the removal of litter from stormwater'.

GPTs have evolved considerably in recent years (Wong and Wootton, 1998). In response to concerns expressed with earlier litter trapping systems, such as trash racks, and net control devices, several innovative GPTs have been developed for capturing gross solids within the piped system (close to the source of litter generation), which separate/divert and treat 'off-line' a design flow proportion of the pipe capacity.

The reason the within pipe 'off-line' devices are so attractive is that, unlike earlier generation litter trapping methods, pollutants are separated and held off-line, away from the main flow stream. This is highly desired, as gross pollutant accumulation and blockage may greatly affect operational performance, especially with sometimes critical hydraulic energy grade lines, and laborious maintenance requirements. Most new propriety devices are constructed with pre-cast concrete components, with some exceptions, and feature either a fixed weir, or floating boom type of diversion mechanism, with other internal components, such as screens or combs.

The various litter trapping technologies known to exist, as outlined above and discovered in the literature review, are now presented.

2.7.2 Drainage entrance litter control

2.7.2.1 Grates and grilles

Grates and grilles have been commonly used to cover stormwater collection pits, with metal bars providing a screen that allows water to pass through, whilst (mostly) large litter and debris are prevented from entering, preventing pipe blockages (Victorian Stormwater Committee, 1999). Despite ease of installation and common usage, the cost of maintenance, risk of matting and blockage and consequent flooding are of concern (Victorian Stormwater Committee, 1999).

2.7.2.2 Baffled (gully) pits

Baffled gully pits are not reported in use in Melbourne with standard urban stormwater systems. However, they are reported in use in older areas of Sydney (Victorian Stormwater Committee, 1999). They are reported as not very efficient in capturing gross solids, as most are scoured during stormevents, with only minor levels of sediment and floating litter being caught (Victorian Stormwater Committee, 1999).

2.7.2.3 Side Entry Pit Traps (SEPTs)

Although it is quite common to have modified side entry pits (SEPs) fitted with grates, there has been a large interest in fitting standard SEPs with litter baskets (which vary in construction) as a means of providing litter capture ability to an otherwise open SEP.

In most cases SEPTs are only utilised where a high concentration of litter is expected, not because they perform poorly in terms of litter capture, but as they have limited capacity, and their cleaning requirements are frequent and labour intensive. Hence they become relatively costly to maintain over a large scale (Allison, 1997). The trapping efficiency of most types of SEPTs will vary depending on factors such as litter load, SEP densities, storage capacity, and upstream curb length (Lewis, 2002). SEPTs are typically cleaned with vacuum plant operating on a monthly to six weekly cycle (Allison et al., 1997b).

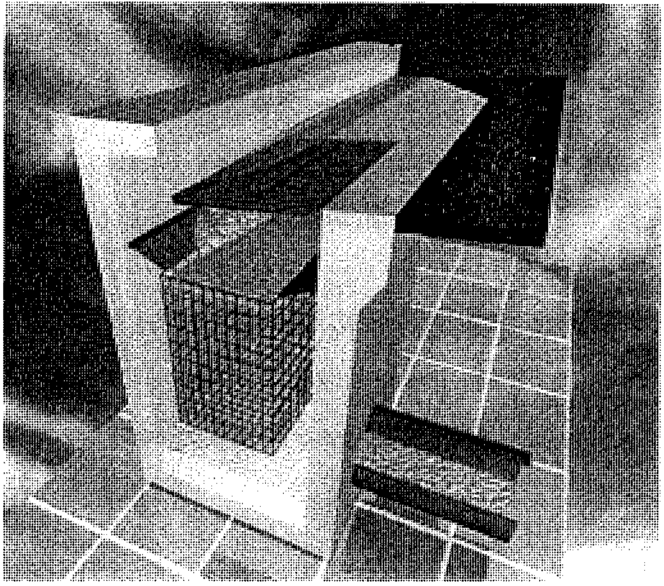
2.7.2.3.1 General SEPTs – litter baskets

This method of litter trapping typically employs a plastic or metal basket fitted within the SEP. Basket openings typically range in size from 5 to 20 millimetres. 'Off the shelf' products and suppliers include 'Banyule basket' (Banyule City Council, personal communication – Colin Rose, 1997), 'Litter basket' (Pit Clear industries), and 'Litter Guard' (Dencal Industries – product information, 1997), to name a few. If installed on all drainage entrances SEPTs can potentially capture 85 per cent of litter load, and up to 75 per cent of the total gross pollutant load (Allison, 1997).

2.7.2.3.2 Ecosol™ RSF 100 and RSF GSP filtration systems

An innovative type of trap developed by Ecosol™, featuring a hydraulic flap for bypassing above design flows, appears to be an effective SEP trapping mechanism. The openings are typically 1.5 mm in size, but it is claimed that 75% (approximately) of the captured pollutants are smaller than this (Ecosol Pty Ltd, Product information, 1999). The RSF 100 is designed for SEPs, the RSF GSP is designed to be fitted to grated pits, and the RSF 100/GSP (refer to Figure 2.5) is designed for grated SEPs. All three are very similar in operation. Lewis (2002) found that the RSF 100 can have a litter removal efficiency of up to 82% by mass, and up to 88% by volume.

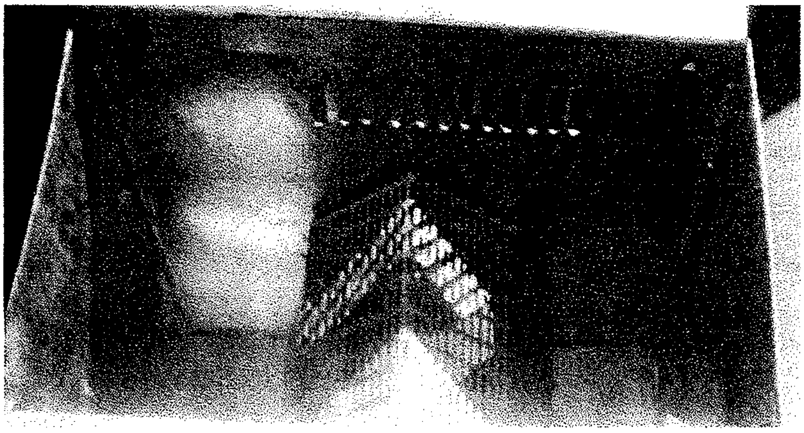
Figure 2.5 The Ecosol™ RSF 100/GSP (Product information, 1999).



2.7.2.3.3 'WeldAll Litter trap' (WeldAll Industries International Pty Ltd)

This type of SEPT, shown in Plate 2.8, is not well known or widely used to date, and no independent performance testing evaluation is known to exist. This trap simply drops into a standard side entry pit, and consists of a perforated metal plate-frame with an apex (to split the incoming side entry flow) which covers the pit outlet pipe, retaining gross solids. A build-up of gross solids in the SEP, coupled with a large storm event, may have the potential to create pit blockage and reduced system capacity and may require frequent cleaning.

Plate 2.8 WeldAll™ Litter trap (WeldAll Industries International Pty. Ltd., Author's photograph, 1999).



2.7.2.3.4 'Enviropod Litter trap' (Ingal Environmental Services Pty Ltd)

Ingal Environmental Services (2002) market a gully insert pit 'Envirtopod™'. Many examples of field experience may be referenced at the company web site: http://www.ingalenviro.com/enviropod.asp. Christpijin (2004) reports on field studies involving this type of trap, as discussed in section 2.6.4.2.

2.7.3 In-line litter control (within piped drainage systems)

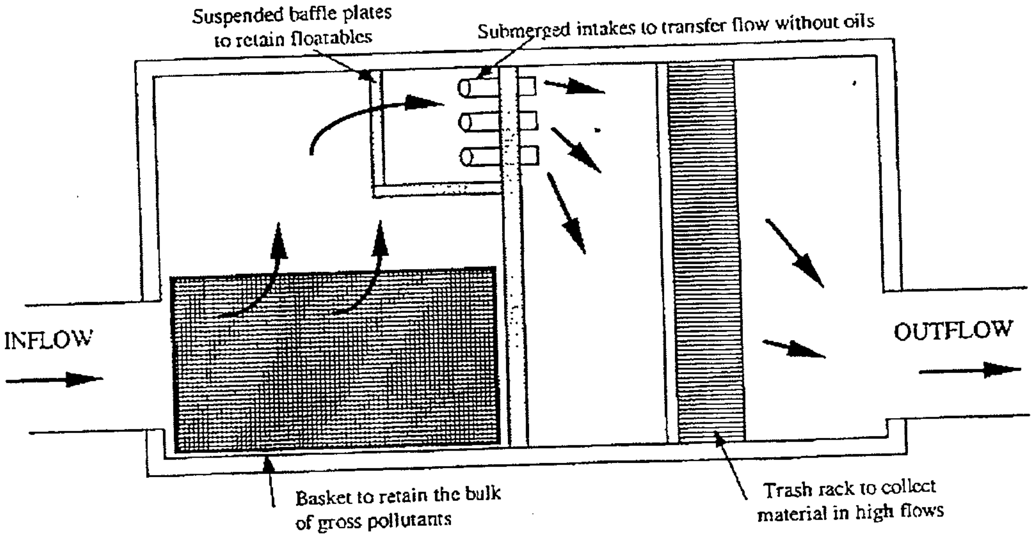
Most of the following GPTs installed within piped drainage systems possess a residual wet sump which may lead to the breakdown of collected pollutants (Victorian Stormwater Committee, 1999).

2.7.3.1 Diston™ trap

The Diston™ trap is a pre-cast concrete litter trapping device that may be fitted to new drainage systems or retrofitted to existing drainage systems (product information, 1999). Diston™ traps may be installed in-line, or preferably fitted on a bypass line, treating a design flow. The trap comprises three chambers (Keller and Winston, 1999). The first chamber separates coarse sediments, whilst the second chamber is fitted with a net bag (20 mm openings) and a weir fitted with a baffled siphon arrangement for low flows (which can retain oils and floatables), and the third chamber contains screen/trash-rack to retain litter bypassing the front cell in high flow events (product information, 1999; Keller and Winston, 1999). Figure 2.6 shows a plan view of a Diston™ trap with no front chamber shown.

An advantage with this trap is that it keeps litter out of contact with stored water where there is not a drowned outlet (product information, 1999). Although laboratory studies have been undertaken showing the system is effective (Keller and Winston, 1999), no field data are available on hydraulic and litter capture performance of this trap.

Figure 2.6 Plan view of the Diston™ trap (source: Allison, 1997).



2.7.3.2 Canberra style minor 'GPT'

The Canberra style minor 'GPT' consists of a sediment sump and downstream trash rack, both in-line and fitted within a concrete lined structure (Brouwer, 1987; Phillips et al., 1989; SPCC, 1989). There are many modifications known (Monash City Council, personal communication David Flemming, 1998). As with all in-line trash rack systems, they are prone to blockage, trapping performance is questionable, upstream backwater effects may cause flooding, and maintenance may be seen as difficult and costly (Victorian Stormwater Committee, 1999). The major 'GPT' system is described in section 2.7.5.3.1.

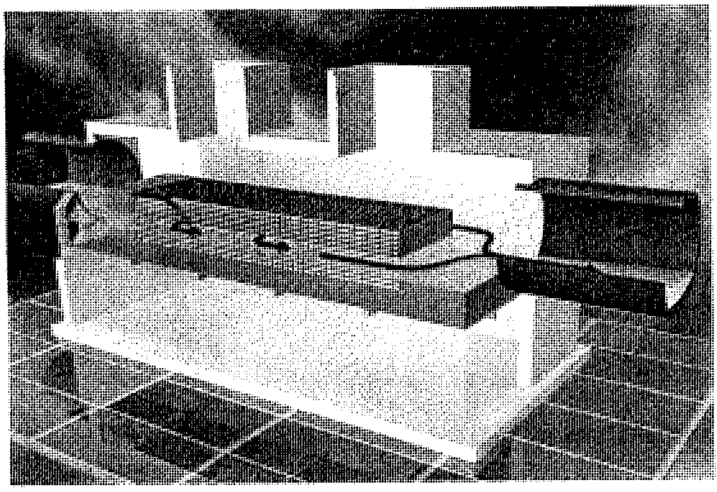
2.7.3.3 Ecosol™ (RSF 4000, RSF 5000 & RSF 6000) solid pollutant filter

The Ecosol™ RSF 6000 (refer to Figure 2.7) is designed to trap gross solids alone, and is also known as a 'Return flow litter basket' (Victorian Stormwater Committee, 1999). The RSF 4000 and RSF 5000 are both similar models to the RSF 6000, however they are both fitted with an oil and grease baffle. The RSF 4000 is also designed to trap gross solids, where the RSF 5000 is designed to trap oil and grease alone. It is claimed that both the RSF 4000 and RSF 6000 will capture 95% of gross pollutants and significant quantities of sediment (product information, 1999). However, it is also claimed that the RSF 6000 is a superior GPT when compared to the RSF 4000, as the RSF 6000 filters gross pollutants down to 1 mm, whereas the RSF 4000 only filters down to 3 mm (product information, 1999). What is not clear is that if they both vary in terms of filtration, how can they both supposedly filter 95% of gross solids.

The RSF 6000 mode of operation can be seen in Figure 2.7. Flow enters the chamber and is directed into the basket system by a 'hydraulic weir', then passes through the basket, filtering gross solids, before exiting the chamber and continuing through the piped system. The force of 'return flow' water leaving the collection basket produces the 'hydraulic weir', or 'hydraulically driven barrier', which diverts incoming flows into the collection basket (Victorian Stormwater Committee, 1999). Flows greater than basket capacity bypass the system avoiding scouring of previously retained pollutants (Victorian Stormwater Committee, 1999). Although laboratory studies have been undertaken showing the system is effective (The University of Adelaide, 1998), no

Australian field data describing the trapping performance are known to exist (Victorian Stormwater Committee, 1999).

Figure 2.7 The Ecosol™ RSF 6000 (Product information, 1999)



Claimed advantages with the RSF 6000 (Victorian Stormwater Committee, 1999) are:

- can be retrofitted into existing drainage systems;
- hydraulically driven barrier minimises head losses;
- can operate in a range of pipe slopes; and
- only requires standard maintenance plant.

Claimed limitations with the RSF 6000 (Victorian Stormwater Committee, 1999) are:

- potentially large structure requiring substantial area for installation; and
- potential breakdown of collected pollutants.

2.7.3.4 CDS Technologies™ Continuous deflective separation system

Figure 2.8 shows a plan section of a CDS GPT under design flow operation. In-flows are diverted away from the piped drainage system on the left of Figure 2.8, by use of a low fixed diversion weir, into the CDS separation and containment chamber (Wong et al, 1997). Event flows (above the design flow rate) pass over this diversion weir and continue in the drainage system untreated, whilst design flows pass into the separation chamber and are kept in circular motion before passing through a perforated circular screen, and discharging back into the drainage system on the right (Wong et al., 1997).

Pollutants that enter with design flows are kept in continuous motion and are prevented from 'blocking' the screen (Victorian Stormwater Committee, 1999). This is achieved by a hydraulic design that ensures the tangential force on an object is significantly higher than the normal force driving the object to the chamber wall (Wong et al., 1997; Victorian Stormwater Committee, 1999). Figure 2.9 shows a section of the circular screen in operation. The separation chamber also contains a wet sump.

Claimed advantages with the CDS include (Victorian Stormwater Committee, 1999):

- very high removal rate;
- low head requirements;
- can be retrofitted into existing drainage systems with minimal visual impact;
- traps coarse sediment, with some fine sediment also retained;
- units with submerged screens can also retain oils; and
- minimal maintenance requirements.

Claimed limitations with the CDS include (Victorian Stormwater Committee, 1999):

- expensive to install;
- potentially large structure requiring substantial area and depth; and
- potential breakdown of collected pollutants in wet sump.

Figure 2.8 Plan section of CDS in operation (product information, 2000)

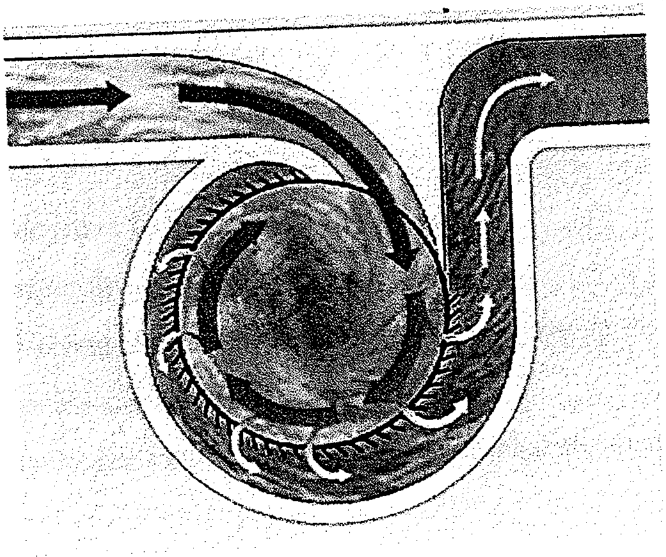
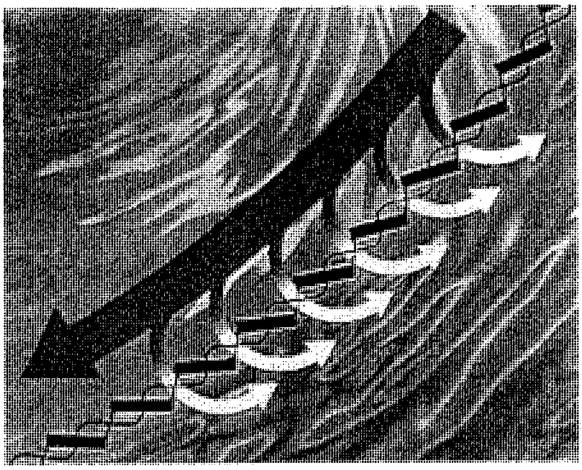


Figure 2.9 Plan section of CDS circular screen (Product information, 2000).



Despite claiming that the CDS has a low head requirement (Victorian Stormwater Committee, 1999), the author considers this dubious, as Allison (1997) claimed that the CDS installed in Coburg features a 400 mm head loss at a flow rate of only 600 L/s. This indicates that the expected head loss associated with full pipe flow conditions may well be significant, which is supported by Wong et al. (1997). Allison et al. (1996; and Allison, 1997) make no assessment of the potential head loss of the CDS under full pipe flow conditions. Head requirements may therefore be considerable, if not high.

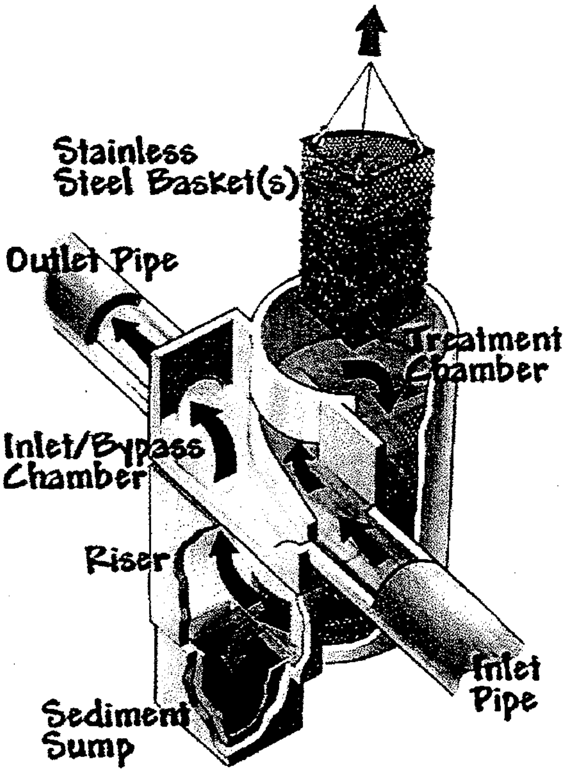
2.7.3.5 CleansAll™ weir diversion and basket retention system

The CleansAll™ device (as shown in Figure 2.10) is manufactured by Rocla Limited. It is similar to the CDS device described above in that it utilises a fixed weir to divert treatment flows away from the drainage system into a treatment chamber. However, the CleansAll™ utilises perforated baskets within the treatment chamber to screen and retain pollutants from the treatment flow.

Components include (refer to Figure 2.10):

- an inlet chamber fitted with diversion weir;
- a treatment chamber fitted with one to four removable stainless steel filtration basket(s) - with associated frame; and
- a chamber outlet and riser channel fitted with a small sediment sump.

Figure 2.10 CleansAll^{TM} GPT (Product information, 1999).



In operation (shown in Figure 2.10), storm flows enter the inlet channel, where the overflow weir diverts treatment flows into the treatment chamber and allows excess flows to spill and bypass. Diverted flows enter the treatment chamber and circulate, allowing pollutants to separate out, before continuing down into (and through) the filtration basket(s). Filtered stormwater continues through to the sediment sump and basket, before travelling up the riser to the outlet behind the diversion weir, returning to the pipe system.

The settling of sinkable pollutants within the baskets is aided as follows (product information, 1999):

- large mesh area ensures mesh flow velocities are small;
- weight of sinkables enables them to settle without being forced against mesh; and
- mesh downward facing grain prevents clogging.

The treatment screen is reported to have an open aperture size of 1 mm by 3 mm, with a head loss 'K value' (refer to equation 2.1 in section 2.6.3.2.1) of up to 1.4 for pipe grade are commercially available, with the largest unit having a maximum pipe flow-rate of 6.5 cumecs (product Information, 1999). Although laboratory studies have been undertaken showing the system is effective (Argue and Pezzaniti, 1998), no field data are known to exist.

2.7.3.6 Q-Guard™ stormwater treatment device

The Q-Guard™ (shown in Figure 2.11) is essentially a concrete treatment chamber with an internal flow control unit and treatment assembly, manufactured by James Hardie Australia Pty Ltd. The treatment chamber includes a residual wet sump type 'treatment module' (for the collection and storage of settleable solids), a riser module, roof slab, access shafts, and lids (product information, 2002). The flow control unit consists of an inclined weir (with side chutes) for directing treatment flows into the treatment chamber (sump), and allowing high flows to overflow and bypass (product information, 2002). The treatment assembly consists of a high flow bypass pipe, a treatment flow outlet, fitted with an inverted conical screen (with an unreported opening size), for the retention of gross pollutants, and an inspection lid (product information, 2002).

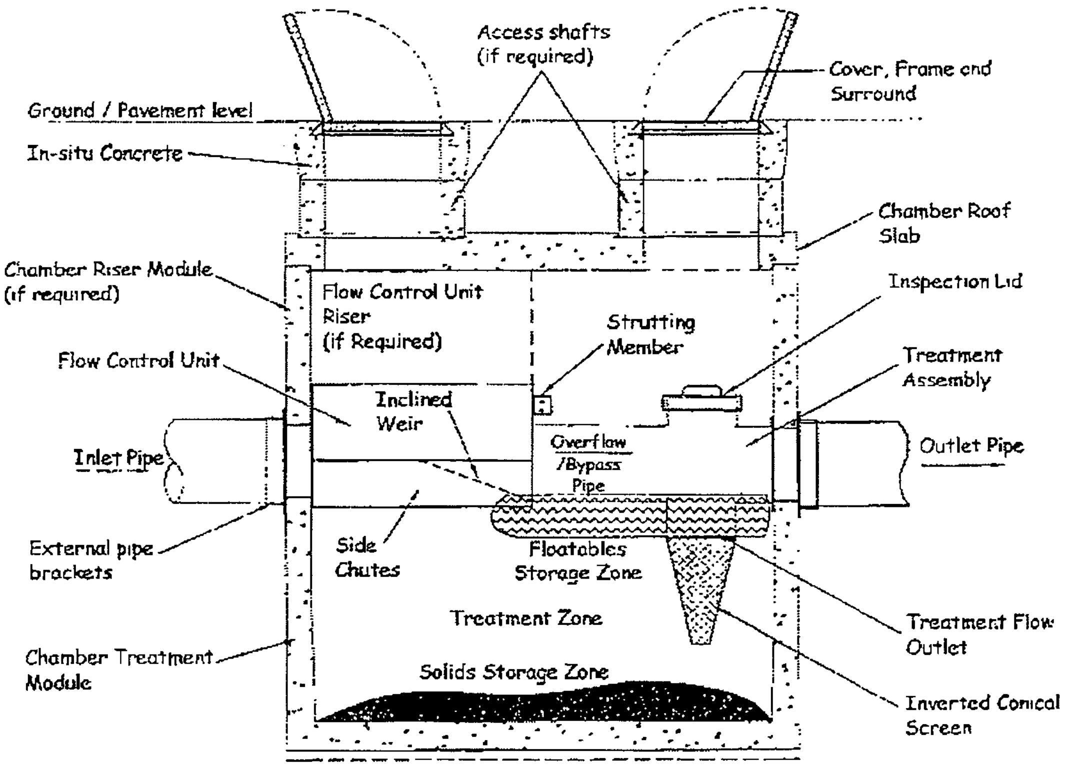
No field monitoring has been reported in the literature. However, based on laboratory testing, the manufacturer claims that the Q-Guard™ (product information – technical manual, 2002):

- removes and retains 'up to 95%' of material greater than 3 mm in size; and
- that a 'K value' of 1.3 should be adopted for full pipe situations in considering hydraulic losses for the device (refer to equation 2.1 in section 2.6.3.2.1).

It is unclear with the first point above about what materials have been used in the laboratory testing and therefore the relevance or usefulness of this information.

The range of Q-Guard™ models available can be installed onto drainage systems with a range of pipe sizes from 225 mm diameter up to 750 mm diameter (product information, 2002). It is recommended that cleaning be performed using eduction or vacuum equipment (product information – maintenance manual, 2002). The conical screen cleaning requirements (or frequency) are not discussed in the literature.

Figure 2.11 Section elevation through 'Q-Guard'^{TM} Stormwater treatment device – by James Hardie Australia Pty Ltd (product information – installation manual, 2002).



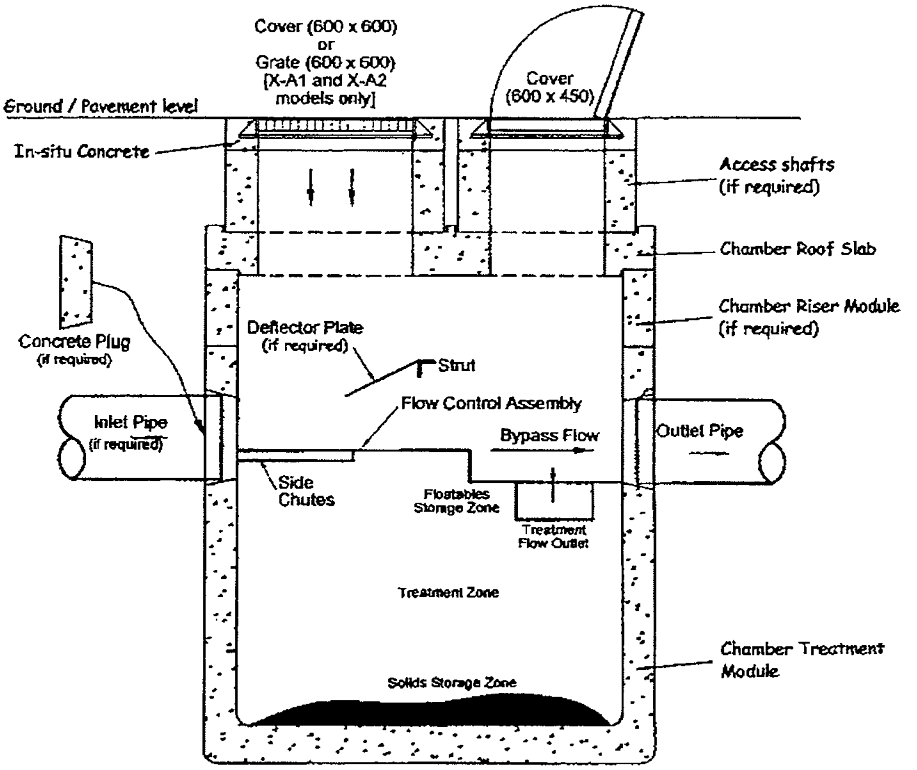
2.7.3.7 The Q-Guard^{TM} (Series X)

The Q-Guard^{TM} Series X, as shown in Figure 2.12, is somewhat similar to the standard Q-Guard^{TM}, but varies in that it may also allow for surface flow to enter (via a grated cover, or in some units a side entry pit), and is primarily intended to capture oils and greases (product information – technical manual, 2002). All flow to the level of the main platform of the flow control assembly are treated, but screening of the treatment flow outlet is not shown or specified in the product information (Q-Guard technical manual, 2002). As with the standard Q-Guard^{TM}, the Q-Guard^{TM} Series X models have not undergone any field monitoring (product information – technical manual, 2002). However, based on laboratory testing, the manufacturer claims that the Q-Guard^{TM} Series X (product information – technical manual, 2002):

- removes and retains 'up to 95%' of free oils and greases;
- removes and retains 'up to 85%' of gross pollutant material greater than 3 mm;
- removes and retains 'up to 100%' of coarse sand and aggregates; and

- that a 'K value' of up to 8.0 be used for full pipe situations in considering hydraulic losses, depending on the proportion of surface grate in-flow.

Figure 2.12 'Q-Guard - Series X'^{TM} Stormwater treatment device, James Hardie Australia Pty Ltd (Product information – Installation manual, 2002).



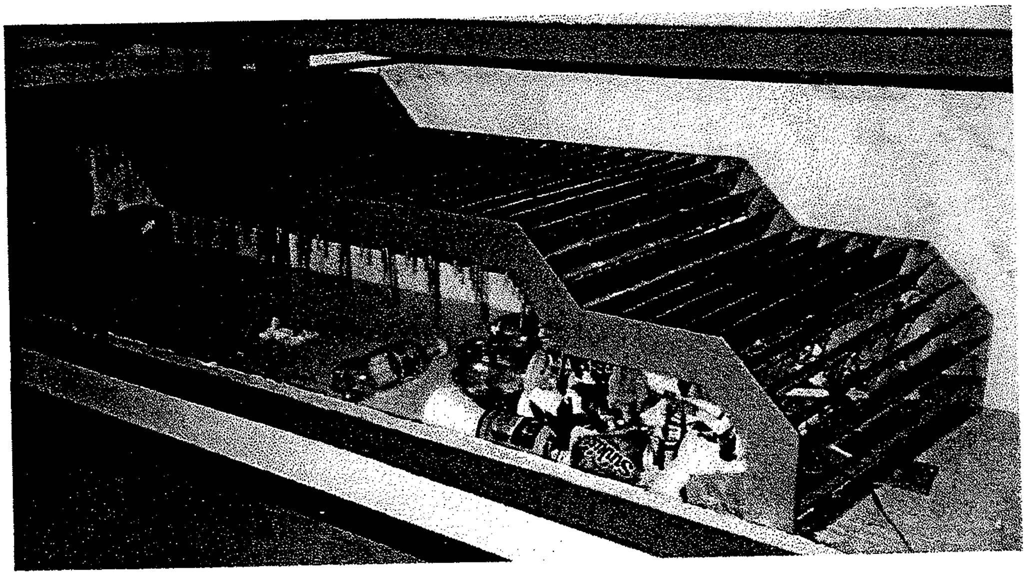
The range of Q-Guard^{TM} Series X models available can be installed onto drainage systems with pipe sizes up to 900 mm diameter (product information, 2002). It is recommended that cleaning be performed using eduction or vacuum truck and tanker (product information – maintenance manual, 2002).

2.7.3.8 Clevertek^{TM} litter filtration system

Clevertek^{TM} is a new type of litter trap, which is yet to be employed, and has been designed without a residual wet sump specifically for keeping litter dry once it has been trapped (product information, 2003). The Clevertek^{TM} system employs use of a diversion weir, which can be set for a design flow that is then directed away from the drainage system into a treatment chamber, and a high flow bypass pipe, which is employed once system flows rise above the design flow and diversion weir (product information, 2003). Plate 2.9 shows an in-line laboratory model of the Clevertek^{TM}.

employed once system flows rise above the design flow and diversion weir (product information, 2003). Plate 2.9 shows an in-line laboratory model of the Clevertek^{TM}.

Plate 2.9 Clevertek^{TM} in-line laboratory model (Authors photograph, with permission from Mr Tim Fisher of Clevertek Pty Ltd, 2003).



The treatment chamber houses a fixed screening system, consisting of a series of horizontal metal bars (perpendicular to the flow stream), which are set in a number of horizontal layers, which allow flows to pass through (product information, 2003). The spacing of horizontal bars can vary depending on the size of the target litter item (Clevertek Pty Ltd, personal communication, Mr Fisher, 2003). Each of the horizontal metal bars has a series of fixed vertical metal spikes (between 100 to 150 mm in length) attached, which are to prevent litter from matting against the horizontal bars, with the majority of spikes pointing downwards into the flow (product information, 2003).

As no Clevertek^{TM} systems are yet known to be installed onto piped drainage systems, there were no performance data or maintenance history available in the literature. It is intended that maintenance would involve removing the grilled covers, tilting up the horizontal bars panels (which are hinged), and cleaning by means of an eductor truck or back-hoe (Clevertek Pty Ltd, personal communication with Tim Fisher, 2003). It is also possible to construct this device within open channels and waterways (Clevertek Pty Ltd, personal communication with Tim Fisher, 2003).

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2.7.3.9 Humegard^{TM} (formerly In-Line Litter Separator – ILLS) floating boom diversion and comb screening system

The Humegard^{TM} is currently manufactured by Humes in Australia. Following a review of the literature, this system was the only in-line GPT known to feature a floating boom diversion system, and is presented in Chapter 5, and is examined in this thesis.

2.7.3.10 BarRack^{TM} GPT

Two BarRack^{TM} GPT systems are known to exist, namely the 'DryCyl' and 'WetCyl' systems (product Information, 2003). This pre-cast concrete GPT, which is claimed to remove 95% of pollutants, consists of a chamber housing an inclined 'cylinder grate', an overflow bypass, and a fixed or removable collection basket with unknown screen properties (product information, 2003). However, it is not detailed which pollutants the performance claim relates to, and no field performance test data are known to exist. This system may be typically fitted to pipes ranging in size from 300 mm to 1200 mm in diameter, but may be made to fit larger diameters (product information, 2003). The 'WetCyl' system is also designed for free-oil collection and contains a wet sump (product Information, 2003). The 'DryCyl' system operates either 'in-line' or 'end of line' with unlimited head loss (product information, 2003). Full details of the head loss requirements are not provided, but a minimum 100 mm head loss is required (product information, 2003). The BarRack^{TM} system may be typically cleaned by eduction methods, but may be fitted with removal collection baskets (product information, 2003).

2.7.4 End of pipe litter control

2.7.4.1 Netting systems

2.7.4.1.1 Net Tech^{TM} – release net system

This type of system simply comprises a net basket/bag, with 20 mm openings (Lewis, 2002), fitted to the end of a pipe with a quick release valve, as shown in Plate 2.10. Whilst the net is fitted, all flows pass through, trapping gross pollutants to the size of the net openings (and smaller) and once the net bag reaches capacity the pressure relief valve activates a release mechanism (Victorian Stormwater Committee, 1999). For maintenance, the net basket/bag is manually released and lifted using a small crane into a truck for emptying (Net Tech^{TM} product information, 1999). Lewis (2002) found that

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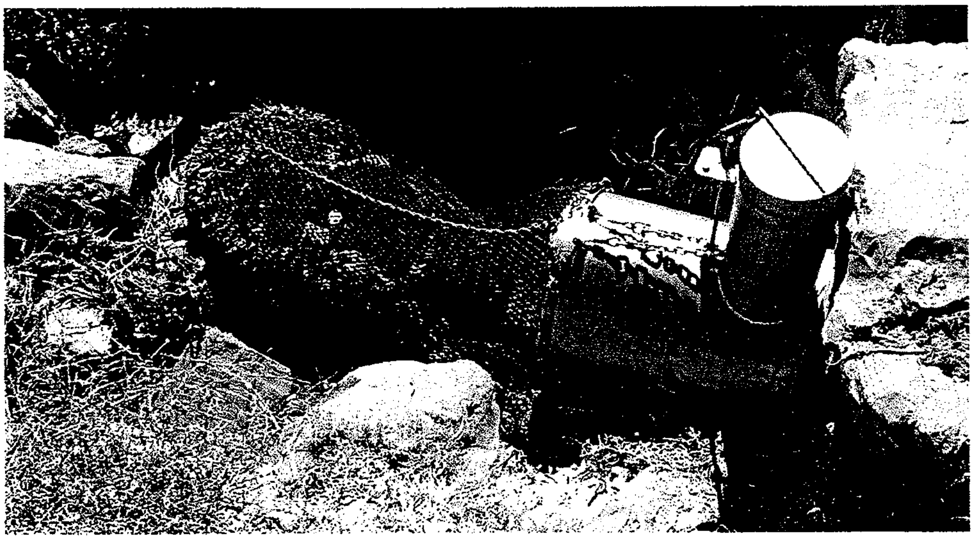
this type of trap can have a capture efficiency of 93% by volume (84% by mass) for litter, and 90% by volume (68% by mass) for total gross pollutant load.

Plate 2.10 Net Tech™ release net system (Mr M Noyce, Melbourne Water, 2002).



Claimed advantages include (Victorian Stormwater Committee, 1999):

- Low installation costs;
- Simple to install at pipe outlets;
- Volume of netting and pore size can be easily altered; and
- Easy to maintain involving no manual handling of pollutants.

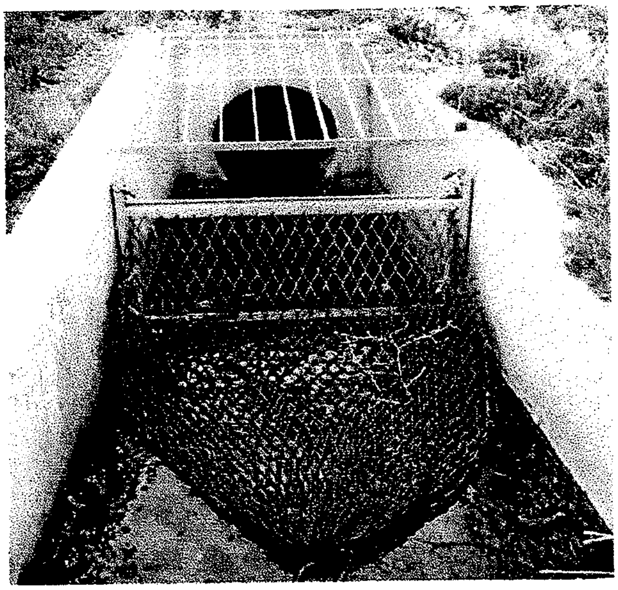
Claimed limitations include (Victorian Stormwater Committee, 1999):

- Can be visually unattractive;
- Could be exposed to vandalism; and
- Potential odours from collected pollutants.

2.7.4.1.2 Fixed net systems

Fixed net bag systems may also be placed at drainage pipe outlets (see Plate 2.11), but may also be used in open channels and waterways (refer to section 2.7.4.1). Fixed net systems do not feature a release mechanism and blockage and head losses may be of concern, as is the expected cleaning frequency. A number of suppliers may be found in Australia. Cleaning requires a truck fitted with a lifting arm (Environmental Solutions (Aust) Pty Ltd, product information, 2003).

Plate 2.11 'Environment and Civil' type net systems (Product information, 1999).



2.7.4.2 Litter collection basket systems

2.7.4.2.1 Litter collection baskets

One of the most well known end of pipe litter basket systems is the North Sydney Litter Control Device (LCD), as shown in Figure 2.13, which employs a trash rack above the baskets to direct flow and litter through the baskets (Brownlee, 1995).

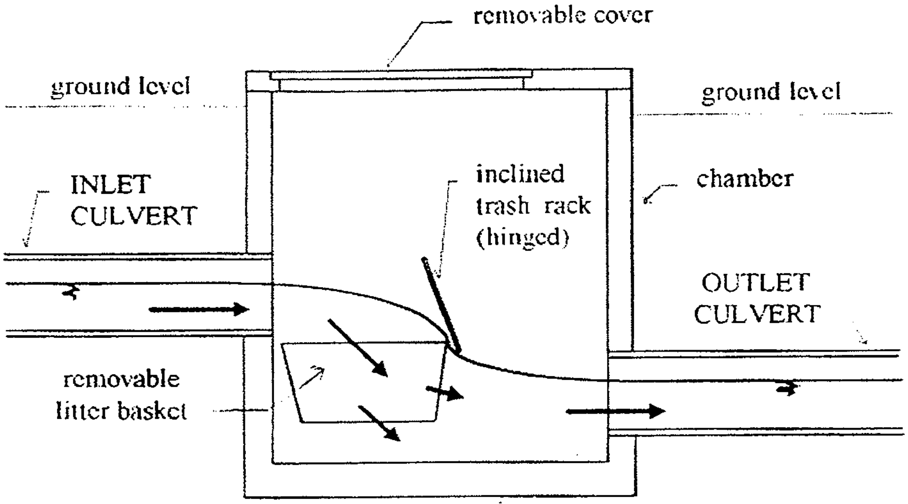
Claimed advantages include (Victorian Stormwater Committee, 1999):

- Can be retrofitted into existing drainage systems;
- Potentially useful in areas of high litter loads;
- Easy to maintain;
- Can be used as a pre-treatment for other measures; and
- Minimal visual impact as installed underground.

Claimed limitations include (Victorian Stormwater Committee, 1999):

- requires large head for effective operation (approximately 1000 mm);
- can cause upstream flooding if blocked; and
- previously caught material may be resuspended if overtopping occurs.

Figure 2.13 North Sydney Litter Control Device (source: Armitage et al, 1998)



Systems similar to the LCD have been employed in Melbourne, as shown in Plate 2.12. The device operation is relatively simple, with water flowing directly from the piped drainage outlet into the baskets situated below the pipe invert. As can be seen, these cages soon clog with gross solids, and are expected to be ineffective.

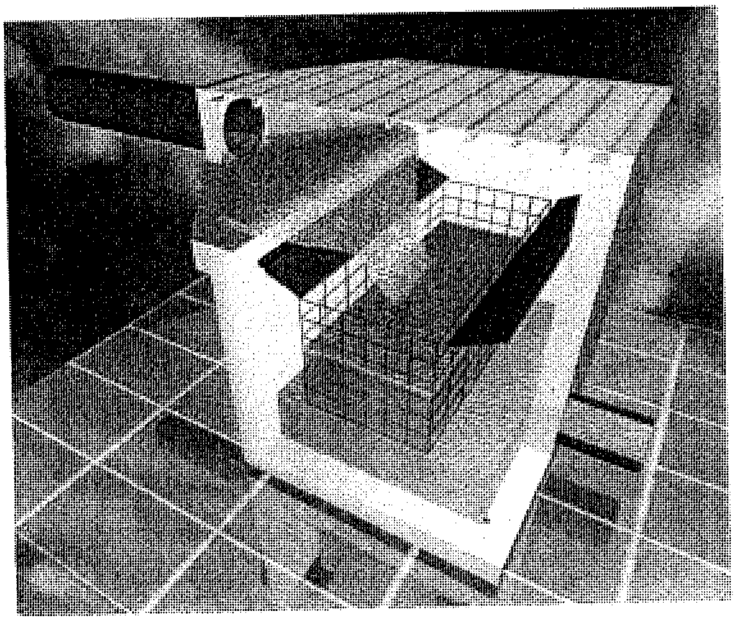
Plate 2.12 Litter cage at drainage outlet (Author's photograph, 1998).

2.7.4.2.2 Ecosol^{TM} (RSF 1000) solid pollutant filter

The Ecosol^{TM} RSF 1000, shown in Figure 2.14, is similar in operation to the Ecosol^{TM} RSF 100, RSF 100/GSP and RSF GSP (already described), with all systems featuring a hydraulic flap (for flows once the basket has reached capacity), however, it is fitted to pipe outlets (product information, 1999).

It is also claimed that the RSF 1000 can filter 95% of gross pollutants, and that gross pollutants down to 3 mm and less are filtered (product information, 1999). No field performance data are known to exist. A significant drop may be required to fit this type of trap. It is expected that eduction methods would be employed in cleaning.

Figure 2.14 Ecosol^{TM} RSF 1000 (Product information, 1999).



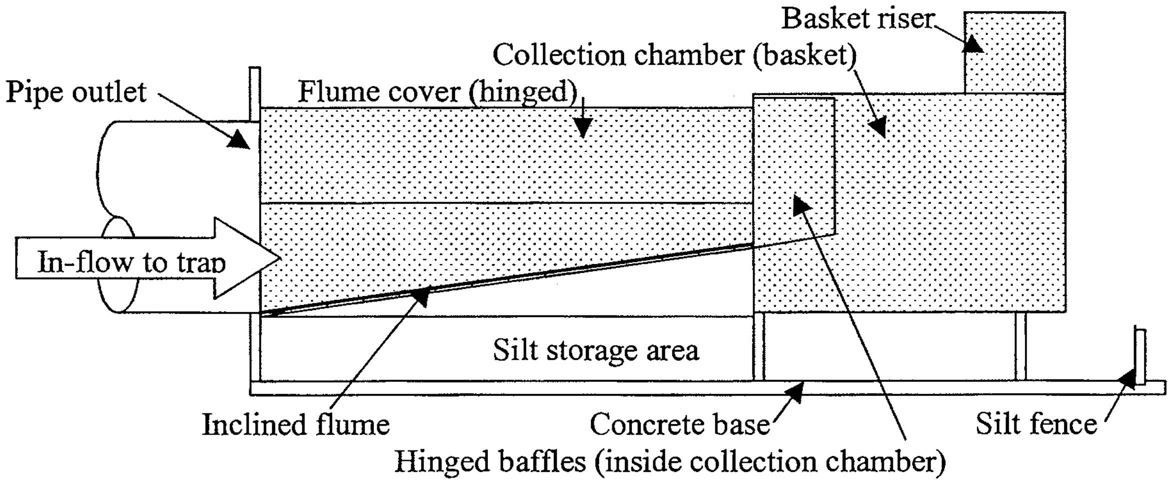
2.7.4.3 The Ski-Jump^{TM} silt and litter trap (after Mr D Nicholas)

The Ski-Jump silt and litter trap (after Mr D Nicholas) is shown (long section) in Figure 2.15. This device is fitted to the piped outlet of a drainage system, and can be fitted to pipes with a nominal diameter of up to 1650 mm (Ski-Jump runoff services, personal communication with D Nicholas, 2003). The device is a metallic structure consisting of the following components (product information, 2002):

- a rising flume (directs flow from pipe into collection chamber/baskets);

- one or more collection chambers (modular baskets);
- two hinged baffles fitted to the first basket (which close as the baskets fills and material builds against them to prevent captured litter escaping to the flume during a bypass event);
- a basket riser (fitted to the chamber for maintenance and access); and
- hinged flume covers (a release mechanism which lifts under extreme events, bypassing above design flows).

Figure 2.15 Long section of Ski-Jump™ silt and litter trap – after Mr D Nicholas, 2002 (Author's figure).



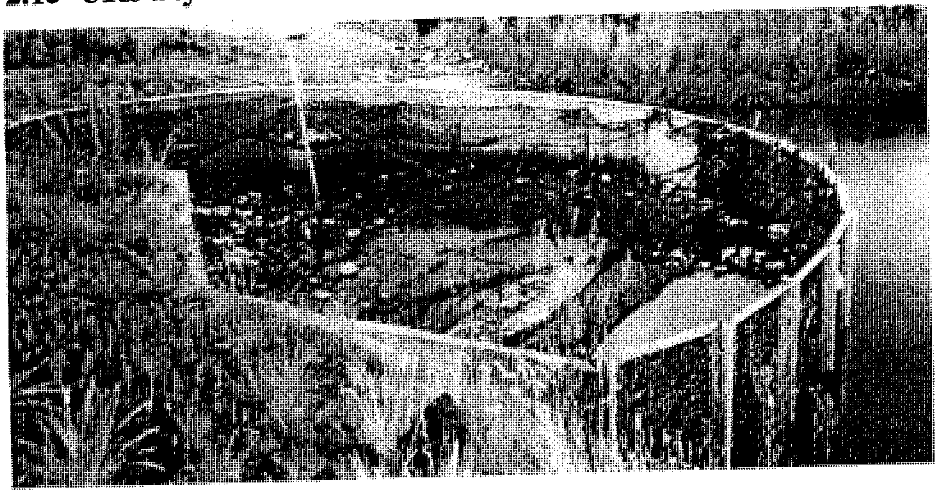
All trap surfaces are made from 5 mm aperture expanded steel mesh that allows water to pass through, filtering out gross pollutants (product information, 2002). An advantage of this device is that trapped litter is kept free of water, allowing it to dry out between runoff events. Energy (head) losses and capture efficiency for this device are not provided in the product literature, however, all material greater than 5 mm is expected to be trapped up to the point of high-flow bypass (ie. flume covers lifting). A drop of 300 to 400 mm at the piped outlet to accommodate this device is recommended. Maintenance requirements of this device are not discussed in the literature. Optional silt and oil trap fittings are also available (product information, 2002).

2.7.4.4 Circular fenced screen system

This method, developed for constructing downstream of a piped outlet, is similar to that tried by Visage (1994) in South Africa (Armitage et al., 1998), known as the

'Enviroscreen'. The author is only aware of two previously constructed devices, both designed by URS Australia Pty Ltd (formerly Woodward Clyde Pty Ltd), and were located in Melbourne at Karkarook wetlands, as can be seen in Plate 2.13 (stormwater inflows enter from a drain to the left).

Plate 2.13 URS Pty Ltd circular screen system (Author's photograph, 1998).



It can be seen that much litter is matting the metal-screened fencing, creating overtopping of the collection area in storm events, and accumulating on the far bank. A considerable gap (of approximately 50 mm) was found at the start of the fencing upon inspection. This would potentially allow a proportion of gross solids to escape, even when the collection area is not overtopped. Melbourne Water has decommissioned one of these devices and replaced it with a net bag system (Melbourne Water, personal communication with Mr M Noyce, 2003).

2.7.4.5 Self cleaning inclined screens

A great number of screens have been tried in an attempt to construct the ideal litter trap, ie. Bondurant and Kemper (1985), Bouvard (1992), Beecham and Sablatnig (1994) (on-line: 15 types, off-line: 23 types), Compion (1997), and Watson (1996) (from Armitage et al., 1998). Self cleaning screens were also examined by Nielson and Carleton (1989). However, the most popular types to date are the Baramy^{TM} trap developed in Australia, and the Stormwater Cleaning System (SCS) developed in South Africa, both of which are similar in make-up and operation.

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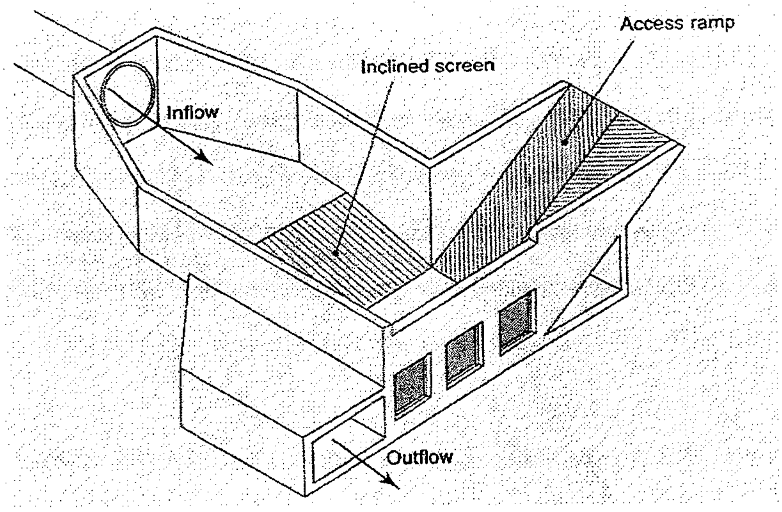
2.7.4.5.1 Baramy™ inclined screen

The most notable inclined screen system within Australia is produced by Baramy™ Pty Ltd (refer to Figure 2.16).

Figure 2.16 Baramy™ downwardly inclined screen (Victorian Stormwater Committee, 1999).



When there is an adequate physical drop available (usually in the order of 700 mm to 1500 mm, but down to 350 mm for some units), this type of GPT becomes suitable (Armitage et al., 1998). Gravity is utilised by allowing the flow to fall through an inclined trash rack, forcing solids greater than the bar spacing to separate into a forward holding compartment. Unless the required head-loss can be designed into the drainage system, inclined screening devices are usually installed at the outlet of a drainage system where a physical drop is available. Although laboratory studies have been undertaken showing the system is effective (Edgtton et al., 1997), no Australian field data describing the trapping performance are available (Victorian Stormwater Committee, 1999). Cleaning is expected to be performed using a 'bobcat' or similar.

Claimed advantages include (Victorian Stormwater Committee, 1999):

- Screen is kept free from blockages so flooding is avoided;
- Pollutants are kept dry before removal;
- Easy to maintain with standard plant;

- Relatively simple to install; and
- Potentially high trapping efficiencies.

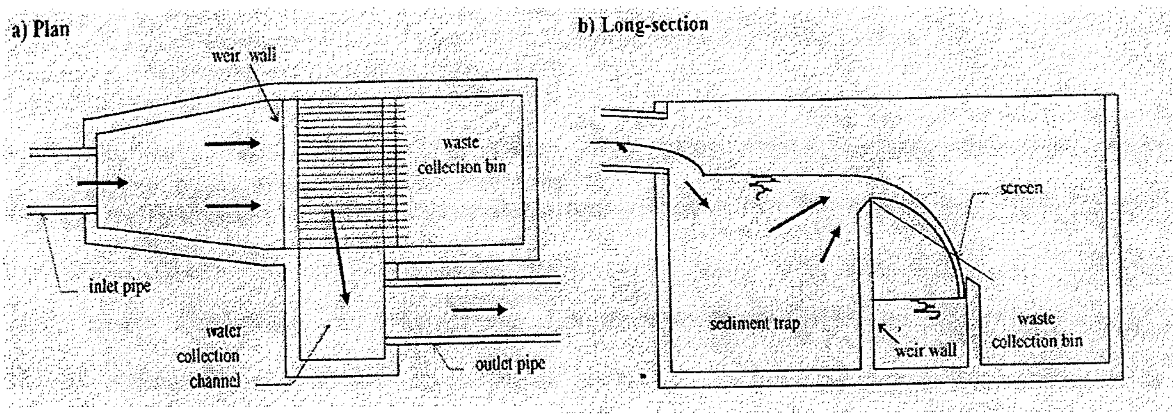
Claimed limitations include (Victorian Stormwater Committee, 1999)

- Limited to sites where a suitable drop in the channel bed is possible; and
- Potentially large structure requiring substantial area.

2.7.4.5.2 Stormwater Cleaning System (SCS); after Nel (1996)

This type of litter trap, shown in Figure 2.17, is similar to the Baramy™ trap discussed above, and was developed in South Africa (Armitage et al., 1998). SCS features screens angled at approximately 45 degrees and can be installed in pipes, at pipe outlets, or in open channel or waterway situations. No performance data are provided in the product literature. Costs and maintenance details are unknown.

Figure 2.17 Stormwater Cleaning System – SCS (source: Armitage et al., 1998).



2.7.4.6 BarRack™ GPT

The BarRack™ system described in Section 2.7.3.10 may also be used at end of pipe.

2.7.5 Open channel and waterway litter control

The pioneering litter traps first employed consisted of basic wire fencing material in coils around fence posts, and screens (MMBW, 1989). The more recent types of traps used in open waterway and channel applications are now presented.

2.7.5.1 Weirs and baffles

Many studies conducted in the Republic of South Africa found that weirs and baffles alone are unsatisfactory in preventing litter from simply continuing in the flow stream through trapping devices. Uys, Wilsenach, Furlong, and Low all investigated various options and combinations of weirs and baffle walls in an attempt to trap litter but with limited success (Armitage et al., 1998).

2.7.5.2 Netting and bag systems

A number of various open channel systems are known to exist, such as those shown in Plate 2.14 and Plate 2.15.

Plate 2.14 'CopaTrawl^{TM}' litter trap (Product information, 1999).

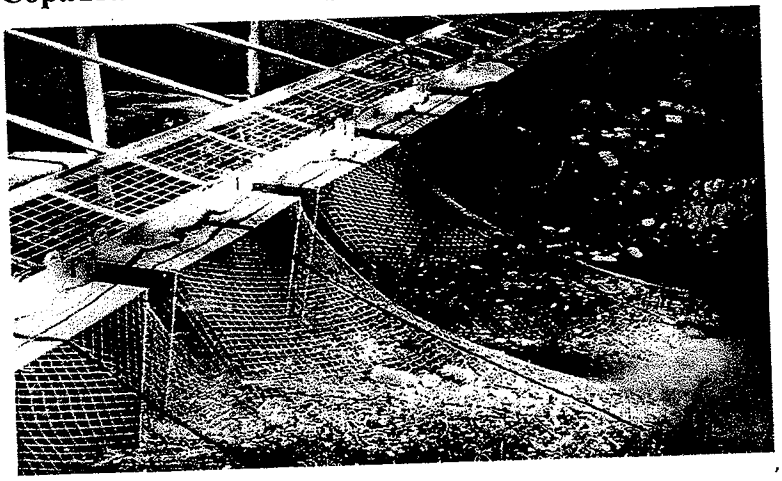
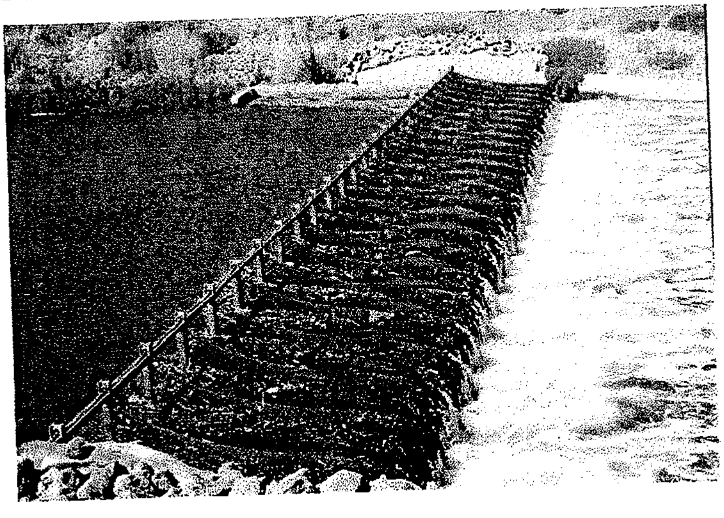


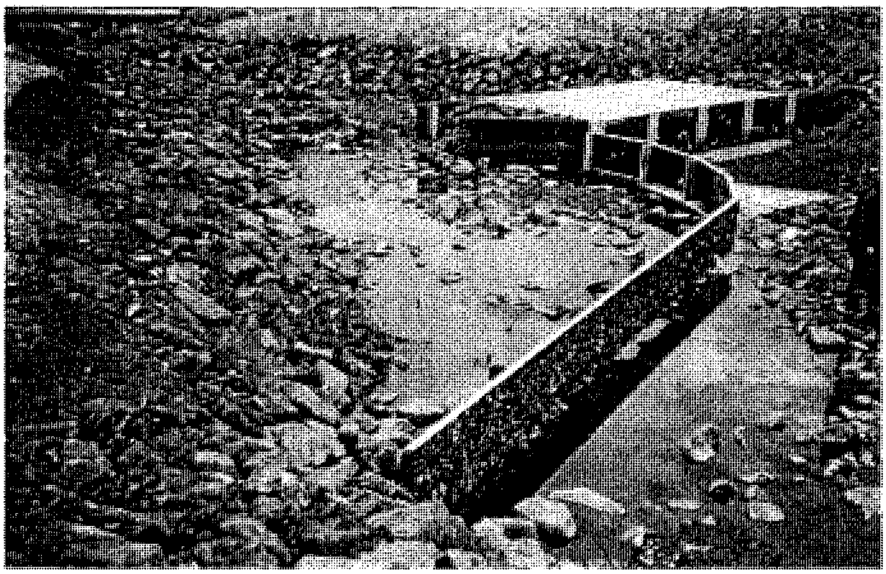
Plate 2.15 'Environment and Civil Pty Ltd' system (Product information, 1997).



