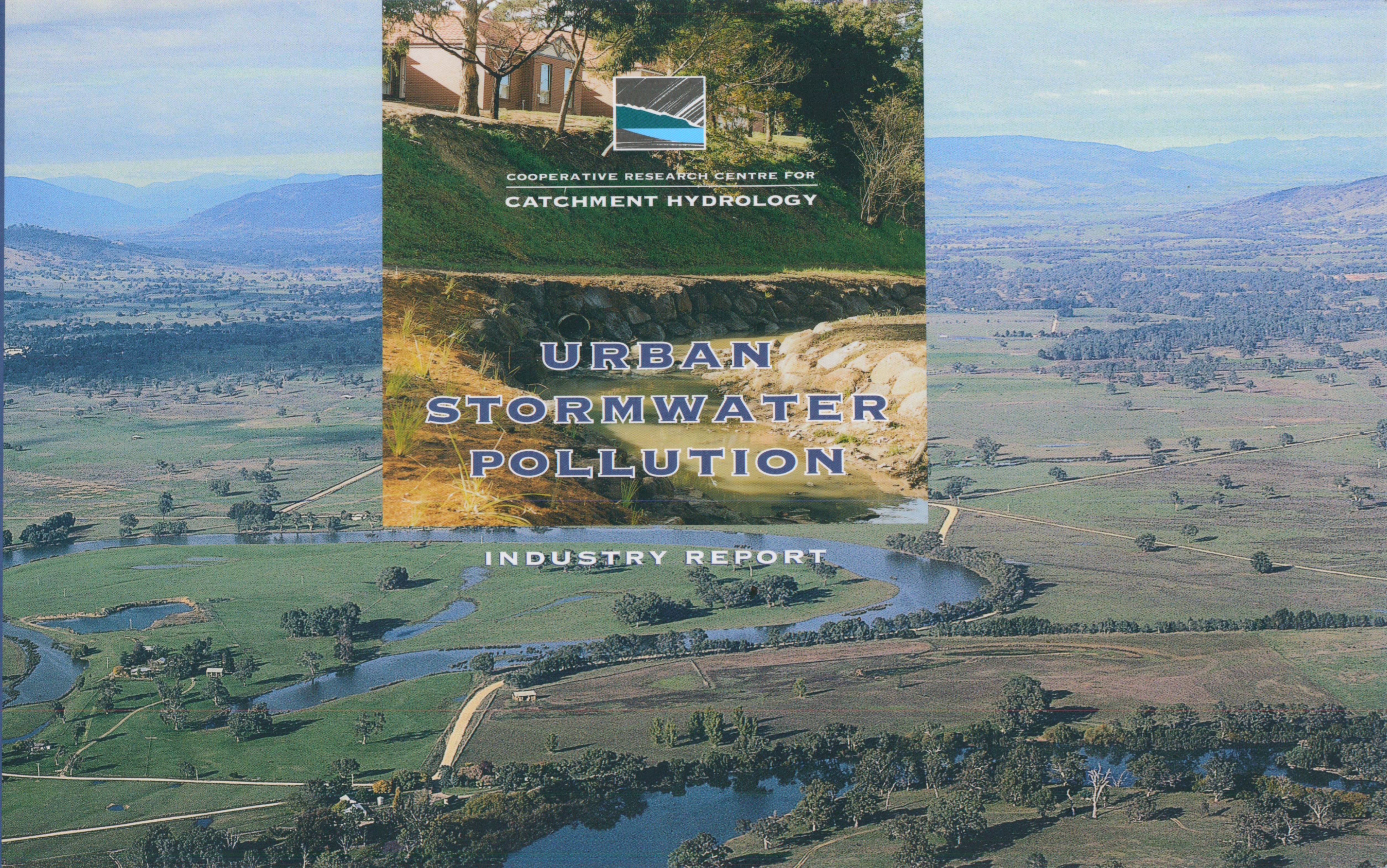
COOPERATIVE RESEARCH CENTRE FOR
CATCHMENT HYDROLOGY

URBAN STORMWATER POLLUTION

INDUSTRY REPORT



URBAN STORMWATER POLLUTION

by

Francis H.S. Chiew, Lance B. Mudgway, Hugh P. Duncan and Thomas A. McMahon

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FOREWORD

This Industry Report is one of a series by prepared by the Cooperative Research Centre (CRC) for Catchment Hydrology to help provide agencies and consultants in the Australian land and water use industry with improved ways of managing catchments.

