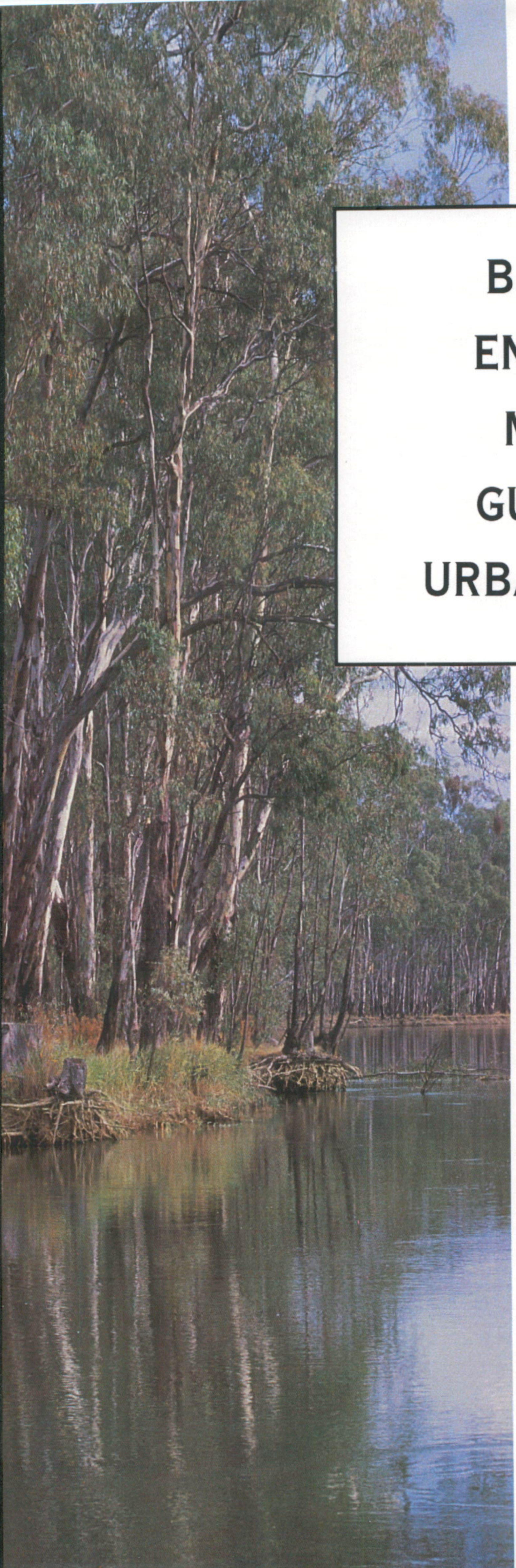

BEST PRACTICE ENVIRONMENTAL MANAGEMENT GUIDELINES FOR URBAN STORMWATER

Background Report to
the Environment Protection
Authority, Victoria,
Melbourne Water Corporation
and the Department of
Natural Resources and
Environment, Victoria

L. B. Mudgway
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Report 97/7
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COOPERATIVE RESEARCH CENTRE FOR
CATCHMENT HYDROLOGY

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PREFACE

This report documents work undertaken by the Cooperative Research Centre for Catchment Hydrology on best practice environmental guidelines for urban stormwater. The work has been carried out in conjunction with the Waterways and Drainage Division of the Melbourne Water Corporation, the Victorian Environment Protection Authority, and the Victorian Department of Natural Resources and Environment. The study forms part of Projects C1 (Pollution loads from urban catchments) and U2 (Pollutant sources, movement, and modelling in urban areas) in the CRC's Urban Hydrology Program.

In addition to the literature review which forms an essential part of this project, the report contains a substantial contribution from the CRC's urban hydrology research program. It is pleasing to see the results of our planned research program applied in such a timely manner to an area of considerable practical significance and community interest.

Professor Russell Mein
Director
Cooperative Research Centre for Catchment Hydrology

ABSTRACT

This report documents work undertaken by the Cooperative Research Centre for Catchment Hydrology on best practice environmental guidelines for urban stormwater.

The major sources of pollution in urban runoff are summarised, and the processes of deposition, interception, build-up, wash-off, transport, and storage are briefly described. The adverse effects of poor quality stormwater on receiving waters are noted.

The impact of land use on pollutant concentrations is described. Concentration means and standard deviations derived from over 500 locations reported in the literature are presented, for 12 water quality parameters and up to 15 land use categories. Observed concentrations can be described very well by the log-normal distribution. Although there are large and statistically significant differences in concentration between forest, agricultural, and urban land uses, differences between the subsets of urban land use (residential, commercial, industrial, and other) are usually small and rarely significant. Australian and worldwide concentrations have been compared, and conversion factors proposed where necessary. Associations between different water quality parameters are found to be weak.

The pollutant removal performance of a wide range of stormwater treatment methods is summarised and tabulated. Storage in ponds and wetlands is the only form of treatment with enough data to permit detailed analysis.

Several existing stormwater quality management manuals and guidelines have been reviewed. Performance objectives generally specify either a volume of stormwater to be treated, or a percentage reduction in suspended solids concentration to be achieved. Direct links to receiving water quality objectives are not apparent.

The Australian and Victorian legislative setting for stormwater management guidelines is described. The State Environment Protection Policy - Waters of Victoria, which tabulates maximum acceptable limits for a range of catchments and quality parameters, is particularly noted.

The proposed performance objective requires that concentrations of suspended solids, total nitrogen, total phosphorus, total lead, and total zinc should either meet the relevant statutory requirements, or be reduced by a specified amount, whichever is more easily achieved. The specified concentration reductions are based on the typical observed performance of a storage occupying one percent of the total catchment area. It is not necessary that the treatment measure actually be a storage. The proposed objective also requires that the mass of gross pollutants greater than 2 mm should be reduced by 65%. Screening tools and performance curves are provided, and the recommended procedure is illustrated by example.

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1. INTRODUCTION

1.1 Stormwater Quality Control Guidelines

The University of Melbourne (a partner in the Co-operative Research Centre for Catchment Hydrology - CRCCH) was asked to join Melbourne Water Corporation - Waterways and Drainage Division (MWC), the Victorian Environment Protection Authority (EPAV) and the Department of Natural Resources and Environment (DNRE) in the development of best practice guidelines for urban stormwater pollution control in Victoria. Both MWC and DNRE are also partners in the CRCCH.

The overall objective of the project is to develop guidelines for best practice in adopting stormwater treatment measures to improve the quality of water draining from existing and new urban areas.

Stormwater management guidelines are required for a number of reasons:

- To increase awareness of stormwater impacts at the catchment level.
- To provide a consistent and equitable standard of water quality across all catchments.
- To provide information and techniques for water quality control.

1.2 Background Development

The behaviour of pollutants in urban runoff and in stormwater treatment facilities is still imperfectly understood, and the availability of data under Australian conditions is limited. To provide a sound technical basis for the stormwater management guidelines to be readily accepted, some initial background work was required. The following issues in particular needed to be addressed:

- With a local perspective, what are the processes and sources of pollutants, and which pollutants are critical to the environmental value of the receiving waters?
- What is the driving force behind pollutant removal from surfaces into runoff, and hence what are the factors that need to be addressed in the design of the stormwater treatment measures (e.g. peak flow, total volume of runoff, peak rainfall intensity etc)?
- What are the relationships between pollutants and between their removal rates? Thus, can one pollutant parameter be used as a surrogate for others to prescribe removal?
- What standards of removal should be set (e.g. storage of the first 25 mm of runoff, storage of all runoff from the 2 year ARI or more frequent storm, removal of 70% of suspended solids) and how is this related to the questions listed above and to the government targets for receiving waters?
- What additional information is required in order to implement stormwater quality control?

This report describes the work undertaken by the CRCCH to assist MWC, EPAV and DNRE with the preparation of the guidelines.

1.3 Layout of Report

Activities were undertaken in two parallel streams. Current work in the CRCCH was adopted and expanded, concurrently with other new work, as shown below:

Introduction and context of urban stormwater quality management guidelines (Chapter 1)

Expansion of Current CRCCH work

Adoption and summary of urban stormwater processes literature review (Chapter 2).

Use of a worldwide data set of stormwater runoff pollutant concentrations (Chapter 3) to:

- establish correlation of concentrations with land use;
- establish relationship between different pollutant concentrations in stormwater runoff;
- establish comparison between Australian and world pollutant concentration data.

Use of a worldwide data set of stormwater storage treatment pollutant concentrations (Section 4.2.1) to:

- determine the most significant descriptors of storage treatment performance;
- establish relationships of outflow pollutant concentration from storage (performance);
- establish correlation between reduction in concentrations of different pollutants.

New Work

An examination and assessment of existing stormwater performance objectives and design criteria (Section 5.1)

A review of current technology for stormwater quality control or treatment (Section 4.1).

A review of current national and state water quality guidelines to determine the framework in which stormwater quality management guidelines are likely to be implemented (Section 5.2).

A review of published data to determine the typical performance of control technologies (Section 4.2)

Development of a performance objective and methodology to identify appropriate stormwater quality control measures (Chapter 6).

2. STORMWATER QUALITY SOURCES AND PROCESSES

This summary has been prepared from a review of urban stormwater quality processes prepared by Duncan (1995b) unless otherwise noted.

2.1 Sources of Pollution

2.1.1 Common Sources

A useful tabulation of common sources of pollutants in urban runoff is provided by CD&M (1993) and reproduced in Table 1.

Table 1. Common sources of pollutants in urban runoff (adapted from CD&M, 1993 and Makepeace et al., 1995)*

Pollutant	Automobiles & roads	Atmospheric deposition	Residential activities	Industrial activities	Construction activities
sediment	pavement wear	air-borne dust	erosion	▨	erosion
nutrients (N and P)	roadside fertiliser	▨	organic matter, fertiliser, cleaners	solvents, cleaners, waste	waste
bacteria & viruses			organic matter, septic		▨
oxygen demand	street litter	wet deposition	organic matter	▨	▨
oil and grease	lubricants and motor fluids (spills, leaks)		paint, solvents	oils, lubricants	▨
heavy metals	Cr, Cu, Pb, Zn, Fe, Cd, Ni, Mn - emissions, lubricants, corrosion, wear of tyres (filler), bearings, brakes	▨	Cd, Cr, Cu, Pb, Zn - corrosion, pesticides, herbicides, fertilisers, weathering of paint, roofs etc	Cd, Cr, Cu, Fe, Ni - metal finishing, combustion products	▨
toxic materials	fuels, herbicides, pesticides, e.g. fuel combustion	PCBs, herbicides, pesticides	herbicides, pesticides (including As)	fuels, pesticides, herbicides, e.g. smelting	herbicides, pesticides
floatables	litter		litter	litter	litter, waste

* Note: grey cells with no text indicate particular sources are not described in the literature; empty cells indicate that the source is not common.

Suspended solids are a major component of urban stormwater pollution, the concentration of SS often being an order of magnitude greater than any other pollutant. Soil erosion from exposed or unstable areas and from construction sites is a major source of SS in urban stormwater. SS itself is a major pollutant, but contaminants from soil chemicals and other pollutants may also become attached to sediment, increasing the impact of SS in receiving waters. A better idea of relative pollutant concentrations and the relationship to land use is provided in Section 3.1.

Other sources of contaminants in urban runoff include:

- solids generation by deterioration of surfaces (mainly roads);
- wear of vehicle components;
- leakage of oils, grease etc from vehicles;
- spills of fluids and/or solids from loads carried by vehicles;

- leakage from septic tanks in unsewered areas;
- sewer overflows in sewered areas;
- corrosion of metal objects and surfaces - particularly galvanised roofs (a major source of Zn);
- vegetation (eg, leaf fall and grass clippings etc);
- litter;
- irregular discharges (e.g. spent oil from car servicing at home, detergents from car washing etc).

All pollutants described above, except vegetation, appear in dissolved or suspended (particulate) form, or as bed load in the stormwater system. In all cases they will be either dissolved or fine particulate in nature and from here on will be referred to as fine and dissolved pollutants. The other main group comprises gross pollutants which consist of vegetative matter and human derived litter, either floating, suspended, or bed load. Their distinguishing feature is that they are too large to be captured effectively by standard sampling techniques. Ellis (1979) found that under-sampling of sediments greater than 5 mm in size was particularly significant, but particles less than 75 μm in size were largely unaffected by the layout of the sampler. Stephenson (1981) reported that particles with nominal diameter less than 40 μm normally mix completely with water. Allison (pers. comm.) used the CDS device and litter basket screen sizes (5 mm), in which a proportion of sediments down to 1 mm in size were captured, as a basis to define the minimum size of gross pollutants. Soil material is defined as particles which are smaller than 2 mm in diameter, a definition common to most national and international soil classification conventions (Hillel, 1980; Turner, et al., 1984). Anything greater than 2 mm in diameter is defined as gravel, which generally do not behave like soil. It seems appropriate that this be used as the cut-off for gross pollutants also, fitting within the size ranges described above.

Gross pollutants, both natural (vegetative matter) and artificial (mainly plastics and paper) are a distinctive problem in urban drainage, particularly as they are usually highly visible. Natural organic litter, such as leaves, seeds, grass clippings, are a possible source of organic matter and nutrients, especially if the material is broken down. Gross pollutants are often the most targeted pollutant in urban areas due to their unsightly appearance, however, their impact on receiving water quality and ecological value may be small compared to the fine particulate and dissolved pollutants.

2.1.2 Deposition

Many pollutants in stormwater originate from the atmosphere. Deposition from the atmosphere can occur in a dry state (dry deposition), or with rainfall (wet deposition). In dry deposition, dust and other solids, often with pollutants attached, are deposited onto surfaces. The sources of the pollutants in dry deposition can be from traffic and industrial emissions and refuse (dust, dirt, litter, vegetation residues etc). Studies have found that deposition fluxes of trace elements can be up to two to four times higher in an urban area compared to the nearby rural fringe. Seasonal variation has also been found, with summer concentrations tending to be higher.

Condensation of atmospheric moisture into raindrops and movement of raindrops in contact with atmospheric pollutants causes pollution of rainfall - sometimes wet deposition of pollutants can be the major source of pollutant (Novotny, 1995). In particular, studies have consistently found that rainfall is the major source of nitrogen in urban runoff, in some cases the total deposition exceeding the load in runoff. Wet deposition can also be a major source of phosphorus, but with much greater spatial variability than for nitrogen. Rainfall can also be a significant source of heavy metals, COD and PCBs.

Sources of contaminants deposited from the atmosphere include seaspray, industrial activities, rural activities, local dust and long range transport from other areas.

2.2 Processes of Pollutant Transport

Pollutants are transported to receiving waters by urban runoff via two pathways:

- surface paths - generally in stormflow events only;
- subsurface paths (baseflow) - generally continuous, although often insignificant.

Some sources of urban stormwater (such as illicit discharges, urban garden irrigation runoff) may appear as low flows in the receiving waters which are not storm event related.

2.2.1 Interception

Rainfall and dry deposition are intercepted by growing plants, plant debris and artificial structures before reaching the ground.

Growing plants apparently increase the total surface area upon which deposition can occur, while possibly reducing the rainfall energy on the ground. A few studies have observed higher concentrations of contaminants in through-fall (rainfall passing through the canopy) than in rainfall. Phosphorus, nitrogen and organic matter in runoff generated from rainfall percolating through plant debris on the ground are often in greater concentrations than direct rainfall. If the plant debris is broken down by freezing and thawing, drying, or physical breaking up, the rate of nutrients released can be greatly increased.

Impermeable surfaces such as roofs and buildings behave similarly to any impervious ground surface, in that pollutants gradually accumulate, and are then washed off by rainfall onto surfaces of lower elevation or directly into stormwater. However, dry deposition on elevated surfaces has been found to be lower in some cases, possibly due to the surface being above the level of the source of some pollutants. Runoff from roofs and fittings generally contains zinc (in the case of galvanised iron roofs) and other corrosion products from the roof material. This contribution depends on the atmospheric concentration of sulphur dioxide (creating acid rain) and the exposed area of metal in the catchment. Another frequently observed effect is an increase in pH as rainwater interacts with the roof materials and other surfaces.

2.2.2 Build-up and Wash-off

Build-up is the process through which dry deposition of pollutants accumulates on impervious surfaces. The build-up generally increases with time, however rates vary between land use and pollutant type. Rates of build-up and resultant loads have been found to be higher for commercial areas than residential, but loads in commercial areas are generally lower than in industrial areas.

Much research work has been concentrated on build-up on roads, where build-up is generally found to be concentrated near the kerb and also greater where the kerbs are higher. This suggests that dry weather removal (to adjacent pervious and impervious areas) also occurs due to disturbance and transfer by traffic and wind. The rate of removal by dry weather disturbance depends on whether pollutants can move back from the adjoining areas onto the surface. Increasing build-up is expected with increasing antecedent dry period, however the shape of the curve cannot be accurately determined. Novotny (1995) suggested a build-up function of the form:

$$\frac{\mathrm{dP}}{\mathrm{dt}} = \mathrm{I} - k\mathrm{P}$$

or in analytical form:

$$P(t) = I(1 - e^{-kt}) / k + P(0)\, e^{-kt}$$

where P(0) = initial load per unit kerb length(kg/m),

P(t) = load per unit kerb length(kg/m) at time t,

I = input of particulate matter by dry deposition per unit kerb length (kg/m/day),

k = coefficient representing re-suspension and removal (1/day) - about 0.2 to 0.4/day (i.e. 20 to 40% of solids is removed daily).

Thus, an equilibrium loading may be reached after a period.

After losses caused by infiltration, interception by surface vegetation, depression storage and ponding, and evaporation from wet surfaces, rainfall mobilises and carries the pollutants to drainage. The process of mobilisation and transport of pollutant from a surface via runoff is called wash-off (Duncan, 1995b). Wash-off from impervious areas is generally greater than from pervious areas, due to greater runoff volume, (e.g. surface detention can be up to 4 times greater on pervious surfaces than impervious surfaces). In many studies, it has been found that the total wash-off load is less than the build-up load in any one rainfall event, indicating that some pollutant load is retained on the surface after rainfall. It has also been reported that the surface pollutant load decreases significantly only after a succession of high intensity rainfall events (Duncan, 1995a). Thus, the quality of surface runoff can be related to the quantity of contaminants accumulated on surfaces and the erosion by rainfall.

There is no consensus between studies as to the actual process and driving force behind wash-off. Duncan (1995b) proposed that when rainfall starts, material is loosened from the surface and suspended in the water film by the energy of the falling raindrops. Rainfall energy exceeds the energy of the resulting overland flow, typically by a factor of several hundred, so the rainfall impact is probably the dominating force maintaining the suspension of particles. If rainfall intensity reduces, it is likely that particles will fall out of suspension, and remain where they are dropped until rainfall energy increases again or the surface dries out and dry weather removal processes take over.

This theory is supported by the first flush effect (described below), as the peak concentration of pollutants often occurs before the peak flow. Thus, storm wash-off should be related to rainfall intensity, for example using a storm wash-off factor of the form $\Sigma_n(aI^b)t$, where I is rainfall intensity in period n of length t, and a and b are fitted parameters. One interesting factor is that many authors have used an exponential decay function to describe wash-off, which does not really work as higher initial loads have to be assumed for higher intensity storms, and the wash-off coefficient is not constant even during a single event. However, some basis for the exponential decay may arise from the fact that atmospheric wash-out can be described by an exponential decay function.

Wash-off may feature a distinctive peak in concentration preceding the flow peak, or first flush. It results from initial mobilisation of accumulated pollutants in the catchment and in the collection system. The magnitude and timing of first flush depends on the size of the catchment, the proportion of impervious area, and the time of concentration of the catchment. For larger catchments, where time of concentration is longer, the first flush from the various sources arrives at the downstream outlet of the catchment at different times, resulting in a longer duration of first flush and lower peak concentration which is consequently less detectable. Higher rainfall intensity tends to increase the magnitude and lead time of the first flush. Lead time also appears to be related to the mobility of pollutants, with the first flush of micro-organisms often observed before that of solids.

The peak concentrations of some contaminants, such as titanium from road marking paint and hydrocarbons from vehicle oils, do not appear until late in the runoff hydrograph. This may be due to the fact that they are associated with the roadway rather than the gutter, and so have further to travel. The first flush effect has been observed in catchments in Melbourne by GHD & EPA (1981) and Moodie (1979), especially with particulate material, where the size of the initial flush depended on the rainfall intensity and size of the catchment.

Mobilisation of pollutants is also influenced by surface disturbance. Wash-off loads from disturbed soil areas can be as much as 100 times that of undisturbed areas. Greater traffic volume on wet roads increases wash-off from roads.

2.2.3 Transport

Transport occurs in concentrated flows as bedload, suspended solids, dissolved matter and gross pollutants.

Some pollutants are particulate in nature, and others can become attached to sediments during wash-off or transport, or adsorb to each other to form larger flocculated particles. Because small particles have a large surface area, the pollutant load attached to small particles tends to be relatively greater than that attached to large particles. The ability of runoff to transport suspended material is highly dependent on the particle size. As flow decreases, the size of particles that can be transported decreases. Hence the particle size distribution of the source material and transported sediment is important in determining the potential impacts on receiving waters.

Particulate material which settles out at the end of an event may be remobilised by later runoff. Resuspension during periods of high flow may be a significant transport mechanism for particulate contaminants. Resuspension in a settling pond or wetland will reduce its removal efficiency, and may even lead to net export of contaminants in some events.

2.2.4 Storage

Urban stormwater is sometimes stored in natural lakes and wetlands, and artificial basins, ponds and wetlands. In nearly all cases of storage, there is an improvement in water quality between the inflow and outflow of the storage feature, although the degree of improvement is highly variable. The main effect of storage is to remove suspended solid matter by sedimentation. Where longer detention time is achieved the greater will be the amount of total and fine suspended solids removed. Removal of other pollutants by sedimentation is dependent on their particle size, or on what size particles they may be attached to. Thus the particle size distribution of the source material and sediment in runoff is again important. Sedimentation also appears to be improved with increasing the storage surface area to catchment area ratio.

Another process by which pollutants are removed from stormwater in storage is biological action. Marsh plants, algae and bacteria that grow on shallow organic rich sediments or on emergent vegetation take up soluble forms of nutrients. However, senescence of vegetation can lead to a net increase in nutrients in the water. This temporary storage may still be important, as nutrients are released at times when they may have less impact on receiving waters (i.e. non-growth period). Settling of particles and screening by vegetation also may remove pollutants (especially phosphorus) only temporarily from the water, as chemical reactions in the sediment may continue to convert particulate forms into dissolved forms which are then able to migrate back into the water body.

Most pollutants are permanently removed from stormwater by gradual burial in the sediments where they become chemically and physically immobile, harvesting by removal of senescent vegetation, dredging of sediment, or in the case of nitrogen by loss to the atmosphere.

2.3 Sources and Processes Affecting Victoria

There is relatively little information available specifically for Victoria, on sources of stormwater pollution and processes of deposition and transport. However, it is generally accepted that the sources and processes described above do apply to Victoria.

Pollutant sources are likely to be similar to those observed elsewhere. Most of the studies in urban stormwater pollution have been carried out in the USA or Europe. Lifestyles and urban planning and design in Victoria are very similar in those countries, particularly the USA. It can be seen from Table 1 that roads and vehicles are a primary source of pollutants in urban stormwater, which is supported by much of the data published on pollutant sources. Roads, and the high dependence on car usage, are dominant features in Victorian urban society, as in the USA and parts of Europe. With building design and urban planning in Victoria originating from Europe, the form of the urban areas are much the same. Materials and methods used in construction of urban areas are also similar. Industrial, commercial and household practices between Victoria and the rest of the world are also not too dissimilar. Therefore, it is unlikely that the sources of pollution in Victoria are going to be much different from elsewhere in the "western" world. However, the source pollutant concentrations may differ due to differences in levels of air pollution, urban density and vehicle use between Victoria and elsewhere.

A similar argument can be applied to the processes. Since the local climate and catchment characteristics fall well within the observed range of worldwide data, the individual processes of deposition, interception, build-up, wash-off, transport, and storage must be assumed to be similar in form. They may, however, differ in magnitude, depending on the actual values of storm and catchment characteristics which apply in a particular case.

Measurement of wet weather pollutant concentrations in catchments in Melbourne were comparable to the range of values observed by other researchers, both Australian and overseas (GHD & EPA, 1981).

2.4 Impacts on Receiving Waters

Receiving waters may be defined as the waters downstream of the area of interest, but not so far downstream that other contributing areas have a dominant effect. The adverse effect of poor quality stormwater on receiving waters is always a significant aspect of urban runoff quality, and sometimes the only one. The receiving waters must have some perceived environmental, aesthetic, or functional value which is affected by poor water quality. The receiving water should also have some characteristics of natural water systems.

The impacts of urban runoff pollution on receiving waters include (Novotny, 1995; CD&M, 1993):

- Eutrophication - over-abundance of aquatic plants which reduce light infiltration into water and when senescent lead to oxygen depletion - caused by excess nutrients. A well known example is blue green algae, which can also be toxic.
- Oxygen depletion - caused by organic material degradation by micro-organisms and oxygen demanding substances.
- Disease - caused by pathogenic organisms which may be consumed in water or food provided from the contaminated water body.
- Sedimentation - caused by particulate matter; sediment also affects photosynthetic and respirative processes.
- Acidification - caused by atmospheric deposition.

- Aesthetic decline - caused by floating litter and organic material, and surface films of oil and grease.
- Reduction in biotic diversity - mortality of organisms due to chronic or acute toxicity caused by pollutants such as heavy metals and agricultural chemicals.

3. RUNOFF POLLUTANT CONCENTRATIONS

It is apparent from many studies that water quality concentration data for urban stormwater is generally log-normally distributed (Duncan, 1996; Novotny, 1995). However, variability of pollutant concentrations between countries, regions and land uses may be significant. Variations in atmospheric conditions (affecting wash-out and dry deposition), climate (affecting rainfall and evaporation) and geography (affecting runoff rates) all impact on the variability of pollutant concentrations in urban runoff. Thus, without due consideration of the variability in these determining factors the uncertainty in estimated pollutant concentrations, particularly where there are no measured data, will be great.

3.1 Impact of Land Use on Pollutant Concentration

Published stormwater event mean concentration (EMC) data from approximately 500 different studies were used to establish relationships to different land uses (H. Duncan, unpublished). There were sufficient studies measuring the following parameters for them to have been analysed:

- suspended solids (SS);
- nutrients: total phosphorus (TP),
  total nitrogen (TN);
- metals: lead (Pb),
  zinc (Zn),
  cadmium (Cd),
  chromium (Cr),
  copper (Cu),
  nickel (Ni);
- biological and chemical oxygen demand (BOD and COD);
- oil and grease.

EMC data were classified according to land use. At the first level, all studies were classified as high urban (> 2/3 of catchment area urbanised), medium urban (1/3 to 2/3 urbanised), or low urban (< 1/3 urbanised). High urban areas were then sub-classified as residential, industrial, commercial, or (by default) other high urban, while low urban areas were sub-classified as forest, agricultural, or (by default) other low urban. In all cases the criterion for inclusion in a named sub-classification was that at least 2/3 of the catchment area was under the specified land use. Catchments without a single dominant land use, or for which the detailed land use was not known, form the 'other' groups. A parallel but independent classification identifies catchments which are > 2/3 roofs, or > 2/3 roads, often where these land uses were studied exclusively.

Charts for the 12 parameters are presented in Appendix A. The variability of pollutant concentrations across land uses appears to be very high, in general being up to an order of magnitude between -1 standard deviation from the mean and +1 standard deviation from the mean. The exception was total nitrogen, which showed smaller standard deviations within a land use, and a smaller variation in the means between land uses.

Since most of the studies looked at catchments consisting of mixed land uses and a land use did not need to be 100% of the area to be classified, the EMCs do not reflect unique land uses. Some variation could also occur within a land use classification. For example, the high urban residential classification covers low density outer urban as well as high density inner urban areas which will differ significantly in the structure types and materials, impervious area and vegetation types. The concentrations and flow hydrographs generated from different land uses are likely to be different for the same rainfall storm, particularly (in the case of flow) if the difference in land use is in the degree of perviousness. The EMCs, being a flow weighted measure, will also be dependent on the runoff characteristics of different land use. Therefore, the accumulation of all the hydrographs and the EMCs from the individual land uses will be dependent on the relative areas of different land uses within the catchment. Thus, differences in the mix of land uses between study catchments could explain some of the variation in pollutant EMCs. Differences between studies in definition of land uses could also explain the variability.

Despite these complications, the variability in the data was very high, indicating that pollutant EMCs also depend on factors other than land use, such as the original sources of pollution, deposition and locality. A potential large source of variation is the variation in rainfall temporal distribution and intensity, as mentioned in Section 2.2.2.

3.1.1 Pollutant Concentrations from Urban Land Uses

Among the essentially urban land uses, suspended solids appear to be in highest concentration from high urban roads and high urban areas and lowest from roofs. Total phosphorus appears to be in highest concentration from high urban areas, in particular residential, and lowest from roofs. Not surprisingly, lead concentrations are highest from roads, although high urban classes also have high lead concentrations, most probably due to the greater density of roads. Lead concentrations from roofs are an order of magnitude lower than other areas, supporting the hypothesis that most lead originates from roads (vehicle emissions). Zinc concentration is highest from zinc roofs by an order of magnitude and marginally the lowest from non-zinc roofs.

There does not appear to be a significant difference in concentrations between residential, commercial and industrial areas for any of the five parameters, where those land uses comprise more than two thirds of the catchment area. Phosphorus and nitrogen are a little higher from residential areas, probably due to greater areas of garden, while zinc is slightly higher from commercial areas, probably due to a larger total roof area. No single urban land use stands out as a major source of all contaminants.

The data are predominantly event mean concentrations over a number of events at each study site, so that temporal variation is mostly removed from the variability. Thus the variability shown is probably more from spatial variation. Spatial variability of pollutants in runoff is most likely due to the variability in atmospheric deposition, relative proportions of land use within classifications and spatial variability in rainfall. In fact, further analysis has shown that there is no statistical difference between the sub-groups under the high urban areas groups. Thus, the land uses could be classified as:

- high and low urban roads;
- roofs;
- high urban;
- agriculture;
- forest.

3.1.2 Pollutant Concentrations from Non Urban Land Uses

The charts in Appendix A indicate that concentrations of SS, TP and TN from agricultural areas are generally higher than all of the urban areas and concentrations of the same parameters from forest areas are much lower than the urban areas. This is important when considering the change in concentrations when an area is urbanised. If the area was previously forested (which can be interpreted to be a natural or pristine catchment), the change in concentrations will be an increase. However, if the catchment to be urbanised was previously developed for agriculture, the change will be on average a decrease for these parameters. Thus an adequate definition of the pre-development background levels need to be made.

It is also important to consider the total loads generated from a catchment. Although in some cases the concentrations are higher from agricultural land than urban land, the average runoff depth from agricultural land is less than urban land. In an urban area, small rainfall events will often generate runoff and resultant loads into receiving waters will be smaller but much more frequent. Thus the total load contributed from urban areas may be considerably larger.

3.2 Pollutant Concentrations in Victoria

The data used in Section 3.1 were mainly from North America and western Europe, with about 10% from Australia. However, using this data as a whole, which are from markedly different climatic zones, geology, land forms, or land use patterns may give results that are not applicable to local conditions. Using the Australian data alone, much less the small number of Victorian studies, would give a much reduced data set in which some land uses were represented poorly or not at all. To help resolve these issues, the Australian and overseas runoff concentration data have been compared.

Due to the lack of data available for Victoria (which comes mostly from two studies in the 1970's) the data for all of Australia was assumed to represent the Victorian situation. GHD & EPA (1981) studied the pollutant concentrations in 13 catchments in the Melbourne Metropolitan area and observed that they were comparable to the range of values observed by other researchers in Australia, lending support to this assumption.

The results of the comparison between World and Australian data are presented below for each parameter. Major land use groups similar to those described above were used to classify the data: All Roads (road area > 66.7%); All High Urban (> 66.6% urban area and roof and road areas each < 66.7%); and All Roofs (roof area > 66.7%). All analysis was conducted on log transformed data. Summary statistics were obtained for each data set and the F-test was used to determine if the variances of the two data sets (World and Australia) were different. The t-test was then used to determine if the population means were significantly different. If the variances were not significantly different (at 95%) then the t-test for similar variances was used, otherwise the t-test for unequal variances was used. In most cases, the one and two tail tests both showed either significant difference, or no significant difference, but where they were different the one-tail t-test was used. In all cases the 95% significance level was used. It has been assumed that the mean is representative of the population, so different means will represent different populations.

Tables of the mean log concentrations for the five land use classifications are provided below for ten parameters. The second column in each land use group represents the p value from the F- or t-test. If p is greater than 0.05, the value is not significantly different between the two populations at 95% significance level. Where $p < 0.05$, the cell has been shaded to indicate that there is significant difference between the populations in that variable. The populations are shown diagrammatically in the accompanying figures, which clearly show the differences (unless the sample number is very small as discussed below).

3.2.1 Suspended Solids

Table 2 and Figure 1 show the differences between the populations of log concentrations of SS. The population of sampled SS data for Australia appears to fall within the World population, for all of the land use groups. This indicates that the sources are not too dissimilar between Australian and non-Australian urban areas. Concentrations from roads and roofs cannot be compared due to inadequate sample size. The source of SS is erosion and dry deposition of dust which must be fairly similar across the world for the populations to be similar. In the absence of information to the contrary, it can be assumed that no adjustment is required to worldwide SS data for any land use for Victorian conditions.

Table 2. Descriptive statistics of the populations of SS from data for Australia and data for the rest of the world

Variable	Pop.	Log Concentration (mg/L)									
		All Data		All Roads		All High Urban		All Roofs		Other	
		value	p	value	p	value	p	value	p	value	p
mean	World	2.17	0.439	2.32		2.20	0.100	1.55		2.03	0.052
	Aust.	2.15		-		2.07		-		2.36	
median	World	2.16		2.31		2.18		1.61		2.04	
	Aust.	2.21		-		2.18		-		2.24	
std. dev.	World	0.52	0.409	0.54		0.47	0.227	0.38		0.59	0.337
	Aust.	0.53		-		0.52		-		0.51	
number	World	327		42		222		11		52	
	Aust.	36		0		26		0		10	

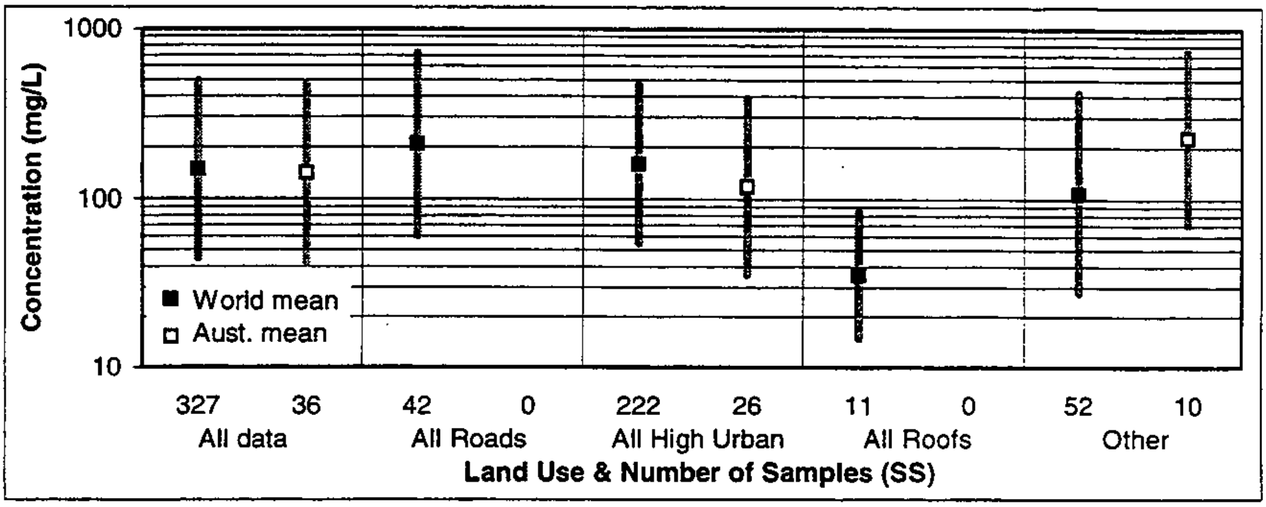


Figure 1. The populations of SS concentrations in Australia and the rest of the world for various land use groups (mean ± 1 standard deviation)

3.2.2 Total Nitrogen

Table 3 and Figure 2 show the differences between the populations of log concentrations of TN. The population of sampled TN data for Australia appears to fall within the World population, for all of the land use groups, indicating that the sources are not too dissimilar. In the absence of information to the contrary, it can be assumed that no adjustment is required to worldwide TN data for any land use for Victorian conditions.

Table 3. Descriptive statistics of the populations of TN from data for Australia and data for the rest of the world

Variable	Pop.	Log Concentration (mg/L)									
		All Data		All Roads		All High Urban		All Roofs		Other	
		value	p	value	p	value	p	value	p	value	p
mean	World	0.40	0.865	0.49		0.41	0.223	0.75		0.33	0.415
	Aust.	0.42		-		0.47		-		0.30	
median	World	0.38		0.37		0.38		0.75		0.37	
	Aust.	0.41		-		0.46		-		0.30	
std. dev.	World	0.35	0.282	0.46		0.28	0.218	0.14		0.44	0.128
	Aust.	0.31		-		0.32		-		0.29	
number	World	189		17		122		2		48	
	Aust.	26		0		18		0		8	

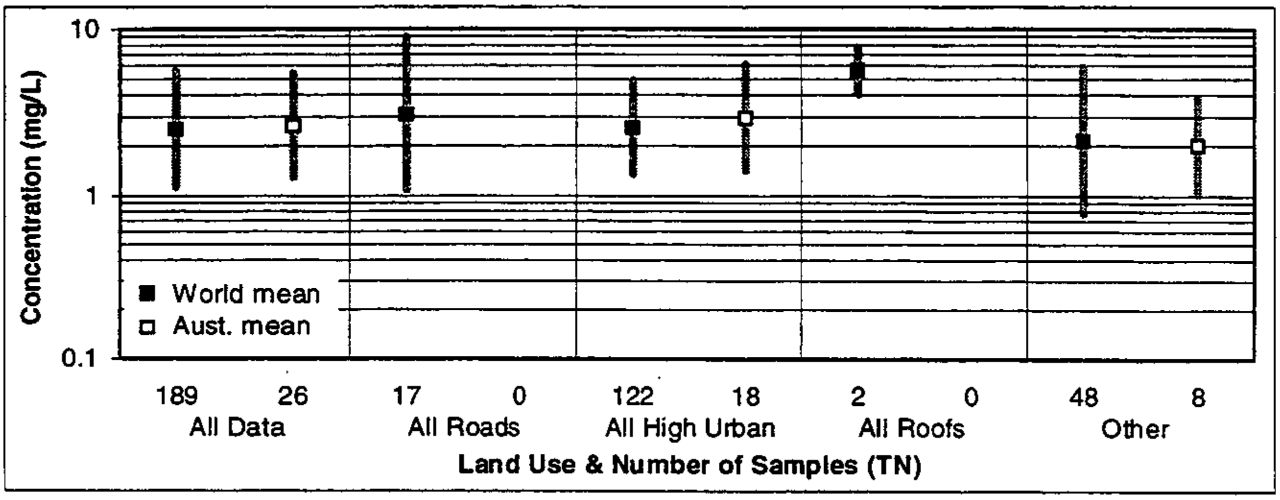


Figure 2. The populations of TN concentrations in Australia and the rest of the world for various land use groups (mean ± 1 standard deviation)

3.2.3 Total Phosphorus

In the case of TP (Table 4 and Figure 3), there are highly significant differences in both the variance and means between the Australian data and World data for all data and for high urban areas. A tendency in the same direction is not significant for the 'other' land use, possibly due to inadequate sample size. Unfortunately there were no road and roof studies conducted in Australia which monitored TP, so these land use groups could not be compared. TP is generally associated with vegetation and soils and so would be expected to be higher in lower density urban areas, such as in Australia. Half of the worldwide data were from North America, which also has low density of urban areas. The lower phosphorus concentrations under Australian conditions are more probably associated with the generally low phosphorus content of Australian soils (thus high superphosphate usage in agriculture), which may lead to phosphorus deficient vegetation. Since phosphorus in runoff is partly derived from leaves and other organic litter, another effect could be the suppression of plant growth due to moisture stress for several months of a typical year. Other sources of phosphorus are detergents, fertiliser, lubricants and industrial wastes (chemical, food and building material) (Makepeace et al., 1995). Lower relative population density may lead to lower usage and production of these.

As both the low soil P and moisture stress effects will tend to apply across all land uses, a uniform adjustment factor for all land uses appears to be most appropriate. The difference between Australian and overseas concentrations calculated from all land uses is -0.13 in the log domain, which is a difference of -0.11 between Australian only and Australian plus overseas data. This transforms to a (rounded) factor of 0.8 in linear coordinates.

Table 4. Descriptive statistics of the populations of TP from data for Australia and data for the rest of the world

Variable	Pop.	Log Concentration (mg/L)									
		All Data		All Roads		All High Urban		All Roofs		Other	
		value	p	value	p	value	p	value	p	value	p
mean	World	-0.49	0.011	-0.53		-0.42	0.025	-0.89		-0.62	0.278
	Aust.	-0.62		-		-0.59		-		-0.71	
median	World	-0.47		-0.55		-0.41		-0.87		-0.58	
	Aust.	-0.57		-		-0.52		-		-0.70	
std. dev.	World	0.41	0.021	0.44		0.34	0.001	0.29		0.52	0.395
	Aust.	0.48		-		0.48		-		0.48	
number	World	253		25		167		6		55	
	Aust.	54		0		40		0		14	

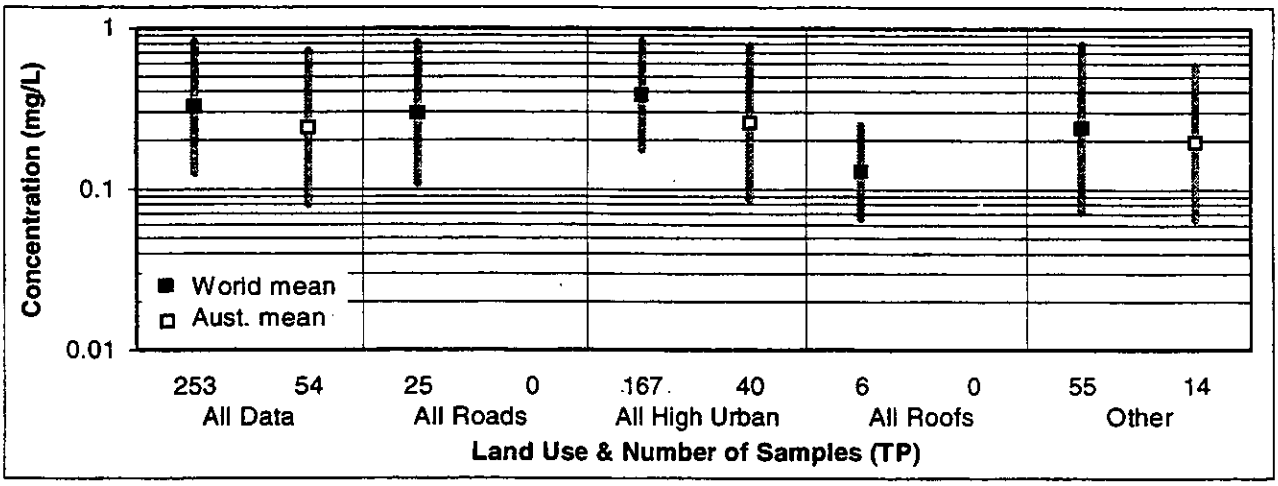


Figure 3. The populations of TP concentrations in Australia and the rest of the world for various land use groups (mean ± 1 standard deviation)

3.2.4 Lead Concentrations

It is quite noticeable, even without analysing the F-test results that the variation in the Pb concentrations from Australian data are much greater than in the world data (not withstanding the small sample sizes - Table 5 and Figure 4). However, the means are not significantly different except in the High Urban areas, where they are almost double the overseas levels. The major source of Pb in urban runoff is from petrol additives and since the greatest density of traffic is in the urban areas, lead pollution would be expected to be highest in these areas. This presents a problem of interpretation, because the Australian data is dominated by a study carried out in Melbourne in 1978, before the introduction of unleaded or low Pb petrol. Only two data points come from 1990 or later. Recently published statistics show that half of all petrol sold in Australia is now unleaded and the Pb content of the remainder has also halved, which suggests that Pb from this source should have dropped by about 75% over the last decade. This is enough to eliminate the observed difference between Australian and overseas lead levels. The two recent studies lend some support to this concept - they both show lead concentrations close to the overseas mean - but with only two points the result can be no more than suggestive.

On balance, it seems preferable to assume that Australian Pb concentrations are not now significantly different from overseas levels and will certainly become closer with the continuing phasing out of leaded petrol. Therefore, no adjustment factors are required.

Table 5. Descriptive statistics of the populations of Pb from data for Australia and data for the rest of the world

Variable	Pop.	Log Concentration (mg/L)									
		All Data		All Roads		All High Urban		All Roofs		Other	
		value	p	value	p	value	p	value	p	value	p
mean	World	-0.91	0.329	-0.65		-0.86	0.002	-1.58	0.201	-1.32	
	Aust.	-1.00		-0.96		-0.55		-1.99		-0.80	
median	World	-0.81		-0.62		-0.77		-1.68		-1.30	
	Aust.	-0.80		-		-0.52		-1.65		-	
std. dev.	World	0.61	0.006	0.53		0.57	0.005	0.54	0.013	0.60	
	Aust.	0.87		-		0.29		1.08		-	
number	World	255		48		169		19		19	
	Aust.	21		1		13		6		1	

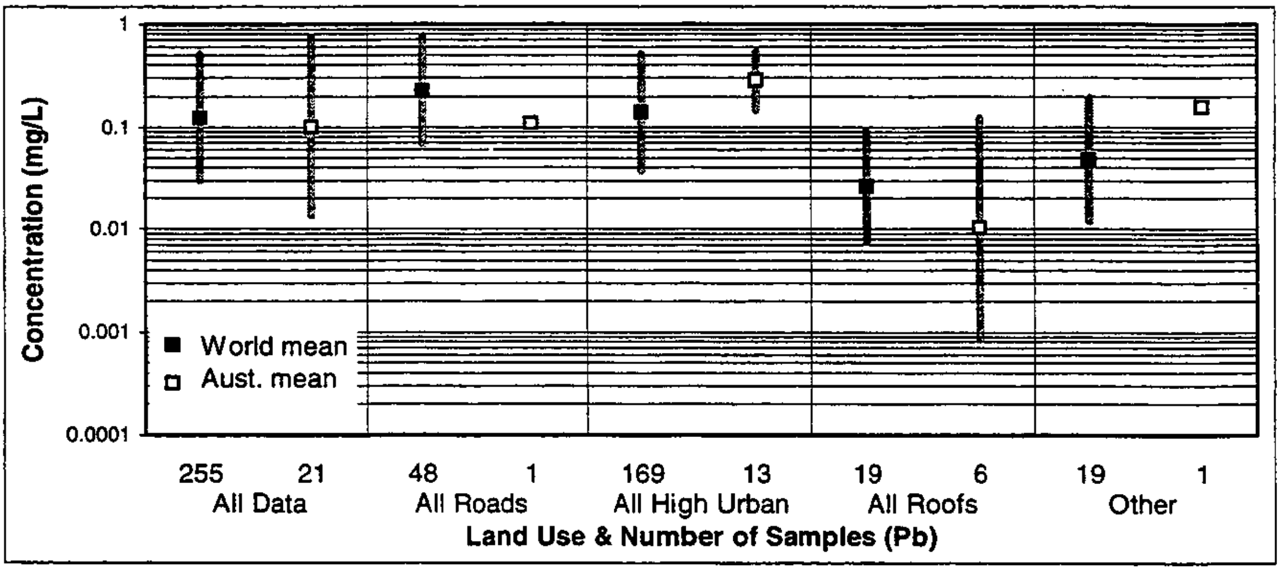


Figure 4. The populations of Pb concentrations in Australia and the rest of the world for various land use groups (mean ± 1 standard deviation)

3.2.5 Zinc Concentrations

The mean Zn concentrations for all data and high urban areas are significantly higher in Australia than overseas levels, although a tendency in the same direction is not significant for roofs (Table 6 and Figure 5). Due to inadequate sample size, concentrations from roads and other land uses cannot be usefully compared. Sources of Zn include wear of tyres and brake pads and corrosion of metal objects (e.g. galvanised iron roofs) (Makepeace et al., 1995). The higher Zn concentrations under Australian conditions are probably associated with the latter source, particularly the traditional and widespread galvanised iron roofs.