Net bag systems, which may be used in multiple cells (as shown) to suit the application, may vary in design make-up and materials (Environment and Civil Pty Ltd product information, 1997; Aquatec-Maxcon Pty Ltd product information, 1999; Environmental Solutions (Aust) Pty Ltd, product information, 2003). No performance data are known to exist. Cleaning is typically performed using a small crane (Environment and Civil Pty Ltd product information, 1997; Environmental Solutions (Aust) Pty Ltd, product information, 2003).

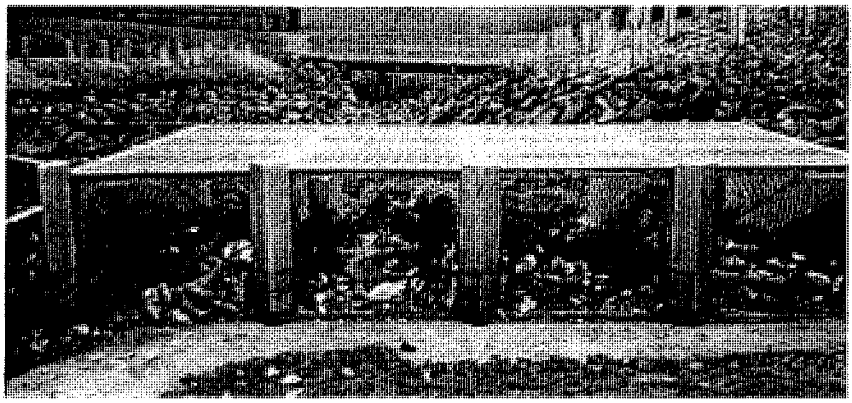
Melbourne Water has also recently employed net bags in open channel/waterway applications, as can be seen in Plates 2.16 and 2.17, which show a contra-shear weir system with net bags employed in Melbourne. The contra-shear weir is made up of fine horizontal steel bars, which divert material suspended in the flow across to the net bags, which are enclosed in metal cages (see Plate 3.9).

Plate 2.16 Contra-shear diversion weir with net bagging system downstream of Preston Main Drain, Melbourne (Author's photograph, 2003).



However, as may be seen in Plate 2.16, the contra-shear weir is prone to matting and clogging from gross pollutants (mostly vegetation), which may require regular cleaning. The contra-shear weir may be replaced with a solid non-porous weir in future applications to minimise capital costs. Cleaning of net bags is performed using a small crane (personal communication with Mr M Noyce, Melbourne Water, 2003). No performance data are known to exist.

Plate 2.17 Netting bag component of a contra-shear diversion weir with net bagging system, Preston Main Drain, Melbourne (Author's photograph, 2003).



2.7.5.3 Trash racks and screens

Traditionally, simple fences were employed in an attempt to capture litter in both natural and man-made watercourses (SPCC, 1989; ASCE, 1992). Throughout the 1980s and 1990s a great deal of research relating to litter control was undertaken, utilising mostly screens and bars, with a vast number of designs tested, ie. Bouvard, 1992; Uys, 1994; Nel, 1996; Watson, 1996; Compion, 1997 (Beecham and Sablatnig, 1994; Armitage et al., 1998).

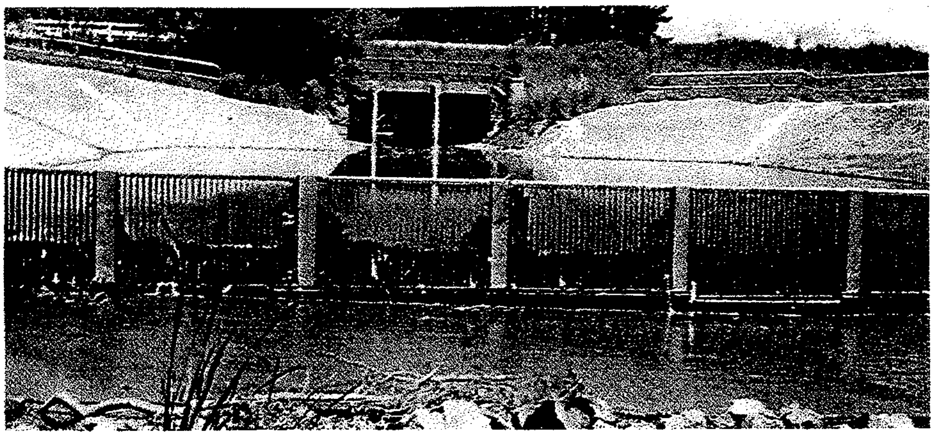
Generally, in-line screens do not have a good record because (Armitage et al., 1998):

- They block, mat and damage easily;
- They require a physical drop or fall, or they may create upstream flooding;
- Maintenance is difficult, and relatively labour intensive; and
- Storage capacity is limited.

2.7.5.3.1 Canberra-style 'Gross Pollutant Trap' ('GPT')

The Canberra style of 'GPT' was developed with the novel concept of a sedimentation pond, constructed with a downstream trash rack, as presented in section 2.7.3.2. The major style 'GPT' is typically located in major floodways and drains from large catchments, as can be seen in Plate 2.18 (Brouwer, 1987; Phillips et al., 1989; ACTPA, 1992). The general trash racks' disadvantages, as already discussed, and frequent maintenance requirements (Goyen et al., 1988), have limited their widespread application.

Plate 2.18 Canberra major style 'GPT' (source: Armitage et al., 1998).



Design curves created for the Canberra style 'GPTs' featured design criteria suited to the capture of sediments, with the provision of design curves for "average annual retention of sediment" (ACTPA, 1992), with exclusion of consideration about gross pollutant loads.

2.7.5.4 Clevertek™ litter filtration system

The Clevertek™ system, as already presented in section 2.7.3.8, is also intended to be employed in open channel/waterway situations, utilising the same design principles. In these situations it is envisaged that maintenance access would be provided so that cleaning may be performed using a bobcat or front-end loader (Clevertek Pty Ltd, personal communication with Mr T Fisher, 2003). Several Clevertek™ systems are constructed in Melbourne on open channel systems (Clevertek Pty Ltd, personal communication with Mr T Fisher, 2003) (also refer to Plates 2.19 and 2.20).

Plate 2.19 Clevertek™ system, Melbourne (Author's photograph, 2004).

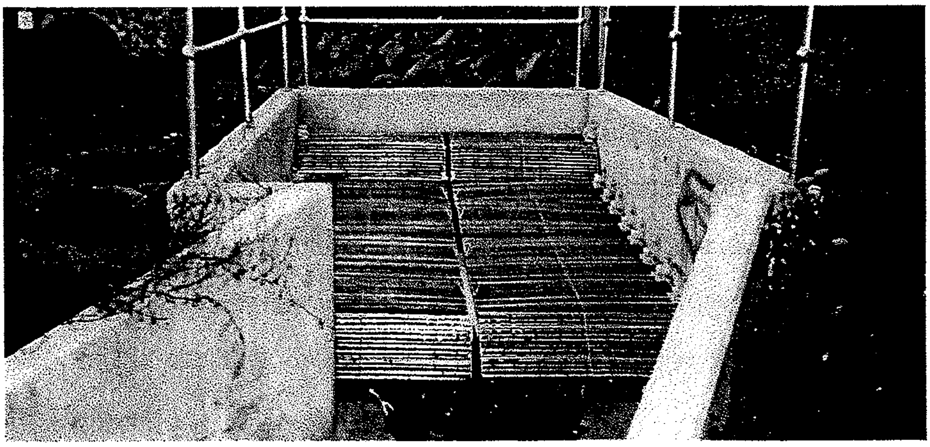
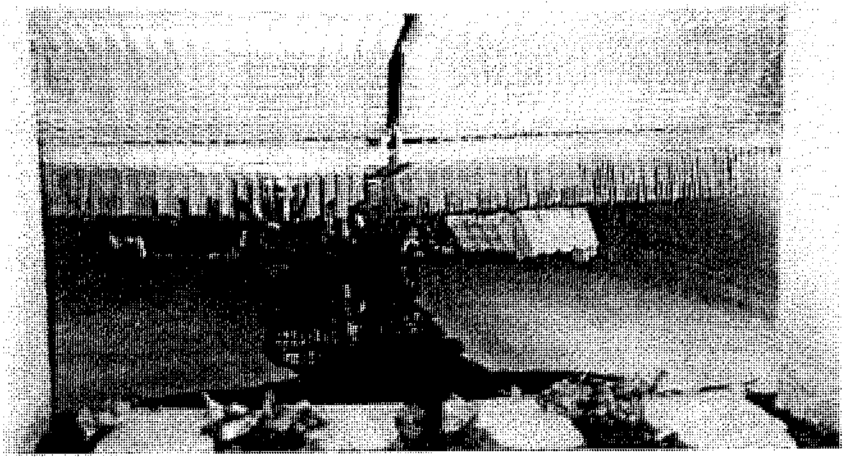


Plate 2.20 Clevertek^{TM} system, Melbourne (Author's photograph, 2004).



2.7.5.5 Floating traps for open water

Floating traps are more suited to tranquil continuously flowing waterways than fast flowing creeks and channels. Captured materials are also believed to be lost when they become waterlogged, drop below the surface, and get swept away with the current (Victorian Stormwater Committee, 1999).

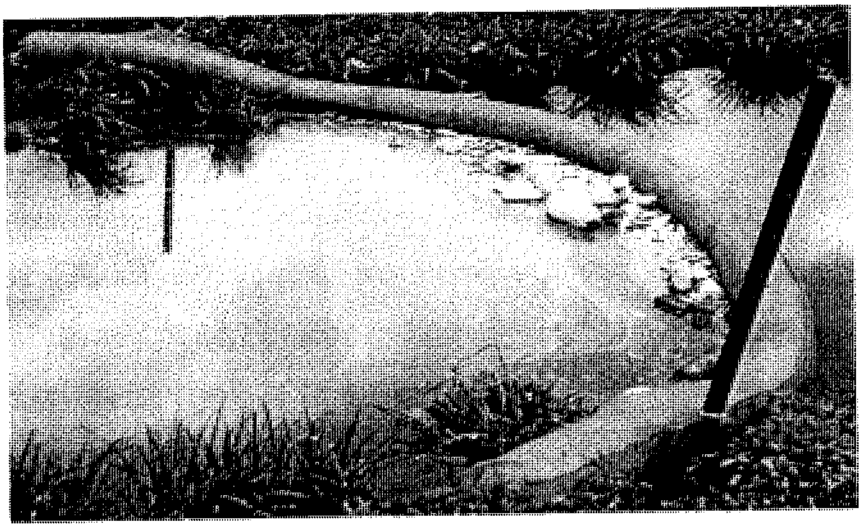
These types of litter traps generally have a poor level of performance, with no bed load being trapped, little suspended material being caught, and they are visually obtrusive (Victorian Stormwater Committee, 1999). However, they are usually capable of retaining a portion of the floating litter, depending on factors such as percentage width of the waterway covered, and location within the waterway (as more litter may be found to travel on a particular side) (SPCC, 1989).

Once litter is flushed into open flowing waterways, the task of litter capture and removal can be difficult, with most floating devices only capturing an estimated 10% of litter (Wong and Wootton, 1998). The nature of these traps also makes it difficult for them to be cleaned. Several types of floating traps will now be discussed briefly. Both are considered difficult to maintain and are unsightly, however they are able to move with the rise and fall of the tide, and are easily relocated to another location (Victorian Stormwater Committee, 1999).

2.7.5.5.1 Flexible floating booms and barriers

Plate 2.21 shows a floating boom used on a small creek to contain floating litter (and other floating pollutants).

Plate 2.21 Floating boom in small creek (Author's photograph, 1999).



The Melbourne Metropolitan Board of Works (MMBW – now Melbourne Water) utilised this type of trapping technique in the late 1980s, and 3,500 cubic metres of material was collected by two booms over a five-year period (MMBW, 1989). Sydney Water also utilised a number of these booms on outlets of channels to Sydney Harbour in the early 1990s, but showed significant concern regarding their suitability and effectiveness (Armitage et al., 1998). On smaller waterways the entire reach may be spanned by the boom, however, with larger waterways only a portion may be spanned.

2.7.5.5.2 The Bandalong™ floating debris trap (FDT)

This type of trap, shown in Plate 2.22, is commonly known as a floating debris trap (FDT), and although no longer manufactured, are still currently in use. The trap consists of polyethylene boom arms fitted with skirts to deflect floating debris through a flap gate into a collection chamber (Victorian Stormwater Committee, 1999). The metal flap gate has been introduced to provide for ebb and flow of tidal locations (product information, 1998).

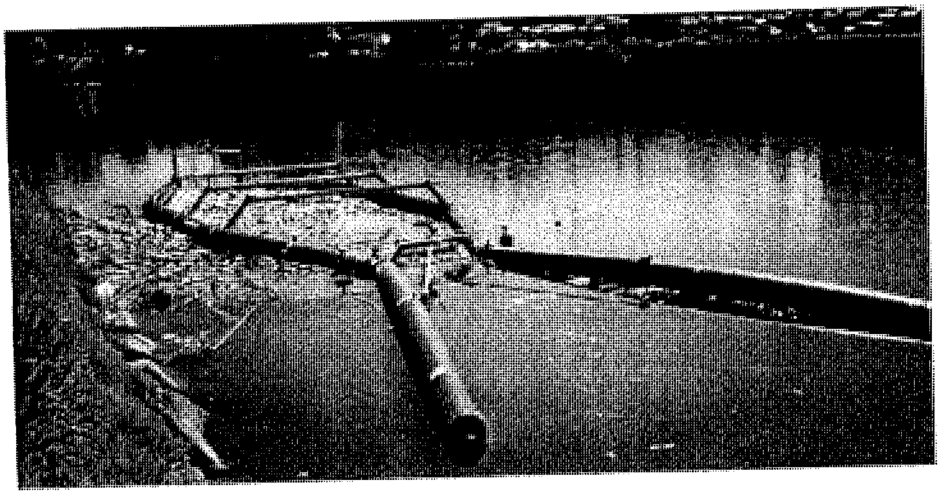
Claimed advantages include (Victorian Stormwater Committee, 1999):

- Enhances aesthetic and recreational potential of downstream waterways;
- Improved retention of collected pollutants;
- Mobile and may be appropriate for retrofitting into existing areas;
- Collects litter at a single location rather than over a large area; and
- Able to rise and fall with changes in flow or tide.

Claimed limitations include (Victorian Stormwater Committee, 1999):

- Gross pollutants may be swept past the boom by the tide, winds and high flows;
- Boom can only capture floating pollutant load;
- Maintenance is difficult, with most boom assemblies cleaned by boat;
- Complete boom spanning of the waterway may be difficult;
- Booms may break away from the banks during high flows; and
- The appearance of the boom and trapped litter can be obtrusive.

Plate 2.22 Bandalong™ floating debris trap, Yarra River (Author's photograph, 1998).



2.7.5.6 Urban Water Environmental Management (UWEM) Concept

The Urban Water Environmental Management system (UWEM) (Figures 2.18 and 2.19) utilises a hydraulically controlled sluice gate to regulate the flow of stormwater in open channels through a facility, whereby a 'treatment' flow is diverted through a series of bars (in rows), screens, baffle walls, and weirs, providing treatment and capture of litter. The UWEM is suitable for very flat channels, as throughout larger storm events, the sluice gate is free to lift, allowing small energy losses, and peak flows can pass without seriously affecting headwater levels upstream. The concept also features a catch-pit, which diverts polluted low flows to a nearby de-grit channel, before discharging through a diaphragm valve into a sewer (Armitage et al, 1998). Catchments of 400 hectares or greater, where flows are > 15.0 cumecs, are suggested.

Claimed advantages include (Victorian Stormwater Committee, 1999):

- high-flow bypass avoids pollutant scouring;
- presents a larger screen area to the flow than conventional trash racks;
- flow through the screens is maximised and regulated by the hydraulic sluice gate;
- suitable for installation in large open channels;
- can capture and hold large amounts of litter; and
- minimal head losses.

Figure 2.18 Plan of a UWEM design (source: Armitage et al., 1998).

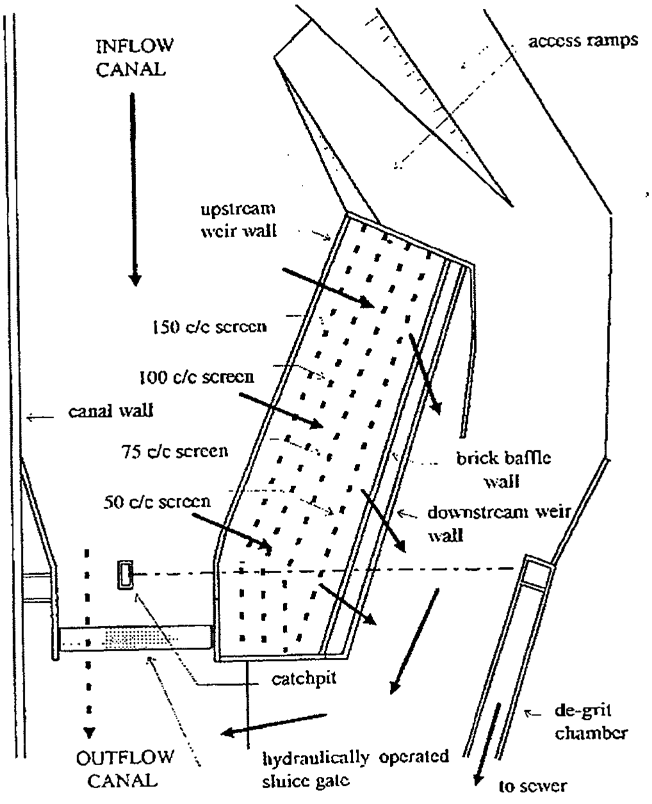
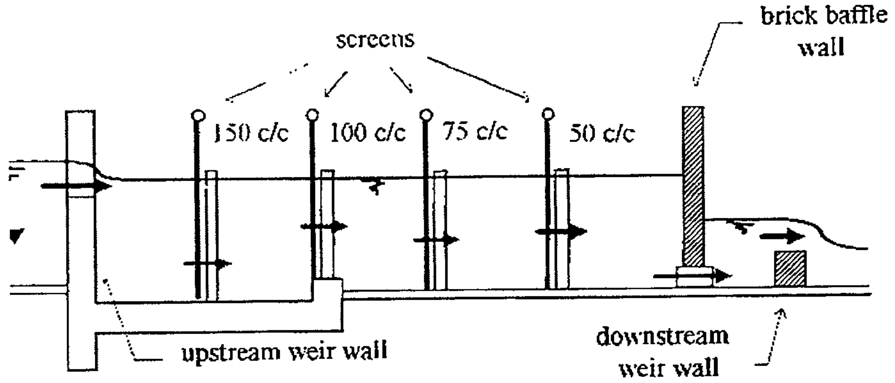


Figure 2.19 Section view of a UWEM design (source: Armitage et al., 1998).



Claimed limitations include (Victorian Stormwater Committee, 1999):

- requires large amounts of land;
- maintenance intensive; and
- the appearance of the rack and trapped litter can be obtrusive.

2.7.5.7 BarRack™ GPT (channel system)

The BarRack channel system (discussed in Sections 2.7.3.10 and 2.7.4.6) uses a bypass weir, where open channel or drain head loss availability is minimal (product Information, 2003). This type of unit can treat high capacity flows whilst still maintaining high retention rates. Pollutants are stored in a dry state (product information, 2003).

2.8 THE IN-LINE LITTER SEPARATOR (ILLS)

Notes:

1. The ILLS is now manufactured under licence by Swinburne University of Technology as the "Humegard™" by Humes.
2. Patents have been issued for Australia (No. 704777), New Zealand (No. 313104), USA (No. 6183633), and the UK (No. 2318308).

2.8.1 Introduction

This chapter presents the design, operation, and design sizing criteria associated with the In-Line Litter Separator (ILLS), a gross pollutant trap developed by Dr D I Phillips within the School of Engineering and Science, Swinburne University of Technology, Melbourne, Australia. Design sizing criteria is based on a Dimensional Rating Number for Melbourne, which is known as the Melbourne Rating Number (MRN). Theoretical developments formulated by Dr Phillips are presented as part of testing on the scale laboratory model and early monitoring of installed prototypes (in Appendix A).

2.8.2 In-line litter separator design overview

2.8.2.1 Design criteria

General criteria considered and claimed as most important in the initial brief for the development of the ILLS were as follows (Phillips, 1998):

- retrofit easily to existing drainage systems;
- low net energy head losses under peak flow conditions;
- removes significant quantities of first flush and most buoyant materials;
- adequate litter holding capacity to minimise maintenance visits;
- non-clogging fail-safe operation;
- geometric and dynamic similarity between laboratory model and installed prototypes, allowing design standardisation for ease of selection, based on catchment area or flows and pipe size.

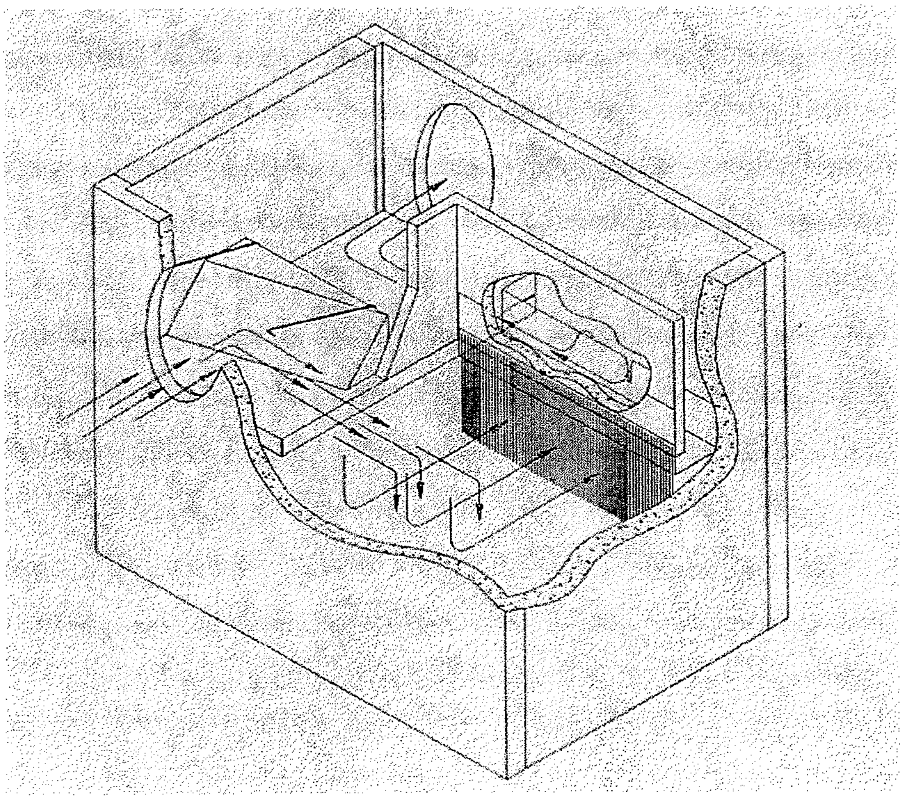
2.8.2.2 ILLS design and operation

The ILLS physically consists of the following:

- separation chamber featuring a hinged 'wedge-shaped' flow diversion boom and resting on a suspended platform;
- 'wet sump' holding chamber (approximately 1.5 metres in depth below the level of the boom resting platform), containing a baffle wall and a metal comb for retaining both floating and settleable materials respectively;
- weir and channel outlet arrangement.

The ILLS operation is shown in Figure 2.20 (with sections of walls and roof cover removed for clarity). The boom is at rest, with all flows passing through the holding chamber, weir, and return channel before returning to behind the boom and drainage system.

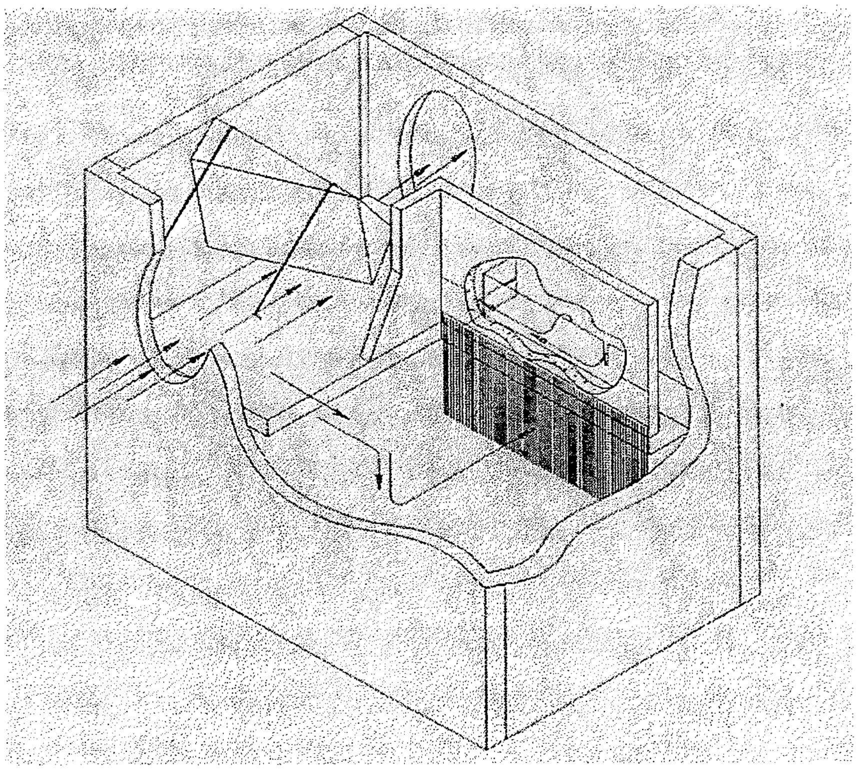
Figure 2.20 ILLS in operation with boom at rest (Courtesy of Humes).



The permanent volume of residual water held in the sump ensures treatment velocities (of the diverted flow) are reduced as they pass through the treatment storage, with both floatable and settleable pollutants separating out of the flow stream. The baffle-holding wall helps retain the floating litter, debris, oils, and other flotsam entering the treatment volume. Within this sump settleable pollutants also separate out whilst the treatment flow passes through a comb (suspended from the baffle wall), over an outlet control weir, and into a return channel before passing behind the boom to re-enter the piped drainage system (as shown in Figure 5.1).

Figure 2.21 shows the ILLS in operation (during above design flow-rates) once the boom has lifted (with sections of walls and roof cover removed for clarity). At this point significant flows are bypassing the treatment sump under the boom and continuing untreated. This allows minimal head losses to be generated, whilst all floating materials are still being separated and retained.

Figure 2.21 ILLS in operation during above design flow rates with boom in lift (Courtesy of Humes).



The ILLS boom is at rest under the vast majority of event runoff conditions. Hence, a direct diversion of runoff flows to the holding chamber is provided, with high hydrologic effectiveness as a consequence. However, unlike other GPTs, as event flows increase the boom lifts, so the ILLS inherently captures flotsam at flow-rates above the design flow, conferring a very high capture efficiency.

2.8.3 The ILLS installation and monitoring program

Development of the ILLS commenced in July 1995 at the behest of Mr M Alyward of the South Eastern Waste Management Group. The group had provided grants to support a Master of Engineering by Research program at Swinburne University, to study the problem of litter generation in urban strip-shopping centres. Mr Alyward brought the ILLS concept to the attention of the Waste Management Council (now Ecorecycle Victoria) and led to Victorian State Government support with a $100,000 grant to Swinburne University to support a two-year research and development program together with grants to supporting councils. Local manufacturers were also invited to participate in the program. The report titled "In-Line Litter Separator: Installation and Monitoring Project – 1998", produced by Dr Phillips, covers all requirements of the Government grant, and includes some preliminary monitoring results from the author of this thesis.

This chapter outlines the theory developed by Dr Phillips as part of the program, which includes the dimensional rating number (DRN), a design aid, as well as setting the scene for the research conducted and presented in the following chapters of this thesis.

2.8.4 Laboratory scale model development

The physical laboratory scale model historical development began with a simple concept, comprising no more than a storage chamber housing a single screened outlet and fitted with a hinged diversion weir (consisting of a sealed length of PVC pipe) and resting platform located in-line to the pipe flow path. Consequent laboratory model testing and observation of both the hydraulic and litter removal characteristics allowed a much better understanding of performance under varied pipe flow conditions to be gained, and subsequent model improvements. Plate 2.23 show the wooden boom that replaced the PVC pipe in the model.

Plate 2.23 Dr Phillips with laboratory model with wooden boom (Swinburne University, c. 1997).

Figure App A.1 in Appendix A shows the final ILLS laboratory model used by Dr Phillips. Hydraulic testing of this scale model was conducted with clean water, and limited to recording water surface levels, with no piezometer readings taken. Fixed pipe inlet and outlet arrangements were used, allowing no variation in head-water and tail-water hydraulic conditions. All flow calibrations were performed using a V-notch weir draining from the collection sump below the model.

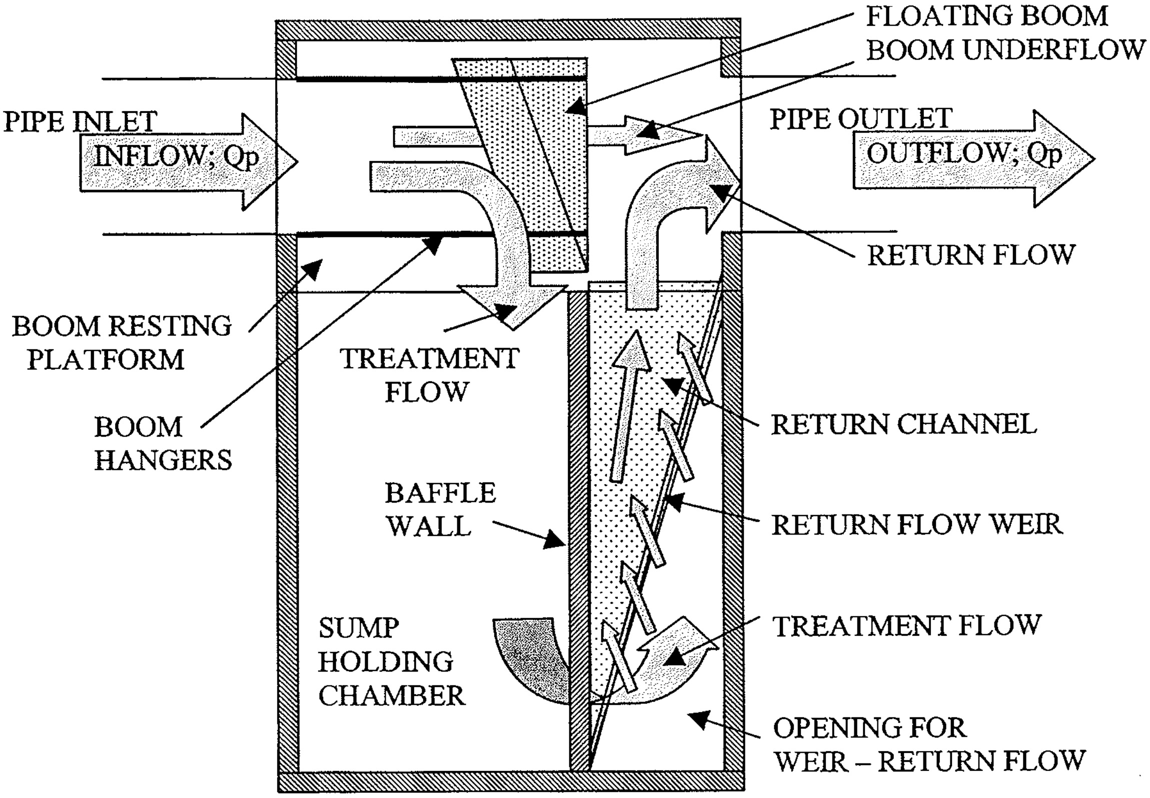
2.8.4.1 Physical scale model testing

The ILLS components, as shown and referred to in Figure 2.22, are now described.

2.8.4.1.1 The floating boom

The floating boom design evolved from a sealed length of PVC pipe, inclined to divert flows, to what is now the standard floating boom, a wedge-shaped hinged boom system, diverting the required pipe treatment flow to the holding chamber. Several types of boom materials and designs were trialled in order to find the optimum shape, including a boom with a curved upstream face, and the current wedge shape, which better deflects design treatment flow into the holding chamber.

Figure 2.22 Plan of ILLS, showing simplified flow paths with boom just lifting.

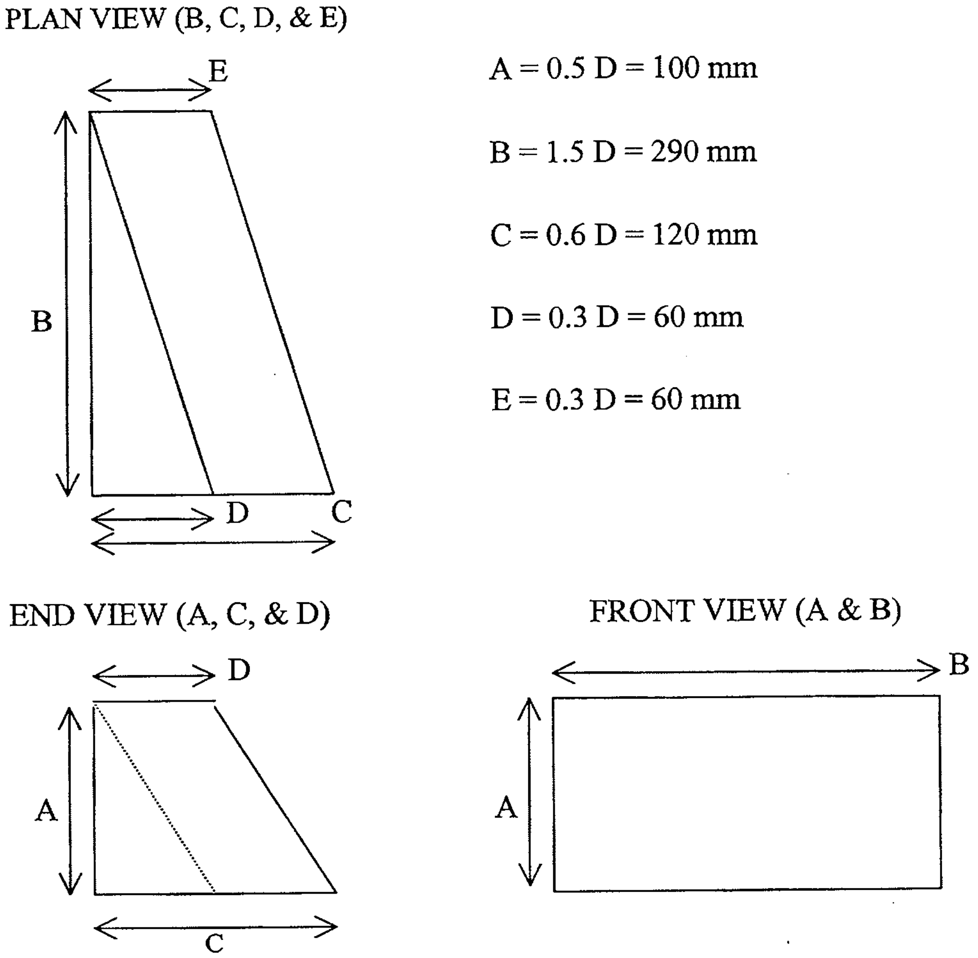


The adopted boom, fitted to the laboratory model, design and dimensions are best shown in Figure 2.23.

2.8.4.1.2 Introduction of the baffle wall

The baffle wall was introduced into the holding chamber to retain floating materials. It was located directly downstream of the arc obstructed by the lifting face of the boom so that it was clear of deflected incoming materials and extending vertically from just below the roof of the chamber to part-way into the sump. The baffle fitted to the laboratory model was submerged approximately 80 mm, but submerged depth was typically much greater when fitted to prototypes.

Figure 2.23 Boom dimensions: plan, front and end views (boom hangers NOT shown).



A = 0.5 D = 100 mm

B = 1.5 D = 290 mm

C = 0.6 D = 120 mm

D = 0.3 D = 60 mm

E = 0.3 D = 60 mm

2.8.4.1.3 Introduction of the outlet weir and channel

The rectangular weir was introduced early in development of the ILLS design to distribute and control the out-flow, ensuring sub-critical outflow conditions (Phillips, 1998) from the main holding chamber, under the baffle wall, and back to the flow separation chamber (behind the boom). A triangular weir was later introduced to improve outlet conditions (as discussed later). Several V-notches were also cut out of the weir face to allow the passing of smaller discharges, referred to as 'trickle flows'.

2.8.4.1.4 Treatment comb suspended under baffle wall

A fully submerged metal wire comb was later installed (suspended under baffle wall) replacing the original outlet screen as a means of improving litter capture performance, especially in the retention of fine plastics, and semi-floatables such as syringes.

A compromise on comb wire spacing was sought, as the adoption of greater wire spacings would allow more materials (especially the loose plastics) to be swept out of the holding compartment to the outlet. Conversely, if the comb spacing was too close, or was to be replaced with a screen with little flow area, the higher velocities would make it more prone to blockage, depending on velocities and hydrodynamic forces acting at the interface. A perforated screen was considered but rejected due to the inadequate through-flow area.

2.8.4.2 Component manufacturing specification for prototypes

The following design considerations came from laboratory scale model testing and development, modelling, and initial field monitoring work in prototype analysis and evaluation (Phillips, 1998). This was the first step in design specification based on prototype evaluation. The pipe diameter was adopted as a preferred design parameter for the boom while both the pipe diameter and peak capacity were adopted for the holding chamber (Phillips, 1998).

2.8.4.2.1 Holding chamber sump

The following relates to the holding chamber specification:

- sump floor level to be no deeper than 4.5 m below the ground surface to allow ease of cleaning with a vacuum suction unit;
- residual sump depth of not less than 1.5 m recommended to provide adequate volumetric storage; and
- design sump volume 'residual capacity' recommendation later based on a Dimensional Rating Number for Melbourne (MRN) after preliminary testing.

2.8.4.2.2 Boom characteristics and specification

Boom dimensions (refer to Figure 2.23) are scaled up in prototypes to the pipe diameter, as indicated in the above figure. Boom specification are (Phillips, 1998):

- Boom hangers are to be hinged at a level above the obvert of the incoming pipe so that they are well clear of incoming trash and debris.
- Boom length '**B**' to pipe diameter '**D**' ratio, to allow adequate under-flow area, is 1.5 as a minimum to ensure that treatment flow (Qw = weir flow) entering the holding chamber does not exceed 0.2Qp maximum.
- Boom height is recommended to be set at half pipe diameter (0.5D).
- Boom face is inclined so that the resulting hydrostatic force on the face produced a clockwise moment about the suspension points to assist boom uplift.
- Boom under-flow area (at full pipe flow) is to be at least equal to the pipe cross-sectional area.
- Boom mass and volume (specific gravity) is such that the corresponding proportion of flow passing through the storage volume (= Weir treatment flows, Qw) produced a maximum flow velocity less than the theoretical critical velocity. The critical velocity, V_{crit}, depends on design particle/item/or material, and is discussed later.
- The length of the separator chamber along the pipe is determined from addition of the front clearance, boom swing plane (arc) and return channel exit width to allow for the boom to swing to its operating up-lift position, as well as catering for the width of the return weir. A minimum clearance in the model of 300 mm was recommended both upstream and downstream of the boom.

2.8.4.2.3 Weir characteristics and specification

The following relates to weir specification:

- Weir crest level to be set at approximately 0.25 of pipe diameter, determined from laboratory observations (Philips, 1998), with 60° V-notches, or V-slots (cut into the weir face down to the pipe level) to pass trickle flows.
- Under upstream super-critical flow conditions, the return weir crest and boom form a barrier that induces a hydraulic jump upstream, resulting in sub-critical flow conditions at the boom face.
- A minimum 150 mm weir clearance to prevent blockage was recommended.

2.8.4.2.4 Baffle wall and comb.

The following relates to the baffle wall and comb specifications:

- Baffle wall to have a nominal 150 mm protrusion into the sump below the natural water level to retain partly immersed, floating litter items.
- Comb to be suspended from the bottom baffle edge to 400 mm above the sump floor. Three mm diameter comb wires had an initial trial spacing (centre to centre) of 30 mm, and was later reduced to 15 mm with commercial units to retain syringes.

2.8.4.2.5 Access

As the ILLS is a defined 'confined space', location of the lids allows maintenance without the need to enter the unit. Sealed gatic lids, provided above the boom, holding sump, and weir (optional), were considered the ideal for maintenance purposes.

2.8.5 ILLS theory

An overview of the following theoretical developments is presented in Appendix A, viz:

- physical modelling including minimum ILLS dimensions;
- numerical modelling, including boom frequency of lift, mass and dimensions;
- laboratory studies, including the following:
  - derivation of the boom-weir equation;
  - boom specific gravity in terms of physical measurements;
- hydrologic modelling, including the following:
  - relationship between pipe flow, weir flow and annual flow treatment;
- triangular return channel, including the following;
  - weir flow equation; and
  - minimum triangular weir-channel dimensions.

2.8.6 ILLS design criteria

2.8.6.1 A Dimensional Rating Number (DRN)

The ILLS dimensional rating number (DRN) is a mathematical expression, based on Melbourne rainfall data, and derived from key design parameters as part of the laboratory modelling (Phillips 1998). The theoretical DRN was developed as an ongoing design aid, allowing comparison of performance evaluation results from monitoring of ILLS prototypes already installed in the field (as part of this thesis), as well as providing a design 'best practice' which could then be used for design sizing of further prototypes.

The primary aim of this research was monitoring of installed prototypes to obtained data for an evaluation of their performance. The DRN, with its theoretical basis, provides a practical means of comparing design criteria with field performance results. Two 'treatment flow' elements of the design were regarded as critical in the development of the DRN, being maximum velocity considerations relating directly to hydraulic efficiency (treatment storage volume and shape, and weir-channel outlet arrangement), viz:

1. the comb suspended beneath the baffle wall, where velocities were required to be minimal so as not to block the baffle comb with sheet plastics, such as plastic bags and wrappers; and
2. the sump, where excessive velocities would re-suspend already deposited materials, including gross solids and sediments.

Phillips (1998) presented theory to which the two following equations were yielded, viz:

Humes Pty Ltd design : $k = C*W/ Q^2 (B+W)$ **Equation 2.14**

SVC Products Pty Ltd design : $k = C/ Q^2$ **Equation 2.15**

Where: 'Q' is the maximum treatment flow ($= Q_w = 0.2*Q_{pmax}$);
'k' is a geometrically dependent constant;
'C' is the holding chamber storage volume; and
'W' and 'B' are the Weir and Boom lengths respectively.

[Note: Equations 2.14 and 2.15 are essentially the same, with a difference in design configuration, with SVC units providing no storage under the boom platform.]

2.8.6.2 Derivation of relationship for Melbourne peak runoff and catchment area

Utilising the rational formulae and Melbourne 5 year ARI rainfall data, it was shown that an expression for the DRN may also be made, based on Table 2.13 below, with the following assumptions (Phillips 1998):

- time of concentration (tc) and catchment area are both proportional to catchment length;

- co-efficients of runoff are constant, Qx/ Q6 = (Cx*Ix*Ax/ C6*I6*A6), results in:

$Q_x/ Q_6 = (I_x*A_x/ I_6*A_6)$ **Equation 2.16**

Where: 'A' is the catchment area (in hectares).

Table 2.13 Five year ARI intensity and discharge ratios for Melbourne

Time of concentration, tc (mins)	Average storm intensity (mm/hr)	Intensity ratio Ix/I6	Catchment area ratio Ax/A6	Discharge ratio Qx/Q6
6	80	1.0	1.0	1.0
9	68	0.85	2.25	1.91
12	60	0.75	4.0	3.0
18	52	0.65	9.0	5.85
24	42	0.53	16.0	8.48
30	37	0.46	25.0	11.5

However, assumptions in Table 2.12 may be questioned, as it may be argued that co-efficients in Equation 2.16 are generally not constant and that catchment characteristics, such as slope and impervious area, may vary between catchments.

Phillips (1998) adopted a curve of best fit based on data presented in Table 2.12 to produce equation 2.17. $Q_x/Q_6 = 1.42\ (A_x/A_6)^{0.67}$ **Equation 2.17**

Assuming a given region and land use, Q_6/A_6 may be considered a constant, which then means if A_6 is approximately equal to 1.0 hectare then $Q_6/(A_6)^{0.67}$ is a constant, say 'K' (Phillips, 1998). Equation 2.17 then simplifies into equation 2.18 (Phillips, 1998).

$Q = 1.42\ K\ (A^{0.67})$ **Equation 2.18**

However, it is not understood what sensitivity is placed on A_6 above and what effect can be expected in Equation 2.18 when $A_6 \neq 1$.

Phillips (1998) then produced the following two equations for the Melbourne Dimensional Rating Number (MRN), where previous symbols apply. No account is taken for areal rainfall intensity reduction, as explained by Phillips (1998).

- Humes Pty Ltd units - $\boxed{MRN = (C*W)/[(B+W)*(A^{4/3})]}$ **Equation 2.19**
- SVC Products Pty Ltd units - $\boxed{MRN = DRN = C/(A^{4/3})}$ **Equation 2.20**

2.8.7 ILLS performance claims

Some general claims have been made relating to the ILLS, known as the Boom Diversion System, and include advantages, limitations and estimated treatment performance (Victorian Stormwater Committee, 1999).

Advantages with the ILLS include the following (Phillips, 1998; Victorian Stormwater Committee, 1999):

- Diverts all flows for treatment to a design flow of 4 in 1 Year ARI;
- Simple to retrofit into existing drainage systems;
- Can potentially retain small oil spills;
- Minimal visual impact as installed underground; and
- Pre-cast units permit easy installation.

Limitations with the ILLS include the following (Victorian Stormwater Committee, 1999):

- Booms capture only floating pollutant load during moderate to high flows;
- Moving parts of the hinged boom require inspection and maintenance;
- Potential for scouring if excessive build-up of pollutants occurs; and
- Potential breakdown of collected pollutants in wet sump.

The following pollutant retention efficiency claims have been made regarding the ILLS (Victorian Stormwater Committee, 1999):

- Gross pollutants - Moderate (40 to 60 % of total load retained);
- Coarse sediments - Low to moderate (10 to 60 % of total load retained);
- Medium sediments - Negligible to low (less than 40 % of total load retained);
- Fine sediments, attached and dissolved pollutants - Negligible (less than 10 % of total load retained);

The following additional claims have been made (Victorian Stormwater Committee, 1999):

- Head requirements - Less than 0.5 metres;
- Installation costs - Between $500 and $1,500 per hectare of catchment; and
- Maintenance costs - Greater than $100 per hectare of catchment per annum).

However, the above claims are very general. For example, head requirements provide a large range when the head loss may be negligible, and the maintenance cost figures have no upper limit. CSR Humes Ltd. (2001) claim that the Humegard™ has a low head loss with a K value of 0.2 and is ideal for application where head loss is critical.

It must be noted that claims regarding the ILLS made above have been presented as a general guide only, and it must be reiterated that these claims have been made on only limited observations and experience, as no field data exist, as is the case with most GPTs. It is therefore the primary focus of this thesis to evaluate the litter capture performance of installed ILLS prototypes, as described in the following chapters.

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2.9 LITERATURE CONCLUSION

This literature review has presented the current challenge we face in managing urban stormwater to improve the quality of receiving water, especially in reducing litter, as well as many other priority pollutants. Litter, especially plastics, were shown to be persistent in our environment, and to have many consequences towards public health, the economy and flooding, ecology, and amenity. Litter was shown to be a priority over recent years with many government strategies and confirmed by much public money being spent on it. The Victorian government State Environment Protection Policy (SEPP) objective of 'no litter in waterways', the development of the Victorian Litter Reduction Strategy, and a best practice performance objective for stormwater of '70% reduction of typical urban annual load' (Victorian Stormwater Committee, 1999) highlight this. Floatable litter was highlighted to be of greatest community comment and concern (Golder Associates, 1995).

This chapter highlighted that many factors may be attributed to littering behaviour, and that the influences society has on litter generation may be attributed to people, products, places, and stakeholders (players) (Clean and Green, 1995). Many factors influence litter loads in stormwater systems, and despite current management approaches, Melbourne's stormwater system receives approximately 1,800 million litter items annually, and approximately 230,000 m^3 of gross pollutants annually (Allison, 1997). However, various other studies around the world have shown varying litter export quantities and compositions. Commercial, business and industrial land use areas were shown to contribute higher amounts of litter to the stormwater system than residential areas. It was highlighted that more effort needs to be devoted to trapping litter closer to generating sources, such as regional and strip shopping centres. The difficulty of research into urban stormwater gross pollutants were discussed.

It was highlighted that two different approaches are commonly used in managing litter, namely non-structural controls and structural controls. Non-structural controls are essentially ways of minimising litter availability for wash-off to the stormwater drainage system, such as education, litter prevention, and street sweeping. Structural controls are physical infrastructure constructed to trap litter with-in the stormwater system such as gross pollutant traps (GPTs). The need and role of GPTs in protecting downstream receiving water beneficial uses, such as aesthetic and environmental quality was highlighted.

Design of a GPT must consider local factors in order to best optimise operating conditions and trap performance. The following need to be given adequate consideration in the design or selection of a GPT as a minimum:

- flow diversion mechanisms;
- peak system flows and energy losses;
- treatment flow rates;
- litter capture performance;
- design size and configuration;
- internal fixtures and components;
- expected volumes of pollutants;
- ongoing maintenance requirements; and
- other considerations (such as odour, mosquitoes, OH&S issues, etc).

The capture performance of a GPT may be summarised as a need to balance the following (some of which are interrelated):

- Hydraulic and hydrologic considerations (a balance between acceptable head loss during flood flows, storage and outlet characteristics, and the design treatment flow);
- Litter capture (trapping) performance; and
- Maintenance.

This chapter presented various known gross pollutant trapping techniques, including their components, mode of operation, claimed advantages, claimed limitations, trapping efficiencies, and maintenance implications. This allowed the reader to gain an appreciation of which trapping techniques are proving to be the more promising and reliable. However, a lack of data still exists on the performance of GPT's (Allison & Pezzaniti, 2003). An overview of current GPT best practices and research (laboratory model studies, field performance monitoring, and a decision support system - DSS) highlighted the dearth of field monitoring and performance evaluation. Claims made by GPT manufacturers vary and are inconsistent. No agreed GPT field monitoring protocol is known to exist.

At present the range and scale of existing gross pollutant traps is considerable, however many of these are impractical and appear to be either inefficient at trapping litter, or labour or capital intensive. Most GPTs utilise a fixed diversion weir, and/or screening rack (or similar), to divert or trap pollutants respectively. The reasons many techniques suffer drawbacks is because they either (Victorian Stormwater Committee, 1999; Allison & Pezzaniti, 2003):

- easily allow litter to block the direct flow path;
- allow higher flows to bypass without litter separation, whilst losing previously captured materials;
- have limited storage capacity;
- servicing and maintenance of the traps is either frequently needed, difficult or expensive; and
- ineffective removal of oils and greases.

A brief description of the ILLS was presented in this chapter, including performance claims, and theoretical details are included in Appendix A. The key feature of the ILLS is the floating boom that normally rests during most storm events (diverting flow for treatment). The boom only rises during above treatment flow-rates, and so creating minimal head-loss, whilst continuing to separate buoyant materials from the flow.

3 FIELD MONITORING AND EVALUATION METHODOLOGY AND PROGRAM

3.1 INTRODUCTION

The previous chapters presented theory relevant to GPT selection, design, and performance, as well as the ILLS background and laboratory model testing work. The literature reviewed found limited studies relating to the performance evaluation of GPTs in general and found no studies that evaluated GPT's based on a methodology that evaluates performance by means of a tagged litter study that determines removal (capture) efficiencies (REs) directly.

This chapter sets out details of the ILLS prototype field performance monitoring and evaluation program conducted by the author, including the methodology of the tagged litter study employed. The program monitored ILLS prototypes installed within the Melbourne and Metropolitan area. An additional commercial ILLS unit was installed within the City of Greater Bendigo.

3.2 PROTOTYPE INSTALLATION AND MONITORING PROGRAM

The ILLS prototypes were installed in two separate rounds between February 1997 and July 1998 with the field research evaluation conducted in the period from May 1997 to November 1998. The installation and monitoring program followed the following sequence:

- First round/ generation of ILLS prototype design, manufacture and installation (following initial ILLS laboratory model developments);
- Monitoring and evaluation of first generation prototypes;
- Further laboratory model testing and enhancement of design theory as developed by Phillips (1998), introduced in Chapter 5, and presented in Appendix A;
- Second round generation of prototype design, manufacture and installations;
- Monitoring and evaluation of some first round prototype installations and second round prototype installations, including an additional commercial ILLS unit installed within the City of Greater Bendigo.

The prototype design data and catchment plans are provided in Chapter 4.

3.2.1 Developments with second generation prototypes

The following general improvements were incorporated into second round prototypes following further laboratory and theoretical developments (Phillips, 1998):

- Boom side-wall clearance increased to help eliminate jamming by small items;
- Boom hangers and wall attachments stiffened following several boom hanger failures (after large storm events);
- Boom shape revised to improve lift; and
- Comb screen underneath baffle wall to improve retention of submerged litter.

3.2.2 Developments following second generation prototypes – City of Greater Bendigo

Commercial units following the installation and monitoring program included the development and adoption of a triangular return channel to ensure sub-critical return flow and hence enhance boom lift at design flows, as discussed in Appendix A.

3.3 SELECTION OF TEST LITTER SAMPLE

The methodology presented in this chapter examines the fate of tagged litter samples. Each sample bag of litter introduced into each ILLS prototype catchment drainage systems contained the representative tagged sample litter items (SLI's) that would then be monitored throughout the project timeframe. This allowed a simulation of litter transport throughout a continuous sequence of recorded rain events, from the inlet pit to the ILLS prototypes under performance evaluation. This monitoring was limited to a range of SLI's across a number of material categories.

3.3.1 Consideration in determining the sample litter items (SLIs) for monitoring

3.3.1.1 Size and frequency of test items

In order to achieve a reliable, identifiable, and easily retrievable test litter sample, litter items chosen were large enough to allow easy identification amongst other gross solids retrieved from the ILLS. Small litter items, such as cigarette butts, although found to constitute a significant proportion of litter transported by urban stormwater by frequency (as reported in section 2.3.3 of previous chapter), were not used because they are very small and too difficult to find and identify amongst the sediments and biomass.

3.3.1.2 Material selection

Litter types were selected based on their persistence (such as with metal cans, hard plastics and polystyrene), their ability to withstand the degrading processes found in urban stormwater drainage systems, as well as their ability to with-stand the waterlogged environment of the GPT pending their retrieval by means of a cleanout. Rigid plastics (eg. bottles, etc.) and non-rigid 'soft' plastics (eg. sheet wrapping, bags, etc.) were accordingly selected as the most persistent and suitable litter items, as opposed to the degradable and breakable items (eg. paper, glass, etc.) which would be too difficult to trace. However, wax coated paper items although slightly degradable were also used. This is consistent with the conclusions of the literature review (section 2.9).

3.3.2 Sample litter items chosen for monitoring

The sample litter items (SLI's) chosen are based on persistent and identifiable (suitable size) types of litter commonly found in urban stormwater consistent with the literature review. Details of the sample litter items (including: dimensions, volumes, dry mass, and specific gravity) are presented in Appendix B, and summarised as follows:

Category 1: Plastic Products:

- PET (polyethylene teraphthalate) bottles (lids on): 390 and 600 ml
- PET (polyethylene teraphthalate) bottles (lids off): 390 and 600 ml
- HDPE (high-density polyethylene) bottles (lids on): 500 ml
- HDPE (high-density polyethylene) bottles (lids off): 500 ml
- Shopping bags: Standard grocery
- *# Drinking straws*
- *# Food wrapping and packets*
- *# Drink cup lids*

Category 2: Metal Products:

- Aluminium cans: 375ml
- *# Food wrapping and packets (foil lined)*

Category 3: Paper Products (Wax Coated):

- Drink cartons: 300 and 600 ml
- Drink cups: 550 ml

Category 4: Polystyrene pieces (50x50x12 mm): 30,000 mm^3

As some of the above items were not always readily available when sourcing items, a full sample was not always used when monitoring each prototype, as will be seen in the results chapter of this thesis. Nine (9) SLI's listed above are primarily target (positive capture) items, that is, they can be expected to be retained by the second generation prototypes fitted with baffle wall combs that have a 30mm spacing. Four (4) SLI's shown above in *Italics and underlined* consist of non-targeted items (non-positive capture items) that are not expected to be retained by prototypes with confidence, as they are have a minimum dimension less than the baffle wall comb spacing. Syringes were also used as an additional test litter item with second round prototype testing and reported separately given their priority. Appendix B presents photographs of the SLIs used in this study.