Through this series of reports and other forms of technology transfer, industry is now able to benefit from the Centre's high-quality, comprehensive research on salinity, forest hydrology, waterway management, urban hydrology and flood hydrology.

This particular Report represents a major contribution from the CRC's urban hydrology program, and presents key findings from the project entitled 'Pollution loads from urban catchments'. (More detailed explanations and research findings from the project can be found in the Reports and Working Documents published by the Centre.)

The CRC welcomes feedback on the work reported here, and is keen to discuss opportunities for further collaboration with industry to expedite the process of getting research outcomes into practice.

Russell Mein

Director, Cooperative Research Centre for Catchment Hydrology

PREFACE

This report summarises the Cooperative Research Centre (CRC) for Catchment Hydrology's research on the project, 'Pollution Loads from Urban Catchments', which included:

- a review of more than 800 studies of urban stormwater quality processes published in the English-language literature
- statistical analyses of overseas and Australian data to characterise urban stormwater quality and urban stormwater treatment by storage
- development of methods for estimating runoff and pollutant loads in urban catchments for different time scales, objectives and data availability
- a modelling study of the dry weather pollutant accumulation process for estimating storm-event and washoff loads.

The report has been written for CRC industry participants, urban drainage authorities, urban water and environmental consultants, and the wider community.

It explains the processes that influence urban stormwater quality, and methods for estimating stormwater runoff and pollution loads. The information in this report represents results from the CRC's research, data analyses and the CRC'c review of Australian and overseas research reported in the urban hydrology literature. Detailed findings of the CRC research in urban stormwater pollution can be found in other CRC research publications and in industry journals and conference proceedings.

The following topics are covered in the report:

- impact of urban development on the natural environment
- stormwater contaminants and their impact on the environment
- sources of urban stormwater pollution
- pollutant buildup and washoff processes
- pollutant transport and storage processes
- stormwater monitoring
- estimation of urban runoff and pollutant loads.