Note that all land uses except forest will include roof runoff, even when roof area is not separately reported. Since all land uses show a tendency in the same direction (although it is not always significant), a uniform adjustment seems to be most appropriate. The difference between Australian and overseas concentrations calculated from all land uses is +0.40 in the log domain, which is a difference of +0.36 between Australian only and Australian plus overseas data. This transforms to a (rounded) factor of 2.3 in linear coordinates.

Table 6. Descriptive statistics of the populations of Zn from data for Australia and data for the rest of the world

Variable	Pop.	Log Concentration (mg/L)									
		All Data		All Roads		All High Urban		All Roofs		Other	
		value	p	value	p	value	p	value	p	value	p
mean	World	-0.60	0.000	-0.46		-0.66	0.000	-0.37	0.276	-0.80	
	Aust.	-0.20		-0.32		-0.19		-0.13		-0.68	
median	World	-0.57		-0.45		-0.63		-0.50		-0.98	
	Aust.	-0.15		-		-0.15		0.08		-	
std. dev.	World	0.49	0.258	0.40		0.42	0.348	0.91	0.170	0.54	
	Aust.	0.43		-		0.37		0.59		-	
number	World	215		44		144		18		9	
	Aust.	21		1		13		6		1	

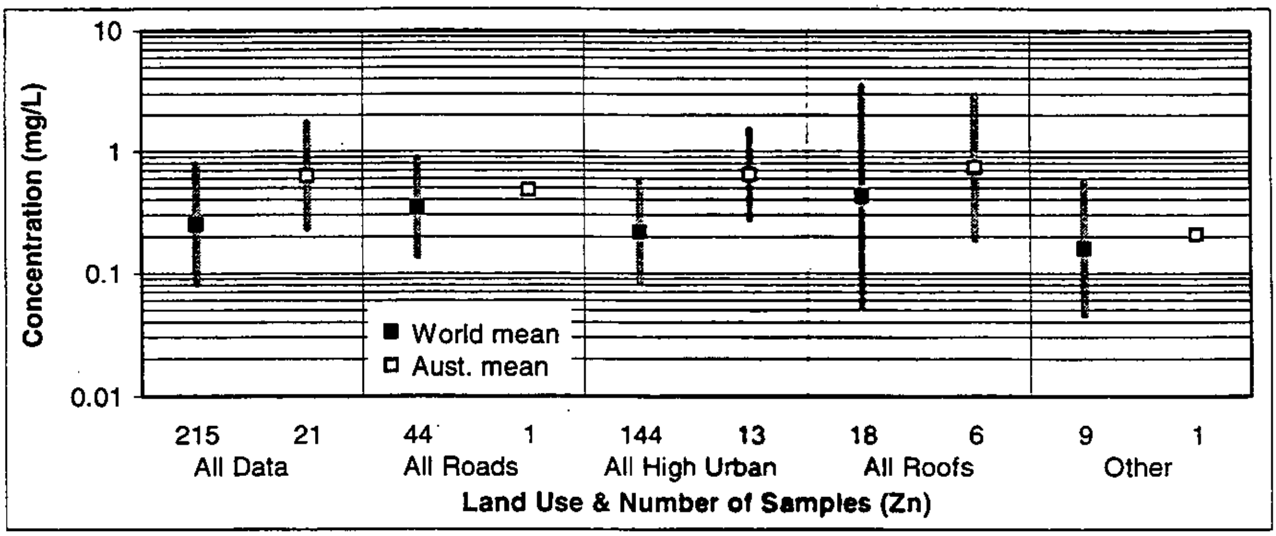


Figure 5. The populations of Zn concentrations in Australia and the rest of the world for various land use groups (mean ± 1 standard deviation)

3.2.6 Comparison Between Australian and World Data for Other Metals

Mean cadmium concentrations tend to be higher in Australia than the rest of the world, but not significantly so (Table 7 and Figure 6). The small sample size may have influenced the analysis in this case. Cd in stormwater may originate from wear of tyres and brake pads, combustion of lubricating oils, emissions from metal-finishing industries, land application of sludge and agricultural chemicals, and corrosion of galvanised metals (Makepeace et al., 1995). Higher concentrations of Cd in Australian stormwater may be due to a larger area of galvanised roofing, as for zinc. This could not be confirmed due to the lack of studies monitoring Cd from roofs, although it will be noted that the Cd concentrations from roofs in the world data are much lower than the other land use groups, indicating that this may only be part of the reason. It could be that there is greater use of galvanised metals for other purposes in Australia, or galvanising practices in Australia use more Cd.

Table 7. Descriptive statistics of the populations of Cd from data for Australia and data for the rest of the world

Variable	Pop.	Log Concentration (mg/L)									
		All Data		All Roads		All High Urban		All Roofs		Other	
		value	p	value	p	value	p	value	p	value	p
mean	World	-2.54	0.014	-2.54		-2.44	0.048	-3.33		-1.98	
	Aust.	-2.16		-2.57		-2.14		-		-2.00	
median	World	-2.51		-2.54		-2.32		-3.17		-1.60	
	Aust.	-2.03		-		-2.03		-		-	
std. dev.	World	0.60	0.072	0.47		0.56	0.186	0.46		0.65	
	Aust.	0.42		-		0.43		-		-	
number	World	73		16		46		8		3	
	Aust.	14		1		12		0		1	

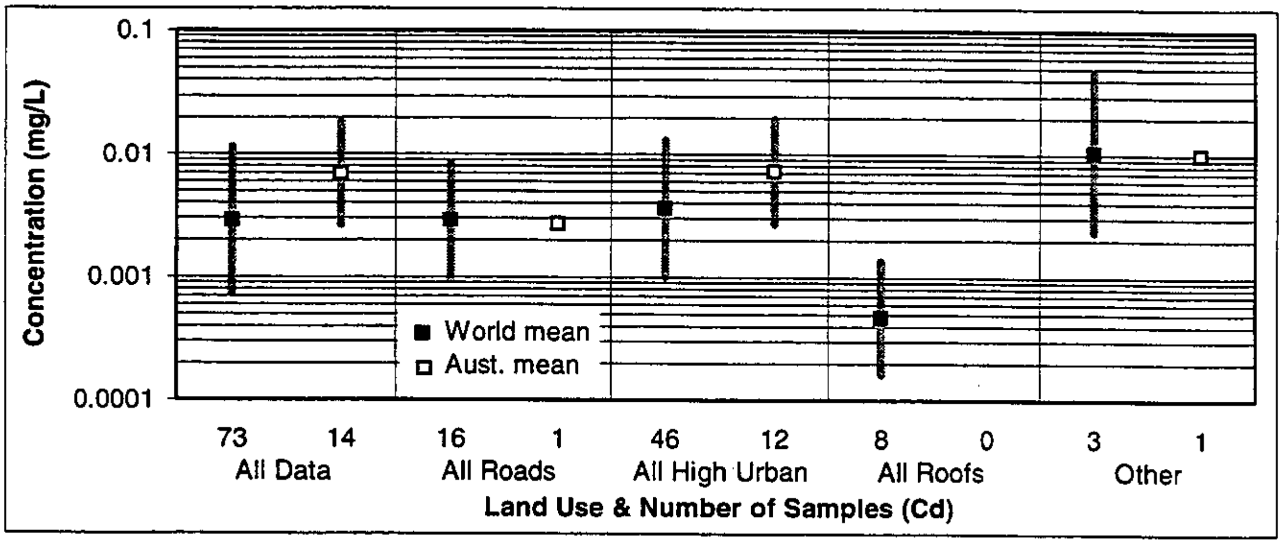


Figure 6. The populations of Cd concentrations in Australia and the rest of the world for various land use groups (mean ± 1 standard deviation)

Although the chromium concentrations from the Australian data appear to be higher than from the rest of the world (Figure 7), the t-test on log means indicates that there is no significant difference (Table 8). This is probably due to the small sample size for Australian data. Cr is used in stainless steel and other metal alloys, engine parts, dyes, paints, ceramics, paper, pesticides and fertilisers (Makepeace et al., 1995). Degradation of painted surfaces by stronger sunlight may cause higher concentrations of Cr in Australian stormwater than elsewhere.

Table 8. Descriptive statistics of the populations of Cr from data for Australia and data for the rest of the world

Variable	Pop.	Log Concentration (mg/L)									
		All Data		All Roads		All High Urban		All Roofs		Other	
		value	p	value	p	value	p	value	p	value	p
mean	World	-1.70	0.097	-1.91		-1.66	0.149	-		-1.73	
	Aust.	-1.46		-		-1.44		-		-1.64	
median	World	-1.70		-1.82		-1.70		-		-1.60	
	Aust.	-1.64		-		-1.66		-		-	
std. dev.	World	0.62	0.260	0.25		0.67	0.220	-		0.23	
	Aust.	0.52		-		0.54		-		-	
number	World	65		9		53		0		3	
	Aust.	13		0		12		0		1	

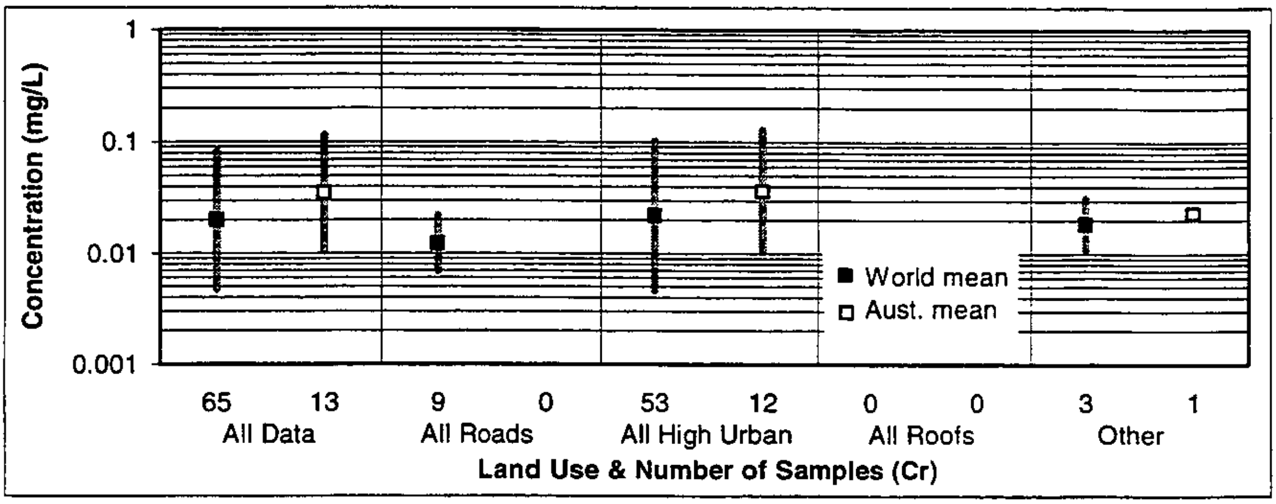


Figure 7. The populations of Cr concentrations in Australia and the rest of the world for various land use groups (mean ± 1 standard deviation)

There is little difference between copper concentrations for Australia and the rest of the world, although the t-test would have been affected by the small sample size (Table 9 and Figure 8).

Table 9. Descriptive statistics of the populations of Cu from data for Australia and data for the rest of the world

Variable	Pop.	Log Concentration (mg/L)									
		All Data		All Roads		All High Urban		All Roofs		Other	
		value	p	value	p	value	p	value	p	value	p
mean	World	-1.29	0.294	-1.00		-1.31	0.221	-1.62		-1.43	
	Aust.	-1.22		-1.09		-1.20		-		-1.59	
median	World	-1.37		-1.12		-1.38		-1.75		-1.41	
	Aust.	-1.32		-		-1.32		-		-	
std. dev.	World	0.52	0.392	0.60		0.47	0.349	0.56		0.25	
	Aust.	0.48		-		0.50		-		-	
number	World	179		27		129		16		7	
	Aust.	14		1		12		0		1	

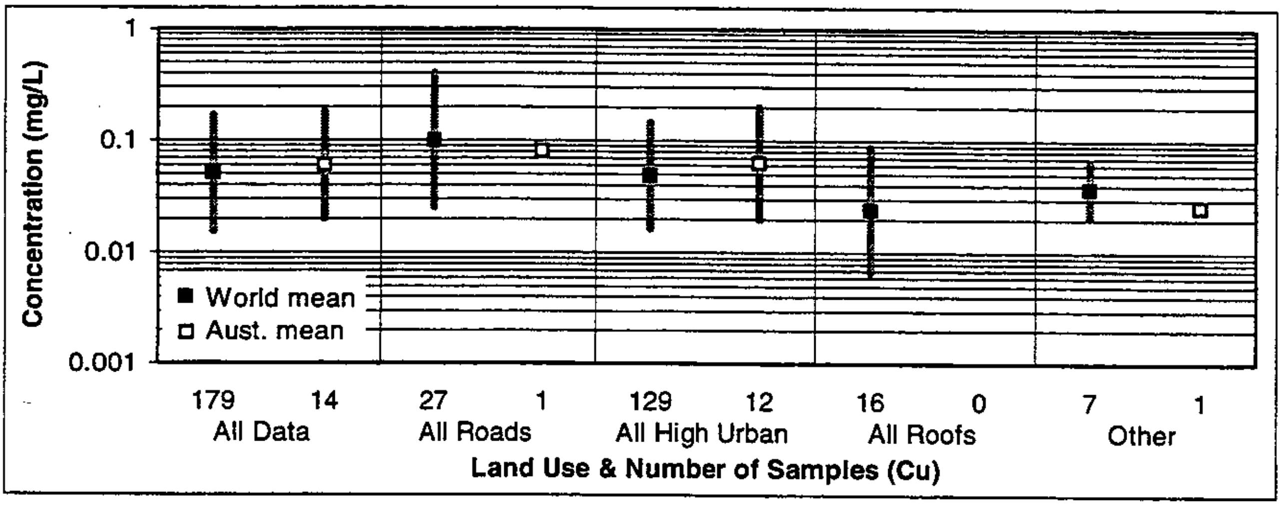


Figure 8. The populations of Cu concentrations in Australia and the rest of the world for various land use groups (mean ± 1 standard deviation)

Despite a small sample size, the t-test showed that the mean nickel concentration in Australia is significantly lower than the rest of the world (Table 10 and Figure 9). Ni is used in welding, metal alloys, engine parts, metal electroplating and food production (Makepeace et al., 1995). It is hard to say whether any or all of these uses are smaller in Australia than the rest of the world. Possibly Ni plating is not used to the same extent as galvanisation in Australia (refer to Zn and Cd).

Table 10. Descriptive statistics of the populations of Ni from data for Australia and data for the rest of the world

Variable	Pop.	Log Concentration (mg/L)									
		All Data		All Roads		All High Urban		All Roofs		Other	
		value	p	value	p	value	p	value	p	value	p
mean	World	-1.47	0.029	-1.35		-1.47	0.048	-		-1.55	
	Aust.	-1.64		-		-1.64		-		-1.66	
median	World	-1.50		-1.35		-1.52		-		-	
	Aust.	-1.64		-		-1.61		-		-	
std. dev.	World	0.30	0.154	0.11		0.32	0.167	-		-	
	Aust.	0.23		-		0.24		-		-	
number	World	41		3		37		0		1	
	Aust.	13		0		12		0		1	

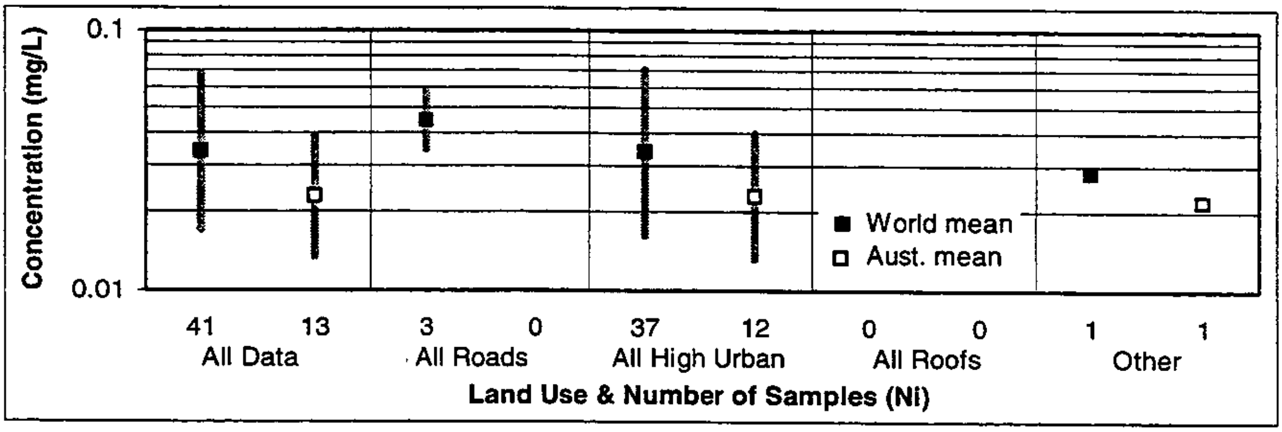


Figure 9. The populations of Ni concentrations in Australia and the rest of the world for various land use groups (mean ± 1 standard deviation)

3.2.7 Biological Oxygen Demand

BOD concentrations in Australia appear to be similar to the world data (Table 11 and Figure 10), although a larger Australian data set may give a different result.

Table 11. Descriptive statistics of the populations of BOD from data for Australia and data for the rest of the world

Variable	Pop.	Log Concentration (mg/L)									
		All Data		All Roads		All High Urban		All Roofs		Other	
		value	p	value	p	value	p	value	p	value	p
mean	World	1.08	0.131	1.22		1.13	0.319	0.60		0.70	
	Aust.	1.18		-		1.17		-		-	
median	World	1.11		1.20		1.11		-		0.65	
	Aust.	1.26		-		1.20		-		-	
std. dev.	World	0.33	0.243	0.28		0.29	0.527	-		0.35	
	Aust.	0.28		-		0.28		-		-	
number	World	140		8		114		1		17	
	Aust.	15		0		14		0		0	

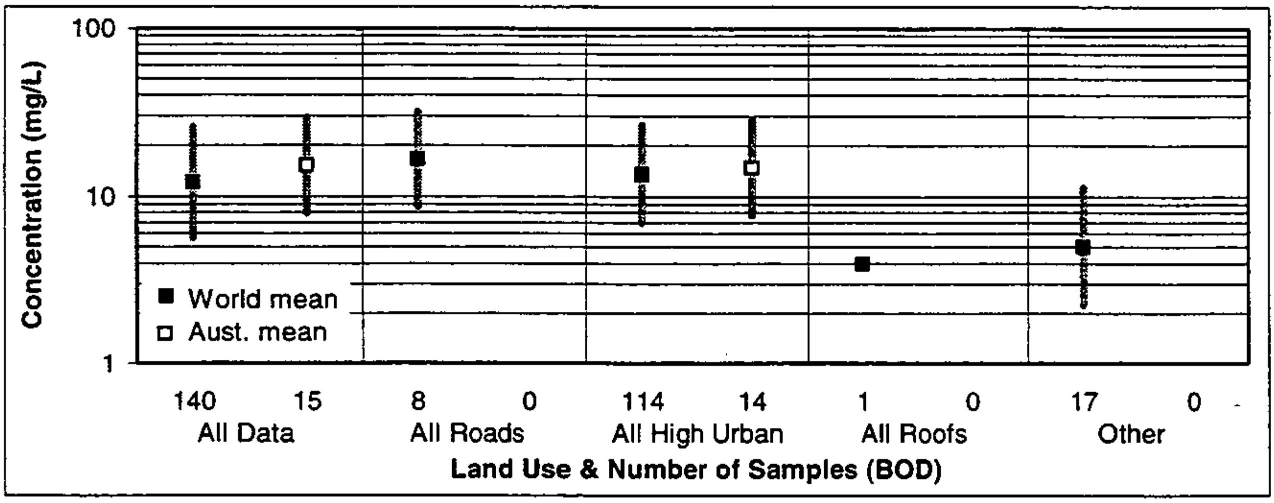


Figure 10. The populations of BOD concentrations in Australia and the rest of the world for various land use groups (mean ± 1 standard deviation)

3.2.8 Factors to Apply to World Data to Estimate Victorian Conditions

It is apparent that the population of parameter concentrations in Australia is sometimes different to that from the remainder of the (developed) world. Thus care must be taken when estimating source pollutant concentrations for Australian conditions. Parameters with significantly higher concentrations in Australia are Zn and Cd and parameters with significantly lower concentrations in Australia are TP and Ni. Lead concentrations were also higher but can be attributed to the slower transition to unleaded fuel use in Australia and the difference will converge as the transition progresses. Use of world data for other parameters should be appropriate.

Factors which should be applied to worldwide concentration data, such as the values shown in the bar charts in Appendix A, are found in Table 12 and are applied by the following:

$$\text{for log data: } C_A = C_{WA} + F,$$

$$\text{for linear data: } C_A = C_{WA} \times F,$$

where C_A = Australian concentration, C_{WA} = worldwide including Australian data concentration and F = the factor. Note that worldwide data discussed earlier in Section 3.1 includes the Australian data. Therefore, the factors must take this into account. For some of the metals, factors were not derived for a number of reasons. Firstly, the reasons for the differences were uncertain and it was not possible to determine if a common factor for the different land use groups could be applied. The second reason is that the sample sizes for these parameters (Cd, Cr, Cu, Ni, BOD) are fairly small, particularly in the analysis of storage concentration reductions (Section 4.2.1). Factoring of these parameter concentrations is not justified at this time as these parameters are unlikely to be specified in any performance objective.

Table 12. Factors (F) to apply to worldwide concentration data to correspond to Victorian conditions

	SS	TP	TN	Pb	Zn	Cd	Cr	Cu	Ni	BOD
just world data (log)	1	-0.13	1	1	0.40	>1*	1	1	<1*	1
world data including Australia (log)	1	-0.11	1	1	0.36	>1*	1	1	<1*	1
world data including Australia (linear)	1	0.80	1	1	2.30	>1*	1	1	<1*	1

* applicability of factor to each land use uncertain - see text above

3.3 Associations Between Pollutants

Most guidelines and manuals for urban stormwater pollution control target suspended solids removal as the primary goal of pollution removal and have little regard to other forms of pollutants. Potentially, there are a large number of pollutant parameters to be removed from urban stormwater from any one area, concentrations for which may be difficult to estimate. However, only a small number of pollutants behave in a similar fashion to suspended solids (as shown in the Section 4.2.2). Thus, approaching stormwater pollution control by using suspended solids exclusively as the basis for a performance criterion may not adequately remove some parameters.

Data were used to compare EMCs of suspended solids, total phosphorus, total nitrogen, lead and zinc. Simple correlation between these parameters was conducted: SS (independent variable) to each of the other parameters, TN (dependent variable) to TP, and Zn (dependent variable) to Pb. Although the correlation equations account for only 40% of the variation or less, the grouping of data points indicate that there are associations between the parameters, but not strong (Table 13). Examples are provided for TP and TN, and Pb and SS (Figure 11). Screening the data, based on the land use values presented in Section 3.1, to eliminate potential outliers did little to improve most of the correlations. Similar results were found by GHD & EPA (1981) who attempted to relate source pollutant concentrations against SS concentration. They found no relationship in soluble parameters and only small correlation between particulate pollutants and SS.

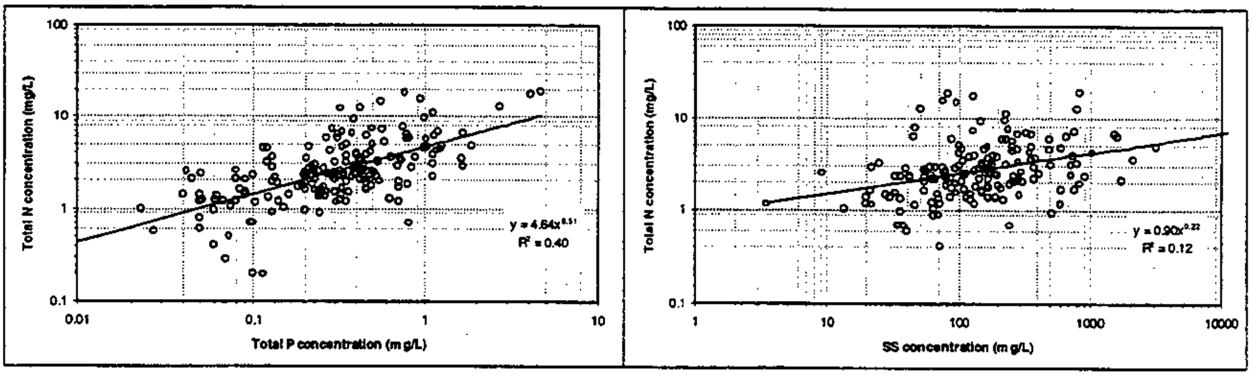
Possible reasons for the weak associations are that pollutant generation is dependent more on impervious area or rainfall than on land use. These two factors are currently being addressed by the CRCCH. In addition, the variation in concentration data is predominantly due to spatial variability (caused by the variability in atmospheric deposition), relative proportions of land use within classifications and spatial variability in rainfall.

As a result of these poor associations, it is apparent that factoring concentrations of a single parameter to estimate concentrations of other parameters will give unreliable results.

Table 13. Summary of the best relationships between key pollutant parameters

Variables		Land-use class removed*	Equation: $y = ax^n$		R^2
dependent (y)	independent (x)		a	n	
TP	SS	roads, roofs, low urban	0.06	0.38	0.24
TN	SS	roads, roofs, low urban	1.06	0.19	0.12
Pb	SS	all roads	0.01	0.53	0.17
Zn	SS	all roofs	0.04	0.39	0.16
TN	TP	high urban commercial	4.64	0.51	0.40
Zn	Pb	all roofs	0.50	0.36	0.17

* 5 studies which were affected by the Mt. St. Helens eruption were already removed.



(a) 186 of a possible 203 data points

(b) 164 of a possible 189 data points

Figure 11. Correlation between (a) TP and TN, with high urban commercial data points not included; and (b) SS and TN, with all low urban data points not included

4. STORMWATER QUALITY CONTROL

4.1 Common Stormwater Quality Control Methods

A large number of stormwater quality treatment devices have been described in recent stormwater quality management guideline documents (ARC, 1992a; CD&M, 1993; GHD, 1995; OMEE, 1994; NSWEPA, 1996b; SCCSMTF, 1992; Schueler, 1987; Whelans, 1993). They vary from devices which simply operate by sedimentation of pollutants to more sophisticated devices which incorporate biological uptake of pollutants. Table 14 lists many common pollution control methods from these documents and summarises the primary pollutant removal.

Table 14. Summary of common urban stormwater pollution control methods and their primary control processes

Description	Pollutants treated								High discharge reduction (A)
	litter	coarse sediment	fine sediment	nutrients	metals	oxygen demand material	oil & grease	pathogens	
Non engineering source controls									
public education	T	T	T	T	T	T	T	T	no
land use planning		T	T	T					T
housekeeping & materials handling	T	T	T	T	T		T		no
alternative products	T			T	T				no
vehicle use reduction			T		T		T		no
drainage signs	T	T	T	T		T		T	no
waste management					T		T		no
Engineering source controls on-site									
reduced lot grading		T							part
on-site detention		T							yes
dry well		T	T	T	T				yes
Engineering source controls near-site									
street cleaning	C6	C4	1	3	3	3	1	1	no
porous pavement & modular pavement	1	6p	S4	S5	S5	3	1	3	yes
oil/grit separator	3	S5	1	2	1	2	C4	2	no
litter basket/trap	C5	3	1	1	1	2	2	1	no
pervious entry pit		p	T	T	T				yes
Engineering source controls off-site conveyance									
entry pit stilling basin	2	S5	1	1	1	2	1	1	no
pervious s.w. pipe & over size pipe trench		p	T	T	T				yes
grassed swale	2	S4		2	S4	2	2	2	part
swale + check dams	2	S4	2	3	S4	3	2	2	part
trash rack	C5	1	1	1	1	2	2	1	no
continuous deflective separator	C6	C6	1	3	1	3	2	1	no
"gross pollutant trap"[a]	C5	C6	1	2	1	2	2	2	no
swirl concentrator / helical bend regulator	concentrates sediment and litter for off-line treatment								

continued over page

Description	Pollutants treated								High discharge reduction (A)
	litter	coarse sediment	fine sediment	nutrients	metals	oxygen demand material	oil & grease	pathogens	
Engineering source controls off-site end of pipe (can be implemented on smaller scale as on/near-site)									
floating booms	C4	1	1	1	1	1	T	1	no
infiltration trench	2	6p	S4	S4	S5	3	2	3	yes
infiltration basin	2	6p	S4	SB4	SB5	3	2	3	yes
sand filter	2	6p	S4	S4	4	4	3	3	no
filter strip	2	S4	1	2	3	2	2	2	part
buffer st. (streamside)		T							part
sedimentation basin	2	S6	1	2	2	2	2	2	no
wet pond	2	6p	S3	SB4	SB4	B3	2	3	yes
ext. det. wet pond	2	6p	2	SB4	SB4	B3	2	3	yes
ext. det. dry basin	2	5p	2	S3	S4	S3	1	2	yes
wetland/marsh	2	6p	S3	SB4	SB5	SB4	4	B4	yes

Legend: A = "yes" or "part" indicates that high flow peak discharge and/or volume is reduced. As a result, pollutant loads will automatically be reduced.
T = target pollutant (removals not presented or unknown).
primary treatment - S = sedimentation,
B = biological uptake,
C = physical capture.
effectiveness - 1 = ineffective (less than 5% removal on average),
2 = low (5 to 20% removal),
3 = low to medium (20 to 40% removal),
4 = medium (40 to 60% removal),
5 = medium to high (60 to 80% removal),
6 = high (greater than 80% removal).
p = generally performed by pre-treatment to avoid risk of clogging.
a = see Section 4.2.5.1 for definition.

4.2 Performance of Treatment Methods

There have been quite a few references to studies which have looked at the performance of various treatment methods in terms of the removal of pollutant. The majority of these studies related to various forms of treatment by storage - wet ponds, wetlands, extended detention basins (wet and dry). These have been analysed in depth as part of a separate study at the CRCCH (Duncan, 1996) and a brief summary is included below. Fewer references presented performance results for other types of treatment. A summary of the results of the non-storage and some of the storage papers is presented in Table 19.

4.2.1 Performance of Storage Treatment

Duncan (1996) presented a statistical overview of urban stormwater treatment by detention in on-stream storages, using data reported in the literature from investigations at 51 separate locations in four countries. A summary of his findings are presented here.

Output concentration of a number of parameters was set as the dependent variable with input concentration and one size variable as the independent variables in a multi-variate analysis of storage pollutant removal. As noted before, output concentration was shown to be log-normally distributed, making it a better measure for statistical analysis than the widely used removal efficiency. Size measures were more readily available in the literature than flow based measures (e.g. mean detention time, overflow rate), so flow based measures could not be tested. Three size measures were used: area ratio (ratio of basin area to catchment area), basin storage (volume of storage per unit catchment area) and average depth (storage volume per unit surface area). In this analysis, all storage types (ponds, wetlands, lakes and combined pond and wetlands) were lumped in together. Later analysis indicated that this was an acceptable simplification.

Where basin size was found to be significant, the area ratio was found to be a good measure and generally the best measure. For some water quality parameters, input concentration is also a highly significant explanatory variable, regardless of whether output concentration or percentage change is required. Area ratio and input concentration together explain up to 89% of the between study variation in output quality expressed as a concentration and up to 65% when expressed as a percentage of input concentration.

The slopes of the outflow concentration curves against inflow concentration are generally positive. Except for TN, the outflow concentrations for a given area ratio appear to be smaller relative to the inflow concentration at high inflow concentration, indicating that performance of storage treatment in terms of the concentration reduction improves with greater inflow concentration. However, in some cases this is not significant as discussed below.

All water quality concentration data are generally log-normally distributed at a 95% confidence level. As for the inflow concentration, outflow quality expressed as a concentration is log-normally distributed. Outflow concentration expressed as a percentage of the inflow concentration is also log-normally distributed, as percentages can be greater than 100 (if scouring occurs). However, expressing the storage performance as the reduction in concentration as a percentage of inflow concentration is not log-normally distributed because it is bounded at 100 and can be less than zero (in circumstances where outflow is greater than inflow concentration). An added drawback of using performance in terms of the concentration reduction as a percentage of inflow concentration is that this value changes for different inflow concentration. Thus, if a certain performance was stated for a given storage, incorrect performance could be derived at different inflow concentrations. The percentage removal also does not take into account any reduction in flow volume through the storage (i.e. load changes more dramatically than concentration). With outflow quality expressed as a concentration or percentage of inflow, a more positive indicator of the benefit to receiving water is provided.

Eleven water quality parameters were analysed and appear to fall into three distinct groups: settling, proportional and rate-limited.

4.2.1.1 Settling Group

- SS, Pb and Zn,
- $C_{out} \propto C_{in}^{0.5}$ and $\propto A_r^{-0.5}$

where C_{in} , C_{out} = parameter inflow and outflow concentrations (mg/L) and A_r = area ratio. Parameters in this group generally have higher output concentration for higher input concentration, but a lower percentage of contaminant in the outflow. This is characteristic of contaminants subject to sedimentation, presumably because higher concentrations tend to include larger particles.

4.2.1.2 Proportional Group

- COD, dissolved and total P, all nitrogen forms except oxidised nitrogen;
- $C_{out} \propto C_{in}$ and $\propto A_r^{-0.1}$

The removal of contaminant in the outflow for parameters in this group is generally not dependent on the input concentration and is generally poor. Thus settling is not a dominant removal process, or maybe more accurately, the contaminants are not chemically immobilised by physical settlement. Increasing area ratio will have a small effect in decreasing output concentration. The basin storage was found to be a slightly better description of basin size for COD concentration than the area ratio.

4.2.1.3 Rate-Limited Group

- oxidised nitrogen (NO_x);
- $C_{out} \propto C_{in}^{1.6}$ and $\propto A_r^{-0.2}$

The lower the inflow concentration of NO_x, the more completely it is removed. This implies a removal process which can handle a given rate of removal, so input concentrations higher than the removal rate will result in poorer removal percentage. Increasing the size of the basin would have small benefits in NO_x removal.

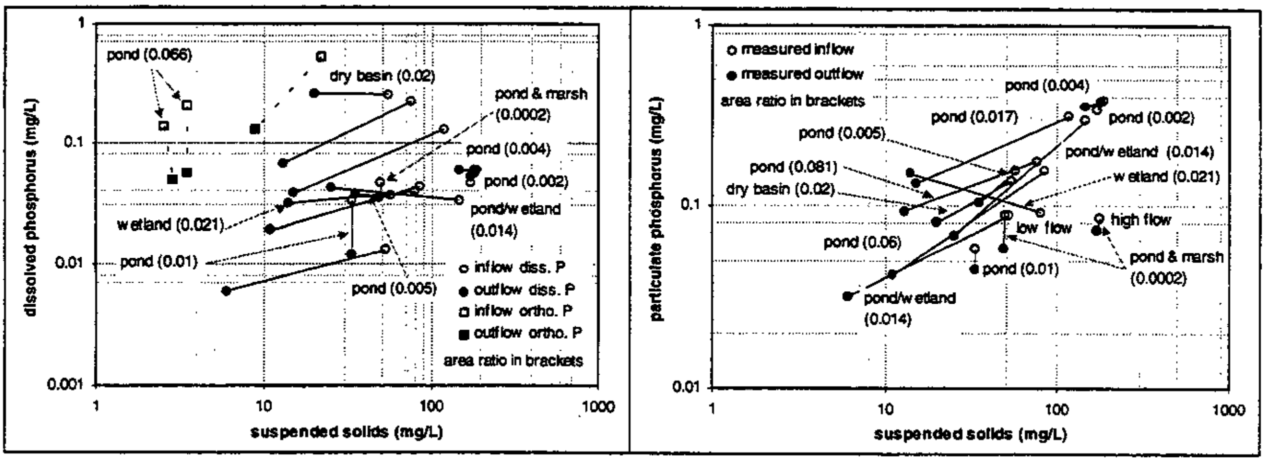
4.2.2 Comparison of Concentration Reductions in Storage

Although modern treatment works are designed for a certain pollutant removal expectation, it is still important to monitor the performance of the treatment device after installation in order to improve on the design criteria for that environment and climate. One such monitoring exercise was conducted by the EWS (1993) on an area called "The Paddocks" in suburban Adelaide. This is a series of wetlands developed in the 1970's to ameliorate flooding impacts and provide for urban stormwater re-use. Measurement of inflow and outflow concentrations during runoff events indicated that metals, organics and TP were all significantly removed and related to the SS removal. However, N and the soluble forms of P were not removed to the same extent and were not related to the SS removal.

The data from Duncan (1996) was used to compare removals of different parameters. Correlation of percentage removals (percentage concentration reduction) offered little information with regard to relationships between parameter removals. For instance, the R^2 value for the correlation between Pb and SS removal was only 0.47. The correlation between these two parameters would be expected to be very strong, due to the common removal process. The data presented in EWS (1993) were in a more useful format, which did not reduce the importance of the inflow concentrations. This graphical method was therefore used in the figures in Appendix B to compare parameter removals.

For each study, the inflow concentrations and outflow concentrations were plotted against each other as clear and shaded circles respectively, with a line joining them (see the examples in Figure 12). For the sake of ease of description, each line is called a removal curve. Where the slope of most of the removal curves is close to 1:1, the reduction in concentration of the variables are similar, suggesting that the removal processes are the same for both parameters or complementary (both removal processes occur together). Slopes of the removal curves similar but not 1:1 indicates that removal of one variable is greater than the other, suggesting different removal process which may be mutually exclusive (i.e. either one process or the other occurs). Scattered removal curves with a range of slopes indicates that the reduction in concentrations of the two variables is unrelated and/or dependent on other factors such as residence time or flow.

Referring to the figures in Appendix B, the association between removals of parameters within each of the three treatment groups is quite strong. However, where concentrations of a parameter in one group is compared to concentration of a parameter in a different group, the associations are variable.



(a) (b)

Figure 12. Removal of (a) dissolved P and (b) particulate P, relative to removal of SS
Note: each set of closed and open circles and removal curve represents one study

4.2.2.1 Grouping Pollutant Parameters by Performance

The number of pollutants required to be analysed for removal can be reduced by grouping those parameters which occur in similar ratios to different land uses and are removed by similar processes. The following pollutant removal groupings are indicated by the analysis in Appendix B:

- Source pollutant concentrations are strongly affected by spatial variability, even within one land use classification and so cannot be grouped.
- SS and most metals are all generally particulate in nature and fall into the settling group. Some metals are more soluble than others and at least one of these should be used for analysis. It is suggested that Pb and Zn be used, as they are the most frequently monitored.
- Removal of TP reflects the removal of particulate P, it being the major component of TP, and is related to removal of SS but smaller due to the equilibrium reactions between the storage bed and water body.
- Removal of TN reflects the removal of all forms of N and is related to removal of SS, but is small compared to TP and SS due to the particulate form being a smaller proportion of N and the complex nature of nitrogen reactions converting N between different forms.
- TOC removal is different from nutrients and SS removal, but cannot be adequately described due to a lack of data.
- Storage treatment data for BOD and COD are limited, but removals appear to be related to TP and SS removal, though smaller and related to TN removal.

Reductions in concentration of most parameters appears to be related to the reduction in concentration in SS. This would indicate that SS could be used as a surrogate parameter for estimating the removal performance of other parameters. That is, given a specified reduction of SS concentration, there would be some confidence in achieving reductions in concentrations of most other parameters. Noting that apart from Pb, reduction in concentrations of SS is the greatest of all parameters tested, it may be more appropriate to use a parameter with the smallest concentration reductions as the surrogate parameter - TN. Apart from metals, which were not compared to TN, the reductions in TN concentrations appeared to be related to the other parameters in a similar way to SS. If TN was to be used as the surrogate, there would be confidence that reductions in concentrations of other parameters would be greater than the specified reduction in concentration of TN.

4.2.3 Performance of Treatment by Infiltration or Sub-Surface Filtration

There are a number of treatment devices which operate by passing the stormwater through a porous media (soil or sand) and discharge the effluent either back into the stormwater (filtration), or into the surrounding soil (infiltration). The most common devices of this type are infiltration trenches, infiltration basins, porous pavement (which is a special case of the infiltration trench) and sand filters. Schueler (1987) grouped infiltration practices (infiltration trenches and basins and porous pavement) together believing that pollutant removal behaviour is similar for these devices.

Infiltration trenches provide only marginal water quantity and erosion control. Based on field tests of rapid infiltration land treatment systems, estimated long term removal for full exfiltration trenches (all inflow is discharged into the soil) are 99% for SS (in pre-treatment), 65 - 75% for TP, 60 - 70% for TN, 95 - 99% for trace metals, 90% for BOD and 98% for bacteria (Schueler, 1987). Depending on design capture, 40 to 50% of storm runoff is captured and exfiltrated over the long term in water quality trenches (designed to only capture first flush). Pollutant removal is higher than runoff capture due to variable concentration, resulting in expected removals of about 75 or 90% of the full exfiltration values (12.5 mm on impervious area, or runoff from 25 mm storm, respectively). GHD (1995) noted that slightly lower removal rates have been reported, in excess of 90% of SS and 60% of TP and TN. Urbonas (1993) tabulated removal rates for different parameters which were very similar to Schueler (1987), indicating that that may have been the source of his data. Scholze et al. (1993) obtained pollutant removals of SS 71%, Pb 25% and Zn 51% for an infiltration trench used as a level spreader for a filter strip, however it was not disclosed whether these figures included the performance of the filter strip or not. These values are significantly lower than other figures quoted.

Infiltration trenches and basins have a poor historical record, attributable to poor site selection, poor design, poor construction technique, too large a drainage area and lack of appropriate maintenance (OMEE, 1994). GHD (1995) quoted a survey reporting that 50% of infiltration trenches partially or totally failed in the first five years after construction and only 38% of infiltration basins were capable of infiltrating runoff five years after construction. Long term performance of infiltration trenches is still questioned due to problems of clogging (ARC, 1992a).

A number of studies have been conducted on the performance of **porous pavement** infiltration, but most do not quote the concentrations of the runoff entering the pavement, so removal performance could not be determined quantitatively. According to a study quoted in GHD (1995), 75% of porous pavements failed within the first five years of construction. However, most other references deferred comment on this, saying that there was insufficient data, or recommending cleaning of porous pavements. In his study of a number of sites, Niemczynowicz (1989) found that the infiltration capacity of porous pavement was approximately 500-600 mm/min, but declined to 65 mm/min after 5 years (maximum of 200, minimum of 1 mm/min), in most cases still sufficient to perform adequately. This would lead to a peak flow reduction up to 80%.

Although not quoting any experimental results, Niemczynowicz (1989) judged that about 50% of SS, P and heavy metals would remain in a porous pavement. Schueler (1987) commented that porous pavement behaves in the same way as an infiltration trench, with long term removal rates from two sites reported to be 82-95% of SS, 65% of TP, 80-85% of TN, 82% of COD, 99% of Zn and 98% of Pb. Experiments on concrete block pavements with different sub-bases by Pratt et al. (1989) reduced effluent volumes to less than 75% of the rainfall. The effluent SS concentrations were found to be around 80% less than typical residential runoff concentrations, however no indication was provided as to the spatial variability between the experimental and control sites. Laboratory studies of polluted runoff on pervious pavements by Pratt (1989) were also conducted to estimate capture of pollutants in the pavement and substrate. Removal of heavy metals was significant (80 to 90%), with Pb and Cr adsorption increasing with depth and Zn removal strongest in the gravel above the soil. Block patterns had some effect on the removals, with Pb varying from 92 to 94% and Zn 77 to 93%. Removal of P was highly variable, while NO_x was leached from the sub-soils. Overland flow was found to be 0.7% of that from an equivalent impermeable concrete pavement! Field studies using polluted snow-melt on existing parking lots and a road in Sweden found that SS concentrations were reduced by 95%, TP by 71%, organic N by 29% (other forms of N were leached from the soils), Pb by 50%, Zn by 62%, Cu by 42% and Cd was increased by 33% (Hogland et al., 1990).

There appears to be no published data on performance of **infiltration basins**. However, Schueler (1987) indicated the potential performances as set out in Table 15.

Driscoll & Strecker (1993) measured removals in three **sand filter** installations of 70-90% of SS, 35-70% of COD, 20-60% of Cu, 65-90% of Pb and 40-80% of Zn. In Texas, sand filters have been found to be effective (OMEE, 1994), although no figures were quoted. Removal rates of 85% SS, 35-50% TP and 40-70% TN were reported for a single study in GHD (1995), however nitrification may cause negative removal of nitrate. Urbonas (1993) presented ranges of pollutant removal for a number of parameters, although the sources of the data were not clearly set out: 60 - 80% SS, TP, BOD and Pb and 10 - 80% Zn. An "amended soil" filtration device was reported to remove greater than 99% of TP and faecal coliforms, 80% of TN and 90% of SS, ammonia and BOD (GHD, 1995).

Table 15. Estimated removal rates for infiltration basins from Schueler (1987)

Basin size rule	Percentage removal					
	SS	TP	TN	metals	BOD	bacteria
0.5 inch from each impervious acre	75	50-55	45-55	75-80	70	75
runoff from a 1 inch storm	90	60-70	55-60	85-90	80	90
2 year ARI runoff	99	65-75	60-70	95-99	90	98

Studies of long term pollutant migration in soils beneath infiltration facilities indicate only limited downward migration. Soluble pollutants such as nitrate, chlorides and gasoline may be an exception (Schueler, 1987). One study found no evidence of groundwater contamination underneath five infiltration basins operating for up to 20 years in California.

4.2.4 Performance of Treatment by Surface Filtration

Fewer treatment devices come under this group, the common ones being swales, filter strips and buffer strips. Their primary process of removal is sedimentation of coarse particles and some fine particles. There appears to have been very little analysis of the performance of these types of treatment, with data found only for swales.