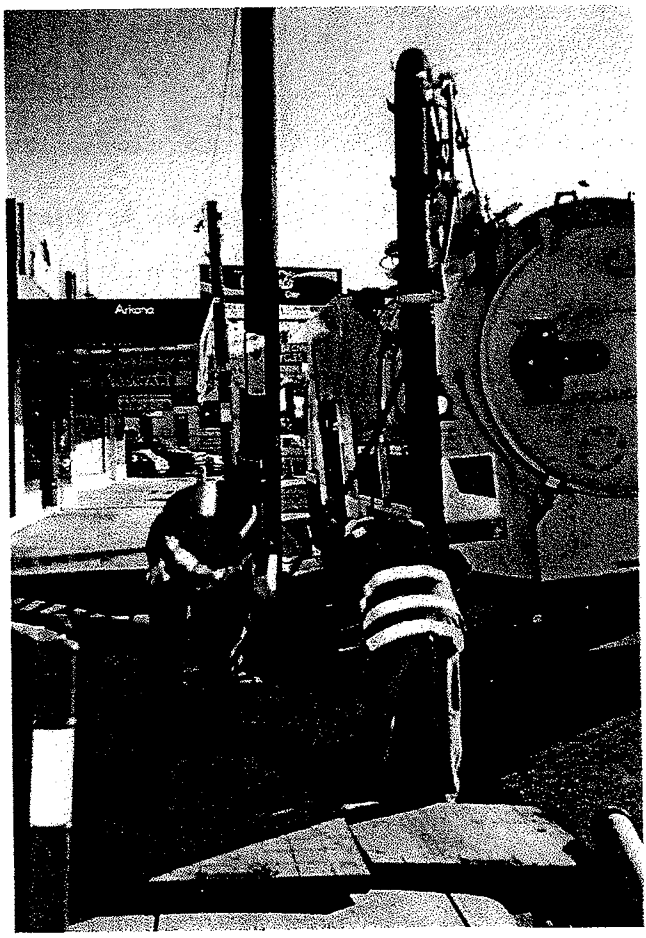
3.4 FIELD MONITORING METHODOLOGY

In order to achieve the aims and objectives of the program, a regular standard monthly monitoring test procedure was developed and adopted to collect the data required for analysis. The following standard monitoring program steps were adopted for data collection in each period (typically monthly), for each prototype installation, for the duration of the research program:

1. Sample litter item (SLI) samples to be used in testing program collected from litter bins around the University. Each programmed litter drop sample was then prepared by sorting SLI's into desired sample size and composition, and marked with a permanent marker (tagged). Typically ten (10) items of the same SLI type (eg. PET bottles with lids) were chosen to provide statistical validity and were prepared for each of the SLI types identified in Section 3.3.2. All tagged SLI's were grouped into typically ten (10) sub-samples, with each containing one item from each SLI type. The availability of some test SLI's limited the size and varied the composition of some litter drops slightly.
2. Initial cleanout of each ILLS unit prior to beginning testing program. No data was collected from this cleanout. As part of the methodology, entry into the ILLS prototypes was deliberately not required, as these structures are considered by definition 'Confined Spaces' where special equipment is required for such entry (Melbourne Water, 1995).

3. SLI's (all sub-samples) recorded and introduced (distributed) into prototype upstream catchment drainage entrance pit inlets, typically on a monthly basis following on from previous cleanouts. The upper reaches of the drainage system were avoided as runoff flows were considered to be too low to transport litter. Inlet pits receiving tagged litter sample bags were checked to ensure that they were free of obstructions that would prevent the transportation of the tagged litter. Cleaning of the inlet pits was performed when necessary;
4. Delayed follow-up cleanout (pump-out) of prototype contents at the end of every test period by eductor (or street sweeper) vacuum truck as shown in Plate 3.1. Each prototype was de-watered to the level of sump materials and sump sediment depths recorded in some instances, allowing an estimate of *In-situ* sump volumes. Observations such as evidence of surcharging and flows overtopping the boom were also recorded. Water soluble paint assisted to determine the later.

Plate 3.1 Photograph of Lonsdale Street ILLS prototype being cleaned by vacuum truck (Author's photograph, 6 November 1998).



5. The contents of each prototype from each cleanout (pump-out) was transported to the respective Council depot for dumping (please refer to Plate 3.2), sorting (please refer to Plates 3.3 and 3.4), and data recording. Data on all SLI's were collected (both tagged and natural untagged).

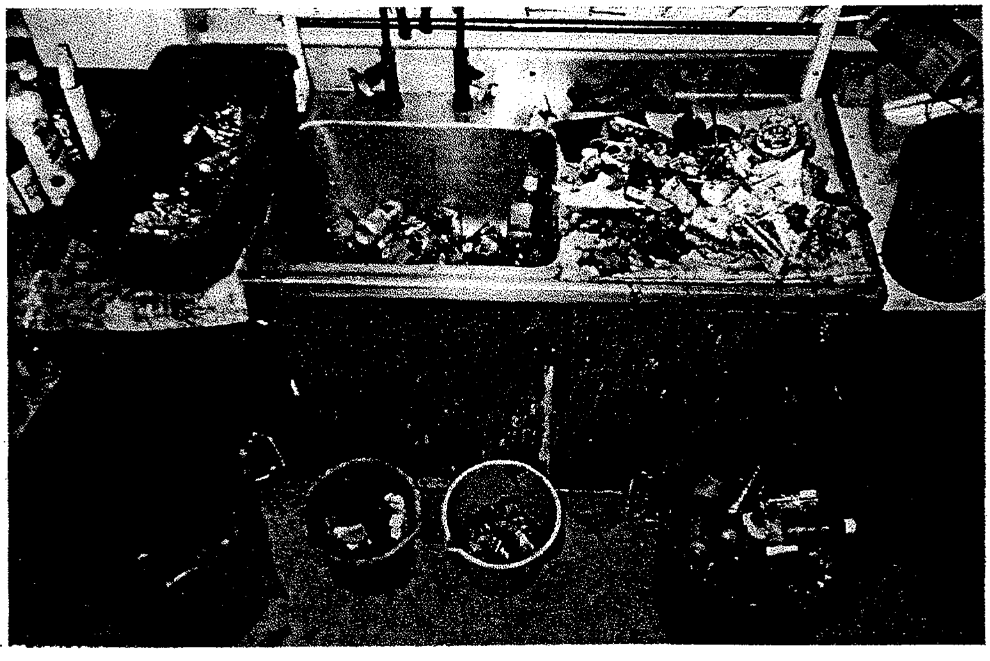
Plate 3.2 Photograph of ILLS contents being dumped at Council depot (Author's photograph, 8 September 1998).

Plate 3.3 Photograph of author manually sorting dumped ILLS contents at Council depot ready for data collection (Author's photograph, 8 September 1998).

6. For the Youth Road prototype a full litter sorting and data recording process, including all litter items (including non-sample litter items), was performed at the University laboratory, as shown in Plate 3.5.

Plate 3.4 Photograph of standard sorting and data collection for litter retrieved from a prototype in the field (Author's photograph, 1998).

Plate 3.5 Photograph of detailed additional sorting and data collection for litter retrieved from Youth Road prototype in laboratory (Author's photograph, 1998).



7. To finish the test program, time was allowed for final flushing of each drainage system to ensure any remaining test SLI's remaining within the drainage network were mobilised and transported to the ILLS prototypes. This was guaranteed by providing a month (typically) at the end of each prototype monitoring period for extra rainfall-runoff events and a corresponding final cleanout of each ILLS prototype and inspection of upstream pits and pipes for un-flushed items.
8. Rainfall data was obtained from the Melbourne Water Corporation and the Bureau of Meteorology for the nearest rainfall gauging station for each ILLS prototype catchment. The rainfall data is presented in Appendix E.

3.5 DATA ANALYSIS METHODOLOGY

The following steps were taken in analysing the data collected from each prototype:

1. Analysis of each pump-out (typically monthly) for the following:
    a. Marking off of recovered litter items on the monthly tally sheets in order to determine the removal efficiencies for each SLI. The removal efficiencies is equal to the number of tagged litter items retrieved from the prototype in that cleanout divided by the number of tagged litter items introduced into the catchment for that period. No analysis of individual clean-out removal efficiencies will be presented in the results, but may be found in Appendix C;
    b. Number of untagged (natural) sample litter items for same sample litter item categories used in tagged litter study above; and
    c. Mass of sump material caught (sediments and total gross pollutants) based on the measured volume an assumed wet density of 2600 kg/m^3.
2. Analysis of all data sets for entire monitoring program including:
    a. Total removal efficiencies (TREs) for each SLI, which is equal to the sum of tagged SLI's retrieved from the prototype over the entire monitoring program divided by the sum of tagged SLI's introduced into the catchment for the entire monitoring program, less those remaining upstream in the drainage system entrance pits. This allowed for the determination of TRE's for each SLI type across the test period. The TRE's allow both number and mass balance to be calculated for each SLI once total inflow numbers and mass inflows are known, but these were not determined and outside the study scope.

b. Average total removal efficiencies for each sample litter item across all prototypes (for second phase of monitoring only);

c. Number of untagged (natural) sample litter items trapped over entire study period (UTP) for each SLI and for each prototype;

d. Estimated number of untagged (natural) sample litter items for each sample litter item across respective study periods (EUP) for each prototype;

e. Total estimated number of untagged SLI's across study period for all SLI types from respective prototype catchments;

f. Estimates of the total mass of sediments and gross pollutants captured and the expected cleaning frequency based on the measured sump depths;

g. Rainfall data (both maximum and summation) is analysed for each pump-out (based on mostly 6 minute rainfall data) and is presented in Appendix E;

h. Comparison between total removal efficiencies for each SLI for each prototype and a target of 70%, based on the aim of achieving a '70% reduction in the typical annual litter load' (Victorian Stormwater Committee, 1999). However, it is noted that this study determines litter capture performance with a frequency analysis, with no mass balance performed.

3.6 CASE STUDIES – ILLS PROTOTYPES FOR FIELD MONITORING

Ten prototypes were installed during the installation and monitoring program, with an additional commercial ILLS installation in the City of Greater Bendigo. The prototypes were installed in two (2) generations (rounds) and monitored across two (2) phases as case studies. These case studies are presented in Chapter 4, together with ILLS design data and catchment plans, with results presented in Chapter 5.

3.7 CONCLUSIONS

This chapter also reported the field research and monitoring program, selection of the tagged litter sample, including identifiable sample litter items, and the monitoring and data analysis methodologies. The task of monitoring and evaluating the field performance of ILLS prototypes required the development of a standard test methodology. The test methodology and data analysis adopted and presented in this chapter sought to address the difficulties inherent in field testing and monitoring stormwater drainage systems. As many complex variables are associated with litter conveyance within stormwater systems, a simple, direct method of field performance assessment was adopted that utilised an easily identifiable litter sample that could be monitored throughout extended periods under varying rainfall-runoff events. The methodology presented allows for performance evaluation of prototypes to be measured based on testing sample litter item removal (capture) efficiencies. The following chapter details the results of the ILLS field monitoring and evaluation.

4 ILLS PROTOTYPE CASE STUDIES: LOCATIONS, DESIGN DATA AND CATCHMENT PLANS

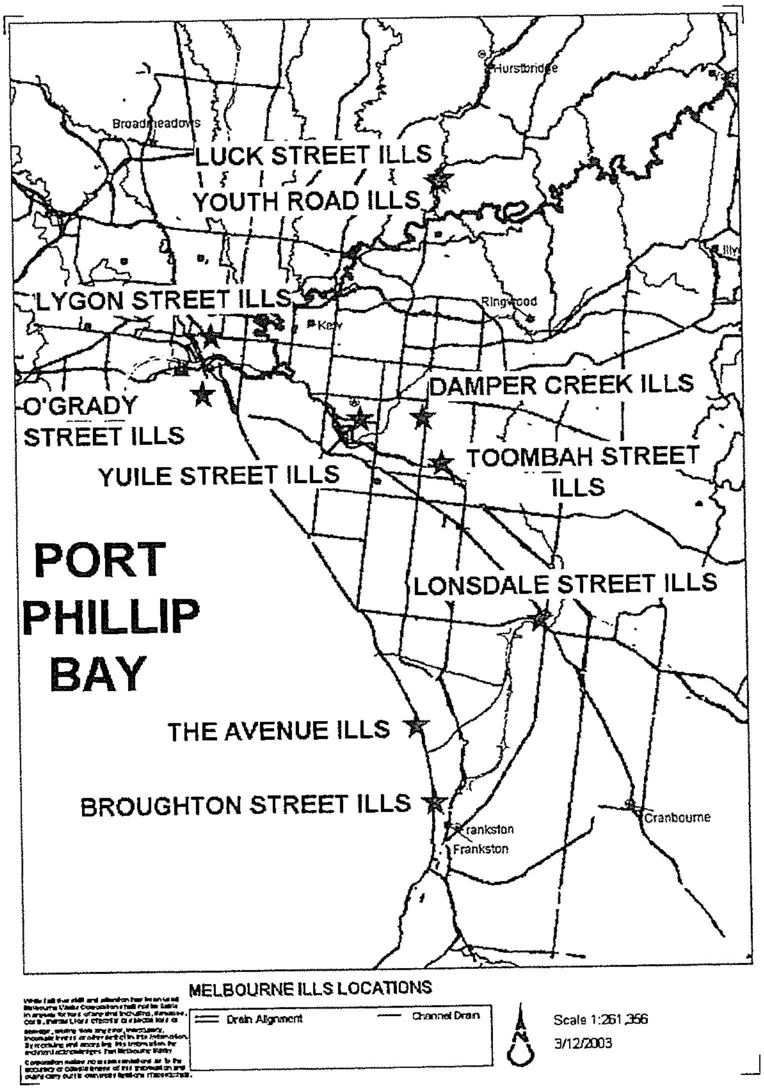
4.1 INTRODUCTION

This chapter presents the details of the ILLS prototypes used in this study, including locations, design data (catchment area, sump volume, etc.) and Melbourne Rating Number (MRN) values (refer to Section 2.8.6.2), along with respective catchment plans.

4.2 LOCATION OF ILLS PROTOTYPES

Figure 4.1. presents a map of the Melbourne and Metropolitan area with locations of ILLS prototypes examined in this study shown.

Figure 4.1 Map of Melbourne and Metropolitan area with locations of ILLS prototypes shown.



4.3 FIRST ROUND (GENERATION) PROTOTYPE INSTALLATIONS

4.3.1 Prototype Case Study #1 – Damper Creek, Monash City Council

Data:

- Site location: Damper Creek, Mt Waverley (Melway reference 61F9)
- Catchment Area = A = 30 Ha.
- Pipe diameter = 1050 mm.
- Pipe grade: 8%.
- Prototype installed: 11 April 1997.
- Prototype details:
  - Manufacturer: SVC Products Pty. Ltd;
  - Sump volume = C = 1.72 cubic meters (instead of the proposed 3.5 cubic meter)
  - MRN = (C*W)/[(B+W)*(A^1.33)] = 0.016, where:
    - Boom width = B = 0 (sump doesn't extend under boom platform)
    - Weir length = W = 1.0 m.

Prototype data is included for completion as some prototype clean outs were performed, as presented in the next chapter, with the finding that testing with sample litter items was not warranted. Therefore no catchment plans or photographs are presented here.

4.3.2 Prototype Case Study #2 – Toombah Street, Monash City Council

Data:

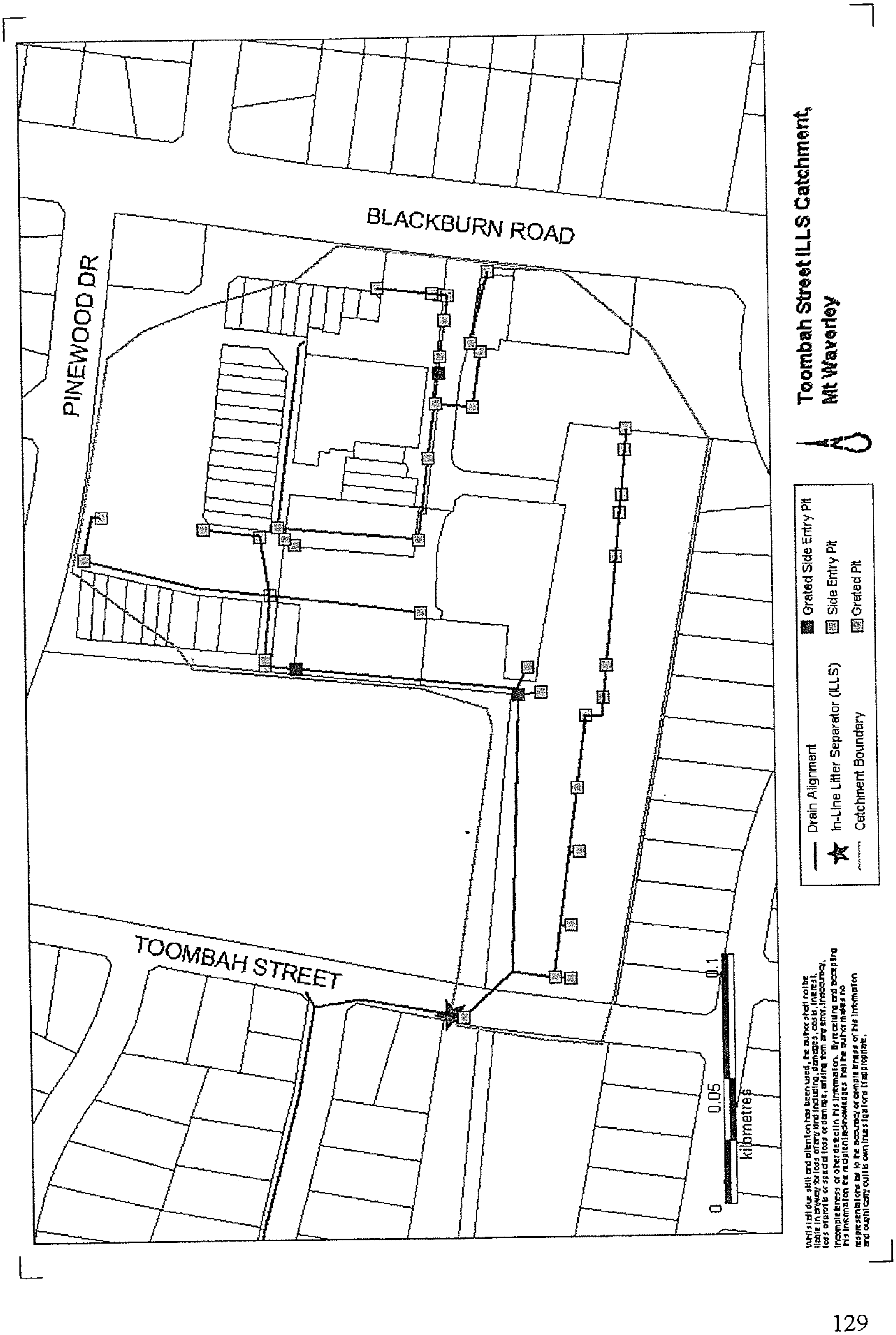
- Site location: Toombah Street, Mt Waverley (Melway reference 70H5)
- Catchment Area = A = 4.54 Ha (Land use: Commercial, car park and roads).
- Pipe diameter = 375 mm.
- Pipe grade: approximately 3%.
- Prototype installed: 28 February 1997.
- Prototype details:
  - Manufacturer: CSR Construction Materials Pty. Ltd.
  - Sump volume = C = 2.70 cubic meters
  - Boom construction: Fibreglass with curved face.
  - MRN = (C*W)/[(B+W)*(A^1.33)] = 0.269, where:
    - Boom width = B = 0.59 m (sump doesn't extend under boom platform)
    - Weir length = W = 1.732 m.

Plate 4.1 shows the installation of the Toombah Street ILLS prototype. Note the restricted return channel opening behind the boom, the rounded faced boom shape, and that the boom is not yet connected to pivot points.

Plate 4.1 Installation of Toombah Street ILLS prototype (Authors Photograph, 1997)

For the Toombah Street ILLS prototype catchment plan refer to Figure 4.2.

Figure 4.2 Catchment Plan for Toombah Street ILLS prototype.

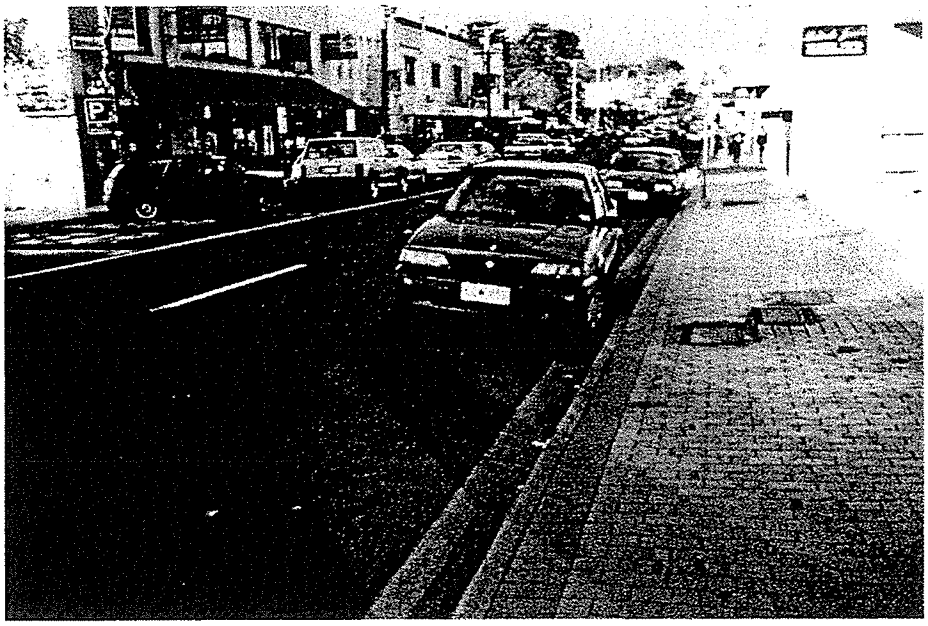


4.3.3 Prototype Case Study #3 – Yuile Street, City of Boroondara

Data:

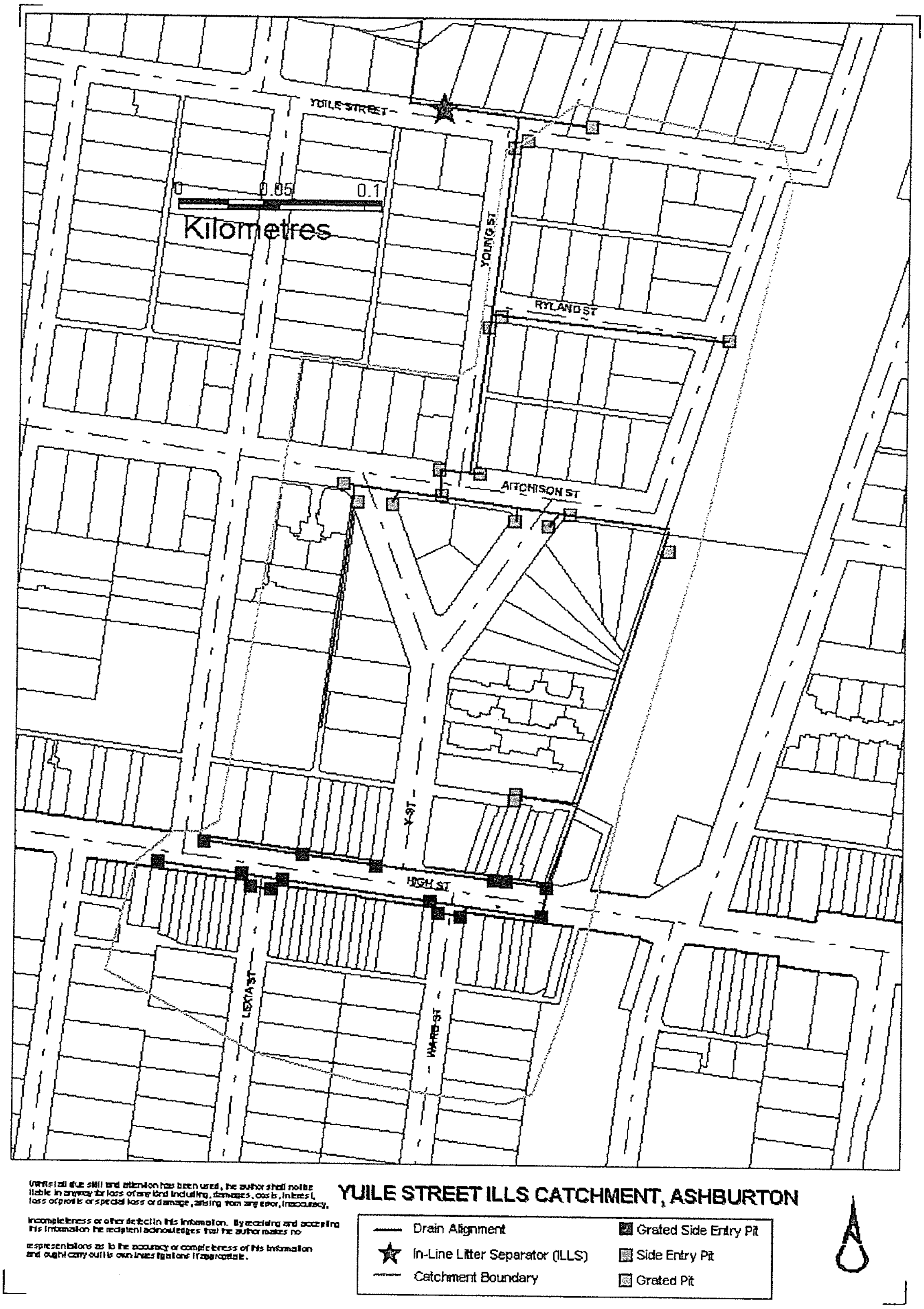
- Site location: Yuile Street, Ashburton (Melway reference 60 D9)
- Catchment Area = A = 9.31 Ha (Land uses: Commercial, car parking, residential and roads).
- Pipe diameter = 600 mm.
- Pipe grade: 1 in 71 (1.41%).
- Prototype installed: 2 May 1997.
- Prototype details:
  - Manufacturer: SVC Products Pty. Ltd.
  - Sump volume = C = 1.75 cubic meters
  - Boom construction: Fibreglass with curved face.
  - MRN = (C*W)/[(B+W)*(A^1.33)] = 0.090, where:
    - Boom width unknown, B = 0 m (sump doesn't extend under boom platform)
    - Weir length = W = 1.22 m.

Plate 4.2 Commercial strip shopping area of the Yuile Street ILLS prototype catchment (Authors Photograph, 1997)



For the Yuile Street ILLS prototype catchment plan refer to Figure 4.3.

Figure 4.3 Catchment Plan for Yuile Street ILLS prototype.

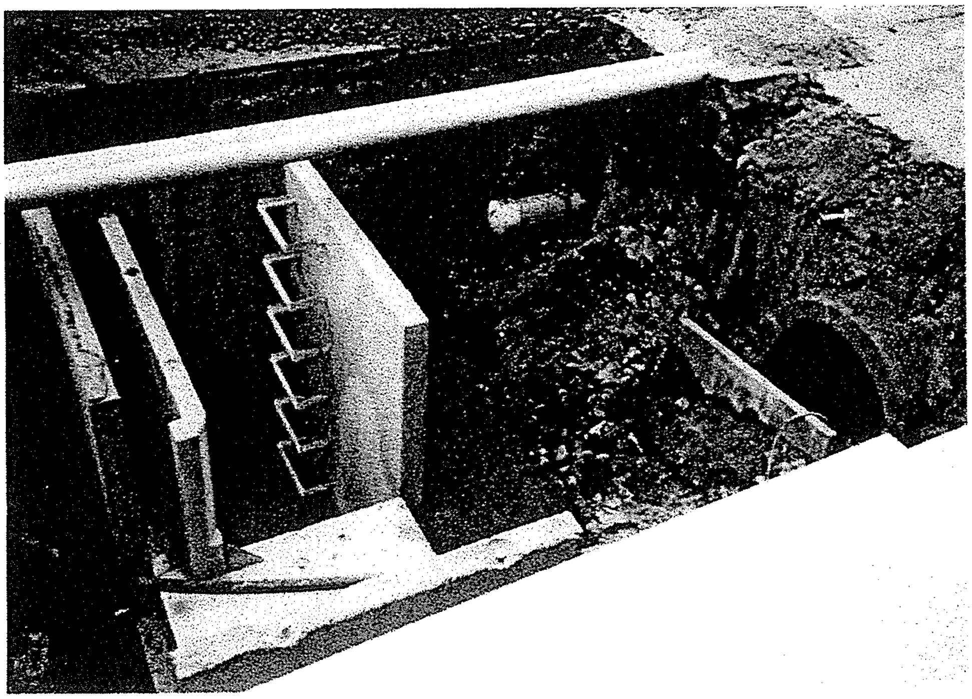


4.3.4 Prototype Case Study #4 –Lygon Street, City of Melbourne

Data:

- Site location: Lygon Street, Carlton (Melway reference 43 H6)
- Catchment Area = A = 7.22 Ha (Land uses: Commercial, car parking and roads).
- Pipe diameter = 685 mm (Brick construction).
- Pipe grade: 1 in 122 (0.82%).
- Prototype installed: 1 May 1997.
- Prototype details:
  - Manufacturer: CSR Construction Materials Pty. Ltd.
  - Sump volume = C = 3.50 cubic meters
  - Boom construction: Wedge shaped with stainless steel construction.
  - MRN = (C*W)/[(B+W)*(A^1.33)] = 0.155, where:
    - Boom width = B = 0.895 m
    - Weir length = W = 1.434 m.

Plate 4.3 Installation of Lygon Street ILLS prototype (Authors photograph, 1997). Note the restricted return channel opening.



For the Lygon Street ILLS prototype catchment plan refer to Figure 4.4.

Figure 4.4 Catchment Plan for Lygon Street ILLS prototype.

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4.3.5 Prototype Case Study #5 – Luck Street, Shire of Nillumbik

Data:

- Site location: Luck Street, Eltham (Melway reference 21 K4)
- Catchment Area = A = 6.50 Ha (Land use: Commercial, car parking and roads, with some residential).
- Pipe diameter = 600 mm.
- Pipe grade: 1 in 200.
- Prototype installed: 15 May 1997.
- Prototype details:
  - Manufacturer: SVC Products Pty. Ltd.
  - Sump volume = C = 1.72 cubic meters
  - Boom construction: Fibreglass with curved face.
  - MRN = (C*W)/[(B+W)*(A^1.33)] = 0.143, where:
    - Boom width = B = 0 (sump doesn't extend under boom platform)
    - Weir length = W = 1.000 m.

Prototype data is included for completion as some prototype clean outs were performed, as presented in the next chapter, with the finding that testing with sample litter items was not warranted. Therefore no catchment plans or photographs are presented here.

4.4 SECOND ROUND (GENERATION) OF PROTOTYPE INSTALLATIONS

4.4.1 Prototype Case Study #6 – Broughton Street, Frankston City Council

Data:

- Site location: Broughton Street, Seaford (Melway reference 99 D3)
- Catchment Area = A = 3.50 Ha (Land use: Commercial, car parking, and roads).
- Pipe diameter = 300 mm.
- Pipe grade: Unknown.
- Prototype installed: 30 October 1997.
- Prototype details:
  - Manufacturer: CSR Construction Materials Pty. Ltd.
  - Sump volume = C = 3.50 cubic meters
  - Boom construction: Wedged shaped boom of galvanized steel construction.

  - MRN = (C*W)/[(B+W)*(A^1.33)] = 0.348, where:
    - Boom width = B = 0.90 m
    - Weir length = W = 1.000 m.

Prototype data is included for completion as some prototype clean outs were performed, as presented in the next chapter, with the finding that testing with sample litter items was not warranted. Therefore no catchment plans or photographs are presented here.

4.4.2 Prototype Case Study #7 – The Avenue, Kingston City Council

Data:

- Site location: The Avenue, Chelsea (Melway reference 97 B2)
- Catchment Area = A = 8.0 Ha (Land use: Commercial, car parking, roads, and residential).
- Pipe diameter = 450 mm.
- Pipe grade: Unknown.
- Prototype installed: 9 December 1997.
- Prototype details:
  - Manufacturer: SVC Products Pty. Ltd.
  - Sump volume = C = 4.37 cubic meters
  - Boom construction: Wedged shaped boom of galvanized steel construction.
  - MRN = (C*W)/[(B+W)*(A^1.33)] = 0.275, where:
    - Boom width unknown; B = 0 m (sump doesn't extend under boom platform)
    - Weir length = W = 2.8 m.

Prototype data is included for completion as some prototype clean outs were performed, as presented in the next chapter, with the finding that testing with sample litter items was not warranted. Therefore no catchment plans or photographs are presented here.

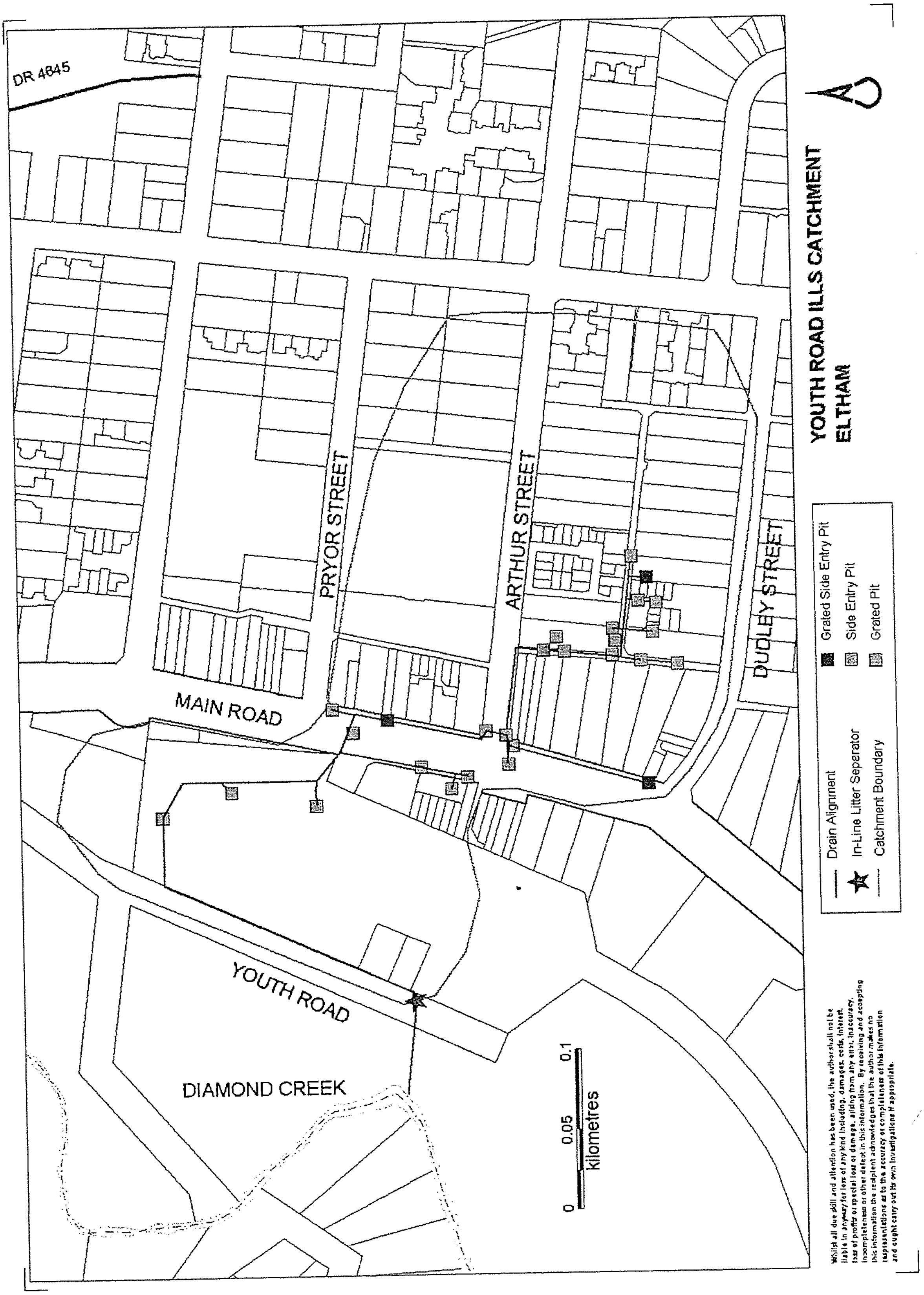
4.4.3 Prototype Case Study #8 – Youth Road, Shire of Nillumbik

Data:

- Site location: Youth Street, Eltham (Melway reference 21 J5)
- Catchment Area = A = 10.07 Ha (Land use: Commercial, car parking, roads, and residential).
- Pipe diameter = 600 mm.
- Pipe grade: Approximately 2%.
- Prototype installed: 27 November 1997.
- Prototype details:
  - Manufacturer: SVC Products Pty. Ltd.
  - Sump:
    - Volume = C = 3.67 cubic meters
    - Surface area = As = 1.445 m^2
  - Boom:
    - Construction: Wedged shaped boom of galvanized steel construction.
    - Width = 1000mm. B = 0 m (sump does not extend under boom platform)
    - Volume: 0.067 m3
    - Mass: 31 kg
  - Baffle Comb:
    - Area: 2.634 m2. Full width baffle extending to floor of sump.
    - Clear spacing: 25mm open width (3 mm wires at 28mm centre spacings)
  - Weir:
    - Length = W = 2.05 m.
    - Height of weir crest above boom platform = 160 mm
    - Width of weir –channel opening = 305 mm
    - Weir return open flow plan area = 0.687 m^2
  - MRN = (C*W)/[(B+W)*(A^1.33)] = 0.170

For the Youth Road ILLS prototype catchment plan refer to Figure 4.5.

Figure 4.5 Catchment Plan for Youth Road ILLS prototype.



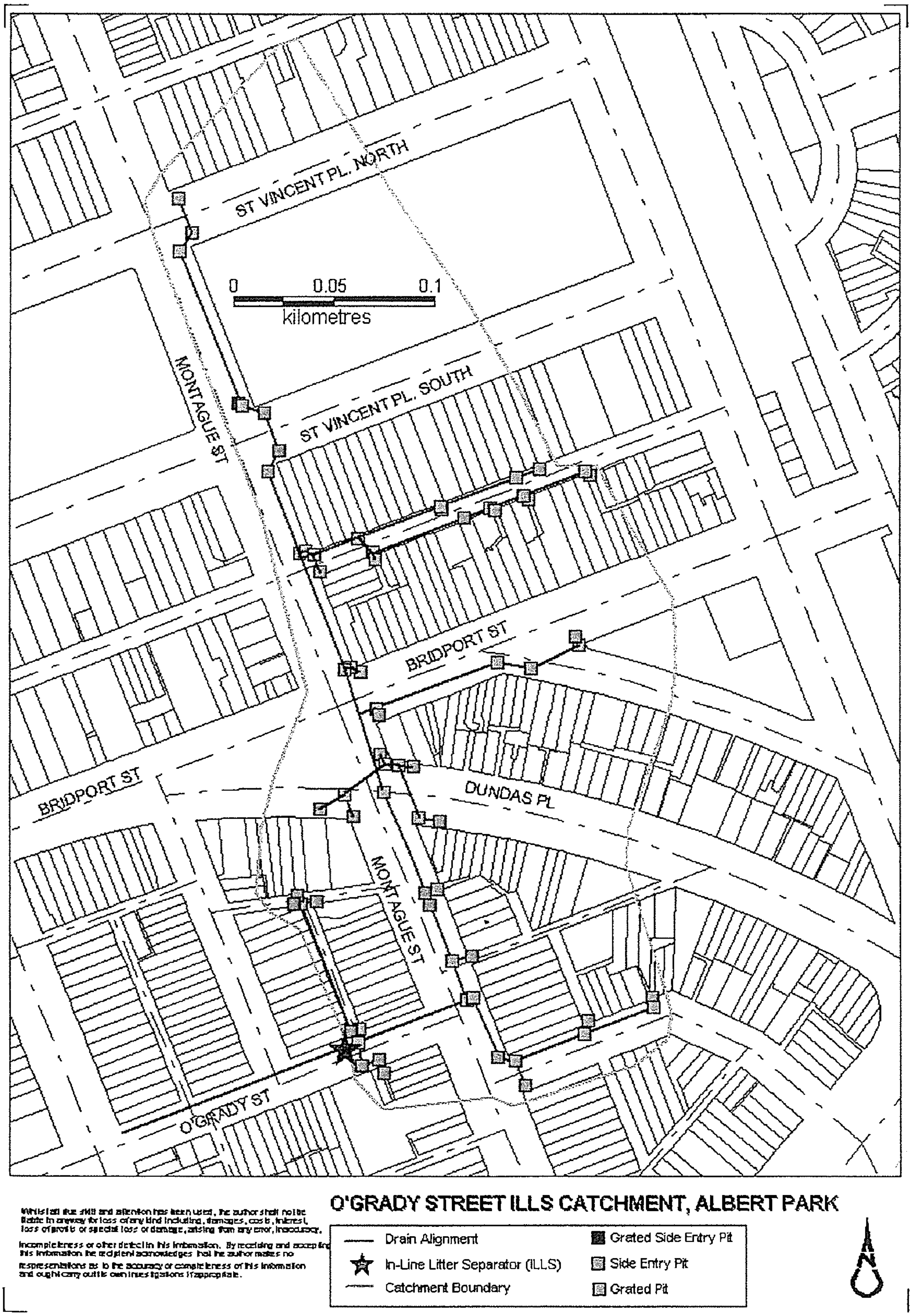
4.4.4 Prototype Case Study #9 – O'Grady Street, Port Phillip City Council

Data:

- Site location: O'Grady Street, Albert Park (Melway reference 57 F4)
- Catchment Area = A = 8.02 Ha (Land use: Commercial, car parking, roads, and residential).
- Pipe diameter = 750 mm.
- Pipe grade: Unknown.
- Prototype installed: 12 December 1997.
- Prototype details:
    - Manufacturer: CSR Construction Materials Pty. Ltd.
    - Sump:
        - Volume = C = 9.86 cubic meters
        - Surface area = As = 3.24 m^2
    - Boom:
        - Construction: Wedged shaped boom of galvanized steel construction.
        - Width = 1100mm. B = 1.1 m (sump does extend under boom platform)
        - Volume: 0.0928 m3
        - Mass: 69 kg
    - Baffle Comb:
        - Area: 2.0 m2.
        - Clear spacing: 27mm open width (3 mm wires at 30 mm centre spacings)
    - Weir:
        - Length = W = 1.83 m.
        - Height of weir crest above boom platform = 190 mm
        - Width of weir –channel opening = 420 mm
        - Weir return open flow plan area = 0.400 m^2
    - MRN = (C*W)/[(B+W)*(A^1.33)] = 0.386

For the O'Grady Street ILLS prototype catchment plan refer to Figure 4.6.

Figure 4.6 Catchment Plan for O'Grady Street ILLS prototype.



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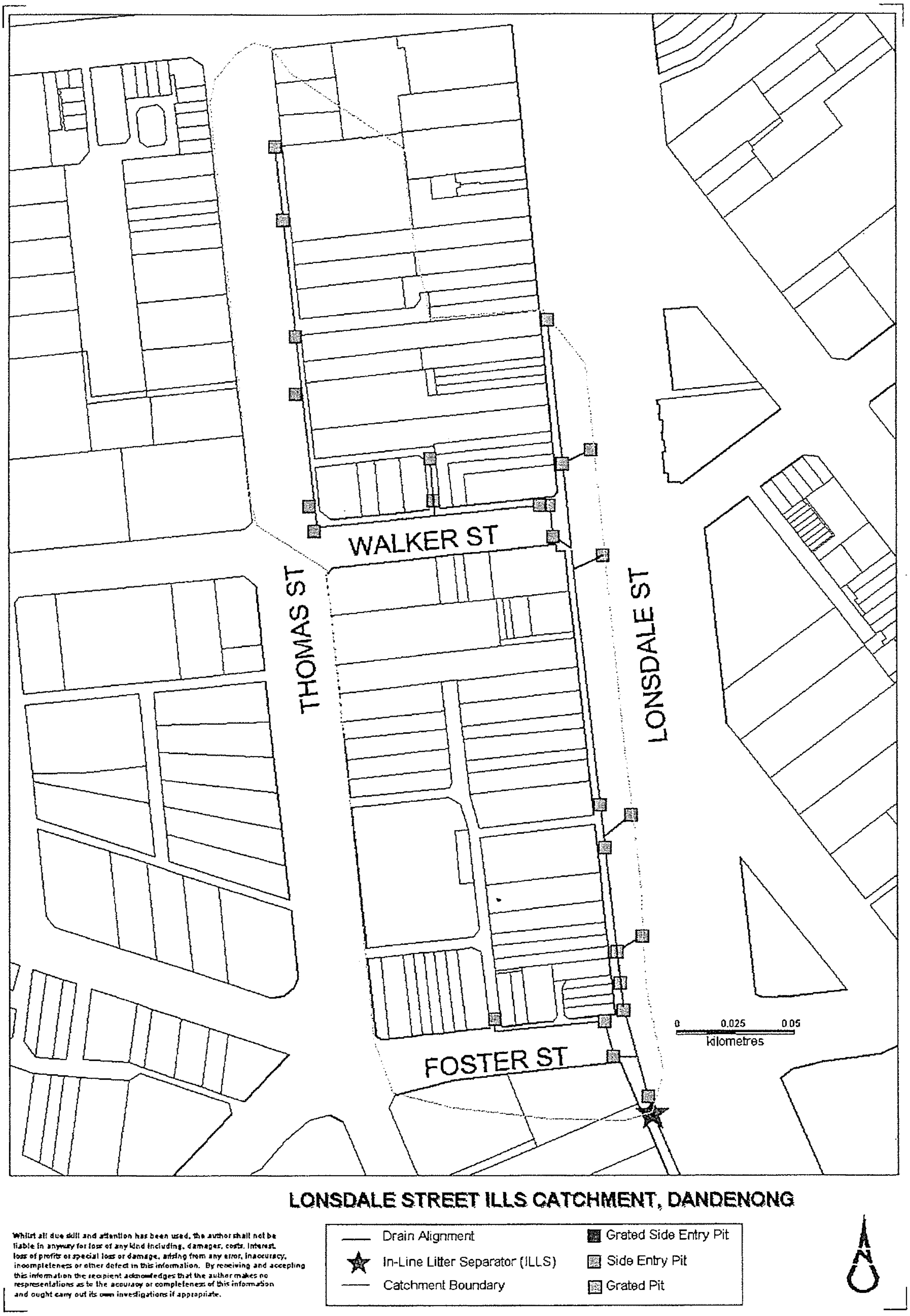
4.4.5 Prototype Case Study #10 – Lonsdale Street, City of Greater Dandenong

Data:

- Site location: Lonsdale Street, Dandenong (Melway reference 90 D8)
- Catchment Area = A = 5.11 Ha (Land use: Commercial, car parking and roads).
- Pipe diameter = 675 mm.
- Pipe grade: Unknown.
- Prototype installed: 16 April 1998.
- Prototype details:
  - Manufacturer: SVC Products Pty. Ltd.
  - Sump:
    - Volume = C = 3.60 cubic meters
    - Surface area = As = 1.80 m^2
  - Boom:
    - Construction: Wedged shaped boom of galvanized steel construction.
    - Width = 900mm. B = 0 m (sump doesn't extend under boom platform)
    - Volume: 0.0486 m3
    - Mass: 25 kg
  - Baffle Comb:
    - Area: 2.66 m2.
    - Clear spacing: 27mm open width (3 mm wires at 30mm centre spacing)
  - Weir:
    - length = W = 2.00 m.
    - Height of weir crest above boom platform = 100 mm
    - Width of weir–channel opening = 300 mm
    - Weir return open flow plan area = 0.660 m^2
  - MRN = (C*W)/[(B+W)*(A^1.33)] = 0.411

For the Lonsdale Street ILLS prototype catchment plan refer to Figure 4.7.

Figure 4.7 Catchment Plan for Lonsdale Street ILLS prototype.



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4.5 ADDITIONAL COMMERCIAL ILLS MONITORED IN SECOND PHASE

4.5.1 Case Study #11 – Williamson Street, City of Greater Bendigo

Data:

- Site location: Williamson Street, Bendigo
- Catchment Area = A = 7.32 Ha (Land use: Commercial, car parking and roads).
- Pipe diameter = 900 mm.
- Pipe grade: 1 in 80 (1.25%)
- Installation: June 1998.
- Commercial ILLS details:
  - Manufacturer: CSR Construction Materials Pty. Ltd.
  - Sump:
    - Volume = C = 9.75 cubic meters
    - Surface area = As = 1.80 m^2
  - Boom:
    - Construction: Wedged shaped boom of galvanized steel construction.
    - Width = 1320mm. B = 1.32 m (sump does extend under boom platform)
    - Volume: 0.1604 m^3
    - Mass: 97 kg
  - Baffle Comb:
    - Area: 1.34 m2.
    - Clear spacing: 27mm open width (3 mm wires at 30mm centre spacing)
  - Weir (Triangular):
    - length = W = 2.263 m.
    - Height of weir crest above boom platform = 215 mm
    - Width of weir–channel opening = 600 mm
    - Weir return open flow plan area = 0.60 m^2
  - MRN = (C*W)/[(B+W)*(A^1.33)] = 0.436

Plate 4.4 shows the Williamson Street ILLS prior to installation.

Plate 4.4 Williamson Street ILLS components prior to installation (photograph kindly supplied by Humes, 1998).

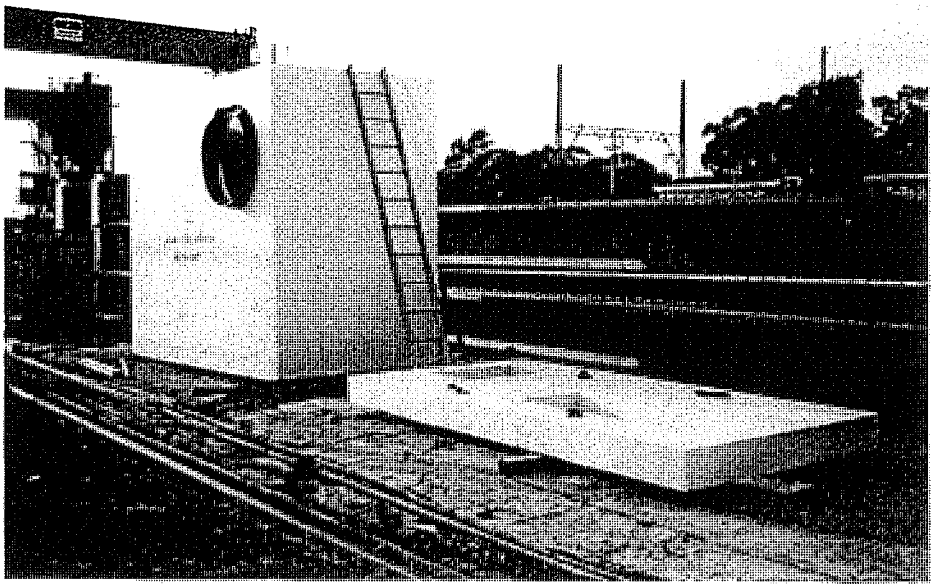


Plate 4.5 Williamson Street ILLS installation (Authors photograph, 1998).

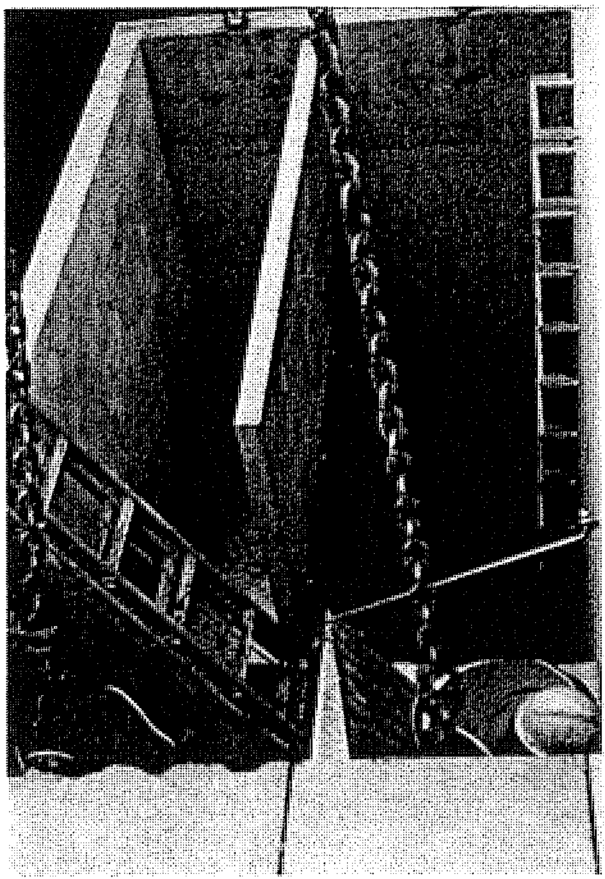
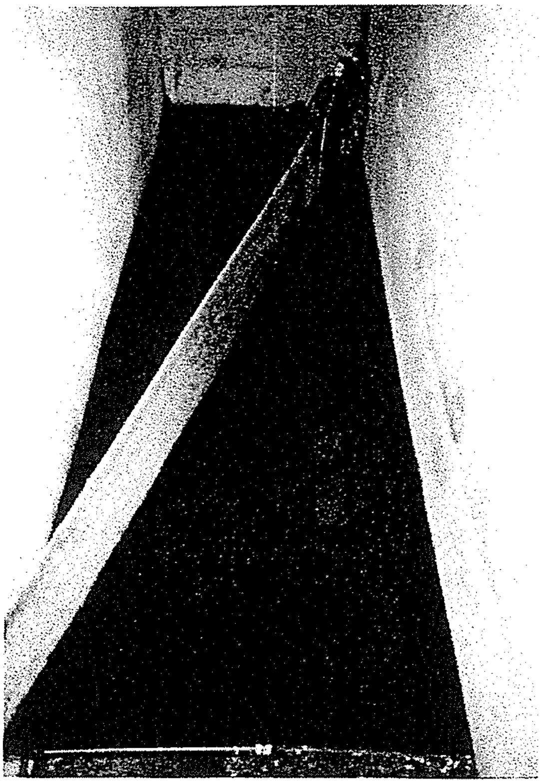
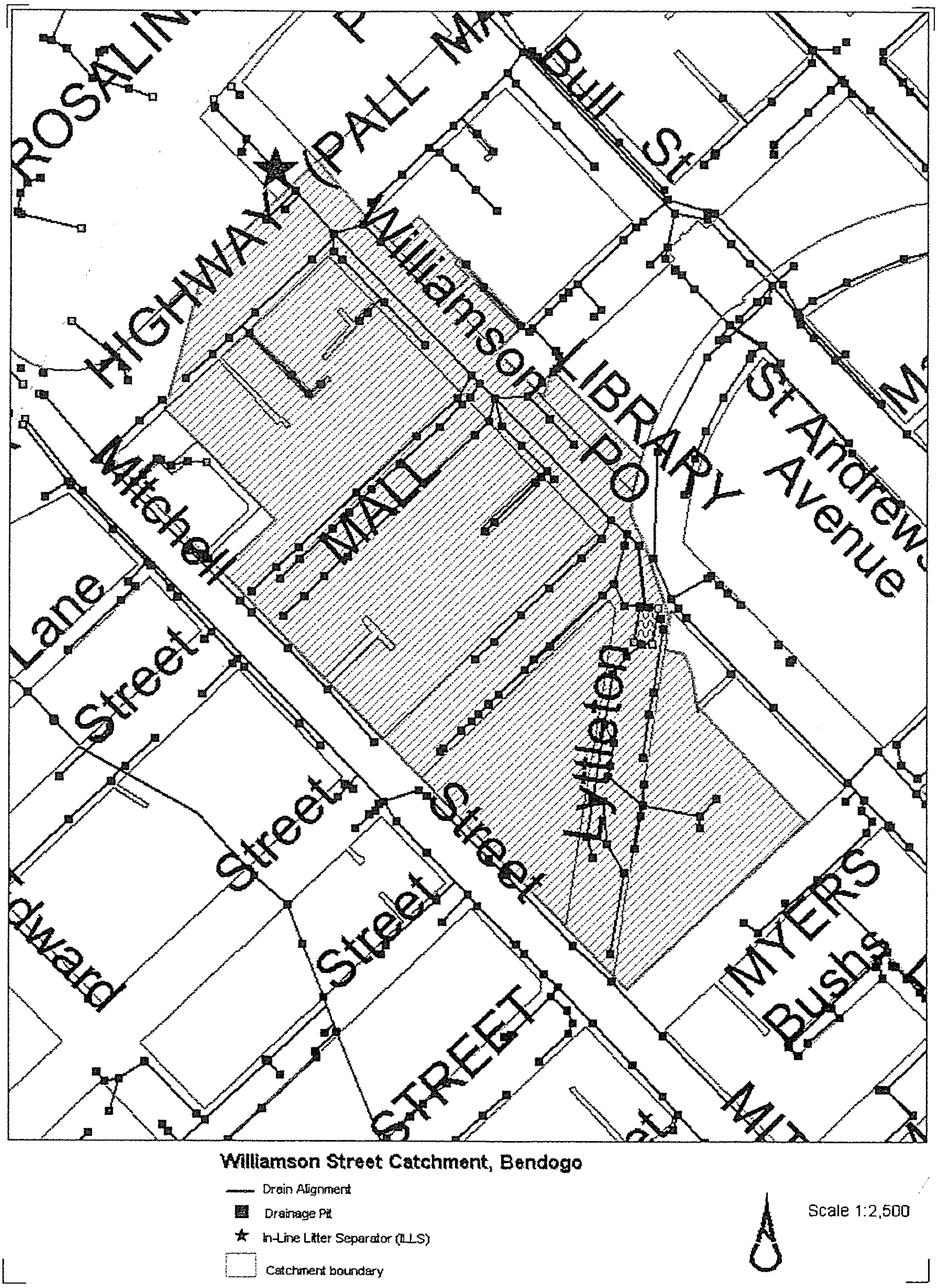


Plate 4.6 Williamson Street ILLS triangular return channel and weir (Authors photograph, 1998).



For the Williamson Street ILLS catchment plan refer to Figure 4.8.

Figure 4.8 Catchment Plan for Williamson Street ILLS.



5 RESULTS OF DATA COLLECTION AND ANALYSIS

5.1 INTRODUCTION

This chapter presents the results of the ILLS installation and monitoring project. Ten ILLS prototypes were installed in two rounds of installations, with an additional commercial unit featuring a triangular return weir-channel installed and monitored in the City of Greater Bendigo. However, only seven (7) of the prototypes were monitored, as discussed in this chapter. The monitoring was undertaken in two (2) phases, where the first phase monitored first round prototype installations, and the second phase monitored both the modified first round prototypes, and second round prototypes.

As previously discussed, the methodology adopted involved determining the number and types of introduced tagged sample litter items captured by each prototype. This data was then used to derive the total removal efficiency (TRE) for each sample litter item (SLI) after the conclusion of the test program for that prototype. Appendix C contains a complete data set relating to the following:

- number of SLI's introduced at the beginning of each period and the number of sample litter items retrieved from a clean-out at the end of each period;
- removal efficiencies (RE) for each SLI's for each cleanout (pump-out);
- total removal efficiencies including an account of the number of SLI's retrieved from catchment drainage entrance pits at the end of the entire study; and
- standard deviations for SLI removal efficiencies.