CONTENTS

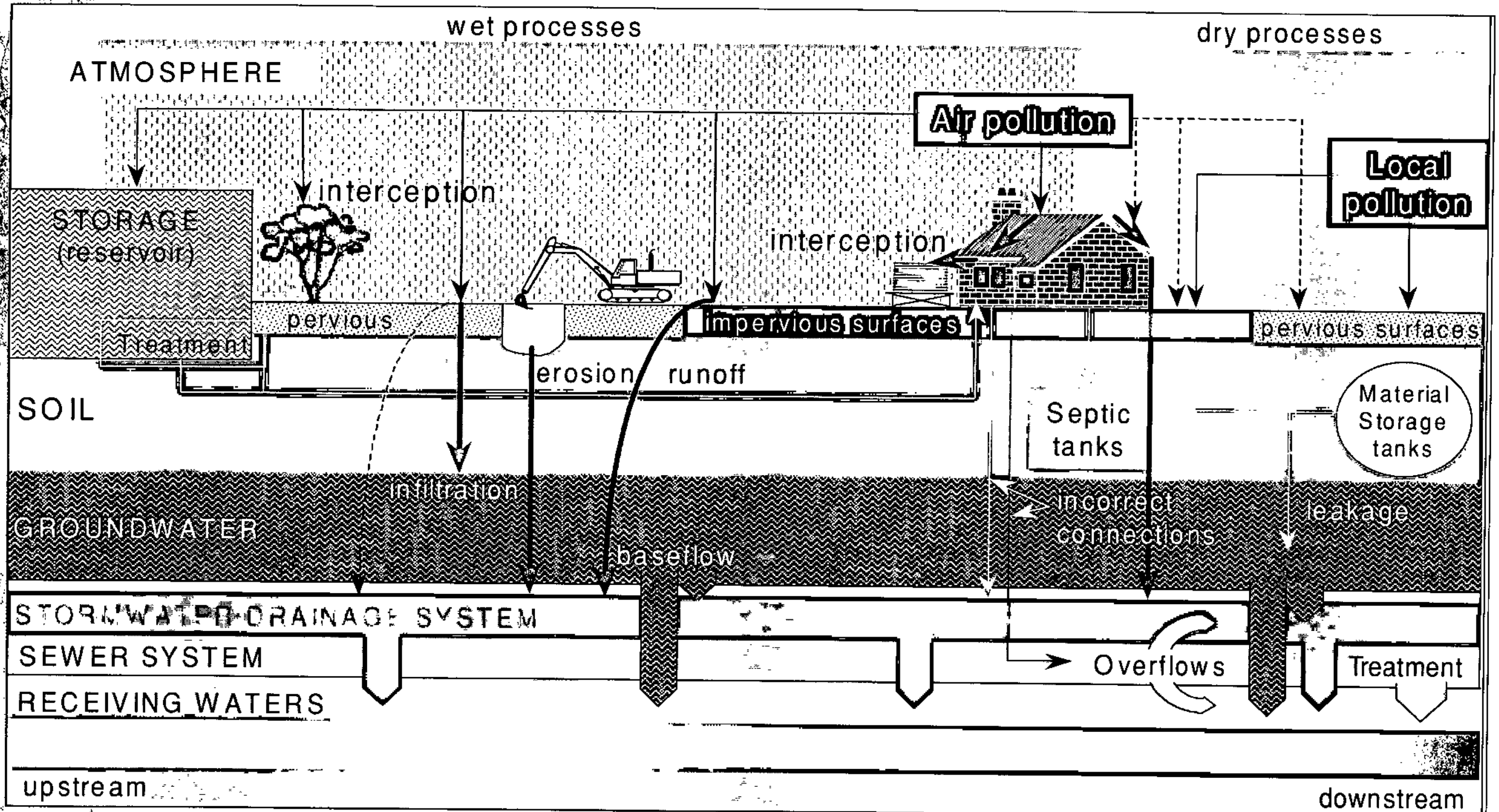


Figure 1: Flow diagram of urban stormwater runoff and pollution processes

INTRODUCTION: STORMWATER AND URBAN DEVELOPMENT

An urban area can vary markedly in size. It may be a large metropolis such as Melbourne, a regional city such as Wagga Wagga or Townsville, or a smaller rural town such as Albany or Cobar.

Stormwater is defined as the water that flows into drains and waterways during and after rainfall in urban areas. Rainwater that cannot infiltrate into the soil is channelled into surface drains and underground pipes, which flow into streams, rivers and bays. The drains and pipes are part of the urban stormwater system (Figure 1).

Stormwater pollution comes from point and non-point sources. Point sources are those where the polluted water is discharged at a single location – such as a factory, or sewage treatment plant. Non-point, or diffuse sources are those where polluted water is generated from a large area and flows into the drainage system at more than one point. This report is mainly concerned with non-point source pollution.

Urban development of agricultural areas results in loss of productive land and modification of the landscape. Urban development of a natural environment leads to loss of habitat for native plants and animals, and significant modification of the landscape.

The impact of urban development on the environment ranges from air pollution to social issues. The main environmental problems are:

Water pollution – Dissolved materials, fine sediments, litter and vegetative matter pollute water in drains, streams and coastal areas.

Increased surface runoff – The volume of stormwater runoff is much higher in urban areas because there is no soil infiltration in areas covered by pavement or buildings.

Changes to the stream environment – Natural streams are often straightened and lined with concrete to move stormwater more quickly to reduce flooding, leading to flash floods and higher peak flows. When storms are frequent, urban flood peaks can be up to 20 times higher than the equivalent pre-urban flood peaks (Figure 2). Changes in flow rates and channel shape and structure may also cause stream habitat degradation and loss of surrounding streambank vegetation.