Measurement of pollutant concentrations down the length of two **grassed swales** by Yousef et al. (1985) indicated removals of TP of 4 and 25%, Pb of 0 and 37%, Zn of 34 and 86%, Cu of -14 and +17%, Cd (one swale only) of 20% and of Fe of 3 and 67%. TN removal was very low and in one swale TN concentration increased over the length of the swale. Other results quoted by Yousef et al. (1985) were 80% removal of Pb, 70% of Zn and 60% of Cu. Calculation of removal on a mass basis was found to give better results due to infiltration in the swale. Although some concentration removals were less than zero, the mass removal was greater than zero due to smaller outflow than inflow. Higher total mass input was found to be the driving force for removal rates. Data were also presented by GHD (1995) from two studies quoting a range of removals: SS 80%, Pb 50 and 80%, Zn 50 to 70%, Cu 50 and 60%, Cd 50% and COD 25%.

Filter strips are said to have limited effectiveness for water quality control, particularly due to short circuiting, which will significantly reduce their performance. This was a common reason for poor performance in some US studies (Schueler, 1987). It was suggested that filter strips should be effective in removing particulate pollutants, however, the effectiveness of filtration devices in removing soluble pollutants will be limited to the amount of infiltration able to occur. Forested filter strips may behave better than grassed ones for this reason. Filter strips are effective in removing particulate pollutants according to GHD (1995). It will be noted that these suppositions are conflicting and generally vague.

Buffer strips are predominantly used to maintain riparian vegetation and are generally not long enough to obtain significant pollutant removal. A suggested value for SS removal in buffer strips is 5 to 25% (Urbonas, 1993). However, their purpose lies in protecting stream banks from erosion and providing habitat along stream corridors.

It has been noted that there is a greater source of information regarding buffer strips and filter strips in the agricultural engineering literature. Some of these have been reviewed by Barling & Moore (1993). Their quoted removals listed in Table 16 and a few of their observations are listed below:

- optimum trapping distances for sand, silt and clay were 3, 15 and 122 m respectively for a flow rate of 1 L/s per m width;
- removal of pollutant is dependent on vegetation species - Bermuda grass removed 95% of SS, compared to 60 to 65% for other grass species, for a flow of 1 L/s/m over 213 m length;
- filtration efficiencies are reduced if vegetation is submerged;
- mechanical sedimentation is the primary mechanism of sediment removal;
- in a settling basin - filter strip system the filter strips retained about half of the load that they received for all parameters;
- where flow was concentrated in a filter strip, the strip was 40-60%, 70-95% and 61-70% less effective in removing SS, P and N respectively than were filters with uniform flow;
- sediment build up occurred in the upper part of the strips, then gradually extended down the strip.

Table 16. Summary of removal in filter and buffer strips, from Barling & Moore (1993)

Study number/comments	strip length (m)	Pollutant removal (%)					
		forested strips			grass or non-forested strips		
		SS	TP	TN	SS	TP	TN
1. clay fraction reduction	4				83		
2. soluble fractions	3.8-4	95	99	95		62	
3. sod filter strips	30				50	50	50
4. cornstalk residue	2.7					70	70
5. grass filter strip	4.6				74	61	54
	9.1				84	79	73

It is clear that some of these conclusions contradict what has been said in the urban literature, particularly when some of the strip lengths are taken into account. This may be for several reasons:

- insufficient research has been undertaken in the urban field to understand the full potential of filter and buffer strips;
- nutrients from rural runoff may be more particulate in nature, thus more amenable to sedimentation in the strips; and
- several of the rural studies have used highly polluted runoff (e.g. dairy runoff waste), for which higher reductions in concentration may be possible.

4.2.5 Performance of Specialised Treatments

4.2.5.1 Devices Designed for Removal of Gross Pollutants

Litter removal devices are often referred to as gross pollutant traps (GPTs). GPTs range from simple traps or racks, to more sophisticated devices such as the continuous deflective separator. Some devices aim to remove coarse sediments as well as litter and many will help to reduce nutrient levels in stormwater by collecting suspended organic material which will release nutrients if left to break down in the stormwater or receiving water. There is also a device commonly known as a "Gross Pollutant Trap" consisting of a coarse sediment basin with a trash rack on the downstream end. To differentiate between the generic type description and this particular device, the name for this device will always be given in inverted commas.

To date most studies have concentrated on loads trapped in litter trapping devices and the distribution of litter types (e.g. organic, plastic, paper etc.) without consideration of the relative amounts passing through or entering the device. Current studies hope to provide some of this data (see Section 4.2.7). Trapping efficiency of a "**GPT**" in Canberra was found to be heavily related to cleaning frequency, with efficiency reducing with increasing sediment content. A second study indicated that trapping efficiency decreased with increased flow (GHD, 1995).

A commonly used device is the simple **trash rack**, located in a stormwater drain or stream, which comes in numerous different forms. Depending on the design, the removal of litter can be quite high, however in most cases significant maintenance is required to clear litter from the rack. Similarly, the **litter trap** has variable removal performance and generally requires significant maintenance. A laboratory test of a trash rack conducted by Nielsen & Carleton (1989) indicated 80 to 100% removal of the hard trash (cans, plastic etc), 40 to 100% of soft trash (chip packets, shopping bags etc) and 10 to 90% of garden refuse (leaves, sticks and grass clippings), depending on approach water velocity.

Another device used successfully in several Australian cities is the **floating boom**, which is a floating net hanging a short distance below the surface of the water within a water course. Tagged litter studies by Melbourne Parks and Waterways found that booms installed partially across the Yarra River in Melbourne trapped between 12 and 50% of released (tagged) litter (Melbourne Parks and Waterways, 1993). Features and the performance of a floating boom and a trash rack in Sydney are summarised in Table 17 (Molinari & Carleton, 1987).

Allison (pers. comm.) has measured the performance of a **continuous deflective separator** (CDS) device in Coburg, Melbourne. Results so far indicate capture of 100% of material greater than 4.7 mm, in the flow through the device (about 99.9% of total flow from the catchment). About 70% of sediment trapped is less than the screen size. Testing of a similar device at laboratory scale has obtained capture of litter of up to 95-100% and capture of sediment of sizes down to 1 mm (Wong et al., 1996).

Table 17. Summary of the differences observed by Molinari & Carleton (1987) between a floating boom and a trash rack

Item	Floating booms	Trash rack
removal	all floating and half of part submerged material intercepted, oil slicks intercepted	smaller material (e.g. leaves, grass) can pass through
high flow	waterlogged material can be drawn underneath the boom	material can be forced over the top
installation	requires permanent pool; quick and simple, therefore transportable	permanent
flooding hazard	none	can be some risk
life	limited	if adequately designed, long
cleaning	does not lend itself to full mechanical clearing	if well designed, mechanical cleaning can be used

Litter baskets (located in side entry pits) were also placed in the Coburg study catchment and the amounts captured and passed through the baskets were measured. Assessment of the results found that 100% coverage of side entry pits achieved around 80% capture of litter, while coverage of the side entry pits draining larger areas (about 40%) achieved around 80% of the maximum capture (i.e. 64% capture of total litter). However, selection of appropriate side entry pits in which to install baskets (assuming 100% coverage is unreasonable) is subject to significant uncertainty. Therefore a 50% coverage may be expected to provide at least 64% capture of litter.

4.2.5.2 Devices Designed to Remove Oil and Grease

Silverman & Stenstrom (1988) reviewed various traditional methods that can remove oil and grease from urban stormwater. Because most oil and grease are hydrocarbons, of which 40 to 60% in urban stormwater is typically in a colloidal or dissolved state, most traditional methods are ineffective (*ibid*). **Oil-water separators** are relatively expensive and limited to waste streams with high concentration of oil and grease. **Corrugated/parallel plate separators** are more cost effective, but removal efficiency can be low. Frequent cleaning is required to remove silt and grit. **Dissolved air flotation** and **high rate filtration**, although higher cost, offer potential for higher efficiency and lower surface area requirements. Coagulants would be required to obtain maximum efficiency, which is impractical at most stormwater discharges. The authors also looked at the relative merits of porous pavements (both asphalt and concrete block), green-belts, wet scrubbing of surfaces and using absorbent materials in storm drain inlets.

Several other authors also indicate that **water quality inlets** (also known as oil/grit separators) are generally ineffective in removing both sediment and oil and grease. This is due primarily to insufficient detention times (OMEE, 1994).

4.2.5.3 Street Sweeping

Several studies have been conducted which have generally concluded that street sweeping has little benefit in removal of pollutants from urban stormwater runoff. The major reason commonly stated is that only material larger than 0.2 mm is generally removed, which is larger than the particle size of most pollutants and larger than the SS size fraction to which most pollutants are bound. Sartor et al. (1974) actually determined the various size fractions removed (Table 18) and found that the removal effectiveness of dust and dirt was 50%, but of litter and debris was 95 to 100%. To achieve 70% removal of dust and dirt, two cleaning cycles would be required.

Table 18. Removal efficiency of particulate size fractions in street sweeping (from Sartor et al., 1974)

Particle size (µm)	Sweeper efficiency (%)
>2000	79
840-2000	66
246-840	60
104-246	48
43-104	20
<43	15
overall	50

Effectiveness of street sweeping was measured continuously for one year in California by Finnemore (1982) with both mechanical and vacuum assisted type machines being tested. The cleaning program was found to be more important than the machine type used. Cleaning twice per day removed up to 50% of total solids and heavy metal loads, but twice per month removed only 5%. The performance depended strongly on the type of surface swept, with removal of 30 to 60% of solids on good asphalt, 40% from poor asphalt, and only 5 to 12% from oil and screenings surfaces. Removals of other parameters were between 30 and 50% on asphalt, and 5 to 13% on oil and screenings. The operational cost per unit weight removal was judged to decrease with increasing the number of passes per year, although it is expected that the cost would increase again at some point (at frequencies around twice weekly), depending on the typical inter-storm dry period length and the build-up and wash-off rates.

Bender & Terstriep (1984) compared the EMCs of runoff from conventionally swept areas with frequencies of once to twice per week to runoff of unswept areas. The mean difference between medians of the log normal populations from the swept and unswept areas were: SS - 34%; Pb - 28%; Fe - 39%; phosphorus - 22%; COD - 35%; and TKN - 20%. The reductions in average loads were 62% and 23% for two different basins in the first period and 56%, 44% , 55% and 14% in a second period. The reduction in the portion of load < 250 µm was minimal. They concluded that street sweeping is effective in removing surface load, but not effective in reducing mean runoff concentrations.

4.2.6 Summary of Mean Concentration Reductions

As much data as could be collated for treatment performances are tabulated and summarised in Table 19. These data were tabulated in the form published in the literature - as the percentage reduction in inflow concentration through a device. However, as described in Section 4.2.1, the data would be better expressed in the form of outflow concentrations or outflow concentrations as a percentage of inflow concentration. In some studies, only a range of removals was given, in which case the mean of the minimum and maximum values in the range was taken. A single value of percent removal for each study was found and the median of all the studies obtained for each device type. Some of the medians in Table 19 could be in significant error due to differences in design of the devices between the studies. For instance, the slope, length and vegetation type of a grassed swale or filter strip varied between studies and has a significant influence on the removal performance.

In general, nutrient removal in any device is poorer than particulate removal. This is not surprising due to their higher proportion of dissolved component which is harder to remove.

It is quite clear that storage with some permanent pool (wet ponds and wetlands) achieves the best overall performance on average for a range of parameters. Infiltration and sub-surface filtration devices also appear to perform well in terms of a range of parameters, but there are still doubts about their long term performance, and maintenance requirements are higher than for storage. Information is lacking on filter and buffer strips to make any strong conclusions about their performance. Grassed swales appear to perform well for treating particulates (SS and most metals), but not so well for nutrients. Street sweeping appears to be fairly limited in performance, particularly when the frequency of sweeping is taken into account. Of the gross pollutant trapping devices, from the limited data available, the CDS and litter baskets appear to be the most effective, although the CDS incurs high initial cost and litter baskets require regular cleaning.

4.2.7 Current Research Work

There are a number of studies being undertaken at the CRCCH which will increase the knowledge available about pollutant generation, transport and treatment processes and also provide a much larger resource of high quality data, particularly for Melbourne. Studies relevant to urban stormwater pollution are:

Blackburn Lake - assessment of stormwater pollution and processes of pollutant removal in a storage (Chris Gippel).

Coburg - review of litter trapping techniques and analysis of litter loads from an urban catchment and performance of devices to remove such load (Robin Allison).

Yallambie, Blackburn Lake - investigation of the transport of pollutants in water pollution control ponds during storm events using computer simulation including validation using dye tests (Phil Scanlon).

World published data - analysis of source pollutant data and relationships to rainfall, land use and other factors (Hugh Duncan).

Table 19. Summary of pollutant removal performance of treatment devices

Treatment control	Pollutant concentration reductions (percent of inflow concentration)																Comments	Sample size
	SS	P			N			Pb	Zn	Cu	Cd	Fe	BOD	COD	bacteria	litter		
		TP	org.P	sol.P	TN	org.N	sol.N											
extended detention	50-75	10-66			10-35			70-90	24-62					20-41	50-90			6 studies
	64	18			19			83	45					30	70			
wet pond	39-98	0-80		70-80	30-85	14-20	24-60	9-95	0-71				0-69	20-70	90-95			13 studies
	69	51	20	75	60	17	42	68	51	40		17	44	30	93			
wetland	40-98	-33-97		0-75	-9-43		13-90	6-94	-29-97	40-99	33-99	12-62	18-34				sol.N = NH_3 for several studies	28 studies 1 ref gives range only
	81	60		59	25	32	60	72	50	66	66	37	26					
infiltration trench	71-99	60-75			60-70			25-99	51-99								50% fail within 5 yrs due to clogging	4 studies 2 refs give range only
	83	65			63			61	74				90		98			
infiltration basin	75-99	50-75			45-70			75-99	75-99	75-99	75-99	75-99	70-90		75-98		50% fail within 5 yrs due to clogging	2 studies both give range only
	87†	63†			58†			87†	87†	87†	87†	87†	80†		87†			
porous pavement	50-95	50-71			<0-85			50-98	62-99	42-50							many fail within 5 yrs	8 studies
	89	65				29	<0	86	85	46	-33		80	82				
sand filter	60-90	35-80			40-70		-110-0	65-90	10-80	20-60			60-80	35-70				3 studies all give range only
	80	57			55		<0	74	53	40			70	53				
filter & buffer strips	5-95	50-79			50-73												grass (including sod & cornstalk residue)	10 studies
	74	66		62	62													
																	forested	1 study
				100			95											
grassed swale		4-25		8-24	-4-11	-4-13	-5-22	0-91	34-90	-14-60	20-50	3-67					sol. N & P often not all of soluble fraction	7 studies
	80	15		16	4	5	9	80	70	50	29	35		25				
CDS																95-100		2 studies 1 field, 1 lab. study
	100*	1‡			1‡											98		
floating boom																12-50	tagged litter study	4 trials
																24		
trash rack																5-14	tagged litter study on 2 small traps	2 trials
																10		
litter baskets																	fitted to 50% of side entry pits	1 study
																65		
street sweeping	37-50	9-28				12-45		5-48				13-60		34-45		95-100	org.N = TKN in some studies; frequent sweeping assumed	5 studies
	41	28		45		27		32	45	45	46	45		35		98		

NOTES

Where only a range was given, the mean of the range is used to estimate the median

No shading = range; grey shading = median

† Values may not be from measured data, and are estimated from the mean of the range

‡ Given vegetative matter contains less than 1% of all TN and TP, and all vegetative matter is captured

* Capture of sediment greater than 1 mm in size

5. WATER QUALITY GUIDELINES FOR URBAN STORMWATER

A number of stormwater quality management manuals and guidelines have been reviewed for this report. Several present criteria for treatment of stormwater in terms of the volume of stormwater which should be treated or the amount of pollutant which should be removed. The following is a summary and analysis of those that were readily available to the CRCCH at the time. Although there have been many more guidelines published around the world, this sample should provide an indication of what has been used elsewhere.

The National Water Quality Management Strategy and the Victorian State Government State Environment Protection Policy provide a framework within which Victorian guidelines would be implemented. This setting is outlined in Section 5.2. But first, can any recent performance objectives be applied in Victoria?

5.1 Stormwater Quality Control Performance Objectives

The performance objectives in the sample of current stormwater quality management guidelines have been analysed and compared, and are discussed below. In general, the performance objectives related to treatment of stormwater to reduce pollutant concentrations. The objectives fell into two basic groups:

- those that specified a volume of stormwater to treat, and
- those that specified a percentage reduction in the SS concentration.

Some of the guidelines attempted to relate the latter to the former, or vice versa. In North America, a probabilistic settling model for suspended solids (Driscoll et al., 1986) has been used as the basis for many treatment sizing criteria, generally for wet basins and wetlands. The treatment volume is estimated from the ratio of STM (stormwater treatment measure) volume to a given storm size (usually the mean storm). An STM volume of 2.5 times the mean storm volume yielding a predicted retention of 75% of SS and an average residence time of 9 days has been adopted. This technique has been translated to New Zealand and to a limited extent adopted in Europe (Sharpin et al., 1995).

5.1.1 Specification of Treatment Volumes

The earliest manual reviewed was produced for the Metropolitan Washington Council of Governments (MWCG) in the USA (Schueler, 1987). This manual provided a very simple method to estimate urban stormwater pollutant load based on the Rational Method using a constant runoff coefficient. Average flow weighted pollutant concentration values from US Nationwide Urban Runoff Program (NURP) data was used to calculate load (USEPA, 1983). Suspended solids concentration data (also from NURP) were related to catchment area via three different curves. The appropriate curve was selected on the basis of the overall classification (low, moderate, or high) of the stability of the channel, channel sediment storage and stream velocity. The average exceedence probabilities of different mean concentrations of various parameters were also tabulated.

No single performance objective as such was defined by Schueler. Different design rules used by state and local government bodies were presented, although no individual rule was recommended. These rules specified a design volume to capture a certain depth of runoff, ranging from 0.5 inches of runoff from impervious areas only, through 2.5 times the runoff from the mean storm (from the whole catchment), to the volume of runoff from the 1 inch storm (from the whole catchment). The mean storm, although not defined, was taken as the average storm volume of all storms. The general design standard was to achieve a given removal of pollutant, based on cost effectiveness, although this was not described. For wet ponds, long term removal of SS was shown to be 75% for a design volume of 2.5 times the mean storm volume, with diminishing return (in terms of removal) for further increasing the volume (and cost), based on the work of Driscoll (1983) and Driscoll et al. (1986). In general, a minimum detention time of 24 hours was recommended for extended detention basins and removal rates were determined on the basis of 6 to 12 hours detention time in idealised conditions.

Although the Washington guidelines (Schueler, 1987) appear to have been used as the basis for many other guidelines, the process by which the various design volume values were obtained is not transparent, limiting the ability of a proponent to select the appropriate design volume or performance objective. A performance objective in terms of pollutant removal was also not given.

Two sets of guidelines have been prepared for Auckland, New Zealand, the earlier being by the Auckland Region Water Board, ARWB (1991). Much of this document derived from Schueler (1987) and later reports from the Metropolitan Washington Council of Governments. Again the simple method of calculating pollutant loads was proposed, using constant concentrations, although some of these were derived from a small amount of Auckland data. Four zones of treatment corresponding to different storm levels were proposed as levels of protection, depending on whether only pollution control was required or stormwater volume control was also required (Table 20). A frequency distribution of rainfall greater than 2 mm (assumed surface detention storage) was established. It was found that 90% of rain events greater than 2 mm were less than approximately 25 mm. A performance objective was derived on the basis of 75 to 90% capture of all rainfall events. Thus, for water quality treatment, 60 mm from the impervious area would have to be captured, equivalent to a less than 0.2 year ARI event. To treat the frequent floods (0.1 to 1 year ARI), the 13 to 25 mm runoff event should be detained for up to 24 hours, or a volume equivalent to 75 mm from the impervious area.

Table 20. Four levels of stormwater treatment recommended by ARWB (1991)

zone	spectrum	range of rainfall ARI	recommended treatment
I	first flush (water quality)	< 0.3 year	capture & detain 75 to 90% of runoff events = volume to hold 60 mm from impervious area
II	frequent floods	0.1 to 1 year	reduce frequency of sub-bankfull floods = capture 12.5 to 25 mm storm for up to 24 hours, = volume to hold 75 mm from impervious area
III	bank-full floods	1 to 10 years	keep post-development flow within pre-development stream channel dimensions = control storms from 1.5 to 3 year ARI
IV	extreme floods	10 to 100 years	safely convey extreme storm events to preserve structural integrity of treatment works

The key point to note from ARWB (1991) is that it specified the capture of a proportion of runoff events, not volume. The document appeared to be primarily concerned with storage treatment, although some infiltration methods were described. The process of deriving the performance objective was more transparent than Schueler (1987) and the actual standards more concrete. However, values were inconsistently quoted through the document and it was difficult to follow through some of the argument in the rainfall analysis.

The rational method was also used in the second Auckland guideline (Auckland Regional Council, ARC, 1992a), which was used to calculate a "water quality volume", the volume of stormwater required to be treated in a given storm. Runoff from the pervious and impervious areas was calculated separately and runoff coefficients differed depending on the drainage status of the soils. On poorly drained soils, it was suggested that runoff entered stormwater from both pervious and impervious areas, whereas on well drained soils, runoff only entered stormwater from directly connected impervious areas. A method to estimate sediment loads was provided and some long term stormflow weighted concentrations were tabulated for a number of pollutants, but there was no suggestion to calculate pollutant loads.

Among other treatment volume criteria, Urbonas (1991) recommended that the design storm for urban runoff quality control should be the frequent storm - ARI 1 to 2 months. Capturing the first 6 to 12.5 mm of runoff from the average density residential development in the US would then result in 80 to 95% capture of all runoff events (not runoff volume). NSWEPA (1996a) noted from US manuals of practice that design events for runoff quality control are the small, frequent events, generally less than the 1 year ARI runoff event. Some other treatment volume criteria were listed by Sharpin et al. (1995). These were:

- Washington DC - the permanent pool volume treats the first flush, while the extended detention volume should be 120 m^3/ha (12 mm) discharged over 24 hours.
- North Texas - for SS control in wet basins and wetlands, the volume equivalent to 50 mm of rainfall should be captured and in extended detention, the volume should be such that it drains over 24 to 40 hours.
- Florida - the extended detention volume of an extended detention wet basin should be equivalent to 25 mm of runoff with less than 50% of the volume discharged in 60 hours; the permanent pool volume should have an annual average residence time of 14 days (used in CD&M, 1993).
- Maryland - the extended detention volume in wet basins should be equal to the 1 year ARI runoff volume, detained for 24 hours; extended detention basins should hold a volume sufficient to detain the 1 year ARI runoff for 24 hours.
- UK - wet basins should be 120 m^3/ha from the total catchment, or 150 m^3/ha from the impervious area (12 and 15 mm respectively), equivalent to 2.5 times the mean storm runoff or a 14 day residence time.
- Denmark - wet basin volume should be 250 to 300 m^3/ha (25 to 30 mm).

Depending on the location and climate, the value of runoff to capture specified in these guidelines varied significantly.

5.1.2 Relating Runoff Capture to Pollutant Removal

Total pollutant removal is related to the volume of stormwater which is made available for treatment (capture) and the removal performance of the treatment. Thus, in an in-line structure, capture can be assumed to be 100%, but the removal performance is low, particularly on the higher flows. In an off-line structure, the capture is a proportion of the total runoff, but the removal rate may be up to 100%, depending on the type of device and parameter. The actual performance of an STM will also depend on whether removal is specified as a reduction in load or concentration.

The performance objective in ARC (1992a) was prescribed as removal of 75% of the SS load. The design storm which would obtain a water quality volume (i.e. treatment volume) sufficient to achieve this treatment performance was described in ARC (1992b). Rainfall modelling using a simulated series of Auckland storms was used to estimate the percentage of total rainfall captured by a device for different design storm volumes of the device. Where the increase in the percentage of rainfall captured became smaller than the relative increase in device volume, this point was chosen as the design storm volume. This storm was found to be 25 mm (3.8 times the mean storm volume, or the approximate 1 month ARI storm), for which an equivalent device volume would capture 80% of all rainfall. If all of this volume was to be treated completely (in storage), an overall removal of 75% of SS would be obtained (ARC, 1992b). It is apparent that total rainfall capture for the 25 mm design storm has been equated with the runoff capture and the load capture (i.e. all 80%). This would only occur if the rainfall runoff coefficient was constant and equal to one and the load is directly proportional to runoff.

In California, Camp Dresser and McKee, CD&M (1993), presented a curve for wet ponds of measured suspended solids removal to basin volume per unit volume of runoff. An 80% removal was recommended, based on the point where marginal increase in treatment efficiency against the marginal increase in size of treatment volume is significantly reduced. This corresponded to a basin size about 2.5 to 3 times the volume of runoff from the mean storm. A formula was presented to calculate basin volume, with mean storm depth and impervious area as independent variables. They used a stormwater runoff model and values of the mean storm event to produce charts of annual runoff capture versus basin volume per unit catchment area for a number of regions. These were prescribed for infiltration and extended detention dry basins, using 85% capture to obtain an equivalent removal to wet ponds. The premise of the volume of capture appeared to be on the percentage of runoff events captured rather than the percentage of runoff volume captured. Several curves were presented for different directly connected impervious areas, using a constant runoff coefficient for each. CD&M (1993) also proposed a 14 day detention time in wet ponds predicated on removal of phosphorus. The more conservative (larger) volume was recommended to be chosen.

In Maryland, the design criterion for wet ponds is to remove 70% of SS from the mean storm, which results in a 9 day residence time (Sharpin et al., 1995). This is equivalent to a volume of 90 m^3/ha (9 mm) for a catchment with 35% impervious area.

In order to reduce the average annual urban TP loads to around rural levels, the ACT Government (1994) specified that a 70% reduction in TP should be achieved.

Wanielista & Yousef (1986) provided calculations of efficiencies for an off-line infiltration basin on a small catchment in Florida, USA, using the Rational Formula to estimate the volume of runoff. Depending on the storage volume of the device, the average removal of BOD, SS, TN and TP together over a 20 year period was estimated for a percentage of storms captured. For example, in a 12.7 mm capacity storage, the authors expect 93% of storms to be treated to 100% efficiency, but 100% of storms to be treated to only 80% efficiency (Table 21). This can be interpreted to mean that some of the volume of 7% of storms will pass through a basin of this size without infiltrating. These efficiencies seem to be very optimistic compared to most of the other performance criteria and observed treatment performances. The State of Florida adopted treatment of runoff from the first inch of rainfall using off-line retention as their design criterion. A method to calculate swale size and swale berm sizes in order to achieve an equivalent performance to off-line storage was also given.

5.1.3 Specification of Pollutant Removal Related to Receiving Water Objectives

None of the above guidelines formally relate the respective performance objectives to any water quality protection objectives. Schueler (1987) compares average exceedence probabilities of different parameter event mean concentration values to US EPA threshold values, but there was no attempt to define a performance objective around this comparison. CD&M (1993) stated four levels of water quality protection goals with some very vague corresponding performance objectives related to existing standards. For example, for the water quality goal of "improved water quality", the future loadings performance objective was "lower than existing". It was, however, stated that the fourth level of water quality goals "meet water quality standards during storm events" would be unobtainable using current technology.

Quantitative analysis of loads (i.e. a load balance) pre- and post-development is very difficult to undertake, usually because of the high data requirements and the many variables involved with hydraulic characteristics and pollutant transport (Novotny, 1995). The only guideline to relate the performance objective to any kind of receiving water quality objective was for Ontario (OMEE, 1994).

Table 21. The percentage of storms captured to obtain a given removal for different storage volumes (from Wanielista & Yousef, 1986)

Average removal efficiency	Storage volume (mm)			
(%)	2.5	6.4	12.7	25.4
100	35	66	93	99
>96	43	74	97	100
>88	48	81	98	
>80	57	93	100	
>72	66	97		
>64	82	100		
>56	100			

OMEE (1994) specified four levels of minimum SS removal based on Ontario fish habitat protection guidelines for developing areas:

Level 1 - corresponding to habitats which limit the overall fisheries productive capacity (e.g. spawning areas, habitats supporting endangered species, highly productive feeding areas) - minimum 80% reduction in SS;

Level 2 - habitat is abundant and not a limiting factor for species productive capacity (e.g. feeding areas, unspecialised spawning habitats) - minimum 70% reduction in SS;

Level 3 - habitat has a low capacity for fish production and does not have reasonable potential for enhancement (e.g. municipal drains, highly altered watercourses) - minimum 60% reduction in SS;

Level 4 - minimum level of acceptable protection intended only for retro-fit and re-development situations - minimum 50% reduction in SS.

Whether SS removal is on a concentration or load basis was not specified, although it is probable that SS removals were specified as concentration. Other parameters are not considered, being regarded as sediment associated (i.e. settling of SS is assumed to also remove significant quantities of nutrients and metals etc.). A stormwater pollution model was used with rainfall data from 14 locations to determine that there was little variability in SS removal between different locations. Dynamic or quiescent settling was determined on the volume of water influent in relation to the volume of water stored in the facility. Particle size fractions and their corresponding settling rates were obtained from US EPA (NURP) data. Treatment volumes were estimated from curves of SS removal against storage volume (m^3/ha), derived using a stormwater rainfall-runoff model which included settlement in storage. One set of rainfall data was used to estimate the required storage volumes for four different treatment types, under the four different protection levels and four different impervious area ratios. An example of the resultant volume for a wet pond (assuming 24 hour detention) was 25 mm storage for level 1 protection in a catchment with 85% impervious area. Wet pond volumes ranged from 6 mm of storage (level 3 and 4, 35% impervious area) to 25 mm.

The basis on which SS removals were developed for each fish habitat protection level was not described. Nor was it shown how these removal rates would achieve maximum allowable SS concentrations in the receiving water corresponding to the fish habitat protection levels, as there was no reference to source concentrations. Thus, the performance objective may not bear any relation to the actual required SS removal. No consideration appears to have been made with regard to the effects of other contaminants on fish habitat, or the effects on other aquatic variables (aquatic vegetation, fish themselves, etc.) or on beneficial uses (water supply, recreation etc.).

In order not to stifle innovation and flexibility by assumed SWMP types in a sub-watershed management plan, the following procedure was recommended in the Ontario guidelines:

- determine watershed concerns;
- determine preliminary recharge estimates (water balance);
- identify SWMP's to address concerns;
- size SWM facility for water quality control based on desired level of protection;
- increase SWM facility active storage volumes and/or add SWMPs to provide for erosion and flood control volumes needed;
- cost SWMPs;
- rank SWMPs based on experience, Steering Committee direction and cost;
- select SWMP Plan;
- configure simulation tools to reflect SWMP plan;
- conduct evaluations and assessment;
- modify SWMP types and sizes if necessary in order to meet watershed or sub-watershed goals.

This would be followed by extensive evaluation and assessment of the SWMP plan, covering water quality treatment, flood control, erosion control and ecological impacts. The guidelines then went on to describe a hierarchy of preferred SWMPs - lot (source) controls, conveyance controls and end-of-pipe controls, within the context of stormwater management planning.

5.1.4 Controlling Stream-Bank Erosion

Another aspect of management of water quality in urban areas is the erosion of stream-banks. In order to control stream-bank erosion, Schueler (1987) and ARC (1992a) specify a design storm for "bank-full" flows, generally regarded as the flow rate responsible for the greatest change in stream channel geometry. Pre-development bank-full flows were reported to be the 2 year ARI event (Schueler, 1987), or the 1.5 to 3 year AEP event (ARC, 1992a). Due to the nature of urban areas (greater impervious area and resultant reduction in losses), runoff from urban areas tends to respond more rapidly and be of greater volume than non-urban areas. Thus, the design storm volume of the pre-development catchment will occur much more frequently post-development. In both reports, a methodology is provided to estimate the post-development storm which is equivalent to the pre-development bank-full storm. Thus, the required additional detention volume in order to reproduce the pre-development bank-full flow can be calculated. ARC (1992a) also provided an equation to estimate the annual sediment load in a channel or stream, based on long term mean concentrations of sediment.

OMEE (1994) requires post development peak flows to be controlled to pre development levels for the 2, 5, 25 and 100 year ARI storms and sometimes the 10 year ARI storm. However, erosion is accounted for by use of an erosion index (E) calculated for the pre- and post-development hydrograph. This is done by estimating the permissible velocity, calculated using particle size and charts plotting mean velocity above which erosion will occur, for example:

$$E = \Sigma(V_t - V_c) * \Delta t \qquad \text{for } V_t > V_c$$

where V_t = velocity in the channel at time t, V_c = the permissible velocity above which erosion will occur and Δt is the time step. The aim is to detain for 24 hours sufficient volume to maintain the pre-development hydrograph erosion index, typically for a 25 mm storm volume. This volume should be compared to the extended detention volumes tabulated for the various fish habitat protection levels outlined in Section 5.1.3 and the larger volume chosen.

Flow variability in Australian streams is much higher than in other countries (McMahon et al., 1992) from where this methodology was developed. As a result, stream channel morphology in Australia tends to vary over time as a result of the large range of event sizes and intervals. Thus the techniques discussed here should be approached with caution when considered for Australian situations.

5.1.5 Summary of Performance Objectives

A number of other guideline documents (EPA(SA), 1995; EPA(SA), 1996; GHD, 1995; SCCSMTF, 1992; Whelans, 1993) were reviewed, but did not stipulate a performance objective.

In Table 22, which summarises the performance objectives, the more recent guidelines have specified a percentage of removal as a performance objective, while in earlier ones a percentage of rainfall or runoff capture has been specified. The disadvantage of the earlier standards is that the proponent could demonstrate compliance to the guidelines in terms of stormwater volume capture without actually achieving a suitable removal of pollutants.

Table 22. Summary of performance objectives, generally for storage, in current practice

Location	water quality		volume capture	
	standard	in relation to	standard	in relation to
Florida, UK, California	TP control			14 day residence time
Washington DC, UK			max. 2.5 × runoff vol. from mean storm	capture of all volume of a majority of runoff events
Texas			runoff from 50 mm rainfall	
Auckland			60-75 mm from impervious area	capture 75-90% of runoff events, or capture of sub bank-full events
Maryland	remove 70% SS	from mean storm		
Auckland	remove 75% SS	point of diminishing return against treatment volume	25 mm (3.8 × runoff vol. of mean storm)	storage device which would capture 80% of rainfall volume
California	remove 80% SS	point of diminishing return against treatment volume		capture of a% of runoff events (infiltration & dry basin) or 2.5 to 3 × runoff from mean storm (wet ponds)
Ontario	remove 50 - 80% of SS	effect on fish habitat in receiving water		
others			12 mm, 25 mm or 1 year ARI storm runoff	

In most cases, only SS was used to define the water quality performance objective, either because it was considered more important than other parameters, or it was assumed that other major parameters behaved similarly to SS. In receiving waters in Australia, often it is nutrients that are of primary concern along with SS. The removal processes for nutrients, a large proportion being dissolved, can be considerably different from SS, requiring a more rigorous performance objective. In addition, it appears that a majority of the SS removal curves were derived from theoretical data (laboratory settling column tests or modelling using settlement rates) rather than actual field monitoring data. Schueler (1987) presented some pollutant removal data from field monitoring studies for a number of parameters, but did not relate this in any way to the capture volume.

It is not always clear whether the percentage removal of SS specified as an objective applied to the total removal (= capture × removal performance), or to the capture volume (= removal performance only). Different performance criteria were developed under different conditions (on-line/off-line) and so may not be comparable. In some cases, there is also little indication of whether the stated removals or performance objectives are in terms of a reduction in load or concentration. A performance objective specified as a load reduction could be achieved by reducing flow without changing concentrations, resulting in no water quality improvement in the immediately downstream waters. Specifying a performance objective as a concentration reduction may not achieve load reductions sufficent to lower concentrations in a receiving water where the catchment is not the sole load contribution. Thus the basis on which the performance objective may be specified (load or concentration) can be important.

In most cases, some form of rainfall frequency analysis was used to determine a capture volume. However, using rainfall frequency as a measure of capture would tend to over-estimate the total volume (ARC, 1992b) as 90% of events may only include 70% or so of the rainfall volume. This is because the biggest events contribute disproportionately bigger volumes. When the fact that loads increase with increasing runoff (i.e. increasing rainfall) is considered, then load capture could be significantly over-estimated. Many studies in rural areas have shown that the greatest loads occur at the largest flows despite having lower concentrations. In urban areas, the smaller events are more frequent and larger than in rural areas. However, loads may still be larger at higher flows as the change in concentration with flow is generally small (Novotny, 1995; Driver & Troutman, 1989), which has been observed in studies in some Melbourne catchments (GHD & EPA, 1981; Moodie, 1979). For a device of given size, the percentage of the maximum load that can be captured will be less than the percentage of maximum volume that is captured. As a result, the actual removal performance of such a device would be lower than that expected from the above guideline documents.

5.2 The Australian Setting for Stormwater Management Guidelines

5.2.1 National Water Quality Management Strategy

The National Water Quality Management Strategy (NWQMS) is being prepared to provide direction to government agencies for control of water quality across Australian waters, both fresh and marine. The NWQMS covers water quality benchmarks, groundwater management, rural, sewage and effluent management. The documents relevant to urban stormwater are Paper No. 10 "Guidelines for Urban Stormwater Management" (Commonwealth of Australia, 1996) and the "Water Quality Guidelines for Fresh and Marine Waters" (ANZECC, 1992). The guidelines are intended to:

- highlight limitations of existing management practices;
- promote organisational structures and procedures;

- assist in formulating and implementing stormwater management plans;
- promote protection of agreed environmental values and the need to determine maximum concentrations and loadings of pollutants to meet them;
- determine management practices necessary to limit export of pollutants from urban areas consistent with sustainable levels;
- provide evaluation techniques, monitoring approaches and community participation techniques;
- provide a selection of management practices.

The guidelines prescribe the preparation of an Urban Stormwater Management Plan (USMP) to facilitate management of urban stormwater. Within this USMP there are four levels of management - catchment, municipal, stormwater and local area, for which individual plans are prescribed.

Catchment management plans prescribe:

- sustainable concentrations of potential pollutants and flow regimes for critical nodes in the catchment;
- allocation of sustainable flows and constituent concentrations and loads across land use categories;
- permissible land uses.

All current and known future environmental values should be identified in the USMP. Water quality objectives (ANZECC, 1992; Victorian Government, 1988) need to be translated into sustainable loadings and concentrations (for the discharge and receiving water body). This requires assessment of flow volumes, peak discharge and flow duration and is preferably undertaken using water quality models.

Municipal plans should be developed to meet the constraints of sustainable flows and constituent loads specified in the catchment plan. They:

- prescribe the pattern of development;
- contain information relevant to the stormwater management plan.

The stormwater management plan prescribes local environmental values and uses including:

- translation of catchment objectives and flow into local management plans;
- the range of land use and location constraints;
- management practices related to flow and pollutant export;
- the range of corridor or drainage measures related to flow attenuation, pollution interception, provision of open space and recreation, conservation areas, stormwater re-use requirements and retention of natural values of streams.

Local area management plans should focus on specific functions, prescribing individual program area management practices. Reference to the stormwater management plan is required when considering local network design parameters, model analysis of overall water quality and hydraulic performance.

5.2.2 Water Quality Objectives in Victoria

The State Environment Protection Policy (SEPP) - Water of Victoria (Victorian Government, 1988) outlines water quality objectives for the waterways of Victoria, with the major goal:

> *"to attain and maintain levels of water quality which are sufficient to protect the specified beneficial uses of the surface waters of the policy area".*

The water quality objective values depend on the classification of the water and the beneficial uses ascribed to that waterway or catchment. The various classifications and beneficial uses are defined in Figure 13. The SEPP covers policy for drainage system design which ensures that erosion of streams and other drainage lines is minimised and makes allowance, where practicable, for the attenuation of peak runoff and the retention and trapping of contaminants in runoff.

The SEPP is a statutory instrument, so water quality criteria in theory can be enforced through regulation and its provisions are legally enforceable and binding on all private individuals and organisations, government departments and agencies and industry. However, the SEPP indicates that implementation of stormwater treatment may be staged, with priority given to existing problems and areas under immediate threat. It is also implied that less stringent policies could be allowed in instances where it is not possible to meet emission or discharge limits using reasonably available technology for that industry or the discharge would not adversely affect any protected beneficial uses of the waters of the policy area.

Catchment classifications (segments):

- Aquatic reserves (proclaimed reference areas);
- Parks and Forest;
- Estuarine;
- Coastal Waters;
- General (other).

Beneficial uses and where they are protected are:

- maintenance of natural aquatic ecosystems and associated wildlife - *all segments*;
- water based recreation - primary, secondary, aesthetic enjoyment - *all segments*;
- agricultural water supply - *parks & forests and general*;
- potable water supply - *aquatic reserves, parks & forests and general*;
- production of molluscs - *all segments*;
- commercial and recreational use of edible fish and crustacea - *all segments*;
- industrial water use - *all segments except aquatic reserves*.

Figure 13. SEPP definition of catchment classifications and beneficial uses

The primary objective of the SEPP is to maintain water quality of all waters at background levels. The background level is the indicator level in waters outside the influence of any waste containing a measurable level of that indicator (i.e. a natural catchment in most cases). The SEPP defines a number of water quality indicator parameters and maximum limits on contaminant concentrations in discharges, some of which are listed in Table 23. Where background levels do not comply with these water quality objectives, the objective is the background level. There are general water quality objectives set out for all waters in Victoria, but in some instances, special values have been determined for specific catchments.

Table 23. Maximum acceptable limits for selected quality parameters set by the SEPP

	As (mg/L)	Cd (mg/L)	Cr (mg/L)	Cu (mg/L)	Ni (mg/L)	Pb (mg/L)	Zn (mg/L)	E. Coli[1] (organisms/100 mL)	D.O.[2] (mg/L)	S.S.[3] (mg/L)	Phosphorus (mg/L)	Nitrogen (mg/L)
DRAFT SCHEDULE F7 (WATERS OF THE YARRA CATCHMENT)												
Aquatic Reserves	0.01	0.0004	0.002	0.001	0.03	0.001	0.01	N[4]	N	N	N	N
Parks and Forests	0.05	0.002	0.01	0.005	0.15	0.005	0.05	200	8 (85)	5 (10)	0.03	0.2
Rural Eastern Waterways	0.05	0.002	0.01	0.005	0.15	0.005	0.05	200	6 (60)	20 (40)	0.05	0.6
Rural Western Waterways	0.05	0.002	0.01	0.005	0.15	0.005	0.05	200	6 (60)	25 (90)	0.05	0.6
Urban Waterways	0.05	0.002	0.01	0.005	0.15	0.005	0.05	200[a] / 1000[b/c]	6 (60)	25 (60)[c]/50 (90)[d] 25 (90)[b]	0.08[a] / 0.1[b]	0.9
Upper Estuary	0.05	0.002	0.01	0.005	0.15	0.005	0.05	1000	6 (60)	50 (90)	X	X
Yarra Port	0.05	0.002	0.01	0.005	0.15	0.005	0.05	1000[5]	6 (60)	25 (60)	X	X
DANDENONG VALLEY												
Mordialloc and Kananook Creek	0.02	0.006	0.02	0.01	0.04	0.02	0.04	1000	4.0 (45)	25 (80)	Q[6]	Q
Tributaries of Mordialloc and Kananook Creeks	0.1	0.0008	0.02	0.02	0.06	0.05	0.25	1000	4.5 (45)	25 (80)	Q	Q
Patterson River	0.01	0.003	0.01	0.005	0.02	0.01	0.02	200	4.0 (45)	25 (80)	Q	Q
Dandenong Creek	0.1	0.0008	0.02	0.02	0.06	0.05	0.25	1000	4.5 (45)	25 (80)	Q	Q
WESTERN PORT												
Peninsula	-	0.0004	0.05	-	0.1	0.03	0.03	1000 (2000)	6 (80)	-	Q	Q
Eastern Catchment	-	0.0004	0.05	-	0.1	0.03	0.03	200 (400)	6.5 (85)	-	Q	Q
WATERS OF VICTORIA												
Schedule F2 (Waters of the Maribyrnong River and Tributaries)	0.05	0.0004	0.01	0.01	0.025	0.004	0.05	1000 (200 where swimming occurs)	5.0 (50)	25 (80)	Q	Q
General Surface Waters	0.01	0.003	0.01	0.005	0.02	0.01	0.02	1000 (200 where swimming occurs)	5 (60)	25 (80)	Q	Q

Notes:
1. Values are limits for geometric means based on at least 5 samples in 42 days. In addition, not more than 20% of samples may exceed twice the value of the limit.
2. Minimum concentration of Dissolved Oxygen. Minimum% saturation given in brackets. For estuarine reaches of Maribyrnong River and Kororoit Creek, minimum% saturation is 60%.
3. Annual median limit for Suspended Solids. In addition, 90% of samples must be below the value given in brackets. For tributaries of the Upper Yarra, the limit is 20 mg/L and 90% of samples must be below 80 mg/L.
4. "N" means natural background level.
5. Limit of 1000 org./100 mL must not be exceeded for more than 10% of samples taken in a year.
6. Qualitative objective only. The nutrient objective states "Water shall be free of substances in concentrations which cause nuisance plant growth".

"a" means the value is the objective for the Yarra River main stream.
"b" means the value is the objective for tributaries of the Yarra River.
"c" means the value is the objective for the urban waterways segment of the Yarra River mainstream upstream of its confluence with Diamond Creek.
"d" means the value is the objective for the urban waterways segment of the Yarra River mainstream downstream of its confluence with Diamond Creek.
"e" means the value is the objective until 31 December 2002, when the objective becomes 200 to protect the beneficial use of primary contact recreation.
"f" means the objective for waters upstream of any authorised discharges of treated sewage or with no authorised discharges of treated sewage.
"X" means to be determined.

5.2.3 Use of NWQMS and SEPP Water Quality Objectives for Stormwater Management in Victoria

The basis for determining compliance of the water quality limits depends on the parameter, but is not well explained in the SEPP document (Victorian Government, 1988). Compliance values of water quality in Schedule F7 (EPA, 1995) are calculated on a different basis from those in the Schedule B of the SEPP, but are better defined. Annual 50th (median) and annual 90th percentile values of concentration of pollutants are required in general to be maintained below corresponding indicator levels. For example, the annual 50th percentile concentration of SS in the urban waterways in the Yarra catchment should be below 50 mg/L, while the 90th percentile should be below 90 mg/L (equivalent values for general surface waters in Victorian Government, 1988, are 25 and 80 mg/L respectively). Other parameters are required to be maintained below a certain level with a maximum percentage variation and in the case of nutrients, concentrations during base flows are required to be maintained below a certain level.

It is assumed that the maximum, mean, median, or 90th percentile water quality objectives apply over the whole range of possible flows. Thus, only the maximum and 90th percentile objective values would apply in wet weather flow conditions, as less than 50% of days would correspond to wet weather events assuming measurement on a daily basis. It is assumed that for toxicants (heavy metals etc.) the limit value should not be exceeded at any time.

There is little information relating sustainable loadings to different species and the SEPP type concentration objective values do not provide sufficient information to allow direct calculation of sustainable loads. Thus, determining performance objectives on sustainable load principles will be difficult. Given the necessity to simplify the performance objective commensurate with available data and knowledge, it would be more appropriate to base a performance criterion on SEPP type wet event water quality objective values. There is sufficient concentration data available to do this as described in Chapter 3. Chapter 6 develops a methodology to derive a performance objective which incorporates the wet event SEPP concentrations.