Data collected on the untagged (natural) sample litter items for each prototype enabled the following to be calculated:

- Number of untagged (natural) sample litter items trapped over entire study period (UTP) for each SLI and for each prototype;
- Estimated number of untagged (natural) sample litter items for each sample litter item across study period (EUP) for each prototype;

Appendix D contains complete data sets relating to the UTP and EUP study results for each ILLS prototype, as well as sump materials depth measurements, which allowed estimates of the total mass of gross pollutants and sediments and expected clean out frequencies to be made.

Additional data for syringes, considered a priority litter item, collected during the second phase of monitoring enabled the average total removal efficiency across all prototypes monitored to be determined for syringes. For the Youth Road ILLS prototype data is also presented for the full analysis of surface and sump tagged sample litter items, untagged SLI's, and non-sample litter items.

5.1.1 General notation used in results tables

The following notation relate to tables used to calculate litter item removal efficiencies:

- Drop total. Denotes number of sample litter items introduced in ILLS catchments over entire study period;
- Retrieved total: Denotes number of sample litter items retrieved from ILLS prototype across all clean-outs;
- PITS: Denotes number of sample litter items retrieved from catchment drainage entrance pits at the end of study;
- TRE: Denotes total removal efficiency per litter item over study period (%); and
- STDVP: Denotes 'standard deviation' ('n' biased method).

The following notation relate to tables used with untagged sample litter item data:

- UTP: Denotes number of untagged (natural) sample litter items retrieved from ILLS prototype over entire study period for each SLI; and
- EUP: Denotes estimated number of untagged (natural) sample litter items from ILLS case study catchment over entire study period for each sample litter item.

5.2 FIRST PHASE ILLS MONITORING AND PERFORMANCE EVALUATION

The first phase of ILLS monitoring and performance evaluation was performed on the initial round (first generation) of five (5) ILLS prototype installations.

5.2.1 Prototype Case Study #1 - Damper Creek, Monash City Council

The Damper Creek prototype was installed in May 1997 and the pipe grade was much steeper than that given by Monash City Engineers. Boom hanger failure was experienced following a storm event not long after installation, due to inadequate strength of boom hanger arms. The fibreglass boom was later replaced by a low timber weir, and a comb was installed under the baffle wall, to help improve litter capture ability. Due to these changes no monitoring was performed on this prototype.

5.2.2 Prototype Case Study #2 - Toombah Street, Monash City Council - first phase of monitoring

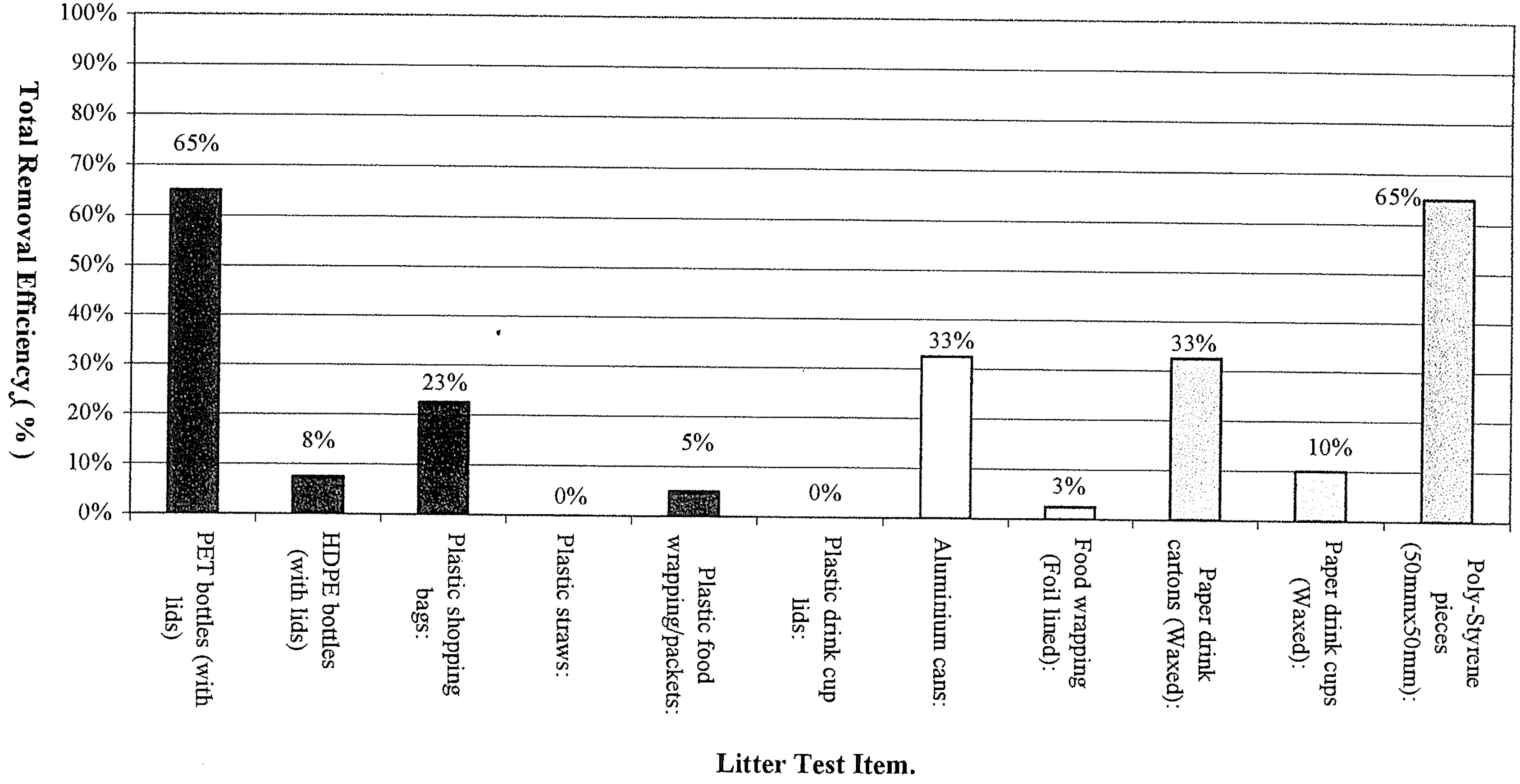
The Toombah Street ILLS prototype was installed in April 1997 and an initial clean-out was performed on the 12 June 1997. Monitoring was conducted over five (5) cleanouts between June and December 1997, but was discontinued in December 1997 due to problems with the boom malfunctioning and jamming in the lift position. Table 5.1 presents a summary of the number of SLI's dropped and retrieved and the total removal efficiency for each SLI for the first phase of monitoring of the Toombah Street ILLS prototype. Appendix C (Table App C.1) includes a complete set of data and Figure 5.1 plots the total removal efficiency for each SLI.

Table 5.1 Total removal efficiencies for Toombah Street prototype for the first phase of monitoring.

SAMPLE LITTER ITEM	Drop Total	Retrieved Total	TRE (%)	STDVP
PET bottles (with lids)	40	26	65%	0.36
HDPE bottles (with lids)	40	3	8%	0.08
Plastic shopping bags:	40	9	23%	0.04
Plastic straws:	40	0	0%	0.00
Plastic food wrapping/packets:	40	2	5%	0.05
Plastic drink cup lids:	20	0	0%	0.00
Aluminium cans:	40	13	33%	0.19
Food wrapping (Foil lined):	40	1	3%	0.04
Paper drink cartons (Waxed):	40	13	33%	0.18
Paper drink cups (Waxed):	30	3	10%	0.09
Poly-Styrene pieces:	40	26	65%	0.36
TOTALS:	**410**	**96**		

No data was collected on untagged litter frequencies for the SLI's, so it was not possible to calculate the estimated number of untagged (natural) sample litter items from ILLS prototype catchment over entire study period for this prototype for each SLI's.

Figure 5.1 Toombah Street - Phase 1. Total Removal Efficiencies for Test Sample Litter Items.



PROTOTYPE: TOOMBAH STREET - CITY OF MONASH
FIRST PHASE OF TESTING (Prior to ILLS prototype modifications)
Total Removal Efficiency for Test Sample Litter Items

Plates 5.1 and 5.2 show the surface of holding chamber of the Toombah Street ILLS prototype covered in litter and other pollutants in the first phase of monitoring.

Plate 5.1 Litter and oil on the surface of the holding chamber of the Toombah Street ILLS prototype (Authors Photograph, September 1997)

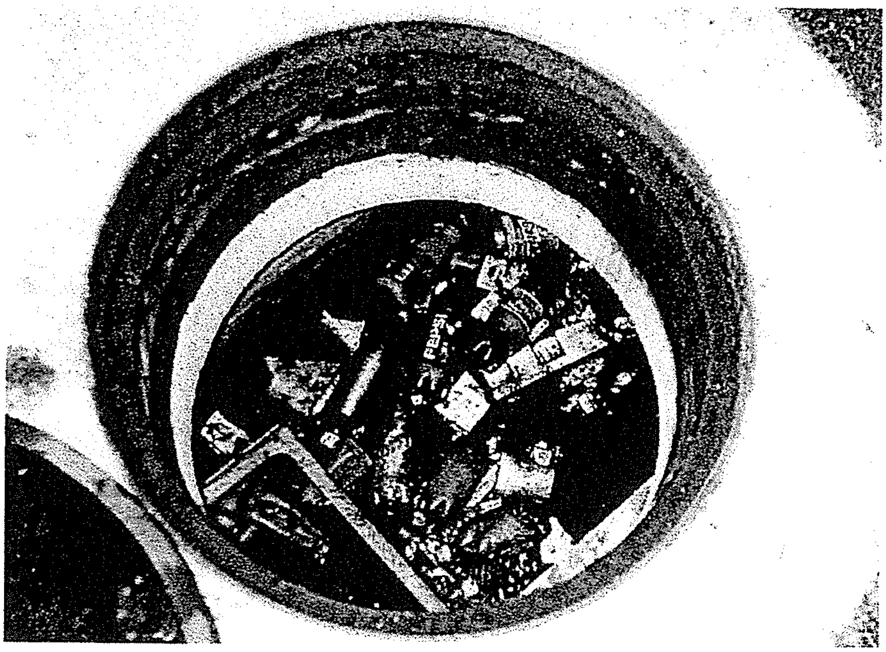
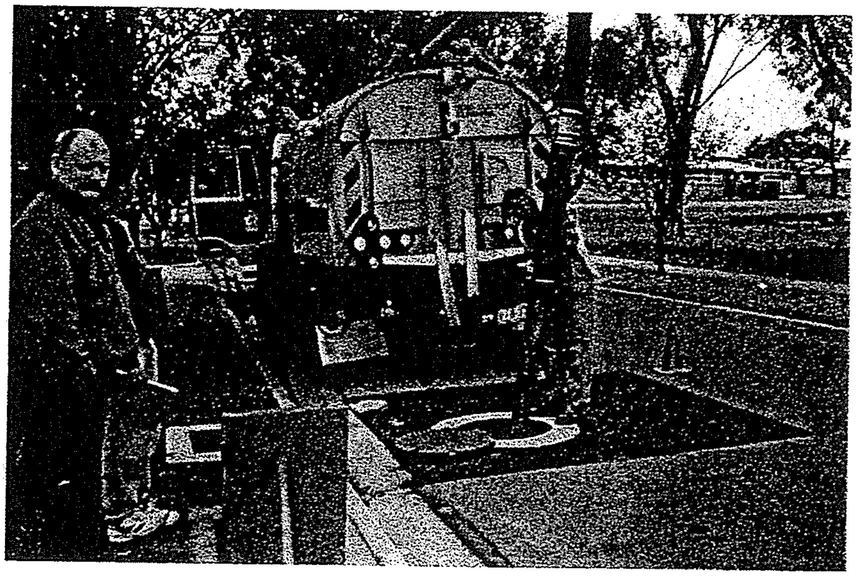


Plate 5.2 Litter and oil on the surface of the holding chamber of the Toombah Street ILLS prototype (Authors Photograph, November 1997)

Plate 5.3 Toombah Street ILLS prototype being cleaned out using vacuum street sweeper (Authors Photograph, August 1997)



Although this prototype was capturing a proportion of the litter load, tested total removal efficiencies were generally poor, with no SLI's receiving a total removal efficiency greater than 70%, and three SLI's receiving a total removal efficiency of 0% (plastic food wrapping/ packets (with and without foil lining) and plastic drinking straws. From observations it was evident that runoff flows and litter were overtopping the ILLS boom, and hence the monitoring results are unreliable. Modifications were required to the boom and boom hangers and removal of the return weir was recommended to increase return flow and boom uplift. A comb was also recommended to assist litter trapping performance.

5.2.3 Prototype Case Study #3 - Yuile Street, City of Boroondara

The Yuile Street prototype was installed in April 1997, with initial cleanout on the 4 July 1997. Four (4) cleanouts were performed between August and November 1997 before boom hanger failure was observed during a large storm event on the 12th of January 1998 and testing was discontinued.

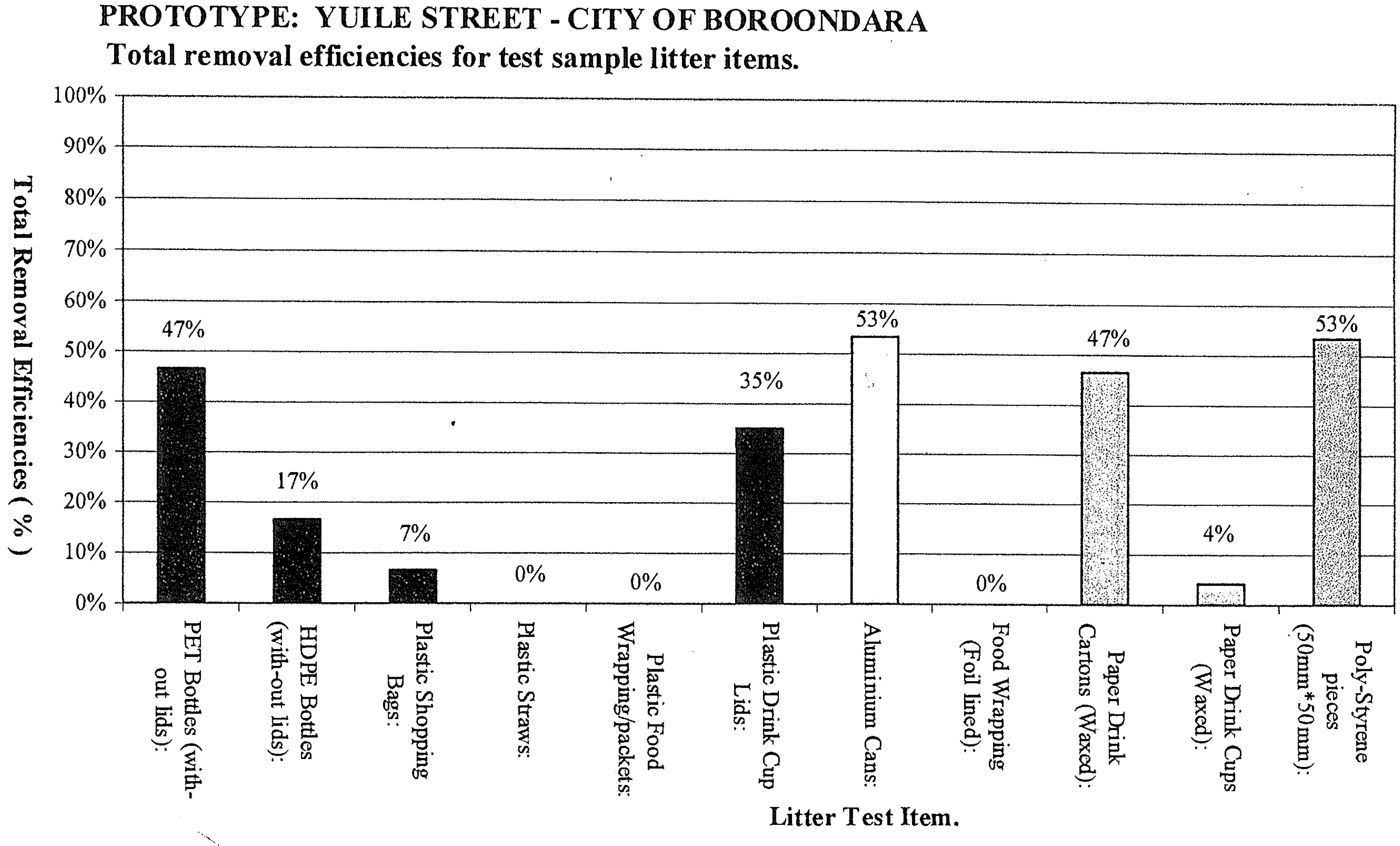
Table 5.2 presents a data summary of the number of SLI's dropped and retrieved and the total removal efficiency for each SLI for the entire first phase of monitoring of the Yuile Street prototype. Appendix C (Table App C.2) presents a complete set of data and Figure 5.2 plots the total removal efficiency for each SLI.

Table 5.2 Total removal efficiencies for Yuile Street prototype monitoring.

SAMPLE LITTER ITEM	Drop Total	Retrieved Total	TRE (%)	STDVP
PET Bottles (with-out lids):	30	14	47%	0.23
HDPE Bottles (with-out lids):	30	5	17%	0.15
Plastic Shopping Bags:	30	2	7%	0.06
Plastic Straws:	30	0	0%	0.00
Plastic food wrapping and packets:	30	0	0%	0.00
Plastic Drink Cup Lids:	20	7	35%	0.14
Aluminium Cans:	30	16	53%	0.46
Plastic food wrapping and packets (Foil lined):	30	0	0%	0.00
Paper Drink Cartons (Waxed):	30	14	47%	0.40
Paper Drink Cups (Waxed):	23	1	4%	0.06
Poly-Styrene pieces:	30	16	53%	0.42
TOTALS:	313	75		

Plate 5.4 Litter on surface of holding chamber of Yuile Street ILLS prototype (Authors Photograph, August 1997).

Figure 5.2 Yuile Street - Phase 1. Total Removal Efficiencies for Test Sample Litter Items.



PROTOTYPE: YUILE STREET - CITY OF BOROONDARA
Total removal efficiencies for test sample litter items.

Table 5.3 presents the number of untagged sample litter items captured in the Yuile Street ILLS prototype, total removal efficiency data for each item, and calculation of the EUP. Appendix D (Table App D.1) provides a complete set of this data.

Table 5.3 Yuile Street. Estimated number of untagged sample litter items from ILLS catchment over study period for each sample litter items.

SAMPLE LITTER ITEM	UTP	TRE (%)	EUP
PET Bottles (with-out lids):	14	47	30
HDPE Bottles (with-out lids):	5	17	30
Plastic Shopping Bags:	15	7	225
Plastic Straws:	3	0	N/A
Plastic food wrapping and packets:	2	0	N/A
Plastic Drink Cup Lids:	3	35	9
Aluminium Cans:	22	53	41
Plastic food wrapping and packets (Foil lined):	3	0	N/A
Paper Drink Cartons (Waxed):	10	47	21
Paper Drink Cups (Waxed):	0	4	0
Poly-Styrene pieces:	27	53	51
TOTALS:	**104**		**407**

Plates 5.5 and 5.6 show the photographs taken during and after a storm event in January 1998 respectively, which resulted in surcharging following boom hanger failure, and given the extended time to correct the problem, no additional monitoring was possible.

Although this prototype was capturing a proportion of the litter load, tested total removal efficiencies were generally poor, with no SLI's receiving a total removal efficiency greater than 70%, and three SLI's receiving a total removal efficiency of 0% (plastic food wrapping/ packets (with and without foil lining) and plastic drinking straws.

The total estimated number of untagged SLI's from prototype catchment over the four (4) month study period for all SLI categories, ie. Sum of EUP, was equal to 407. A total of 225 plastic shopping bags, and zero paper drink cups (waxed), were estimated as exporting from this catchment over the study period.

Plate 5.5 Yuile Street ILLS prototype surcharging during large flow event following boom hanger failure (Authors photograph, January 1998).

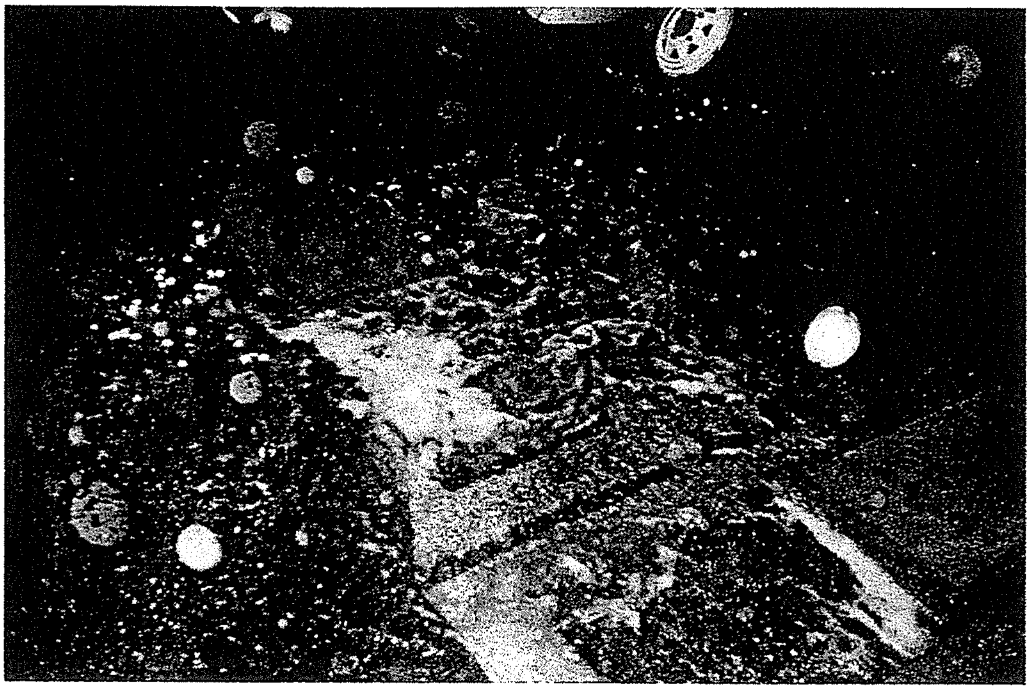
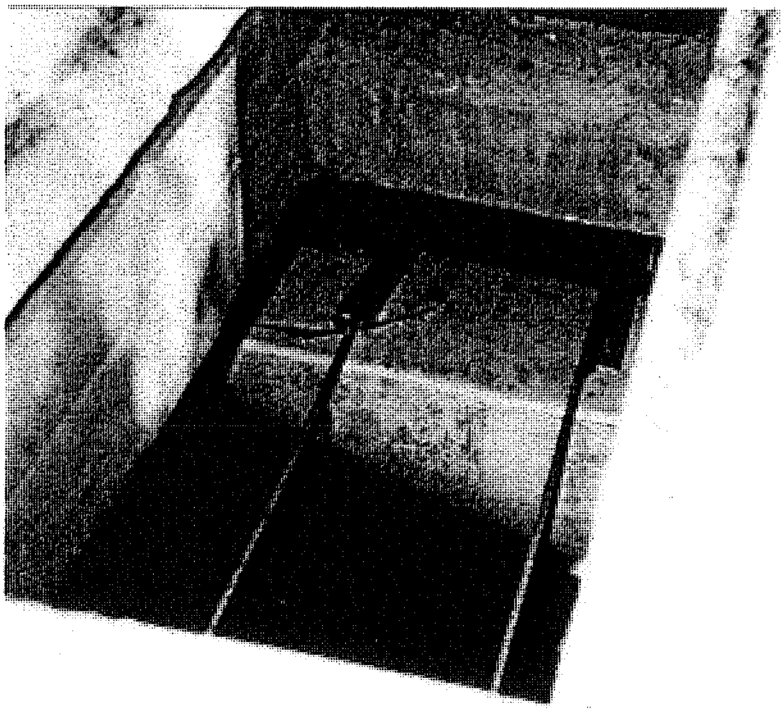


Plate 5.6 Yuile Street ILLS prototype (following surcharging event) with boom hanger failure and boom against pipe outlet (Authors photograph, January 1998).



5.2.4 Prototype Case Study #4 - Lygon Street, City of Melbourne - first phase of monitoring

The Lygon Street ILLS prototype was installed in June 1997 and cleaned out initially on the 7th July 1997. Seven (7) cleanouts were performed between July 1997 and March 1998 in the first phase of monitoring before monitoring was discontinued in March 1998 due to poor capture performance and boom hanger failure (refer to Plate 5.10).

Table 5.4 presents a data summary of the number of SLI's dropped and retrieved and the total removal efficiencies for each SLI for the entire first phase of monitoring of the Lygon Street ILLS prototype. Appendix C (Table App C.3) presents a complete set of data. Figure 5.3 plots the total removal efficiencies for each SLI.

Table 5.4 Total removal efficiencies for Lygon Street prototype in the first phase of monitoring.

SAMPLE LITTER ITEM	Drop Total	Retrieved Total	TRE (%)	STDEVP
PET Bottles (with lids):	35	17	49%	0.41
PET Bottles (without lids):	35	12	34%	0.32
HDPE Bottles (with lids):	25	4	16%	0.15
HDPE Bottles (with-out lids):	25	2	8%	0.08
Plastic Shopping Bags:	50	21	42%	0.26
Plastic Straws:	40	6	15%	0.16
Plastic food wrapping and packets:	20	6	30%	0.08
Plastic Drink Cup Lids:	30	5	17%	0.24
Aluminium Cans:	50	25	50%	0.30
Plastic food wrapping and packets (Foil lined):	40	14	35%	0.13
Paper Drink Cartons (Waxed):	50	24	48%	0.32
Paper Drink Cups (Waxed):	34	2	6%	0.11
Poly-Styrene pieces:	50	31	62%	0.32
TOTALS:	**484**	**169**		

Table 5.5 presents the number of untagged sample litter items captured in the Lygon Street ILLS prototype in the first phase of monitoring, total removal efficiency data, and calculation of the EUP. Appendix D (Table App D.2) provides a complete set of this data.

Table 5.5 Lygon Street - First phase. Estimated number of untagged sample litter items from ILLS catchment over study period for each sample litter items.

SAMPLE LITTER ITEM	UTP	TRE (%)	EUP
PET Bottles (with lids):	33	49%	68
PET Bottles (without lids):	18	34%	53
HDPE Bottles (with lids):	15	16%	94
HDPE Bottles (with-out lids):	7	8%	88
Plastic Shopping Bags:	28	42%	67
Plastic Straws:	97	15%	647
Plastic food wrapping and packets:	36	30%	120
Plastic Drink Cup Lids:	3	17%	18
Aluminium Cans:	67	50%	134
Plastic food wrapping and packets (Foil lined):	6	35%	17
Paper Drink Cartons (Waxed):	6	48%	13
Paper Drink Cups (Waxed):	7	6%	119
Poly-Styrene pieces:	65	62%	105
TOTALS:	388		1541

Plates 5.7 and 5.8 both show the surface of the Lygon Street ILLS prototype holding chamber in the first phase of monitoring. Note the large amounts of cigarette butts present in both Figures.

Plate 5.7 Lygon Street ILLS prototype holding chamber (Authors photograph, October 1997).

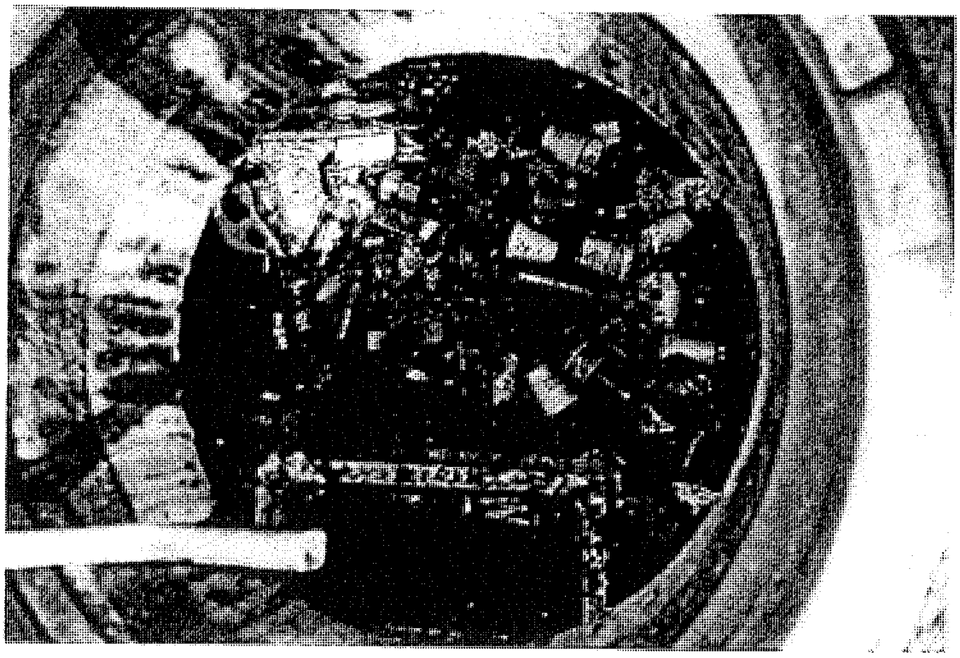


Figure 5.3 Lygon Street - Phase 1. Total Removal Efficiencies for Test Sample Litter Items.

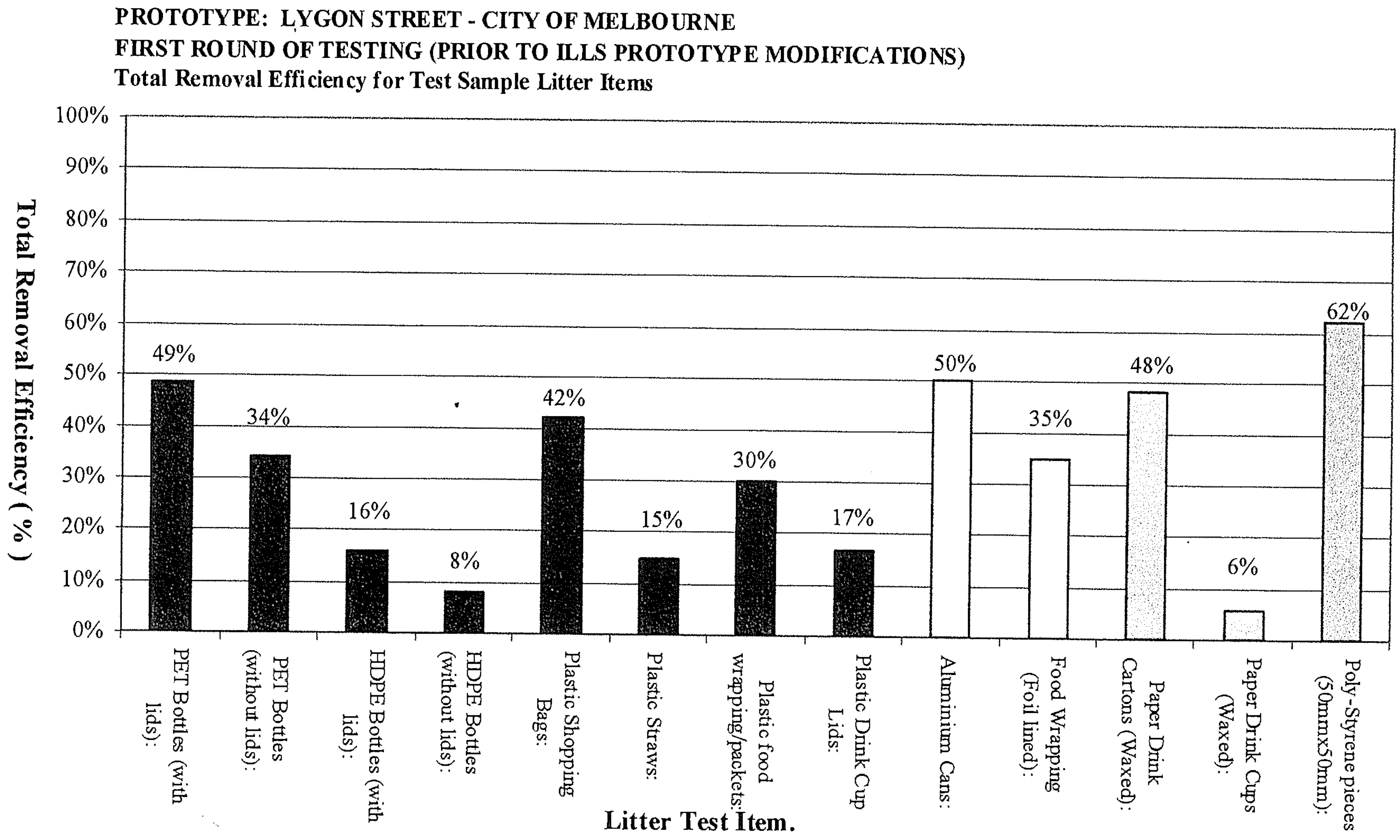


Plate 5.8 Lygon Street ILLS prototype holding chamber (Authors photograph, December 1997).

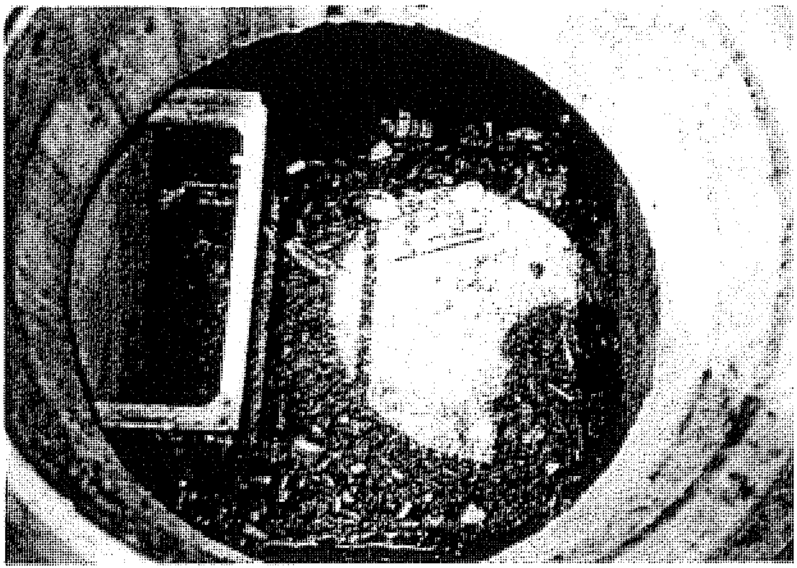


Plate 5.9 shows the Lygon Street ILLS prototype during a runoff event showing lack of return flow behind the boom and lack of boom uplift.

Plate 5.9 Lygon Street ILLS prototype during runoff event showing lack of room for return flow behind boom (Authors photograph, March 1998).

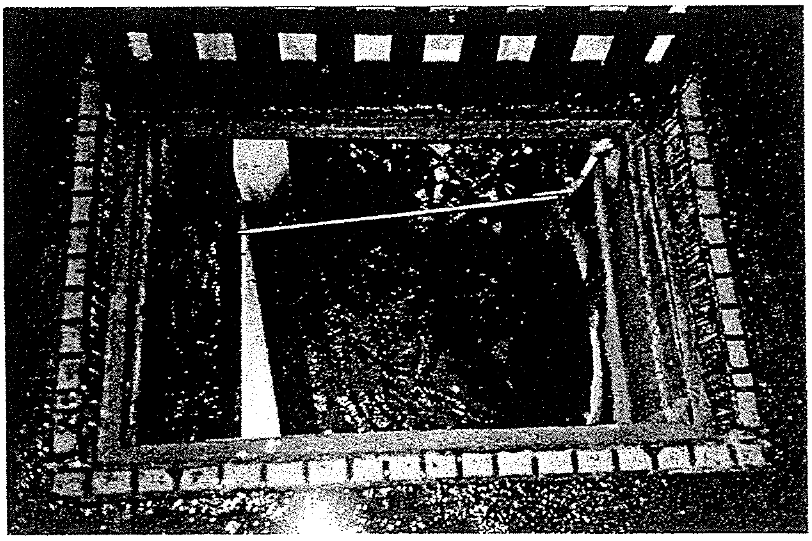
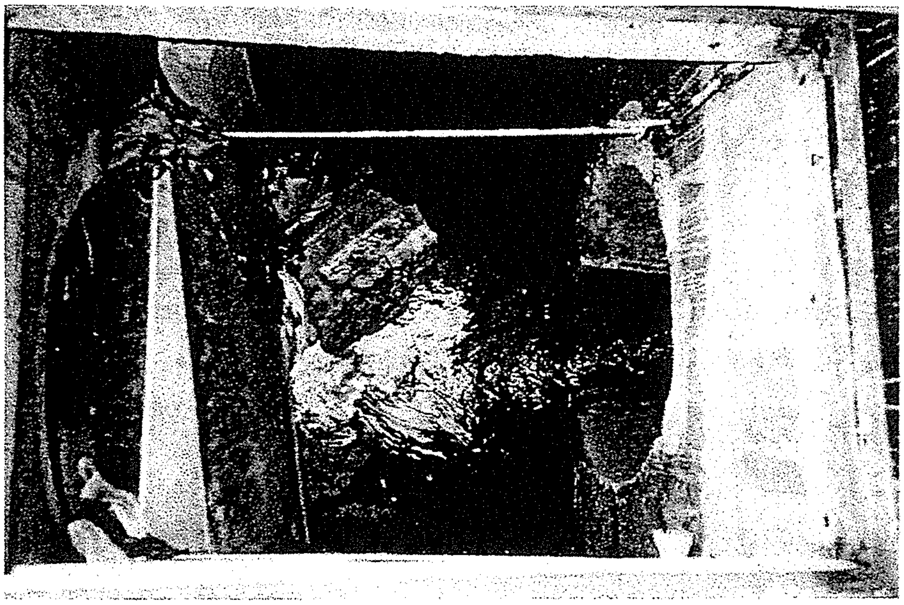


Plate 5.10 shows boom hanger failure with the Lygon Street ILLS prototype following a large flow event where the boom has been pushed back against the downstream outlet pipe. Litter caught on boom hangers provides evidence of boom overtopping and a large piece of concrete can be observed up against the boom face.

Plate 5.10 Lygon Street ILLS prototype boom separator chamber showing boom hanger failure and evidence of boom overtopping (Authors photograph, 28 March 1998).



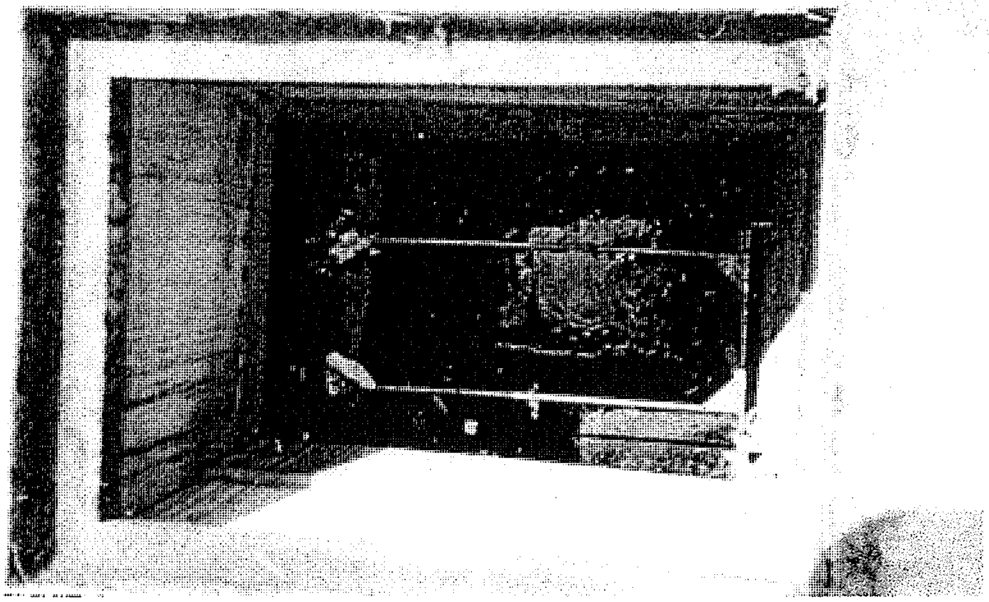
Although this early prototype was capturing a proportion of the litter load, the tested litter capture performance was generally poor, with no SLI's receiving a total removal efficiencies greater than 70%. The total estimated number of untagged sample litter items from ILLS prototype catchment over the 8 month study period for all sample litter item, ie. Sum of EUP, was equal to 1541. To note was that a total of 647 plastic drinking straws were estimated as exporting from this catchment over the study period. Monitoring data also allowed estimates of total gross pollutant and sediments mass to be made, and the mass retrieved between clean outs varied greatly from 165kg for pump-out #3 to 2000kg for pump-out #1.

A lack of return weir flow to the boom and boom over topping was observed and was believed to explain the poor capture performance of this prototype. It was believed that the lack of return flow to the boom causing the boom overtopping was created by the narrow return weir-channel, as observed in Plate 5.9. Modifications were then made (refer to Section 5.6.2) to rectify this perceived problem and this prototype was consequently monitored again in the second phase of monitoring (also detailed in Section 5.5.2) following modifications.

5.2.5. Prototype Case Study #5 - Luck Street, Shire of Nillumbik

The Luck Street ILLS prototype was installed in July 1997 and was not monitored due to it's poor performance, with very little litter observed to be trapped during storm events following the initial cleanout. This was likely to be due to the under sizing of the sump capacity and to boom hanger failure following a substantial storm event shortly after unit installation, which left the boom jammed in a position above the floor (Plate 5.11). Monitoring was never undertaken because of these deficiencies.

Plate 5.11 Luck Street. Boom separator chamber showing boom hanger failure and evidence of boom overtopping (Authors photograph, August 1997).



It may also be seen from Plate 5.11 above that litter is caught on the boom hangers, providing evidence of event flows overtopping boom, attributed to the narrow weir-channel opening and lack of return weir flow.

5.3 SUMMARY OF RESULTS FOR LITTER TOTAL REMOVAL EFFICIENCY (TRE) FOR FIRST PHASE OF PROTOTYPE MONITORING

Table 5.6 summarises the total removal efficiencies across each sample litter item from monitoring of first phase prototypes, as already presented in this chapter. No data was collected for the Toombah Street ILLS prototype.

Table 5.6 Summary of total removal efficiencies and average by sample litter item from first phase prototype monitoring.

SAMPLE LITTER ITEMS	**Toombah Street - Phase 1 (%)**	**Yuile Street (%)**	**Lygon Street - Phase 1 (%)**	**Average TRE (%)**	**Average STDVP**
Poly-Styrene pieces:	65	53	62	60	0.37
PET bottles (with lids):	65	N/A	49	57	0.39
Aluminium cans:	33	53	50	45	0.32
Paper drink cartons (Waxed):	33	47	48	43	0.30
PET bottles (with-out lids):	N/A	47	34	41	0.28
Plastic shopping bags:	23	7	42	24	0.12
# 'Plastic drink cup lids:	*0*	*35*	*17*	*17*	*0.13*
# Food wrapping and packets (Foil lined):	*3*	*0*	*35*	*13*	*0.06*
HDPE bottles (without lids):	N/A	17	8	13	0.12
HDPE bottles (with lids):	8	N/A	16	12	0.12
# 'Plastic food wrapping and packets:	*5*	*0*	*30*	*12*	*0.04*
Paper drink cups (Waxed):	10	4	6	7	0.09
# 'Plastic straws:	*0*	*0*	*15*	*5*	*0.05*

Table Note: Those items shown in Table 5.6 above in *Italics* denoted with a (#) are non-positive capture litter item which are only included for information.

At this point in the ILLS installation and monitoring program it was clear that the first round of prototypes monitored were generally performing poorly, as all sample litter item total removal efficiencies were below 70%. This is discussed in the next chapter.

5.4. NATURAL LITTER LOADS (FOR SAMPLE TEST LITTER ITEMS) FOR FIRST PHASE PROTOTYPE MONITORING

Table 5.7 presents a summary of the estimated number of untagged sample litter items, for the types used in the tagged litter study, from ILLS catchments over study period for each SLI in the first phase of prototype monitoring. No data was collected for the Toombah Street ILLS prototype.

Table 5.7 Estimated number of untagged sample litter items from ILLS catchment over study period for each sample litter item for first phase monitoring period.

SAMPLE LITTER ITEM (SLI)	Yuile Street	Lygon Street - Phase 1
PET bottles (with lids):	N/A	68
PET bottles (without lids):	30	53
HDPE bottles (with lids):	N/A	94
HDPE bottles (without lids):	30	88
Plastic shopping bags:	225	67
# 'Plastic drinking straws:	*N/A*	*647*
# 'Plastic food wrapping/packets:	*N/A*	*120*
# 'Plastic drink cup lids:	*9*	*18*
Aluminium cans:	41	134
# Food wrapping (Foil lined):	*N/A*	*17*
Paper drink cartons (Waxed):	21	13
Paper drink cups (Waxed):	0	119
Poly-Styrene pieces:	51	105
Total all items:	**407**	**1543**
Totals (Tagged items):	**398**	**741**

Table Note: Those items shown in Table 5.7 above in *Italics* denoted with a (#) are non-positive capture litter item which are only included for information.

5.5 SECOND PHASE MONITORING AND PERFORMANCE EVALUATION

The second phase of ILLS monitoring and performance evaluation was performed on the ILLS modified prototypes following the first round of installations and first phase of monitoring, as well as additional second phase installations, as outlined in the previous chapter.

5.5.1 Prototype Case Study #2 - Toombah Street, Monash City Council - second phase of monitoring

The Toombah Street ILLS prototype was modified in July 1998 following boom hanger problems and observation of restricted weir return flow in the first phase of monitoring. These modification included boom modifications (boom shortened slightly to alleviate jamming and boom hangers stiffened), weir removal to increase return flow behind boom, and comb installation under baffle wall to improve litter retention.

The initial cleanout of this prototype to begin it's second phase of monitoring was performed on the 25th August 1998. Three (3) cleanouts were conducted between August and November 1998.

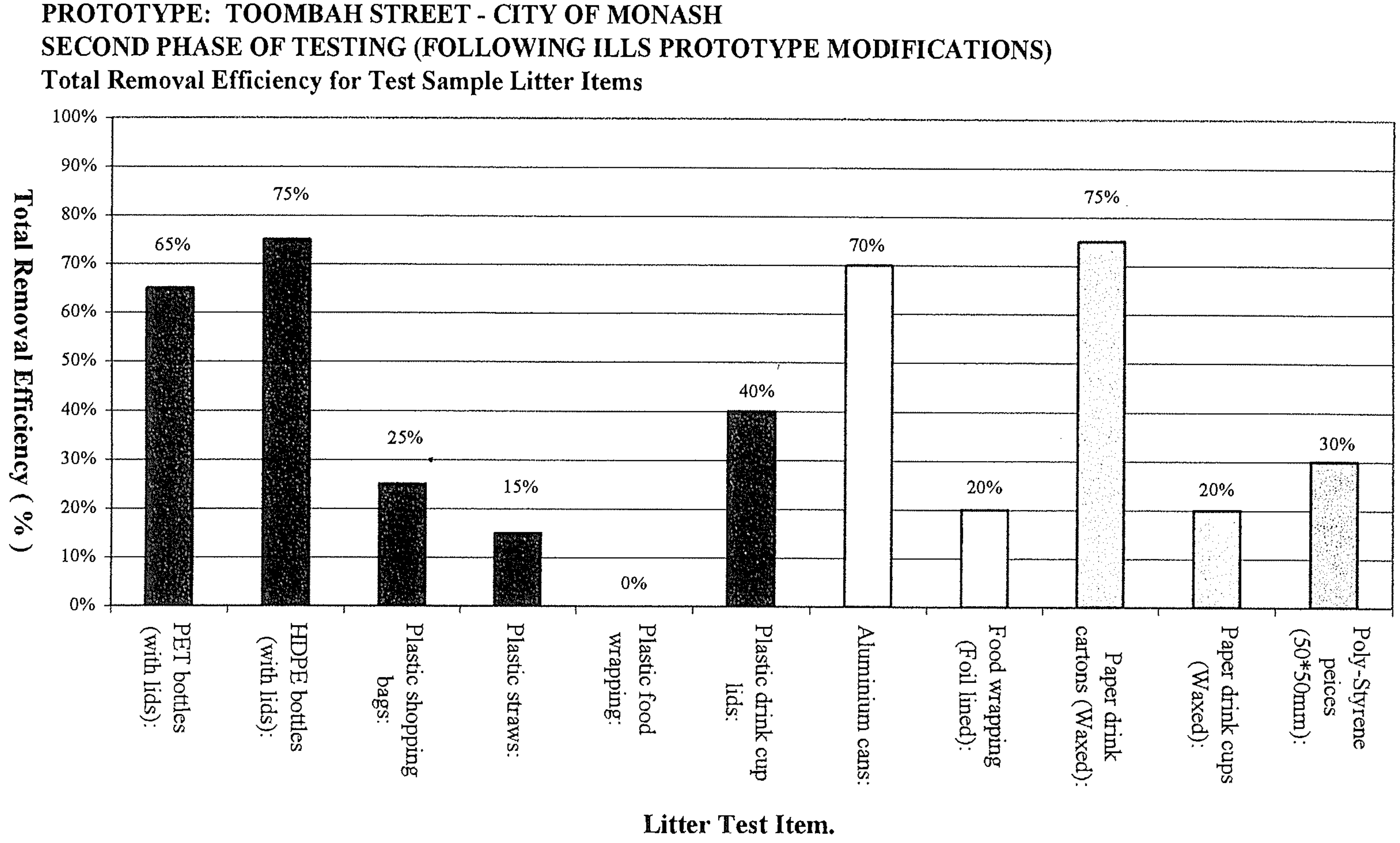
Table 5.8 presents a data summary of the number of SLI's dropped and retrieved and the total removal efficiencies for the second phase monitoring of the Toombah Street ILLS prototype. Appendix C (Table App C.4) presents a complete set of data. Figure 5.4 plots the total removal efficiency for each SLI.

Table 5.8 Total removal efficiencies for Toombah Street prototype in the second phase of monitoring.

SAMPLE LITTER ITEM	Drop Total	Retrieved Total	TRE (%)	STDEV
PET Bottles (with lids):	40	26	65%	0.05
HDPE Bottles (with lids):	8	6	75%	0.00
Plastic Shopping Bags:	20	5	25%	0.05
Plastic Straws:	20	3	15%	0.15
Plastic food wrapping and packets:	10	0	0%	0.00
Plastic Drink Cup Lids:	20	6	40%	0.00
Aluminium Cans:	20	14	70%	0.20
Plastic food wrapping and packets (Foil lined):	10	2	20%	0.00
Paper Drink Cartons (Waxed):	20	15	75%	0.05
Paper Drink Cups (Waxed):	10	2	20%	0.00
Poly-Styrene pieces:	20	6	30%	0.30
TOTALS:	**198**	**85**		

This prototype experienced improved performance in the second phase of monitoring following the modifications detailed above. Total removal efficiencies varied from as low as 0% for plastic food wrapping to as high as 75% for HDPE bottles (with lids on) and paper drink cartons. Three (3) of the eleven SLI's tested received total removal efficiencies greater than 70%, but only five SLI's received total removal efficiencies greater than 25%. No structural failures were observed in this testing phase, but further incidences of boom jamming due to material wedging between the boom and side walls, and boom flow and litter overtopping were observed, effectively corrupting monitoring results. Therefore, no data was collected for un-tagged SLI's, and therefore no analysis was possible for the EUP. No photographs were taken of this prototype in the second phase of monitoring.

Figure 5.4 Toombah Street - Second Phase. Total Removal Efficiencies for Test Sample Litter Items.



5.5.2 Prototype Case Study #4 - Lygon Street, City of Melbourne - second phase of monitoring

Modifications to the Lygon Street prototype were undertaken to improve performance including the removal of the weir-channel, to increase return flow behind the boom, to improve boom lift, installation of stronger hangers and a comb under the baffle wall to help retain captured litter items. The initial cleanout for the second phase of monitoring was performed on the 31st July 1998 followed by three (3) cleanouts between July and December 1998.

Table 5.9 presents a summary of the SLI's dropped and retrieved and the total removal efficiencies for the second phase of monitoring of the Lygon Street ILLS prototype. Appendix C (Table App C.5) presents a full set of data. Figure 5.5 plots the total removal efficiencies for each SLI.

Table 5.9 Total removal efficiencies for the Lygon Street prototype for second phase of monitoring.

SAMPLE LITTER ITEM	Drop Total	Retrieved Total	TRE (%)	STDVP
PET Bottles (with lids):	30	28	93%	0.17
PET Bottles (without lids):	30	22	73%	0.12
HDPE Bottles (with lids):	27	20	74%	0.18
HDPE Bottles (with-out lids):	4	2	50%	0.33
Plastic Shopping Bags:	30	19	63%	0.17
Plastic Straws:	10	7	70%	0.00
Plastic food wrapping and packets:	10	4	40%	0.00
Plastic Drink Cup Lids:	20	8	40%	0.30
Aluminium Cans:	30	23	77%	0.17
Plastic food wrapping and packets (Foil lined):	20	14	70%	0.25
Paper Drink Cartons (Waxed):	30	28	93%	0.05
Paper Drink Cups (Waxed):	20	7	35%	0.35
Poly-Styrene pieces:	50	36	72%	0.13
TOTALS:	**311**	**218**		

Table 5.10 presents the number of untagged sample litter items captured in the Lygon Street ILLS prototype, total removal efficiencies, and calculation of the EUP. Appendix D (Table App D.3) provides a complete set of this data.

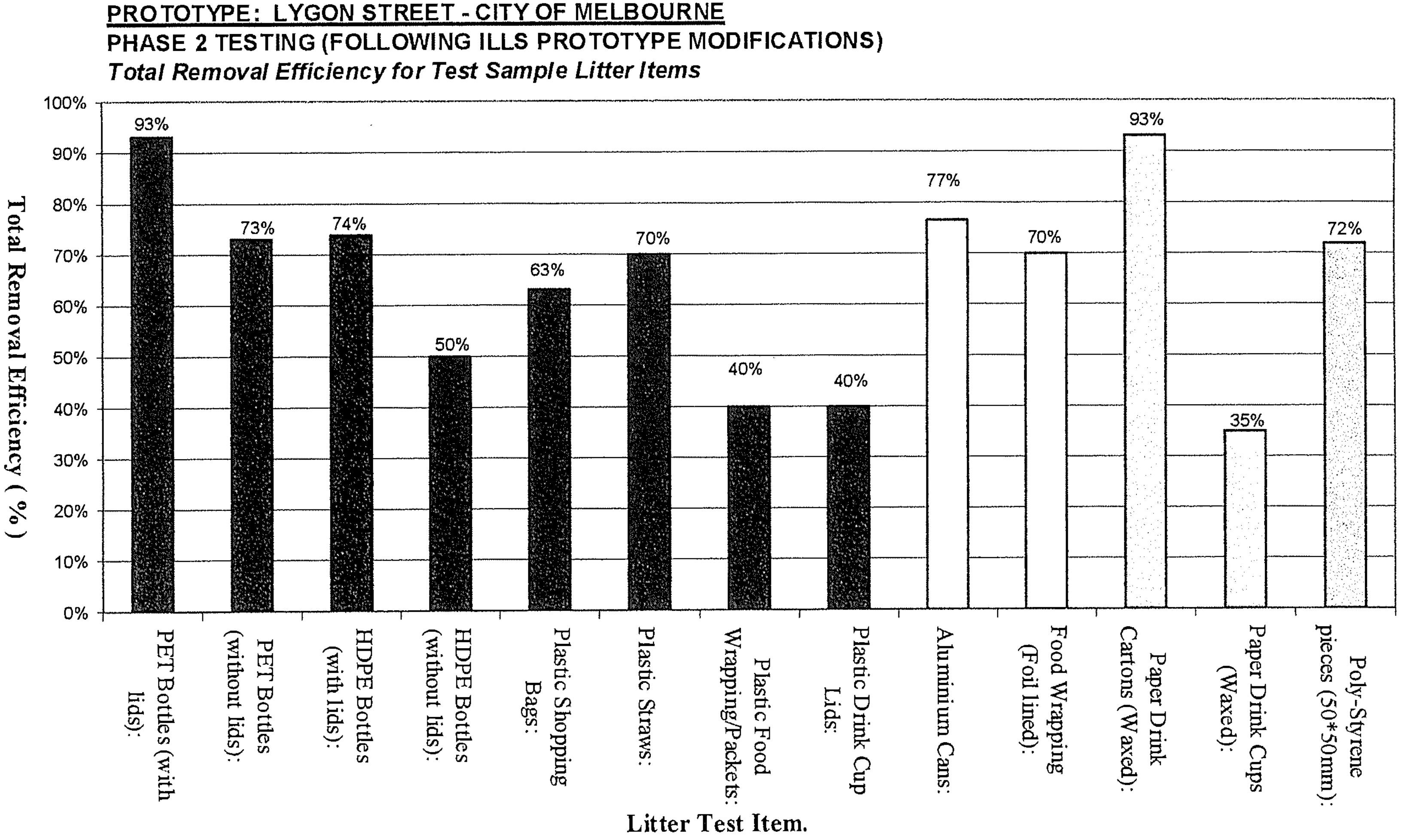
Table 5.10 Lygon Street - Second phase. Estimated number of untagged sample litter items from ILLS catchment over study period for each sample litter item

SAMPLE LITTER ITEM	UTP	TRE (%)	EUP
PET Bottles (with lids):	11	93%	12
PET Bottles (without lids):	7	73%	10
HDPE Bottles (with lids):	1	74%	1
HDPE Bottles (with-out lids):	1	50%	2
Plastic Shopping Bags:	3	63%	5
Plastic Straws:	27	70%	39
Plastic food wrapping and packets:	7	40%	18
Plastic Drink Cup Lids:	6	40%	15
Aluminium Cans:	12	77%	16
Plastic food wrapping and packets (Foil lined):	35	70%	50
Paper Drink Cartons (Waxed):	4	93%	4
Paper Drink Cups (Waxed):	3	35%	9
Poly-Styrene pieces:	19	72%	26
TOTALS:	136		207

Overall this prototype performed very well in this second phase of monitoring, with no structural failures observed, and capture performance much improved when compared with the first phase of monitoring, following the removal of the weir-channel and addition of the comb. These results may however be attributed to observed high base flow conditions, which may have been responsible for transporting tagged litter to the prototype when the boom was at rest and velocities in the holding chamber were low and conducive to settling. Unfortunately, no photographs were taken of this prototype in the second phase of monitoring.