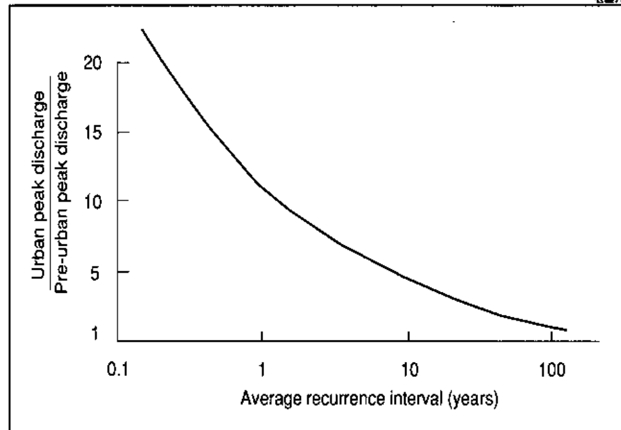
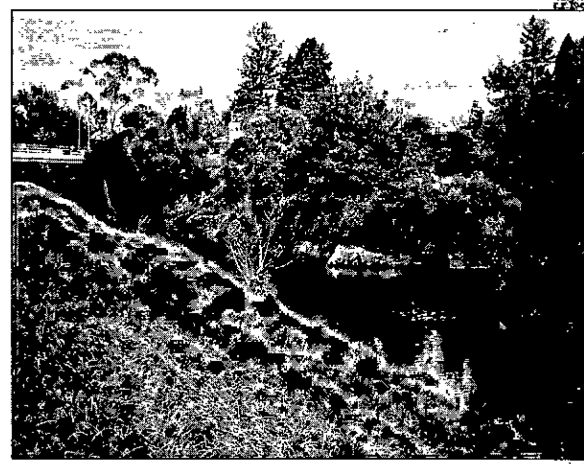
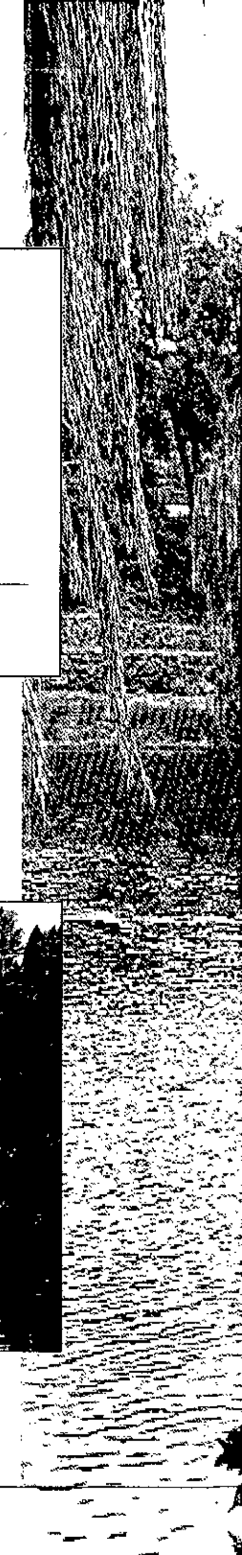


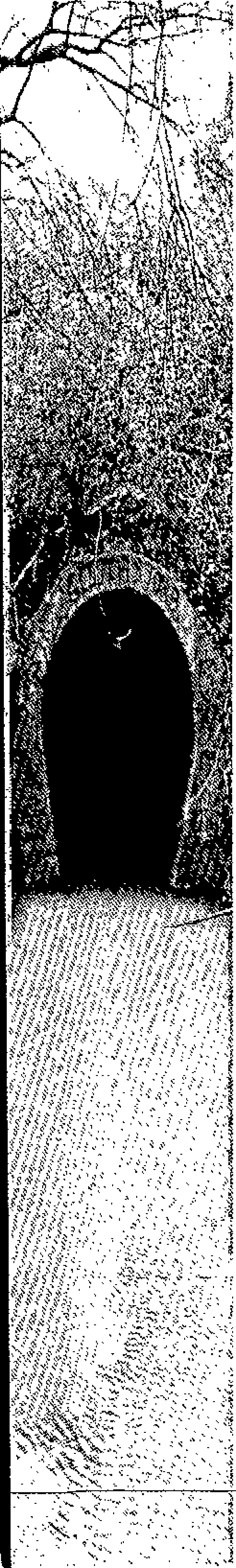
Figure 2: Ratio of flood peaks in an urban catchment relative to a 'pre-urban' catchment from a Canberra paired-catchment study

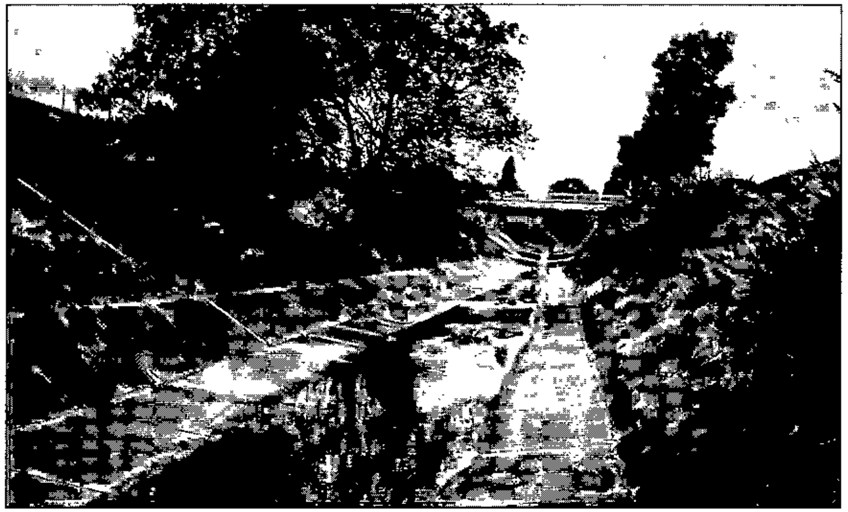
Changes in flow rates, stream morphology and plant and animal habitat can affect the reproduction, feeding and movement of aquatic organisms. Vegetation removal can accelerate streambank erosion.