6. STORMWATER MANAGEMENT GUIDELINES

Before planning and design of urban stormwater treatment can be undertaken there are a number of factors that need to be determined:

- what and where are the receiving waters;
- what are the environmental values and beneficial uses of the receiving waters (or what could they potentially be);
- in an existing urban area, what are the key parameters affecting the receiving water and what is the susceptibility of the receiving water to degradation from the key parameters;
- what would background levels of pollutants be in the receiving waters and what are the current loads and concentrations of pollutants in runoff (applies mainly to existing developed areas);
- what are the principal processes of removal of pollutants into stormwater;
- does first flush occur, and if so, what proportion of the load occurs in the first flush.

In order to provide a practical approach to achieving an appropriate improvement in stormwater quality, these factors need to be addressed.. In the case of the first two points and part of the fourth, they are defined in the SEPP - Waters of Victoria and the various schedules.

The following sections describe some possible approaches to the development of stormwater management guidelines.

6.1 Estimation of Pollutant Loads

Estimation of pollutant loads at the sub-catchment scale is required in order to determine the amount of pollutant to be removed. Ideally, pollutant loads should be calculated from measured flows and concentrations. However, monitoring urban catchments at an appropriate temporal and spatial scale is uneconomic, although some basic measurements and a knowledge of catchment land uses could be used to find where a catchment lies in the range of concentrations set out in Chapter 3.

Without monitoring, stormwater concentrations could be estimated from the mean values provided in Chapter 3. However, this would be a poor option because of the spatial and temporal variability in pollutant EMCs. The added difficulty in using this sort of data is determining the areas of the different components of land use in the catchment. Ideally, these EMCs should be flow weighted to take into account the differences in flow from different land uses. This requires either prior or existing monitoring from all of the sub-catchments containing single land uses, or estimating flows from rainfall using a runoff coefficient or model.

Alternatively, a statistical method using rainfall intensity-frequency-duration curves and pollutant concentrations associated with these curves (i.e. EMCs associated with each different rainfall event) could be used. This does not differ greatly from the methods described by ARC (1992a) and Schueler (1987), except for a more accurate estimation of pollutant loads. However, this method requires sufficient pollutant concentration data at various locations to enable a statistical association between rainfall and pollutant concentrations to be developed.

It should be noted that several existing manuals and guidelines have attempted to address this issue, but have not produced a sound method. It is considered that the use of mean EMCs calculated from world-wide data and factored for Australian data, will provide more appropriate estimates of pollutant concentrations.

6.2 Pollutant Removal

The approach of a number of current guidelines to treatment is purely from a pollutant removal point of view (i.e. treat a certain volume of runoff). This method generally aims to achieve an appropriate outcome by prescribing cost effective treatment, but fails to allow for small inflow pollutant concentrations where large removal may not be necessary. In general, the pollutant removal curves (e.g. pollutant removal versus volume of storage per unit catchment area) do not take into account the variability (both temporal and spatial) which may significantly affect the accuracy of the curves. There is also no direct connection between the performance objectives, source pollutant concentrations and loads, and receiving water quality objectives.

An alternative method would be to use the bi-variate treatment equations developed by Duncan (1996) (Section 4.2.1) and vary the size dimension within realistic limits until the estimated outflow concentration converges on the target value (presuming that inflow concentration has been estimated). However, this technique would suffer from the same failing as above in that the variation in removal behaviour would not be taken into account.

Because pollutant removal can be variable, it may be necessary to develop pollutant removal curves for say the 90% confidence limit (i.e. 90% confident of the given removal) against the various treatment parameters. Alternatively, the largest percentage of events where outflow concentration can exceed target concentrations could be specified, such that dilution in the receiving waters will enable target concentrations not to be exceeded. In any analysis of pollutant removal, the variability of inflow and treatment should be taken into account in a statistical way.

Most of the existing guidelines and manuals which provide some form of performance objective have related these to treatment rather than source control. Non-structural source controls are listed and described in CD&M (1993), EPA(SA) (1995), EPA(SA) (1996), SCCSMTF (1992) and Whelans (1993). However, little information is provided on how they perform alone or in combination, or the most effective way to implement them.

6.3 Performance Monitoring

The guidelines should advocate some monitoring of control measures. This would enable better estimation of inflow concentrations and effectiveness of control measures in the future. As a result, development of better performance objectives for Victorian conditions could be developed with an improved understanding of removal processes. The guidelines should also suggest which parameters should be measured and an appropriate frequency of measurement.

6.4 Performance Objective

In general there are two basic approaches to guidelines for urban stormwater treatment:

- identify values of receiving waters and specify the level of treatment to protect the values; or
- prescriptive requirements to pass a certain volume of flow through the treatment devices which are designed to meet minimum treatment standards.

The latter approach is the one commonly used in the guidelines reviewed above, which sacrifices flexibility for simplicity. The former approach can be treated in two ways by:

- requiring proponents to assess the assimilative capacity or resilience of the receiving waters and demonstrate the ability of control measures to provide the required level of protection; or
- prescribing minimum design standards to be adopted for different levels of environmental value (i.e. using the SEPP water quality criteria).

For any approach selected, a design methodology must be prepared to enable proponents to determine appropriate selection and sizing of treatment devices. This must take into account the target and the technical and economical feasibility of the process.

From the literature it was found that the performance objectives adopted by other administrative jurisdictions are generally specific to those localities. They also appear to poorly define the relationship between the performance objective, stormwater runoff flow and loads and the receiving water quality outcome.

6.4.1 Ideal Objective

The proposed performance objective[1] to be adopted for Victoria should build on the better components of the approaches used in existing standards, make use of all available data, while taking into account the circumstances and characteristics in Victoria. The main ideals the performance objective should try to achieve are as follows:

- simple to use,
- practical and cost effective,
- prescriptive,
- encouraging innovation,
- flexible, and
- justifiable and defensible (i.e. based on sound scientific method).

It should be noted that some of these ideals are conflicting. The largest conflict to resolve is the degree of prescription in the performance objective and methodology, to secure acceptance of the guidelines by the wider community and ensure adequate protection of receiving waters, while not inhibiting innovative practices and improvement on current technology. The performance objective and methodology must be sufficiently prescriptive to ensure a minimum treatment standard which is both attainable and effective, but not so prescriptive that freedom to explore new technologies is limited.

The other conflict to resolve is to be simple and practical, while obtaining a justifiable and defensible outcome based on sound technical methods. One way to resolve this conflict is to make sure that the outcomes are fully transparent. That is, all assumptions, uncertainties and steps are documented and the whole methodology is transparent to the user.

The performance objective should also be equitable and applicable to all organisations or communities who discharge to urban stormwater. This is particularly difficult when addressing the disparities between constraints in new "green-fields" development and in existing urban areas with respect to area available, cost, and differences in regulatory controls. Making the performance objective a longer term target for existing areas may also help to make implementation more equitable, as measures could be installed in existing areas as old infrastructure is replaced.

Achieving the SEPP values of water quality objectives for stormwater is likely to be difficult, due to their low value relative to stormwater runoff concentrations and the inability of existing technology to achieve such low concentrations within current economic and space constraints. This is particularly the case for dissolved pollutants, such as N and P. Thus using the SEPP water

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[1] The performance objective is not to be confused with the water quality objectives. The performance objective specifies an action to be taken (e.g. remove 80% SS on a concentration basis). The water quality objective specifies an outcome to be achieved (e.g. the 90th percentile value of SS concentration should be less than 80 mg/L).

quality objective concentration values as the performance objective directly is unlikely to produce a guideline which is acceptable to developers and drainage authorities and as a result, uptake is likely to be low.

Most of the SEPP objective values are prescribed in terms of a concentration limit, although the NWQMS specifies conversion of these into "sustainable loads". However, given the current scarcity of urban stormwater flow and concentration data, this latter step will often be very difficult. Therefore, it would seem appropriate at this time to prescribe a performance objective in terms of pollutant concentration.

It is important that a methodology be built around a performance objective or criterion which has a strong basis in existing data and reasonable simplifications and assumptions. Such a methodology would indicate that the performance objective adopted is achievable. This is the difficulty with adopting methodologies and performance objectives from recent guidelines, as supporting data, assumptions and/or simplifications are not provided or are unrealistic. In addition, many of them were derived with a certain locality and climate in mind, resulting in somewhat site specific standards.

6.4.2 Derivation of Fine and Dissolved Pollutant Performance Objective

An appropriate point to begin deriving a performance objective is from where data are available and some relationships have been developed. As described in Section 4.2.1, relationships have been established for average treatment of a number of parameters in storage. Also available is information regarding typical event mean concentrations for a number of parameters (Chapter 3). This data can be used directly in the storage treatment equations.

There is some scope for relating SEPP or ANZECC water quality objectives to the performance objective. For instance, the SEPP water quality objective for SS specifies the maximum limit of the 50th percentile (median) and 90th percentile values. The latter limit is in most cases likely to correspond to wet event conditions and as such could be an ideal limit to compare storage to removal. The SEPP water quality objectives for other parameters (particularly metals) are generally threshold limit concentrations based on toxicity, which cannot be exceeded at any time. Using storage as the treatment method and the wet weather limits of the SEPP objectives as the target value will provide a sound basis for the development of a performance objective.

It should be noted that this is only one of a number of possible approaches to deriving a stormwater management guideline (see Table 22). However, it is one which attempts to utilise as much available data as possible and relate the performance objective to individual catchments. Another approach would be to determine the volume of runoff capture required from a daily load exceedence and then the equivalent pollutant removals. However, the basis for selection of the appropriate exceedence could not be defined (see Appendix C).

If storage treatment was to be used as a basis for the performance objective, a difficulty arises in selection of an appropriate area ratio to adopt in the storage removal equations. There are two possible methods to determine this:

- estimate typical area ratios used in existing treatment ponds and wetlands;
- estimate the optimum capture of stormwater volume which would receive full treatment and for an optimum storage depth, calculate an equivalent area ratio.

6.4.2.1 Optimum Capture Volume

Because many existing ponds were originally constructed purely for water quantity control, the direct area ratio method may be biased towards this objective rather than the optimum water quality control objective. Consequently the latter method was explored and is described in full in Appendix C. Unfortunately, an optimum volume or load capture could not be found, as the large events contribute a considerable proportion of the cumulative runoff volume and load (see Appendix C). In addition, each step in the procedure involved significant uncertainty (in particular calculating runoff using a rainfall-runoff coefficient and calculating load using a load-flow relationship), potentially resulting in a very high uncertainty in the value obtained. Thus, a modification of the direct area ratio method is proposed and is described below.

6.4.2.2 Storage Area Ratio

A storage area of 1% of the catchment appears to be the smallest area ratio that produces reasonable reductions in concentrations of SS (40 to 80%), TP (35 to 45%), Pb (60 to 85%) and Zn (30 to 80%) (Appendix D). It is also only marginally greater than common values quoted for installed water quality treatment ponds. To confirm this, various storage volume design criteria (Section 5.1) were assembled and the equivalent area ratios determined, based on a 50% impervious urban area (Table 24). The average pond and wetland depths from studies of pond/wetland performance were used to estimate the area ratio (1.4 and 0.66 m respectively, or 1.2 m average). These depths are within the ranges specified by a number of existing stormwater treatment guidelines (generally 1 to 2 m for ponds and 0.1 to 0.3 m over two thirds of the storage area for wetlands). Daily rainfall data for Yan Yean (as a substitute for Melbourne) and Jervis Bay (as a substitute for Sydney) were used to determine the rainfall duration curves and partial series frequency curves (see method and curves in Appendix C). These stations combined long records of data with few missing or accumulated rainfall days, as identified by Lavery et al. (1992). Using the rainfall-runoff coefficient relationship described in Appendix C for a 50% impervious area, runoff was calculated from the rainfall exceedence curves. Although a 2 year ARI storm frequency was not specified in any of the criteria, it is frequently used as the "bank-full" flow frequency and specified for control of stream-bank erosion and was included for comparison.

An illustration of the effect of area ratio on outflow concentrations is provided for a number of parameters in Appendix D. From Table 24, an area ratio of 1% of the catchment area is not an unreasonable expectation for storage treatment.

6.4.3 Derivation of Gross Pollutant Performance Objective

The performance objective described so far is incomplete in that it does not take into account gross pollutants. Gross pollutants consist of both vegetative matter (the predominant load) and human derived material. Normal measurements of pollutants in stormwater do not include gross pollutants, primarily because they do not fit in the sample bottles. However, vegetative matter in particular breaks down in the receiving water (or treatment storage) releasing the constituent nutrients.

Even though the input concentrations used in the storage removal relationships do not take into account pollutant load carried in gross pollutants, the output concentrations do, as it is a measure of the fine and dissolved as well as broken down vegetative matter pollutants. However, removals calculated for other forms of treatment often do not take into account nutrients contained in vegetative matter, which may bypass or pass through the device intact. Thus, it would be necessary to determine the total concentration of nutrients in both the water and vegetative matter to determine the equivalent removal to storage. Preliminary analysis of vegetative matter sampled from areas in Coburg (Melbourne) shows that the TP and TN loads of the vegetative matter is between one and two orders of magnitude less than the fine and dissolved TP and TN loads (i.e. 1 to 10%). Thus the proportion of the TP and TN removed in the treatment device from vegetative matter may be negligible compared to the removal of fine and dissolved nutrients. Therefore, it will be sufficient to prescribe removal of fine and dissolved nutrients only.

Table 24. Summary of area ratios equivalent to various runoff capture volume criteria for Sydney and Melbourne

Criterion (capture)	Reference	Storm vol. (mm)		Daily exceed. (%)		Runoff (mm)		Equivalent area ratio (%)^0		Mean area ratio (%)^1	
		YY^2	JB^2	YY	JB	YY	JB	YY	JB	YY	JB
90% of runoff events	ARWB (1991)	16	28	2.5	2.7	3	10	0.2 0.5 0.3	0.7 1.5 0.8		
80% of the volume from all rainfall events	ARC (1992a)	12.5	28	3.8	2.7	2	10	0.1 0.3 0.2	0.7 1.5 0.8		
runoff from a 1 inch storm	Wanielista & Yousef (1986)	25	25	1.0	3.3	8	8	0.6 1.2 0.7	0.6 1.1 0.7		
runoff from a 50 mm storm	Sharpin et al. (1995)	50	50	0.1	1.1	28	28	2.0 4.2 2.3	2.0 4.2 2.3		
1 inch of runoff	Schueler (1987)	47	47	0.2	1.3	25	25	1.8 3.8 2.1	1.8 3.8 2.1		
30 mm of runoff	Sharpin et al. (1995)	52	52	0.1	1.0	30	30	2.1 4.6 2.5	2.1 4.6 2.5		
1 inch of runoff from impervious area	Galli (1992)	47	47	0.2	1.3	12.5	12.5	0.9 1.9 1.0	0.9 1.9 1.0		
2.5 × mean storm runoff	Schueler (1987) & CD&M (1993)	4.6^3	9.1^3	12	10	0.5	2.5	0.1 0.1 0.1	0.2 0.4 0.2		
3 × mean storm runoff	CD&M (1993)	4.6^3	9.1^3	12	10	0.6	3.0	0.1 0.1 0.1	0.2 0.5 0.3		
80% SS removal - pond	OMEE (1994)	42	42	0.2	1.6	19	19	1.4 -	1.4 -		
80% SS removal - wetland	OMEE (1994)	28	30	0.6	2.7	10.5	10.5	- 1.6	- 1.6		
2 month ARI storm^4	Urbonas (1993)	15	20	3	4.5	2.5	6	0.2 0.4 0.2	0.4 0.9 0.5		
1 year ARI storm^5	Sharpin et al. (1995)	32	55	0.45	0.9	13	33	0.9 2.0 1.1	2.4 5.0 2.8	0.9 1.7 1.0	1.1 2.3 1.3
2 year ARI storm^4		38	70	0.3	0.5	18	50	1.3 2.7 1.5	3.6 7.6 4.2	0.9 1.8 1.1	1.3 2.7 1.5

Notes: 0. three figures in each cell are for ponds, wetlands and overall average respectively;
1. not including and including the 2 year ARI storm values;
2. YY = Yan Yean, JB = Jervis Bay;
3. mean storm depth;
4. 50% exceedence from partial series; 2 month ARI > 10 mm, 2 year ARI > 30 mm for Yan Yean and 50 mm for Jervis Bay.
5. 8.3% exceedence from partial series > 10 mm

Removal of fine and dissolved pollutants from stormwater generally relies on sedimentation in relatively still water, fine grade filtering, or biological activity. Removal of gross pollutants, however, generally relies on coarse filtering or physical trapping by some method as well as sedimentation of heavier materials. As can be seen in Table 19, removal of gross pollutants is generally achieved by devices specifically developed for this purpose. Gross pollutants also accumulate rapidly in standard pollutant treatment devices, quickly reducing their effectiveness and causing other problems (in particular, aesthetic appearance of storages and clogging of filtration and infiltration devices). Capture of gross pollutants in some traps decreases with increasing flow and capture is likely to be either relatively constant regardless of inflow load, or decrease with increasing inflow load. This contrasts with fine and dissolved pollutants, for which removal generally increases with increasing inflow concentration. Thus, applying the same removal standard to gross pollutants as the fine and dissolved pollutants may be inappropriate.

Analysis of various methods of gross pollutant removal was undertaken in order to determine an appropriate level of removal required (Table 25). Some of these results (particularly the first three) are very approximate, but give an indication of the magnitude of removal. The Coburg results (Robin Allison pers. comm.) indicate that installation of litter baskets in side entry pits (SEPs) or use of a continuous deflective separator device covering a large proportion of the catchment will obtain at least a 65% removal of gross pollutants. The Coburg study has also indicated that using a street sweeper to vacuum litter from the baskets every 4 to 6 weeks would be much more economical than actual street sweeping, which to achieve a reasonable removal requires at least a weekly frequency. On this basis, with a lack of data to support any other value, a 65% removal by mass is deemed appropriate. Street sweeping can generally be expected to remove particles greater than 2 mm in size and the CDS device can remove all particles greater than the screen aperture size and a proportion of particles greater than 1 mm in size. It is therefore recommended that gross pollutant removal should be specified for a size range greater than 2 mm.

Table 25. Estimated gross pollutant removal by various methods

Method of gross pollutant removal	Approx. removal (% by mass)	Source
trash rack	10	Sydney/Canberra
“gross pollutant trap”	15	?
floating boom	10	Melbourne Water
litter baskets (covering 50% of SEPs)	65	Coburg (R. Allison)
continuous deflective separation	95	Coburg (R. Allison)
street sweeping	40	various published data

6.4.4 Final Definition

Assuming that storage treatment methods provide the best overall treatment performance for a range of parameters (a not unreasonable assumption) and using this as a basis for the performance objective and adding a gross pollutant removal requirement, these two elements together will achieve a significant improvement on previous performance objectives. This performance objective, while being simple, still provides flexibility for innovation, as complete freedom would be left to the proponent to select whatever methods are appropriate to meet the performance objective. On the other hand, it is also sufficiently prescriptive to provide a considerable contribution towards protection of receiving water quality. The proposed performance objective is described in Figure 14.

If the guidelines were to be implemented in a whole catchment framework, an integrated stormwater management approach could be adopted, where treatment would occur in the most appropriate locations and across a range of scales (local sub-catchment to whole region). Where the performance objective cannot be achieved in one area, contribution could be made through drainage tariffs, for example, toward implementing treatment on a catchment scale, or improving treatment in other areas where the performance objective can be met economically.

A Performance Objective for Best Practice Environmental Management Guidelines in Urban Stormwater

🔔 *The concentration of SS, TP, TN, Pb and Zn shall be reduced by the smaller of:*

- *the equivalent to that of the average on-line storage, or*
- *that required to achieve the corresponding statutory water quality objective value appropriate to wet event conditions.*

🔔 *The mass of gross pollutants greater than 2 mm in size shall be reduced by 65%.*

Determined by:

✽ estimating the stormwater event mean runoff concentrations of SS, TP, TN, Pb and Zn;

✽ estimating the storage outflow concentration corresponding to these runoff concentrations, using a given area ratio;

✽ determining the wet event SEPP water quality objective values and comparing the values to the mean storage outflow concentrations.

Figure 14. A performance objective for best practice management guidelines in urban stormwater

6.5 Selection of Appropriate Treatment Controls

The performance objective derived in the previous section needs to be incorporated into a methodology, which takes the user through the following steps:

- establishing the need to implement stormwater pollution control;
- improving knowledge of stormwater processes and placing stormwater pollution control within the context of urban stormwater planning and design;
- estimating the required performance objective;
- selecting appropriate treatment control methods to meet the performance objective in the area considered.

The first two steps can be provided by information described in Chapter 2. The latter two steps are of more interest here and are expanded in Table 26. An example is provided to show some of the outcomes and demonstrate the use of the methodology (see Appendix E).

Table 26. The methodology steps to select appropriate treatment control devices

General	Detail
1. Define water quality objectives	- Identify catchment location. - Identify receiving waters. - Define beneficial uses. - Adopt appropriate Victorian SEPP water quality objective values.
2. Estimate catchment pollutant concentrations	- Estimate proportions of major land use groups. - Estimate mean wet event SS concentration (C_{in}) from Figure 15(a). Measured EMCs should be used if available for sufficient storms. - Factor concentrations to Victorian conditions and to allow for different geology[2].
3. Determine removal requirement	- For C_{in} of SS, estimate mean removal based on storage treatment, for 1% area ratio (C_{out}) from Figure 15 (b). - Note the SEPP 90th percentile objective value (C_{SEPP90}). - Calculate the amount to be removed, as concentration, being the lesser of (C_{in}-C_{SEPP90}) and (C_{in}-C_{out}).
	Repeat steps 2 and 3 for TP, TN, Zn and Pb, using Figure 16 to Figure 19 and appropriate SEPP criteria values (TP & TN criteria are related to prevention of nuisance growth, metals to toxicity thresholds).
4. Determine gross pollutant removal	Gross pollutants removal is independent of storage treatment. Adopt overall removal of gross pollutants (greater than 2 mm) is 65%.
5. Screen treatment controls - create short-list of feasible treatments	Select appropriate treatment controls according to: - topography/slope, - soils, - area available and catchment area, - groundwater/bedrock depth, - temperature concerns (relate to water quality criteria), - water quantity mitigation, - environmental and community amenity; using screening tools in Figure 20 to Figure 27.
6. Select treatment control	Optimise various treatments based on area, total removal required and mean removals obtained from Table 19.

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[2] Very little comparison or analysis of catchments of different geology which are otherwise similar have been undertaken or published, so geology is not taken into account here.

6.5.1 Definition of Water Quality Objectives

As discussed previously, the receiving waters should first be identified. These are then classified according to type (e.g. aquatic reserve, parks and forest), which may be specified in the appropriate schedule of the SEPP (Victorian Government, 1988). The beneficial uses as defined in the same schedule are then determined (there may be more than one). The appropriate values of the water quality objectives are identified for each of the beneficial uses and/or receiving water classification and the lowest value selected for each parameter.

The guidelines should define all schedules in the SEPP and their areas of coverage. Where no schedule covers the catchment in consideration, the guidelines should direct the proponent to the main SEPP document (Victorian Government, 1988) and ANZECC (1992) as appropriate.

6.5.2 Estimation of Catchment Pollutant Concentrations

Using the diagrams labelled (a) in Figure 15 to Figure 19, which are simplified from those presented in Section 3.1, the event mean runoff concentrations can be estimated, by weighting the different land use concentrations by area. Only mean concentrations for SS, TP, TN, PB and Zn are estimated, as they represent the range of different removal processes. In any case, the sample sizes used to obtain the event mean concentrations and/or storage treatment relationships for other parameters were small enough to significantly increase the uncertainty in these values. Runoff concentrations are calculated for the Blackburn Lake example in Appendix E.

Adjustment factors to apply to the worldwide mean concentrations to account for Victorian conditions are (from Table 12):

SS × 1.0
TP × 0.8
TN × 1.0
Pb × 1.0
Zn × 2.3

6.5.3 Determination of Removal Requirement (Performance Objective Value)

Once the land use area weighted event mean concentration value is obtained, it is simply a matter of reading off the storage outflow concentration on the Y-axis of the diagrams labelled (b) in Figure 15 to Figure 19. This outcome should be compared to the appropriate SEPP value (Section 6.5.1) and the larger used as the performance objective. That is, if the SEPP objective value is greater than the possible storage outflow concentration, it is only necessary to achieve the SEPP value, but if the reverse is true, then only the achievable outcome (the storage outflow concentration) is prescribed. The figures also show the equivalent percentage of pollutant concentration remaining in the outflow and the equivalent percentage of pollutant stored (presumed removed). The value can be expressed as outflow concentration in mg/L, percent remaining, or percent stored. The example for Blackburn Lake (Appendix E) illustrates potential values.

The only other specification required is to remove 65% by mass of gross pollutants greater than 2 mm in size.

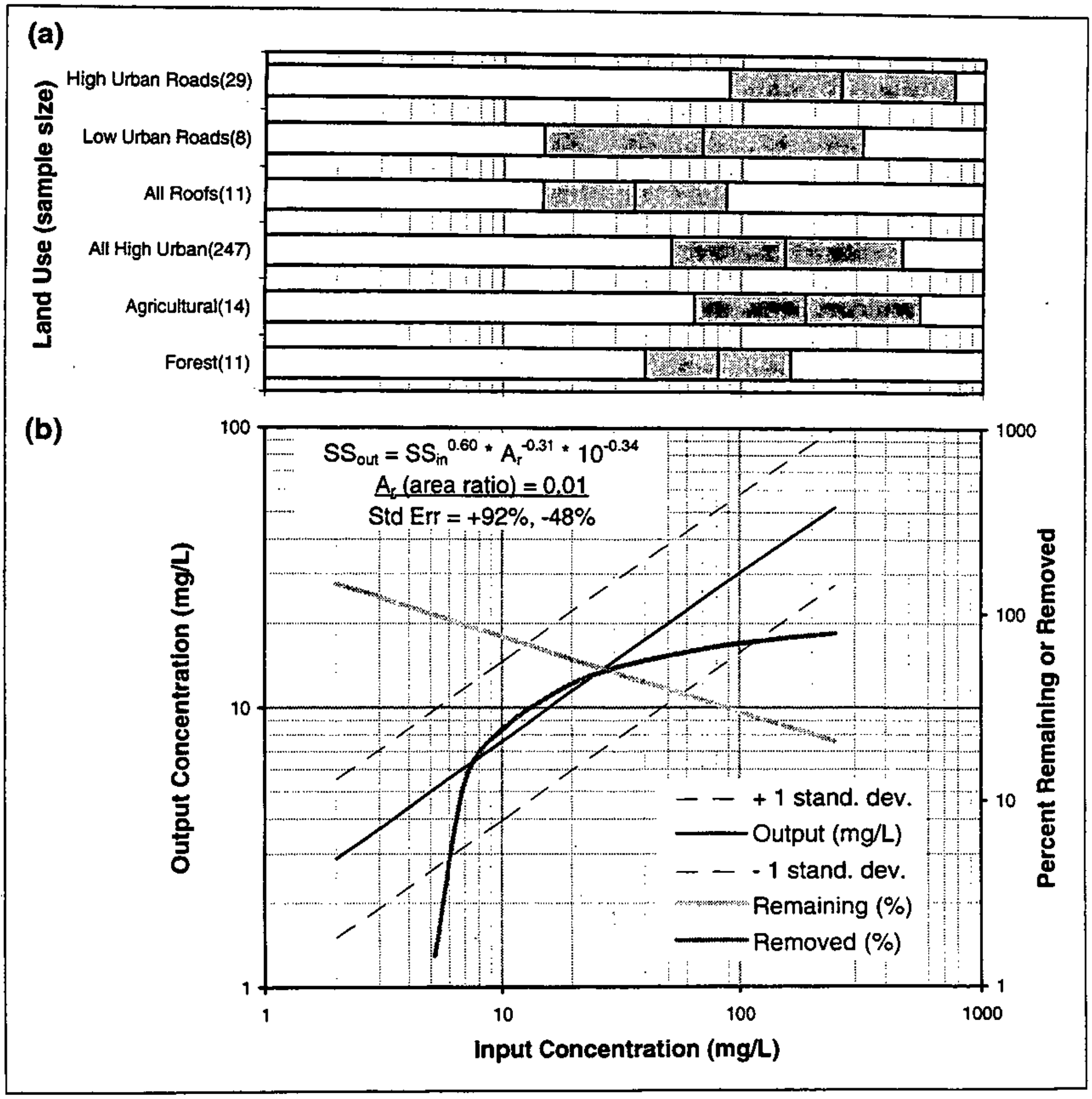


Figure 15. Performance objective for SS based on storage treatment

(a) Mean source concentrations of SS, and

(b) Treatment concentrations in storage for area ratio = 1%

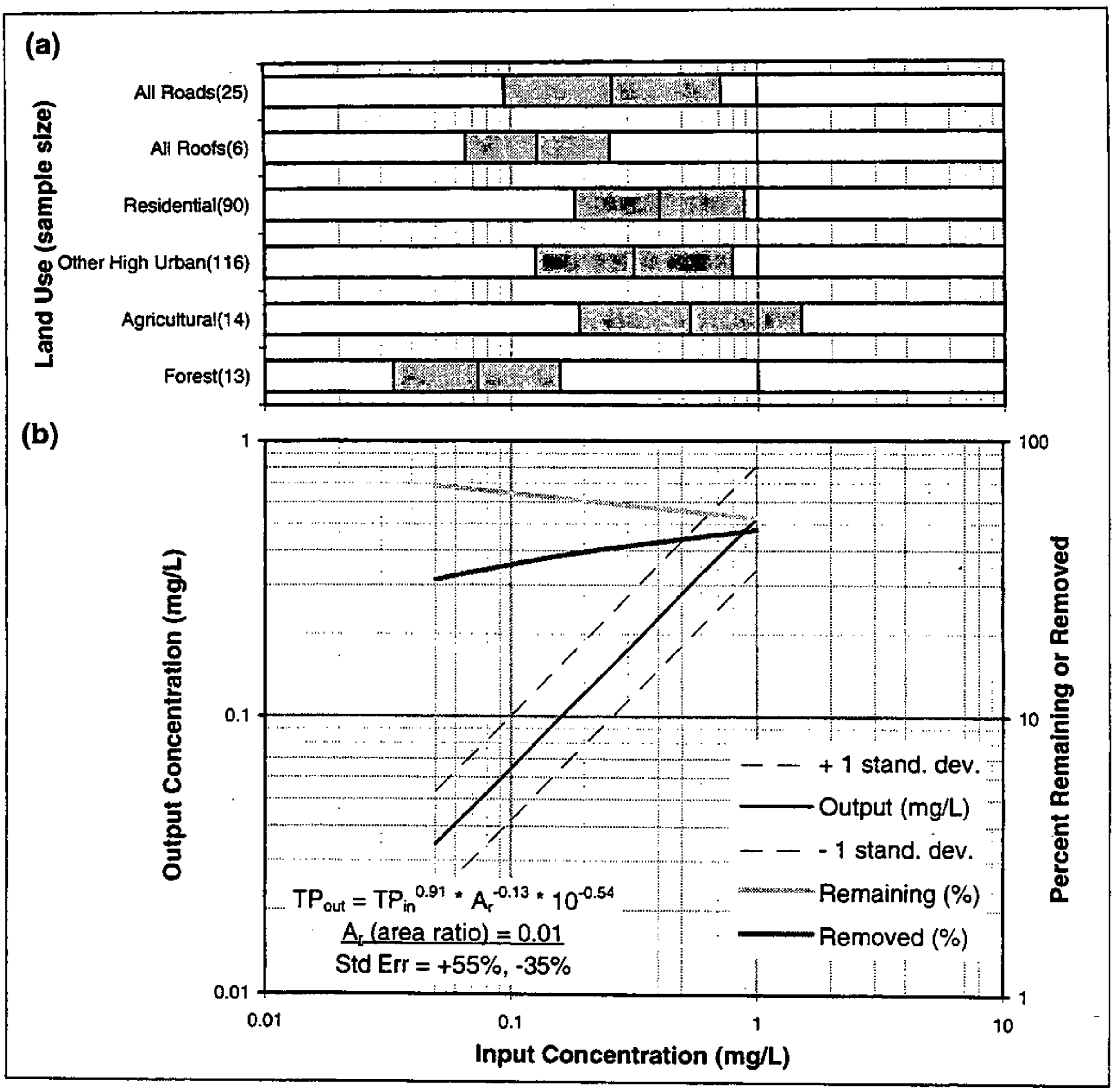


Figure 16. Performance objective for TP based on storage treatment

(a) Mean source concentrations of TP, and

(b) Treatment concentrations in storage for area ratio = 1%

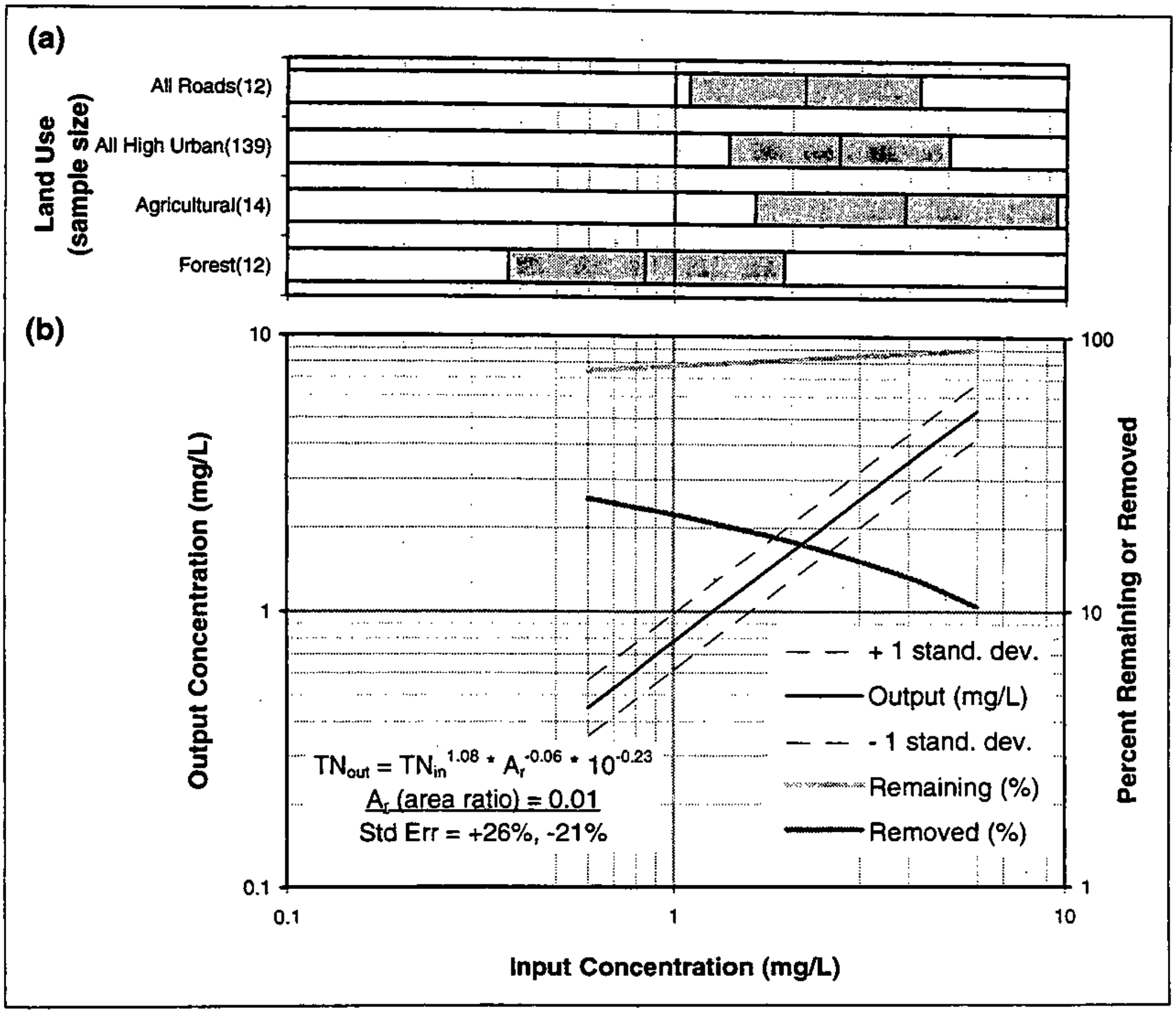


Figure 17. Performance objective for TN based on storage treatment

(a) Mean source concentrations of TN, and

(b) Treatment concentrations in storage for area ratio = 1%

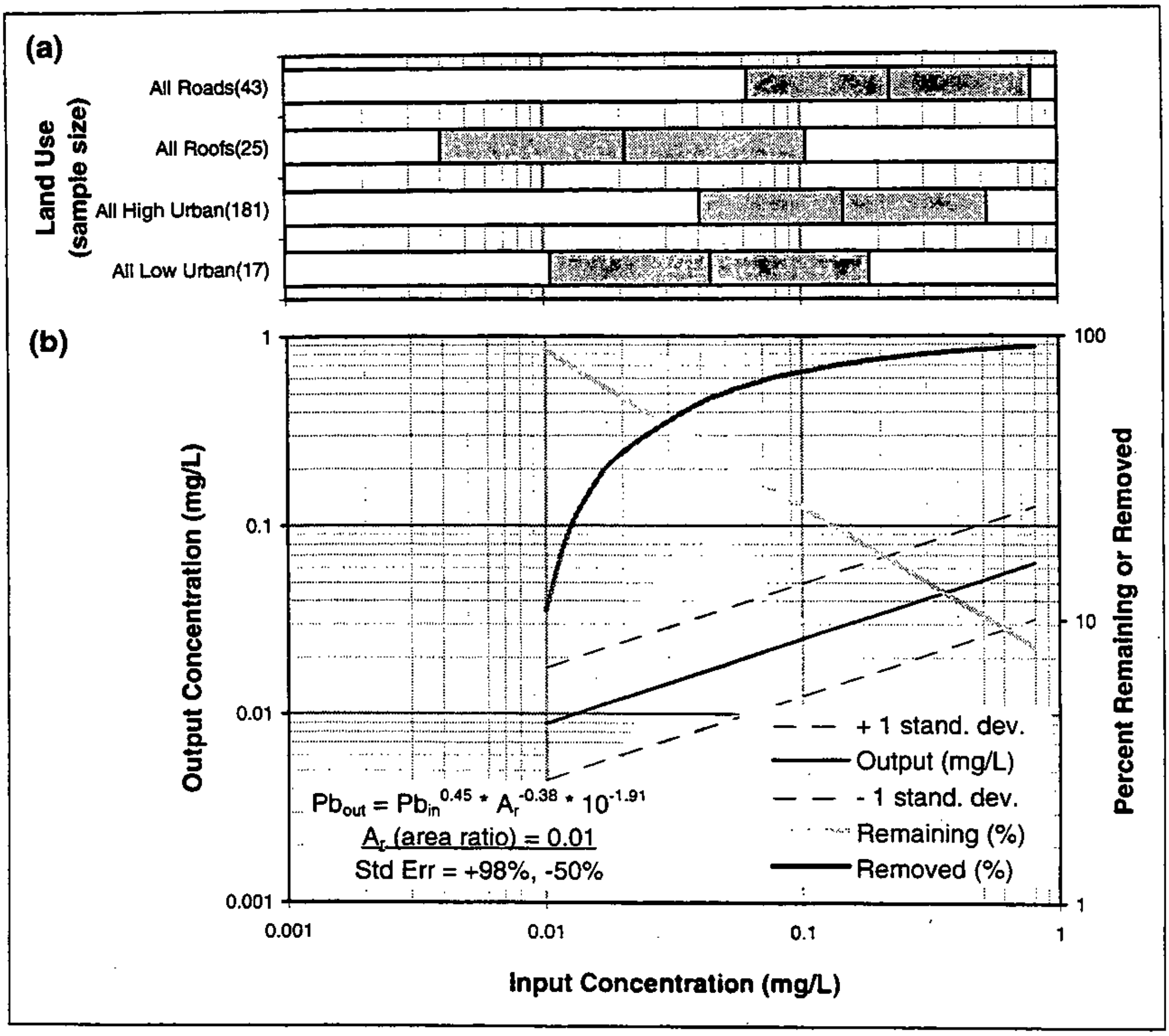


Figure 18. Performance objective for Pb based on storage treatment

(a) Mean source concentrations of Pb, and

(b) Treatment concentrations in storage for area ratio = 1%

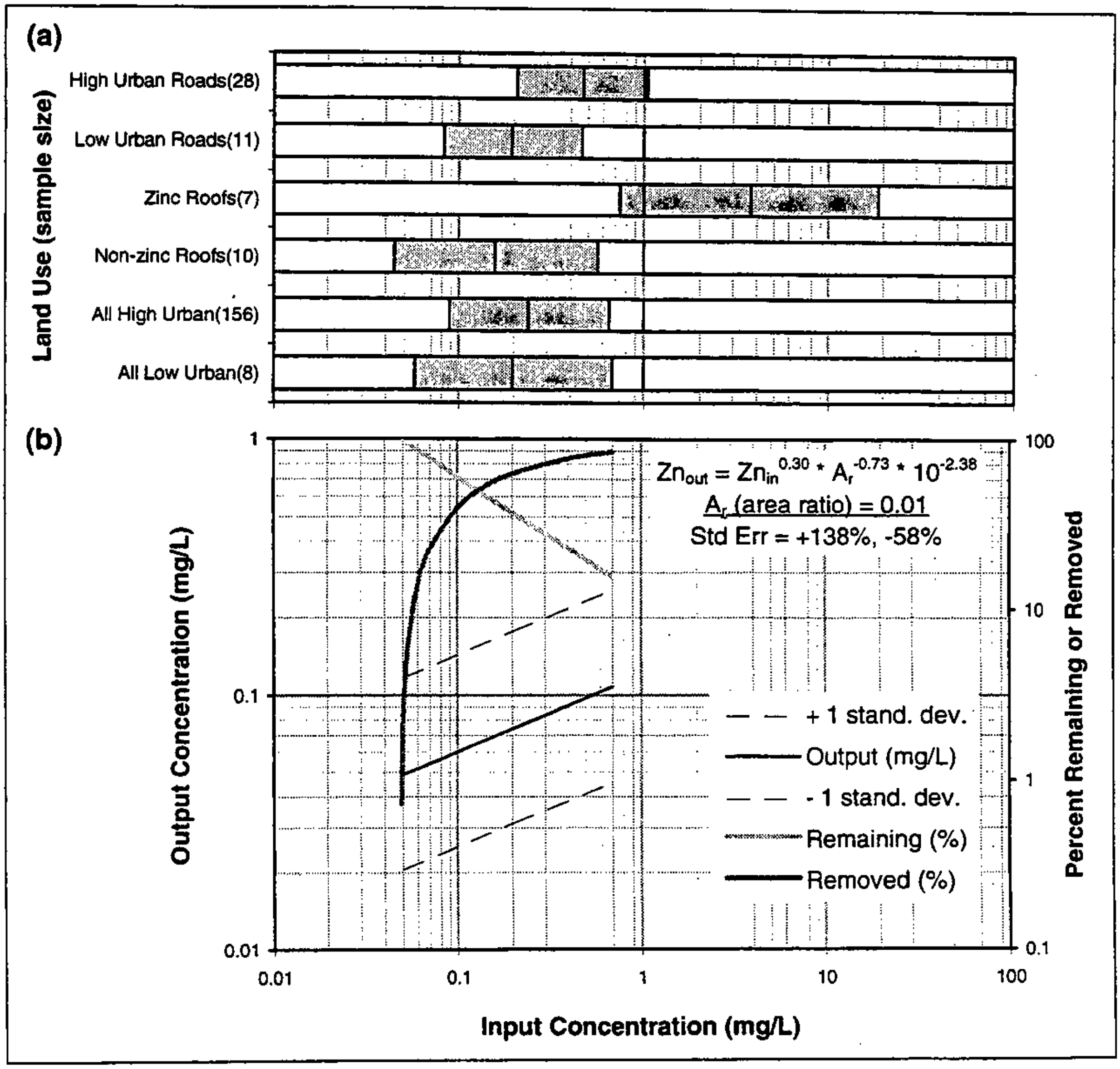


Figure 19. Performance objective for Zn based on storage treatment

(a) Mean source concentrations of Zn, and

(b) Treatment concentrations in storage for area ratio = 1%

6.5.4 Screening of Treatment Controls

The selection of the treatment controls (or stormwater treatment measures - STMs) for the catchment under consideration will depend on a wide range of criteria. All the common STMs (and any others which the proponent may wish to add) should be assessed against a number of categories, tabulated in the screening tools provided in Figure 20 to Figure 27. Each STM can be accepted or rejected on the basis of each screening category. Those devices which are rejected on the basis of the key criteria can then be eliminated from the list of acceptable STMs. In some catchments all the STMs may be rejected on this basis. If this is the case, the STMs rejected on the basis of the fewest categories can be adopted. The Blackburn Lake example (Appendix E) illustrates the use of the screening tools.

The **area served** is the range of catchment area from which the STMs can effectively treat the runoff. Figure 20 provides a guide to the area served by a range of common STMs. Area served has been adopted for a range of STMs from a number of publications. As can be seen in Table 27, there is a wide variation in some of the values. Thus, some of the areas determined may not be appropriate for Australian catchments, so no area values are shown in Figure 20. Although catchment areas may be greater than the capability of the STM, some STMs can be distributed economically over a catchment to each serve smaller areas within the catchment.

A further limitation that the catchment may place on suitable STMs is the **land use**. For example, porous pavement cannot be used in sites expecting heavy traffic and swales can only be used in conjuction with low density areas or roads (Schueler, 1987). In Figure 20, the STMs are categorised by whether land use is not usually a restriction on their use, sometimes a restriction on their use or usually a restriction to their use.

Table 27. Range of catchment areas (ha) capable of being served by STMs for a number of locations

STM	Location (reference)					
	Washington DC (Schueler, 1987)	Auckland (ARC, 1992a)	Australia (GHD, 1995)	California (CD&M, 1993)	USA (Novotny, 1995)*	other
pond	> 4-8		> 4	large/ reg.	large	
wetland	> 4-8		> 4	large/ reg.	med./large	
dry ext. detention	> 7-9		> 8	larger	med./large	
wet ext. detention	> 3-8		> 4	large/ reg.	med./large	
infiltration basin	0-3 to 8-14		12 - 120		small/ med.	> 2
infiltration trench	< 2-3	< 4	< 2		small	< 8
porous pavement	0-1 to 2-7		0.1 - 1		small/ med.	
sand filter		< 4	< 20	< 40	small/ med.	
grass swale	< 2-4		< 2	a few acres	small	
filter strip	< 2-4	< 2	< 2-10	a few acres	small	
oil/grease trap	< 0.5-1		< 0.4	small	small	
"GPT"			> 8			
CDS			various = no limit?			

* Novotny (1995) classified the areas as large > 16 ha, medium = 4 to 16 ha and small < 4 ha.

Figure 21 shows some site conditions which may preclude certain STMs from being used in a catchment. They are:

Slope - some non-storage STMs require small flow velocities, which requires a small slope. Others, such as porous pavement require small slopes in order that infiltration can be maximised. The STMs are categorised on the maximum slope on which the STM can be used.

Hydraulic head - some STMs require a fall in water level between the inflow and outflow in order to work effectively.

Water table depth - in some STMs, a high water table will reduce their effectiveness, especially as a high water table will restrict infiltration. Most infiltration STMs will be effective when the water table is greater than one metre below the surface.