All SLI's received total removal efficiencies greater than 35%, with the highest recorded being 93% for PET bottles (with lids on). Two thirds (eight of the twelve SLI's tested) received total removal efficiencies greater than 70%. Continuously high base flow conditions were also observed and may have influenced some total removal efficiency results. Observation of Table 5.12 shows that the sum of the total estimated number of untagged SLI data, over the 16 month study period, for all sample litter item was equal to 205, and that no single SLI EUP value exceeded 50.

Figure 5.5 Lygon Street - Phase2. Total Removal Efficiencies for Test Sample Litter Items.



5.5.3 Prototype Case Study #6 - Broughton Street, Frankston City Council

Testing was not deemed warranted due to evidence of boom overtopping at beginning of monitoring period.

5.5.4 Prototype Case Study #7 - The Avenue, Kingston City Council

The initial cleanout of the The Avenue ILLS prototype was performed on the 10 February 1998. Monitoring was discontinued following several clean-outs as repeated pit blockages upstream and resulting in litter test items being removed by Council employees. A problem with retrieving material that was built up behind the comb, which extended to floor level, was noted. Short circuiting was also observed from the boom to the return weir-channel during event flows.

5.5.5 Prototype Case Study #8 - Youth Road, Shire of Nillumbik

The Youth Road ILLS prototype was installed in January 1998 and the initial cleanout was performed on the 11th February 1998. Seven (7) tagged litter drops and eight (8) cleanouts were then performed between February 1998 and June 1999. Table 5.11 presents a summary of the total removal efficiencies for monitoring of the Youth Road ILLS prototype. Appendix C (Table App C.6) presents a full set of data. Figure 5.6 plots the total removal efficiencies for SLI.

Table 5.11 Total removal efficiencies for the Youth Road prototype.

SAMPLE LITTER ITEM	Drop Total	Retrieved Total	TRE (%)	STDVP
PET Bottles (with lids):	70	67	96%	0.10
PET Bottles (without lids):	30	24	80%	0.14
HDPE Bottles (with lids):	67	57	87%	0.18
Plastic Shopping Bags:	70	19	27%	0.23
Plastic Straws:	90	3	3%	0.07
Plastic food wrapping and packets:	50	14	28%	0.13
Plastic Drink Cup Lids:	36	11	31%	0.09
Aluminium Cans:	69	54	78%	0.14
Plastic food wrapping and packets (Foil lined):	56	18	32%	0.21
Paper Drink Cartons (Waxed):	70	61	87%	0.17
Paper Drink Cups (Waxed):	46	27	59%	0.35
Poly-Styrene pieces:	90	80	89%	0.13
TOTALS:	744	435		

Table 5.12 presents the number of untagged sample litter items captured in the Youth Road ILLS prototype, total removal efficiencies, and calculation of the EUP. Appendix D (Table App D.4) provides a complete set of this data.

Table 5.12 Youth Road. Estimated number of untagged sample litter items from ILLS catchment over study period for each sample litter items

SAMPLE LITTER ITEM	UTP	TRE (%)	EUP
PET Bottles (with lids):	79	96%	83
PET Bottles (without lids):	37	80%	46
HDPE Bottles (with lids):	19	87%	22
Plastic Shopping Bags:	19	27%	70
Plastic Straws:	59	3%	1770
Plastic food wrapping and packets:	202	28%	721
Plastic Drink Cup Lids:	15	31%	49
Aluminium Cans:	41	78%	52
Plastic food wrapping and packets (Foil lined):	67	32%	208
Paper Drink Cartons (Waxed):	24	87%	28
Paper Drink Cups (Waxed):	16	59%	27
Poly-Styrene pieces:	66	89%	74
TOTALS:	644		3150

Plate 5.12 Youth Road ILLS prototype holding chamber showing trapped litter on surface (Authors photograph, April 1998).

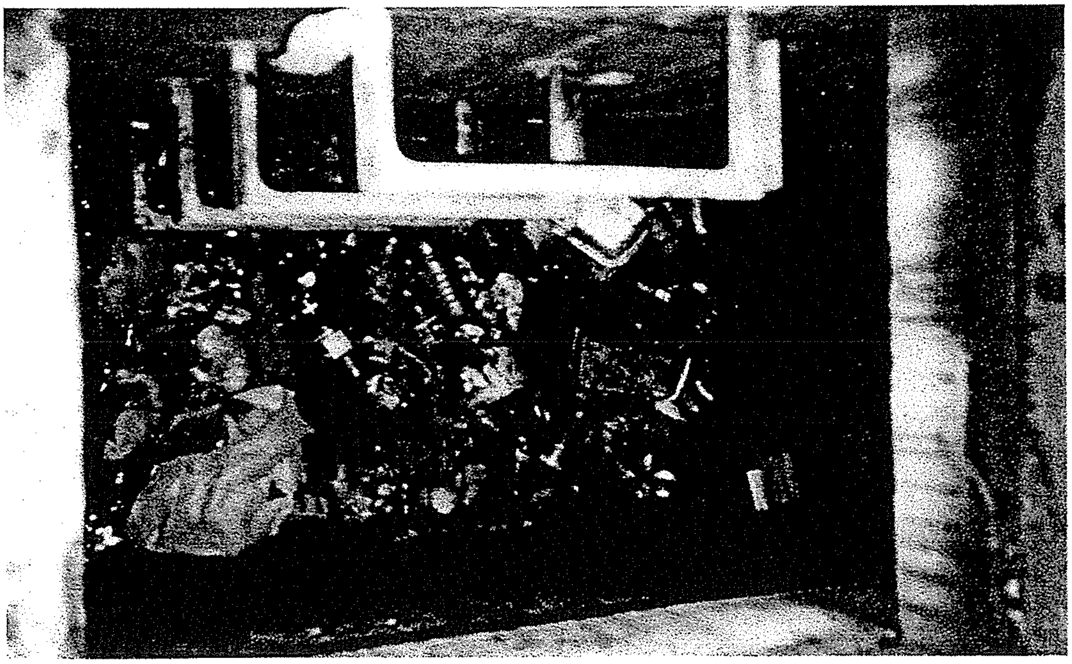


Figure 5.6 Youth Road. Total Removal Efficiencies for Test Sample Litter Items.

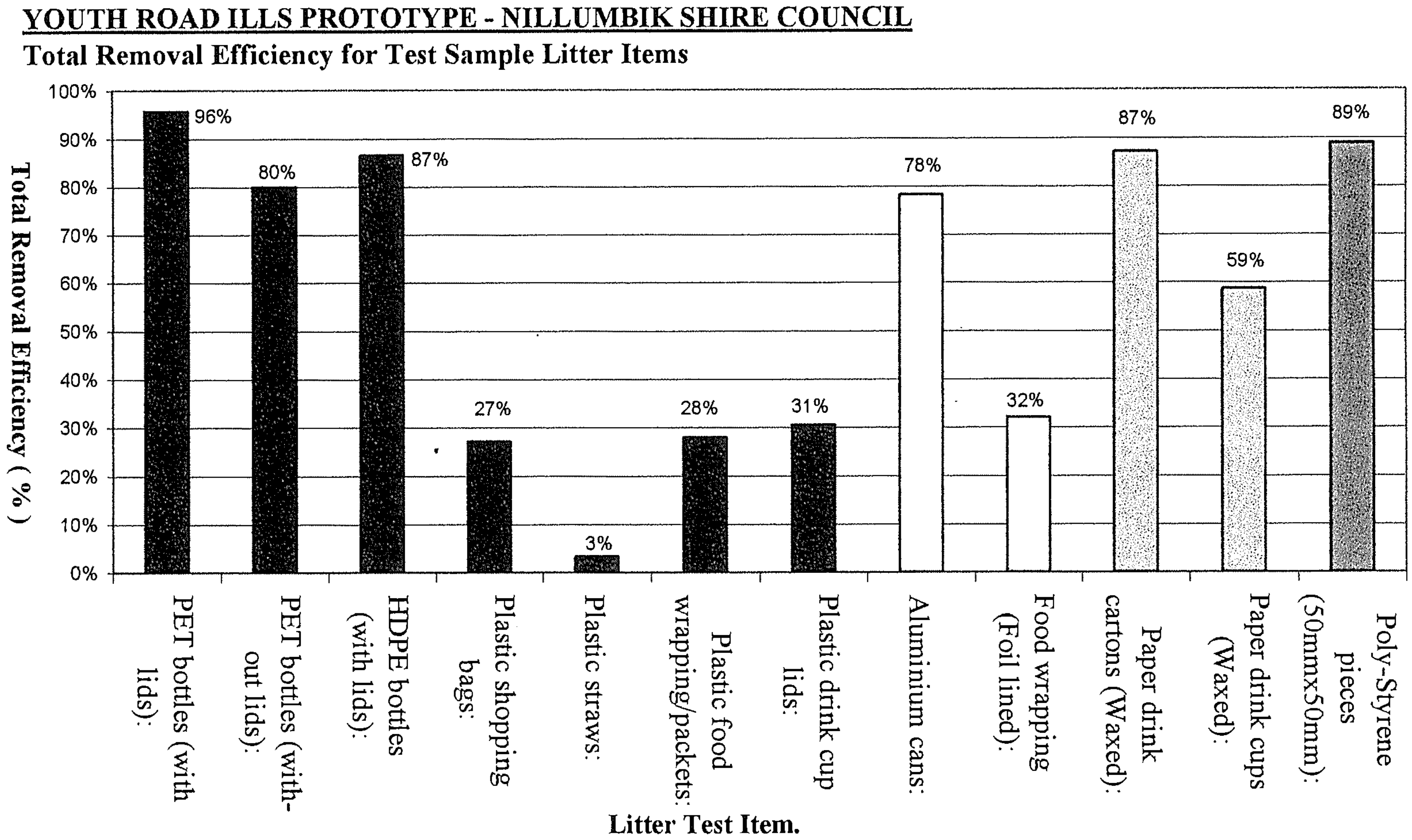


Plate 5.13 Youth Road ILLS prototype boom separator chamber showing boom in rest position and trapped litter (Authors photograph, May 1998).

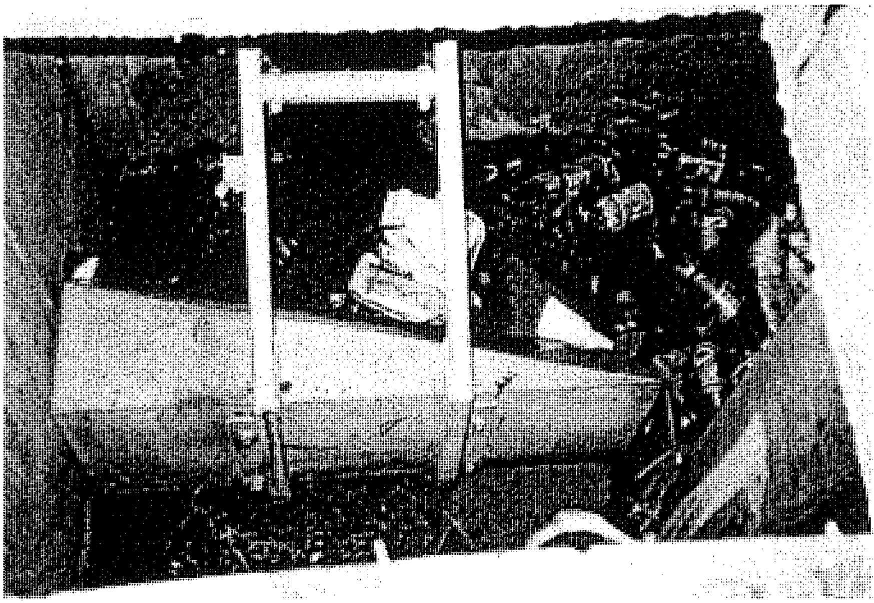


Plate 5.14 shows the Youth Road ILLS prototype boom separator chamber during a near full pipe runoff event with the boom observed in a full lift position. Note the minimal head loss associated with minimal drop in water levels between upstream and downstream of the boom.

Plate 5.14 Youth Road prototype boom separator chamber showing boom in lift position during large runoff event (Authors photograph, October 1998).

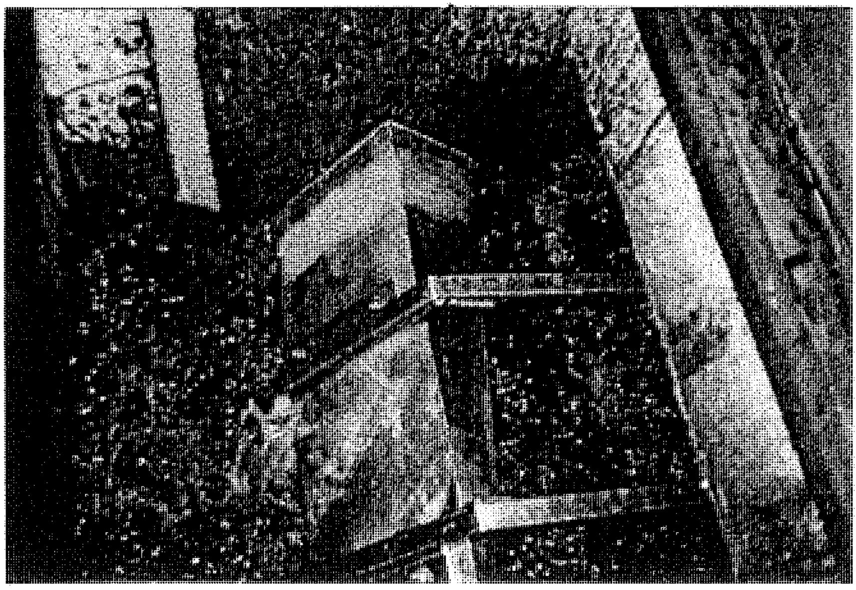
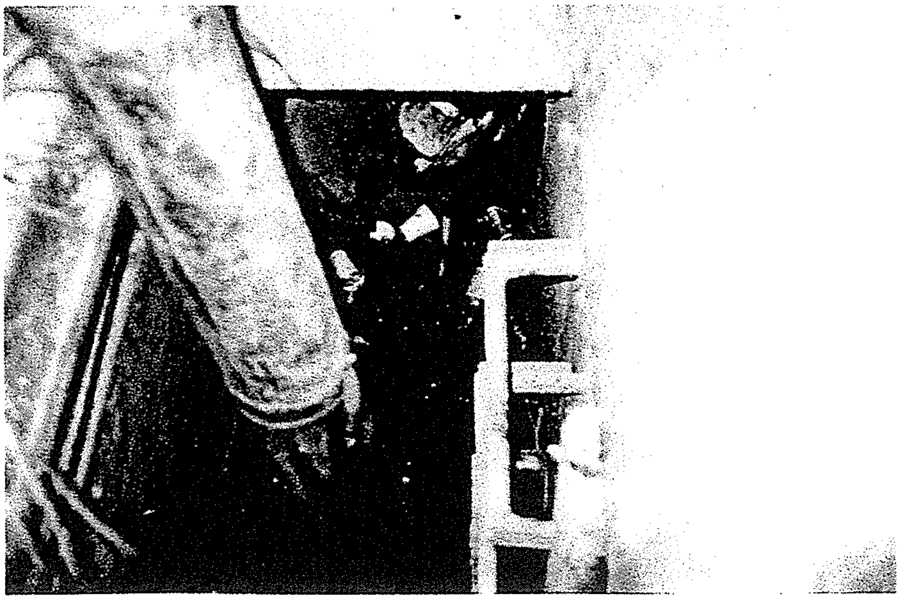


Plate 5.15 Youth Road ILLS prototype holding chamber showing litter on surface and vacuum street sweeper truck hose retrieving litter (Authors photograph, 30 September 1998).

A follow-up cleanout of this ILLS prototype was performed in 2003, as shown in Plate 5.16, and the holding chamber sump was observed to be full of gross pollutants and sediments, with material accumulated to the level of the boom resting platform, indicating a lack of maintenance.

Plate 5.16 Youth Road. Holding chamber full of gross pollutants and sediment following a lack of cleaning (Authors photograph, May 2003).



Overall this prototype performed well, although total removal efficiencies varied greatly from as low as 3% for plastic drinking straws up to as high as 93% for PET bottle (with lids on). Half of the SLI's received total removal efficiencies greater than 70%. The total estimated number of untagged SLI's from the prototype catchment over the entire 16 month study period for all SLI's, ie. Sum of EUP, was equal to 3151. Totals of 1770 plastic drinking straws, 721 plastic food wrapping/ packets, 208 plastic food wrapping/ packets (foil lined), 83 PET bottles (with lids), and 74 polystyrene pieces were estimated as exporting from this catchment over the study period. Monitoring data also allowed estimates of total gross pollutant and sediments mass to be made, and the mass retrieved between clean outs varied from 500kg for pump-out #2 to 900kg for pump-out #7.

It was observed during a large rainfall event, where the piped drainage systems was flowing at pipe full capacity, that the hinged floating boom operated effectively, as designed, with minimal operating head loss. This was evident with a minimal drop between the upstream and downstream surface water levels across the boom chamber observed. A problem was observed with retrieving material from behind the baffle wall comb, which extends to floor level, during cleaning. The material accumulated behind this comb was un-accessible, difficult to retrieve, and design challenge.

5.5.6 Prototype Case Study #9 - O'Grady Street, Port Phillip City Council

The O'Grady Street ILLS prototype was installed in January 1998. The boom platform was set approximately 50mm lower than the level of the pipe invert during construction for reasons unknown to the author (refer to Plate 5.17). The initial cleanout was performed on the 4th February 1998. Five (5) tagged litter drops and six (6) cleanouts were performed between February 1998 and June 1999. Table 5.13 presents a data summary of the number of SLI's dropped and retrieved and the total removal efficiencies for the monitoring of the O'Grady Street ILLS prototype. Appendix C (Table App C.7) presents a full set of data. Figure 5.7 plots the total removal efficiency results. Table 5.14 presents the number of untagged sample litter items captured in this prototype, total removal efficiencies, and calculation of the EUP. Appendix D (Table App D.5) provides a complete set of this data.

Table 5.13 Total removal efficiencies for the O'Grady Street prototype - second phase of monitoring.

SAMPLE LITTER ITEM	Drop Total	Retrieved Total	TRE (%)	STDVP
PET Bottles (with lids):	50	46	92%	0.46
PET Bottles (without lids):	20	17	85%	0.55
HDPE Bottles (with lids):	50	46	92%	0.42
Plastic Shopping Bags:	50	12	24%	0.21
Plastic Straws:	30	2	7%	0.05
Plastic food wrapping and packets:	20	1	5%	0.05
Plastic Drink Cup Lids:	35	13	37%	0.18
Aluminium Cans:	50	41	82%	0.42
Plastic food wrapping and packets (Foil lined):	40	6	15%	0.15
Paper Drink Cartons (Waxed):	50	39	78%	0.23
Paper Drink Cups (Waxed):	40	11	28%	0.24
Poly-Styrene pieces:	70	65	93%	0.48
TOTALS:	**505**	**299**		

Table 5.14 O'Grady Street. Estimated number of untagged sample litter items from ILLS catchment over study period for each sample litter items.

SAMPLE LITTER ITEM	UTP	TRE (%)	EUP
PET Bottles (with lids):	22	92%	24
PET Bottles (without lids):	10	85%	12
HDPE Bottles (with lids):	5	92%	5
Plastic Shopping Bags:	17	24%	71
Plastic Straws:	19	7%	285
Plastic food wrapping and packets:	44	5%	880
Plastic Drink Cup Lids:	9	37%	24
Aluminium Cans:	26	82%	32
Plastic food wrapping and packets (Foil lined):	31	15%	207
Paper Drink Cartons (Waxed):	7	78%	9
Paper Drink Cups (Waxed):	5	28%	18
Poly-Styrene pieces:	168	93%	181
TOTALS:	**363**		**1748**

Plate 5.17 shows the boom separator chamber of the O'Grady Street ILLS prototype during dry weather conditions, with no based flow, with the holding chamber sump flooding the boom platform with approximately 50mm of water. This problem was created when the whole ILLS prototype was installed lower than the pipe invert level.

Figure 5.7 O'Grady Street. Total Removal Efficiencies for Test Sample Litter Items.

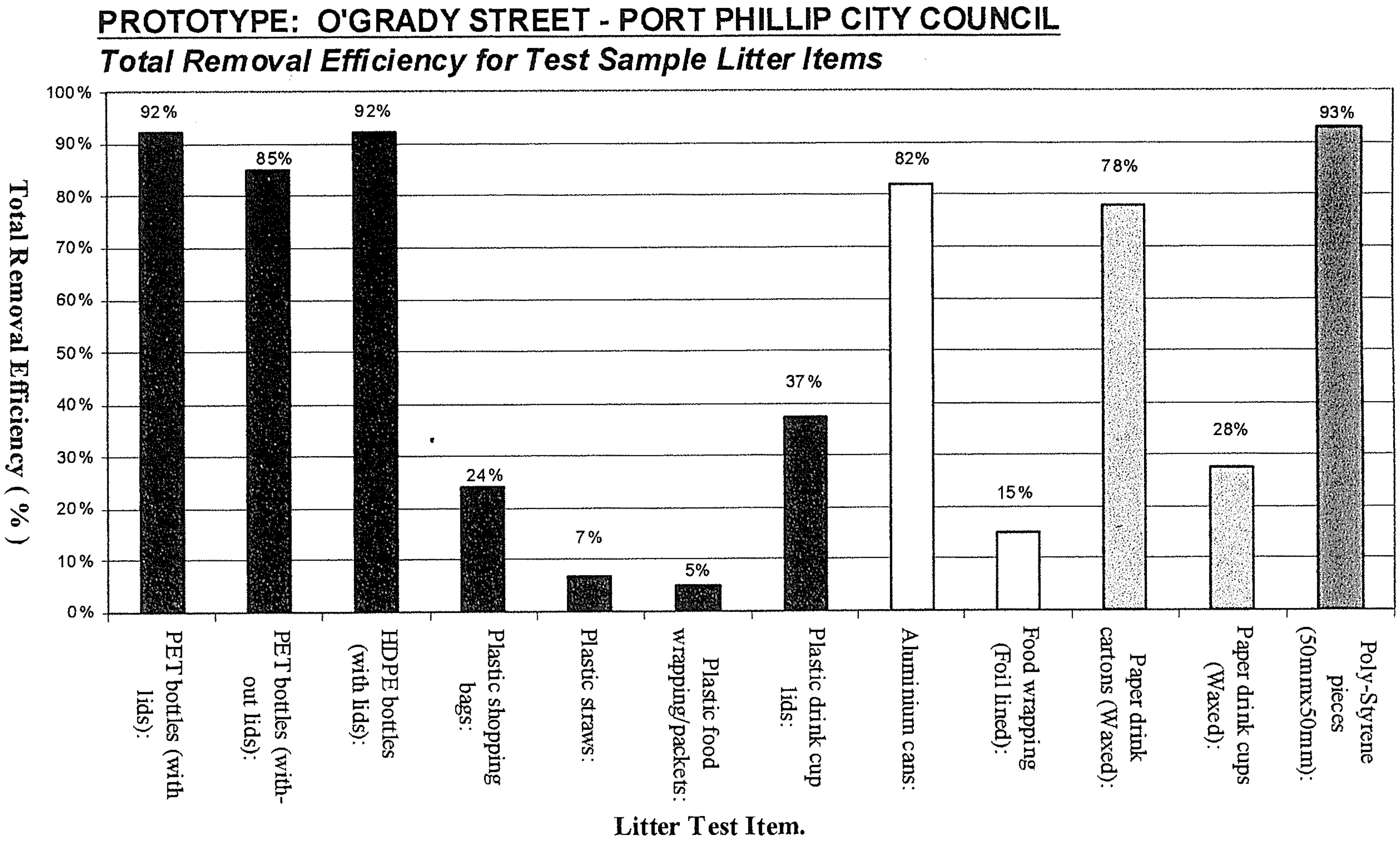


Plate 5.17 O'Grady Street ILLS prototype showing approximately 50mm of residual water in boom separator chamber (Authors photograph, April 1998).

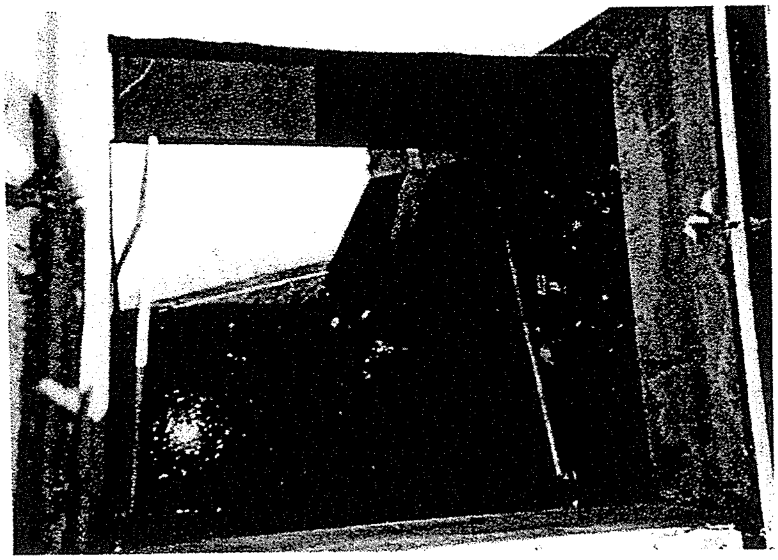


Plate 5.18 shows the boom separator chamber of the O'Grady Street ILLS prototype during a flow event. A plastic bag can be observed downstream of the boom.

Plate 5.18 O'Grady Street ILLS prototype. Boom separator chamber during flow event (Authors photograph, July 1998).

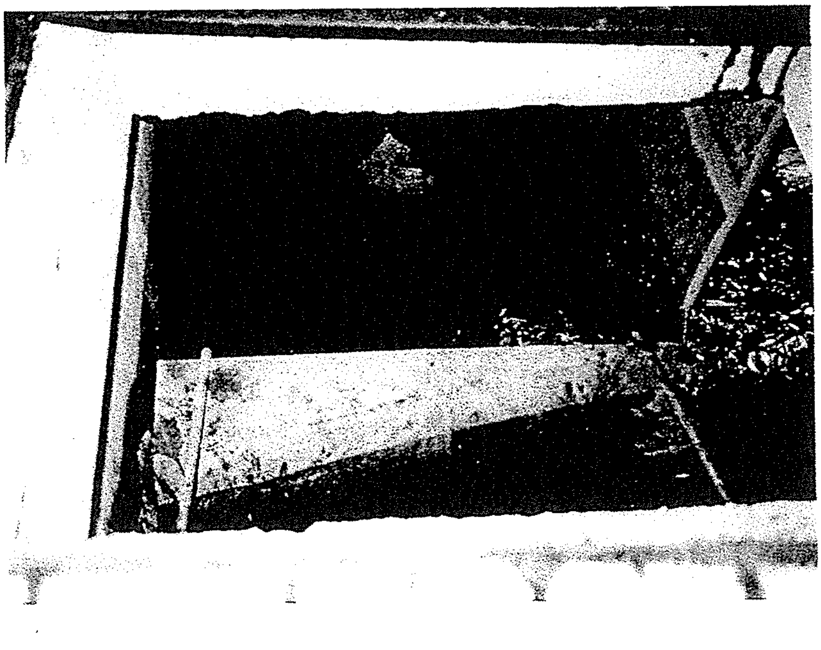


Plate 5.19 shows the boom separator chamber and the holding chamber of the O'Grady Street ILLS prototype clogged with gross pollutants following a lack of maintenance.

Plate 5.19 O'Grady Street prototype. Boom separator chamber clogged with gross pollutants following a lack of cleaning (Authors photograph, May 2003).

Although total removal efficiency results varied greatly from as low as 5% for plastic food wrapping/ packets, up to 93% for polystyrene pieces, overall this prototype performed well. Half of the SLI's received total removal efficiencies greater than 70%. The total estimated number of untagged SLI's from ILLS prototype catchment over the entire 16 month study period for all SLI's, ie. Sum of EUP, was equal to 1748. To note was that a total of 285 plastic drinking straws, 880 plastic food wrapping/ packets, 207 plastic food wrapping/ packets (foil lined), and 181 polystyrene pieces were estimated as exporting this catchment over the study period.

Monitoring data also allowed estimates of total gross pollutant and sediments mass to be made, and varied greatly from 1200kg to 4400kg for pump-outs #2 and #5. An inspection in May 2003 found the importance of regular cleaning when the accumulation of gross pollutants and sediment had filled the sump and were observed in front of the floating boom, which may prevent boom lift during storm events.

5.5.7 Prototype Case Study #10 - Lonsdale Street, City of Greater Dandenong

The Lonsdale Street ILLS prototype was installed in June 1998 and the initial cleanout was conducted on the 26th June 1998, with three (3) consecutive litter drops and cleanouts between July and December 1998. Table 5.15 presents a summary of the number of SLI's dropped and retrieved and total removal efficiencies for this prototype.

Appendix C (Table App C.8) presents a full set of data. Figure 5.8 plots the total removal efficiencies for this prototype.

Table 5.15 Total removal efficiencies for the Lonsdale Street prototype.

SAMPLE LITTER ITEM	Drop Total	Retrieved Total	TRE (%)	STDVP
PET Bottles (with lids):	25	19	76%	0.20
PET Bottles (without lids):	20	19	95%	0.05
HDPE Bottles (with lids):	30	20	67%	0.25
HDPE Bottles (with-out lids):	27	2	7%	0.05
Plastic Shopping Bags:	30	13	43%	0.05
Plastic Straws:	20	6	30%	0.20
Plastic food wrapping and packets:	10	6	60%	0.00
Plastic Drink Cup Lids:	20	9	45%	0.25
Aluminium Cans:	30	19	63%	0.20
Plastic food wrapping and packets (Foil lined)	20	7	35%	0.35
Paper Drink Cartons (Waxed):	30	19	63%	0.20
Paper Drink Cups (Waxed):	29	12	41%	0.01
Poly-Styrene pieces:	50	39	78%	0.18
TOTALS:	341	190		

Table 5.16 presents the number of untagged sample litter items captured in the Lonsdale Street ILLS prototype, total removal efficiencies, and calculation of the EUP. Appendix D (Table App D.6) provides a complete set of this data.

Table 5.16 Lonsdale Street. Estimated number of untagged sample litter items from ILLS catchment over study period for each sample litter items.

SAMPLE LITTER ITEM	UTP	TRE (%)	EUP
PET Bottles (with lids):	30	76%	39
PET Bottles (without lids):	11	95%	12
HDPE Bottles (with lids):	3	67%	5
HDPE Bottles (with-out lids):	2	7%	27
Plastic Shopping Bags:	9	43%	21
Plastic Straws:	10	30%	33
Plastic food wrapping and packets:	129	60%	215
Plastic Drink Cup Lids:	11	45%	24
Aluminium Cans:	31	63%	49
Plastic food wrapping and packets (Foil lined):	39	35%	111
Paper Drink Cartons (Waxed):	9	63%	14
Paper Drink Cups (Waxed):	19	41%	46
Poly-Styrene pieces:	34	78%	44
TOTALS:	337		640

Figure 5.8 Lonsdale Street. Total Removal Efficiencies for Test Sample Litter Items.

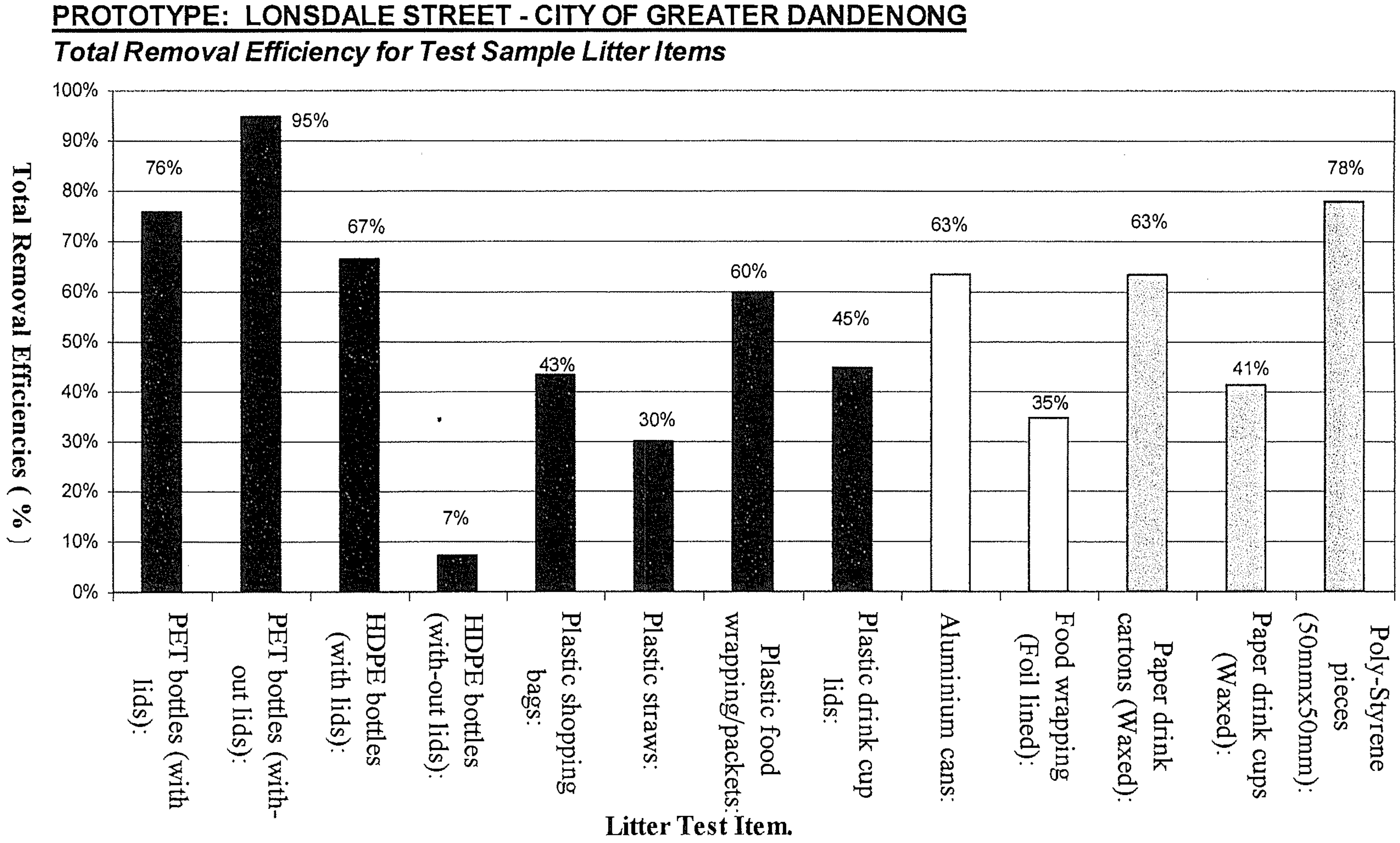


Plate 5.20 below shows the holding chamber surface of the Lonsdale Street ILLS prototype showing trapped floatable litter.

Plate 5.20 Surface of Lonsdale Street ILLS prototype holding chamber showing trapped floatable litter (Authors photograph, 23 September 1998).

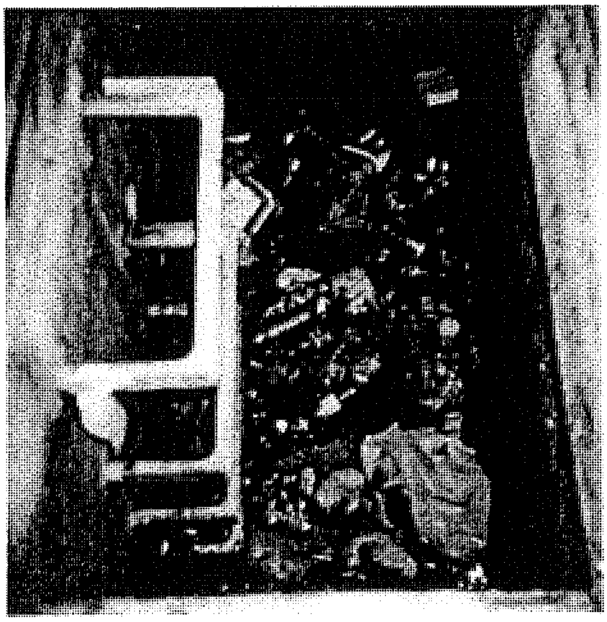


Plate 5.21 shows Syringes retrieved from the holding chamber of the Lonsdale Street ILLS prototype on the 23rd September 1998.

Plate 5.21 Syringes retrieved from the Lonsdale Street ILLS prototype (Authors photograph, 23 September 1998).

Overall, this prototype performed reasonably well, with total removal efficiencies varying greatly from 7% for HDPE bottles (without lids), up to 95% for PET bottle (without lids). Apart from HDPE bottles (with out lids), all remaining twelve (12) SLI's tested received a total removal efficiency of 30% or greater. A comparison between the removal efficiency result for PET bottles (with lids) and PET bottles (without lids) is an irregular result in this instance, as in other case study results presented in this chapter, bottles (both PET and HDPE) with lids off tend to have lower removal efficiencies than for the bottles with lids on. Three SLI's, PET bottles (with lids and with out lids) and Polystyrene pieces, all received total removal efficiencies greater than 70%.

The total estimated number of untagged SLI's from ILLS prototype catchment over the entire 5.5 month study period for all SLI's, ie. Sum of EUP, was equal to 640. To note was that a total of 215 plastic food wrapping/ packets and 111 plastic food wrapping/ packets (foil lined) were estimated as exporting from this catchment over the study period. A total of twelve (12) syringes were retrieved from this prototype in a single clean out performed on the 23rd of September 1998.

It must be noted that the limited five (5) month monitoring period for this prototype may not allow a great deal of confidence in the results for this prototype.

5.5.8 Case Study #11 - Commercial ILLS at Williamson Street, City of Greater Bendigo

The Williamson Street commercial ILLS unit was installed in June 1998 with the initial cleanout conducted on the 7 July 1998. Four (4) tagged litter drops and four (4) cleanouts were performed in the monitoring period between July and December 1998.

Table 5.17 presents a summary of the number of SLI's dropped and retrieved and the total removal efficiency results for each SLI for the Williamson Street ILLS. Appendix C (Table App C.9) presents a full set of data and Figure 5.9 plots the total removal efficiencies. Table 5.18 presents the number of untagged sample litter items, captured in the Williamson Street ILLS, total removal efficiencies, and calculation of the EUP. Appendix D (Table App D.7) provides a complete set of this data.

Table 5.17 Total removal efficiencies for the Williamson Street ILLS.

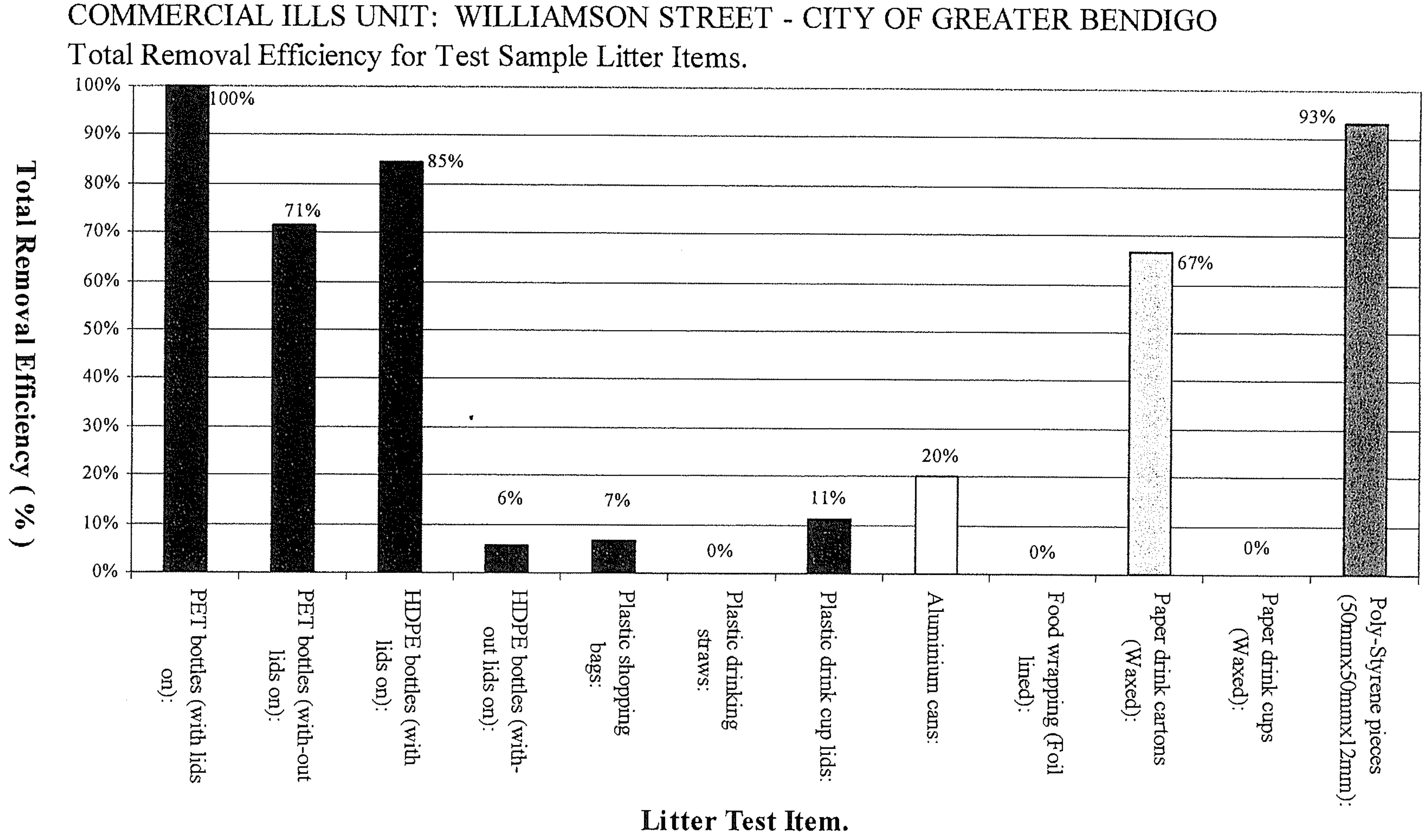
SAMPLE LITTER ITEM	Drop Total	Retrieved Total	PITS	TRE (%)	STDVP
PET Bottles (with lids):	40	35	5	100%	0.13
PET Bottles (without lids):	30	20	2	71%	0.81
HDPE Bottles (with lids):	40	33	1	85%	0.13
HDPE Bottles (with-out lids):	18	1	0	6%	0.05
Plastic Shopping Bags:	30	2	0	7%	0.05
Plastic Straws:	10	0	0	0%	0.00
Plastic Drink Cup Lids:	10	1	1	11%	0.00
Aluminium Cans:	40	7	5	20%	0.08
Plastic food wrapping and packets (Foil lined)	20	0	0	0%	0.00
Paper Drink Cartons (Waxed):	40	26	1	67%	0.09
Paper Drink Cups (Waxed):	10	0	0	0%	0.00
Poly-Styrene pieces:	60	56	0	93%	0.10
TOTALS:	348	181	15		

Table 5.18 Williamson Street. Estimated number of untagged sample litter items from ILLS catchment over study period for each sample litter items.

SAMPLE LITTER ITEM	UTP	TRE (%)	EUP
PET Bottles (with lids):	39	100%	39
PET Bottles (without lids):	12	71%	17
HDPE Bottles (with lids):	7	85%	8
HDPE Bottles (with-out lids):	0	6%	0
Plastic Shopping Bags:	10	7%	150
Plastic Straws:	14	0%	N/A
Plastic Drink Cup Lids:	4	11%	36
Aluminium Cans:	30	20%	150
Plastic food wrapping and packets (Foil lined):	13	0%	N/A
Paper Drink Cartons (Waxed):	7	67%	11
Paper Drink Cups (Waxed):	6	0%	N/A
Poly-Styrene pieces:	32	93%	34
TOTALS:	**174**		**445**

Overall, this ILLS unit experienced a less than average performance, with total removal efficiencies varying from as low as 0% for plastic drinking straws, food wrapping (foil lined), and paper drink cups (wax lined), up to as high as 100% for PET bottle (with lids). Only five (5) of the twelve (12) SLI's tested received total removal efficiencies greater than 20%. This was unexpected, as this ILLS featured the new triangular weir/ channel arrangement, and it was expected it may perform well.

Figure 5.9 **Williamson Street. Total Removal Efficiencies for Test Sample Litter Items.**



The total estimated number of untagged SLI's from the catchment over the five (5) month study period for all SLI's, ie. Sum of EUP, was equal to 445. To note was that a total of 150 plastic shopping bags and 150 aluminium cans were estimated as exporting from this catchment over the study period. No photographs were taken during monitoring.

5.6 SUMMARY OF LITTER TOTAL REMOVAL EFFICIENCY RESULTS FOR SECOND PHASE OF MONITORING OF ILLS PROTOTYPES

Table 5.19. presents a summary of all total removal efficiencies from the second phase of prototype monitoring, including the commercial ILLS unit in Bendigo, as presented in this chapter. Results from the Toombah Street (second phase of monitoring) have been excluded due to observations of event flows and litter overtopping the boom during the monitoring program and monitoring test results are seen as unreliable.

From Table 5.19 it may be observed that, for the second phase of monitoring, performance results were reasonably good, with varied total removal efficiencies, but with five (5) out of the nine (9) positive capture SLI's tested receiving average total removal efficiencies above 70%. This result was a significant improvement on the first phase monitoring results is discussed more in the next chapter.

5.7 NATURAL LITTER LOADS (FOR SAMPLE TEST LITTER ITEMS) FOR SECOND PHASE OF PROTOTYPE MONITORING

Table 5.20 presents a summary of the estimated untagged (natural) SLI's from case study catchments across the study periods for the SLI types used in the tagged litter study in the second phase of prototype monitoring, EUP results. No data was collected for the Toombah Street prototype. The large variations in total EUP values will be discussed in the following chapter. The following notes relate to Table 5.20, viz:

1. All results expressed as percentages.
2. Those items shown above in *Italics* denoted with a (#) are non-target sample litter item which are only included for information.

Table 5.19 **Summary of total removal efficiencies (percentages) and overall averages for second phase prototype monitoring.**

SAMPLE LITTER ITEMS	**Toombah Street - Phase 2**	**Lygon Street - Phase 2**	**Youth Road**	**O'Grady Street**	**Lonsdale Street**	**Williamson Street**	**Average TRE (%)**	**Average STDVP**
PET bottles (with lids):	65	93	96	92	76	100	91	0.19
Poly-Styrene pieces:	30	72	89	93	78	93	85	0.22
PET bottles (with-out lids):	N/A	73	80	85	95	71	81	0.33
HDPE bottles (with lids):	75	74	87	92	67	85	81	0.19
Paper drink cartons (Waxed):	75	93	87	78	63	67	78	0.13
Aluminium cans:	70	77	78	82	63	20	64	0.20
# Plastic drink cup lids:	*40*	*40*	*31*	*37*	*45*	*11*	*33*	0.14
Plastic shopping bags:	25	63	27	24	43	7	33	0.13
Paper drink cups (Waxed):	20	35	59	28	41	0	33	0.16
# Plastic food wrapping/packets:	*0*	*40*	*28*	*5*	*60*	*N/A*	*33*	0.04
# Food wrapping (Foil lined):	*20*	*70*	*32*	*15*	*35*	*0*	*30*	0.16
# Plastic straws:	*15*	*70*	*3*	*7*	*30*	*0*	*22*	0.08
HDPE bottles (without lids):	N/A	50	N/A	N/A	7	6	21	0.14

Note (for Table 5.19 only):

1. All results expressed as percentages.

Note (for Table 5.19 and 5.20):

2. Those items shown in *Italics* denoted with a (#) are non-positive capture litter item which are only included for information.

Table 5.20 **Estimated untagged sample litter item frequencies (EUP) from ILLS catchments for second phase of ILLS monitoring (various monitoring periods).**

SAMPLE LITTER ITEM	**Lygon Street - Phase 2**	**Youth Road**	**O'Grady Street**	**Lonsdale Street**	**Williamson Street**
PET bottles (with lids):	12	83	24	39	39
PET bottles (with-out lids):	10	46	12	12	17
HDPE bottles (with lids):	1	22	5	5	8
HDPE bottles (without lids):	2	N/A	N/A	27	0
Plastic shopping bags:	5	70	71	21	150
# 'Plastic drinking straws:	39	1770	285	33	N/A
# 'Plastic food wrapping and packets:	18	721	880	215	N/A
# 'Plastic drink cup lids:	15	49	24	24	36
Aluminium cans:	16	52	32	49	150
# Food wrapping (Foil lined):	50	208	207	111	N/A
Paper drink cartons (Waxed):	4	28	9	14	11
Paper drink cups (Waxed):	9	27	18	46	N/A
Poly-Styrene pieces:	26	74	181	44	34
Total All items:	207	3150	1748	640	445
Total (Target items):	100	451	376	281	409

5.8 ANALYSIS FOR SYRINGES WITH SECOND PHASE OF MONITORING

Syringe were considered a priority litter items and data was recorded in the second phase of monitoring. However, they were excluded in the second phase monitoring results for consistency with the first phase of monitoring. Table 5.21 presents the syringe total removal efficiency for each case study, as well as the overall average total removal efficiency for syringes across all case studies in the second phase of monitoring. A complete set of data may be found in Table App C.10.

Table 5.21 Determination of syringes total removal efficiencies for second phase of monitoring and overall average total removal efficiency.

CASE STUDY	DROPED	RECOVERED	TRE (%)	STDVP
Lygon St - Phase 2	30	20	67%	0.21
Youth Rd	70	42	60%	0.42
O'Grady St	50	31	62%	0.36
Lonsdale St	30	17	57%	0.42
Williamson St	40	10	25%	0.11
TOTAL:	**220**	**120**		
		Average TRE :	**54%**	

Table 5.22 presents untagged (natural) syringe frequencies recovered during ILLS second phase of monitoring. A complete set of data may be found in Table App D.8.

Table 5.22 Untagged syringes recovered during second phase monitoring.

CASE STUDY	SYRINGES RECOVERED BY PUMP-OUT
Lygon St - Phase 2	0
Youth Rd	3
O'Grady St	0
Lonsdale St	13
Williamson St	1
TOTAL	**17**

Please refer to Plate 5.21 which shows the twelve (12) syringes recovered from the Lonsdale Street ILLS prototype in the first pump-out.

5.9 ADDITIONAL ANALYSIS OF YOUTH ROAD ILLS PROTOTYPE

Note: No data recorded for PO #8 for the split between surface and sump materials.

5.9.1 Analysis of tagged sample litter items

For the Youth Road prototype data was also collected to calculate the proportion of tagged sample litter items recovered from the surface or the sump of the prototype throughout the second phase of monitoring, as presented in Table 5.11 (and Table App C.6). Table 5.23 and Table 5.24 present summaries of the data in Appendix G (Tables App G1 and G2) with surface and sump tagged target (positive) SLIs by item type and pump-out respectively.

Table 5.23 Summary of retrieved floating proportion of tagged sample litter items for Youth Rd ILLS by sample litter items.

	ITEM RETRIEVAL			% FROM SURFACE
STANDARD LITTER ITEM (SLI)	SURFACE	SUMP	TOTAL	
PET bottles (with lids):	67	0	67	100%
PET bottles (with-out lids):	20	2	22	91%
HDPE bottles (with lids):	56	0	56	100%
Plastic shopping bags:	13	6	19	68%
Aluminium cans:	13	39	52	25%
Paper drink cartons (Waxed):	51	10	61	84%
Paper drink cups (Waxed):	0	27	27	0%
Poly-Styrene pieces:	79	0	79	100%
TOTALS:	299	84	383	**78%**
	AVERAGE % FROM SURFACE:			71%

Table 5.24 Summary of retrieved floating proportion of tagged sample litter items for Youth Rd ILLS by pump-out.

		ITEM RETRIEVAL			
PUMP OUT No.	DATE	SURFACE	SUMP	TOTAL	% SURFACE
1	18/3/1998.	36	8	44	82%
2	30/4/1998.	30	22	52	58%
3	11/6/1998.	38	8	46	83%
4	16/7/1998.	45	6	51	88%
5	2/9/1998.	56	15	71	79%
6	30/9/1998.	43	12	55	78%
7	17/11/1998.	51	13	64	80%
	TOTALS:	299	84	383	**78%**
	AVERAGE % FROM SURFACE:				**78%**

5.9.2 Analysis of untagged (natural) sample litter items

Data was also collected for the Youth Road ILLS prototype on the proportion of tagged sample litter items recovered from the surface or the sump of the prototype, as presented in Table 5.12 (and Table App D.4). Table 5.25 and 5.26 present summaries of surface and sump untagged target (positive) sample litter items by item type and pump-out respectively. For complete data sets please refer to Tables App G 3 and 4.

Table 5.25 Summary of untagged sample litter items for Youth Rd ILLS prototype by sample litter item.

	ITEM RETRIEVAL			% ON SURFACE
STANDARD LITTER ITEM	SURFACE	SUMP	TOTAL	
PET bottles (with lids):	57	0	57	**100%**
PET bottles (with-out lids):	10	13	23	**43%**
HDPE bottles (with lids):	14	0	14	**100%**
Plastic shopping bags:	4	8	12	**33%**
Aluminium cans:	5	28	33	**15%**
Paper drink cartons (Waxed):	13	10	23	**57%**
Paper drink cups (Waxed):	2	11	13	**15%**
Poly-Styrene pieces:	39	0	39	**100%**
TOTALS:	**144**	70	**214**	**67%**
			AVERAGE % ON SURFACE:	**58%**

Table 5.26 Summary of untagged sample litter items for Youth Rd ILLS prototype by pump-out.

		ITEM RETRIEVAL			
Pump-out No.	**Date**	**Surface (Floating)**	**Sump**	**Total**	**% UTSLI (SURFACE)**
1	18/3/1998.	23	2	25	92%
2	30/4/1998.	23	8	31	74%
3	11/6/1998.	21	8	29	72%
4	16/7/1998.	15	21	36	42%
5	2/9/1998.	14	0	14	100%
6	30/9/1998.	20	10	30	67%
7	17/11/1998.	28	21	49	57%
	TOTALS:	144	70	214	**67%**
			AVERAGE % TSLI (SURFACE):		**72%**

5.9.3 Analysis of non-sample litter items

Data on all non-sample litter items larger than cigarette butts in size were also collected throughout the second phase of monitoring for the Youth Road ILLS prototype.

Table 5.27 presents a summary of the non-sample litter items data separated into surface and sump materials, which allows the determination of percentage of material caught by the ILLS surface (floating). All non-sample litter items data is presented in Appendix F.

Table 5.27 Full analysis of non-sample litter items (greater than cigarette butts in size) for Youth Road ILLS prototype by pump-out.

		NSLI's			
Pump-out #	**Date**	**Surface (Floating)**	**Sump**	**Total**	**% Surface (Floating)**
1	18/3/1998.	21	7	28	75%
2	30/4/1998.	21	35	56	38%
3	11/6/1998.	22	75	97	23%
4	16/7/1998.	53	70	123	43%
5	2/9/1998.	27	56	83	33%
6	30/9/1998.	16	9	25	64%
		160	252	412	**39%**

5.10 ILLS SUMP GROSS POLLUTANT AND SEDIMENT DEPTH MEASUREMENTS AND ESTIMATIONS OF MASS AND EXPECTED CLEANOUT FREQUENCIES

Throughout this study sump depth readings were also collected for a number of prototypes during cleanouts to allow the estimates of mass of gross pollutants and sediments in the sump and to allow an estimate to be made of the expected cleanout frequencies. Table 5.28 presents a summary of this data for the prototypes where it was collected, namely: Lygon Street (Phase 1); Youth Road; O'Grady Street and Lonsdale Street. Table 5.29 presents an analysis of the rates of sump accumulation and expected cleanout frequencies based on clean outs being triggered once accumulation reaches half (750mm) to two-thirds (1000mm) of the full capacity depth of 1500 mm .

Table 5.28 ILLS prototype data collected on gross pollutant and sediment depth and mass data by pump-out.

PROTOTYPE	PUMP-OUT NUMBER							AVERAGE	STDVP
	1	2	3	4	5	6	7		
Lygon Street - Phase 1.									
Sump depth (mm)	430	40	40	90	200	130	No data	155	135
Mass (kg)	2000	205	165	400	935	600	No data	718	629
Youth Road									
Sump depth (mm)	160	100	150	140	110	150	200	144	31
Mass (kg)	750	500	700	650	550	700	900	679	122
O'Grady Street									
Sump depth (mm)	No data	210	300	210	320	No data	-	260	50
Mass (kg)	No data	1200	3000	3000	4400	No data	-	2900	1136
Lonsdale Street									
Sump depth (mm)	No data	220	300	No data	-	-	-	260	40
Mass (kg)	No data	1300	1800	No data	-	-	-	1550	250

Table 5.29 ILLS prototype rates of sump accumulation and expected clean out frequencies.

PROTOTYPE	SUMP ACCUMULATION			CLEAN OUTS PER ANNUM		EXPECTED CLEAN OUT FREQUENCY (months)
	TOTAL (mm)	TIME (weeks)	RATE (mm/week)	HALF FULL (= 750mm)	2/3 FULL (= 1000mm)	
Lygon Street Phase 1)	930	25	37	2.6	1.9	5 to 6
Youth Road	1010	37	27	1.9	1.4	6 to 8
O'Grady Street	1040	35	30	2.1	1.5	6 to 8
Lonsdale Street	520	9	58	4.0	3.0	3 to 4

These results are discussed in the following chapter (section 6.8.3).

5.11 CONCLUSION

This chapter presented the results of the field monitoring and performance evaluation component of the ILLS installation and monitoring program. Field monitoring and evaluation was conducted on those prototypes observed to be capturing sufficient quantities of litter, i.e. performing satisfactorily to warrant monitoring, and also included monitoring of a commercial ILLS unit in the City of Greater Bendigo. A number of prototypes were rejected in the field monitoring because they proved to be very poor at capturing litter or experienced some form of boom hanger or boom overtopping failure.

For those ILLS prototypes successfully monitored data was collected which allowed analysis and calculation of the parameters set out in the methodology and summarized in the introduction to this chapter, including total removal efficiencies for each sample litter item and EUP values for ILLS prototypes. Rainfall data (Appendix E) was collected but not examined in this thesis with removal efficiency and mass of gross pollutants and sediments data for individual pump-outs.

Syringes were also monitored as part of the second phase of monitoring, and data was presented. A full analysis was undertaken for the Youth Road ILLS prototype which sorted materials into surface and sump materials for the following:

- Tagged sample litter items;
- Untagged sample litter items; and
- Non-sample litter items.

6 DISCUSSION

6.1 INTRODUCTION

The research program results confirmed the findings of the literature review that vast amounts of litter are transported through urban drainage system into receiving waters. The ILLS prototypes installed downstream of litter 'hot spots', such as strip shopping centres, is likely to capture significant amounts of litter now transported to receiving waters.