Urban creek in Melbourne







Concrete-lined channel

Increased temperatures – In urban environments, power use, fuel burning, crowding of people and animals, and heat storage by roads and buildings - which have high thermal inertia compared to natural surfaces - can increase ambient temperatures. Higher temperatures increase cooling costs in summer, increase evaporation and irrigation demands, affect the behaviour of people and animals, and may modify local weather.

Air pollution – Gases and fine particles suspended in the atmosphere can fall to the ground or be washed out by rainfall, causing acid rain. Air pollution is caused by vehicle emissions, industrial emissions, bushfires, wind-blown dust, pesticides and herbicides.

Soil pollution – Contaminants can be leached into groundwater or trapped in the soil, where they can build up and cause soil contamination. Groundwater contaminants can find their way to streams, wetlands, lakes, and coastal waters.

Health risks – People in cities and towns require an adequate supply of fresh water and effective waste-water disposal. Although Australian cities have developed infrastructure to prevent health problems associated with water supply and waste-water disposal, the risk of water contamination and consequent widespread epidemics is much greater than in rural areas.

Social impact – Urban development changes the way people live and interact. Being further removed from natural environments, they are less aware of the inter-dependence between a healthy environment and a healthy community.

Visual impact – Plastics, paper and other discarded litter in city areas and urban waterways are unsightly.

Common pollutants in urban stormwater

Stormwater pollution comprises fine particles and dissolved materials (micro-pollutants), and litter and vegetation (gross pollutants). A pollutant is a material present in a concentration greater than that which naturally occurs in the water, air or soil.

The typical range of wet weather pollutant concentrations for urban, rural and forested (natural) areas are presented here in the form of bar charts (Figures 3, 4, 5 and 6). These show the mean – and the mean ± one standard deviation – of values reported in more than 500 Australian and overseas studies as analysed by the CRC (about two-thirds of all reported values lie in this range).

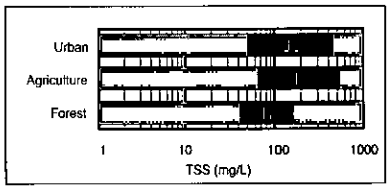


Figure 3: Typical range of suspended solids (TSS) in different catchment types

Sediments (soil and other fine solid particles) - Suspended solids (SS) is the term used to describe sediments suspended in water. Suspended solids often have other pollutants attached to them. Turbidity, a water-quality parameter that quantifies the cloudiness of water, is often related to suspended solids. In urban areas, sediments are often associated with construction activity. Suspended-solid concentrations in urban stormwater are typically two to ten times greater than in undisturbed catchments (Figure 3).

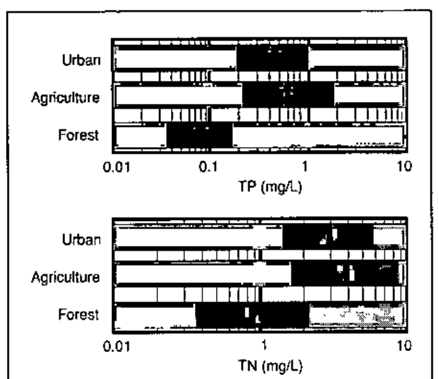
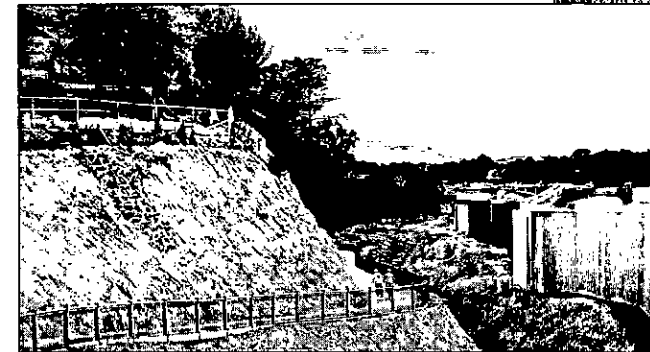


Figure 4: Typical range of nitrogen (TN) and phosphorus (TP) concentrations in different catchment types

Sediments can smother aquatic habitat and reduce water-channel capacity. Turbidity reduces light penetration in water, affecting aquatic plant growth. Sediments also reduce the aesthetic appeal of waterways and increase the need for filtration in water supplies.