Depth to bedrock - the depth to bedrock or an impermeable layer will affect STMs in the same way as a high water table. Bedrock may also interfere with construction of subsurface devices. The restriction on the latter may be reduced or eliminated by careful design or placement of the STM, hence the additional category on which to screen the STMs in Figure 21.

One of the main site constraints is the **area available** within the catchment which can be used to install STMs. This may be available as one area, or spread over the catchment in several smaller sub-areas. Screening of STMs on this basis is shown in Figure 22, based on the percentage of the catchment area required for each STM. Some STMs can be placed underground. Most guidelines for storage treatment recommend that between 0.2% and 5% of the catchment area be provided for treatment (see Table 24, also Somes & Wong, 1994). However, this is dependent on the catchment location and particular area ratios have not been determined for Australia.

Some STMs are also limited by the requirement for **pre-treatment** to remove pollutants which may reduce the effectiveness of the STM. For example, infiltration devices will become clogged by coarse sediment within a few years of commission. In Figure 22, the pre-treatments required are listed: oil and grease, coarse sediment and gross pollutants. Figure 22 also shows where the STMs can be used as a pre-treatment device for the same pollutants.

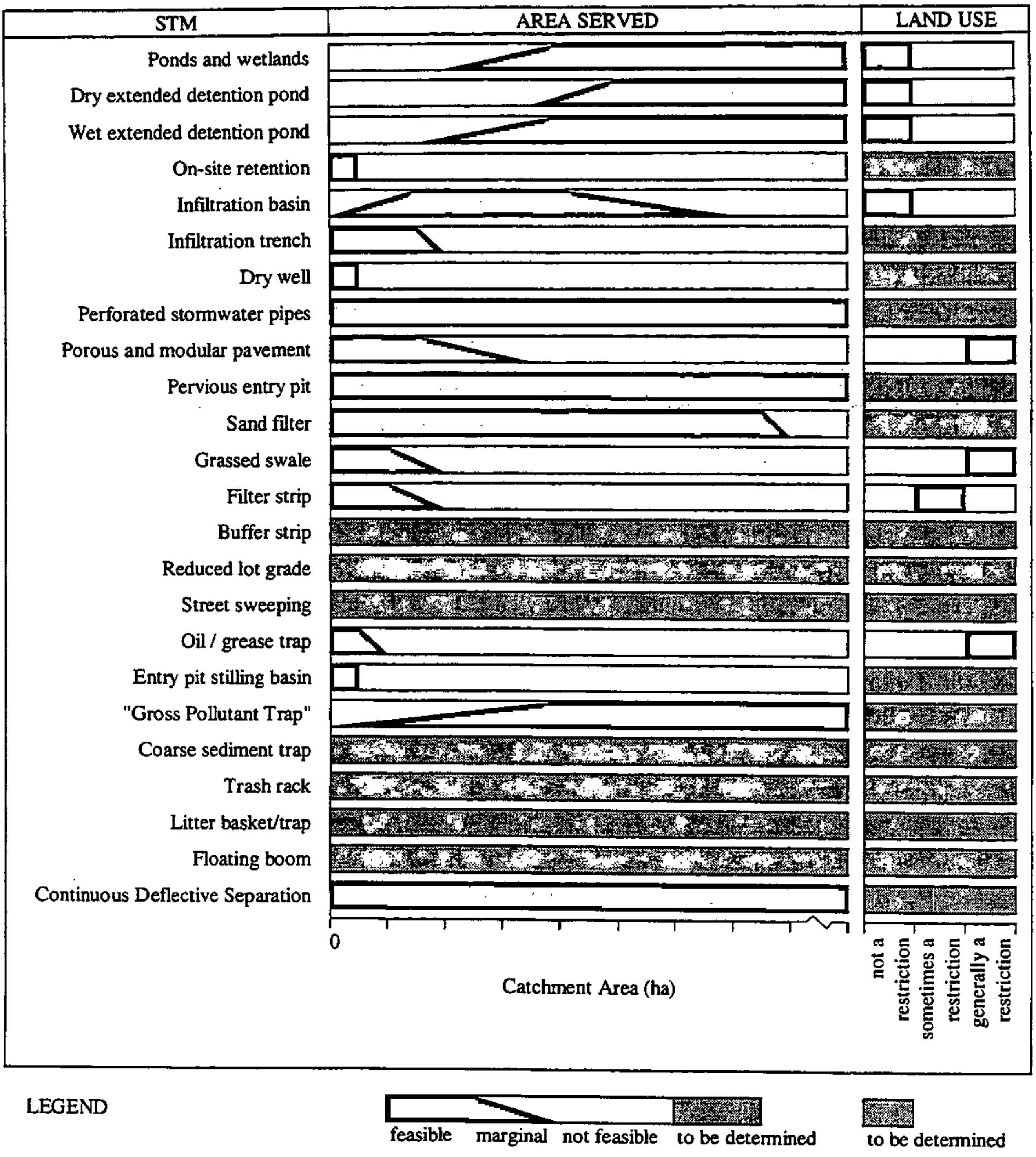
Figure 23 shows the range of **soil types** suitable for installation of different STMs. The soil types are shown in both a descriprive classification and by the typical infiltration rates. Most infiltration devices require more permeable soils, while storage facilities with permanent pool require less permeable soils. Soil **fertility** is also of concern, as some STMs require fertile soils to maintain a vegetation base to remain effective.

Many STMs can provide additional benefits for the environment, or conversely can impact on the environment. These benefits or impacts are shown in Figure 24 and are described below:

Aquatic habitat enhancement - STMs which enable aquatic plants to grow will provide habitat for fish, aquatic mammals and other beneficial species of aquatic life. Open water areas may also be utilised by waterfowl. The STMs are categorised in Figure 24 on the basis of how much potential there is for aquatic habitat: little, moderate or high.

Wildlife habitat enhancement - STMs which offer buffer zones present opportunites to provide habitat for terrestial wildlife. Trees, shrubs and grasses provide food and shelter for wildlife. The STMs are categorised on the basis of how much potential there is for aquatic habitat: none, low, moderate or high.

Thermal impact - the temperature in some STMs will rise, which may restrict their use in waterways where the ecology is sensitive to temperature changes. The STMs are categorised on the amount of potential temperature increase: none, small or large.



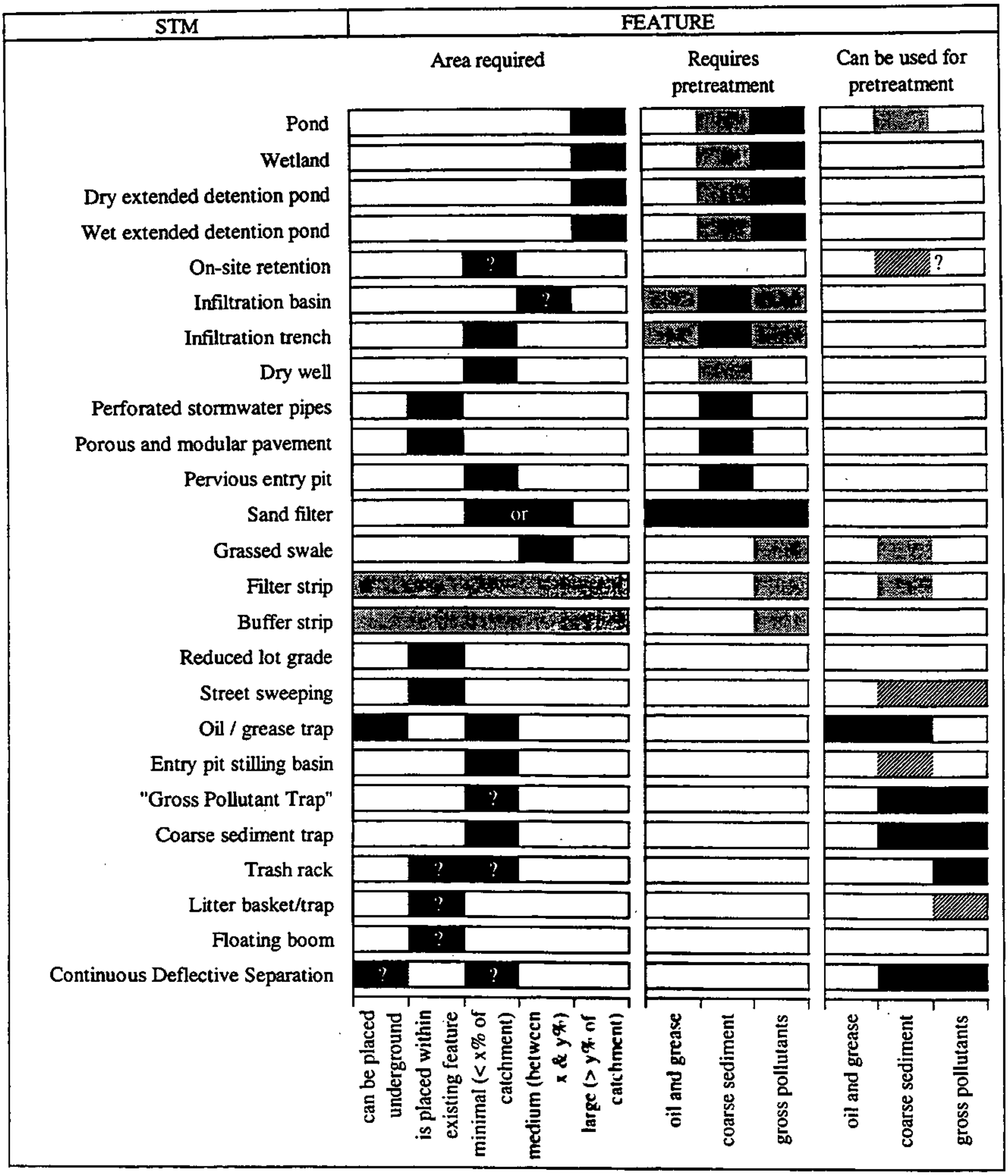
Note: Areas served have not as yet been determined for local conditions (see text).

Figure 20. Screening tool to select devices by catchment area served

STM	FEATURE										
	Slope				Hydraulic head		Depth to water table		Depth to bedrock		
	must be < 2%	must be < 5%	can be > 5% with careful design	can be > 5%	fall not required	fall is required	must be > 1 m	no restriction	must be > 1 m	can be < 1 m with careful design	no restriction
Pond				■	■			■		■	
Wetland				■	■			■			■
Dry extended detention pond				■		■		■		■	
Wet extended detention pond				■	■			■		■	
On-site retention	■				■ ?		■		▨	▨	▨
Infiltration basin			■		■		■		■		
Infiltration trench			■		■		■		■		
Dry well			■		■		■		■		
Perforated stormwater pipes				■	■		■		■		
Porous and modular pavement		■			■		■		■		
Pervious entry pit				■	■		■ ?		■ ?		
Sand filter				■		■		■		■	
Grassed swale		■			■		■			■	
Filter strip		■			■		■			■	
Buffer strip			■ ?		■ ?		■		▨	▨	▨
Reduced lot grade		■			■ ?			■	▨	▨	▨
Street sweeping				■	■ ?			■			■
Oil / grease trap				■	■			■		■	
Entry pit stilling basin				■ ?		■ ?		■		■ ?	
"Gross Pollutant Trap"				■	■ ?			■	■		
Coarse sediment trap				■ ?	■ ?			■			■ ?
Trash rack				■ ?		■ ?		■			■ ?
Litter basket/trap				■ ?		■ ?		■			■ ?
Floating boom				■ ?	■ ?			■			■ ?
Continuous Deflective Separation				■ ?	■ ?			■		■ ?	

Note: categories for some STMs are not available in the literature to hand - whole bar is shaded ▨ or a question mark "?" indicates confirmation is required.

Figure 21. Screening tool to select devices by available site conditions



STM	FEATURE										
	Area required					Requires pretreatment			Can be used for pretreatment		
	can be placed underground	is placed within existing feature	minimal (< x% of catchment)	medium (between x & y%)	large (> y% of catchment)	oil and grease	coarse sediment	gross pollutants	oil and grease	coarse sediment	gross pollutants
Pond					■		▒	■		▒	
Wetland					■		▒	■			
Dry extended detention pond					■		▒	■			
Wet extended detention pond					■		▒	■			
On-site retention			■ ?							▨	?
Infiltration basin				■ ?		▒	■	▒			
Infiltration trench			■			▒	■	▒			
Dry well			■				▒				
Perforated stormwater pipes		■					■				
Porous and modular pavement		■					■				
Pervious entry pit			■				■				
Sand filter			■	or ■		■	■	■			
Grassed swale				■				▒		▒	
Filter strip	░	░	░	░	░			▒		▒	
Buffer strip	░	░	░	░	░			▒			
Reduced lot grade		■									
Street sweeping		■								▨	▨
Oil / grease trap	■		■						■	■	
Entry pit stilling basin			■							▨	
"Gross Pollutant Trap"			■ ?							■	■
Coarse sediment trap			■							■	■
Trash rack		■ ?	■ ?								■
Litter basket/trap		■ ?									▨
Floating boom		■ ?									
Continuous Deflective Separation	■ ?		■ ?							■	■

LEGEND

2 cells may be shaded, for when device is or is not located underground

☐ not required/can't be used
▒ may be required/may be used
■ is required/readily useable
▨ readily useable - is a near source control anyway

Note: Categories for some STMs are not available in the literature to hand - whole bar is shaded thus ░.
Question mark "?" indicates confirmation is required.

Figure 22. Screening tool to select devices by potential treatment area and pre-treatment

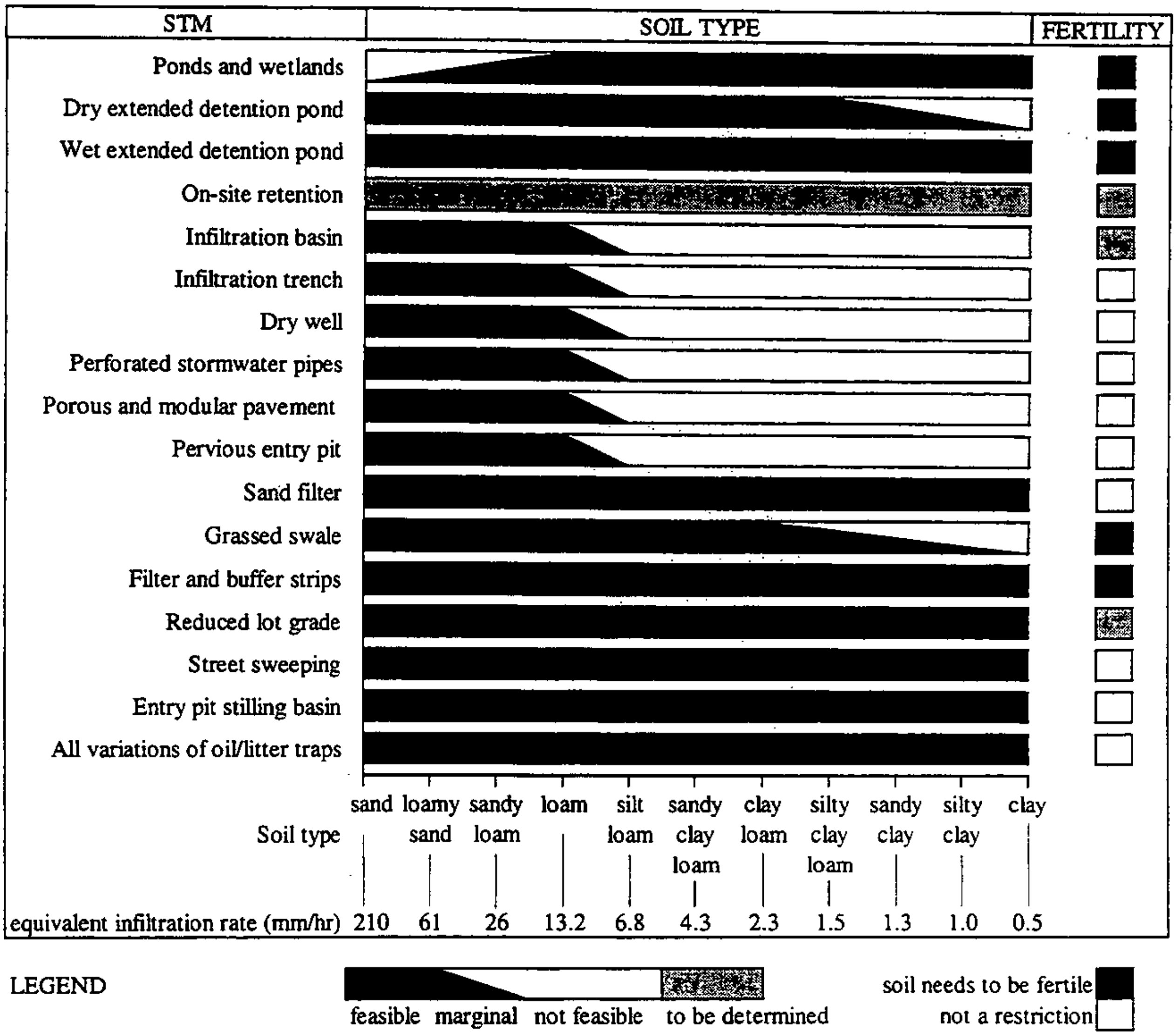
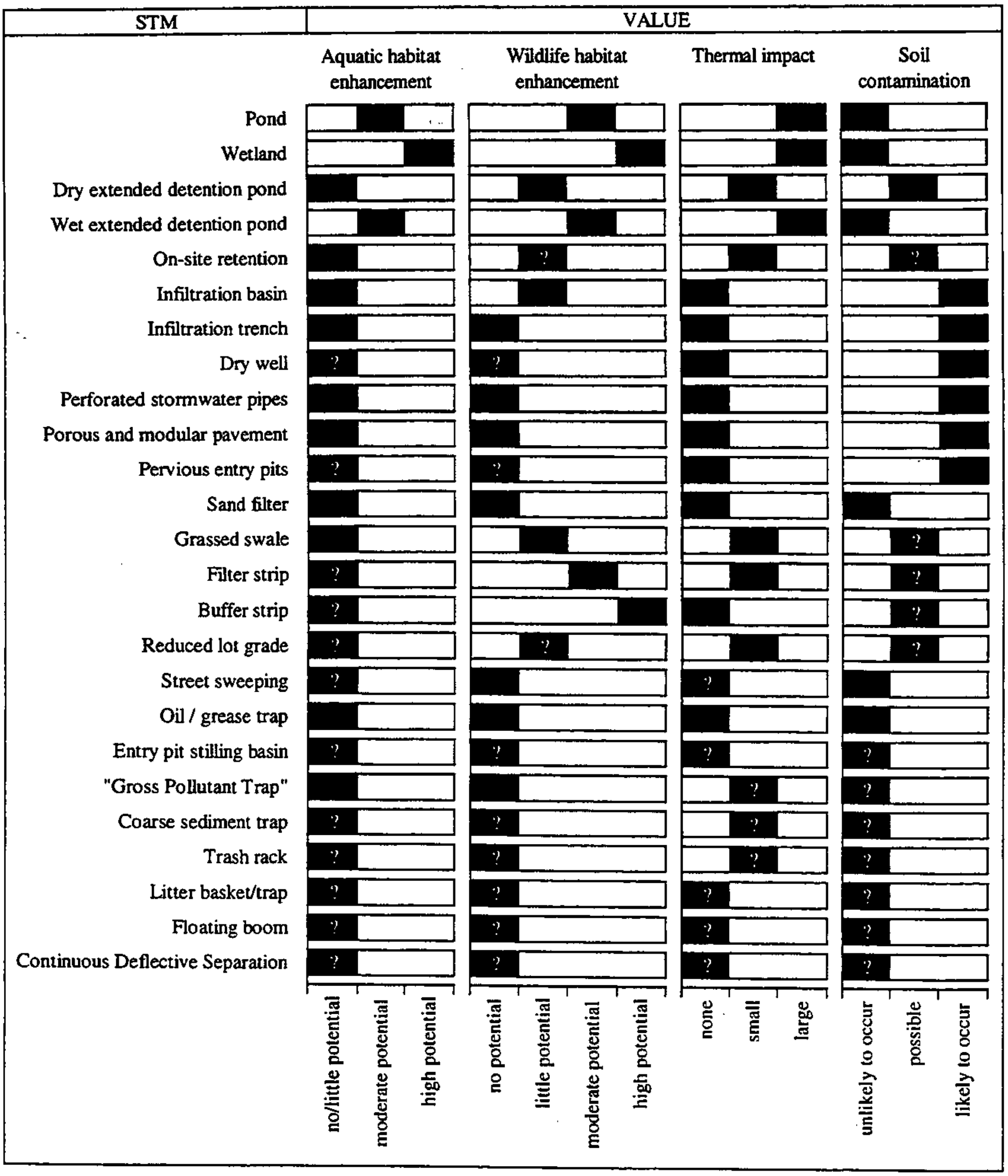


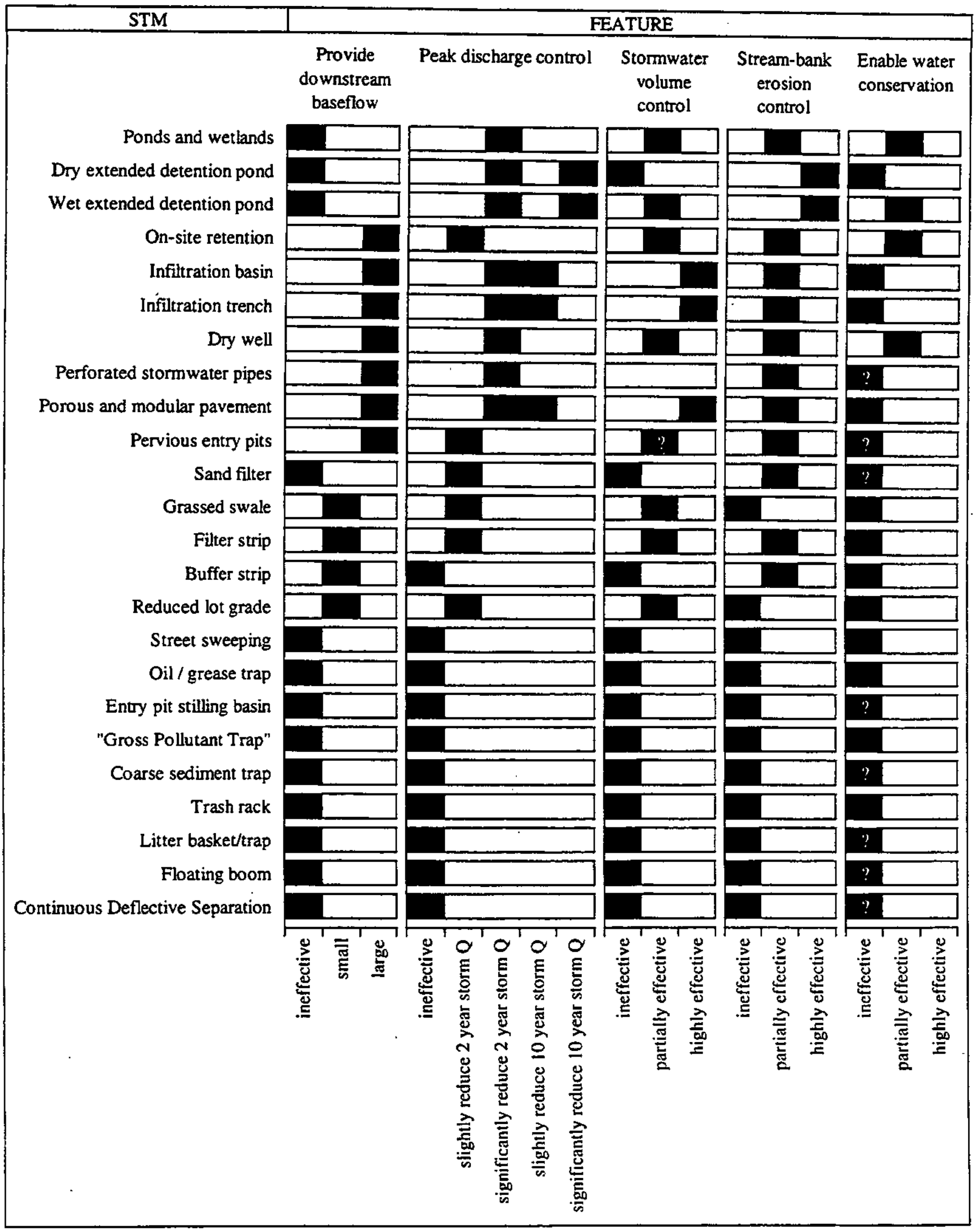
Figure 23. Screening tool to select devices by soil type



STM	VALUE												
	Aquatic habitat enhancement			Wildlife habitat enhancement				Thermal impact			Soil contamination		
	no/little potential	moderate potential	high potential	no potential	little potential	moderate potential	high potential	none	small	large	unlikely to occur	possible	likely to occur
Pond		■				■				■	■		
Wetland			■				■			■	■		
Dry extended detention pond	■				■				■			■	
Wet extended detention pond		■				■				■	■		
On-site retention	■				■ ?				■			■ ?	
Infiltration basin	■				■			■					■
Infiltration trench	■			■				■					■
Dry well	■ ?			■ ?				■					■
Perforated stormwater pipes	■			■				■					■
Porous and modular pavement	■			■				■					■
Pervious entry pits	■ ?			■ ?				■					■
Sand filter	■			■				■			■		
Grassed swale	■				■				■			■ ?	
Filter strip	■ ?					■			■			■ ?	
Buffer strip	■ ?						■	■				■ ?	
Reduced lot grade	■ ?				■ ?				■			■ ?	
Street sweeping	■ ?			■				■ ?			■		
Oil / grease trap	■			■				■			■		
Entry pit stilling basin	■ ?			■ ?				■ ?			■ ?		
"Gross Pollutant Trap"	■			■					■ ?		■ ?		
Coarse sediment trap	■ ?			■ ?					■ ?		■ ?		
Trash rack	■ ?			■ ?					■ ?		■ ?		
Litter basket/trap	■ ?			■ ?				■ ?			■ ?		
Floating boom	■ ?			■ ?				■ ?			■ ?		
Continuous Deflective Separation	■ ?			■ ?				■ ?			■ ?		

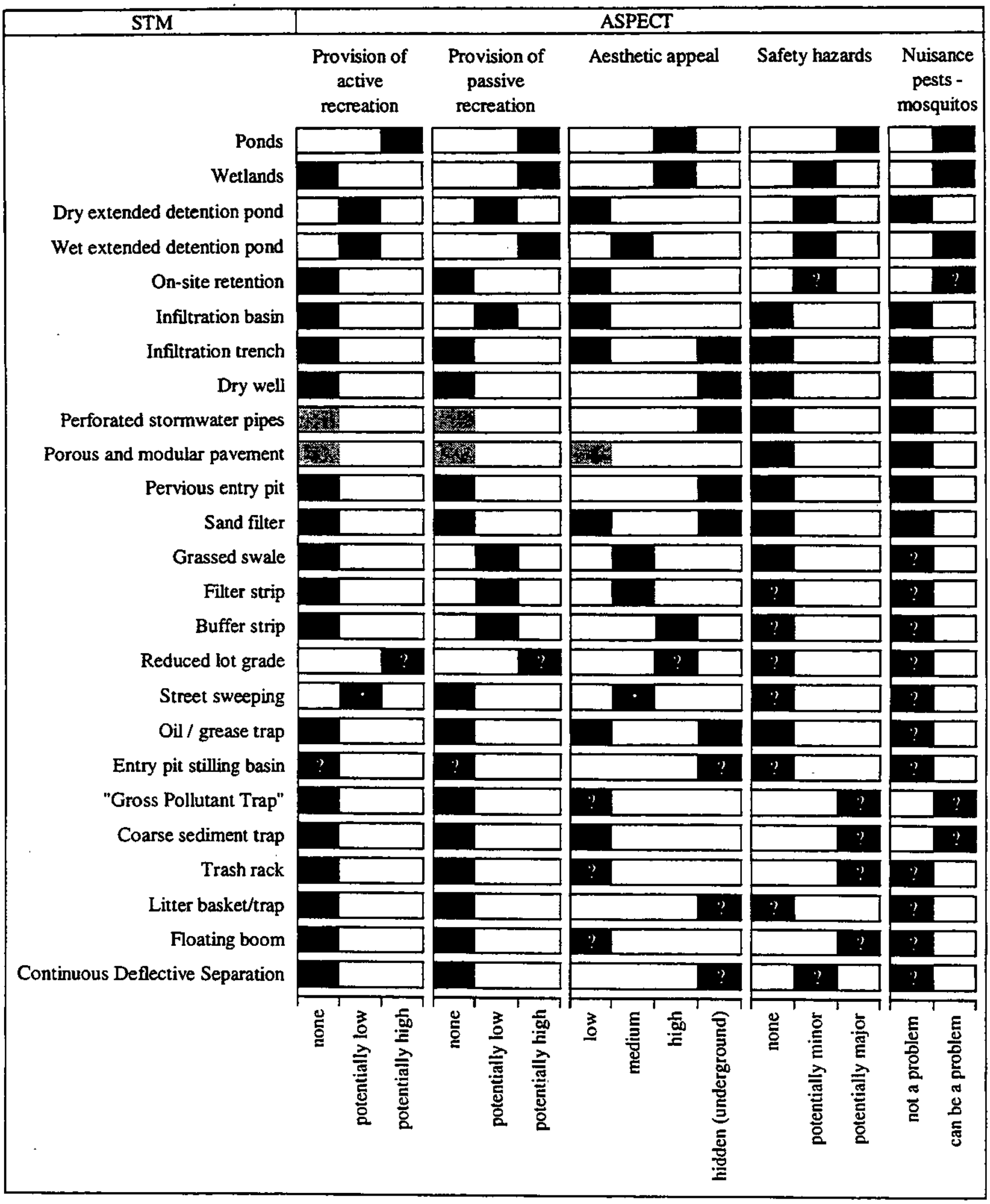
Note: where little information is available, or confirmation is required, a"?" is shown.

Figure 24. Screening tool to select devices by potential environmental impacts



STM	Provide downstream baseflow: ineffective	Provide downstream baseflow: small	Provide downstream baseflow: large	Peak discharge control: ineffective	Peak discharge control: slightly reduce 2 year storm Q	Peak discharge control: significantly reduce 2 year storm Q	Peak discharge control: slightly reduce 10 year storm Q	Peak discharge control: significantly reduce 10 year storm Q	Stormwater volume control: ineffective	Stormwater volume control: partially effective	Stormwater volume control: highly effective	Stream-bank erosion control: ineffective	Stream-bank erosion control: partially effective	Stream-bank erosion control: highly effective	Enable water conservation: ineffective	Enable water conservation: partially effective	Enable water conservation: highly effective
Ponds and wetlands	■					■				■			■			■	
Dry extended detention pond	■					■		■	■					■	■		
Wet extended detention pond	■					■		■		■				■		■	
On-site retention			■		■					■			■			■	
Infiltration basin			■			■	■				■		■		■		
Infiltration trench			■			■	■				■		■		■		
Dry well			■			■				■			■			■	
Perforated stormwater pipes			■			■							■		?		
Porous and modular pavement			■			■	■				■		■		■		
Pervious entry pits			■		■					?			■		?		
Sand filter	■				■				■				■		?		
Grassed swale		■			■					■		■			■		
Filter strip		■			■					■			■		■		
Buffer strip		■		■					■				■		■		
Reduced lot grade		■			■					■		■			■		
Street sweeping	■			■					■			■			■		
Oil / grease trap	■			■					■			■			■		
Entry pit stilling basin	■			■					■			■			?		
"Gross Pollutant Trap"	■			■					■			■			■		
Coarse sediment trap	■			■					■			■			?		
Trash rack	■			■					■			■			■		
Litter basket/trap	■			■					■			■			?		
Floating boom	■			■					■			■			?		
Continuous Deflective Separation	■			■					■			■			?		

Figure 25. Screening tool to select devices by the flow impact mitigation possible



STM	ASPECT														
	Provision of active recreation			Provision of passive recreation			Aesthetic appeal				Safety hazards			Nuisance pests - mosquitos	
	none	potentially low	potentially high	none	potentially low	potentially high	low	medium	high	hidden (underground)	none	potentially minor	potentially major	not a problem	can be a problem
Ponds			■			■			■				■		■
Wetlands	■					■			■			■			■
Dry extended detention pond		■			■		■					■		■	
Wet extended detention pond		■				■		■				■			■
On-site retention	■			■			■					■ ?			■ ?
Infiltration basin	■				■		■				■			■	
Infiltration trench	■			■			■			■	■			■	
Dry well	■			■						■	■			■	
Perforated stormwater pipes	▨			▨						■	■			■	
Porous and modular pavement	▨			▨			▨				■			■	
Pervious entry pit	■			■						■	■			■	
Sand filter	■			■			■			■	■			■	
Grassed swale	■				■			■			■			■ ?	
Filter strip	■				■			■			■ ?			■ ?	
Buffer strip	■				■				■		■ ?			■ ?	
Reduced lot grade			■ ?			■ ?			■ ?		■ ?			■ ?	
Street sweeping		■ •		■				■ •			■ ?			■ ?	
Oil / grease trap	■			■			■			■	■			■ ?	
Entry pit stilling basin	■ ?			■ ?						■ ?	■ ?			■ ?	
"Gross Pollutant Trap"	■			■			■ ?						■ ?		■ ?
Coarse sediment trap	■			■			■						■ ?		■ ?
Trash rack	■			■			■ ?						■ ?	■ ?	
Litter basket/trap	■			■						■ ?	■ ?			■ ?	
Floating boom	■			■			■ ?						■ ?	■ ?	
Continuous Deflective Separation	■			■						■ ?		■ ?		■ ?	

LEGEND

▨ Replaces existing feature - therefore there will be no improvement or decrease
• Street sweeping provides a cleaner, safer surface for active recreation.
Two cells may be shaded, if device is or is not located underground.
Where the information available is questionable, a "?" has been shown.

Figure 26. Screening tool to select devices by community amenity

STM	ITEM													
	Water requirement				Maintenance requirement				Initial cost			Overall "value"		
	none	permanent pool	maintenance &/or operation	irrigation	none	minor	moderate	major	low	medium	high	low	medium	high
Ponds		■		■			■				■			■
Wetlands		■		■			■				■			■
Dry extended detention pond				■			■				■		■	
Wet extended detention pond		■		■			■				■			■
On-site retention				■		■			■				■	
Infiltration basin	■						■				■	■		
Infiltration trench	■						■				■		■	
Dry well	■					■					■		■	
Perforated stormwater pipes	■		■				■				■		■	
Porous and modular pavement	■		■				■				■			
Pervious entry pit	■					■					■	■		
Sand filter	■						■				■			■
Grassed swale				■			■			■				
Filter strip				■			■			■?			■	
Buffer strip				■			■?			■?				
Reduced lot grade	■				■						■?			
Street sweeping			■					■			■		■	
Oil / grease trap	■						■?			■		■		
Entry pit stilling basin	■							■	■?					
"Gross Pollutant Trap"	■							■			■?			
Coarse sediment trap	■							■			■?			
Trash rack	■							■?		■?				
Litter basket/trap	■							■	■?					
Floating boom	■							■?	■?					
Continuous Deflective Separation	■						■				■?			

Note: Some information available is questionable - as indicated by "?".
Where the bar is not filled, no information is readily available.

Figure 27. Screening tool to select devices by considerations not included in Figure 20 to Figure 26

Soil contamination - where polluted stormwater infiltrates into the surrounding soil, there is potential to pollute the soil and local groundwater. Although a few studies have noted little contamination below infiltration STMs (see Section 4.2.3), there are few data to confirm these results in Australia and contamination will be dependent on the local soil type and groundwater conditions. The STMs are categorised on the basis of the likelihood of soil contamination.

Some STMs also provide benefits in terms of stormwater discharge and volume which may be of concern in catchments where urbanisation causes increased flooding and/or erosion. Some STMs, particularly those utilising infiltration, restore low flows to the waterways by increasing **baseflows.** Small continual flows during inter-storm periods are important to maintain the waterway ecology and aquatic life. The STMs have been categorised in Figure 25 by their ability to provide baseflows to the downstream waterway: ineffective, small or large.

Detention of flow reduces the **peak discharge** of high flow events passing through an STM. This benefits the waterways by reducing the size of floods and consequent environmental damage that may occur and protects the community from damage to infrastructure. The degree of flood protection is indicated in Figure 25 by whether the STMs are ineffective in discharge control or will slightly or significantly reduce the 2 and 10 year ARI peak discharges.

STMs may also benefit the waterway by reducing the **volume** of water passing downstream with each event. This helps to restore the natural catchment flow regime. In Figure 25, the STMs are categorised on the basis of whether they are ineffective, partially effective or highly effective in reducing stormwater volume passing downstream. **Stream-bank erosion** is often connected with the occurrence of "bank-full" flows (see Section 5.1.4), which generally occur more frequently in urban areas. STMs which reduce the frequency of bank-full flows help by reducing the most erosive flows. The STMs have been categorised in Figure 25 on the basis of whether they are ineffective, partially effective or highly effective in reducing the frequency of downstream erosive flows.

A further water quantity aspect, which is important in the context of water sensitive urban design, is how STMs facilitate reductions in water use, or more effective use of the stormwater resource. In Figure 25, the ability of the STMs to **enable water conservation** by water re-use or reduction in water consumption is categorised as ineffective or effective to a small or large degree.

STMs can enhance the community value of an area by providing recreation and a pleasant outlook, but may also detract from the community value by increasing safety hazards or increasing potential pest problems. These are shown in Figure 26 and described below:

Provision of active recreation - active recreation, such as ball sports can be encouraged on or around those STMs which provide sufficient open space. STMs such as street sweeping can also enhance active recreation where the treatment provides a cleaner, safer surface on which to play hard-surface sports (e.g. basketball and roller-hockey). The STMs are categorised on the basis of the potential to provide active recreation: none, low or high.

Provision of passive recreation - there is large scope for STMs to provide an environment in which passive recreation can be pursued, such as walking, bird-watching, picnicking and cycling. STMs are categorised on no, low, or high potential to offer passive recreation opportunities by providing shaded areas, natural settings, bushland, trees and open space.

Aesthetic appeal - STMs which enhance the visual outlook of an area will be favoured against those that are unattractive. Those STMs which can be hidden (i.e. can be installed fully underground) may also improve the aesthetic appeal of an area, or at least not detract from it. STMs are categorised on whether the aesthetic appeal of the facility is low, medium or high. A further category is added for those STMs which can be hidden.

Safety hazards - some STMs introduce new safety hazards that may not be present before installation, for example, steep side slopes on wet ponds increases the risk of a person falling in and drowning. The STMs are categorised in Figure 26 on the potential degree of increased hazard that may occur: none, minor or major.

Nuisance pests - the numbers of nuisance pests and insects, especially mosquitos, breeding as a result of the STM may increase. The STMs are categorised whether or not there is a potential pest problem that could be incurred through their installation.

The final issues to be considered are shown in Figure 27 and described below.

Water requirement - some STMs require water input other than the stormwater discharge in order to continue to operate effectively. This may be for maintenance of a permanent pool or irrigation during extended dry periods, for operation, or for maintenance purposes (e.g. cleaning and flushing).

Maintenance requirement - virtually all STMs have some requirement for maintenance and upkeep. This can be minimal (e.g. regular inspection and occasional cleaning) or major (e.g. weed control, sediment removal, replanting of vegetation, flushing). The STMs are categorised as requiring no, minor, moderate or major maintenance based on the resources required to perform maintenance activities.

Initial cost - the capital cost required to install STMs varies significantly and is categorised as low, medium or high in Figure 27.

Overall "value" - the overall valuse of the different STMs are summarised in the final criterion (low, medium or high) taking into consideration the key issues from Figure 20 to Figure 27.

6.5.5 Final Selection of Treatment Controls

Mean pollutant removals measured for various devices are tabulated in Table 19. These values can be used as further screening of the common treatment types. Obviously, if storage methods of removal have not been eliminated in Section 6.5.4, installation of a properly designed storage with an area ratio of 1% would achieve the performance objective. However, other treatments may be preferred to storage, in which case the following steps could be taken:

➊ Determine the pollutant removals (Table 19) for all six parameters (SS, TP, TN, Pb, Zn, litter) corresponding to each short-listed device.

Note: removals may have to modified depending on site conditions. For example, if infiltration devices were to be used on marginal infiltration rate soils, the volume of runoff that is treated could be reduced.

➋ Determine the best performing short-listed device.

➌ Determine the area of the catchment for which the best performing short-listed device can treat runoff.

Note: If the land uses in the catchment vary significantly, it may be necessary to first adjust the expected STM removal value by the difference in storage removal expected with different inflow concentration. This is because the flow (therefore the load) from impervious areas will be greater than from more pervious areas.

➍ Factor the mean removal value of each parameter for the best performing short-listed device by the ratio of area treatable by the device to total catchment area.

➎ If the resultant removals for any of the six parameters is less than the corresponding performance objective value, determine the next best performing short-listed device and repeat the steps ❸ and ❹. Keep repeating this step until the total removal for all six parameters is equal to or greater than the corresponding performance objective value.

Some iteration may be required in this process, in order to obtain the simplest combination of devices. Some of the smaller devices listed in Table 14 and/or in the screening tools have not been tested in terms of pollutant removal. However, in most cases they are a simple variation on other more common devices which have been monitored and the same removals as listed in Table 19 could be used. A combination of treatment controls have been selected in Appendix E to illustrate the procedure. This procedure allows any other device not listed to also be included, so long as the proponent is able to demonstrate that whatever combination of controls is chosen can achieve the performance objective values.

7. CONCLUSIONS AND RECOMMENDATIONS

This report describes background technical details for the development of `environmental management guidelines for urban stormwater in Victoria. The sources and processes of urban stormwater pollution are summarised in order to provide a context for management guidelines and some understanding of the need to control urban stormwater quality. Current CRCCH studies using a large quantity of data obtained from worldwide published studies were used to indicate the potential concentrations of various parameters from different land uses. Runoff pollutant concentrations were found to be log-normally distributed. In general, pollutant concentrations are highly variable, even within a single land use, due to differences in definition of land use by the different studies and differences in climate and source concentrations. The world data were compared to data from Australia only, in order to to establish the pollutant concentrations differences in the two data sets. It was also found that there is little correlation between different pollutant parameters, even when different land uses were taken into account, indicating that the deposition and wash-off processes for various parameters differ.

Other worldwide data being analysed by the CRCCH was used to assess the performance of treatment in storage devices. The storage outflow concentrations were found to be log-normally distributed and dependent most significantly on the inflow concentration and the area ratio of the storage. Parameters fall into three different groups - settling, proportional and rate limited, depending on whether they are particulate or dissolved. The performance of storage is best expressed by the inflow and outflow concentration, or the outflow concentration as a percentage of the inflow concentration. Reductions in pollutant parameter concentrations were compared and it was found that most reductions were a relatively constant proportion of others. This indicated that one parameter (e.g. SS) could be used as a surrogate for others when specifying a pollutant reduction objective.

A number of existing stormwater management guidelines and manuals were reviewed and it was concluded that there were various shortcomings in most existing approaches. The common shortcoming was that the progression between various steps in the guidelines were not fully described and there appeared to be some lack of scientific basis in some of the approaches. As a result, two new approaches were proposed, one of which was found to be unsatisfactory. The approach proposed is based on new information available from current work being undertaken by the CRCCH. The performance objective proposed is based on the downstream pollutant concentrations equivalent to that of a storage of a given area ratio. A gross pollutant reduction percentage of 65% is also proposed. This is based on limited data available from current CRCCH research in gross pollutant removal.

Treatment performance of a number of other devices was also reviewed and briefly analysed, using data published in various journals, conference papers and reports. Very little data are readily available and the variability and uncertainty in the pollutant removals tabulated reflect this.

As a result of the findings and proposals described in this report, the following recommendations are made:

- That the performance objective (described in Section 6.4) be adopted in the proposed guidelines for urban stormwater environmental management.

- That this performance objective and supporting methodology be implemented as part of a larger urban stormwater management planning process, as prescribed in the National Water Quality Management Strategy (Section 5.2.1).

- ❉ That the summary of urban stormwater pollution provided in Chapter 2 should be used to introduce the problem in the proposed guidelines for urban stormwater environmental management.

- ❉ That the following additional research is required:
  - determine removal rates for a greater range of treatment processes other than storage;
  - estimate appropriate catchment areas served by each STM under a range of climate conditions;
  - determine relationships between pollutant load or concentration and flow for Australian conditions (to calculate load duration curve);
  - determine the impact of geology on source pollutant concentrations;
  - collect appropriate data to conduct the above analysis, from published papers and reports and if necessary by additional monitoring;
  - acquire the remainding information necessary to complete the screening tools shown in Figure 20 to Figure 27.

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APPENDIX A.

POLLUTANT LAND USE DISTRIBUTIONS

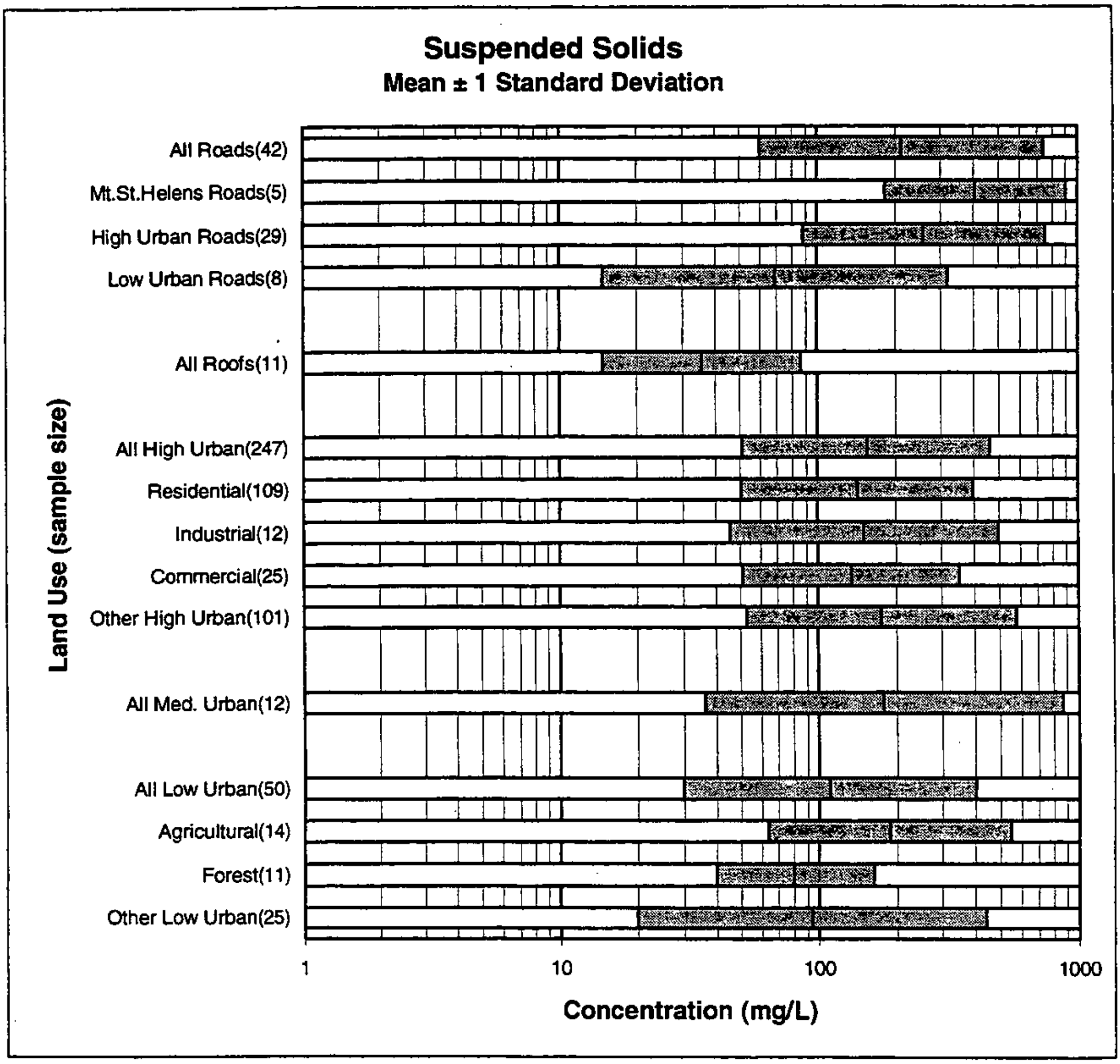

Figure A1. Mean Suspended Solids concentrations in runoff from different land uses, and mean ± 1 standard deviation.