This chapter reviews the results of the ILLS prototype monitoring program, and reviews the limitations of the adopted methodology outlined in Chapter 6, together with factors that influence the performance of the ILLS, as outlined in Chapter 4.

6.2 RESULTS FROM FIRST PHASE OF ILLS PROTOTYPE MONITORING

6.2.1 Prototype Case Study #1 – Damper Creek, Monash City Council

This early ILLS prototype was undersized, as it was proposed to have a sump capacity (C) of 3.5 cubic meters, but only 1.5 cubic meters was provided. It was also realized during installation that the pipe draining into this unit was at a much steeper grade (approximately 8%) than indicated on the plans provided by Council and is likely to have produced excessive velocities and limited this ILLS unit's ability to trap litter. The fiberglass boom was also considered to be too light and the boom hangers had too much movement at the attachment point. For those reasons monitoring was not carried out on this prototype.

6.2.2 Prototype Case Study #2 – Toombah Street, Monash City Council – first phase of monitoring

Section 5.2.2 reported that this prototype was monitored for six (6) months in the first phase of monitoring before evidence of boom jamming and boom overtopping during storm events led to discontinued monitoring. Table 5.1 reported that this prototype captured 65% of both PET bottles (lids on) and polystyrene, slightly less than 70%. Table 5.1 also reported that this prototype captured 33% or less for the remaining SLI's tested, and that no SLI's received a TRE 10% or more above the average for all three prototypes monitored, as shown in Table 5.6.

Table 5.6 also showed for this prototype that:

- aluminium cans obtained a 33% TRE, 12% less than the 45% average;
- waxed paper cartons obtained a 33% TRE, 10% less than the 43% average;
- plastic drink cup lids obtained a 0% TRE, less than the 17% average; and
- foil lined food wrapping and packets obtained a 3% TRE, 10% less than the 13% average for all prototypes.

These poor results led to modifications (explained in section 5.5.1), including boom modifications, comb installation and removal of the weir-channel. The results of additional monitoring are given in section 6.4.1 of this chapter. The performance of this prototype may have also been compromised by the boom pedestal located on the boom floor.

6.2.3 Prototype Case Study #3 – Yuile Street, City of Boroondara

As was stated in Section 5.2.3 that monitoring of the Yuile Street ILLS prototype was undertaken for four (4) months before the fiberglass boom jammed in a lift position due to distortion of the light boom hangers. The boom was never fixed and monitoring discontinued. Table 5.2 reported that this prototype was capable of capturing 53% of aluminium cans and polystyrene pieces, with all remaining SLI's reported with total removal efficiencies below 50%. The performance of this prototype was considered poor.

Table 5.6 presented that plastic drink cup lids obtained a 35% total removal efficiency, 18% higher than the 17% average for all first phase prototypes. Plastic shopping bags obtained a 7% total removal efficiency, 17% less than the 24% average for all prototypes. Food wrapping and packets (with and without foil lining) both obtained total removal efficiencies of 0%. Table 5.3 presented that the total estimated number of untagged SLI's exporting from the catchment over the study period, total EUP, was equal to 407.

6.2.4 Prototype Case Study #4 – Lygon Street, City of Melbourne – first phase of monitoring

It was shown in Section 5.2.4 that monitoring of the Lygon Street ILLS prototype was undertaken in the first phase of monitoring for eight (8) months before boom hanger failure led to discontinuation of monitoring in March 1998 pending further modifications. Further additional testing of this prototype took place in the second phase of monitoring as discussed in Section 6.4.2 of this chapter. Table 5.4 and Figure 5.9 reported that this prototype captured less than 50% for all SLI's except polystyrene pieces which had a total removal efficiency of 62%. No SLI's received a total removal efficiency 10% (or more) below the average for all first phase prototypes. Plastic shopping bags obtained a 42% total removal efficiency, 18% greater than the 24% average for all prototypes. Food wrapping and packets (foil lined) obtained a 35% total removal efficiency, 22% more than the 13% average for all prototypes. Food wrapping and packets obtained a 30% total removal efficiency, 18% more than the 12% average for all prototypes. Plastic drinking straws obtained a 15% total removal efficiency, 10% more than the 5% average for all prototypes.

The Lygon Street ILLS prototype total removal efficiencies prior to modifications were poor and may be explained by the narrow return weir-channel, which was restricting return flow behind the boom and creating boom overtopping in flow events.

Table 5.5 presented that over the eight (8) month study period 1541 untagged sample litter items were estimated as exporting from the prototype catchment, including 33 PET bottles (with lids), 97 plastic drinking straws, 36 plastic food wrapping/packets, 67 aluminium cans, and 65 polystyrene pieces, as well as approximately 4.3 tonnes of sediments and organic material.

6.2.5 Prototype Case Study #5 – Luck Street, Shire of Nillumbik

No results were obtained for this prototype following early boom hanger failure. Evidence of boom overtopping was observed and may have been attributed to by a narrow return weir-channel that restricted the return channel capacity. As the prototype was not modified, testing was abandoned.

6.3 DISCUSSION OF THE RESULT SUMMARIES FOR THE FIRST PHASE OF ILLS PROTOTYPE MONITORING

6.3.1 Total removal efficiency results

It was shown in Table 5.6 that for the first phase of ILLS prototype monitoring, SLI average total removal efficiencies (across all three prototypes monitored) were less than satisfactory, with no SLI's receiving a total removal efficiency result, or an average total removal efficiency result across all three prototypes, above 70%. However, the following SLI's received average total removal efficiencies across all prototypes marginally lower than the best practice objective, viz: 60% for polystyrene pieces and 57% for PET bottles (with lids on). The remaining SLI's had an average total removal efficiencies less than 45% across all prototypes, with half of the SLI's receiving an average total removal efficiencies of 17% or less across all prototypes.

This unsatisfactory result, as well as ongoing laboratory modeling, led to a consecutive review of theory and the second phase of ILLS installations and monitoring, which included monitoring of two of the first round installation prototypes that were modified to improve performance.

6.3.2 Estimated total number of untagged SLI's from catchments over study periods

Table 5.7 presented the estimated number of untagged SLI's from the prototype catchments over the study periods (EUP's) values for the prototypes monitored in the first phase of monitoring. No untagged SLI data was collected for Toombah Street. Total EUP values of 407 and 1543 were recorded for the Yuile Street and Lygon Street prototypes respectively. The total EUP values for target (positive capture) SLI's vary from as low as 398 for Yuile St to as high as 741 for Lygon Street. This variation will be explained better in section 6.5.2 of this thesis.

6.4 DISCUSSION OF RESULTS FOR SECOND PHASE OF ILLS PROTOTYPE MONITORING

The second phase of ILLS prototype monitoring was more extensive and intensive than the first phase of monitoring, with more prototypes being monitored, including first and second round installations, for (generally) longer periods of time. This was considered justified as the second phase installations followed the first phase monitoring results, which identified deficiencies, a review of theory, and design modifications including improved sizing and additional prototype components, which also led to several of the first phase prototype installations being modified and also re-monitored.

6.4.1 Prototype Case Study #2 – Toombah Street, Monash City Council – Phase 2 monitoring and evaluation

Further testing was conducted in the second phase of monitoring on this prototype following modifications, including shortening to the boom (which was jamming), removal of the weir (to allow more return flow behind boom) and installation of a comb. Although only two (2) litter drops and three (3) pump-outs were performed, the data presented in Table 5.8 and Figure 5.15 showed that following the modifications this prototype captured 70% or more of aluminium cans, HDPE bottles (with lids), and paper drink cartons (waxed). This prototype captured between 30% and 65% for PET bottles (with lids), plastic drink cup lids, and polystyrene pieces. This prototype also captured below 30% of plastic shopping bags, plastic food wrapping/packets (with foil lining), plastic drinking straws, paper drink cups (waxed), and plastic food wrapping/packets (without foil lining).

Although an improvement in the capture performance of the Toombah Street ILLS prototype was observed boom over topping was still observed, and thus this may explain the PET bottles (with lids) and polystyrene total removal efficiency results of 65% and 30% respectively, well below the average values across all prototypes (92% and 85% respectively). No data was collected for untagged SLI's, and therefore the total estimated number of untagged sample litter items from the prototype catchment was not calculated.

6.4.2 Prototype Case Study #4 – Lygon Street, City of Melbourne – second phase of monitoring and evaluation

Further testing conducted followed modifications in the second phase of monitoring (strengthening) to the boom hangers, removal of the weir-channel (to allow more return flow behind boom) and installation of a comb underneath the baffle wall.

Table 5.9 and Figure 5.16 showed that following modifications this prototype captured 70% or more of the following SLI's: polystyrene pieces, aluminium cans, PET bottles (both with and without lids), HDPE bottles (with lids), plastic drinking straws, plastic food wrapping/ packets (with foil lining), and paper drink cartons (waxed), thus exceeding 70% for these eight (8) SLI's. This prototype also captured between 35% and 63% for all remaining SLI's: plastic food wrapping/packets (with-out foil lining), HDPE bottles (with-out lids), plastic shopping bags, plastic drink cup lids, and paper drink cups (waxed).

The following SLI's had TRE's much higher than the averages across all prototypes monitored in the second phase of monitoring:

- paper drink cartons (waxed) (93%, 15% higher than 78% average);
- plastic shopping bags (63%, 30% higher than 33% average);
- plastic food wrapping and packets (foil lined) (70%, 40% higher than 30% average);
- plastic drinking straws (70%, 48% higher than 22% average); and
- HDPE bottles (with-out lids) (50%, 29% higher than 21% average).

Table 5.10 presented that the estimated number of untagged SLI's exporting from the catchment over the study period, total EUP, was equal to 205.

Care must be taken when using the results for the second phase of monitoring and evaluation of the Lygon Street ILLS prototype, as only three (3) pump-outs were performed, and there was further evidence of boom overtopping from a single event, which may have reduced the TRE's. However, these performance results show that this modified ILLS prototype performed well.

Observations of continuously high base flow conditions may have also attributed to the high capture performance for a number of SLI's, such as the 70% total removal efficiency result for both the food wrapping and packets with foil lining and plastic drinking straws, which received total removal efficiency values across all prototypes of only 30% and 22% respectively. The total removal efficiency for plastic shopping bags was also very high at 63%. It may be possible that these items were transported to this prototype during the sustained high base flow conditions that were sufficient to mobilise and transport items from entrance pits. Once these items had reached the holding chamber it is likely that the velocities with in the chamber would be negligible and allow conditions conducive to the settlement of items without them being transported through to the comb, return channel and back into the drainage system.

6.4.3 Prototype Case Study #6 – Broughton Street, Frankston City Council

No monitoring was undertaken following evidence of boom overtopping not long after installation. The boom's mass was not provided by the manufacturer, so that analysis of boom behavior was not possible, but it appeared that the boom was too heavy.

6.4.4 Prototype Case Study #7 – The Avenue, Chelsea, Kingston City Council

Monitoring was discontinued not long after commencement after due to repeated problems with blockage within the drainage system and the continued removal of tagged sample litter items by Council employee.

6.4.5 Prototype Case Study #8 – Youth Street, Shire of Nillumbik

Seven (7) tagged litter drops and eight (8) cleanouts were performed on the Youth Road ILLS prototype between February 1998 and June 1999. Overall TRE results were presented in Table 5.11 and Figure 5.18 and showed that this prototype captured 70% or greater of polystyrene pieces, aluminium cans, PET bottles (both with and without lids), HDPE bottles (with lids), and paper drink cartons (waxed). This prototype received TRE's less than the 70% best practice objective for the remaining six (6) SLI's.

Paper drink cups (waxed) obtained a 59% total removal efficiency, almost twice as much as the average total removal efficiency for all prototypes (26% more than 33% average), and plastic drinking straws obtained a 3% TRE, 19% less than the 22% average total removal efficiency for all prototypes.

Table 5.12 presented that over the sixteen (16) month study period 3151 untagged sample litter items were estimated as exporting from the prototype catchment, including 1770 plastic drinking straws, 721 plastic food wrapping/ packets, 208 plastic food wrapping/ packets (foil lined), 83 PET bottles (with lids), and 74 polystyrene pieces, as well as approximately 4.75 tonnes of sediments and organic material collected over 9 months of the monitoring period.

Observation of the hinged boom in a full lift position whilst the piped drainage systems was flowing at pipe full capacity during a large runoff event indicated that minimal head loss occurred, as evidenced by the same upstream and downstream water levels in the boom chamber. Accumulated material from behind the baffle wall comb, which extends to floor level could not be removed.

6.4.6 Prototype Case Study #9 – O'Grady Street, Albert Park, Port Phillip City Council

Five (5) tagged litter drops and Six (6) cleanouts were performed on the O'Grady Street ILLS prototype between February 1998 and June 1999. Table 5.13 and Figure 5.23 showed that this prototype captured 70% or more for half of the SLI's tested; viz: polystyrene pieces, aluminium cans, PET bottles (both with and with-out lids), HDPE bottles (with lids), and paper drink cartons (waxed). This prototype also captured 37% of plastic drink cup lids and 28% or less for the five (5) remaining SLI's. Total removal efficiency values varied greatly, from as low as 5% for plastic food wrapping/ packets up to 93% for polystyrene pieces, and this may have been attributed to the boom platform level being set during installation approximately 50mm below the pipe invert level.

Aluminium cans obtained an 82% total removal efficiency, 18% more than the 64% average for all prototypes. Plastic food wrapping and packets obtained a 5% total removal efficiency, 28% less than the 33% average for all prototypes. Plastic food wrapping and packets (foil lined) obtained a 15% total removal efficiency, 15% less than the 30% average for all prototypes. Plastic drinking straws obtained a 7% total removal efficiency, 15% less than the 22% average for all prototypes.

Table 5.14 presented that over the sixteen (16) month study period 1748 untagged sample litter items were estimated as exporting from the prototype catchment, including 285 plastic drinking straws, 880 plastic food wrapping/ packets, 207 plastic food wrapping/ packets (foil lined), and 181 polystyrene pieces, as well as approximately 11.6 tonnes of sediments and organic material collected over 8.5 months of the monitoring period.

6.4.7 Prototype Case Study #10 – Lonsdale Street, Dandenong, City of Greater Dandenong

Three (3) tagged litter drops and three (3) cleanouts were performed on the Lonsdale Street ILLS prototype between July and December 1998. Table 5.15 (and Figure 5.27) showed that this prototype captured greater than 70% for three (3) of the thirteen (13) SLI's, namely: PET bottles (with lids on and with lids off), and polystyrene pieces. Another four (4) SLI's recorded total removal efficiencies between 60% and 70%, slightly less than 70%, namely: HDPE bottles (with lids on), paper drink cartons (waxed), plastic food wrapping and packets, and aluminium cans. The remaining six (6) SLI's received total removal efficiencies below 60%, viz: plastic shopping bags, plastic drinking straws, drink cup lids, food wrapping and packets (foil lined), paper drink cups (waxed), and HDPE bottles (with-out lids).

PET bottles (without lids) obtained a 95% total removal efficiency, 14% greater than the 81% average for all prototypes and plastic food wrapping and packets obtained a 60% total removal efficiency, 27% higher than the 33% average for all prototypes. PET bottles (with lids) obtained a 76% total removal efficiency, 16% less than the 92% average for all prototypes, HDPE bottles (with lids) obtained a 67% total removal efficiency, 14% less than the 81% average for all prototypes, paper drink cartons (waxed) obtained a 63% total removal efficiency, 15% less than the 78% average for all prototypes, and HDPE bottles (with-out lids) obtained a 7% total removal efficiency, 14% less than the 21% average for all prototypes.

Table 5.16 presented that for this prototype over the five (5) month study period 640 untagged sample litter items were estimated as exporting from the catchment, including 215 plastic food wrapping and packets and 111 plastic food wrapping/packets (foil lined). Twelve (12) foreign syringes were also recovered in the first cleanout of this prototype in September 1998.

It was noted that the limited study period may not lend confidence in the reliability of the results.

6.4.8 Case Study #11 – Commercial ILLS - Williamson Street, City of Greater Bendigo

Four (4) tagged litter drops and four (4) cleanouts were performed in the five (5) month monitoring period between July and December 1998. Table 5.17 and Figure 5.30 showed this ILLS was capable of capturing 100% of PET bottles (with lids on), 93% of polystyrene pieces, 71% of PET bottles (with-out lids), 85% of HDPE bottles (with lids on), with all four of these SLI's exceeding 70%. The 67% of paper drink cartons (waxed) captured was slightly less than the best practice objective. The remaining seven (7) SLI's received total removal efficiencies of 20% or less. The performance of this commercial ILLS unit was less than the average in the second monitoring phase and unexpected, as this ILLS featured the new triangular weir/ channel arrangement. These results may be under estimates, as the upstream drainage system was not inspected following the program.

For the Williamson Street ILLS, no SLI's received a total removal efficiency 10% (or more) above the average for all second phase prototypes. The following SLI's obtained total removal efficiencies 10% (or more) less than the average for all second phase prototypes:

- aluminium cans (20%, 44% lower than 64% average);
- plastic drink cup lids (11%, 22% lower than 33% average);
- plastic shopping bags (7%, 26% lower than 33% average);
- paper drink cups (waxed) (0%, 33% lower than 33% average);
- plastic food wrapping and packets (foil lined) (0%, 30% lower than 30% average);
- plastic drinking straws (0%, 22% lower than 22% average); and
- HDPE bottles (without lids) (6%, 15% lower than 21% average).

These results highlight the poor performance of this prototype with many SLI's.

Table 5.18 presented that over the five (5) month study period 445 untagged sample litter items were estimated as exporting from the ILLS catchment, including 150 plastic shopping bags and 150 aluminium cans.

6.5 DISCUSSION ON SUMMARY OF LITTER REMOVAL EFFICIENCY RESULTS FOR THE SECOND PHASE OF ILLS PROTOTYPE MONITORING

6.5.1 Discussion of total removal efficiency (TRE) results

Table 5.19 showed that the following SLI's obtained average total removal efficiencies across the five prototypes monitored in the second phase exceeded 70%:

- PET bottles (with lids) (91%);
- polystyrene pieces (85%);
- PET bottles (with-out lids) (81%);
- HDPE bottles (with lids) (81%); and
- paper drink cartons (waxed) (78%).

The Toombah Street results were excluded due to frequent instances of boom overtopping.

Aluminium cans obtained an average total removal efficiency of 64% across all five prototypes in the second phase of monitoring, and would have been above 70% if it wasn't for the 20% total removal efficiency of the Williamson Street prototype. All remaining seven (7) SLI's obtained an average total removal efficiency across the five prototypes being considered in second phase of monitoring between 21% and 33%, also severely affected by the Williamson Street prototype results. No SLI's had an average total removal efficiency across the five (5) prototypes monitored less than 21%.

The variation in total removal efficiencies for SLI's was significant between prototypes, ranging from 21% for polystyrene pieces, up to 70% for both foil lined food wrapping and packets and plastic drinking straws. Once again the large variations can be attributed to the poor performance results for the Williamson Street commercial unit.

It was discussed with the Lygon Street prototype that the high total removal efficiencies for some SLI's may have been attributed to the high base flow conditions that may have allowed litter transportation and conditions with in the ILLS chamber conducive to settling.

HDPE bottles (without lids), although only tested with three (3) prototypes in this monitoring phase, received a very low average total removal efficiency result, which varies from aluminium cans, which are also an open container, and is unexplainable.

Total removal efficiency results may also be conservative minimum values, despite upstream drainage entrances being checked at the completion of the study and an allowance of time given to flush remaining items, as some tagged SLI's may have in fact been trapped somewhere within the upstream drainage systems of prototypes.

6.5.2 Discussion of total estimated number of untagged SLI's from prototype catchments over study periods (EUP results)

Table 5.20 summarised the total estimated number of untagged SLI's for each prototype catchment over the individual study periods (EUPs). It was shown that the EUP values, as well as the total EUP values across all SLI's for each prototype, vary significantly. The total EUP values for target (positive capture) SLI's vary from as low as 100 for Lygon Street to as high as 451 for Youth Road. This variation may be explained by many factors, such as littering behavior, drainage entrance types, or by the management practices employed within the catchments, such as sweeping, bin locations, etc. An examination of the factors which govern these supply rates was not undertaken in this thesis.

6.6 DISCUSSION OF SYRINGE TOTAL REMOVAL EFFICIENCIES AND UNTAGGED FREQUENCIES FOR SECOND PHASE OF MONITORING

Data on removal efficiencies of syringes, considered to be a priority litter item, as well as untagged (natural) frequencies, was collected in the second phase of prototype monitoring. It was presented in Table 5.21 that the average total removal efficiency (across all five prototypes) for syringes was 54%, with four prototypes having a total removal efficiency between 57% and 67%. The remaining prototype (Williamson St, City of Greater Bendigo) had a much lower total removal efficiency of only 25%. These findings are not surprising as syringes were smaller than the comb bar spacing of prototypes and the commercial unit.

It can be seen from Table 5.30 that the frequency of untagged (natural) syringe frequencies range from zero (Lygon Street and O'Grady Street) to thirteen (Lonsdale Street, Dandenong). A total of seventeen (17) untagged syringes were encountered in the monitoring of the five (5) second phase prototypes during the entire second phase of monitoring. These findings may be attributed to socio-economic factors.

6.7 ADDITIONAL ANALYSIS FOR YOUTH ROAD PROTOTYPE

This section discusses the results of the additional analysis conducted on the Youth Road prototype. *Note: The Youth Road results did not consider changes to SLI properties with time once captured within the wet sump of the ILLS holding chamber and therefore may not characterise the floating proportions transported during runoff events.*

6.7.1 Tagged standard litter items (TSLI's)

Table 5.23 shown that for the range of eight (8) target tagged SLI's used, the percentage of trapped items found on the ILLS surface varied from 0% (paper drink cups (waxed)) to 100% (PET bottles (with lids on), HDPE bottles (with lids on) and polystyrene pieces). It may be observed that six (6) of the tagged SLI's had a percentage of tagged SLI's on the surface of 68% or greater, whilst the remaining two (2) item types had a percentage of tagged SLI's on the surface of 25% or less. This shows that the greater proportion of the SLI used in this study were highly floatable, and several items highly settleable.

From Table 5.23, the average percentage of floating tagged SLI's was 71%. This was less than the 78% overall percentage of floating tagged SLI's. This difference is due to the proportion of SLI's with a greater floating proportion. 78% of tagged SLI's were floating overall with a 71% average, indicating greater proportions of floatable items.

Table 5.24 shows that when the percentage of floating tagged SLI's are compared for each pump out of the Youth Road prototype there was a variation of 30% in the percentages (between 58% for pump out #2 and 88% for pump out #4). 78% average and total tagged SLI's were floating when reported by pump-out.

6.7.2 Untagged sample litter items

From Table 5.25, which shows the comparisons of floating percentages for each untagged SLI, it can be seen that for the range of eight (8) tagged SLIs used, the percentage of items found on the surface varied from 15% (paper drink cup lids and aluminium cans) to 100% (PET and HDPE bottles (with lids on) and polystyrene). It may also be seen that a more even spread of percentages for untagged SLIs for items was found on the surface (four items with percentages < 43%, one items with 43%, and three items with 100%). For the range of SLI's chosen, the average of untagged SLI's found on the surface was 58%.

Table 5.26 shows that when the percentage of floating untagged SLI's are compared for each pump out of the Youth Road prototype there was a variation of 58% in the percentages (between 42% for pump out #4 and 100% for pump out #5). The overall percentage of floating untagged SLI's was 58%, and the overall average percentage of floating untagged SLI's was 67%. The overall percentage of floating untagged SLI's by pump out was 67% and the average percentage of floating untagged SLI's trapped by pump out was 72%.

6.7.3 Non-sample litter items

Examination of Table 5.27 shows that for all other untagged litter items, which were not an SLI, the percentage of items found floating on the surface was 39%. Percentages (floating) ranged from 23% (pump-out #3) to 75% (pump-out #1).

6.8 DISCUSSION OF PROTOTYPE MONITORING AND PERFORMANCE EVALUATION METHODOLOGY

6.8.1 Selection of study pollutant removal performance and sample litter items

This study was able to successfully examine the performance of the ILLS prototypes in terms of a select pollutant type, namely common human derived litter found in urban stormwater that degrade the appearance of receiving waters and pose harm to aquatic life. The sample litter items selected were easily retrieved from the vast quantities of other pollutants. Future studies may consider other pollutants, such as all gross pollutants, sediments, hydrocarbons and other associated pollutants that are known to impact on receiving aquatic environment. Observations as part of this study found large numbers of cigarette butts, which are very commonly found in urban stormwater, floating trapped with-in the ILLS chamber suggest that the ILLS may also be effective at their removal.

The selected sample litter items and the number of tagged items chosen for this study was justified as the study had to be manageable within the time and resource constraints. The SLI's chosen are commonly found in urban stormwater and are large enough to be easily identified amongst the large quantities of gross pollutants and sediments found in urban stormwater systems. No other research findings detailing the litter stream found in stormwater by item were uncovered in the literature review, so only limited guidance could be drawn from the literature towards the SLI's selected, and as such they were based mostly on larger litter items commonly found in initial ILLS clean outs.

The confidence level for recovering litter items from a GPT's trapped contents varies significantly based on the item size, so this factor helped the selection of sample litter items. The confidence in recovering smaller litter items, such as cigarette butts, from the retrieved prototypes contents may be considered low, whilst the confidence level may be higher for the recovery of larger items, such as cans and bottles. Appendix F presents that cigarette products, bottle top lids, sheet plastic, and aluminium foil wrapping pieces were all observed with a significant frequency in a full analysis of the Youth Road prototype. However, these small items were not considered suitable for the chosen methodology due to time and resources required to retrieve such items from prototype contents once retrieved and dumped for sorting. Other non sample litter items recorded low frequencies, but this may have been attributed to either low capture performances or exist in urban stormwater in low frequency.

It must be noted in this study that each SLI category chosen possesses an inherent natural size range. For example, PET bottles vary greatly in size from 290ml up to 3 litres. All other SLI's show some form of size variation. However, the SLI samples introduced into ILLS catchments as part of this study were reasonably consistent in size for that item type, determined on the most numerous size found for that item from bins around the University. No analysis of size was undertaken for natural untagged SLI's trapped within prototypes to determine the natural size range of tagged SLI's due to time and resource constraints. Given sufficient time, the study may have included an evaluation of the size range for each tagged SLI type. This information could have then been used in the preparation of test tagged litter samples to represent the natural untagged SLI's range found in urban stormwater, reflecting the actual litter stream, if a trend could be found. The typical sizes used for each SLI may in fact vary from what is typically found in urban stormwater. With regards to polystyrene, although tagged items used in this study were standardized in size to 50mm by 50mm by 12 mm, the natural polystyrene found in the prototypes, accounted as untagged SLI's, varied greatly in size from small beads to very large pieces of boxes.

It may be expected that closed containers receive greater total removal efficiency results, as with all buoyant items. A comparison between the removal efficiency result for bottles (PET or HDPE) with lids on and off, in all cases except for Lonsdale Street, it was shown that bottles with lids off have removal efficiencies lower than for bottles with lids on. This may be attributed to bottles with lids off being susceptible to filling of water and therefore become transported in the bottom of the flow profile, and therefore are more likely to be swept under the boom when in lift position. The results indicate that the ILLS is capable of retaining a greater proportion of floating litter items as was expected.

6.8.2 Duration of prototype monitoring and error associated with short term results

The duration of monitoring was generally limited, effecting the reliability of results. As previously discussed, limited sample sizes across litter drops and consecutive cleanouts, may have affected the accuracy of some prototype performance results. A much longer period of monitoring, enabling more litter drops and cleanouts would have led to more statistically reliable total removal efficiency values. Difficulties with checking the upstream up-stream drainage system for remaining SLI's exacerbated this problem.

For both the Yuile Street prototype and Williamson Street commercial ILLS, the total removal efficiencies determined for some SLI's were null, but in some cases a number of untagged SLI's were discovered throughout various cleanouts for that same SLI type, indicating an error in the calculation of the EUP values. That is, a substantial number of these untagged SLI's types may be passing these ILLS prototypes.

6.8.3 Maintenance requirements

This study did not endeavor to examine maintenance requirements in detail. However, sump depth measurements were taken for a number of prototypes and was presented in the previous chapter (Table 8.28). The typically monthly sump accumulation of gross pollutants and sediments varied between 144 and 260 mm per clean out, indicating that the sump capacity (1500 mm deep) would typically require cleaning once every three (3) to eight (8) months. This suggests that a typical cleaning frequency of twice a year may be sufficient. However, this would depend on the catchment land use, socio-economic and other factors such as festivals. A lack of cleaning was observed with the O'Grady Street prototype following the study period (Plate 8.19), where gross pollutants and sediment had been allowed to accumulate with-in this prototype to the stage where pollutants had accumulated in front of the floating boom, which would most likely prevent boom lift during storm runoff events.

The cleaning frequency for individual GPTs may be better defined through monitoring and research which examines pollutant export from the catchment, capture and breakdown processes within the sump. Therefore, the estimated monthly cleaning frequency given for the ILLS in the urban stormwater best practice environmental management guidelines (Victorian Stormwater Committee, 1999) may be over estimating the cleaning frequency.

The retrieval of trapped material via eductor truck was observed as a superior method, with less time and effort than with street sweeper vacuum trucks, which although more economical were often slow and of limited capacity. The cleaning frequency may also vary depending on seasonal factors, such as heavy rainfall or leaf fall.

6.8.4 Water quality issues associated with wet sump conditions

It was identified in Chapter 3 that GPTs with a residual wet sump may effect downstream water quality (Southcott, 1995), as trapped pollutants may reduce and release into the water column, i.e. other pollutants (such as metals) may possibly be released from the sediments trapped within a GPT. However, water quality monitoring of the ILLS was outside the scope of this study.

Although pollutants will be transported to receiving water if a GPT (or other treatment method) is not employed, it's the conditions within the GPT between storm events that may provide for this release of otherwise un-available pollutants that are mostly fixed to sediments, and gross pollutants such as litter. It may also be that litter trapped within GPTs may attract and fix pollutants with-in the wet sump. Design provision for base flows bypass as well as a regular cleaning regime may play a role in minimising any possible undesirable pollution release from GPT's to receiving waters. It has been reported that organic fractions of gross pollutants are not a significant problem to receiving waters in terms of total nutrient load (Allison and Chiew, 1997).

6.8.5 Litter generation and mobilisation from the catchment

On a micro scale with-in the catchment of each ILLS prototype, it is expected that the hydrologic and hydraulic conditions between each and every drainage entry pit (in which tagged litter was introduced) would vary, affecting tagged litter mobilisation and transport. It was noted with some case studies that litter wasn't always mobilised and transported within the same period following the tagged litter drop prior to the next cleanout, with some litter items being found trapped in ILLS prototypes one or two cleanouts later than the cleanout following a particular litter drop. This would effect the litter removal efficiencies (REs) of individual cleanouts (pump-outs). However, the overall TRE's at the end of the study would remain valid because sufficient time was given for run-off to mobilise and transport all tagged sample litter items to the ILLS prototype prior to the final cleanout.

6.8.6 Hydrologic factors affecting results

Ideally, the monitoring period should have been much longer to allow more varied rainfall and runoff conditions. The variation between litter removal (capture) efficiencies of the ILLS prototypes could be explained by the following factors:

- differing catchment and drainage system characteristics;
- antecedent rainfall conditions due to spatial variation;
- different monitoring periods and rainfall conditions due to sequential installation of the prototypes:
  - ILLS prototypes installed at different times and over several installation phases;
  - variations in timing of clean outs. Pump-outs were staged on differing dates (typically monthly). No account of this was taken in the results; and
  - seasonal rainfall variations.

The boom design must achieve several objectives. As discussed in the literature of this study, the boom dimensions and weight (specific gravity) and the outlet and storage characteristics determine hydrologic effectiveness, and are therefore important in the trapping performance. The boom must also be wide enough to provide for adequate boom under flow, and it must be heavy enough to divert the treatment flows (Q_w), and without obstructing peak flows and unacceptable energy losses within the drainage system.

6.8.7 Hydraulic conditions and efficiency and internal screening

Characteristics such as the pipe grade at the ILLS location within the drainage system, as well as ILLS component and unit configurations, all varied, allowing for differing hydraulic conditions, both within the drainage system and within the ILLS prototypes themselves. Two manufacturers produced the prototypes and consequently there were variations between the ILLS units. Differing hydraulic regimes between the prototypes may well have also led to variations in litter separation and retention and therefore performance results. The pipe grades at the prototype installation site, and the consequential inflow velocities, may have had an effect on the litter separation characteristics of the boom in the lift position.

Insufficient resources were available in this study to monitor and evaluate the hydraulic characteristics and performance of the drainage systems and prototypes during run-off events. Instrumentation, such as flow and level data recorders, as well as instrumentation for measuring boom lift, may hold the key to understanding the 'true' operating performance, which would compliment any gross pollutant, sediment or other pollutant monitoring. Under 'ideal' monitoring conditions, instrumentation would allow the relationships between the following hydraulic variables to be calibrated:

- Drainage system flow profiles and inflow rate (Qp);
- Weir (treatment) flowrate (Qw);
- Derivation of boom under flow during boom lift;
- Stage-storage and storage-discharge relationships; and
- Energy (head or shock) losses against pipe flow (Qp).

As discussed in the literature, hydraulic efficiency and screening, which governs capture and retention performance of a GPT, are linked to several important determinants, namely:

- inlet and outlet flow conditions;
- treatment storage volume and it's depth and shape; and
- screening of the outlet.

The resultant internal treatment velocities, based on the internal GPT characteristics, for a design 'treatment' flow rate (Qw), will determine the proportion of material entrained within the flow that may be retained in the storage treatment volume. The ILLS internal outlet weir length and open width (which affects the weir flow area and velocities) and the weir height (which affects the boom lift frequency) determine the outflow conditions and hence affect the hydraulic efficiency. While the complex flow patterns have not been adequately researched due to practical difficulties, the 'black box' approach, using a DRN to account for these factors was successful in performance improvement for second generation prototypes.

6.8.8 Event monitoring and instrumentation

Intensive event monitoring of prototype inflow and outflow gross pollutant concentration and load data, was not undertaken in this instillation and monitoring program due to insufficient resources. Event concentration monitoring, including upstream, downstream and within prototype, and the utilisation of flow data recording and boom lift instrumentation may have allowed more detailed prototype performance evaluation.

Total gross pollutant loads and compositions (including non SLIs), sediments and other pollutants for the following would have been ideal:

- a greater number of prototypes;
- transported throughout the drainage systems by varying rainfall-runoff events over time and varying seasons;
- retrieved from the ILLS prototypes (trapped content);
- passing through the ILLS prototype without being trapped; and
- bypassing the ILLS prototype altogether, ie. (passing under the flow diversion boom).

The use of instrumentation would have also allowed for valuable data to be collected for calibrating variables such as pipe flow and boom lift and allow numerical modelling.

6.9 RECOMMENDATIONS FOR DESIGN

The results of the field testing and monitoring program lead to a progressive improvement in subsequent prototypes with the following:

- A fixed weir under boom (boom pedestal). This boom pedestal was utilised on the Toombah Street ILLS only, which had problems with a heavy boom and consequential boom overtopping. The boom pedestal may improve capture performance of the ILLS through diverting more flow into the ILLS (greater treatment flow) improving hydrologic effectiveness and pollutant separation from the pipe flow stream;
- A screen and comb under baffle wall to help retain suspended material.

The following additional items may also be considered for future research and development of the ILLS:

- Specialised diversion systems;
- Alternative screening and combing systems – under baffle wall and across weir interface;
- Open waterway conditions and applicability;
- Consideration towards provision for base flow bypass for water quality purposes;
- Use of filtration media for enhanced treatment of low flows;
- The introduction of a method to allow sump draw down between rain events and minimise maintenance requirements, such as discharge to sewer;
- Use of chemical additives (such as detergents and flocculants) to stabilise or separate captured pollutants;
- Aeration and/or oxygen injection. May be used to increase dissolved oxygen (DO) levels if severe depletion is experienced between events; and
- UV treatment. May be fitted to the outlet to help kill bacteria.

7 CONCLUSION

7.1 OVERVIEW OF LITERATURE

It was highlighted in this thesis that litter is an enormous problem in society, creating drainage blockages, visual pollution, harming wildlife, and posing a risk to human health. Vast quantities of litter and other pollutants are transported to our waterways, bays and beaches from strip shopping areas and other commercial centres via an hydraulically efficient urban piped drainage network. Litter reduction strategies and campaigns focussing on non-structural solutions have had minimal impact on reducing the problem to date, with the community bearing the huge cost of cleaning up litter from our receiving waters.

In recent years there has been growing support for trapping litter and gross pollutants within the urban piped stormwater drainage network using structural measures, such as Gross Pollutant Traps (GPTs). Recent GPT's that divert a design flow away from the piped drainage system using a fixed diversion weir into a holding (treatment) chamber enable medium to large sized flow events to bypass. The use of GPT's is promising, as they are able to provide litter capture to a good portion of runoff, but most have inherent limitations or drawbacks. Some of the potential or claimed limitations with GPT's include: expensive construction and/ or installation costs; liable to matting or blockage; inadequate storage capacity (thus requiring frequent maintenance); difficult and expensive to maintain; high energy (head) losses during peak flows (leading to drain surcharging and upstream flooding); and poor litter capture and retention.

Performance issues with GPTs were also discussed in this thesis. It was highlighted that the overall performance of a GPT was determined by litter trapping and retention ability, energy (head) loss requirements and ongoing maintenance requirements.

7.2 THE IN-LINE LITTER SEPARATOR (ILLS)

The development of an In-Line Litter Separator (ILLS) laboratory model at Swinburne University of Technology by Dr. Donald Phillips allowed the ILLS to evolve into a unique GPT which could be manufactured as prototypes ready for field monitoring and evaluation (as per this study) and commercial production. The ILLS is now manufactured by Humes Pty Ltd as the Humegard^{TM} in Australia and the USA.

Not all prototypes underwent the same level of testing and monitoring, as some were undersized or displayed serious inherent design faults and consequently performed unsatisfactorily in terms of litter capture. The two stage manufacturing and installation program facilitated ongoing laboratory testing, theoretical development and field monitoring that led to major improvements in second round prototypes. It was the field testing and monitoring component of the program that forms the basis of this thesis.

The methodology adopted for the study sought to determine the fate of tagged sample litter items (SLIs) introduced into drainage systems within the catchments on a typically monthly basis upstream of the ILLS prototypes. The SLIs used in this tagged litter study were representative of the urban litter stream, ranging from positive capture items (with a size greater than the comb spacings), such as larger bottles, to those items smaller than the positive SLI's, such as plastic drinking straws. The contents of each ILLS prototype was retrieved approximately monthly (via eductor truck or street sweeper truck) and examined in order to determine trap capture performance, untagged litter frequencies for each SLI, and in some cases the total mass of gross pollutants and sediments. The number of introduced tagged SLIs caught was recorded on tally sheets, allowing capture efficiencies to be deduced for each prototype. The drainage system was examined for SLI's following the conclusion of testing where possible.

This process led to the determination of the total removal efficiency for each SLI and each prototype. The number of untagged SLI's from each catchment across the study periods were also recorded.

7.4 SUMMARY OF FINDINGS WITH FIRST PHASE OF MONITORING

Several first round prototype installations (Damper Creek and Luck Street) were undersized, malfunctioned, and captured very little litter, and consequently were excluded from the program. Total removal efficiencies results for the tested SLI's, across the prototypes monitored in the first phase of monitoring (ie. (Toombah Street, Yuile Street and Lygon Street), were all below seventy percent (70%) and considered unsatisfactory. This led to continued laboratory modelling and a review of theory and design sizing in the second round of installations. Four of the positive capture SLIs received an average total removal efficiency (across prototypes monitored) of less than seventeen percent (17%).

The Lygon Street prototype received estimated that six hundred and forty seven (647) untagged plastic drinking straws (that where not a positive capture SLI) exported during the eight (8) months in the first phase of monitoring with a total removal efficiency of only fifteen percent (15%). For the Toombah Street prototype, plastic drink cup lids received a total removal efficiency of zero percent (0%) and for the Yuile Street prototype food wrapping and packets (both with and without foil lining) both received a zero (0) total removal efficiencies.

7.5 SUMMARY OF FINDINGS WITH SECOND PHASE OF MONITORING

For both the Toombah Street and Lygon Street prototypes, the total removal efficiencies for a number of SLIs between the first and second monitoring phases increased. These increases are likely to have been attributed to the modifications, including the introduction of the comb beneath the baffle wall and removal of the weir in both prototypes to allow greater return flow to the boom. However, evidence of boom overtopping was observed with both prototypes, and far more frequently (all pump-outs) with the Toombah Street prototype, where-as only observed as evident with the final pump-out period with the Lygon Street prototype, so therefore the Lygon Street prototype results were included. The Toombah Street boom overtopping can be attributed to the very heavy boom (specific gravity of 0.952) and lack of return flow to the boom, even with the weir removed.

Second generation prototypes installed at both Broughton Street and The Avenue were not monitored. The Broughton Street prototype experienced frequent boom overtopping that can be attributed to a heavy boom. Monitoring results were corrupted with The Avenue ILLS prototype when tagged SLI's were removed from the catchment drainage system by Council staff.

Table 7.1 shows the average total removal efficiency across the prototypes monitored in the second phase (Toombah Street excluded) for each SLI. Aluminium cans would have also received an average total removal efficiencies above 70% if it wasn't for the poor result for the additional prototype at Williamson Street, Bendigo.

Table 7.1 Average total removal efficiencies for second phase monitoring for each sample litter item.

SAMPLE LITTER ITEMS	Average total removal efficiency (across all prototypes) (%)
PET bottles (with lids)	***91***
Polystyrene pieces (50mmx50mmx12mm)	***85***
PET bottles (with-out lids)	***81***
HDPE bottles (with lids)	***81***
Paper drink cartons (Waxed)	***78***
Aluminium cans	64
# Plastic drink cup lids	33 #
Plastic shopping bags	33
Paper drink cups (Waxed)	33
# Plastic food wrapping and packets	33 #
# Plastic food wrapping and packets (Foil lined)	30 #
# Plastic drinking straws	22 #
HDPE bottles (without lids)	21

Notes for Table 7.1:

1. Toombah Street results excluded.
2. SLI's shown in ***bold Italics*** are above 70%.
3. # are not positive capture SLI's, i.e. minimum dimension < baffle comb spacing.

The first generation prototype booms were prone to jamming, with material wedging between the boom and side walls. This was due to a combination of inadequate boom weight, backflow depths, buoyancy, and end clearances. This problem was eliminated in second round prototypes by the adoption of minimum boom lengths and weights (and hence increased buoyant uplift), increased boom end clearances, stiffer boom hanger assemblies and the complete redesign of the return weir/ channel. No boom problems were encountered with second generation prototypes incorporating these changes.

Total removal efficiency results may also be considered conservative as some tagged SLI's may have been trapped within the upstream drainage systems despite allowing some time for runoff flushing them through and manual inspection of inlet pits.

The total estimated number of untagged SLI's (target SLI's only) across the study period varied from as low as 100 items recovered from the Lygon Street (Carlton) prototype, to 451 items recovered from the Youth Road (Eltham) prototype. This variation may be attributed to different drainage entrance types, geographic areas, catchment land uses, socio-economic factors and different management practices employed, such as sweeping, bin locations, etc. that were not examined in this study.

Syringes were also monitored in the second phase of monitoring as they were identified as a priority litter item, but they were not included in the sample of SLI's and performance results to remain consistent with the first phase monitoring. An average total removal efficiency of fifty three percent (53%) was recorded for syringes for the five second phase prototypes monitored, and a total of seventeen (17) untagged (natural) syringes were recorded, with twelve (12) syringes recorded in a single pump-out of the Lonsdale Street (Dandenong) prototype on the 23 of September 1998.

Additional data collection and analysis of clean outs for the Youth Road prototype provided details of the proportion of litter floating on the surface. Tagged SLI's had an average of seventy one percent (71%) by SLI and seventy eight percent (78%) by pump out, untagged SLI's had an average of fifty one percent (51%) by SLI and fifty six percent (56%) by pump out, and all remaining litter items (non sample) had forty six percent (46%) of items by pump out floating on the surface. Observation of this prototype during a large storm event witnessed flows at almost full pipe capacity and the floating boom operating as intended with negligible hydraulic head (energy) losses.

To improve syringe capture performance it is recommended that the comb mean wire clearance can be reduced greatly. However, an open flow area reduction would increase flow velocities through the interface, the chance of blockage, and percentage of runoff treated. A compromise and balance between open flow area and wire spacings/ screen type would need to be established. An inclined comb or screening at the weir interface could also be examined as an alternative.

7.6 CONCLUSION

This thesis presented a methodology for field performance evaluation of the ILLS in terms of litter capture ability. The research program enabled a 'snap shot' to be taken of the capture and retention ability of prototypes for a range of litter items commonly found in the urban waste stream.

The prototypes tested in the second phase of monitoring, which included several generations of prototypes, including design modifications between generations that improved the ILLS capture performance, with all prototypes exceeding 70% total removal efficiency for five (5) SLI's. However, total removal efficiencies for the Lygon Street prototype appear to have been influenced by high base flows that, with wind assistance, helped transport litter items to the prototype where they were intercepted in dry conditions conducive for trapping.

It was shown that the total estimated number of untagged SLI's across the study period varied from as low as 207 for the Lygon Street (Carlton) ILLS prototype catchment, to 3150 for the Youth Road (Eltham) ILLS prototype catchment.

The employment of floating boom technologies, such as the ILLS, in piped urban stormwater drainage systems is indeed promising given their ability to trap all the floating material of greatest community comment and concern with negligible head loss in the drainage system, ensuring minimum risk of upstream surcharging and flooding. However, while the relatively short duration of the program was indicative of the ILLS performance in terms of pollutant capture and retention, much longer periods of testing are required to confirm the results.

Street sweeper vacuum trucks, whilst more economical, were considered a less favourable method of cleaning due to their slow nature and limited capacity. Eduction trucks were considered superior in the retrieval of trapped material contained in the holding chamber sump. It is recommended that a cleaning frequency of twice per year may be sufficient based on the data collected in this study. However, this would vary depending on factors already discussed in this chapter. Pollutant breakdown processes within the sump may also influence the cleaning frequency.

Issues and limitations of the methodology were also discussed, including: selection of study pollutant removal performance and sample litter items, duration of prototype monitoring and error associated with short term results, water quality issues associated with wet sump conditions, litter generation and mobilisation from the catchment, hydrologic factors affecting results, hydraulic conditions and efficiency, internal screening, and need for event monitoring and instrumentation in any further reseach.

The ILLS has proven to be an effective means of removing litter from urban stormwater. It may even be regarded as a very effective gross pollutant trap given the high litter capture performance with regards to the floating litter proportion, which is of most community comment and concern, but also submerged litter when the boom was at rest most of the time. It follows that if capture performance was to be also determined by aesthetics then a very high capture performance may be achieved, as the floating proportion of litter may be the largest proportion by volume. It may therefore be concluded that this study may have provided a conservatively lower estimate of the capture performance by considering litter frequencies alone. Litter retention may also be greatly increased with a reduced comb spacing of say approximately 12mm and this has now been adopted in commercial units.

Whilst early prototypes revealed inherent design and manufacturing deficiencies, these were addressed in later prototypes that performed well in capturing and retaining a high proportion of the introduced sample litter items. Under commercial realities and the ongoing nature of research and development, and the flexibility for design changes and improvements, it may be that future research will be required to validate performance claims resulting from manufacturers design modifications and current standardisation of the ILLS (Humegard^{TM}).

The results of this study indicated that the ILLS has the potential to be a very effective tool for stormwater managers in removing litter and other pollutants currently being transported through hydraulically efficient urban piped drainage systems, especially floating litter and debris, that ultimately cause degradation to receiving waters and the environment.

8 RECOMMENDATIONS FOR FURTHER RESEARCH

The research contained in this thesis has presented an evaluation of the performance of a number of In-Line Litter Separator (ILLS), or Humegard^{TM}, prototypes leading to estimates of the annual litter exported from the catchments served by the prototypes. Further monitoring and research is recommended to understand the following:

- Urban runoff pollutant characteristics and management techniques;
- The long term performance of the ILLS in removing urban stormwater pollutants;
- The performance of the ILLS compared to other GPT's currently employed; and
- The improvements in performance of the commercial ILLS (Humegard^{TM}) following further design improvements.

In order to achieve further performance evaluation, intensive monitoring could be undertaken on a number of purpose made prototypes, feature an adjustable holding chamber, together with adjustable internal components, for calibration and design optimisation purposes. The monitoring may include instrumentation fitted to monitor rainfall, flows, boom lift, water levels at critical points (holding chamber and weir), as well as intensive event netting. It is evident from the present program that such research could be resource intensive and costly, and the benefits would need to be evaluated critically.

8.1 MONITORING OF URBAN STORMWATER POLLUTANTS

The following are considered important factors in understanding pollutant (such as litter and sediment) generation and export and may require further research:

- Pollutant types, sources, characteristics, and associations (fixations);
- Pollutant build-up and accumulation:
    - Period between rainfall events;
    - Non structural BMP's (education, behavior, other management practices, etc..).
- Pollutant wash-off and mobilization:
    - Hydrology (event rain duration, intensity and volume);
    - Drainage connectivity and entrance types (grating, opening sizes, etc); and
    - Structural BMP's.

8.2 THE ROLE OF THE HUMEGARD™ WITHIN URBAN STORMWATER DRAINAGE SYSTEMS

The role of the Humegard™ in various applications may vary, and may be determined by the following, which require further research:

- The values of downstream receiving waters, and to what degree they need protection from urban runoff pollutants, such as litter and sediments, which may also be associated with other pollutants (fixations); and
- The effectiveness of other stormwater management BMP's.

8.3 THE PERFORMANCE OF THE HUMEGARD™

Further monitoring beyond this study is required to better understand performance of current Humegard™. On going monitoring of the Humegard™ to determine performance in terms of the following is recommended:

- Hydraulic performance in terms of energy 'head' losses and pollutant capture:
  - o Boom design optimisation between allowable energy 'head' loss ('K' factor) and pollutant capture using instrumentation; and
  - o Storage and outlet design.
- Pollutant capture performance (separation, capture and retention):
  - o Optimum design and sizing of residual 'wet' sump holding chambers and internal components. These design considerations may focus on peak design flow optimisation, which may be based on the following:
    - ▪ Drainage system hydrologic and hydraulic characteristics;
    - ▪ Critical settling and scour velocities through holding chamber for priority pollutants, which may include pollutants currently passing through to the outlet;
  - o Effect of maintenance frequency on performance and residual water quality between runoff events.
- Life cycle cost/ benefit assessments:
  - o Maintenance activities: method, frequency and costs; and
  - o Asset capital costs and replacement costs based on deterioration and design life.

8.4 THE PERFORMANCE OF THE HUMEGARD^{TM} FOLLOWING DESIGN IMPROVEMENTS

Further research may lead to innovations and improvements being adopted in the design and manufacture of the Humegard^{TM}. It is recommended that design improvements, as listed in chapter 9, be considered for research testing, viz:

- Specialised diversion systems;
- Alternative screening and combing systems – under baffle wall and across weir interface;
- Open waterway conditions and applicability;
- Consideration towards provision for base flow bypass for water quality purposes;
- Use of filtration media for enhanced treatment of low flows;
- The introduction of a method to allow sump draw down between rain events and minimise maintenance requirements, such as discharge to sewer;
- Use of chemical additives (such as detergents and flocculants) to stabilise or separate captured pollutants;
- Aeration and/or oxygen injection to increase dissolved oxygen (DO) levels; and
- UV treatment.

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APPENDIX A OVERVIEW OF THEORY ASSOCIATED WITH THE ILLS DEVELOPMENT.

1. PHYSICAL MODELLING

Phillips (1998) demonstrated from laboratory studies that ILLS minimum dimensions for commercial production could be obtained. This was especially true for the boom shape and dimensions, and it was proved that the boom would always deflect materials into the holding chamber throughout all flow conditions, and when in full lift (during above design flow conditions), minimal head-losses would result. Table App. A.1. below sets out the minimum ILLS dimensions based on physical modelling (Phillips, 1998).

Table App A.1. Minimum ILLS dimensions (Phillips, 1998)

Nominal pipe diameter (mm)	Width of separator pit (mm)	Length of separator pit (mm)	Head-room above pipe obvert (mm)	Boom height (mm)	Boom length (mm)
300	510	450	180	150	430
375	638	563	225	188	618
450	765	675	270	225	745
525	893	788	315	263	873
600	1020	900	360	300	1000
675	1148	1013	405	338	1128
750	1275	1125	450	375	1255
825	1403	1238	495	413	1383
900	1530	1350	540	450	1510
1050	1785	1575	630	525	1765

2. NUMERICAL MODELLING

2.1. Frequency of boom lift

Phillips (1998) demonstrated that the frequency of boom lift can be determined based on the boom mass and volume (specific gravity), and the flow depth required for buoyancy, which engages the principles of hydrologic theory based various assumptions, which will not be included here but may be referred to.

Taking the rational formulae $Q=C*I*A/ 360$ and it's derivative $Q_x/Q_5 = (C_x*I_x/C_5*I_5)$ (Phillips, 1998), intensity ratios, and the 'C' values may be substituted to construct Table App. A.2 below, which determines the depth of flow as a proportion of pipe diameter. Table App. A.2 shows storm intensity data, Q_x/Q_5 ratios, and d/D ratios for various event ARI's and annual frequencies (for Melbourne).

Table App. A.2. Storm Intensities (Ix mm/hr), Q_x/Q_5 Ratios, and d/ D Ratios for various event ARI's and duration's (Melbourne).

			tc = 0.1 hr			tc = 0.20 hr			tc = 0.30 hr			
ARI	Annual Frequency	Runoff C' Value	Ix (mm/ hr)	Qx/ Q5	d/ D	Ix (mm/ hr)	Qx/ Q5	d/ D	Ix (mm/hr)	Qx/ Q5	d/ D	Average d/ D
5	-	0.865	67	1	1	62	1	1	51	1	1	1
2	-	0.765	60	0.79	0.67	47	0.67	0.6	40	0.69	0.61	0.65
1	1 in 1 Yr	*0.72*	45	0.56	0.54	37	0.5	0.5	30	0.49	0.49	0.51
0.5	2 in 1 Yr	*0.72*	27	0.34	0.4	21.5	0.29	0.36	16.5	0.27	0.35	0.34
0.33	3 in 1 Yr	*0.72*	16	0.2	0.29	12.4	0.17	0.28	9.7	0.16	0.27	0.28
0.25	4 in 1 Yr	*0.72*	6.5	0.08	0.19	5.3	0.07	0.19	4.4	0.07	0.19	0.19

From Table App. A.2, Table App A.3. below may be constructed as a summary.

Table App A.3. Frequency per annum of varying pipe flow depths.

ARI (Years)	Annual Frequency	Average d/ D
5	-	1
2	-	0.65
1	**1 in 1 Yr**	0.51
0.5	**2 in 1 Yr**	0.34
0.333	**3 in 1 Yr**	0.28
0.25	**4 in 1 Yr**	0.19

2.2. Boom mass and lift frequency

After first expressing the area of the mean boom cross-section immersed at depth 'd', 'A_{im}', Phillips (1998) demonstrated that the volume and mass may be calculated. This allows the designer to set the boom lift point and frequency based on the boom mass.

Boom mean cross sectional area, $A_{im} = ((0.45*D*d)-(0.3*d^2))$. **Equation 1**

Assuming a 20 mm clearance at either end of the boom the design mass may be calculated (Phillips, 1998) and Table App. A.4. below constructed.

Boom mass $= ((0.45*D*d)-(0.3*d^2))*((1.5*D)-20)*(10^{-6})$ kg **Equation 2**

Table App. A.4. Boom mass and lift frequency per nominal pipe diameter (Phillips, 1998).

			NOMINAL PIPE DIAMETER (mm)											
ARI (Years)	ARI (with-in year)	d/ D	200	300	375	450	525	600	675	750	825	900	1050	1200
1	1 in 1 Yr	0.51	1.7	5.8	11.4	19.9	31.7	47.5	67.8	93.2	124.3	161.6	257.2	384.5
0.5	2 in 1 Yr	0.34	1.4	4.8	9.4	16.3	26.0	39.0	55.7	76.5	102.0	132.6	211.1	315.6
0.33	3 in 1 Yr	0.28	1.1	4.0	7.8	13.6	21.7	32.5	46.3	63.7	84.9	110.4	175.7	262.7
0.25	4 in 1 Yr	0.19	0.8	2.9	5.7	9.9	15.8	23.7	33.8	46.4	61.9	80.4	128.0	191.4
0.2	5 in 1 Yr	0.10	0.5	1.6	3.2	5.6	8.9	13.3	19.0	26.1	34.8	45.2	72.0	107.7
0.17	6 in 1 Yr	0.05	0.2	0.8	1.7	2.9	4.6	6.9	9.8	13.5	18.0	23.4	37.3	55.7

2.3. Boom dimensions

In Table App A.5 below, Phillips (1998) proposed boom dimensions for all pipe sizes up to and including 1050mm in nominal diameter, based on the proportional relationship of the wedge shaped boom, as discussed in physical modelling. It has been noted that booms fitted to the small pipe sizes are prone to jamming. The boom dimensions for the 200 mm nominal pipe diameter relate to the laboratory model.

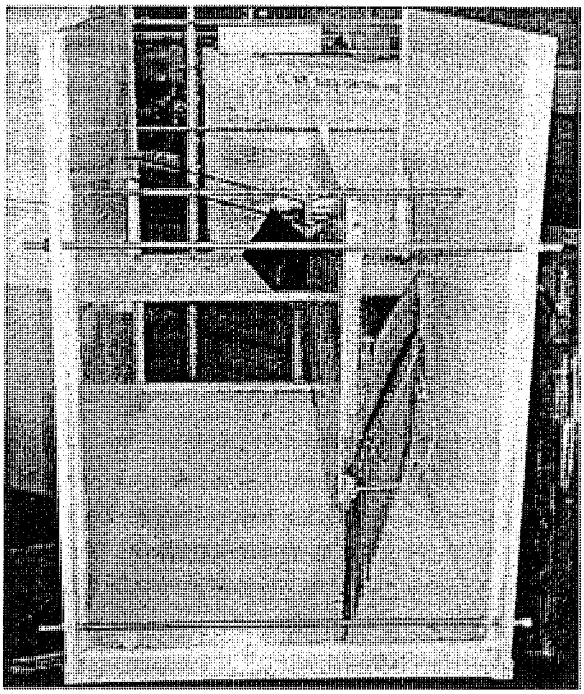
Table App. A.5. Boom dimensions per nominal pipe diameter (Phillips, 1998).