Construction sites are a source of sediment in urban waterways

Nutrients (mainly nitrogen and phosphorus) – These elements are essential to living organisms, but excessive levels can upset the natural balance of a waterway ecosystem. Phosphorus (P) and nitrogen (N) can be dissolved, or attached to sediment particles. The dissolved form of phosphorus is mainly phosphate (PO_4). The dissolved forms of nitrogen include ammonia (NH_3 and NH4) and oxidised nitrogen (NO_2 and NO_3). The particulate form of nitrogen is mainly organic. Total kjeldahl nitrogen (TKN) is the unit used to quantify total organic and ammonia nitrogen.

Nutrients in urban areas come from sewer overflows, industrial discharges, animal waste, fertilisers, domestic detergents, and septic tank seepage. Rainfall is also a significant contributor of nitrogen. Nutrient concentrations in urban stormwater are often slightly lower than in agricultural areas. However, total phosphorus (TP) concentrations in urban stormwater are typically two to ten times that of forested catchments, and total nitrogen (TN) concentrations in urban areas are two to five times the levels in undeveloped catchments (Figure 4).

Turbid water in an urban channel

Laboratory testing for water-quality parameters

In the process of eutrophication, excess nutrients promote the growth of one species of aquatic plant, such as blue-green algae, to the exclusion of others. The thick mats of algae formed at the water surface reduce light penetration and oxygen exchange between the water and atmosphere. Eutrophication can choke waterways, making them unsuitable for other life forms or for recreational and water-supply use. The decomposing vegetation causes odours and lowers oxygen levels in the water. Blue-green algal blooms are also toxic to animals and humans.

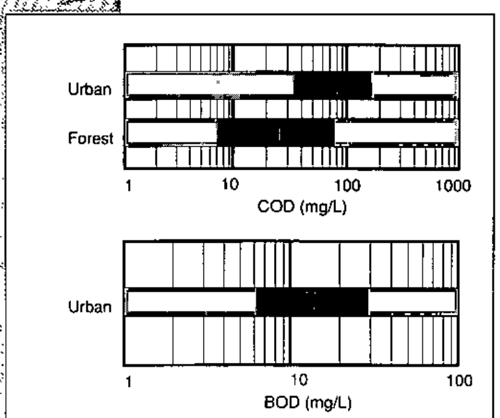


Figure 5: Typical range of chemical and biochemical oxygen demand (COD and BOD) in urban and forested catchments

Oxygen-demanding materials – Biodegradable organic debris, such as decomposing food and garden wastes and organic material in sewage, contribute to oxygen depletion in stormwater. Chemical oxygen demand (COD) and biochemical oxygen demand (BOD) are measures of the oxygen used when these materials react with chemicals and biological substances in the water. COD and BOD levels in urban stormwater are typically two to five times higher than levels in streams in agricultural and forested catchments (Figure 5).

Low oxygen levels can kill aquatic life and encourage anaerobic micro-organism growth. Nutrients and metals attached to sediments are also released at an increased rate under such conditions.

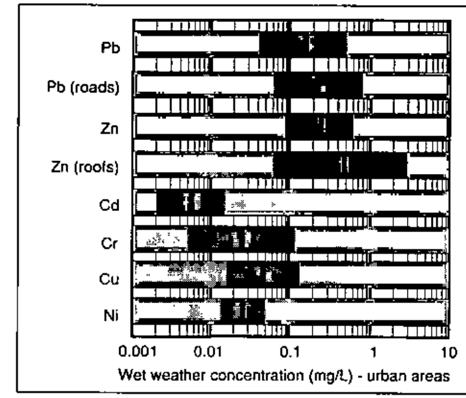


Figure 6: Typical range of wet-weather concentrations of heavy-metal pollutants in urban catchments.

Metals – These include lead (Pb), zinc (Zn), copper (Cu), chromium (Cr), cadmium (Cd) and nickel (Ni) and other inorganic substances (Figure 6). Heavy metals come from vehicle emissions, wear of vehicle components such as tyres and brakes, road and pavement degradation, and water-pipe and roof corrosion. The amount of heavy metals in urban areas is generally much higher than in rural areas.

Heavy metals are toxic to animals, birds and humans. Toxic effects can be either chronic (gradual build-up causes long-term illness and eventual death) or acute (high concentration causes sudden illness or death). Some toxins are transferred up the food chain and concentrate in consumer species (Figure 7).