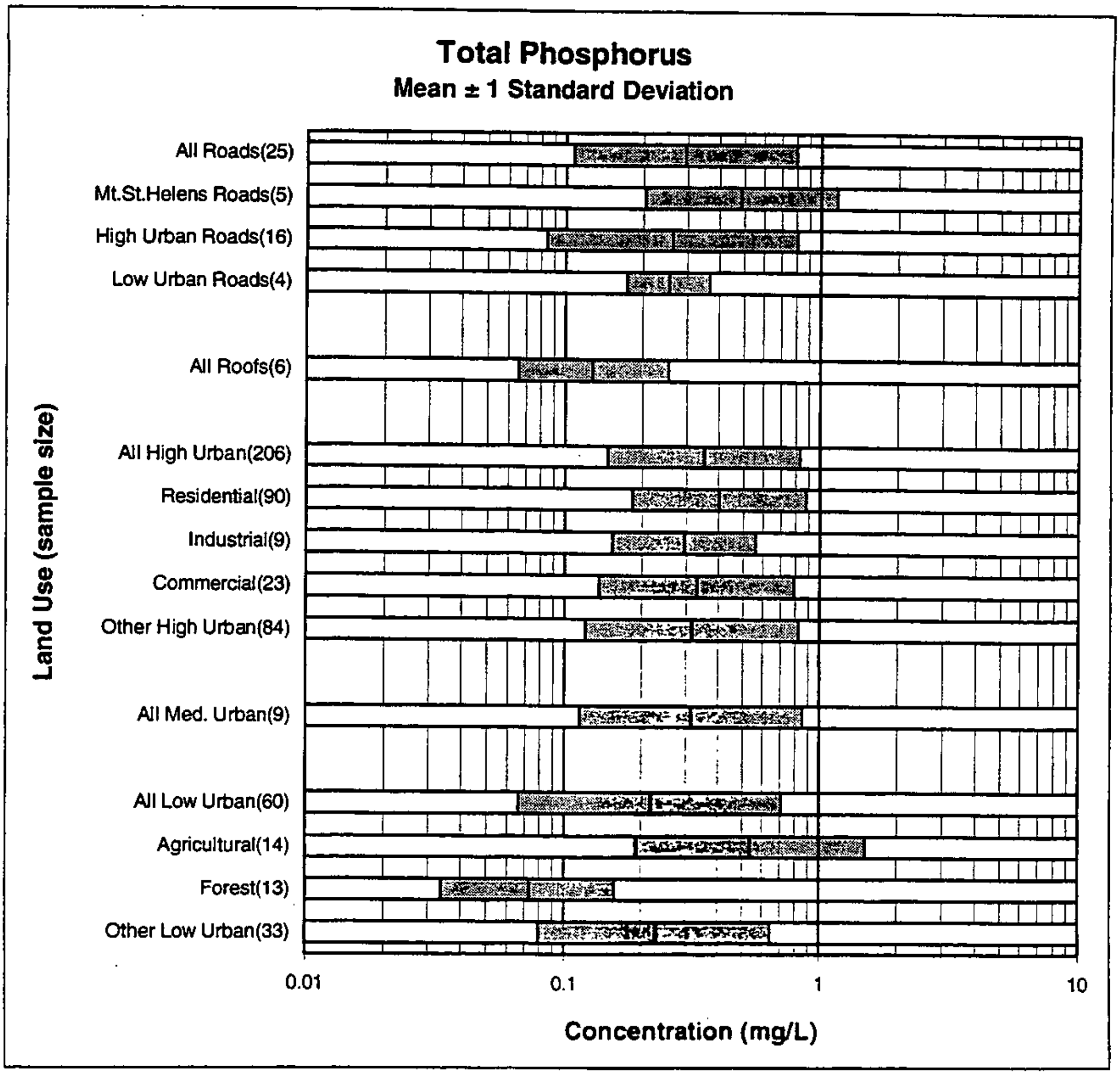

Figure A2. Mean Total Phosphorus concentrations in runoff from different land uses, and mean ± 1 standard deviation.

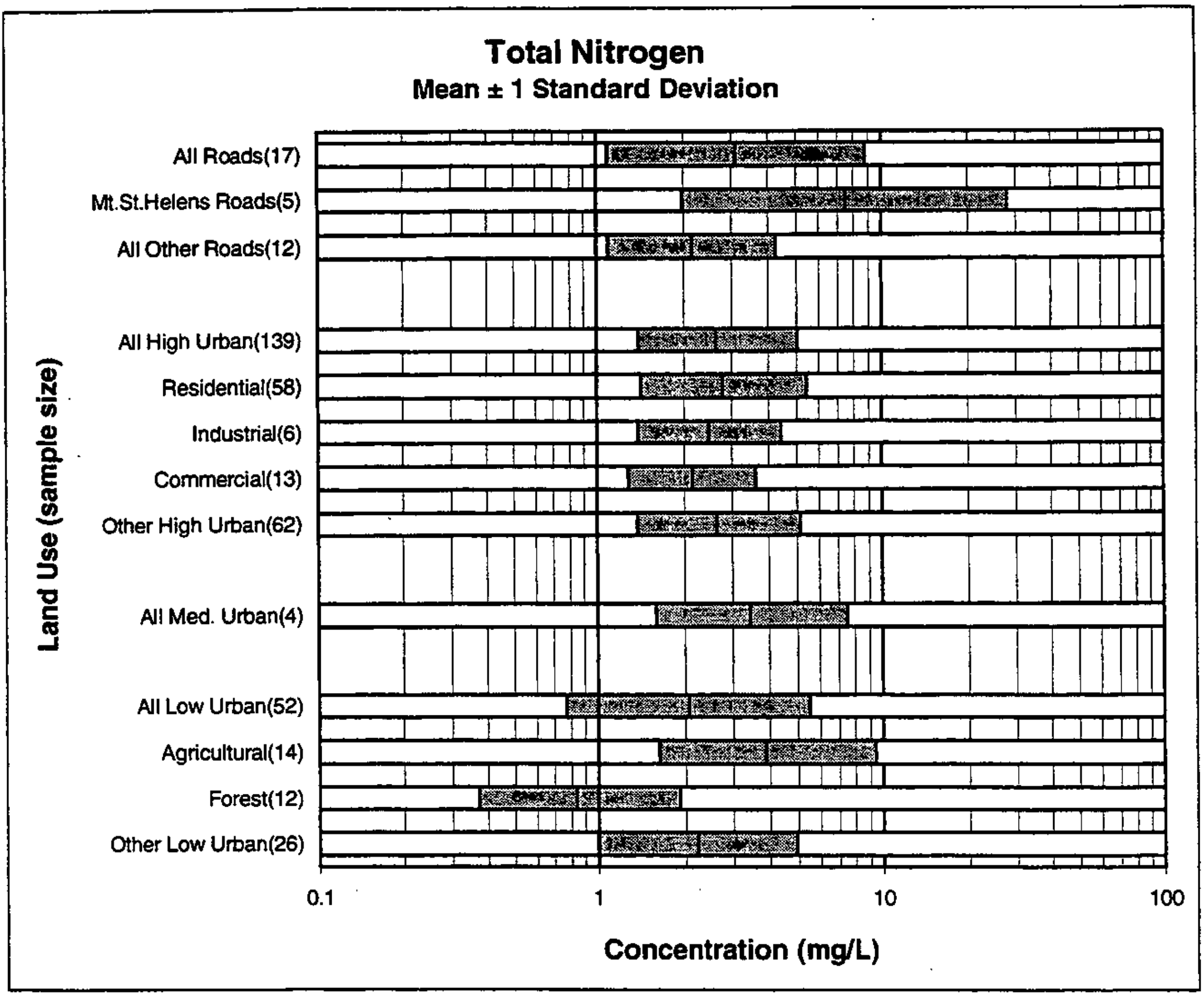

Figure A3. Mean Total Nitrogen concentrations in runoff from different land uses, and mean ± 1 standard deviation.

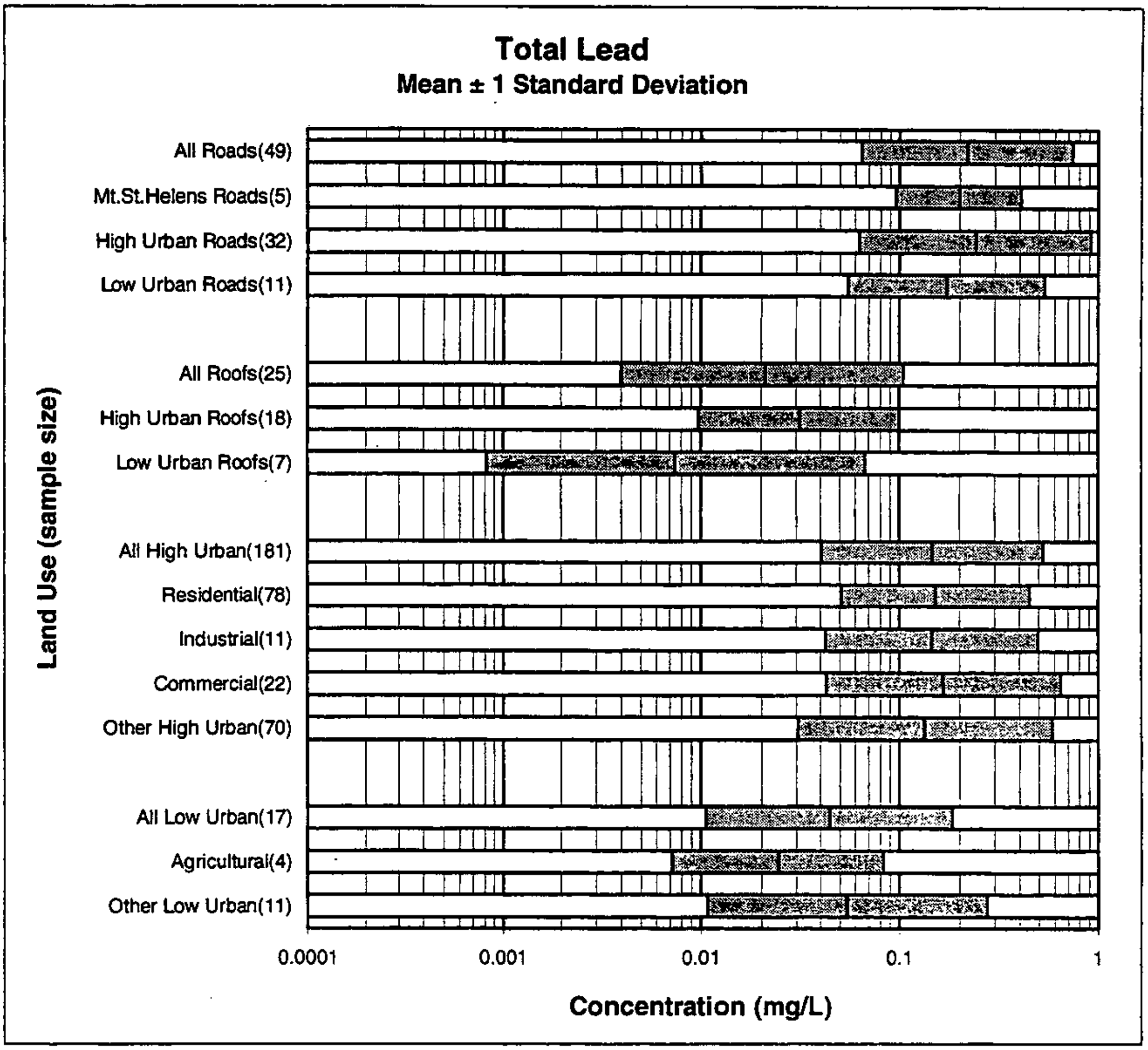

Figure A4. Mean Lead concentrations in runoff from different land uses, and mean ± 1 standard deviation.

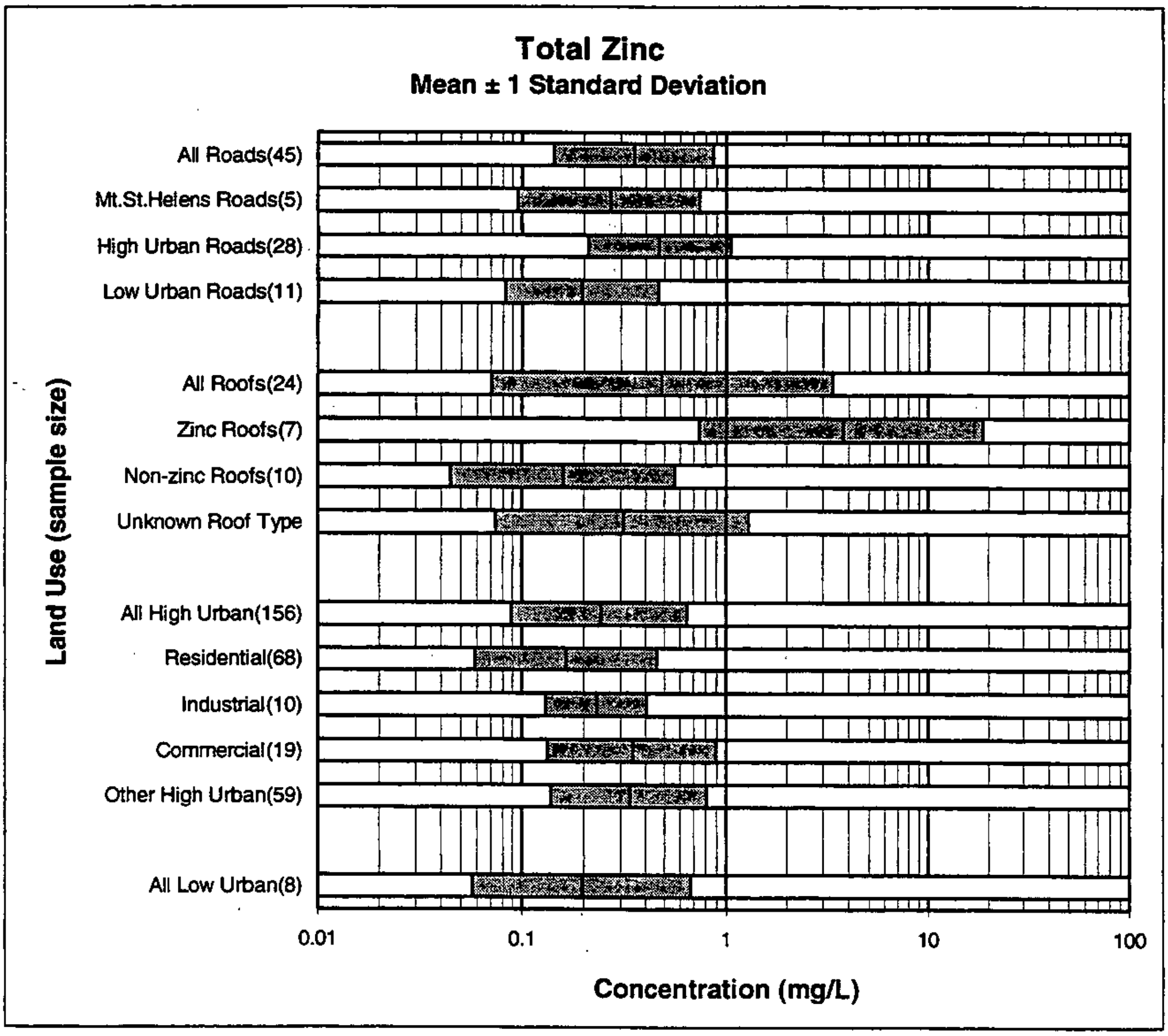

Figure A5. Mean Zinc concentrations in runoff from different land uses, and mean ± 1 standard deviation.

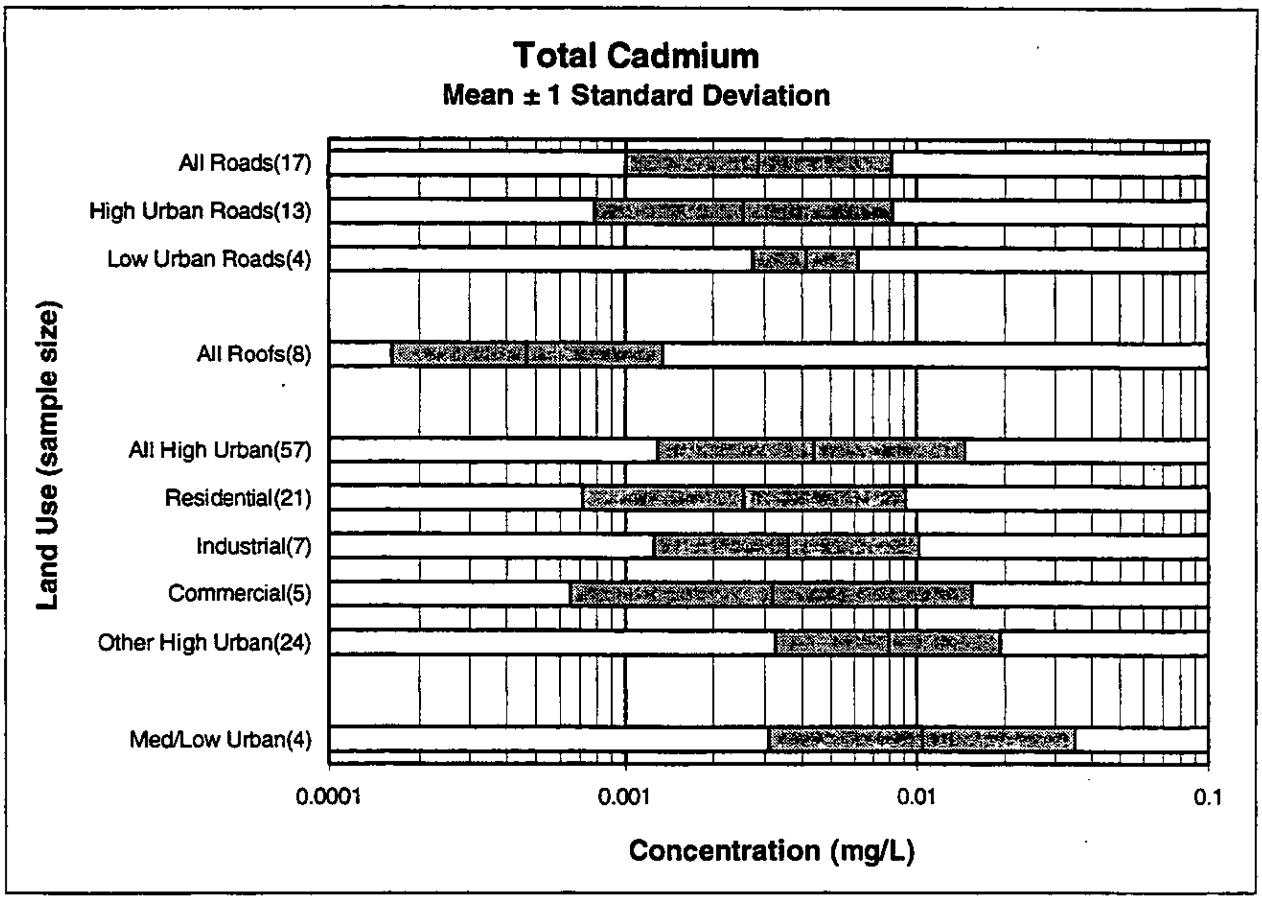

Figure A6. Mean Cadmium concentrations in runoff from different land uses, and mean ± 1 standard deviation.

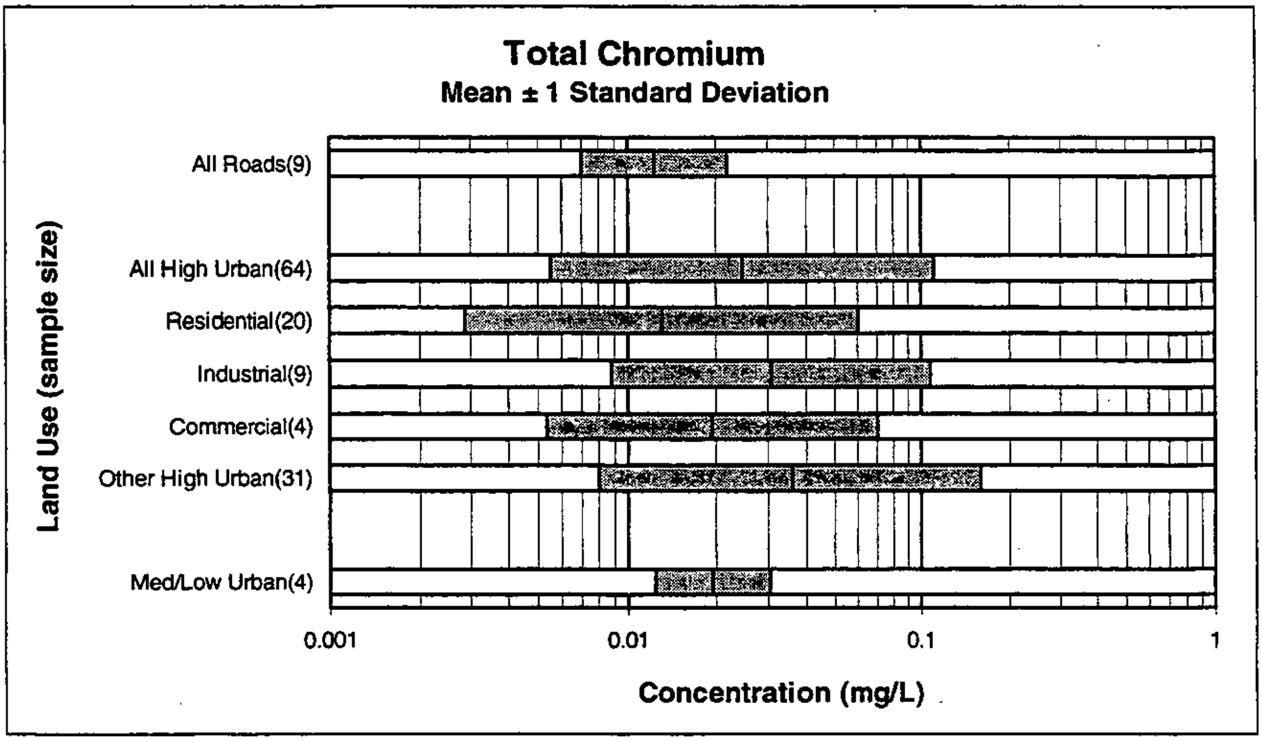

Figure A7. Mean Chromium concentrations in runoff from different land uses, and mean ± 1 standard deviation.

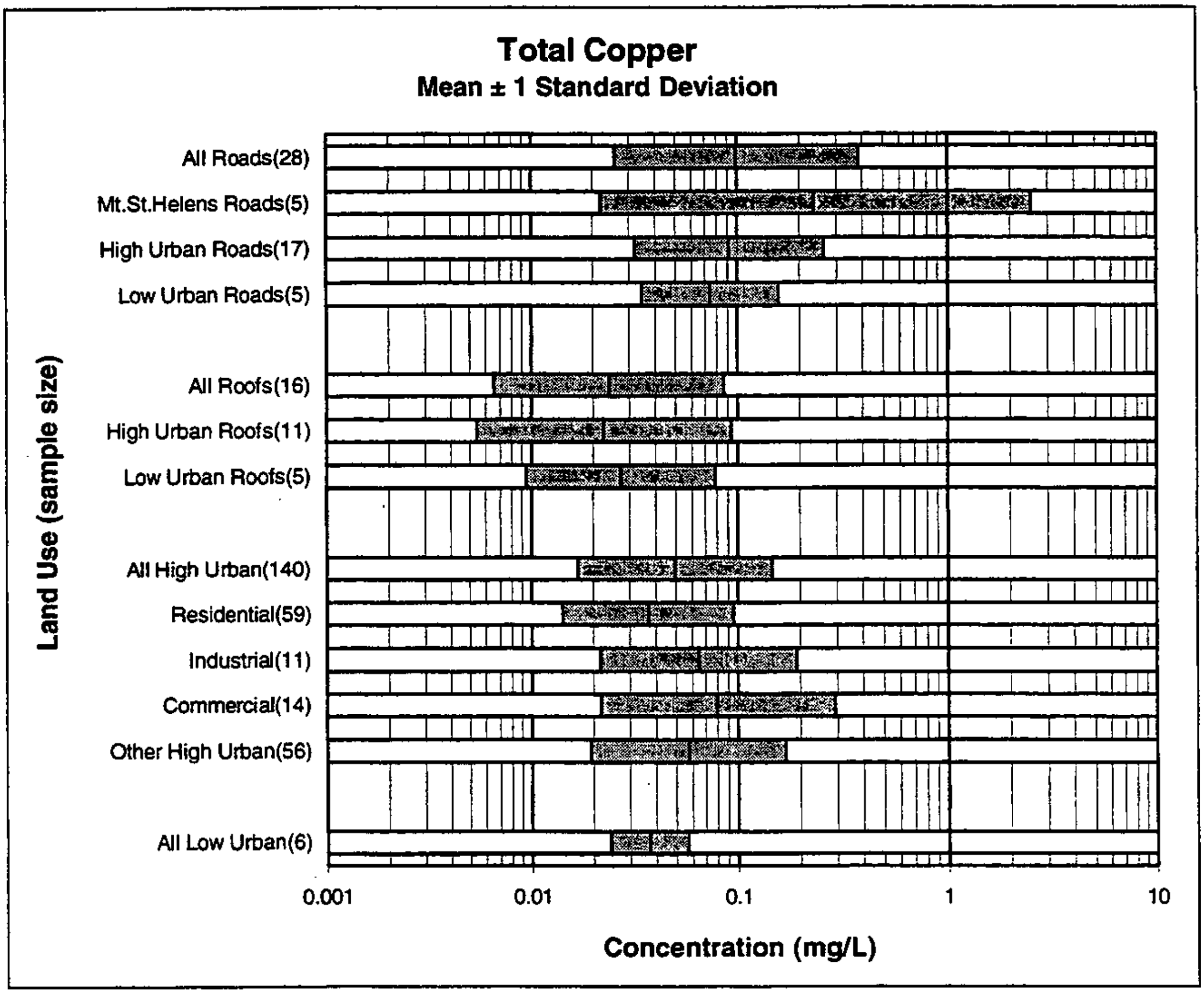

Figure A8. Mean Copper concentrations in runoff from different land uses, and mean ± 1 standard deviation.

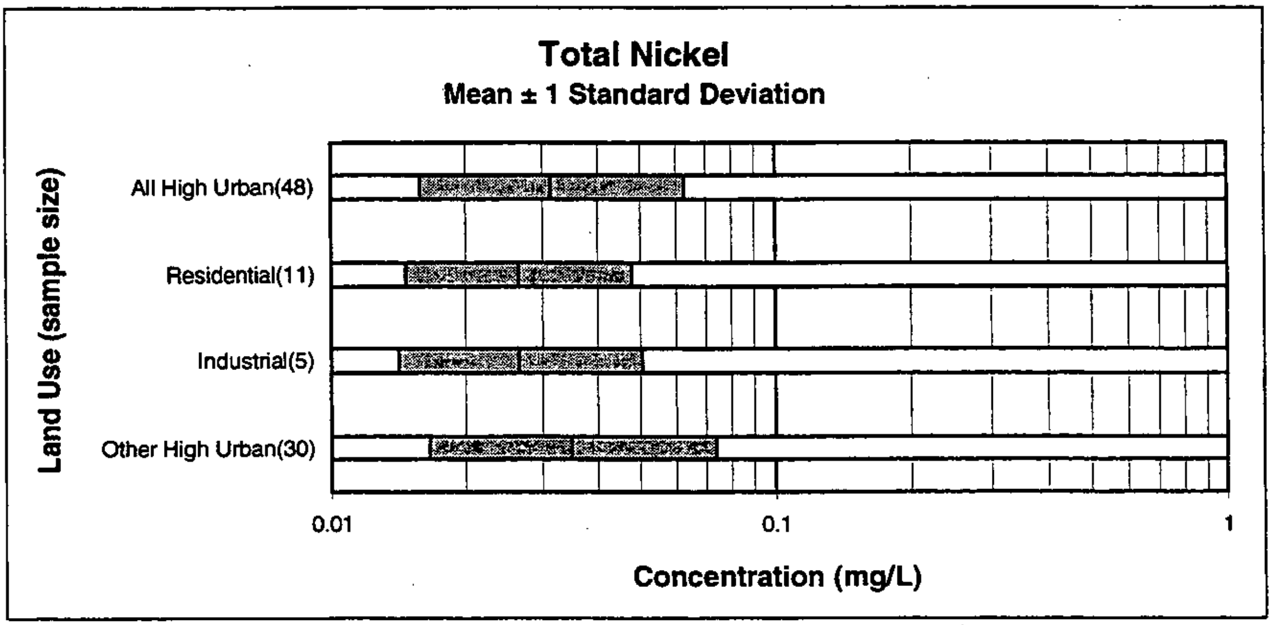

Figure A9. Mean Nickel concentrations in runoff from different land uses, and mean ± 1 standard deviation.

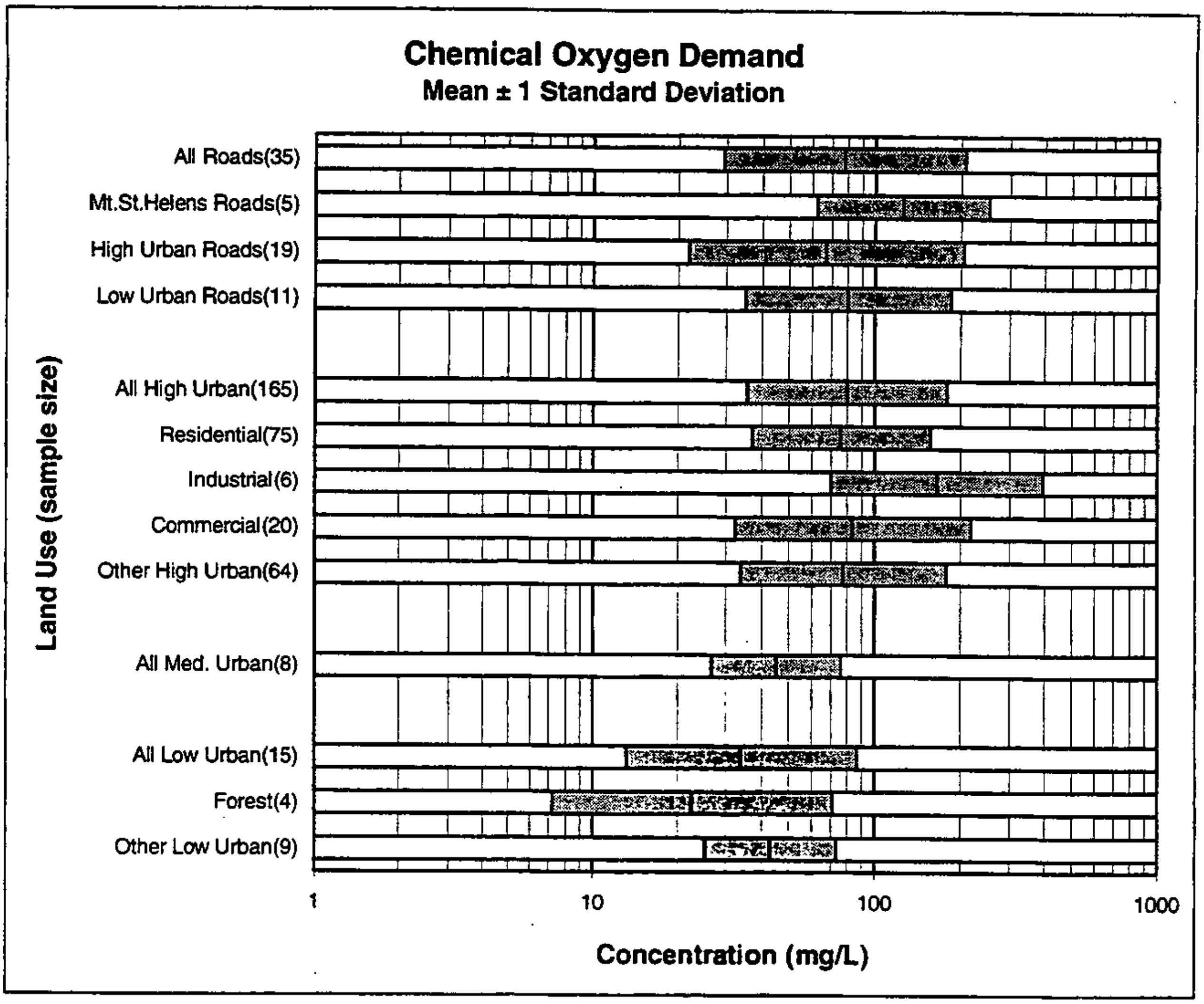

Figure A10. Mean COD concentrations in runoff from different land uses, and mean ± 1 standard deviation.

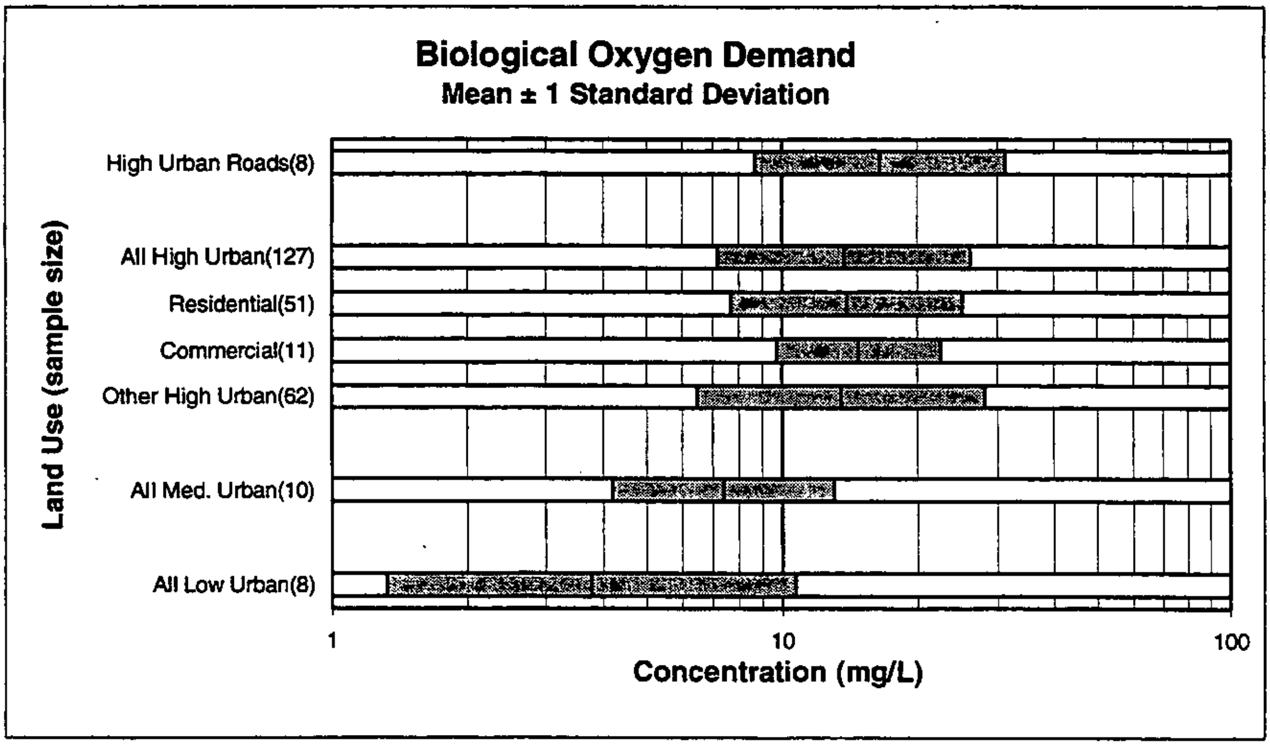

Figure A11. Mean BOD concentrations in runoff from different land uses, and mean ± 1 standard deviation.

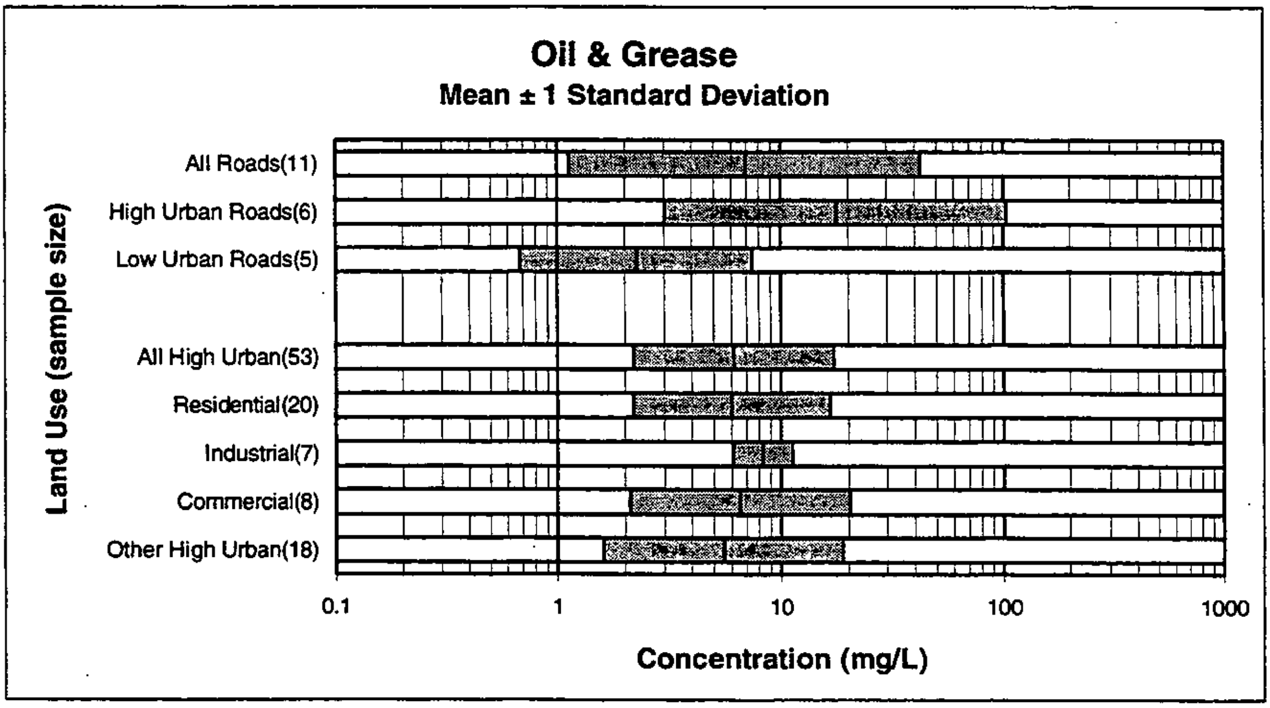

Figure A12. Mean Oil and Grease concentrations in runoff from different land uses, and mean ± 1 standard deviation.

APPENDIX B.

RELATIONSHIPS BETWEEN POLLUTANT REMOVAL

RELATIONSHIPS BETWEEN POLLUTANT REMOVAL

For each study, the inflow concentrations and outflow concentrations were plotted against each other as clear and shaded circles respectively, with a line joining them. For the sake of ease of description, each line is called a removal curve. Where the slope of most of the removal curves is close to 1:1, the reduction in concentration of the variables are similar, suggesting that the removal processes are the same for both parameters or complementary (both removal processes occur together). Slopes of the removal curves similar but not 1:1 indicates that removal of one variable is greater than the other, suggesting different removal process which may be mutually exclusive (ie. either one process or the other occurs). Scattered removal curves with a range of slopes indicate that the reduction in concentrations of the two variables is unrelated and/or dependent on other factors such as residence time or flow.

B1. Comparison between Nutrient and Suspended Solids Concentration Reductions in Storage

The reductions in concentration of various forms of phosphorus and nitrogen were plotted against the reduction in SS concentration, as shown in the Figures B1 to B8. There appears to be no relationship between dissolved P concentration reduction and SS concentration reduction (Figure B2), suggesting different removal processes. This is because the dissolved P is removed not by settling, but predominantly by biological means.

Concentration reductions of particulate P are smaller than corresponding concentration reductions in SS (as shown by the slope of most removal curves being less than 1 in Figure B3). However, the slopes for the individual studies are very similar, indicating that particulate P behaves similarly to SS in storage (ie., is settleable). The slopes of the removal curves may be less than 1 because the particles to which the P is attached are in the fine fraction of the size range and take longer to settle or because chemical reactions in the settled sediments may cause P to become dissolved and be available to move back into the water body.

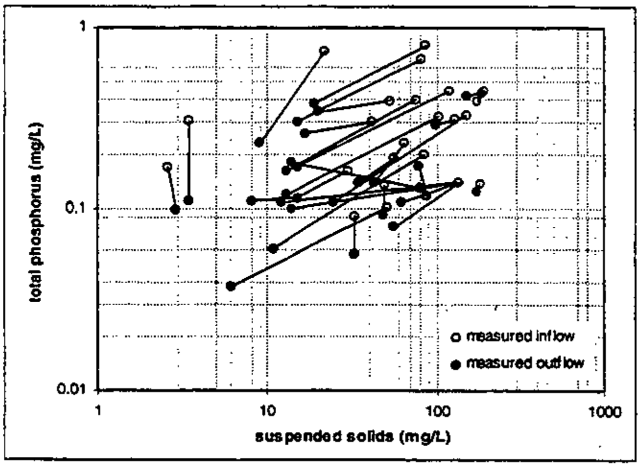

Figure B1. TP and SS inflow and outflow concentrations in storage.

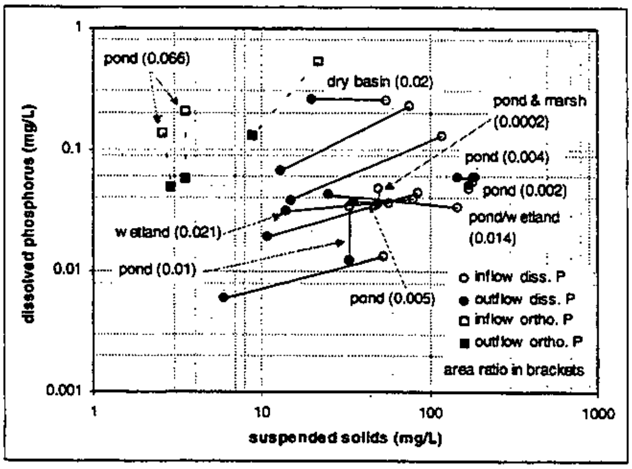

Figure B2. Reductions in dissolved P and SS concentrations in storage.

The components of TN are TKN, organic N, ammonia N, and oxidised N. Ammonia N and organic N comprise TKN, and TKN and oxidised N comprise TN. Similar to TP, reduction in concentrations of TN and its components is small compared to reduction in concentration of SS, but the slopes of the removal curves for each study are mostly similar (Figure B4). Thus, one or more components of TN is removed by a similar process to SS. It is indicated in the comparison between oxidised N (NO_x) and SS concentrations that the higher the inflow concentration of NO_x, the smaller the reduction in NO_x concentration regardless of SS concentration (Figure B5). This supports the rate-limited theory described in Section 4.2.1.3.

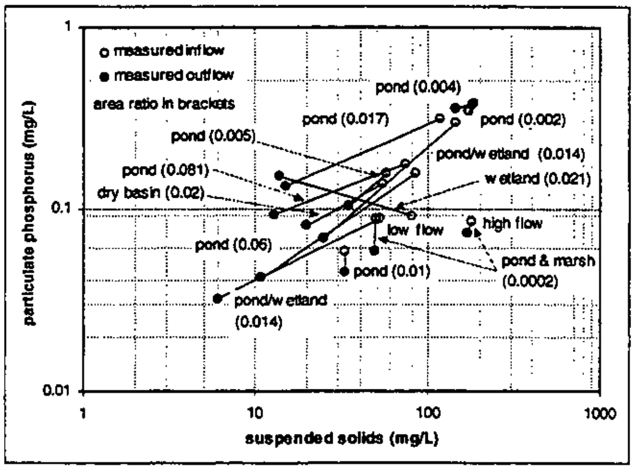

Figure B3. Particulate P and SS concentration reduction in storage.

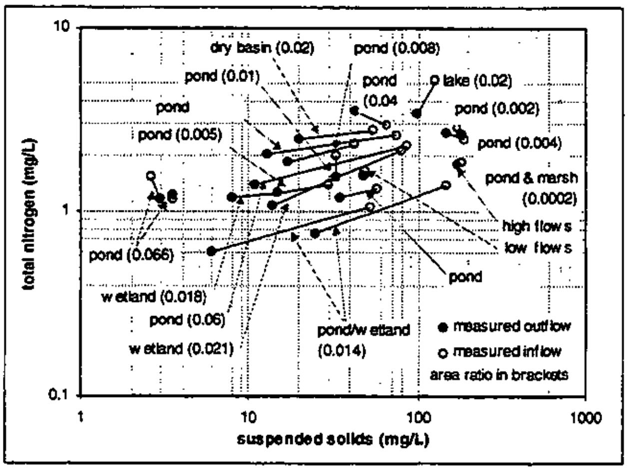

Figure B4. TN and SS concentration reduction in storage.

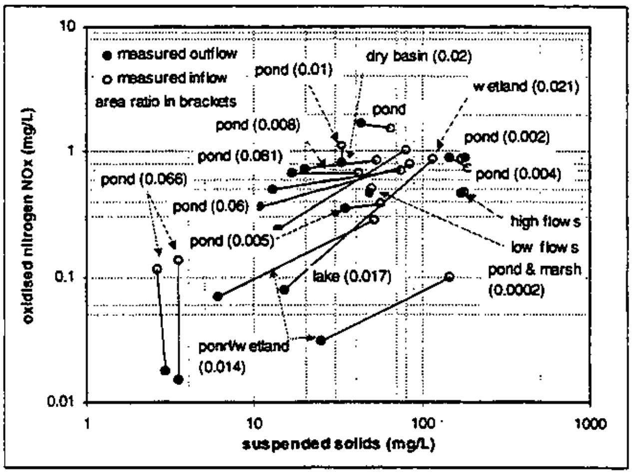

Figure B5. Reductions in dissolved N (NO_x) and SS concentrations in storage.