		NOMINAL PIPE DIAMETER (mm)											
Dimension		**200**	**300**	**375**	**450**	**525**	**600**	**675**	**750**	**825**	**900**	**1050**	**1200**
B (mm)	= 1.5*D	300	450	563	675	788	900	1013	1125	1238	1350	1575	1800
G (mm)	= 0.5*D	100	150	188	225	263	300	338	375	413	450	525	600
H (mm)	= 0.6*D	120	180	225	270	315	360	405	450	495	540	630	720
I (mm)	= 0.3*D	60	90	113	135	158	180	203	225	248	270	315	360
J (mm)	= 0.3*D	60	90	113	135	158	180	203	225	248	270	315	360

3.0. LABORATORY STUDIES.

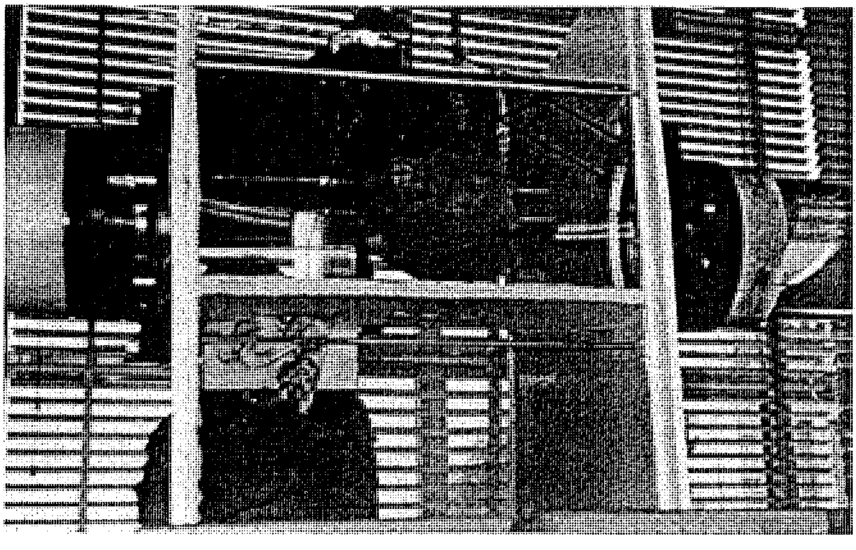
This section covers the preliminary laboratory experimental testing performed by Phillips (1998). Figure App A.1. shows the ILLS laboratory model used by Phillips.

Figure App A.1. ILLS laboratory model (Authors photograph, 1998).



As already highlighted, the boom operates by remaining at rest for most storm events (those with small runoff flow-rates) whilst lifting clear in larger events, which then ensures minimal head loss when the critical pipe capacity is reached (please refer to Figure App. A.2.). This function ensures that a majority of runoff flows are diverted for treatment, whilst larger events do not overload the treatment storage area, preventing the scour of retained pollutants, i.e. the treatment flow reaches a maximum (at around a quarter pipe capacity) before diminishing to zero at pipe capacity.

Figure App. A.2. ILLS laboratory model under full pipe flow conditions showing minimal head-loss (Author's photograph, 1998).



The boom length and weight are considered the primary factors for which the maximum treatment flow rate (Q_w) is dependant and must be understood in order to determine the optimum boom lift frequency.

In order to obtain the optimum boom lift frequency for the ILLS, this section presents a theoretical approach (Phillips, 1998) to relate the boom mass to the proportion of pipe flow capacity diverted for treatment (ie. Q_w/ Q_{pm}), based on laboratory testing. An equation is given which may be used to derive the required boom mass for a selected configuration and lift frequency, as well as determining the optimum boom lift frequency for the ILLS.

It was demonstrated (Phillips, 1998) that:

> *"..for a boom length of 1.5 times the diameter (1.5D), the boom weight for optimum flow treatment is ideally that which limits the frequency of boom lift to four times annually".*

3.1. Derivation of Boom-weir equation from laboratory model testing

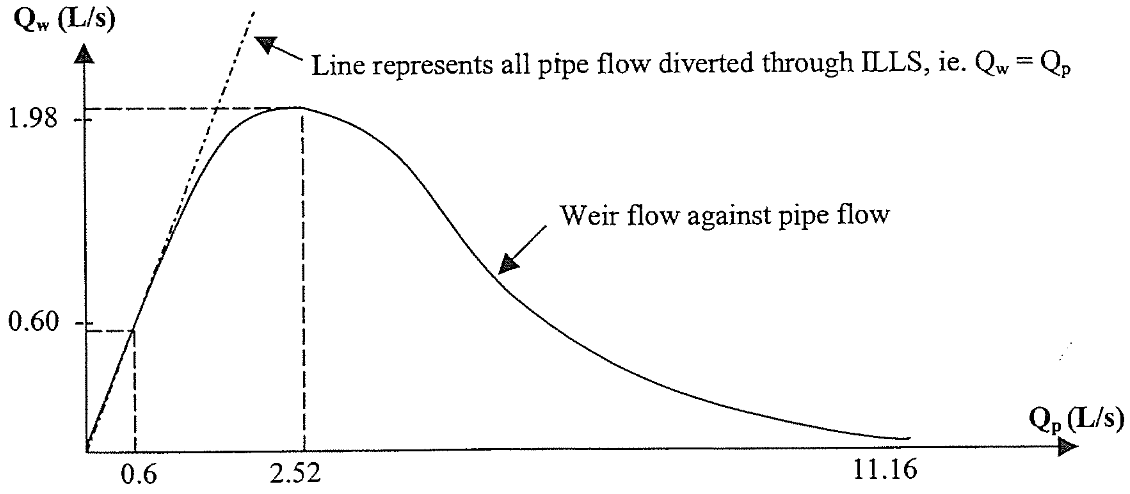
Table App. A.6 below was constructed from experimental data obtained from laboratory testing and shows pipe flow, boom underflow, and weir flow (Phillips, 1998).

Table App. A.6. Laboratory experimental results for pipe flow, boom underflow, and weir flow (Phillips, 1998).

Pipe flow, Q_p (L/s)	Boom under-flow, Q_{bu} (L/s)	Weir flow, Q_w (L/s)	Remarks
11.16	11.16	0	Pipe at full capacity
6.39	N/A	N/A	Pipe at half depth
2.52	0.54	1.98	Weir nappe defined
0.6	0	0.6	Boom at point of lift

From the table App. A.6., Phillips demonstrated that Figure App. B.3. may be constructed.

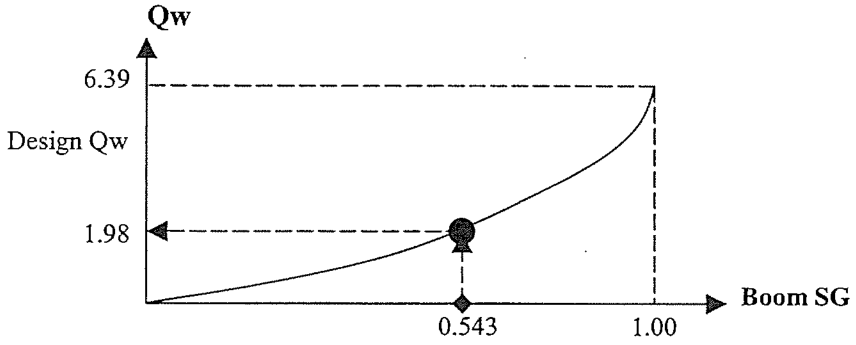
Figure App. A.3. Graph of weir flow against pipe flow from laboratory tests (Phillips, 1998).



With the model boom set at a mass of 1.0 kg, and a volume of 0.00184 cubic meters, Phillips (1998) calculated the specific gravity to be 0.543. Figure App. A.4. is a graph of the boom SG versus peak weir flow (Q_w) plotted from the experimental data (Phillips, 1998), from which the following equation was then presented with proof, viz:

$$Q^{o}_{w} = 0.442*(SG)^2 + 0.128*SG \qquad \textbf{Equation 3}$$

Figure App. A.4. Design selection of boom mass.



This relationship gives the designer the flexibility of adjusting the boom mass to suit any specific requirement for the weir flow. This may be particularly useful on sites where space is at a premium, or severe limitations exist (such as competing services), as a reduced footprint area and volume are inevitable, and hence also require a lighter boom to accommodate a reduced treatment flow-rate.

3.2. Boom SG in terms of physical measurements

Equation 3 is however itself insufficient for design purposes, as the boom SG also needs to be equated to the boom depth of immersion and dimensions before a true relationship for treatment flow can be given. The boom specific gravity (SG) by definition is as follows:

$$SG = \frac{\text{weight of boom (= weight of water displaced)}}{\text{weight of equivalent volume of water}} \qquad \textbf{Equation 4}$$

As the boom weight has already been provided in Equation 2 (in terms of the pipe diameter 'D' and flow depth 'd'), it may then be proven that the boom SG may be simplified to Equation 5:

$$\text{Boom SG} = [(0.45Dd - 0.3d^2)*6.67\ ]/\ D^2 \qquad \textbf{Equation 5}$$

Equations 2 and 4 may now be combined to provide Equation 6 and Table App. A.7.

$$Q_w/\ Q_{pm} = \{0.442[(0.45Dd - 0.3d^2)*6.67]^2/\ D^4\} + \{0.128[(0.45Dd - 0.30d^2)*6.67]/\ D^2\} \qquad \textbf{Equation 6}$$

Table App. A.7. Derivation of weir flow as a proportion of maximum pipe flow (Qw/ Qpm) versus frequency of boom lift.

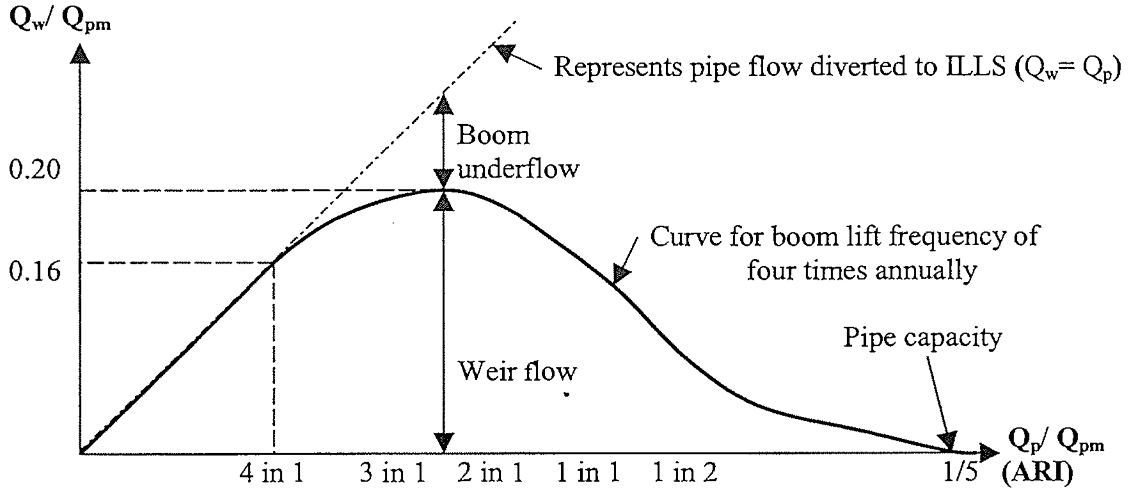
ARI (Years)	Frequency of boom lift/ annum	d/ D	D	d*D	d^2	D^2	0.45*D*d	0.30*d^2	Qw/ Qpm
5	-	1.00	1	1	1	1	0.45	0.3	0.57
2	-	0.65	0.64	0.64	0.4096	1	0.288	0.123	0.68
1	1 in 1 Yr	0.51	0.53	0.53	0.2809	1	0.239	0.0843	0.60
0.500	2 in 1 Yr	0.34	0.375	0.375	0.1406	1	0.169	0.0422	0.42
0.333	3 in 1 Yr	0.28	0.285	0.285	0.0812	1	0.128	0.0244	0.30
0.250	4 in 1 Yr	0.19	0.17	0.17	0.0289	1	0.076	0.0087	0.15

4.0. HYDROLOGIC MODELLING

4.1. Relationship between pipe flow and weir flow

Based on the laboratory testing presented above, Figure App. A.5 can be plotted (Phillips, 1998). This graph shows that for any storm event, the weir treatment flow (Q_w) will not exceed 20% of the pipe capacity, providing a boom is fitted with a mass which offers a 4 in 1 Year (3 month) ARI design lift frequency.

Figure App. A.5. Graph of relationship between weir and pipe flow (Phillips, 1998).

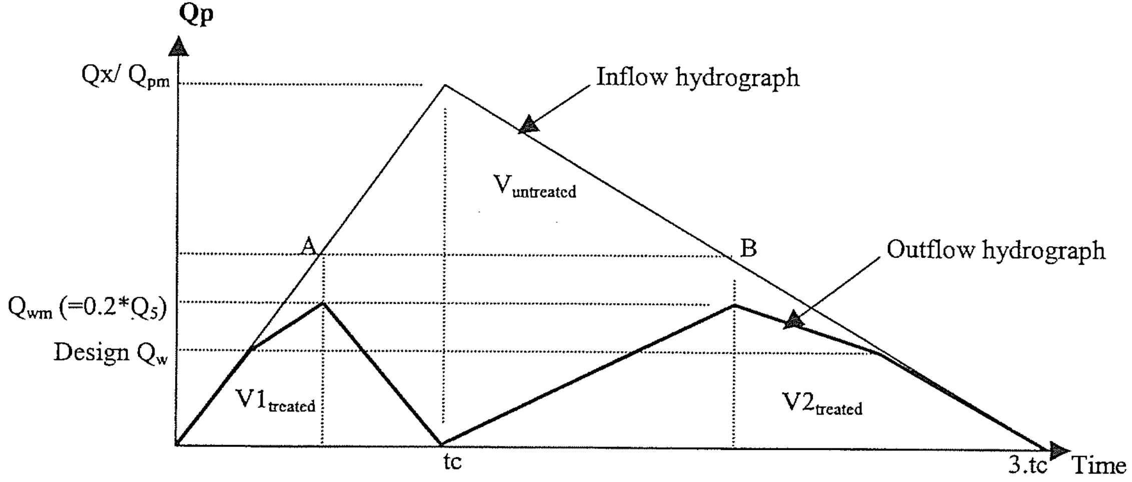


It may also be seen from Figure App. A.5. that all flow in a 4 in 1 Year ARI storm event will be treated, where the boom will be just on the point of lift. All larger events will raise the boom creating boom underflow which begin by rising slowly. The untreated boom underflow will increase rapidly (as a proportion of pipe flow) once weir flows (Q_w) exceed the maximum weir flow ($0.20*Q_{pm}$). All pipe flow becomes boom underflow in a pipe full situation.

4.2. Annual flow treatment

The percentage of annual runoff flow treated may now be estimated based on theory already presented. The procedure adopted by Phillips (1998) involves utilising a design inflow triangular hydrograph with a peak flow rate equal to that of the drainage system's capacity, typically a 5 year ARI design event with its peak at a time of concentration of t_c and base length $3t_c$, as shown in Figure App. A.6. The simplified outflow hydrograph shown is characteristic of the ILLS weir over flow.

Figure App. A.6. Simplified hydrograph for hydrologic modelling.



NOTES:

1. Inflow and outflow hydrographs simplified.
2. 'A' & 'B' represent the points at which a maximum weir treatment flow rate (Q_{wm}) occurs;
3. $V_{untreated}$ = area between inflow and outflow hydrographs represents the untreated boom underflow volume;
4. $V_{treated}$ (= $V1_{treated}$ + $V2_{treated}$) = area under outflow hydrograph represents the weir overflow volume;
5. Boom lift and rest occur at the design Q_w flow rate;

Phillips (1998) calculated that the summation of all boom underflow to be equal to $5.14*Q_5*t_c$, where $Q_5 = C_5*I_5*A$.

After adopting the following equation for volumetric runoff, viz:

$V_{tot} = C*P*A$, where: **Equation 7**

C_v = volumetric co-efficient of runoff;
P = average annual rainfall (mm);
A = Catchment area (Ha);

Phillips (1998) also calculated the boom underflow as a percentage of total runoff within any five (5) year period utilising the following resultant equation:

$V_{bu} = (5.14* C_5*I_5*A*t_c/ 5*C_v*P*A)*100$ (%) **Equation 8**

For Melbourne the following values were adopted (Phillips, 1998):

$C_5 = 0.865$ (Table App. A.2.)
P = 656 mm (Melbourne).
$C_v = 0.66$.

Based on the above theoretical assumptions the percentage of the mean annual runoff passing through the ILLS holding chamber may be calculated, viz (Phillips, 1998):

% of MAR treated $= 100 - (5.14*0.865*51*18*100/\ 5*0.66*656*60)$

$= 100 - 3.14 =$ **96.86 (say 97) %**

Phillips also points out that under intensive urban re-development the pipe capacity may be reduced considerably, and when the above theory is re-calculated with such assumptions, an estimated 93% may still be treated as weir flow. As already discussed however, a fair proportion of this runoff would occur in low intensity events where very little litter is mobilised and transported to the GPT, demonstrating that the percentage of annual flow treated is not necessarily a good indicator of treatment performance.

5.0. TRIANGULAR RETURN CHANNEL

A late development with the ILLS design was the development of a triangular weir, which superseded the rectangular weir–channel adopted on installed prototypes and monitored as part of this thesis. The triangular weir-channel inherits an extended weir length, and allows a reduced comb spacing whilst still providing a similar flow area. The triangular weir-channel ensures optimised sub-critical flow conditions in the channel and behind the boom, creating adequate return flow depths at the design flow to ensure optimum boom lifting conditions.

Although being too late for the prototypes installation program, the theory produced (Phillips 1998) was consequently utilised with installations of later generation ILLS. For this reason the author pursued the monitoring and evaluation of an additional installation in Bendigo, which featured the new triangular weir-channel arrangement, as presented later as an individual case study in this thesis.

As already shown, at a flow depth where $d = 0.3*D$, the maximum weir flow ($0.2*Q_{pm}$) is produced, where symbols have their usual meaning. If $Q_w = v_w*A_w$, where the sub-script '$_w$' denotes the weir flow, average channel velocity and cross sectional area respectively, then A_w may be substituted ($A_w = W*0.3*D$) to give (Phillips, 1998):

$Q_{w\,max} = v_w*W*0.3*D$ **Equation 9**

where 'W' is the weir/ channel width.

For flow in the channel and behind the boom to be super-critical, the 'Froude number' (F_r) must be less than or equal to 1.0, ie. $F_r = v_w/gd =< 1.0$, which may then be rearranged and substituted into equation 9 above to give equation 10, viz:

$Q_{p\,max} = 2.573*W*D^{3/2}$ **Equation 10**

Equation 9 may be used to produce Table App. A.8. (Phillips 1998).

Table App. A.8. Minimum ILLS dimensions.

Nominal pipe diameter, D (mm)	Pipe capacity (L/s)	End Width 'W' (mm)	Ratio of W/ D.
300	140	335	1.1
375	250	425	1.1
450	400	515	1.1
525	600	615	1.2
600	900	760	1.3
675	1200	845	1.3
750	1600	960	1.3
825	2200	1145	1.4
900	2500	1300	1.4
1050	4000	1445	1.4

Table App. A.9. below may also be produced from this theory.

Table App. A.9. Minimum triangular weir – return channel dimensions, based on varying pipe grades.

	Pipe grade 4.0 % (1 in 25)			Pipe grade 2.5 % (1 in 40)			Pipe grade 1.5 % (1 in 66.7)		
Pipe diameter, D (mm)	Qpmax (L/s)	Width 'W' (mm)	Ratio of W/ D.	Qpmax (L/s)	Width 'W' (mm)	Ratio of W/ D.	Qpmax (L/s)	Width 'W' (mm)	Ratio of W/ D.
300	193	456	1.52	154	364	1.21	118	279	0.93
375	351	594	1.58	277	469	1.25	215	364	0.97
450	570	734	1.63	451	581	1.29	349	449	1.00
525	860	879	1.67	680	695	1.32	527	538	1.03
600	1228	1027	1.71	971	812	1.35	752	629	1.05
675	1681	1178	1.75	1330	932	1.38	1029	721	1.07
750	2230	1334	1.78	1760	1053	1.40	1363	816	1.09
825	2870	1489	1.80	2270	1177	1.43	1758	912	1.11
900	3620	1648	1.83	2860	1302	1.45	2217	1009	1.12
1050	5460	1972	1.88	4320	1560	1.49	3340	1206	1.15
1200	7800	2306	1.92	6160	1821	1.52	4770	1410	1.18

APPENDIX B SAMPLE LITTER ITEMS USED IN TAGGED LITTER MONITORING

The sample litter items chosen for this study and presented in chapter 6 of this thesis are detailed below in Table App B1 with their various material categories.

Table App. B1. Sample litter items and details (dimensions, volume, dry mass and specific density)

SAMPLE LITTER ITEM	DIMENSIONS (mm)	VOLUME (ml)	MASS (DRY) (g)	MASS DENSITY (kg/m^3)
Category 1: Plastic Products:				
PET bottles (with lids):	200 x 50 dav;	390 (##)	31.3	80
	236 x 57 dav	600 (##)	30.5	51
PET bottles (with-out lids):	200 x 50 dav;	390	28.7	74
	236 x 57 dav	600	27.9	47
HDPE bottles (with lids):	175 x 60 dav	500 (##)	32.8	66
HDPE bottles (without lids):	175 x 60 dav	500	29.6	59
Plastic shopping bags:	Min. 520x290 (x5 min)	Approx. 750	6.9	Approx. 9.2
	Max. 520x290 (x200 max)	Approx. 30,000	6.9	Approx. 0.2
# Plastic drinking straws:	*206 x 8 dav*	*10.4*	*0.9*	*87*
# Plastic food wrapping/packets:	*Min. Area: 8,000 mm^2*	*Approx. 0.7*	*0.7*	*Approx. 1000*
	Max. Area: 27,000 mm^2	*Approx. 200*	*2.8*	*Approx. 14*
# Plastic drink cup lids:	*0.25 x 92 dav*	*1.67*	*1.8*	*Approx. 1000*
Category 2: Metal Products:				
Aluminium cans:	115 x 65 dav	375	14.9	40
# Food wrapping (Foil lined):	*Min. Area: 7,500 mm^2*	*Approx. 100*	*0.9*	*Approx. 9*
	Max. Area: 50,000 mm^2	*Approx. 5.3*	*5.3*	*Approx. 1000*
Category 3: Paper Products (Wax Coated):				
Paper drink cartons (Waxed):	71 x 71x 96 (max); and	300	16.9	56
	72 x 71x 157 (max)	600	24	40
Paper drink cups (Waxed):	126 x 75 dav	550	9.4	17
Category 4: Polystyrene:	50 x 50 x 12	30 (##)	0.7	23
Category: Syringes (1 ml internal):	No data.	1 (##)	2.3	Approx. 1000

NOTES (Table App. B1):

1. dav denotes average diameter (mm).

2. # : Denotes sample litter items (*also shown in Italics*) which are non-positive (non priority) items, as they are smaller than the ILLS baffle wall comb spacings (typically 30mm) and are included for information only.

3. ## : Denotes sample litter items with fixed volume (solid material or enclosed) with fixed specific gravity. Remaining sample litter items may vary in volume, mass and specific gravity, as they are open and prone to carry water and solids.

PHOTOGRAPHS OF SAMPLE LITTER ITEMS (SLI's) USED IN STUDY

This section presents photographs of the sample litter items presented in Table App B1.

Category 1: Plastic Products	
PET (Polyethylene teraphthalate) bottles (lids on and lids off) – Two (2) separate SLI's.	Refer to Plate App. B1.
HDPE (high-density polyethylene) bottles (lids on and lids off) - Two (2) separate SLI's	Refer to Plate App. B2.
Shopping bags	Refer to Plate App. B3.
# Drinking straws	Refer to Plate App. B4.
# Food wrapping/ packets (No foil lining) - One (1) SLI's	Refer to Plate App. B5.
# Drink cup lids	Refer to Plate App. B6.
Category 2: Metal Products	
Aluminium cans	Refer to Plate App. B7.
# Food wrapping and packets (with foil lining)	Refer to Plate App. B8.
Category 3: Paper Products (Wax Coated)	
Drink Cartons (various sizes)	Refer to Plate App. B9.
Drink cups (various sizes)	Refer to Plate App. B10.
Category 4: Polystyrene Products	
Pieces (50mm x 50mm x 12mm).	Refer to Plate App. B11.
Category: Syringes (additional test item used with second phase of monitoring)	
Syringes (1 ml internal)	Refer to Plate App. B12.

CATEGORY 1: PLASTIC PRODUCTS

Plate App. B1. Plastic PET (Polyethylene teraphthalate) bottles (lids on shown)

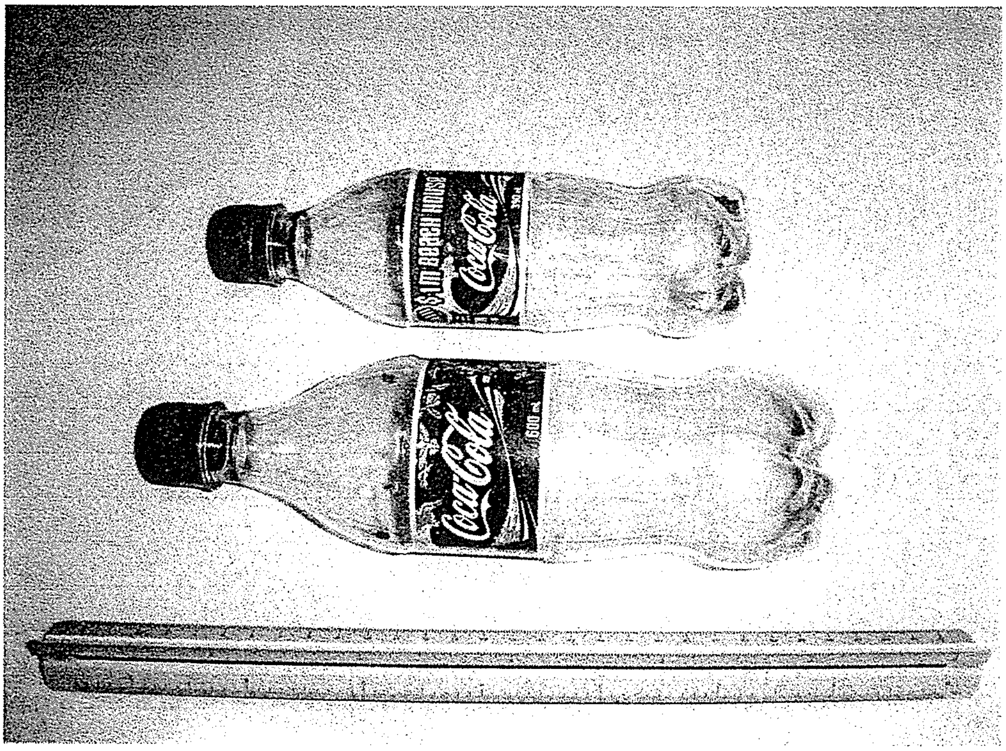


Plate App. B2. Plastic HDPE (high-density polyethylene) bottles (lids on shown)

Plate App. B3. Plastic shopping bags

Plate App. B4. Plastic drinking straws (# Non priority item)

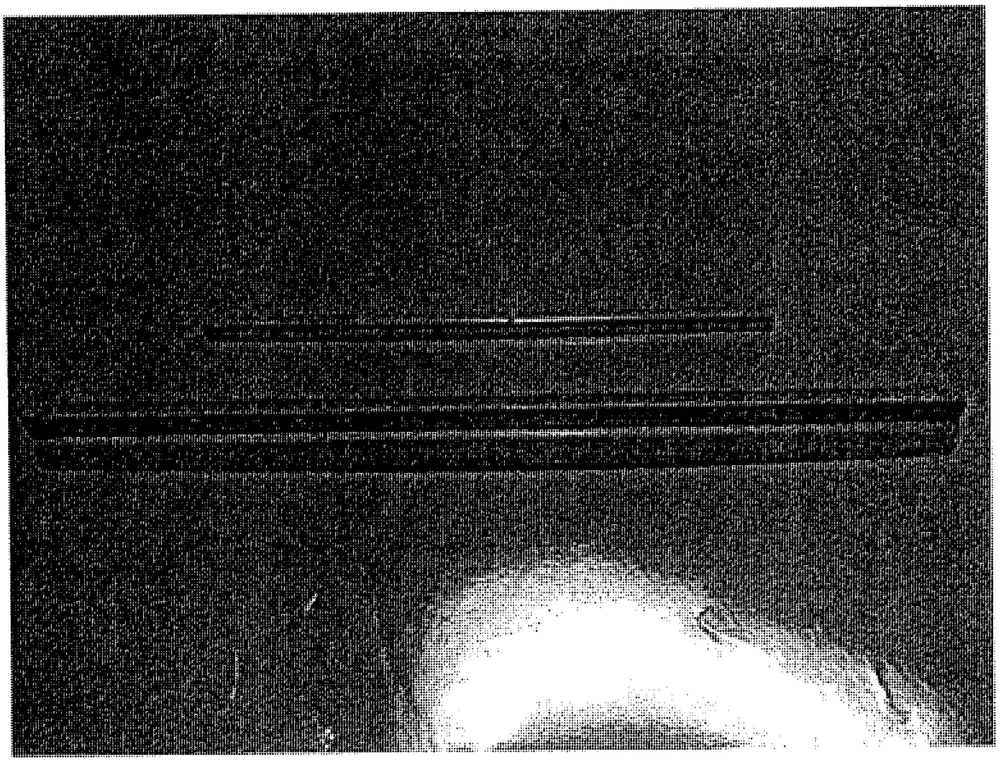


Plate App. B5. Plastic food wrapping and packets (No foil lining) (# Non priority item)

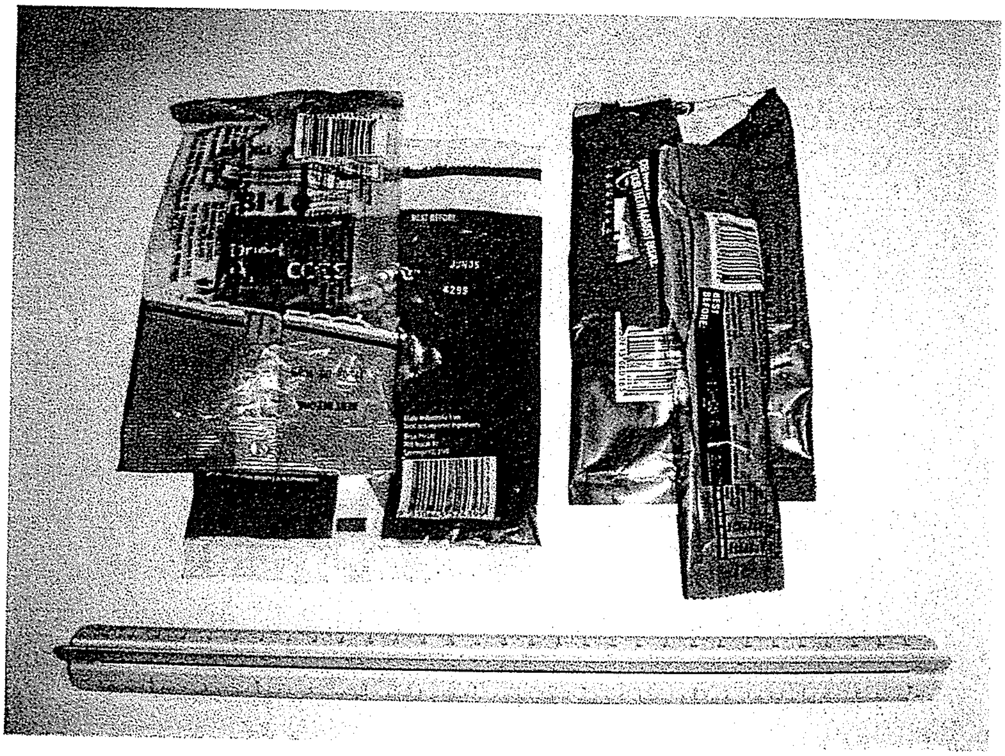
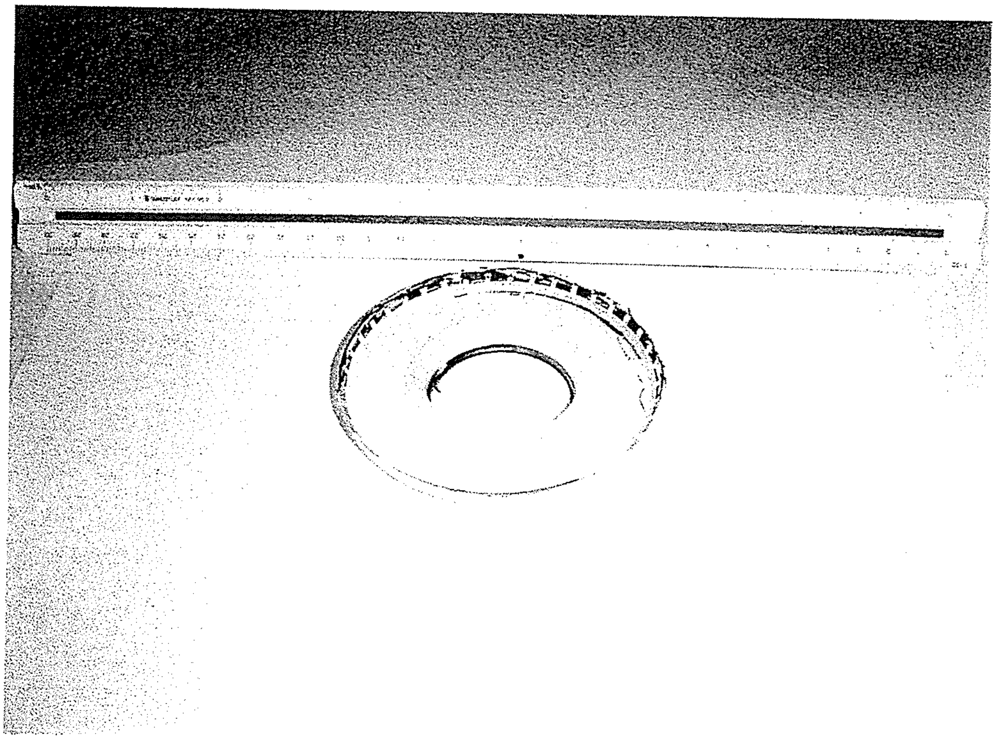


Plate App. B6. Plastic drink cup lids (# Non priority item)



CATEGORY 2: METAL PRODUCTS

Plate App. B7. Aluminium can

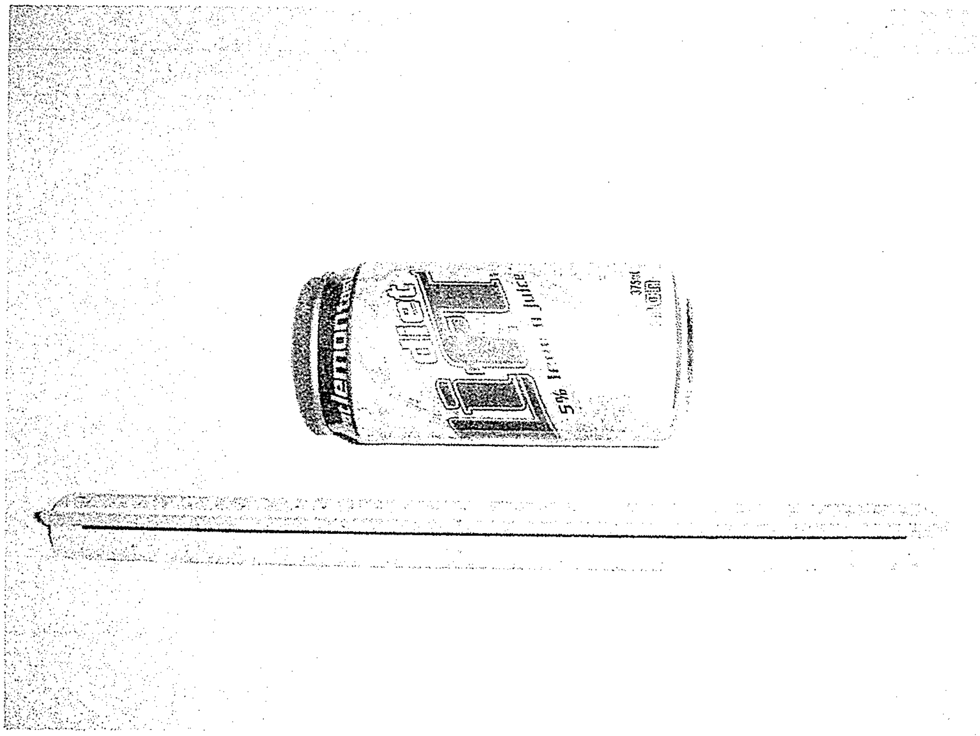


Plate App. B8. Foil lined food wrapping and packets (# Non priority item)

CATEGORY 3: PAPER PRODUCTS (WAX COATED)

Plate App. B9. Paper drink cartons – wax coated (various sizes)

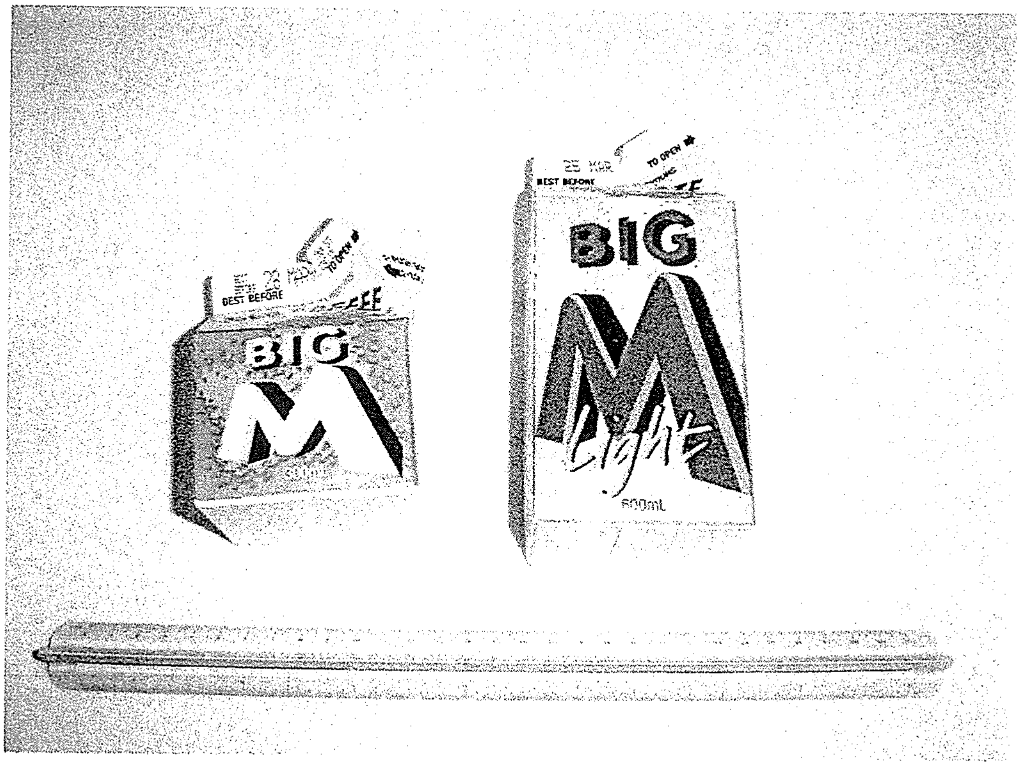
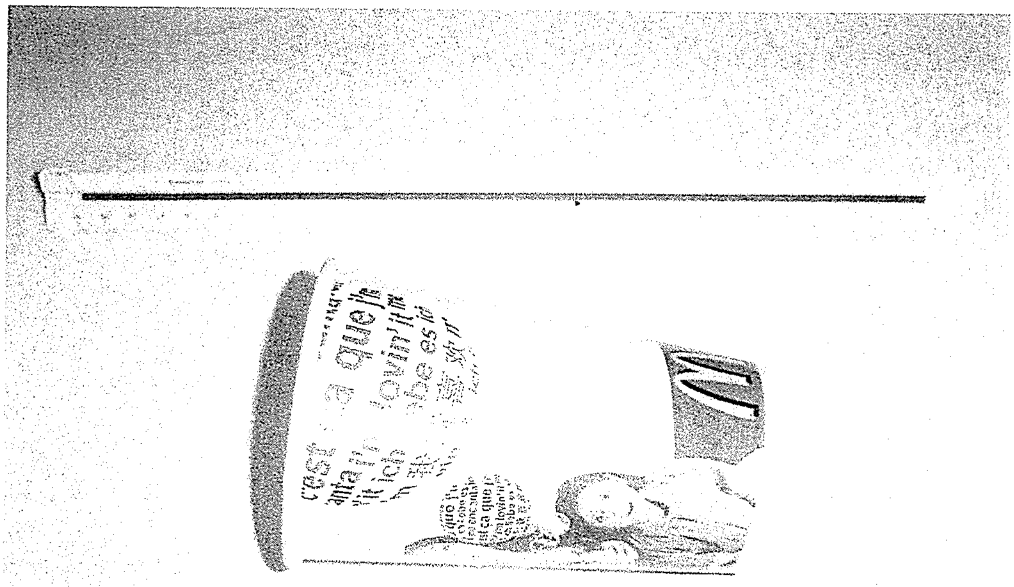
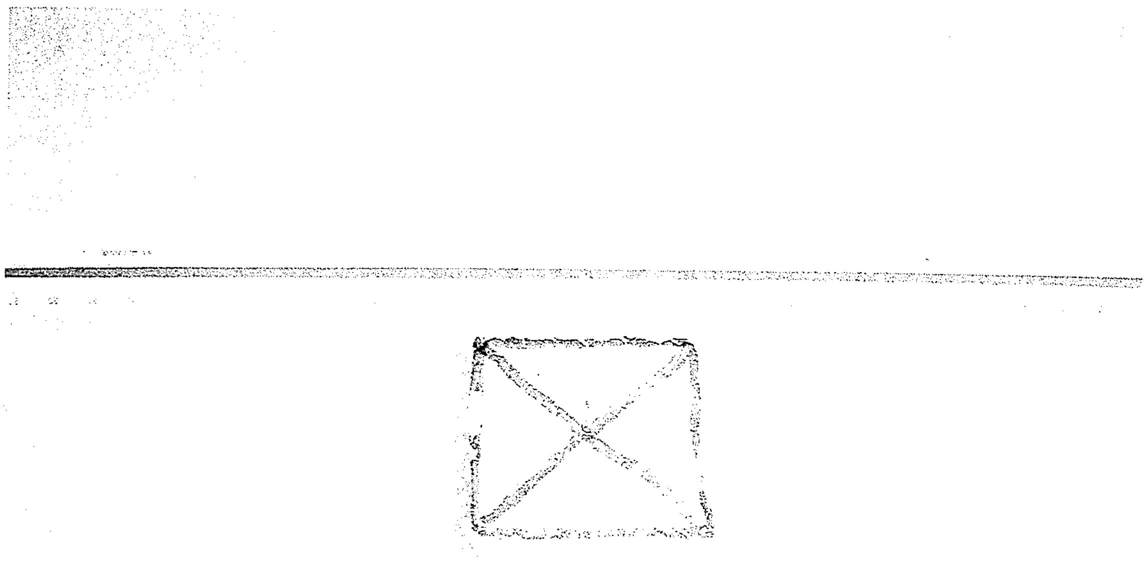


Plate App. B10. Paper drink cups – wax coated (various sizes)



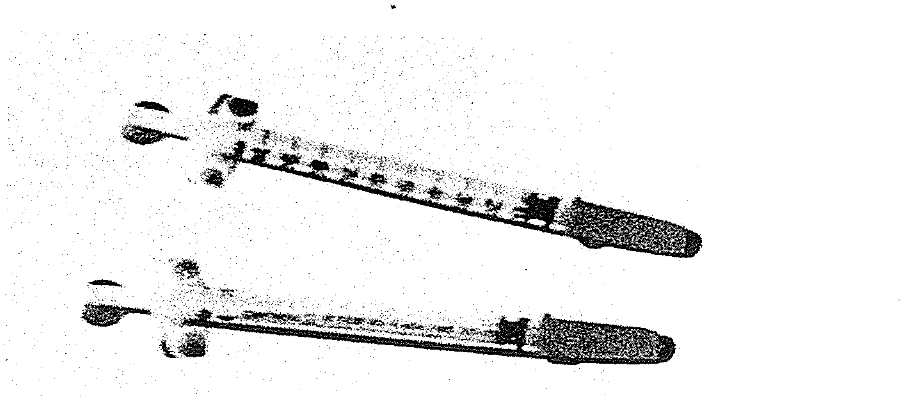
CATEGORY 4: POLYSTYRENE PRODUCTS

Plate App. B11. Polystyrene Pieces (50mm x 50mm x 12mm)



CATEGORY: SYRINGES (ADDITIONAL TEST ITEM USED WITH SECOND PHASE OF MONITORING)

Plate App. B12. Syringes (1 ml)



APPENDIX C DATA TABLES – LITTER ITEMS INTRODUCED AND RETREIVED AND LITTER REMOVAL EFFICIENCIES

This Appendix presents the data tables that were used to record data used in this study for determining sample litter item removal efficiencies for each ILLS prototype, including the following:

- Litter items dropped (introduced) into the ILLS prototype catchments;
- Litter items retrieved from ILLS prototype upon cleaning;
- Removal Efficiency for each ILLS prototype clean-out;
- Total Removal Efficiencies (TRE's) for all sample litter items;
- Standard deviations for Removal Efficiencies ('n' type biased method); and
- Confidence intervals (based on alpha = 0.05 and calculated standard deviations).

Syringes, although not included as a sample litter item, were also monitored in the second phase of monitoring and are included at the end this Appendix. The data tables presented in this Appendix do not include foreign (untagged) sample litter items, which are presented in Appendix D.

FIRST PHASE ILLS MONITORING AND PERFORMANCE EVALUATION

Prototype Case Study #1 – Damper Creek, Monash City Council

No monitoring undertaken.

Prototype Case Study #2 – Toombah Street, Monash City Council - Phase 1 monitoring

Please refer to Table App C.1.

Prototype Case Study #3 – Yuile Street, City of Boroondara

Please refer to Table App C.2.

Prototype Case Study #4 –Lygon Street, City of Melbourne - Phase 1 monitoring

Please refer to Table App C.3.

Prototype Case Study #5 – Luck Street, Shire of Nillumbik

No monitoring undertaken.

SECOND PHASE ILLS MONITORING AND PERFORMANCE EVALUATION

Prototype Case Study #2 – Toombah Street, Monash City Council, Phase 2

Please refer to Table App C.4.

Prototype Case Study #4 – Lygon Street, City of Melbourne - Phase 2 monitoring

Please refer to Table App C.5.

Prototype Case Study #6 – Broughton Street, Frankston City Council

No monitoring undertaken.

Prototype Case Study #7 – The Avenue, Kingston City Council

No monitoring undertaken.

Prototype Case Study #8 – Youth Road, Shire of Nillumbik
Please refer to Table App C.6.

Prototype Case Study #9 – O'Grady Street, Port Phillip City Council
Please refer to Table App C.7.

Prototype Case Study #10 – Lonsdale Street, City of Greater Dandenong
Please refer to Table App C.8.

Prototype Case Study #11 – Williamson Street, City of Greater Bendigo
Please refer to Table App C.9.

Syringe total removal efficiency data for second phase of monitoring
Please refer to Table App C.10.

Table App C.1 Toombah Street – Phase 1. Capture Efficiencies for Sample Litter Items

Initial pump-out (clean-out): 12/6/1997

	NUMBER OF TAGGED LITTER ITEMS INTRODUCED INTO ILLS CATCHMENT PITS.					NUMBER OF TAGGED LITTER ITEMS RECOVERED FROM ILLS & REMOVAL EFFICIENCIES (%) BY PUMP-OUT.											
	1st Drop:	2nd Drop:	3rd Drop:	4th Drop:	Drop	PO-1	RE	PO-2	RE	PO-3	RE	PO-4	PO-5	RE		TRE	
SAMPLE LITTER ITEM	27/06/1997	23/07/1997	02/09/1997	08/10/1997	**Total**	16/07/1997	(%)	07/08/1997	(%)	22/09/1997	(%)	17/10/1997	04/12/1997	(%)	**PITS**	(%)	**STDVP**
PET bottles (with lids):	10	10	10	10	40	2	20%	4	40%	9	90%	5	6	110%	0	65%	0.36
HDPE bottles (with lids):	10	10	10	10	40	0	0%	1	10%	0	0%	1	1	20%	0	8%	0.08
Plastic shopping bags:	10	10	10	10	40	2	20%	2	20%	2	20%	2	1	30%	0	23%	0.04
Plastic straws:	10	10	10	10	40	0	0%	0	0%	0	0%	0	0	0%	0	0%	0.00
Plastic food wrapping/packets:	10	10	10	10	40	1	10%	0	0%	0	0%	0	1	10%	0	5%	0.05
Plastic drink cup lids:	0	10	10	0	20	0	N/A	0	0%	0	0%	0	0	N/A	0	0%	0.00
Aluminium cans:	10	10	10	10	40	4	40%	0	0%	4	40%	3	2	50%	0	33%	0.19
Food wrapping (Foil lined):	10	10	10	10	40	0	0%	0	0%	0	0%	1	0	10%	0	3%	0.04
Paper drink cartons (Waxed):	10	10	10	10	40	1	10%	3	30%	3	30%	4	2	60%	0	33%	0.18
Paper drink cups (Waxed):	10	10	10	0	30	2	20%	0	0%	0	0%	0	1	N/A	0	10%	0.09
Poly-Styrene pieces:	10	10	10	10	40	4	40%	2	20%	9	90%	6	5	110%	0	65%	0.36
TOTALS:	**100**	**110**	**110**	**90**	**410**	**16**	**16%**	**12**	**11%**	**27**	**25%**	**22**	**19**	**44%**	**0**		

LEGEND:

PO-# Denotes ILLS prototype pump-out (clean) number
RE: Denotes litter item Removal (capture) Efficiency for that period/pump-out.
TRE: Denotes Total Removal (capture) Efficiency per litter item for entire study period (%).
PITS: Denotes items retrieved from catchment pits at end of study
N/A: Denotes Not Applicable. No tagged litter items dropped in that period.
STDVP: Denotes .Standard Deviation ('n' biased method).

Table App C.2 Yuile Street – Phase 1. Capture Efficiencies for Sample Litter Items.

Initial pump-out (clean-out): 4/7/1997

	NUMBER OF TAGGED LITTER ITEMS INTRODUCED INTO ILLS CATCHMENT PITS.				NUMBER OF TAGGED LITTER ITEMS RECOVERED FROM ILLS & REMOVAL EFFICIENCIES BY PUMP-OUT.									
	1st Drop:	2nd Drop:	3rd Drop:	Drop	PO-1	PO-2	RE	PO-3	RE	PO-4	RE		TRE	
SAMPLE LITTER ITEM	04/07/1997	12/09/1997	16/10/1997	Total	05/08/1997	12/09/1997	(%)	10/10/1997	(%)	12/11/1997	(%)	**PITS**	(%)	**STDVP**
PET Bottles (with-out lids):	10	10	10	30	3	3	60%	6	60%	2	20%	0	47%	0.23
HDPE Bottles (with-out lids):	10	10	10	30	2	0	20%	3	30%	0	0%	0	17%	0.15
Plastic Shopping Bags:	10	10	10	30	1	0	10%	1	10%	0	0%	0	7%	0.06
Plastic Straws:	10	10	10	30	0	0	0%	0	0%	0	0%	0	0%	0.00
Plastic Food Wrapping/packets:	10	10	10	30	0	0	0%	0	0%	0	0%	0	0%	0.00
Plastic Drink Cup Lids:	10	0	10	20	2	0	20%	5	N/A	0	0%	0	35%	0.14
Aluminium Cans:	10	10	10	30	6	2	80%	8	80%	0	0%	0	53%	0.46
Food Wrapping (Foil lined):	10	10	10	30	0	0	0%	0	0%	0	0%	0	0%	0.00
Paper Drink Cartons (Waxed):	10	10	10	30	5	2	70%	7	70%	0	0%	0	47%	0.40
Paper Drink Cups (Waxed):	10	3	10	23	1	0	10%	0	0%	0	0%	0	4%	0.06
Poly-Styrene pieces:	10	10	10	30	6	4	100%	4	40%	2	20%	0	53%	0.42
TOTALS:	**110**	**93**	**110**	**313**	26	11	34%	34	29%	4	4%	0		

LEGEND:

PO-# Denotes ILLS prototype pump-out (clean) number

RE: Denotes litter item Removal (capture) Efficiency for that period/pump-out (%).

TRE Denotes Total Removal (capture) Efficiency per litter item for entire study period (%).

PITS: Denotes items retrieved from catchment pits at end of study

N/A: Denotes Not Applicable. No tagged litter items dropped in that period.

STDVP: Denotes .Standard Deviation ('n' biased method).

Table App C.3 Lygon Street – Phase 1. Capture Efficiencies for Sample Litter Items.

Initial pump-out (clean-out): 7/7/1997

	NUMBER OF TAGGED LITTER ITEMS INTRODUCED INTO ILLS CATCHMENT PITS.						NUMBER OF TAGGED LITTER ITEMS RECOVERED FROM ILLS & REMOVAL EFFICIENCIES BY PUMP-OUT.														
	1st Drop:	2nd Drop:	3rd Drop:	4th Drop:	5th Drop:	Drop	PO-1	PO-2	RE	PO-3	PO-4	RE	PO-5	RE	PO-6	RE	PO-7	RE		TRE	
SAMPLE LITTER ITEM	16/07/1997	30/09/1997	18/11/1997	23/12/1997	02/02/1998	Total	06/08/1997	03/09/1997	(%)	08/10/1997	05/11/1997	(%)	03/12/1997	(%)	16/01/1998	(%)	10/03/1998	(%)	PITS	(%)	STDVP
PET Bottles (with lids):	5	5	5	10	10	35	0	0	0%	2	3	100%	5	100%	5	50%	2	20%	0	49%	0.41
PET Bottles (without lids):	5	5	5	10	10	35	0	0	0%	2	2	80%	3	60%	5	50%	0	0%	0	34%	0.32
HDPE Bottles (with lids):	5	5	5	0	10	25	0	0	0%	2	0	40%	1	20%	0	N/A	1	10%	0	16%	0.15
HDPE Bottles (without lids):	5	5	5	10	0	25	0	0	0%	1	0	20%	0	0%	1	10%	0	N/A	0	8%	0.08
Plastic Shopping Bags:	10	10	10	10	10	50	3	0	30%	4	1	50%	8	80%	5	50%	0	0%	0	42%	0.26
Plastic Straws:	10	10	0	10	10	40	0	0	0%	2	0	20%	0	0%	4	40%	0	0%	0	15%	0.16
Plastic food wrapping/packets:	10	10	0	0	0	20	0	1	10%	2	0	20%	3	0%	0	N/A	0	N/A	0	30%	0.08
Plastic Drink Cup Lids:	10	0	10	0	10	30	0	0	0%	0	0	N/A	0	0%	0	N/A	5	50%	0	17%	0.24
Aluminium Cans:	10	10	10	10	10	50	0	0	0%	4	3	70%	9	90%	5	50%	4	40%	0	50%	0.30
Food Wrapping (Foil lined):	10	10	10	0	10	40	0	1	10%	0	4	40%	4	40%	3	N/A	2	20%	0	35%	0.13
Paper Drink Cartons (Waxed):	10	10	10	10	10	50	1	1	20%	4	4	80%	9	90%	4	40%	1	10%	0	48%	0.32
Paper Drink Cups (Waxed):	10	8	10	6	0	34	0	0	0%	0	2	25%	0	0%	0	0%	0	N/A	0	6%	0.11
Poly-Styrene pieces:	10	10	10	10	10	50	3	3	60%	6	4	100%	9	90%	5	50%	1	10%	0	62%	0.32
TOTALS:	**110**	**98**	**90**	**86**	**100**	**484**	**7**	**6**	**10%**	**29**	**23**	**54%**	**51**	**52%**	**37**	**38%**	**16**	**16%**	**0**		

LEGEND:

PO-# Denotes ILLS prototype pump-out (clean) number
RE: Denotes litter item Removal (capture) Efficiency for that period/pump-out (%).
TRE: Denotes Total Removal (capture) Efficiency per litter item for entire study period (%).
PITS: Denotes items retrieved from catchment pits at end of study
N/A: Denotes Not Applicable. No tagged litter items dropped in that period.
STDVP: Denotes Standard Deviation ('n' biased method).

Table App C.4 Toombah Street – Phase 2. Capture Efficiencies for Sample Litter Items.

Initial pump-out (clean-out): 25/8/1998

	NUMBER OF TAGGED LITTER ITEMS INTRODUCED INTO ILLS CATCHMENT PITS.			NUMBER OF TAGGED LITTER ITEMS RECOVERED FROM ILLS & REMOVAL EFFICIENCIES BY PUMP-OUT.							
	1st Drop:	2nd Drop:	**Drop**	PO-1	RE	PO-2	PO-3	RE		TRE	
SAMPLE LITTER ITEM	25/08/1998	13/10/1998	**Total**	28/09/1998	(%)	29/10/1998	26/11/1998	(%)	**PITS**	(%)	**STDEV**
PET bottles (with lids):	20	20	40	14	70%	12	0	60%	0	65%	0.05
HDPE bottles (with lids):	0	8	8	0	N/A	6	0	75%	0	75%	0.00
Plastic shopping bags:	10	10	20	2	20%	3	0	30%	0	25%	0.05
Plastic straws:	10	10	20	3	30%	0	0	0%	0	15%	0.15
Plastic food wrapping:	10	0	10	0	0%	0	0	N/A	0	0%	0.00
Plastic drink cup lids:	10	10	20	4	40%	2	2	40%	0	40%	0.00
Aluminium cans:	10	10	20	9	90%	5	0	50%	0	70%	0.20
Food wrapping (Foil lined):	10	0	10	2	20%	0	0	N/A	0	20%	0.00
Paper drink cartons (Waxed):	10	10	20	8	80%	7	0	70%	0	75%	0.05
Paper drink cups (Waxed):	10	0	10	2	20%	0	0	N/A	0	20%	0.00
Poly-Styrene pieces:	10	10	20	0	0%	6	0	60%	0	30%	0.30
TOTALS:	**110**	**88**	**198**	**44**	**37%**	**41**	**2**	**48%**	**0**		

LEGEND:

PO-# Denotes ILLS prototype pump-out (clean) number
RE: Denotes litter item Removal (capture) Efficiency for that period/pump-out.
TRE: Denotes Total Removal (capture) Efficiency per litter item for entire study period (%).
PITS: Denotes items retrieved from catchment pits at end of study
N/A: Denotes Not Applicable. No tagged litter items dropped in that period.
STDVP: Denotes .Standard Deviation ('n' biased method).