Zinc from metal roofing – source of pollution

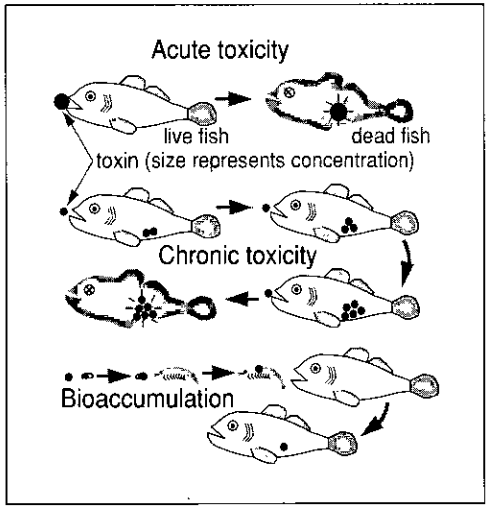


Figure 7: Effects of heavy metal toxicity on aquatic animals

Toxic organic wastes – These come from garden and household chemicals (herbicides and pesticides), industrial chemicals, and landfill-waste leachates. Organic pollutants can accumulate in an ecosystem, causing long-term toxicity.

Pathogenic micro-organisms – These include bacteria, viruses and protozoa found in soil, decaying vegetation, sewer overflows, septic tank seepage and animal wastes. The Escherichia coli (E. coli) bacterium is a widely used indicator of faecal pollution levels in stormwater.

The biggest impact of water-borne micro-organisms is on human health. Bacteria and pathogens excreted in human and animal faeces may initiate outbreaks of infectious hepatitis and gastro-intestinal diseases. Micro-organism levels in urban waterways are generally highest after heavy storms.

Hydrocarbons – These come from oil and grease used for combustion, lubrication, and protective coatings, and from surfactants in detergents. Typical oil and grease concentrations in urban areas range from 2 to 20 milligrams per litre (mg/L). Oil spills in urban areas are common and can cause short-term toxicity problems. Surfactants damage biological membranes of aquatic plants and animals.

Litter – This includes plastics, paper, bottles and other rubbish discarded by people. Litter is aesthetically unpleasant, smells and attracts vermin. Some litter, such as broken glass and syringes, can pose health risks. Some plastic packaging can strangle water birds. Litter and plants refuse such as dead leaves are commonly termed gross pollutants due to their large unit size. The impact of the above pollutants in waterways is illustrated in Figure 8.

Litter buildup in commercial area

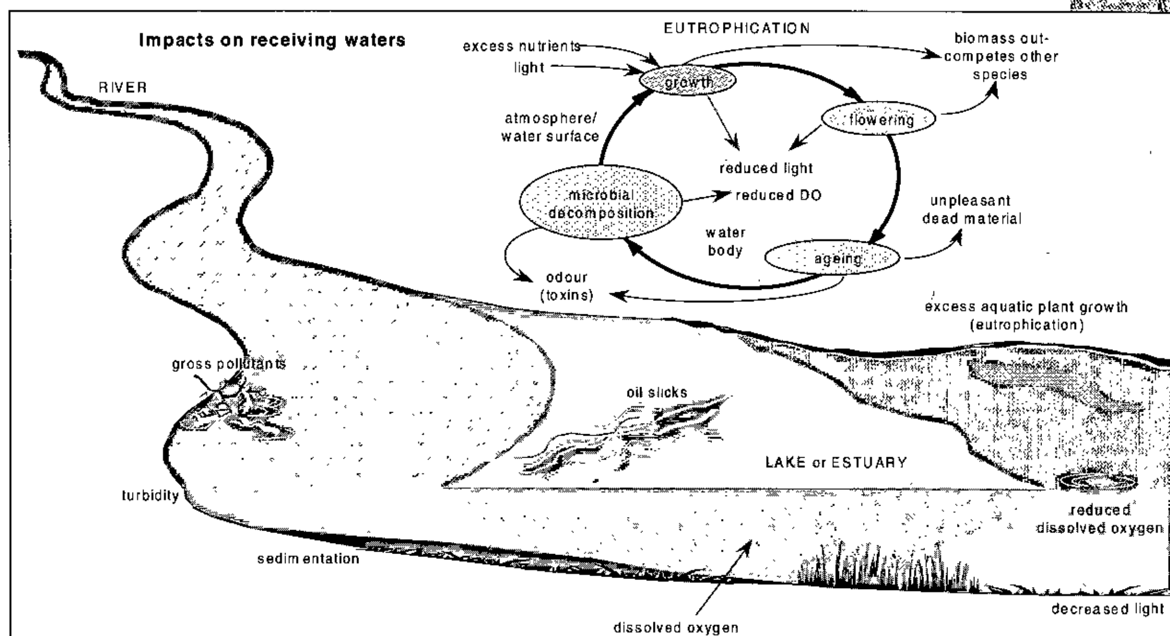
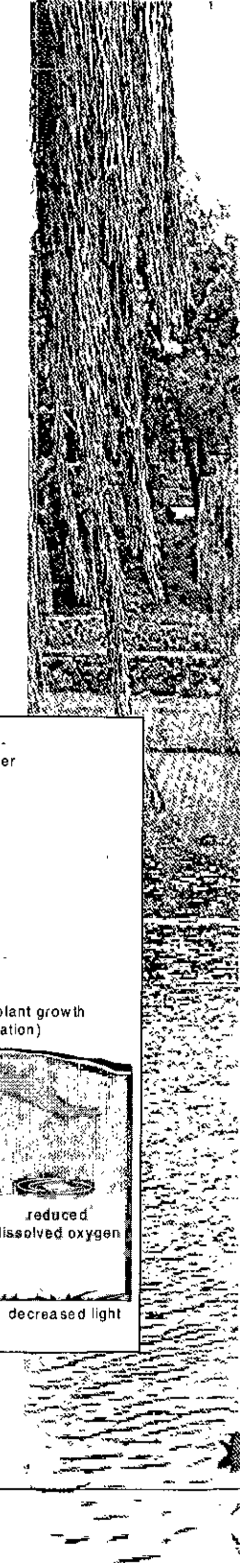