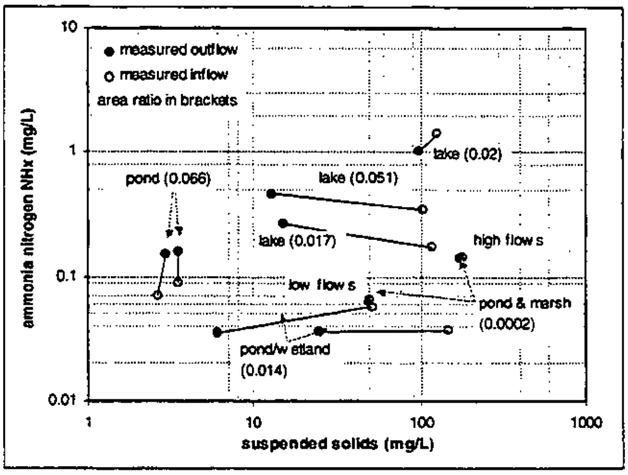

Figure B6. Reductions in ammonia N (NH_x) and SS concentrations in storage.

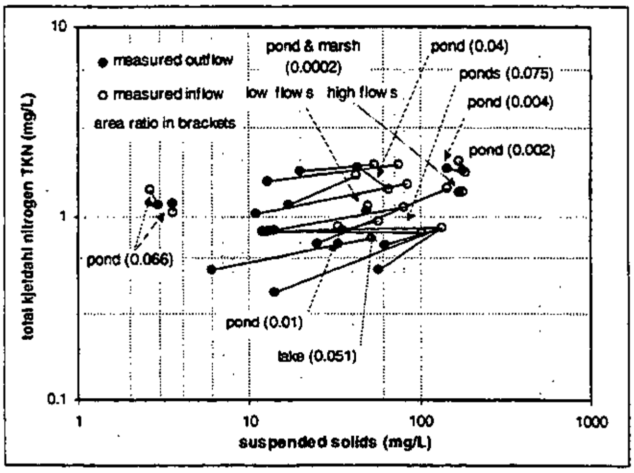

Figure B7. Reductions in TKN and SS concentrations in storage.

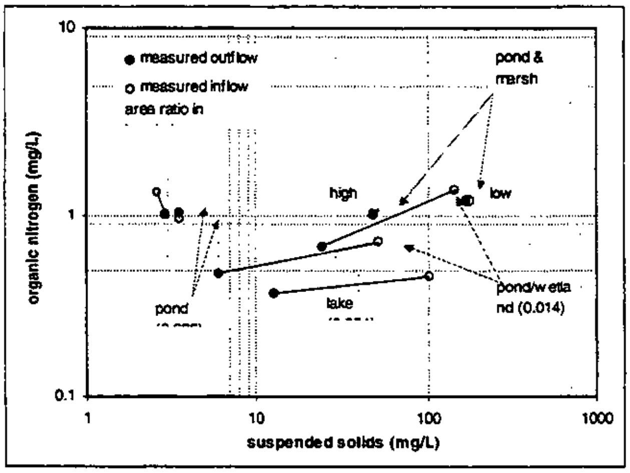

Figure B8. Reductions in organic N and SS concentrations in storage.

B2. Comparison between Nutrient Concentration Reductions in Storage

The reductions in concentration of various forms of P and N were compared to the reduction in concentration in TP or TN, as shown in the Figures B9 to B14. It should be noted that the sample sizes for some of the components of N are small. Thus, the comparisons are uncertain, however, they are shown to provide some indication of their behaviour in storage relative to TN.

Reductions in concentration of dissolved P varied with respect to the reductions in concentration of TP (Figure B9), the processes of removal varying depending on volatilisation, plant uptake, or adsorption to particles (to then become particulate). Inflow concentrations of dissolved P are also generally less than inflow concentrations of TP (in some cases up to 90 % lower). Reduction in concentrations of particulate P and TP were similar in magnitude for each study (Figure B10). These results indicate that:

1. particulate P generally comprises the greatest part of TP (also suggested in Sharpin, 1995[1] from Australian data), and
2. removal of TP is predominantly achieved by removal of particulate P, which is by sedimentation

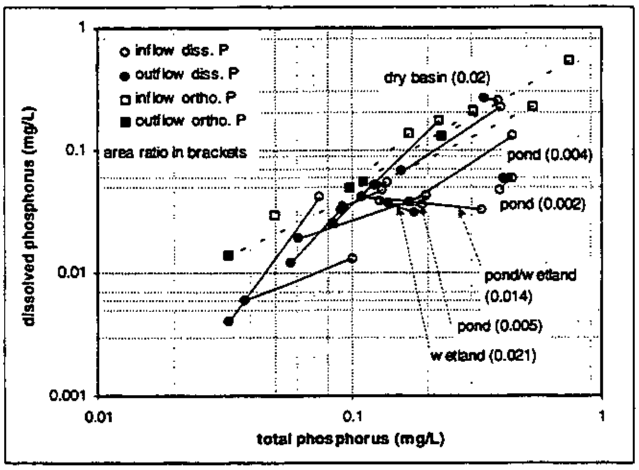

Figure B9. Reductions in dissolved and total P concentrations in storage.

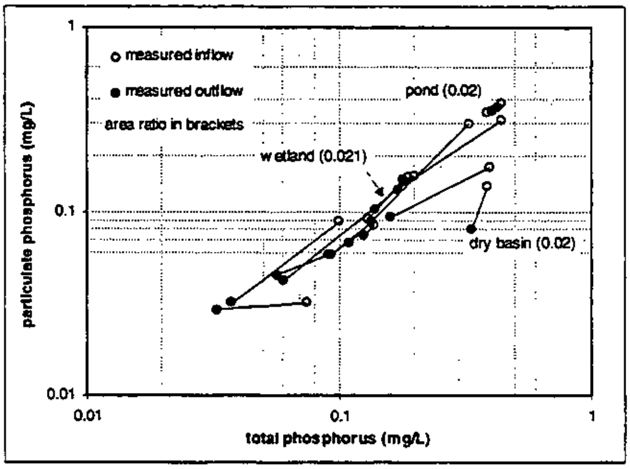

Figure B10. Reductions in particulate and total P concentrations in storage

Comparison of storage concentrations between the components of N, and TN, show that organic N is the largest component of TKN, which in turn is the largest component of TN (Figures B11 and B12) (as indicated by Sharpin, 1995 from Australian data). Organic N is less soluble than the other forms of N, and as such may be more settleable. NH_x and NO_x are often a product of nitrogen reactions in storage and sediments (after conversion from organic N) rather than an actual source pollutant. Removal of NH_x and NO_x may be facilitated by plant uptake, adsorption to soils (NH_4), and release as N_2 to the atmosphere by volatilisation (NH_4) or denitrification (NO_3).

The reduction in concentrations of both organic N and TKN shows very strong correlation to reduction in concentration of TN, with slopes of the removal curves in the order of 1:1 (Figures B11 and B12). The reduction in concentrations of the dissolved forms of N also show some relationship to reduction in concentration of TN, with slopes close to 1:1 (Figures B12 and B13). In fact, the slopes for NO_x tend towards steeper than 1:1. Thus removal of TN can be affected by

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[1] Sharpin, M.G. (1995), Stormwater Quality Characteristics From Urban and Non-Urban Catchments in South-Eastern Australia. *Proceedings, AWWA 16th Federal Convention*, Darling Harbour, Sydney, Aust. pp. 389-395.

a number of processes acting on all forms of N, although the similarity in slopes of the removal curves for TN versus SS probably reflects the sedimentation of the particulate portion of the organic N, the major component of TN.

Removals of TN relative to TP are very closely correlated, with the removal curves falling close to a single line, and generally parallel with slopes generally less than 1:1 (Figure B14). This indicates that removal of P will usually achieve removal of a smaller proportion of N.

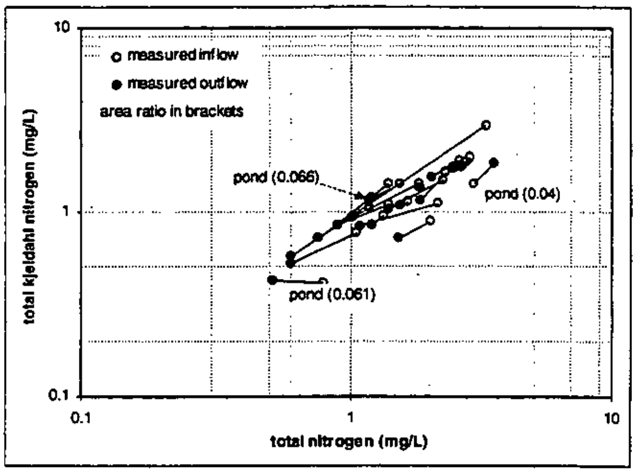

Figure B11. Reductions in TKN and TN concentrations in storage.

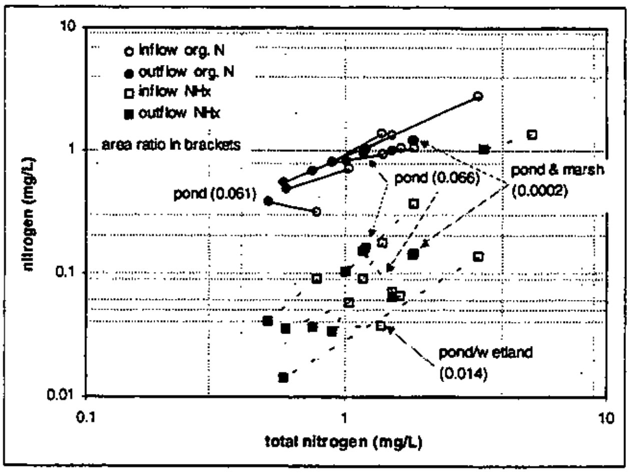

Figure B12. Reductions in organic N and NH$_x$, and TN concentrations in storage.

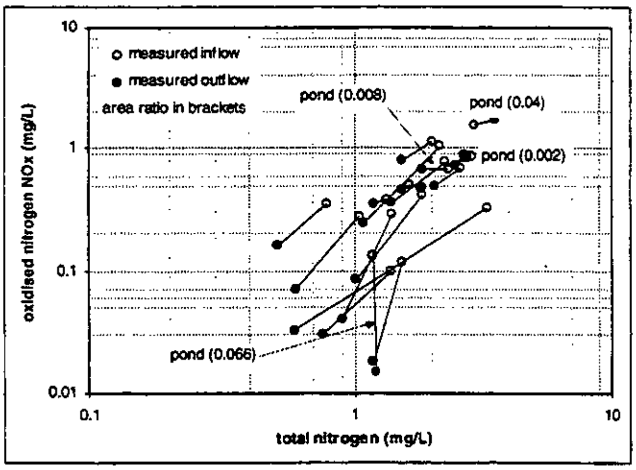

Figure B13. Reductions in NO$_x$ and TN concentrations in storage.

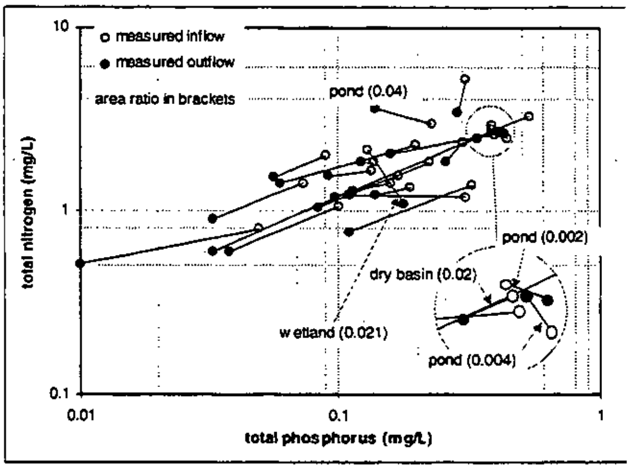

Figure B14. Reductions in TN and TP concentrations in storage.

B3. Comparison between Nutrient and Organic Carbon Concentration Reductions in Storage

The reductions in concentration of various forms of P and N, and SS were compared to the reduction in concentration in total organic carbon (TOC), as shown in the Figures B15 to B17. However, it should be noted that the number of samples are insufficient to offer a realistic comparison.

Comparison of the few data points available for total organic carbon (TOC) to SS and nutrient concentrations indicates that reduction in concentrations of SS, TP, or TN have little bearing on the reduction in concentration of TOC, or vice versa. This may be because most of the TOC is probably transported in vegetative matter, which is not measured in the inflow. The vegetative matter would then settle in storage, while the dissolved portion passes through to the outlet.

Break-down of the vegetative matter in storage will release the constituent carbon and nutrients for uptake by plants, or release to other forms (in the case of N and P).

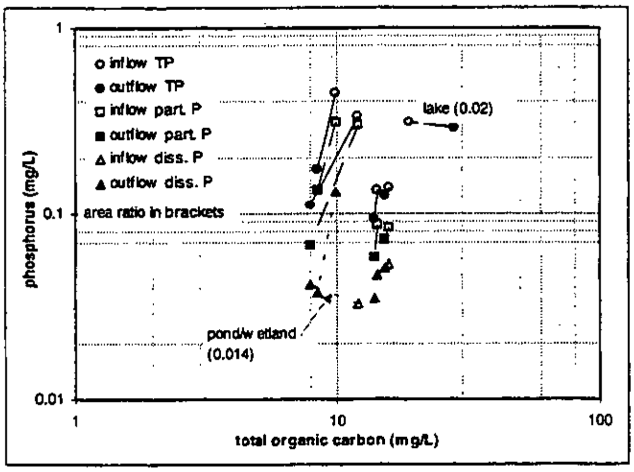

Figure B15. Reductions in P and TOC concentrations in storage.

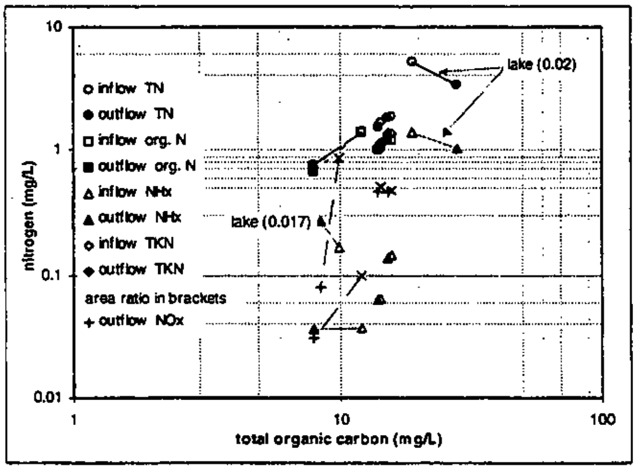

Figure B16. Reductions in nitrogen and TOC concentrations in storage.

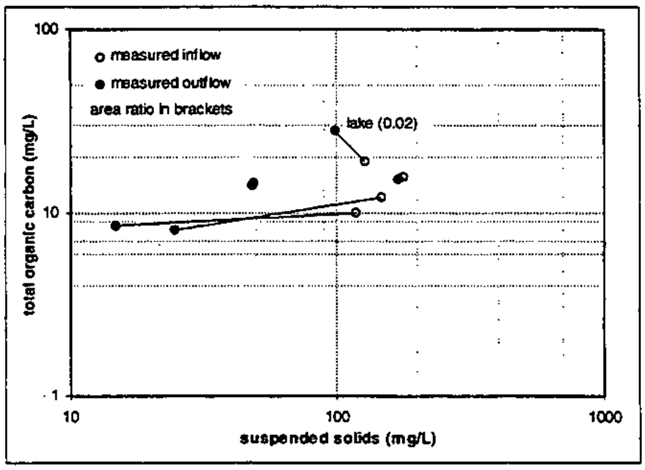

Figure B17. Reductions in SS and TOC concentrations in storage.

B4. Comparison between Oxygen Demand and Nutrient Concentration Reductions in Storage

The reductions in concentration of COD and BOD were compared to the reduction in concentration in TP, TN, and SS, as shown in the Figures B18 to B23. Again, the number of studies are limited, particularly those in which BOD was measured.

Biota, feeding on organics and nutrients, create a biological oxygen demand (BOD). Similarly, chemical reactions in solution or sediments, and chemical transformations from dissolved to solid contaminants create a chemical oxygen demand (COD). Thus, it should be expected that removal of nutrients would reduce BOD concentrations in the outflow, and removal of nutrients and other contaminants (eg., SS) will reduce COD in the outflow. This appears to be the case in most studies, with the removal curves of BOD and COD versus TP being of similar slope (less than 1:1 - Figure B18 and B19). Removal of BOD and COD is greater relative to TN, as a consequence of TN removal being fairly low compared to other parameters (Figures B20 and B21). The slopes of the removal curves for BOD relative to SS are consistent with slopes less than 1:1 (Figures B22 and B23). Slopes of the removal curves for COD are slightly steeper, reflecting the possible flocculation of pollutants in the reactions.

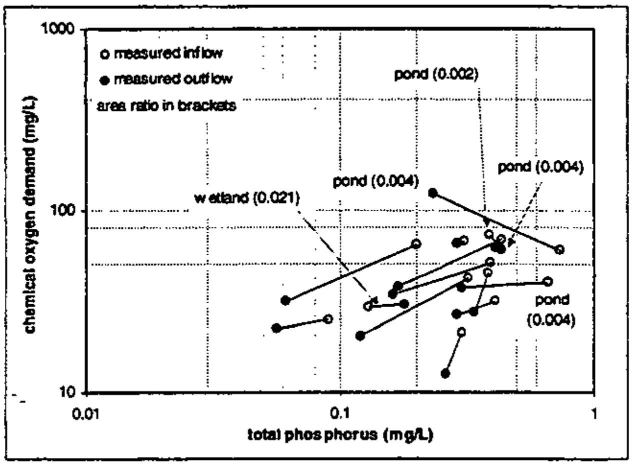

Figure B18. COD and TP inflow and outflow concentrations in storage.

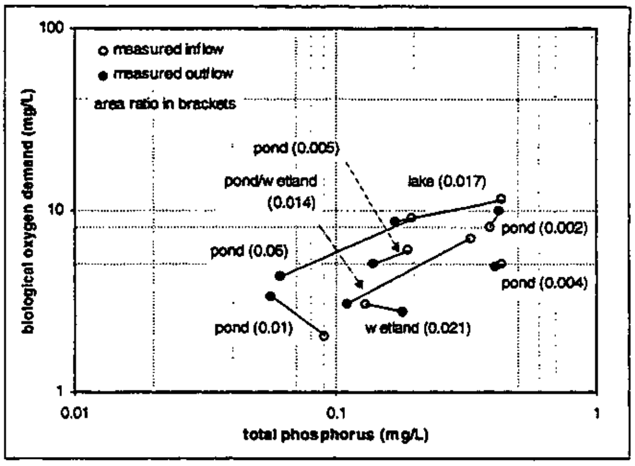

Figure B19. BOD and TP inflow and outflow concentrations in storage.

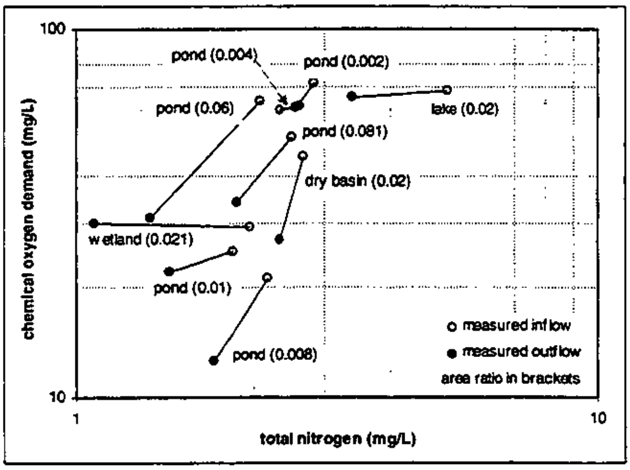

Figure B20. COD and TN inflow and outflow concentrations in storage.

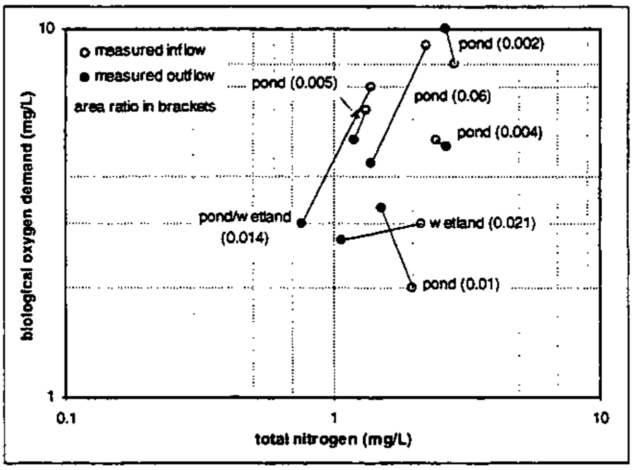

Figure B21. BOD and TN inflow and outflow concentrations in storage.

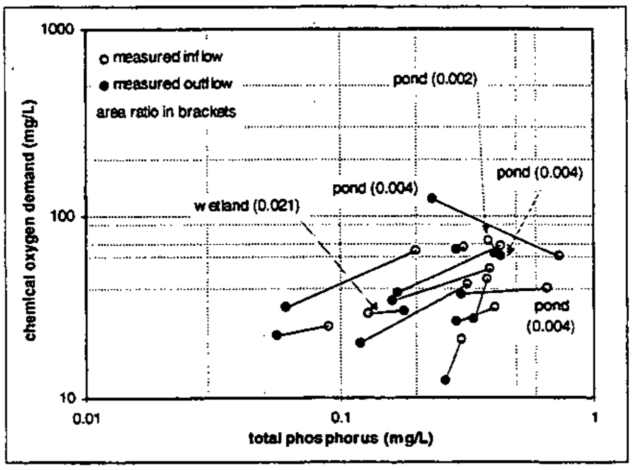

Figure B22. COD and SS inflow and outflow concentrations in storage.

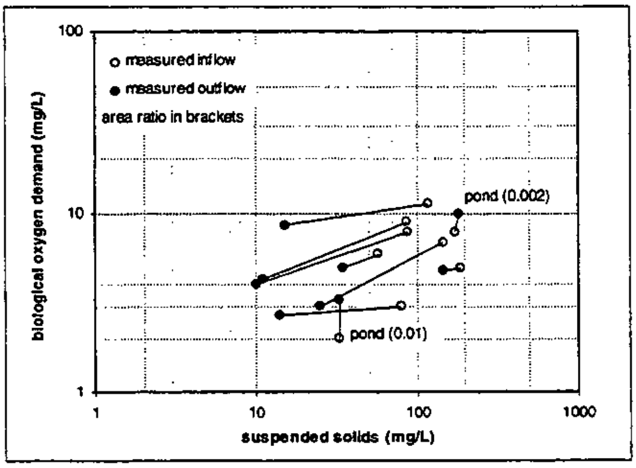

Figure B23. BOD and SS inflow and outflow concentrations in storage.

B5. Comparison Between Metals and Suspended Solids Concentration Reductions in Storage

The reductions in concentration of some heavy metals (Pb, Zn, Cd, Cu, and Fe) were compared to the reduction in concentration in SS and between each other in as shown in Figures B24 and B33.

The concentration reduction of Pb is proportional to the concentration reduction in SS in most of the studies (Figure B24). There is greater variation in the concentration reductions of Zn and Cu when compared to SS (Figures B25 and B26), indicating that although removal of Zn and Cu is partly related to removal of SS, there is some other factor involved in the removal process. Pb is predominantly particulate in nature, explaining the good relationship with SS concentration reduction. Both Zn and Cu can sometimes be dissolved, in which case they will not be all removed by settling as SS and Pb are. The component of dissolved metal would be dependent on other factors, such as temperature and the source, and the removal process is different to that for SS.

Although Cu is not grouped in the storage treatment analysis due to inadequate sample size, the fact that concentration reductions are similar to those of Zn when plotted against SS concentration reductions suggests that Cu may also belong to the settling group. Makepeace et al. (1995)[2] indicated that Cu is mostly associated with dissolved solids and sometimes colloidal material. However, Makepeace et al. (1995) also indicated that Zn was similarly associated with dissolved solids, and absorbed to SS and colloidal material. This supports inclusion of Cu in the settling group.

There is an insufficient number of samples measuring both SS and Cd, and both SS and Fe. Makepeace et al. (1995) indicated that Fe is associated with suspended solids, suggesting that it would fall in the settling group. Removal of Cd compared to Pb is relatively poor (Fig B32) for four of six studies, and removal of Cd compared to Zn fell in two groups: one with poor removal of Cd, and the other with high removal of Cd compared to Zn (Figure B33). This data suggests that Cd is settleable only in certain conditions (eg., in the presence of a coagulating agent). Makepeace et al. (1995) indicated that Cd is also associated with dissolved solids and sometimes with colloidal material.

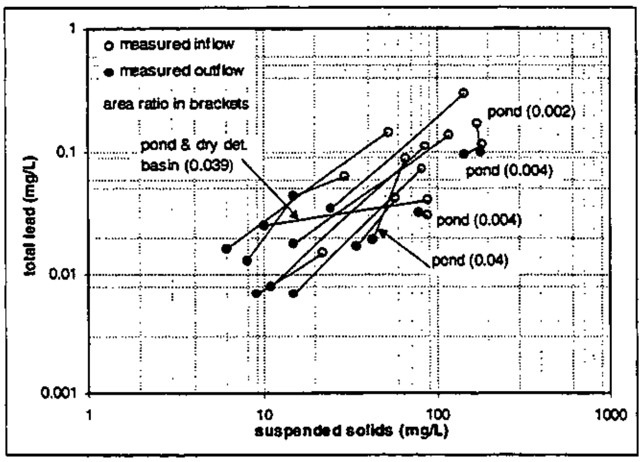

Figure B24. Pb and SS inflow and outflow concentrations in storage.

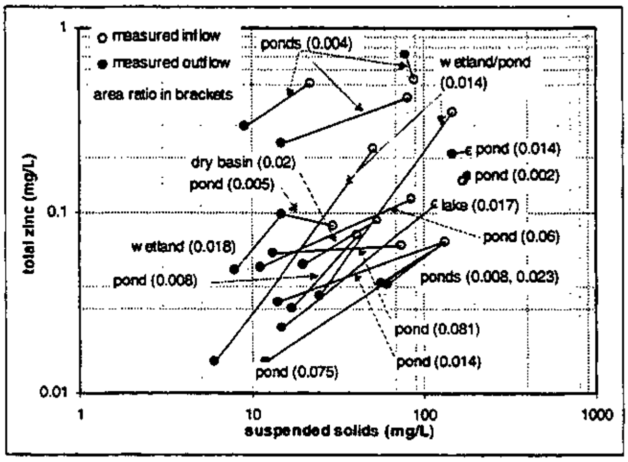

Figure B25. Zn and SS inflow and outflow concentrations in storage.

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[2] Makepeace, D.K., Smith, D.W. & Stanley, S.J. (1995), Urban Stormwater Quality: Summary of Contaminant Data. *Critical Reviews in Environmental Science and Technology* 25(2) pp. 93-139.

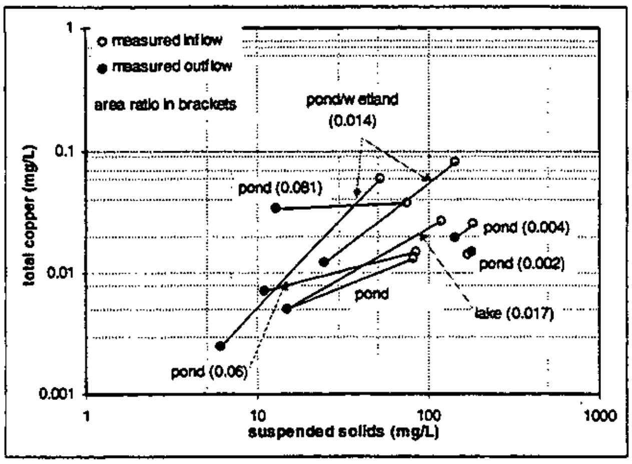

Figure B26. Concentrations of Cu and SS in storage.

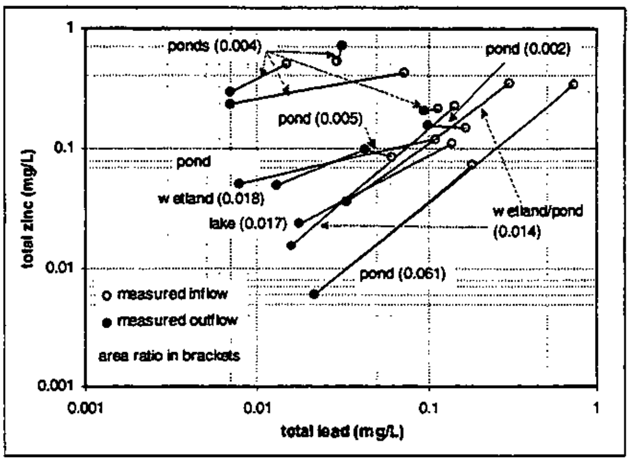

Figure B27. Concentrations of Zn and Pb in storage.

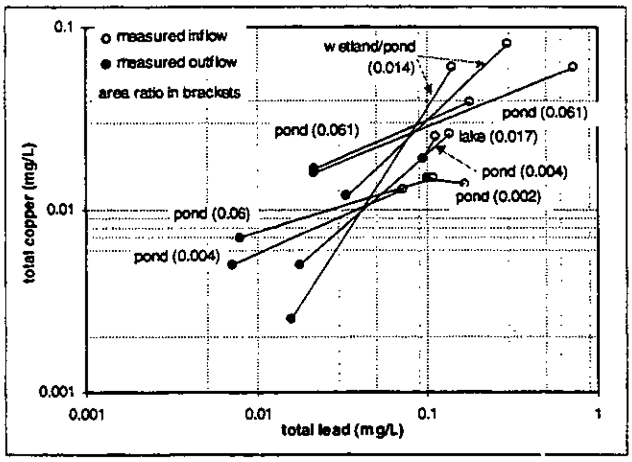

Figure B28. Concentrations of Cu and Pb in storage.

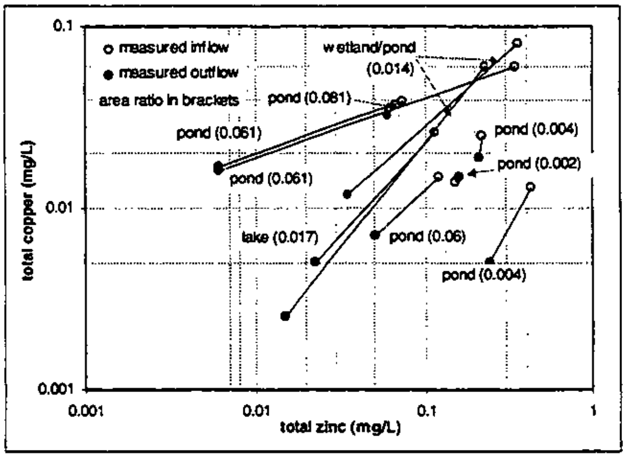

Figure B29. Concentrations of Cu and Zn in storage.

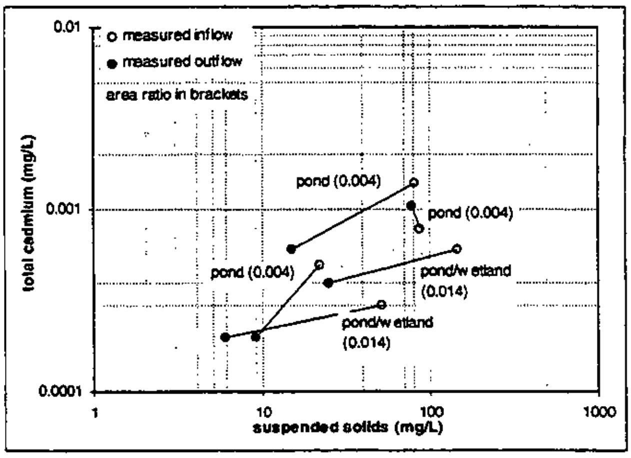

Figure B30. Concentrations of Cd and SS in storage.

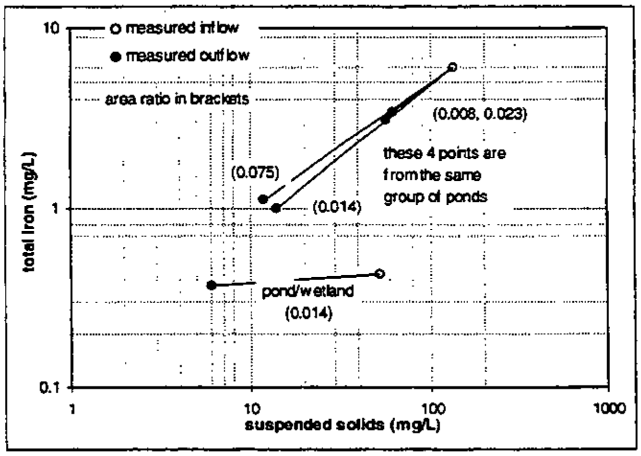

Figure B31. Concentrations of Fe and SS in storage.

Other metals which Makepeace et al. (1995) indicated are associated with suspended solids are Cr and Ni, for which insufficient data were available from the published studies to analyse removal by storage.

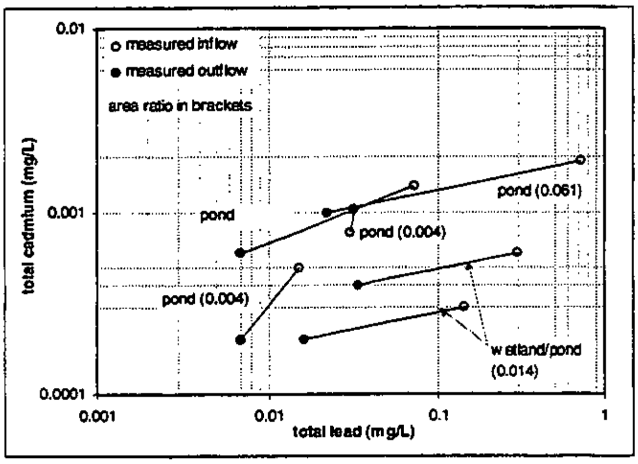

Figure B32. Concentrations of Cd and Pb in storage.

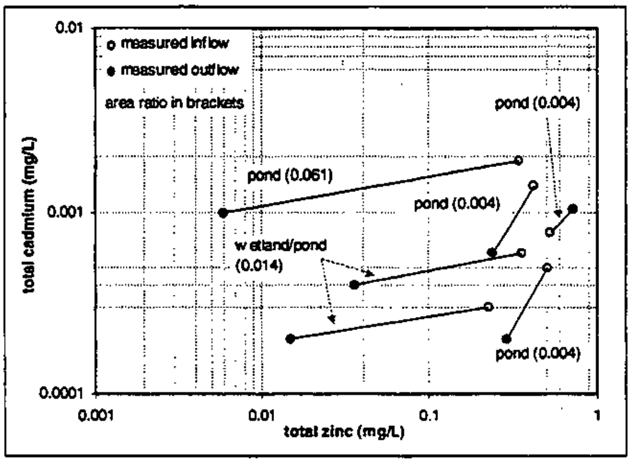

Figure B33. Concentrations of Cd and Zn in storage.

B6. Summary

The number of pollutants required to be analysed for removal can be reduced by grouping those parameters which occur in similar ratios to different land uses, and are removed by similar processes. The following pollutant removal groupings have been identified:

- Source pollutant concentrations are strongly affected by spatial variability, even within one land use classification, and so cannot be grouped.
- SS and most metals are all generally particulate in nature, and fall into the settling group. Some metals are more soluble than others, and at least one of these should be used for analysis. It is suggested to use Pb and Zn, being the parameters monitored most often.
- Removal of TP reflects the removal of particulate P, it being the major component of TP, and is related to removal of SS but smaller due to the equilibrium reactions between the storage bed and water body.
- Removal of TN reflects the removal of all forms of N, and is related to removal of SS, but is small compared to TP and SS due to the particulate form being a smaller proportion of N and the complex nature of nitrogen reactions converting N between different forms.
- TOC removal is different to nutrients and SS removal, but cannot be adequately described due to a lack of data.
- Storage treatment data for BOD and COD are limited, but removals appear to be related to TP and SS removal, though smaller, and related to TN removal.

Reductions in concentration of most parameters appears to be related to the reduction in concentration in SS. This would indicate that SS could be used as a surrogate parameter for estimating the removal performance of other parameters. That is, given a specified reduction of SS concentration, there would be some confidence in achieving reductions in concentrations of most other parameters. Noting that apart from Pb, reduction in concentrations of SS is the greatest of all parameters tested, it may be more appropriate to use a parameter with the smallest concentration reductions as the surrogate parameter - TN. Apart from metals, which were not compared to TN, the reductions in TN concentrations appeared to be related to the other parameters in a similar way to SS. If TN was to be used as the surrogate, there would be confidence that reductions in concentrations of other parameters would be greater than the specified reduction in concentration of TN.

APPENDIX C.

RAINFALL, FLOW, AND LOAD DURATION CURVES

RAINFALL, FLOW, AND LOAD DURATION CURVES

There are a number of issues listed below that are associated with published methods and are used to calculate the volume of runoff required to be captured to provide a certain pollutant removal performance:

- description of the methodology used is usually scant;
- often only SS capture has been considered;
- often pollutant removal curves presented are not related, or only loosely related, to the volume of runoff actually treated;
- pollutant loads are not related to flow;
- sometimes the rainfall analysis (frequency curves) are not directly related to volume of rainfall.

An attempt was made to try to derive a volume capture criteria using appropriate analysis of daily rainfall. This would in effect enable the frequency of volume of rainfall to be estimated (rather than the frequency of events). An additional important step was to progress the analysis to develop a duration curve for the load captured by a device as a percentage of the load able to be captured by the largest device possible. The key to the method was to be able to pick a value of exceedence (and the equivalent load capture percentage) which represented the optimum capture of stormwater for treatment. The basis for this value was on the presumption that at some point in the load capture (%) duration curve, the slope would begin decreasing at lower exceedence. The various steps that were taken to obtain this value are described below, with the corresponding outcomes.

C1. Daily Rainfall Frequency

Firstly, the daily rainfall frequency, in terms of the percentage of days of higher rainfall, was determined for a long period of data. Data for Yan Yean (Bureau of Meteorology station 086131, about 40 km north of Melbourne CBD) was used in preference to other stations, as it is one of the high quality rainfall stations identified by Lavery et al. (1992) with a very long record (from 1877) with very few missing or accumulated days of rainfall. The analysis was carried out for the period 1910 to 1990, excluding 1919.

The data set was sorted and ranked, and plotting positions (P) for each day calculated using

$$P = m / (n + 1)$$

where m = the rank, and n = the total number of days of record (in this case 29220). The percentage exceedence value was obtained by subtracting P from one and multiplying by 100. The resultant rainfall duration curve is shown in Figure C1.

C2. Daily Runoff Frequency

The next step was to estimate runoff from the rainfall. A simple method was preferred, so a runoff coefficient was applied which varied with rainfall and catchment impervious area. In this test, an impervious area of 50 % was assumed, based on the expected average for the whole of Melbourne. The proportion of area assumed to be contributing to runoff was estimated, with a corresponding runoff coefficient of 1 for each added rainfall increment. The rainfall increments, showing the method of calculation, are tabulated in Table C1. The resultant rainfall-runoff relationship is shown in Figure C2. The coefficients obtained from Table C1 and Figure C2 are quite similar to those derived from Figure 14.13 in Australian Rainfall and Runoff for a 50 % impervious catchment, over the range of ARI covered by the figure and associated adjustment factors, although in this case a daily time period rather than storm events is being used.

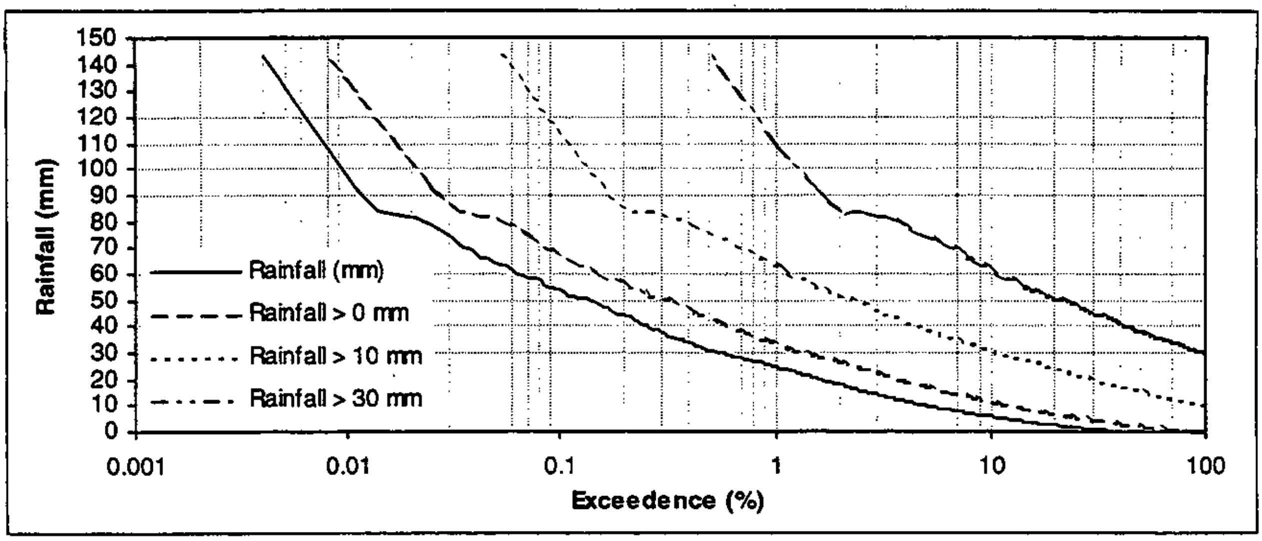

Figure C1. Rainfall duration curves for Yan Yean (086131) for the whole daily series and three partial series.

Table C1. Rainfall increments used to estimate the runoff coefficient.

Rainfall (mm)		Area contributing from 1 ha		Runoff (mm)		Runoff	Comments
Daily A	Increment $B=A_i-A_{i-1}$	Impervious C	Pervious D	Increment $E=B\times(C+D)$	Total $F=E_i+E_{i-1}$	Coefficient $G=F/A$	
0							
5	5	0	0	0	0	0.00	
10	5	0.3	0	1.5	1.5	0.15	all directly connected impervious areas
15	5	0.35	0	1.75	3.25	0.22	
20	5	0.4	0	2	5.25	0.26	
25	5	0.45	0.05	2.5	7.75	0.31	start pervious areas
30	5	0.5	0.1	3	10.75	0.36	all impervious area
40	10	0.5	0.25	7.5	18.25	0.46	
50	10	0.5	0.5	10	28.25	0.57	all area
60	10	0.5	0.5	10	38.25	0.64	
70	10	0.5	0.5	10	48.25	0.69	
80	10	0.5	0.5	10	58.25	0.73	
90	10	0.5	0.5	10	68.25	0.76	
100	10	0.5	0.5	10	78.25	0.78	

Estimation of the runoff was simply a matter of multiplying the daily rainfall value by the corresponding runoff coefficient. The runoff duration curve is shown in Figure C3.

At a given exceedence (e_i) the volume treated by any device designed to capture a runoff of q_i (V_i) will be equal to the area under the duration curve as shown in Figure C4. If the runoff duration curve is integrated, a curve is obtained which describes the volume treated for a given exceedence. A device designed to capture the most extreme runoff (e_n, q_n) will treat 100% of all runoff (V_n). Dividing the integrated runoff duration curve by V_n provides a curve describing the proportion of total runoff treated by a device designed to capture the e_ith runoff event (Figure C5). The actual device volume and equivalent rainfall can then be read from Figures C1 and C3 using the chosen e_i.

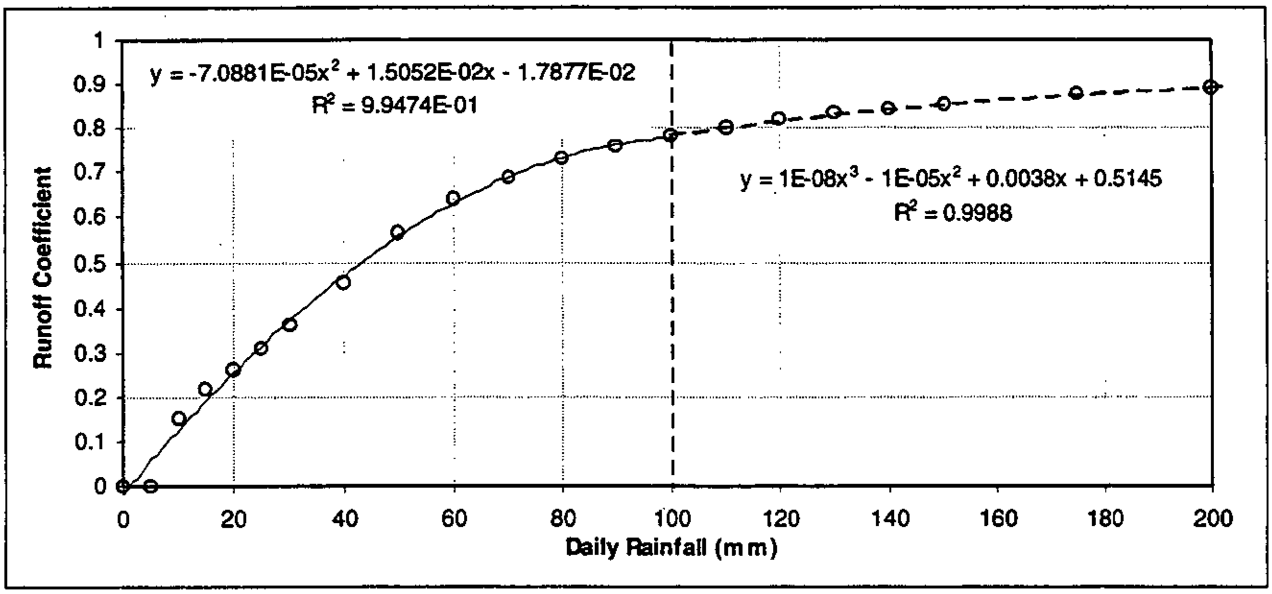

Figure C2. Rainfall runoff coefficient relationship for 50 % impervious area.

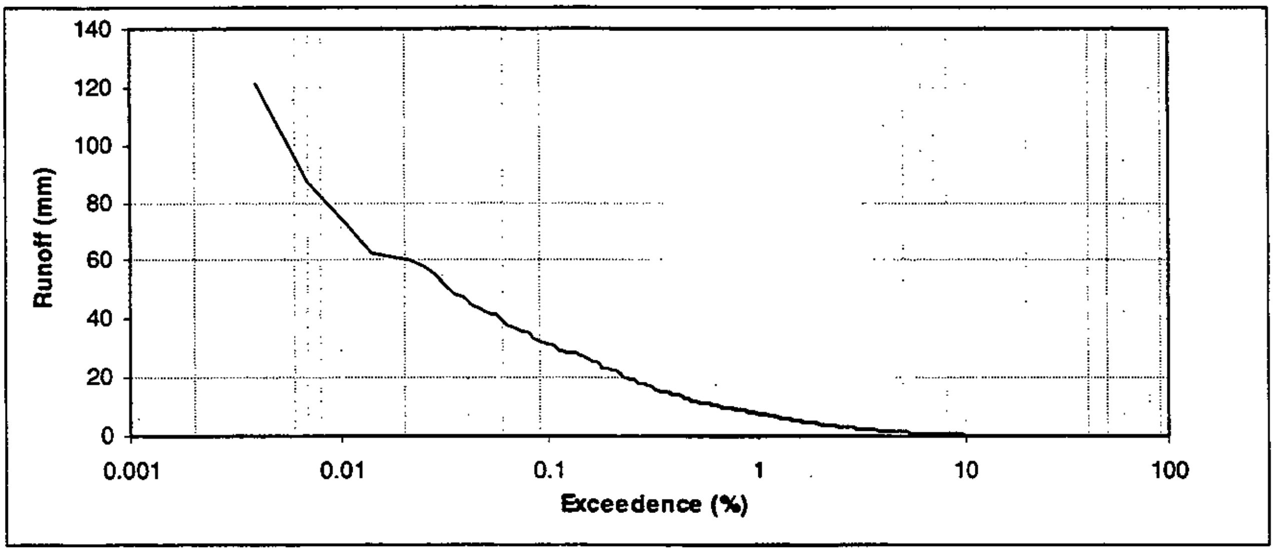

Figure C3. Runoff duration curve for Yan Yean rainfall.