Table App C.5 Lygon Street – Phase 2. Capture Efficiencies for Sample Litter Items.

Initial pump-out (clean-out): 31/7/1998

	NUMBER OF TAGGED LITTER ITEMS INTRODUCED INTO ILLS CATCHMENT PITS.				NUMBER OF TAGGED LITTER ITEMS RECOVERED FROM ILLS & REMOVAL EFFICIENCIES (%) BY PUMP-OUT.								
	1st Drop:	2nd Drop:	3rd Drop:	**Drop**	PO-1	RE	PO-2	RE	PO-3	RE		TRE	
SAMPLE LITTER ITEM	14/08/1998	22/09/1998	28/10/1998	**Total**	08/09/1998	(%)	13/10/1998	(%)	09/12/1998	(%)	**PITS**	(%)	**STDVP**
PET Bottles (with lids):	10	10	10	30	10	100%	7	70%	11	110%	0	93%	0.17
PET Bottles (without lids):	10	10	10	30	6	60%	9	90%	7	70%	0	73%	0.12
HDPE Bottles (with lids):	8	10	9	27	7	88%	5	50%	8	89%	0	74%	0.18
HDPE Bottles (without lids):	3	0	1	4	2	67%	0	N/A	0	0%	0	50%	0.33
Plastic Shopping Bags:	10	10	10	30	8	80%	4	40%	7	70%	0	63%	0.17
Plastic Straws:	10	0	0	10	7	70%	0	N/A	0	N/A	0	70%	0.00
Plastic Food Wrapping/Packets:	10	0	0	10	4	40%	0	N/A	0	N/A	0	40%	0.00
Plastic Drink Cup Lids:	10	0	10	20	0	0%	2	N/A	6	60%	0	40%	0.30
Aluminium Cans:	10	10	10	30	10	100%	7	70%	6	60%	0	77%	0.17
Food Wrapping (Foil lined):	10	0	10	20	9	90%	1	N/A	4	40%	0	70%	0.25
Paper Drink Cartons (Waxed):	10	10	10	30	10	100%	9	90%	9	90%	0	93%	0.05
Paper Drink Cups (Waxed):	10	0	10	20	0	0%	0	N/A	7	70%	0	35%	0.35
Poly-Styrene pieces:	20	20	10	50	17	85%	11	55%	8	80%	0	72%	0.13
TOTALS:	**131**	**80**	**100**	**311**	**90**	**68%**	**55**	**66%**	**73**	**67%**	**0**		

LEGEND:

PO-# Denotes ILLS prototype pump-out (clean) number

RE: Denotes litter item Removal (capture) Efficiency for that period/pump-out (%).

TRE: Denotes Total Removal (capture) Efficiency per litter item for study period (%).

PITS: Denotes items retrieved from catchment pits at end of study

N/A: Denotes Not Applicable. No tagged litter items dropped in that period.

STDVP: Denotes .Standard Deviation ('n' biased method).

Table App C.6 Youth Road. Capture Efficiencies for Sample Litter Items.

Initial pump-out (clean-out): 11/2/1998

	NUMBER OF TAGGED LITTER ITEMS INTRODUCED INTO ILLS CATCHMENT PITS							
	1st Drop:	2nd Drop:	3rd Drop:	4th Drop:	5th Drop:	6th Drop:	7th Drop:	Drop
SAMPLE LITTER ITEMS	15/02/1998	26/03/1998	11/05/1998	14/06/1998	06/08/1998	10/09/1998	19/10/1998	Total
PET bottles (with lids):	10	10	10	10	10	10	10	70
PET bottles (with-out lids):	0	0	0	0	10	10	10	30
HDPE bottles (with lids):	10	10	8	10	10	10	9	67
Plastic shopping bags:	10	10	10	10	10	10	10	70
Plastic straws:	10	10	10	20	25	5	10	90
Plastic food wrapping/packets:	0	0	10	10	10	10	10	50
Plastic drink cup lids:	0	0	10	10	10	6	0	36
Aluminium cans:	10	10	10	10	10	10	9	69
Food wrapping (Foil lined):	10	0	10	10	10	6	10	56
Paper drink cartons (Waxed):	10	10	10	10	10	10	10	70
Paper drink cups (Waxed):	0	10	10	0	10	6	10	46
Poly-Styrene pieces:	10	10	10	10	20	20	10	90
TOTALS:	**80**	**80**	**108**	**110**	**145**	**113**	**108**	**744**

	NUMBER OF TAGGED LITTER ITEMS RECOVERED FROM ILLS & REMOVAL EFFICIENCIES BY PUMP-OUT																	
	PO-1	RE	PO-2	RE	PO-3	RE	PO-4	RE	PO-5	RE	PO-6	RE	PO-7	PO-8	RE		TRE	
SAMPLE LITTER ITEMS	18/03/1998	(%)	30/04/1998	(%)	11/06/1998	(%)	16/07/1998	(%)	02/09/1998	(%)	30/09/1998	(%)	17/11/1998	08/06/1999	(%)	PITS	(%)	STDVP
PET bottles (with lids):	10	100%	10	100%	10	100%	10	100%	8	80%	8	80%	11	0	110%	0	96%	0.10
PET bottles (with-out lids):	0	N/A	0	N/A	0	N/A	0	N/A	7	70%	7	70%	8	2	100%	0	80%	0.14
HDPE bottles (with lids):	10	100%	5	50%	8	100%	10	100%	9	90%	7	70%	8	1	100%	0	87%	0.18
Plastic shopping bags:	0	0%	1	10%	2	20%	5	50%	7	70%	3	30%	1	0	10%	0	27%	0.23
Plastic straws:	0	0%	0	0%	0	0%	0	0%	2	8%	1	20%	0	0	0%	0	3%	0.07
Plastic food wrapping/packets:	0	N/A	0	N/A	1	10%	5	50%	2	20%	3	30%	3	0	30%	0	28%	0.13
Plastic drink cup lids:	0	N/A	0	N/A	2	20%	1	10%	3	30%	2	33%	3	0	N/A	0	31%	0.09
Aluminium cans:	9	90%	10	100%	7	70%	6	60%	8	80%	6	60%	6	2	89%	0	78%	0.14
Food wrapping (Foil lined):	1	10%	0	N/A	3	30%	3	30%	6	60%	0	0%	5	0	50%	0	32%	0.21
Paper drink cartons (Waxed):	8	80%	8	80%	8	80%	10	100%	9	90%	6	60%	12	0	120%	0	87%	0.17
Paper drink cups (Waxed):	0	N/A	8	80%	0	0%	0	N/A	9	90%	2	33%	8	0	80%	0	59%	0.35
Poly-Styrene pieces:	10	100%	9	90%	10	100%	10	100%	14	70%	16	80%	10	1	110%	0	89%	0.13
	48	**60%**	**51**	**64%**	**51**	**48%**	**60**	**60%**	**84**	**58%**	**61**	**44%**	**75**	**6**	**73%**	**0**		

LEGEND:

PO-# Denotes ILLS prototype pump-out (clean-out) number
RE: Denotes litter item Removal (capture) Efficiency for that period/pump-out (%).
TRE: Denotes Total Removal (capture) Efficiency per litter item for entire study period (%).
PITS: Denotes items retrieved from catchment pits at end of study
STDVP: Denotes Standard Deviation ('n' biased method).

Table App C.7 O'Grady Street. Capture Efficiencies for Sample Litter Items.

Initial pump-out (clean-out): 11/2/1998

	NUMBER OF TAGGED LITTER ITEMS INTRODUCED INTO ILLS CATCHMENT PITS						NUMBER OF TAGGED LITTER ITEMS RECOVERED FROM ILLS & REMOVAL EFFICIENCIES BY PUMP-OUT														
	1st Drop:	2nd Drop:	3rd Drop:	4th Drop:	5th Drop:	Drop	PO-1 #	RE	PO-2	RE	PO-3	RE	PO-4	RE	PO-5	PO-6	RE		TRE	
SAMPLE LITTER ITEM	13/02/1998	27/03/1998	22/06/1998	06/08/1998	02/10/1998	Total	16/03/1998	(%)	03/06/1998	(%)	29/07/1998	(%)	08/09/1998	(%)	27/10/1998	08/06/1999	(%)	PITS	(%)	STDVP
PET bottles (with lids):	10	10	10	10	10	50	10	100%	7	70%	9	90%	3	30%	17	0	170%	0	92%	0.46
PET bottles (with-out lids):	0	0	0	10	10	20	0	N/A	0	N/A	0	N/A	3	30%	14	0	140%	0	85%	0.55
HDPE bottles (with lids):	10	10	10	10	10	50	9	90%	8	80%	10	100%	3	30%	16	0	160%	0	92%	0.42
Plastic shopping bags:	10	10	10	10	10	50	0	0%	1	10%	3	30%	2	20%	6	0	60%	0	24%	0.21
Plastic straws:	10	10	0	0	10	30	1	10%	1	10%	0	N/A	0	N/A	0	0	0%	0	7%	0.05
Plastic food wrapping/packets:	10	0	0	10	0	20	1	10%	0	N/A	0	N/A	0	0%	0	0	N/A	0	5%	0.05
Plastic drink cup lids:	5	10	10	10	0	35	0	0%	2	20%	2	20%	5	50%	4	0	N/A	0	37%	0.18
Aluminium cans:	10	10	10	10	10	50	7	70%	8	80%	9	90%	2	20%	15	0	150%	0	82%	0.42
Food wrapping (Foil lined):	10	0	10	10	10	40	0	0%	0	N/A	1	10%	1	10%	4	0	40%	0	15%	0.15
Paper drink cartons (Waxed):	10	10	10	10	10	50	7	70%	9	90%	8	80%	4	40%	11	0	110%	0	78%	0.23
Paper drink cups (Waxed):	10	10	0	10	10	40	0	0%	6	60%	0	N/A	1	10%	4	0	40%	0	28%	0.24
Poly-Styrene pieces:	10	10	10	20	20	70	10	100%	6	60%	10	100%	5	25%	34	0	170%	0	93%	0.48
TOTALS:	**105**	**90**	**80**	**120**	**110**	**505**	**45**	**41%**	**48**	**53%**	**52**	**65%**	**29**	**24%**	**125**	**0**	**104%**	**0**		

Legend:

PO-# Denotes ILLS prototype pump-out (clean-out) number

RE: Denotes litter item Removal (capture) Efficiency for that period/pump-out (%).

TRE: Denotes Total Removal (capture) Efficiency per litter item for entire study period (%).

PITS: Denotes items retrieved from catchment pits at end of study

N/A: Denotes Not Applicable. No tagged litter items dropped in that period.

NOTE: # Pump-out #1 only includes surface materials, as sump was not pumped out.

STDVP: Denotes Standard Deviation ('n' biased method).

Table App C.8 Lonsdale Street. Capture Efficiencies for Sample Litter Items.

Initial pump-out (clean-out): 26/6/1998

	NUMBER OF TAGGED LITTER ITEMS INTRODUCED INTO ILLS CATCHMENT PITS				NUMBER OF TAGGED LITTER ITEMS RECOVERED FROM ILLS & REMOVAL EFFICIENCIES BY PUMP-OUT							
	1st Drop:	2nd Drop:	3rd Drop:	Drop	PO-1	RE	PO-2	PO-3	RE		TRE	
SAMPLE LITTER ITEMS	15/07/1998	20/08/1998	05/10/1998	Total	23/09/1998	(%)	06/11/1998	03/12/1998	(%)	PITS	(%)	STDVP
PET bottles (with lids):	5	10	10	25	9	60%	10	0	100%	0	76%	0.20
PET bottles (with-out lids):	0	10	10	20	10	100%	9	0	90%	0	95%	0.05
HDPE bottles (with lids):	10	10	10	30	10	50%	10	0	100%	0	67%	0.25
HDPE bottles (with-out lids):	10	10	7	27	2	10%	0	0	0%	0	7%	0.05
Plastic shopping bags:	10	10	10	30	8	40%	5	0	50%	0	43%	0.05
Plastic straws:	0	10	10	20	5	50%	1	0	10%	0	30%	0.20
Plastic food wrapping/packets:	0	10	0	10	6	60%	0	0	N/A	0	60%	0.00
Plastic drink cup lids:	0	10	10	20	7	70%	1	1	20%	0	45%	0.25
Aluminium cans:	10	10	10	30	10	50%	9	0	90%	0	63%	0.20
Food wrapping (Foil lined):	0	10	10	20	7	70%	0	0	0%	0	35%	0.35
Paper drink cartons (Waxed):	10	10	10	30	10	50%	9	0	90%	0	63%	0.20
Paper drink cups (Waxed):	9	10	10	29	8	42%	3	1	40%	0	41%	0.01
Poly-Styrene pieces:	10	20	20	50	19	63%	20	0	100%	0	78%	0.18
TOTALS:	**74**	**140**	**127**	**341**	**111**	**55%**	**77**	**2**	**58%**	**0**		

LEGEND:

PO-# Denotes ILLS prototype pump-out (clean) number

RE: Denotes litter item Removal (capture) Efficiency for that period/pump-out (%).

TRE: Denotes Total Removal (capture) Efficiency per litter item for study period (%).

PITS: Denotes items retrieved from catchment pits at end of study

N/A: Denotes Not Applicable. No tagged litter items dropped in that period.

STDVP: Denotes .Standard Deviation ('n' biased method).

Table App C.9 Williamson Street. Capture Efficiencies for Sample Litter Items.

Initial pump-out (clean-out): 7/7/1998

	NUMBER OF TAGGED LITTER ITEMS INTRODUCED INTO ILLS CATCHMENT PITS					NUMBER OF TAGGED LITTER ITEMS RECOVERED FROM ILLS & REMOVAL EFFICIENCIES BY PUMP-OUT										
	1st Drop:	2nd Drop:	3rd Drop:	4th Drop:	Drop	PO-1	RE	PO-2	RE	PO-3	RE	PO-4	RE		TRE	
SAMPLE LITTER ITEMS	07/07/1998	28/08/1998	25/09/1998	09/11/1998	Total	28/08/1998	(%)	25/09/1998	(%)	09/11/1998	(%)	01/12/1998	(%)	**PITS**	(%)	**STDVP**
PET bottles (with lids on):	10	10	10	10	40	8	80%	8	80%	11	110%	8	80%	5	100%	0.13
PET bottles (with-out lids on):	0	10	10	10	30	0	N/A	2	20%	0	0%	18	180%	2	71%	0.81
HDPE bottles (with lids on):	10	10	10	10	40	9	90%	7	70%	10	100%	7	70%	1	85%	0.13
HDPE bottles (with-out lids on):	0	10	0	8	18	0	N/A	1	10%	0	N/A	0	0%	0	6%	0.05
Plastic shopping bags:	10	10	0	10	30	1	10%	0	0%	0	N/A	1	10%	0	7%	0.05
Plastic drinking straws:	0	10	0	0	10	0	N/A	0	0%	0	N/A	0	N/A	0	0%	0.00
Plastic drink cup lids:	0	0	0	10	10	0	N/A	0	N/A	0	N/A	1	10%	1	11%	0.00
Aluminium cans:	10	10	10	10	40	1	10%	1	10%	2	20%	3	30%	5	20%	0.08
Food wrapping (Foil lined):	0	10	0	10	20	0	N/A	0	0%	0	N/A	0	0%	0	0%	0.00
Paper drink cartons (Waxed):	10	10	10	10	40	7	70%	7	70%	5	50%	7	70%	1	67%	0.09
Paper drink cups (Waxed):	0	0	0	10	10	0	N/A	0	N/A	0	N/A	0	0%	0	0%	0.00
Poly-Styrene pieces:	10	20	20	10	60	10	100%	16	80%	21	105%	9	90%	0	93%	0.10
TOTALS:	60	110	70	108	348	36	60%	42	34%	49	64%	54	49%	15		

LEGEND:

PO-# Dcnotes ILLS prototype pump-out (clean-out) number
RE: Denotes litter item Removal (capture) Efficiency for that period/pump-out (%).
TRE: Denotes Total Removal (capture) Efficiency per litter item for entire study period (%).
PITS: Denotes items retrieved from catchment pits at end of study
N/A: Denotes Not Applicable. No tagged litter items dropped in that period.
STDVP: Denotes .Standard Deviation ('n' biased method).

Table App C.10 Syringe total removal efficiency data for second phase of monitoring

DETERMINATION OF AVERAGE TOTAL REMOVAL EFFICIENCY OF SYRINGES FOR ALL CASE STUDIES

	NUMBER OF SYRINGES INTRODUCED INTO ILLS CATCHMENT PITS								NUMBER OF SYRINGES RECOVERED FROM ILLS BY PUMP-OUT										
	1st	2nd	3rd	4th	5th	6th	7th	Drop	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6	PO-7	PO-8		TRE	
CASE STUDY	Drop	Drop	Drop	Drop	Drop	Drop	Drop	Total									PITS	(%)	STDVP
Lygon St - Phase 2	10	10	10	N/A	N/A	N/A	N/A	30	7	9	4	N/A	N/A	N/A	N/A	N/A	0	67%	0.21
Youth Rd	10	10	10	10	10	10	10	70	1	5	3	10	7	3	13	0	0	60%	0.42
O'Grady St	10	10	10	10	10	N/A	N/A	50	4	4	6	5	12	0	N/A	N/A	0	62%	0.36
Lonsdale St	10	10	10	N/A	N/A	N/A	N/A	30	10	7	0	N/A	N/A	N/A	N/A	N/A	0	57%	0.42
Williamson St	10	10	10	10	N/A	N/A	N/A	40	3	2	4	1	N/A	N/A	N/A	N/A	0	25%	0.11
							TOTAL:	220									Ave TRE.	54%	

LEGEND: PO-# Denotes ILLS pump-out (clean-out) number

TRE: Denotes Total Removal (capture) Efficiency for entire study period (%).

PITS: Denotes items retrieved from catchment pits at end of study

N/A: Denotes Not Applicable in that period.

STDVP: Denotes .Standard Deviation ('n' biased method).

NOTE: 1. Refer to monitoring results earlier in this chapter for Drop and Pump-out dates.

2. All Syringes used are one (1) ml.

APPENDIX D DATA COLLECTION AND ANALYSIS RELATING TO ESTIMATED NUMBERS OF UNTAGGED STANDARD LITTER ITEMS FROM CATCHMENT AND SEDIMENT DEPTH AND MASS DATA FOR MONITORING PERIODS.

This Appendix presents the data tables that were used to record the following:

- Number of untagged (natural) sample litter items trapped in each prototype over entire study period (UTP) for each SLI;
- Estimated number of untagged standard litter items coming from respective catchments over entire study period (EUP) for each prototype and for each SLI based on results of item total removal efficiencies;
- Mass of gross pollutants and sediment (based on sediment depth data for some prototypes).

The data tables presented in this Appendix do not include the frequencies of litter items used to determine TRE's for each SLI, which are presented in Appendix C.

FIRST PHASE ILLS MONITORING AND PERFORMANCE EVALUATION

Prototype Case Study #1 – Damper Creek, Monash City Council

No monitoring undertaken.

Prototype Case Study #2 – Toombah Street, Monash City Council - Phase 1

No data collected for un-tagged (natural) standard litter items (UTSLI's).

Prototype Case Study #3 – Yuile Street, City of Boroondara

Please refer to Table App D.1.

Prototype Case Study #4 –Lygon Street, City of Melbourne - Phase 1

Please refer to Table App D.2.

Prototype Case Study #5 – Luck Street, Shire of Nillumbik

No monitoring undertaken.

SECOND PHASE ILLS MONITORING AND PERFORMANCE EVALUATION

Prototype Case Study #2 – Toombah Street, Monash City Council, Phase 2

No data collected for un-tagged (natural) standard litter items (UTSLI's).

Prototype Case Study #4 – Lygon Street, City of Melbourne - Phase 2 monitoring

Please refer to Table App D.3.

Prototype Case Study #6 – Broughton Street, Frankston City Council

No monitoring undertaken.

Prototype Case Study #7 – The Avenue, Kingston City Council

Testing corrupted.

Prototype Case Study #8 – Youth Road, Shire of Nillumbik

Please refer to Table App D.4.

Prototype Case Study #9 – O'Grady Street, Port Phillip City Council
Please refer to Table App D.5.

Prototype Case Study #10 – Lonsdale Street, City of Greater Dandenong
Please refer to Table App D.6.

Prototype Case Study #11 – Williamson Street, City of Greater Bendigo
Please refer to Table App D.7.

Syringe total removal efficiency data for second phase of monitoring
Please refer to Table App D.8.

Table App D.1 Yuile Street – Phase 1. Number of untagged standard litter items captured in ILLS prototype, total removal efficiencies and estimated number of untagged standard litter items from catchment over study period.

Initial pump-out (clean-out): 4/7/1997

	NUMBER OF UN-TAGGED LITTER ITEMS RECOVERED FROM ILLS BY PUMP-OUT						
	PO-1	PO-2	PO-3	PO-4			
SAMPLE LITTER ITEM	05/08/1997	12/09/1997	10/10/1997	12/11/1997	**UTP**	**TRE**	**EUP**
PET Bottles (with-out lids):	3	4	5	2	**14**	47%	30
HDPE Bottles (with-out lids):	1	1	2	1	**5**	17%	30
Plastic Shopping Bags:	3	6	3	3	**15**	7%	225
Plastic Straws:	0	3	0	0	**3**	0%	N/A
Plastic Food Wrapping/packets:	0	1	1	0	**2**	0%	N/A
Plastic Drink Cup Lids:	0	0	2	1	**3**	35%	9
Aluminium Cans:	7	4	8	3	**22**	53%	41
Food Wrapping (Foil lined):	0	1	0	2	**3**	0%	N/A
Paper Drink Cartons (Waxed):	3	6	0	1	**10**	47%	21
Paper Drink Cups (Waxed):	0	0	0	0	**0**	4%	0
Poly-Styrene pieces:	3	1	21	2	**27**	53%	51
TOTALS	**20**	**27**	**42**	**15**	**104**		407

LEGEND:

PO-# Denotes ILLS prototype pump-out (clean out) number

UTP Denotes number of untagged standard litter items trapped over entire study period per item

TRE Denotes Total Removal (capture) Efficiency data from tagged litter testing program (%)

EUP Denotes estimated number of untagged standard litter items coming from catchment over 4.25 month test period (=UTP/TRE)

N/A Not applicable, as TRE has null value.

Table App D.2 Lygon Street – Phase 1. Number of untagged standard litter items captured in ILLS prototype, total removal efficiencies and estimated number of untagged standard litter items from catchment over study period.

Initial pump-out (clean-out): 7/7/1997

	NUMBER OF UN-TAGGED STANDARD LITTER ITEMS RECOVERED FROM ILLS BY PUMP-OUT									
	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6	PO-7			
SAMPLE LITTER ITEM	06/08/1997	03/09/1997	08/10/1997	05/11/1997	03/12/1997	16/01/1998	10/03/1998	**UTP**	**TRE**	**EUP**
PET Bottles (with lids):	4	5	6	6	3	7	2	**33**	49%	68
PET Bottles (without lids):	4	2	2	3	2	4	1	**18**	34%	53
HDPE Bottles (with lids):	2	1	2	1	4	5	0	**15**	16%	94
HDPE Bottles (without lids):	1	0	1	1	2	2	0	**7**	8%	88
Plastic Shopping Bags:	3	1	5	5	9	4	1	**28**	42%	67
Plastic Straws:	0	1	0	0	5	84	7	**97**	15%	647
Plastic Food Wrapping/packets:	0	8	2	8	8	7	3	**36**	30%	120
Plastic Drink Cup Lids:	0	3	0	0	0	0	0	**3**	17%	18
Aluminium Cans:	2	9	9	8	14	15	10	**67**	50%	134
Food Wrapping (Foil lined):	0	0	0	4	0	0	2	**6**	35%	17
Paper Drink Cartons (Waxed):	4	0	1	1	0	0	0	**6**	48%	13
Paper Drink Cups (Waxed):	3	1	0	1	0	1	1	**7**	6%	119
Poly-Styrene Pieces:	3	8	7	12	15	11	9	**65**	62%	105
TOTALS	**26**	**39**	**35**	**50**	**62**	**140**	**36**	**388**		1541
TOTAL SUMP DEPTH OF GROSS POLLUTANTS & SEDIMENTS (mm)	**430**	**40**	**40**	**90**	**200**	**130**	**No Data**	**155**	**.= Average Depth (mm)**	
TOTAL MASS OF GROSS POLLUTANTS & SEDIMENTS (kg)	**2000**	**205**	**165**	**400**	**935**	**600**	**No Data**	**720**	**.= Average mass (kg)**	

LEGEND:

PO-#	Denotes ILLS prototype pump-out (clean out) number
UTP	Denotes number of untagged standard litter items trapped over entire study period per item
TRE	Denotes Total Removal (capture) Efficiency data from tagged litter testing program (%)
EUP	Denotes estimated number of untagged standard litter items coming from catchment over 8 month test period (=UTP/TRE)

Table App D.3 Lygon Street – Phase 2. Number of untagged standard litter items captured in ILLS prototype, total removal efficiencies and estimated number of untagged standard litter items from catchment over study period.

Initial pump-out (clean-out): 31/7/1998

	NUMBER OF UN-TAGGED STANDARD LITTER ITEMS RECOVERED FROM ILLS BY PUMP-OUT					
	PO-1	PO-2	PO-3			
SAMPLE LITTER ITEM	08/09/1998	13/10/1998	09/12/1998	UTP	TRE	EUP
PET Bottles (with lids):	5	6	#	**11**	93%	12
PET Bottles (without lids):	3	4	#	**7**	73%	10
HDPE Bottles (with lids):	0	1	#	**1**	74%	1
HDPE Bottles (without lids):	1	0	#	**1**	50%	2
Plastic Shopping Bags:	3	0	#	**3**	63%	5
Plastic Straws:	23	4	#	**27**	70%	39
Plastic Food Wrapping/Packets:	7	0	#	**7**	40%	18
Plastic Drink Cup Lids:	1	5	#	**6**	40%	15
Aluminium Cans:	1	11	#	**12**	77%	16
Food Wrapping (Foil lined):	8	27	#	**35**	70%	50
Paper Drink Cartons (Waxed):	3	1	#	**4**	93%	4
Paper Drink Cups (Waxed):	0	3	#	**3**	35%	9
Poly-Styrene pieces:	7	12	#	**19**	72%	26
TOTALS:	**62**	**74**	**0**	**136**		**207**

LEGEND:

PO-# Denotes ILLS prototype pump-out (clean out) number
UTP Denotes number of untagged standard litter items trapped over entire study period per item
TRE Denotes Total Removal (capture) Efficiency data from tagged litter testing program (%)
EUP Denotes estimated number of untagged standard litter items coming from catchment over 4.25 month test period
\# Denotes No data collected.

Table App D.4 Youth Road. Number of untagged standard litter items captured in ILLS prototype, total removal efficiencies and estimated number of untagged standard litter items from catchment over study period.

Initial pump-out (clean-out): 11/2/1998

	NUMBER OF UN-TAGGED STANDARD LITTER ITEMS RECOVERED FROM ILLS BY PUMP-OUT										
	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6	PO-7	PO-8			
SAMPLE LITTER ITEM	18/03/1998	30/04/1998	11/06/1998	16/07/1998	02/09/1998	30/09/1998	17/11/1998	08/06/1999	**UTP**	**TRE**	**EUP**
PET bottles (with lids):	13	9	10	4	3	7	9	24	79	96%	83
PET bottles (with-out lids):	4	2	4	2	2	0	4	19	37	80%	46
HDPE bottles (with lids):	0	1	3	1	3	2	4	5	19	87%	22
Plastic shopping bags:	0	6	3	0	0	4	2	4	19	27%	70
Plastic straws:	7	0	7	17	8	6	7	7	59	3%	1770
Plastic food wrapping/packets:	23	9	6	29	40	6	66	23	202	28%	721
Plastic drink cup lids:	1	2	2	5	0	1	2	2	15	31%	49
Aluminium cans:	3	1	3	0	0	3	14	17	41	78%	52
Food wrapping (Foil lined):	5	4	0	11	0	2	20	25	67	32%	208
Paper drink cartons (Waxed):	1	2	4	2	3	2	6	4	24	87%	28
Paper drink cups (Waxed):	0	3	1	4	0	2	3	3	16	59%	27
Poly-Styrene pieces:	7	6	0	4	3	10	7	29	66	89%	74
TOTALS	64	45	43	79	62	45	144	162	644		3150
TOTAL SUMP DEPTH OF GROSS POLLUTANTS & SEDIMENTS (mm)	**160**	**100**	**150**	**140**	**110**	**150**	**200**	No data	145	.= Average depth (mm)	
TOTAL MASS OF GROSS POLLUTANTS & SEDIMENTS (kg)	750	500	700	650	550	700	900	No data	680	.= Average mass (kg)	

LEGEND:

PO-# Denotes ILLS prototype pump-out (clean out) number
UTP Denotes number of untagged standard litter items trapped over entire study period per item
TRE Denotes Total Removal (capture) Efficiency data from tagged litter testing program (%)
EUP Denotes estimated number of untagged standard litter items coming from catchment over 16 month test period (=UTP/TRE)

Table App D.5 O'Grady Street. Number of untagged standard litter items captured in ILLS prototype, total removal efficiencies and estimated number of untagged standard litter items from catchment over study period.

Initial pump-out (clean-out): 4/2/1998

	NUMBER OF UN-TAGGED STANDARD LITTER ITEMS RECOVERED FROM ILLS BY PUMP-OUT								
	PO-1 #	PO-2	PO-3	PO-4	PO-5	PO-6			
SAMPLE LITTER ITEMS	16/03/1998	03/06/1998	29/07/1998	08/09/1998	27/10/1998	08/06/1999	UTP	TRE	EUP
PET bottles (with lids):	6	2	4	0	5	5	22	92%	24
PET bottles (with-out lids):	0	4	0	0	1	5	10	85%	12
HDPE bottles (with lids):	3	1	0	0	0	1	5	92%	5
Plastic shopping bags:	2	0	8	1	5	1	17	24%	71
Plastic straws:	11	2	2	3	1	0	19	7%	285
Plastic food wrapping/packets:	5	5	12	3	14	5	44	5%	880
Plastic drink cup lids:	0	2	0	1	3	3	9	37%	24
Aluminium cans:	2	12	2	0	6	4	26	82%	32
Food wrapping (Foil lined):	2	5	7	0	12	5	31	15%	207
Paper drink cartons (Waxed):	0	1	3	0	2	1	7	78%	9
Paper drink cups (Waxed):	0	0	2	0	3	0	5	28%	18
Poly-Styrene pieces:	23	39	60	2	20	24	168	93%	181
TOTALS:	**54**	**73**	**100**	**10**	**72**	**54**	**363**		**1748**
TOTAL SUMP DEPTH OF GROSS POLLUTANTS & SEDIMENTS (mm)	**N/A**	**210**	**300**	**210**	**320**	**N/A**	**260**	**.= Average depth (mm)**	
TOTAL MASS OF GROSS POLLUTANTS & SEDIMENTS (kg)	**N/A**	**1200**	**3000**	**3000**	**4400**	**N/A**	**2900**	**.= Average mass (kg)**	

LEGEND:

PO-# Denotes ILLS prototype pump-out (clean out) number

UTP Denotes number of untagged standard litter items trapped over entire study period per item

TRE Denotes Total Removal (capture) Efficiency data from tagged litter testing program (%)

EUP Denotes estimated number of untagged standard litter items coming from catchment over 5.25 month test period (=UTP/TRE)

NOTE: # Pump-out #1 only includes surface materials, as sump was not pumped out.

Table App D.6 Lonsdale Street. Number of untagged standard litter items captured in ILLS prototype, total removal efficiencies and estimated number of untagged standard litter items from catchment over study period.

Initial pump-out (clean-out): 26/6/1998

	NUMBER OF UN-TAGGED STANDARD LITTER ITEMS RECOVERED FROM ILLS BY PUMP-OUT					
	PO-1	PO-2	PO-3			
SAMPLE LITTER ITEM	23/09/1998	06/11/1998	03/12/1998	**UTP**	**TRE**	**EUP**
PET bottles (with lids):	14	16	0	**30**	76%	39
PET bottles (with-out lids):	5	6	0	**11**	95%	12
HDPE bottles (with lids):	1	2	0	**3**	67%	5
HDPE bottles (with-out lids):	2	0	0	**2**	7%	27
Plastic shopping bags:	5	4	0	**9**	43%	21
Plastic straws:	5	5	0	**10**	30%	33
Plastic food wrapping/packets:	95	34	0	**129**	60%	215
Plastic drink cup lids:	2	8	1	**11**	45%	24
Aluminium cans:	24	7	0	**31**	63%	49
Food wrapping (Foil lined):	21	18	0	**39**	35%	111
Paper drink cartons (Waxed):	7	2	0	**9**	63%	14
Paper drink cups (Waxed):	5	13	1	**19**	41%	46
Poly-Styrene pieces:	16	18	0	**34**	78%	44
TOTALS	**202**	**133**	**2**	**337**		**640**
TOTAL SUMP DEPTH OF GROSS POLLUTANTS & SEDIMENTS (mm)	**N/A**	**210**	**300**	**255**	**.= Average depth (mm)**	
TOTAL MASS OF GROSS POLLUTANTS & SEDIMENTS (kg)	**N/A**	**1200**	**3000**	**2100**	**.= Average mass (kg)**	

LEGEND:

PO-#	Denotes ILLS prototype pump-out (clean out) number
UTP	Denotes number of untagged standard litter items trapped over entire study period per item
TRE	Denotes Total Removal (capture) Efficiency data from tagged litter testing program (%)
EUP	Denotes estimated number of untagged SLI's from catchment over 5.25 month test period (=UTP/TRE)

Table App D.7 Williamson Street. Number of untagged standard litter items captured in ILLS prototype, total removal efficiencies and estimated number of untagged standard litter items from catchment over study period.

Initial pump-out (clean-out): 7/7/1998

	NUMBER OF UN-TAGGED (NATURAL) STANDARD LITTER ITEMS RECOVERED FROM ILLS BY PUMP-OUT (UTSLI)						
	PO-1	PO-2	PO-3	PO-4			
SAMPLE LITTER ITEMS	28/08/1998	25/09/1998	09/11/1998	01/12/1998	UTP	TRE	EUP
PET bottles (with lids on):	13	10	11	5	39	100%	39
PET bottles (with-out lids on):	1	3	5	3	12	71%	17
HDPE bottles (with lids on):	2	3	2	0	7	85%	8
HDPE bottles (with-out lids on):	0	0	0	0	0	6%	0
Plastic shopping bags:	7	2	0	1	10	7%	150
Plastic drinking straws:	3	4	7	0	14	0%	N/A
Plastic drink cup lids:	1	0	2	1	4	11%	36
Aluminium cans:	13	3	7	7	30	20%	150
Food wrapping (Foil lined):	8	0	5	0	13	0%	N/A
Paper drink cartons (Waxed):	0	2	4	1	7	67%	11
Paper drink cups (Waxed):	1	3	2	0	6	0%	N/A
Poly-Styrene pieces:	0	9	19	4	32	93%	34
TOTALS :	**49**	**39**	**64**	**22**	**174**		**445**

LEGEND:

PO-# Denotes ILLS prototype pump-out (clean out) number

UTP Denotes number of untagged standard litter items trapped over entire study period per item

TRE Denotes Total Removal (capture) Efficiency data from tagged litter testing program (%)

EUP Denotes estimated number of untagged standard litter items coming from catchment over 5 month test period (=UTP/TRE)

N/A Not applicable, as T.R.E. has null value.

Table App D.8 Number of untagged syringes captured in ILLS prototypes over study period.

	NUMBER OF SYRINGES RECOVERED FROM ILLS BY PUMP-OUT								
CASE STUDY	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6	PO-7	PO-8	**TOTAL**
Lygon St - Phase 2	0	0	0	N/A	N/A	N/A	N/A	N/A	**0**
Youth Rd	1	0	0	0	0	1	1	0	**3**
O'Grady St	0	0	0	0	0	0	N/A	N/A	**0**
Lonsdale St	12	1	0	N/A	N/A	N/A	N/A	N/A	**13**
Williamson St	0	0	1	0	N/A	N/A	N/A	N/A	**1**
								TOTAL	**17**

LEGEND:

PO-# Denotes ILLS prototype pump-out (clean out) number

N/A: Denotes Not Applicable in that period.

NOTE: Refer to monitoring results earlier in this chapter for pump-out dates.

APPENDIX E RAINFALL DATA

Rainfall data presented in this Appendix is analysed mostly from 6 minute data.

Prototype Case Study #1 – Damper Creek, Monash City Council
No monitoring undertaken.

Prototype Case Study #2 – Toombah Street, Monash City Council
Melbourne Water Corporation Notting Hill rain gauge station
Phase 1 monitoring rainfall data
RAINFALL DATA BETWEEN TAGGED LITTER DROPS AND PUMP-OUTS

Pump out:	1	2	3	4	5
Dates:	27-6-97 to 16-7-97	23-7-97 to 7-8-97	2-9-97 to 22-9-97	8-10-97 to 17-10-97	17-10-97 to 4-12-97
Rainfall Max (mm/6mins)	1.2	0.2	3.6	1.0	4.6
Rainfall Sum (mm)	14.8	4.6	39.4	9.6	96.8
Count blank (no data)	0	0	0	0	46
Count total (excl. blanks)	4560	3601	4801	2161	11475
Count total (incl. blanks)	4560	3601	4801	2161	11521

Phase 2 monitoring rainfall data
RAINFALL DATA BETWEEN TAGGED LITTER DROPS AND PUMP-OUTS

Pump out:	1	2	3
Dates:	25-8-98 to 28-9-98	13-10-98 to 29-10-98	29-10-98 to 26-11-98
Rainfall Max (mm/6mins)	1.4	2.4	1.4
Rainfall Sum (mm)	53.8	34.6	68.2
Count blank (no data)	2	1	0
Count total (excl. blanks)	8159	3840	6721
Count total (incl. blanks)	8161	3841	6721

Notes:
1. Rainfall for third pump-out includes all rainfall between second and third pump-outs, as there was no tagged litter drop between these two pump-outs.

Prototype Case Study #3 – Yuile Street, City of Boroondara
Melbourne Water Corporation Ashwood rain gauge station
RAINFALL DATA BETWEEN TAGGED LITTER DROPS AND PUMP-OUTS

Pump out:	1	2	3	4
Dates:	4-7-97 to 5-8-97	5-8-97 to 12-9-97	12-9-97 to 10-10-97	16-10-97 to 12-11-97
Rainfall Max (mm/6mins)	0.8	6.6	1.4	6.4
Rainfall Sum (mm)	20.0	85.5	29.2	78.2
Count blank (no data)	0	0	0	0
Count total (excl. blanks)	7681	9121	6721	6481
Count total (incl. blanks)	7681	9121	6721	6481

RAINFALL DATA BETWEEN PUMP-OUTS

Pump out:	1	2	3	4
Dates:	4-7-97 to 5-8-97	5-8-97 to 12-9-97	12-9-97 to 10-10-97	10-10-97 to 12-11-97
Rainfall Max (mm/6mins)	0.8	6.6	1.4	6.4
Rainfall Sum (mm)	20.0	85.5	29.2	80.2
Count blank (no data)	0	0	0	0
Count total (excl. blanks)	7681	9121	6721	7921
Count total (incl. blanks)	7681	9121	6721	7921

Prototype Case Study #4 –Lygon Street, City of Melbourne
Melbourne Water Corporation North Wharf rain gauge station

Phase 1 monitoring rainfall data

RAINFALL DATA BETWEEN TAGGED LITTER DROPS AND PUMP-OUTS

Pump out:	1	2	3	4	5	6	7
Dates:	16-7-97 to 6-8-97	6-8-97 to 3-9-97	30-9-97 to 8-10-97	8-10-97 to 5-11-97	18-11-97 to 3-12-97	23-12-97 to 16-1-98	2-2-98 to 10-3-98
Rainfall Max (mm/6mins)	0.4	4.2	0.8	1.2	1.0	1.6	2.8
Rainfall Sum (mm)	4.2	42.2	2.6	34.6	5.8	7.0	63.6
Count blank (no data)	0.0	0.0	0.0	0.0	5.0	0.0	0.0
Count total (excl. blanks)	5041	6721	1921	6721	3596	5761	8641
Count total (incl. blanks)	5041	6721	1921	6721	3601	5761	8641

RAINFALL DATA BETWEEN PUMP-OUTS

Pump out:	1	2	3	4	5	6	7
Dates:	7-7-97 to 6-8-97	6-8-97 to 3-9-97	3-9-97 to 8-10-97	8-10-97 to 5-11-97	5-11-97 to 3-12-97	3-12-97 to 16-1-98	16-1-98 to 10-3-98
Rainfall Max (mm/6mins)	0.4	4.2	1.8	1.2	4.8	1.6	6.8
Rainfall Sum (mm)	10.0	42.2	43.2	34.6	44.8	12.4	146.8
Count blank (no data)	0.0	0.0	0.0	0.0	5.0	0.0	0.0
Count total (excl. blanks)	7201	6721	8401	6721	6716	10561	12721
Count total (incl. blanks)	7201	6721	8401	6721	6721	10561	12721

Phase 2 monitoring rainfall data

RAINFALL DATA BETWEEN TAGGED LITTER DROPS AND PUMP-OUTS

Pump out:	1	2	3
Dates:	14-8-98 to 8-9-98	22-9-98 to 13-10-98	28-10-98 to 9-12-98
Rainfall Max (mm/6mins)	0.4	1.8	2.4
Rainfall Sum (mm)	6.4	59.4	62.0
Count blank (no data)	0	0	1953
Count total (excl. blanks)	6001	5041	8128
Count total (incl. blanks)	6001	5041	10081

RAINFALL DATA BETWEEN PUMP-OUTS

Pump out:	1	2	3
Dates:	31-7-98 to 8-9-98	8-9-98 to 13-10-98	13-10-98 to 9-12-98
Rainfall Max (mm/6mins)	0.6	2.0	2.8
Rainfall Sum (mm)	25.0	81.2	78.8
Count blank (no data)	0	0	1953
Count total (excl. blanks)	9361	8401	11728
Count total (incl. blanks)	9361	8401	13681

Prototype Case Study #5 – Luck Street, Shire of Nillumbik

No monitoring undertaken.

Prototype Case Study #6 – Broughton Street, Frankston City Council

No monitoring undertaken.

Prototype Case Study #7 – The Avenue, Kingston City Council

No monitoring undertaken.

Prototype Case Study #8 – Youth Street, Shire of Nillumbik

Melbourne Water Corporation Lower Plenty rain gauge station

RAINFALL DATA BETWEEN TAGGED LITTER DROPS AND PUMP-OUTS

Pump out:	1	2	3	4	5	6	7	8
Dates:	15-2-98 to 18-3-98	26-3-98 to 30-4-98	11-5-98 to 11-6-98	14-6-98 to 16-7-98	6-8-98 to 2-9-98	10-9-98 to 30-9-98	19-10-98 to 17-11-98	17-11-98 to 8-6-99
Rainfall Max (mm/6mins)	3.4	5.8	3.6	1.4	0.4	2.0	17.0	11.2
Rainfall Sum (mm)	48.0	59.4	106.0	66.4	18.6	44.0	79.2	410.6
Count blank (no data)	139	146	11	7	10	35	229	361
Count total (excl. blanks)	7062	8255	7430	7674	6472	4766	6732	46150
Count total (incl. blanks)	7201	8401	7441	7681	6482	4801	6961	46511

RAINFALL DATA BETWEEN PUMP-OUTS

Pump out:	1	2	3	4	5	6	7	8
Dates:	11-2-98 to 18-3-98	18-3-98 to 30-4-98	30-4-98 to 11-6-98	11-6-98 to 16-7-98	16-7-98 to 2-9-98	2-9-98 to 30-9-98	30-9-98 to 17-11-98	17-11-98 to 8-6-99
Rainfall Max (mm/6mins)	3.4	5.8	3.6	1.4	1.0	2.0	17.0	11.2
Rainfall Sum (mm)	48.0	64.4	111.8	67.2	41.6	50.2	123.6	410.6
Count blank (no data)	139	147	54	7	88	35	519	361
Count total (excl. blanks)	8112	10174	10026	8394	11434	6686	11002	46150
Count total (incl. blanks)	8251	10321	10080	8401	11522	6721	11521	46511

Prototype Case Study #9 – O'Grady Street, Port Phillip City Council

Melbourne Water Corporation St Kilda Marina rain gauge station

RAINFALL DATA BETWEEN TAGGED LITTER DROPS AND PUMP-OUTS

Pump out:	1	2	3	4	5	6
Dates:	13-2-98 to 16-3-98	27-3-98 to 3-6-98	22-6-98 to 29-7-98	6-8-98 to 8-9-98	2-10-98 to 27-10-98	27-10-98 to 8-6-99
Rainfall Max (mm/6mins)	5.2	2.8	1.4	0.6	2.6	8.4
Rainfall Sum (mm)	58.0	106.0	51.0	23.4	69.2	352.8
Count blank (no data)	8	142	8	0	281	851
Count total (excl. blanks)	7433	16179	8873	7921	5720	53061
Count total (incl. blanks)	7441	16321	8881	7921	6001	53912

RAINFALL DATA BETWEEN PUMP-OUTS

Pump out:	1	2	3	4	5	6
Dates:	4-2-98 to 16-3-98	16-3-98 to 3-6-98	3-6-98 to 29-7-98	29-7-98 to 8-9-98	8-9-98 to 27-10-98	27-10-98 to 8-6-99
Rainfall Max (mm/6mins)	5.2	2.8	1.8	0.6	2.6	8.4
Rainfall Sum (mm)	78.6	110.2	100.4	33.4	98.4	352.8
Count blank (no data)	20	303	27	11	327	860
Count total (excl. blanks)	9581	18669	13424	9840	11444	53061
Count total (incl. blanks)	9601	18972	13451	9851	11771	53921

Prototype Case Study #10 – Lonsdale Street, City of Greater Dandenong

Melbourne Water Corporation Greens Road (Keysborough) rain gauge station

RAINFALL DATA BETWEEN TAGGED LITTER DROPS AND PUMP-OUTS

Pump out:	1	2	3
Dates:	15-7-98 to 23-9-98	5-10-98 to 6-11-98	6-11-98 to 3-12-98
Rainfall Max (mm/6mins)	3.0	3.0	5.2
Rainfall Sum (mm)	73.6	71.4	65.4
Count blank (no data)	0.0	0.0	0.0
Count total (excl. blanks)	16800.0	7680.0	6480.0
Count total (incl. blanks)	16800	7680	6480

RAINFALL DATA BETWEEN PUMP-OUTS

Pump out:	1	2	3
Dates:	26-6-98 to 23-9-98	23-9-98 to 6-11-98	6-11-98 to 3-12-98
Rainfall Max (mm/6mins)	3.0	3.0	5.2
Rainfall Sum (mm)	97.6	95.4	65.4
Count blank (no data)	0.0	0.0	0.0
Count total (excl. blanks)	20249.0	10560.0	6480.0
Count total (incl. blanks)	20249	10560	6480

Prototype Case Study #11 – Williamson Street, City of Greater Bendigo
Bureau of Meteorology Bendigo rain gauge station

RAINFALL DATA BETWEEN TAGGED LITTER DROPS AND PUMP-OUTS

Pump out:	**1**	**2**	**3**	**4**
Dates:	7-7-97 to 28-8-97	28-8-97 to 25-9-97	25-9-97 to 9-11-97	9-11-97 to 1-12-97
Rainfall Max (mm/24hrs)	13	12.6	15.6	39.8
Rainfall Sum (mm)	66.8	48.8	52	76.6
Count blank (no data)	0	0	0	0
Count total (excl. blanks)	53	28	45	22
Count total (incl. blanks)	53	28	45	22

Note: Only 24 hour rainfall data available.

APPENDIX F NON-STANDARD LITTER ITEMS RETRIEVED FROM ALL CLEAN-OUTS OF YOUTH STREET ILLS PROTOTYPE

The data presented in this Appendix was obtained during a full analysis of all clean-outs for the Youth Street ILLS prototype. The data consists of all litter items outside of the standard litter item categories used in the tagged litter study, ie. non-standard litter items (NSLIs). For each clean-out surface NSLIs were netted off to allow a sort of both the surface and sump NSLIs.

CLEAN-OUT #1 (18th March 1998)

Surface/ floating NSLIs
1*1ml syringe
6*PET bottle tops/lids
2*corks
1*child's toy
1*Foam rubber
1*lip sunscreen tube
2*corks
6*cigarette wrappers
1*cigarette carton
TOTAL floating NSLIs = 21

+ 20*cigarette butts

Sump NSLIs
1*yo-yo
6*Aluminium foil pieces
TOTAL sump NSLIs = 7

CLEAN-OUT #2 (30th April 1998)

Surface/ floating NSLIs
1*small plastic sheet
2*plastic cigarette carton wrapper
1*cigarette carton (empty)
1*cigarette lighter (empty)
1*Tennis ball
1*sauce satchel
2*chup chup sticks
1*plastic cricket ball
1*rubber ball
1*rubber foam
2*pen caps
5*cigarette wrappers
1*cigarette carton
1*cigarette lighter
TOTAL floating NSLIs = 21

+ 96 cigarette butts

Sump NSLIs
1*empty yoghurt container
19*plastic sheets (large)
2*plastic sheets (small)
1*plastic cutlery
1*plastic (LDPE) bottle lid (for HDPE bottle)
1*plastic bottle top (pull top)
2*plastic (PET) bottle lids
2*brown polar cups
6*Aluminium foil pieces
TOTAL sump NSLIs = 35

CLEAN-OUT #3 (11th June 1998)

Surface/ floating NSLIs
5*plastic sheets (small)
1*plastic (PET) bottle lid
2*Aluminium foil pieces
1*cigarette carton (empty)
1*plastic food container
2*lip sunscreen tube
1*Biro
1*sauce satchel
2*chup chup sticks
1*plastic bubble wrap (100mm*100mm)
1*roll-on deodorant (empty)
1*light bulb
3*odd hard plastic items
TOTAL floating NSLIs = 22

Sump NSLIs
2*plastic sheets (large)
22*plastic sheets (small)
2*plastic cigarette packet wrappers
1*plastic cutlery
34*Aluminium foil pieces (small)
3*Aluminium foil pieces (large)
1*metal screw top lid for drink bottle
2*chup chup sticks
7*odd hard plastic items
TOTAL sump NSLIs = 75

CLEAN-OUT #4 (16th July 1998)

Surface/ floating NSLIs
4*plastic sheets (large)
5*plastic sheets (small)
1*plastic bubble wrap
1*1ml syringe packet
2*plastic (LDPE) bottle lid (for HDPE bottle)
6*plastic (PET) bottle lids

3*plastic wrapper for cigarette carton
1*cigarette carton (empty)
1*hair tie
5*odd hard plastic items
1*rubber balloon
15*chup chup sticks
4*plastic lid for polystyrene cup
1*foam rubber
1*plastic dummy
1*ice cream stick
1*tic-tac container
TOTAL floating NSLIs = 53

Sump NSLIs
5*plastic sheets (large)
6*plastic sheets (small)
5*plastic wrapper for cigarette carton
42*Aluminium foil pieces (small)
1*Biro
1*chup chup sticks
1*plastic 'six pack' holder
2*plastic straps
7*odd hard plastic items
TOTAL sump NSLIs = 70

CLEAN-OUT #5 (2nd September 1998)
Surface/floating NSLIs
1*plastic sheets (large)
4*plastic sheets (small)
1*plastic bubble wrap
1*plastic (LDPE) bottle lid (for HDPE bottle)
1*brown polar cups
4*plastic wrapper for cigarette carton
4*plastic (PET) bottle lids
1*plastic strap
1*Aluminium foil pieces (small)
1*beer keg top
1*food container
1*sauce satchel
5*chup chup sticks
1*cotton bud stick
TOTAL floating NSLIs = 27

Sump NSLIs
1*plastic sheets (large)
19*plastic wrapper for cigarette carton
33*Aluminium foil pieces (small)
2*food container
1*plastic lid for polystyrene cup
TOTAL sump NSLIs = 56

CLEAN-OUT #6 (30th September 1998)
Surface/ floating NSLIs
2*cigarette carton (empty)
2*plastic wrapper for cigarette carton
1*plastic (PET) bottle lids
2*Aluminium foil pieces (small)
3*plastic food container
1*plastic food container lid
2*sauce satchel
1*chup chup sticks
1*biro
1*watch band
TOTAL floating NSLIs = 16

Sump NSLIs
4*plastic sheets (large)
3*plastic wrapper for cigarette carton
2*Aluminium foil pieces (small)
TOTAL sump NSLIs = 9

CLEAN-OUTS #7 & #8 (17th November 1998 & 8th June 1999 respectively)
No data.

APPENDIX G DATA TABLES FOR ADDITIONAL ANALYSIS OF YOUTH ROAD ILLS PROTOTYPE

This Appendix presents data recorded to determine the number of tagged and untagged sample litter item used in the study to determine the proportion floating on the ILLS surface.

Table App G.1 and App G.2 refer to the number of tagged sample litter items retrieved from the Youth Road ILLS prototype surface and sump respectively for each sample litter items by pump-out.

Table App G.3 and App G.4 refer to the number of untagged sample litter items retrieved from the Youth Road ILLS prototype surface and sump respectively for each sample litter items by pump-out.

Table App G.1 Youth Road - Number of untagged sample litter items retrieved from ILLS surface for each sample litter items by pump-out.

	NUMBER OF TAGGED SAMPLE LITTER ITEMS RECOVERED FROM ILLS SURFACE BY PUMP-OUT							
	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6	PO-7	
SAMPLE LITTER ITEM	18/03/1998	30/04/1998	11/06/1998	16/07/1998	02/09/1998	30/09/1998	17/11/1998	**TOTAL**
PET bottles (with lids):	10	10	10	10	8	8	11	**67**
PET bottles (with-out lids):	0	0	0	0	7	6	7	**20**
HDPE bottles (with lids):	8	6	8	10	9	7	8	**56**
Plastic shopping bags:	0	1	1	4	5	1	1	**13**
# 'Plastic straws:	*0*	*0*	*0*	*0*	*1*	*0*	*0*	***1***
# 'Plastic food wrapping and packets:	*0*	*0*	*0*	*0*	*0*	*0*	*0*	***0***
# 'Plastic drink cup lids:	*0*	*0*	*0*	*0*	*0*	*0*	*0*	***0***
Aluminium cans:	1	1	1	2	5	0	3	**13**
# Food wrapping and packets (Foil lined):	*0*	*0*	*0*	*0*	*3*	*0*	*0*	***3***
Paper drink cartons (Waxed):	7	3	8	9	8	5	11	**51**
Paper drink cups (Waxed):	0	0	0	0	0	0	0	**0**
Poly-Styrene pieces:	10	9	10	10	14	16	10	79
Total All items:	**36**	**30**	**38**	**45**	**60**	**43**	**51**	**303**
Total (Target items):	**36**	**30**	**38**	**45**	**56**	**43**	**51**	**299**

NOTES:

1. Those items shown above in *Italics* denoted with a (#) are non-positive capture litter item which are only included for information.

Table App G.3 Youth Road - Number of untagged sample litter items retrieved from ILLS surface for each sample litter items by pump-out.

	NUMBER OF UNTAGGED SAMPLE LITTER ITEMS RETREIVED FROM ILLS SURFACE BY PUMP-OUT							
	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6	PO-7	
SAMPLE LITTER ITEM	18/03/1998	30/04/1998	11/06/1998	16/07/1998	02/09/1998	30/09/1998	17/11/1998	**TOTAL**
PET bottles (with lids):	13	9	10	6	3	7	9	**57**
PET bottles (with-out lids):	4	1	2	1	2	0	0	**10**
HDPE bottles (with lids):	0	1	3	1	3	2	4	**14**
Plastic shopping bags:	0	0	3	0	0	0	1	**4**
# *'Plastic straws:*	*7*	*0*	*3*	*16*	*7*	*6*	*5*	***44***
# *'Plastic food wrapping and packets:*	*15*	*2*	*3*	*20*	*5*	*5*	*9*	***59***
# *'Plastic drink cup lids:*	*0*	*0*	*0*	*1*	*0*	*0*	*0*	***1***
Aluminium cans:	1	0	0	0	0	0	4	**5**
# *Food wrapping and packets (Foil lined):*	*1*	*1*	*0*	*2*	*0*	*2*	*3*	***9***
Paper drink cartons (Waxed):	1	2	1	2	3	1	3	**13**
Paper drink cups (Waxed):	0	0	1	1	0	0	0	**2**
Poly-Styrene pieces:	4	10	1	4	3	10	7	**39**
Total All items:	**46**	**26**	**27**	**54**	**26**	**33**	**45**	**257**
Total (Target items):	**23**	**23**	**21**	**15**	**14**	**20**	**28**	**144**

NOTES:

1. Those items shown above in *Italics* denoted with a (#) are non-positive capture litter item which are only included for information.

Table App G.4 Youth Road - Number of untagged sample litter items retrieved from ILLS sump for each sample litter items by pump-out.

	NUMBER OF UN-TAGGED STANDARD LITTER ITEMS RECOVERED FROM ILLS SUMP BY PUMP-OUT							
	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6	PO-7	**TOTAL SUMP**
SAMPLE LITTER ITEM	18/03/1998	30/04/1998	11/06/1998	16/07/1998	02/09/1998	30/09/1998	17/11/1998	
PET bottles (with lids):	0	0	0	0	0	0	0	**0**
PET bottles (with-out lids):	0	1	2	6	0	0	4	**13**
HDPE bottles (with lids):	0	0	0	0	0	0	0	**0**
Plastic shopping bags:	0	3	0	0	0	4	1	**8**
# *'Plastic straws:*	*0*	*0*	*4*	*1*	*1*	*0*	*2*	***8***
# *'Plastic food wrapping/packets:*	*8*	*7*	*3*	*9*	*35*	*1*	*57*	***120***
# *'Plastic drink cup lids:*	*1*	*2*	*2*	*4*	*0*	*1*	*2*	***12***
Aluminium cans:	2	1	3	9	0	3	10	**28**
# *Food wrapping (Foil lined):*	*4*	*3*	*0*	*9*	*0*	*0*	*17*	***33***
Paper drink cartons (Waxed):	0	0	3	3	0	1	3	**10**
Paper drink cups (Waxed):	0	3	0	3	0	2	3	**11**
Poly-Styrene pieces (50mmx50mm):	0	0	0	0	0	0	0	**0**
Total All items:	**15**	**20**	**17**	**44**	**36**	**12**	**99**	**243**
Total (Target items):	**2**	**8**	**8**	**21**	**0**	**10**	**21**	**70**

NOTES:

1. Those items shown above in *Italics* denoted with a (#) are non-positive capture litter item which are only included for information.