It can be seen from the inset in Figure C5 that the slope of the volume capture duration curve continues to increase with decreasing exceedence. This makes it difficult to identify an optimum volume of capture by the method described at the start of this Appendix.

C3. Daily Load Duration Curve

A further step can be added by calculating the load exceedences, using a flow-concentration, or flow-load relationship. Regressions between flow and a number of pollutant parameters have been developed by the USEPA (Driver and Troutman, 1989)[3]. These relationships fell into three basic groups, but were all of exponential form with the exponent close to one (ie., almost linear). The exponent for SS load to flow was about 1.1, while the exponents for TP was about 0.9 and the other parameters (TN, metals, DS, COD) were about 0.8.

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[3] Driver, N.E. & Troutman, B.M. (1989), Regression Models for Estimating Urban Storm-Runoff Quality and Quantity in the United States, *Jour. Hydrol.* 109, pp. 221-236.

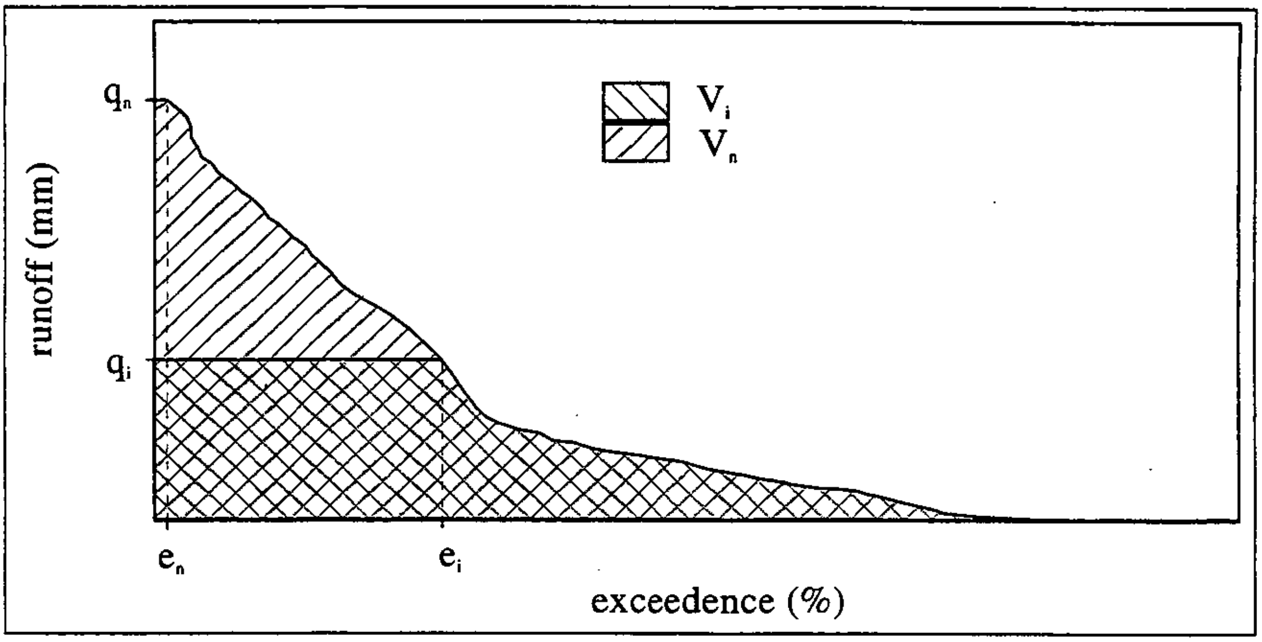

Figure C4. Schematic runoff duration curve showing method to calculate percentage runoff volume exceedence.

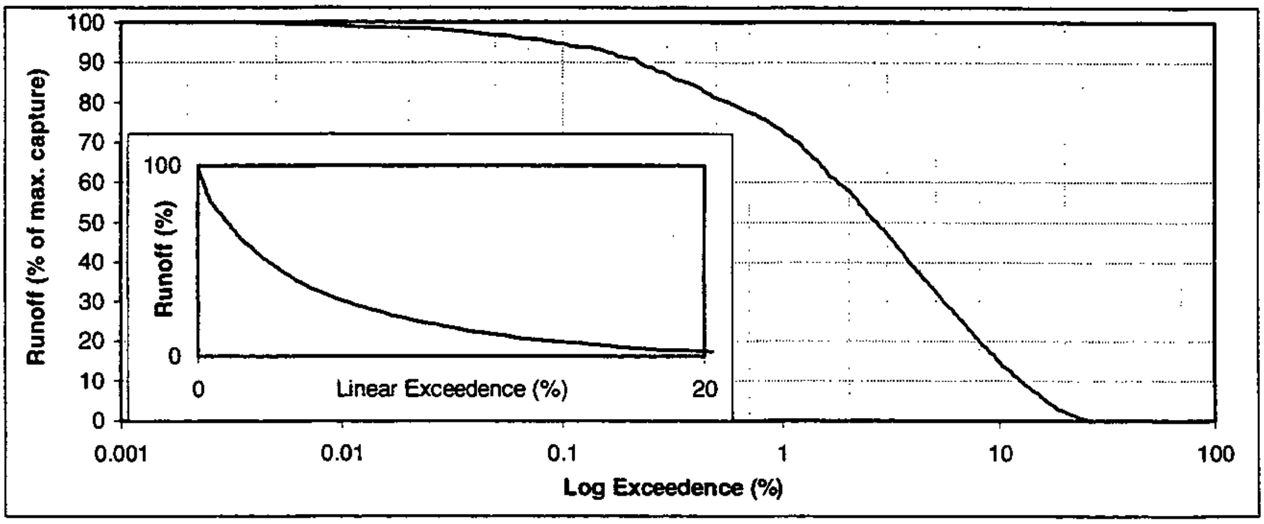

Figure C5. Runoff as a percentage of the maximum possible capture for Yan Yean rainfall.

A similar procedure to that described for runoff, above, can be followed to obtain the load capture duration curve. Because the exponents on the load-flow regression curves are so close to one, the shapes of the load capture duration curves are very similar to the runoff capture duration curves.

It should be noted that the mean stormwater runoff quality was found to be different in Australia from overseas for TP, PB, Zn, Cd, and Ni. Thus the flow-load relationships used in the analysis above, being from US data, may not be totally appropriate for the example provided, or for other Australian locations. This was amplified by Sharpin (1995)[4], who correlated EMCs of SS, TP, and TN against event mean runoff volumes using both linear and power functions, and found that less than 25 % of the regressions were statistically significant at the 5 % level. No regressions were shown to indicate the degree of scatter.

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[4] Sharpin, M.G., (1995), Stormwater Quality Characteristics From Urban and Non-Urban Catchments in South-Eastern Australia. *Proceedings, AWWA 16th Federal Convention*, Darling Harbour, Sydney, Aust. pp. 389-395

APPENDIX D.

EFFECT OF POND AREA RATIO ON OUTFLOW CONCENTRATION

EFFECT OF POND AREA RATIO ON OUTFLOW CONCENTRATION

The area ratio (A_r) is the ratio of the surface area of the storage to the total area of the catchment. The descriptive variable which most significantly affected the output concentrations from storage treatment was the area ratio. This was the case for all the key pollutant parameters - SS, TP, TN, Pb, and Zn. In a bi-variate analysis, the standard error was least when area ratio was used with inflow concentration to explain the outflow concentration. However, the standard errors obtained are still high due to inadequate sample sizes.

For SS (Figure D1), an area ratio of 0.05 would on average return an outflow concentration between 13 % of a high inflow concentration and 40 % of a low inflow concentration (87 and 60 % reduction, respectively). This is a factor of 3.2 over the range of inflow concentrations plotted. An area ratio of 0.001 would on average achieve an outflow concentrations of only 40 % of a high inflow concentration, and SS would be scoured from a storage of this size when inflow concentrations are smaller than 30 mg/L. This is a factor of 7.2 over the range of inflow concentrations plotted. For a given inflow concentration, the range of outflow concentrations for different area ratios can vary by a factor of up to 7.5 at low inflow concentration, and a factor of up to 3.1 at high inflow concentrations. The 1:1 line shown in Figure D1 indicates at what inflow concentration, on average, scouring begins to occur. Considering that inflow concentrations are rarely smaller than 10 mg/L (Figure A1), a storage area greater than 0.5 % of the catchment should be used to treat suspended solids, so as to achieve reasonable concentration reductions.

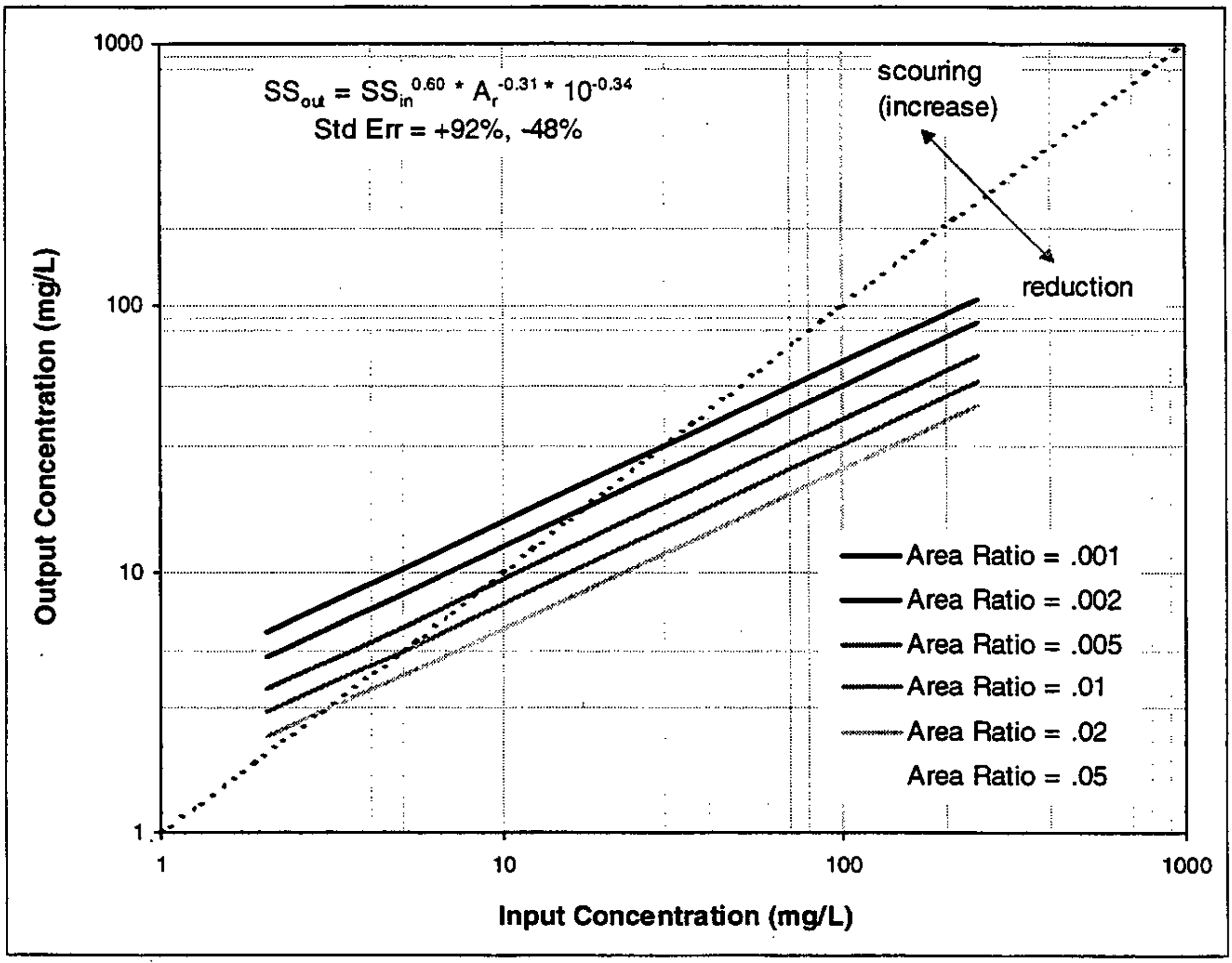

Figure D1. Outflow SS concentrations from storage treatment with different area ratios.

As can be seen in Figure D2, area ratio has less affect on TP outflow concentrations than SS, as shown by the closeness of the curves. At high inflow concentrations, the range of outflow concentrations for different area ratios varies by a factor of up to 1.6 compared to 3.2 for SS. This factor is constant over the range of inflow concentrations. It can also be noted that, on average, TP is not scoured from the storage, regardless of the area ratio (down to 0.001). Another feature to note is that the range of concentration reduction over the range of inflow concentration is also much smaller than for SS - a factor of 1.4 over the range compared to between 3.1 and 7.2 for SS. This indicates that outflow concentration of TP from storage is less sensitive to area ratio and inflow concentration than SS, and that storage is overall less effective.

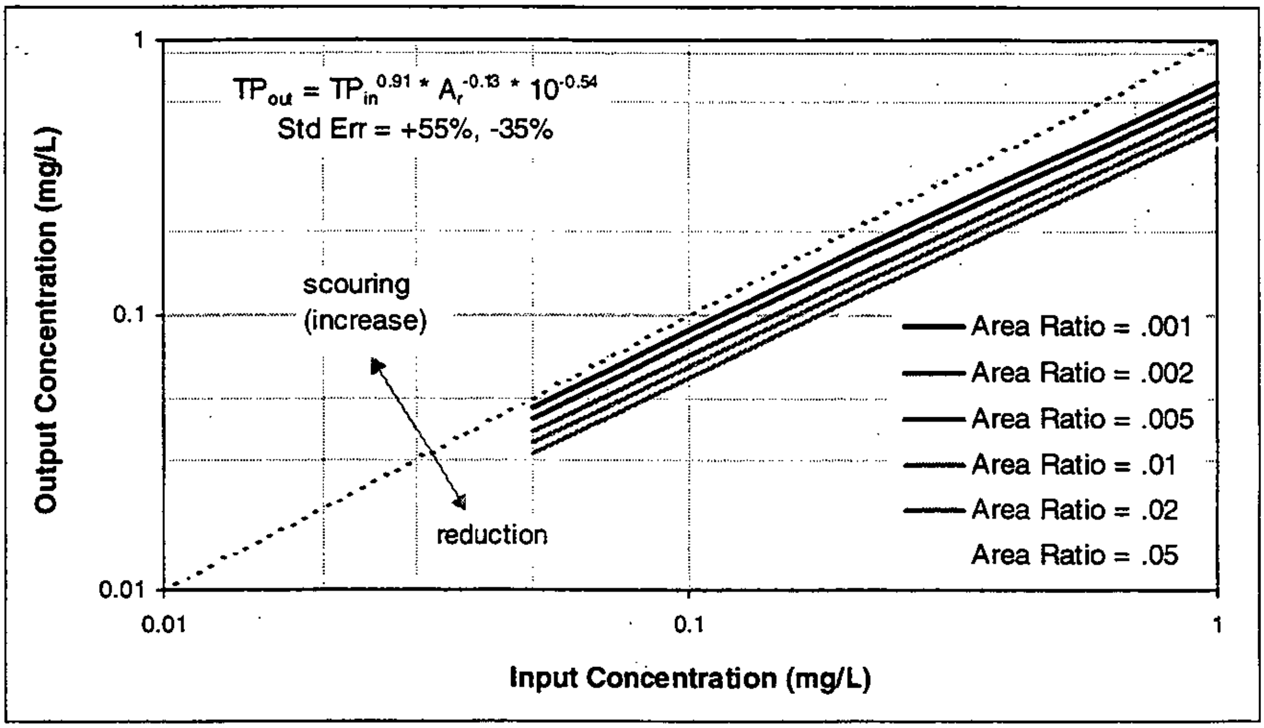

Figure D2. Outflow TP concentrations from storage treatment with different area ratios.

The effect of storage on TN compared to SS is the same as the comparison between TP and SS, although more marked (Figure D3). However, the slope of the set of curves appears to be greater, and shows that scouring of TN occurs on average in the smaller storages at higher inflow concentration. Thus, a larger storage area ratio (at least 0.005) is preferable to treat TN, particularly if inflow concentrations are high. However, reduction in TN concentrations in storage is generally small, so designing the storage primarily for nitrogen removal may not be practical.

Pb behaves very similarly to suspended solids in storage, the outflow concentration being as sensitive to area ratio and inflow concentration (Figure D4). In order to prevent scouring of Pb from the storage and achieve reasonable concentration reduction, it is preferable to ensure the area ratio is greater than 0.5 %, although over the typical range of lead concentrations, scouring is not likely to occur (Figure A4 - high urban values).

The significance of area ratio and inflow concentration to outflow concentrations is greatest for Zn (Figure D5). At high concentrations of Zn (0.7 mg/L), reductions of greater than 90 % can be obtained in a storage with an area ratio of greater than 0.02. The concentration reduction can vary by a factor of 6.5 over the range of inflow concentrations plotted, and by a factor of 18 over the range of area ratios. It can also be seen that scouring will occur in a storage with area ratio of 0.001, for all typical inflow concentrations (Figure A5 - high urban). Thus a minimum area ratio of 0.5 % is required.

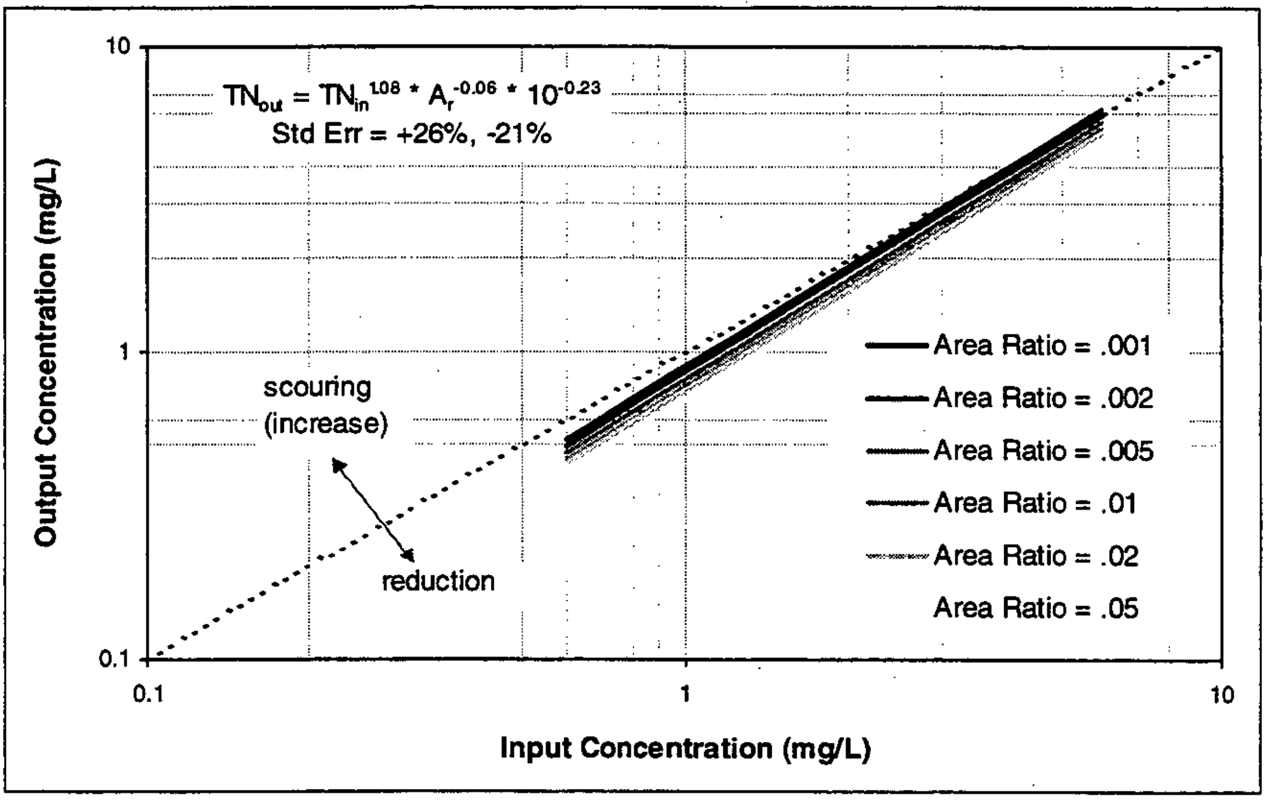

Figure D3. Outflow TN concentrations from storage treatment with different area ratios.

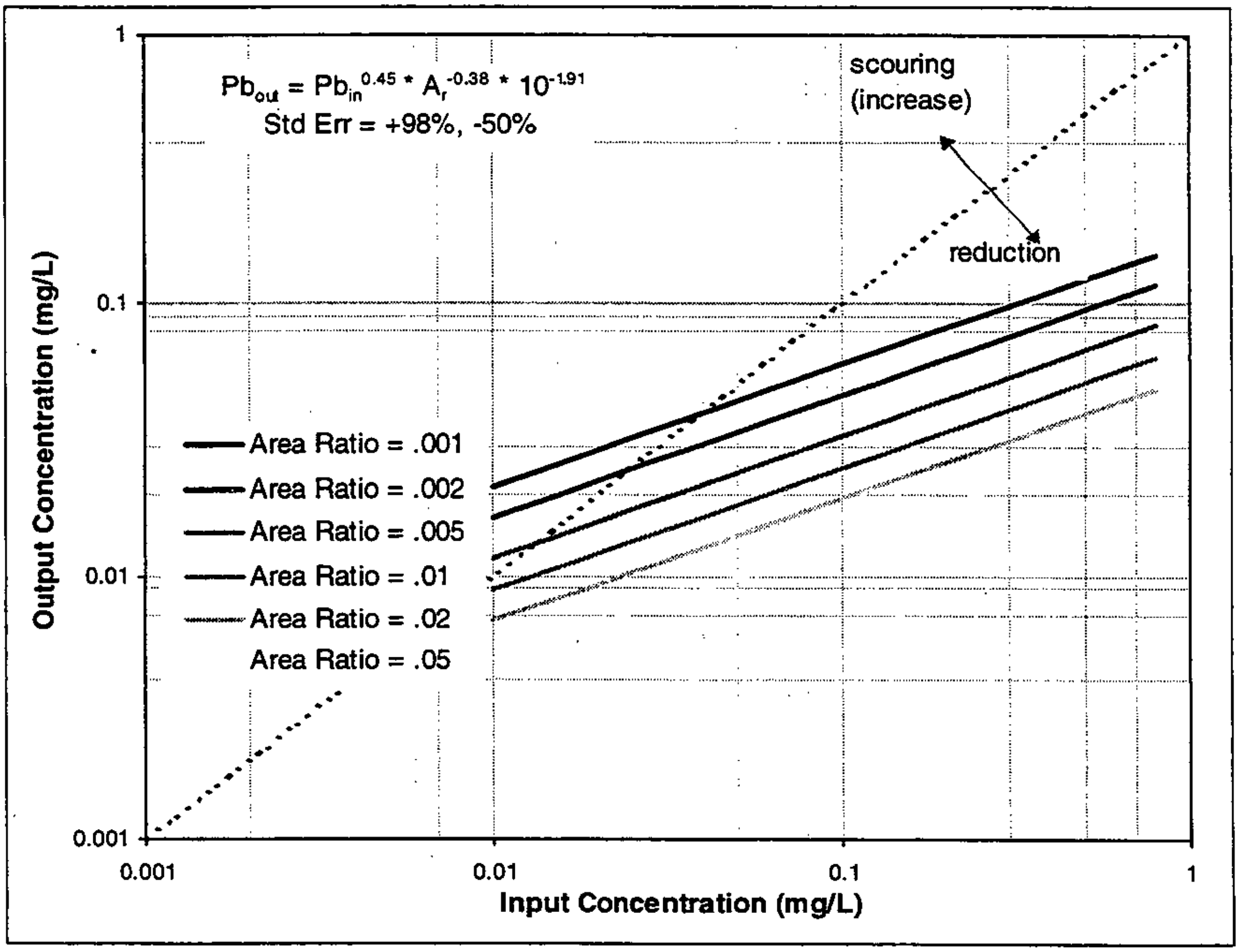

Figure D4. Outflow Pb concentrations from storage treatment with different area ratios.

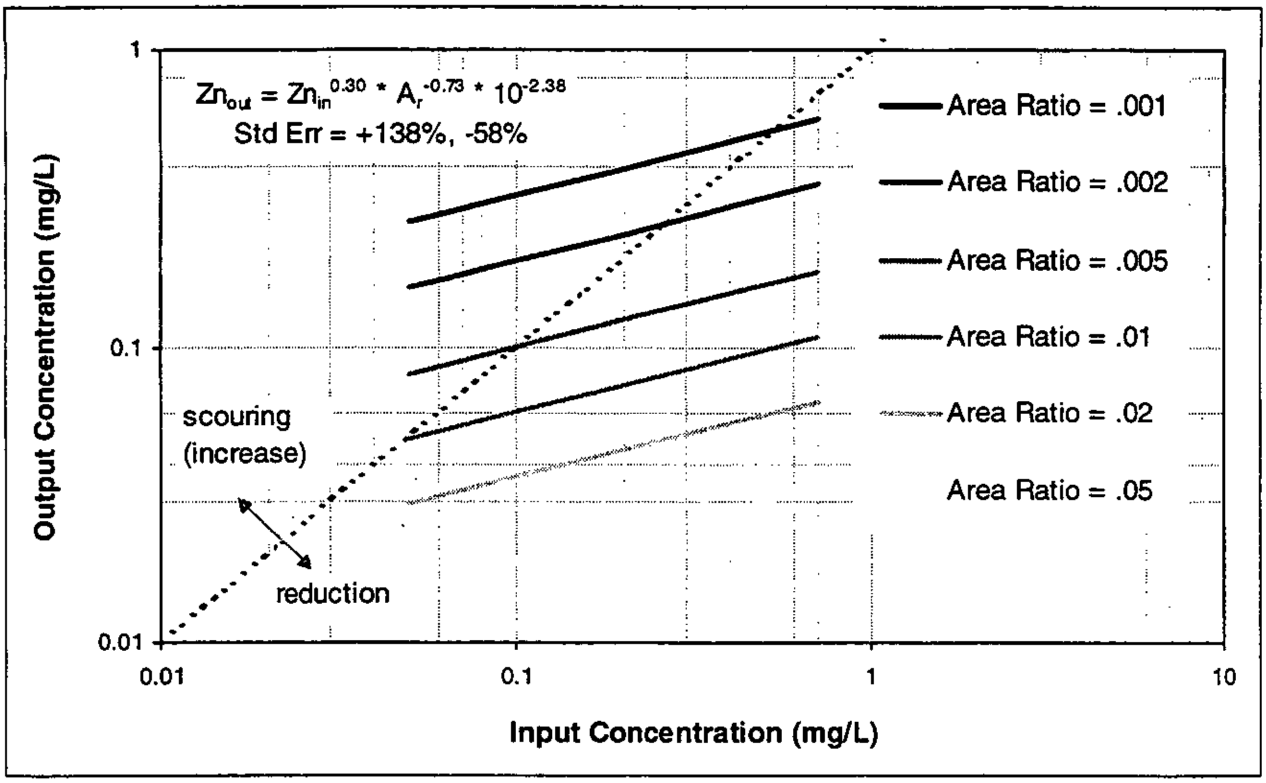

Figure D5. Outflow Zn concentrations from storage treatment with different area ratios.

APPENDIX E.

BLACKBURN LAKE - AN EXAMPLE OF THE METHODOLOGY

BLACKBURN LAKE - AN EXAMPLE OF THE METHODOLOGY

A CRCCH study is currently in progress with the objective to examine the long term performance of Blackburn Lake as a treatment pond. Blackburn Lake is located in Blackburn, on the headwaters of a tributary of Gardiners Creek, itself a tributary of the Yarra River, and was created around the turn of the century. The lake is situated in a sizeable reserve and sanctuary area. Upstream of the lake, much of the creek is in relatively natural form.

The Blackburn Lake catchment outside the sanctuary area is approximately 235 hectares in area, distributed in the following land uses:

- residential (146 ha);
- commercial, including schools etc. (34 ha);
- industrial (42 ha); and
- reserves (13 ha).

E1. Water Quality Objectives (Step 1)

The Blackburn Lake catchment falls into Schedule F7 (Waters of the Yarra Catchment - EPA, 1995[5]). The receiving waters would best be defined as the tributaries of the Yarra River, which is under the "Urban Waterways" classification. In this classification, beneficial uses are:

- maintenance of aquatic ecosystems (in part highly modified, with some habitat values),
- passage of indigenous fish,
- preservation & maintenance of indigenous riparian vegetation,
- recreation (secondary active and passive),
- production of edible fish & crustacea,
- agricultural water use, and
- industrial water use.

The SS 90th percentile (wet event) for these waters (urban waterways - tributaries) should not exceed 90 mg/L (EPA, 1995). Nutrient limits in EPA (1995) are specified only for dry weather flows, so the values in ANZECC (1992)[6] were used:

TP indicative range = 10 - 100 µg/L, and
TN indicative range = 100 - 750 µg/L.

The lowest toxic threshold water quality criteria values corresponded to the protection of aquatic ecosystems (ANZECC, 1992):

Pb = 1 µg/L, and
Zn = 5 µg/L.

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[5] EPA, 1995, *Protecting Water Quality in the Yarra Catchment,*. State Environment Protection Policy (Waters of Victoria) draft Schedule F7 (waters of the Yarra Catchment) and draft Policy Impact Assessment. EPA publ. no. 471.

[6] ANZECC, 1992, *National Water Quality Management Strategy - Australian Water Quality Guidelines for Fresh and Marine Waters.* Australian and New Zealand Environment and Conservation Council.

E2. Catchment Runoff Concentrations (Step 2)

In the Blackburn Lake catchment, the distribution of land use is:

residential = 0.62
commercial = 0.14
industrial = 0.18
reserve = 0.06

For most water quality parameters, the land use in the Blackburn Lake catchment can be treated as undifferentiated high urban. The exception is TP, for which residential concentrations are different from general high urban concentrations. Therefore the following event mean concentrations can be used:

SS (Figure 15a):		150 mg/L
TP (Figure 16a):	0.8 × (0.4 mg/L × 62 % + 0.3 mg/L × 38 %)/100 =	0.29 mg/L
TN (Figure 17a):		2.7 mg/L
Pb (Figure 18a):		0.15 mg/L
Zn (Figure 19a):	0.25 mg/L × 2.3 =	0.58 mg/L

E3. Estimation of the Performance Objectives (Steps 3 and 4)

The performance objectives, based on storage treatment, resulting from the expected runoff concentrations can be seen in Table E1.

Table E1. Performance objective values.

Parameter	Concentration (mg/L)			Performance objective		
	inflow	storage outflow	SEPP objective value	concentration (mg/L)	outflow (% of inflow)	stored (% of inflow)
SS (Figure 15b)	150	40	90	90	60	40
TP (Figure 16b)	0.29	0.17	0.1 (max)	0.17	59	41
TN (Figure 17b)	2.7	2.2	0.75 (max)	2.2	81	19
Pb (Figure 18b)	0.15	0.03	0.001	0.03	20	80
Zn (Figure 19b)	0.58	0.1	0.005	0.1	17	83

E4. Screening for Suitable Treatment Devices (Step 5)

Obviously, storage treatment is feasible in the Blackburn Lake catchment, through the existence of the lake. However, it can be assumed for the purposes of illustrating the use of the screening tools that the land where the lake is located is not available.

Some other characteristics of the catchment which are required are:

- catchment area 235 ha
- open space area available within the catchment for treatment less than 2.0 ha (< 1 %)
- soil type low permeability, fertile
- water table > 2 m depth
- bedrock > 2 m depth
- slopes in the catchment less than 7 %, and in the areas available for treatment less than 5 %

As it is a predominantly residential area, passive recreation, aesthetic appeal, and safety hazard minimisation would be important factors. Provision of habitat for native bird-life is also likely to be important. Temperature increases must be less than 2°C (EPA, 1995).

The final short-list of STMs for Blackburn Lake catchment is:

[1] grassed swales and sand filters;

[2] on-site retention, reduced lot grading, entry pit stilling basins, litter baskets, floating boom, CDS (in conjunction with other STMs);

[3] perforated stormwater pipes, porous pavement, street sweeping (only suitable if STMs in [1] and [2] do not remove sufficient pollutants).

The basis of the selection of these can be seen in Table E3.

E5. Final Selection of Treatments Based on Removal (Step 6)

Table E2 shows the optimisation of the short-listed STMs, and the corresponding pollutant removals that can be expected. The removals may be over-estimated due to some of the areas treated by different STMs overlapping - the more downstream STM will receive a lower concentration than the source value, thus achieve lower removal. Some adjustment to the areas covered by each STM would be required in order to achieve the performance objective for TP.

Table E2. Selection of appropriate treatment devices in the Blackburn Lake catchment (devices selected in darker shade).

STM	Area treated	Removals (from Table 19, and weighted by area)											
	(ha)	SS		TP		TN		Pb		Zn		litter	
swale	160[1]	80	54	15	10	4	3	80	54	70	48	0	0
sand filter	47[2]	80	16	57	11	55	11	74	15	53	11	0	0
CDS	235[3]	20?	20	0	0	0	0	0	0	0	0	98	98
litter baskets	235[3]	0	0	0	0	0	0	0	0	0	0	65	65
porous pavement	20[4,5]	60	3	49	2	30	2	65	3	64	3	0	0
perforated pipes	235[3,5]	60	40	49	33	30	20	65	43	64	43	0	0
	100[6]		17		14		9		18		18		
total			87		35		23		87		77		65
perform. standard			40		41		19		80		83		65

Notes:
1. area able to be treated by swales is assumed to be the residential area and schools, where existing nature strips can be used.
2. Area able to be treated by sand filters assumed to be areas close to the available treatment areas (about 20 % of the catchment).
3. All of the catchment can be covered (note only 50 % of side entry pits would be covered by litter baskets).
4. Area able to be converted to porous pavement is assumed to be only low mass traffic areas (footpaths and car parks) in the commercial and industrial areas (say 10 % of those areas).
5. Removals have been reduced by one third due to low infiltration rate in soils resulting in frequent bypass of the infiltration media.
6. Area assumed to cover those areas not able to be covered by other STMs.

Table E3. Suitability of the common treatment controls in the Blackburn Lake catchment (y = suitable, n = not suitable), based on Figures 20 to 27.

STM	area served	land use	slope	hydr head	water table depth	bed rock depth	area req't	soil type	soil fertil	aqua habit	wild life habit	therm imp't	soil cont-amin	base flow	peak disch cont'l	water vol cont'l	bank eros'n	water cons	active rec'n	pass rec'n	aesth appeal	safety hazard	pests	water req't	maint req't	initial cost	short listed
pond	y	y	y	y	y	y	n	y	y	y	y	y5	y	n	y	y	y	y	y	y	y	n	n	y	y	n	n
wetland	y	y	y	y	y	y	n	y	y	y	y	y5	y	n	y	y	y	y	n	y	y	y5	n	y	y	n	n
dry basin	y	y	y	y	y	y	n	y4	y	n	y4	y	y	n	y	n	n	n	y4	y4,5	n	y5	y	y	y	n	n
wet ext detent'n	y	y	y	y	y	y	n	y	y	y	y4	y5	y	n	y	y	y	y	y4	y	y4	y5	n	y	y	n	n
on-site retent'n	y1	y	y3	y	y	y	y	y4	y	n	y4	y	y	y4	y	y	y	y	n	n	n	y	n	y	y	y	y2
infiltrat'n basin	y?	y	y	y	y	y	n	n	y	n	n	y	n	y	y	y	y	n	n	y4,5	n	y	y	y	y	n	n
infiltrat'n trench	y1,2	y	y	y	y	y	y	n	y	n	n	y	n	y	y	y	y	n	n	n	y	y	y	y	y	n	n
dry well	y1	y	y	y	y	y	y	n	y	n	n	y	n	y	y	y	y	y	n	n	y	y	y	y	y	n	n
perforated pipes	y	y	y	y	y	y	y	n	y	n	n	y	n	y	y	y	y	n	n	n	y	y	y	y	y	y6	y7
porous pavem't	n1,2	y3	y	y	y	y	y	y4	y	n	n	y	n	y	y	y	y	n	n	n	y	y	y	y	y	y6	y7
perv entry pits	y1	y	y	y	y	y	y	n	y	n	n	y	n	y	y4	y	y	n	n	n	y	y	y	y	y	n	n
sand filter	y1	y	y	y	y	y	y	y	y	n	n	y	y	n	y4	n	y	n	n	n	y	y	y	y	y	n	y
swale	y1	y3	y3	y	y	y	y	y	y	n	y4	y	y	y4	y4	y	n	n	n	y4	y4	y	y	y	y	y	y
filter strip	n	y3	y3	y	y	y	y	y	y	n	y	y	y	y4	y4	y	y	n	n	y	y4	y	y	y	y	y	n
buffer strip	n	y3	n	y	y	y	y	y	y	n	y	y	y	y4	n	n	y	n	n	y	y	y	y	y	y	y	n
reduced grade	y1,2	y	y3	y	y	y	y	y	y	n	y4	y	y	y4	y4	y	n	n	y	y	y	y	y	y	y	n	y2
street sweeping	y	y	y	y	y	y	y	y	y	n	n	y	y	n	n	n	n	n	y	n	y	y	y	y	n	n	y7
oil/grease trap	y1,2	y3	y	y	y	y	y	y	y	n	n	y	y	n	n	n	n	n	n	n	y	y	y	y	y	y	y2,7
entry pit stilling basins	y1,2	y	y	y	y	y	y	y	y	n	n	y	y	n	n	n	n	n	n	n	y	y	y	y	n	y6	y2
"GPT"	y	y	y	y	y	y	y	y	y	n	n	y	y	n	n	n	n	n	n	n	n	n	n	y	n	n	n
coarse sed trap	y	y	y	y	y	y	y	y	y	n	n	y	y	n	n	n	n	n	n	n	n	n	n	y	n	n	n
litter baskets	y1	y	y	y	y	y	y	y	y	n	n	y	y	n	n	n	n	n	n	n	y	y	y	y	n	y	y2
trash rack	y	y	y	y	y	y	y	y	y	n	n	y	y	n	n	n	n	n	n	n	n	n	y	y	n	y	n
floating boom	y	y	y	y	y	y	y	y	y	n	n	y	y	n	n	n	n	n	n	n	n	n	y	y	n	y	y2
CDS	y	y	y	y	y	y	y	y	y	n	n	y	y	n	n	n	n	n	n	n	y	y	y	y	y	n	y2

1. a number could be distributed over the catchment, not necessarily in the primary areas available for treatment
2. could be used in conjunction with other devices
3. on parts of the catchment only
4. suitable, but will not provide full benefits
5. careful design would be required to achieve full benefits or prevent impacts
6. suitable if integrated with on-going infrastructure replacement program
7. suitable only if no other device is found suitable

APPENDIX F.

GLOSSARY AND NOMENCLATURE

GLOSSARY AND NOMENCLATURE

The following is a list of abbreviations, terminology, and nomenclature used throughout this report.

ACT: Australian Capital Territory
AEP: average exceedence probability
ANZECC: Australia and New Zealand Environment and Conservation Council
A_r: area ratio = ratio of the surface area of a storage pond to the total area of the catchment
ARC: Auckland Regional Council
ARI: Average recurrence interval
ARWB: Auckland Regional Water Board
As: arsenic
ASCE: American Society of Civil Engineers
AWWA: Australian Water and Wastewater Association
BMP: best management practice (often equated to STM)
BOD: biological oxygen demand
CD&M: Camp Dresser and McKee
Cd: cadmium
CDS: continuous deflective separator
C_{in}: inflow concentration to a STM
COD: chemical oxygen demand
C_{out}: outflow concentration from an STM
Cr: chromium
Cu: copper
CRCCH: Co-operative Research Centre for Catchment Hydrology
diss. N: dissolved nitrogen
diss. P: dissolved phosphorus
DNRE: Department of Natural Resources and Environment
DO: dissolved oxygen
EMC: event mean concentration
EPAV: Environment Protection Authority of Victoria
Fe: iron
GHD: Gutteridge Haskins and Davey
GPT: gross pollutant trap
"GPT": gross pollutant trap consisting of a coarse sediment basin and trash rack
IEAust: Institution of Engineers, Australia
Mn: manganese
MWC: Melbourne Water Corporation
MWCG: Metropolitan Washington Council of Governments (Washington DC)
N: nitrogen
NH_x: ammonia nitrogen - ammonia ($x = 3$) and ammonium ($x = 4$)
Ni: nickel
NO_x: oxidised nitrogen - nitrate ($x = 3$) and nitrite ($x = 2$)
NURP: (US) Nationwide Urban Runoff Program

NWQMS:	(Australian) National Water Quality Management Strategy
OMEE:	Ontario Ministry of Environment and Energy
org. N:	organic nitrogen
oxid. N:	oxidised nitrogen - nitrate and nitrite
p:	the probability of the null hypothesis being true
P:	phosphorus
part. P:	particulate phosphorus
Pb:	lead
PCB:	polychlorinated biphenols
pH:	measure of acidity
SEP:	side entry pit - roadside drainage entry pits into the stormwater system
SEPP:	State Environment Protection Policy (Victoria)
SS:	suspended solids
STM:	stormwater treatment measure (often called a BMP)
SWMP:	stormwater management practice (equivalent to STM)
TKN:	total kjeldahl nitrogen (organic plus ammonia nitrogen)
TN:	total nitrogen
TOC:	total organic carbon
TP:	total phosphorus
USMP:	urban stormwater management plan
Zn:	zinc

bank-full flood:	the flood flow at which the water level reaches the top of the stream banks - the flood which is generally regarded to be that which is responsible for greatest change in stream channel geometry;
bed load:	larger particles which are transported in flow along the bed of the carrier (stream or pipe);
beneficial use:	a use or feature of (storm) water which is of benefit to the community and/or individuals;
biological uptake:	adsorption of materials by plants, animals and micro-organisms;
buffer strip:	a strip of vegetated land, usually adjacent to streams, which provides riparian vegetation and protection of the stream from erosion;
bypass:	diversion of stormwater to pass directly downstream;
colloidal:	in a colloid form - an emulsion layer of elements/compounds on very fine particles or chemical precipitates;
continuous deflective separator:	a self-cleaning device which separates gross pollutants from stormwater using a screen centrifugal motion of the water;
detention time:	the time for which stormwater is detained;
detention:	detaining stormwater on a temporary basis (around 1 - 14 days);
dry basin:	a storage designed to temporarily store stormwater;
dry well:	small infiltration trench;
end-of-pipe controls:	treatment of pollution away from the point of generation, generally at the downstream end of the catchment;

entry pit stilling basin:	drainage entry pit with a stilling basin to allow coarse sediment to settle;
exfiltration:	discharge of stormwater to a downstream water body via groundwater;
extended detention:	temporary storage of stormwater, usually contains vegetation resistant to periodic submergence in water;
filter strip:	a strip of vegetated land with small, even slope;
filtration:	percolation of stormwater through a porous media or vegetation, with discharging downstream;
fine and dissolved pollutants:	pollutants which are of fine particulate (< 2 mm), or in dissolved nature;
floating boom:	a boom with a net or skirt attached which floats in the stormwater channel and collects floating material;
flocculation:	a process whereby very fine particles and chemical precipitates come together to form a larger particle;
gross pollutants:	pollutants which are large in size - generally greater than 2 mm in size;
imperviousness:	the proportion or amount of impervious area in a catchment;
infiltration:	percolation of stormwater into a porous media;
infiltration basin:	a basin with a porous floor through which stormwater may infiltrate;
infiltration trench:	a trench filled with a porous media through which stormwater may pass slowly and infiltrate into the surrounding soil;
litter basket:	plastic or metal baskets with holes, installed in side entry pits to capture gross pollutants;
log-normal distribution:	where the parameter plots as a straight line on a log normal probability axes;
mg/L:	milligrams per litre, a measure of concentration (mass per unit volume), 1 mg/L = 1 ppm;
modular pavement:	pavement blocks separated by and placed on top of a porous material allowing stormwater to infiltrate into the surrounding soil;
off-line controls:	stormwater is diverted away from the carrier into a control device (ie., separate from the transport system);
off-site controls:	treatment of pollution away from the point of generation, not to be confused with off-line controls;
on-line controls:	all stormwater pass through the control device (ie., within the transport system);
on-site controls:	minimisation or treatment of pollution at the point of generation (source control);
oil/grit separator:	(also known as water quality inlet) - a concrete tank with 2 or 3 segments trapping floating oil and allowing coarse sediment to settle;
oversize pipe trench:	stormwater drainage pipe trench which is larger than standard and acts similarly to an infiltration trench (usually incorporates pervious pipe);
particulates:	pollutants which are in a solid state;

performance objective:	a level of stormwater quality control to be strived for - specifies an action (eg., reduce SS concentration by 80 %), alternatively described as a performance standard, guideline or criteria;
perviousness:	the proportion or amount of pervious area in a catchment;
pervious entry pit:	drainage entry pit with a small stilling basin and diversion to a small infiltration trench;
pervious pipe:	stormwater drainage pipe with permeable walls to allow infiltration into surrounding soil;
porous pavement:	a pavement surface which is porous (asphalt with the larger aggregate removed), placed on a bed of porous material, enabling stormwater to infiltrate into the surrounding soil;
receiving waters:	a water body which is downstream of the catchment under consideration, and has some environmental value or beneficial use;
removal (of pollutant):	reduction in concentration by retention within a STM;
retention:	retaining stormwater for a long period, sometimes permanently;
sand filter:	a filter of course media through which stormwater is filtered;
side entry pits:	roadside drainage entry points;
sedimentation:	the process of particle settlement within a water body;
suspended solids:	particulate material suspended in the water body or stream;
source control:	minimisation or treatment of pollution at the point of generation (on-site control);
storage:	detention of stormwater in a body of water of cross section larger than the water carrier;
swale:	a wide shallow vegetated channel of small slope;
trash rack:	a rack within a stream on which gross pollutants are caught. Some designs include a storage which facilitates self cleaning of the rack
treatment:	improving quality by removal of pollutant from the stormwater;
water quality inlet:	see oil/grit separator;
water quality objective:	a maximum level of water quality concentration or load which should not be exceeded - specifies an outcome (eg., the 90th percentile concentration of SS should not be greater than 90 mg/L);
wet pond:	a permanent storage, usually 1 to 3 m deep providing still water for sedimentation;
wetland:	a permanent shallow storage containing aquatic and emergent vegetation providing still water for sedimentation and biological uptake of pollutants.

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Murray-Darling Basin Commission

Southern Rural Water

The University of Melbourne

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