Figure 8: The impact of pollutants on rivers, lakes and coastal waters



SOURCES OF STORMWATER

When rain falls onto land, it either percolates into the soil or runs off the surface into streams, which flow into rivers and finally the ocean (Figure 9). Water in soil may evaporate, be transpired by plants, or make its way through the ground to rivers and lakes. Water vapour transpired by plants and evaporated from soil and water bodies forms clouds.

This natural water cycle has been modified by urban development, streamflow diversion and dams (Figure 10). Human activity has also significantly increased soil erosion and introduced contaminants into the cycle, which eventually end up either in the ocean or consumed by aquatic organisms.

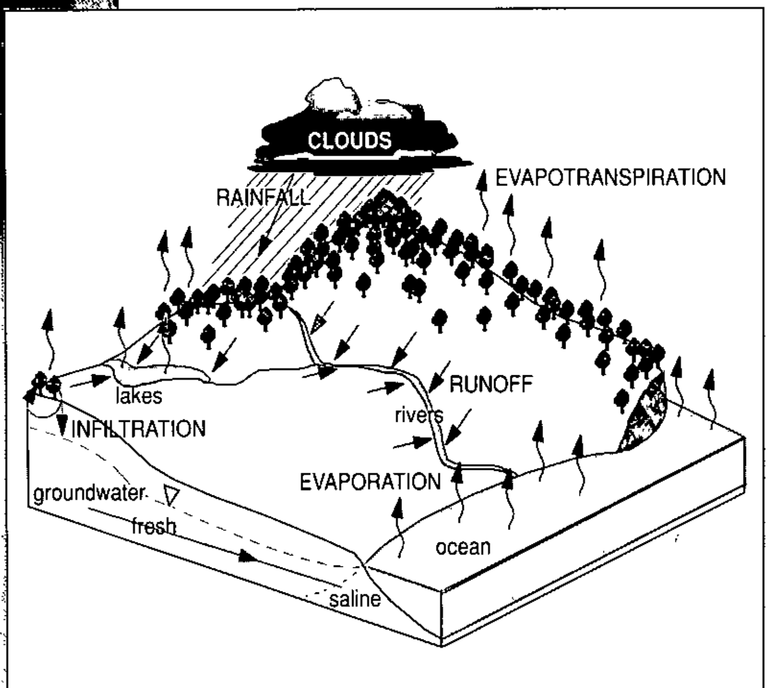


Figure 9: The natural water cycle

Water enters urban areas as rainfall, through the reticulated water supply, or in streams and rivers. Rainfall within an urban catchment is stored in soil, evaporated, or passed into the stormwater drainage system. Impervious surfaces such as roofs or pavements drain directly into the stormwater system via side entry pits in road gutters, or directly through drainpipes.

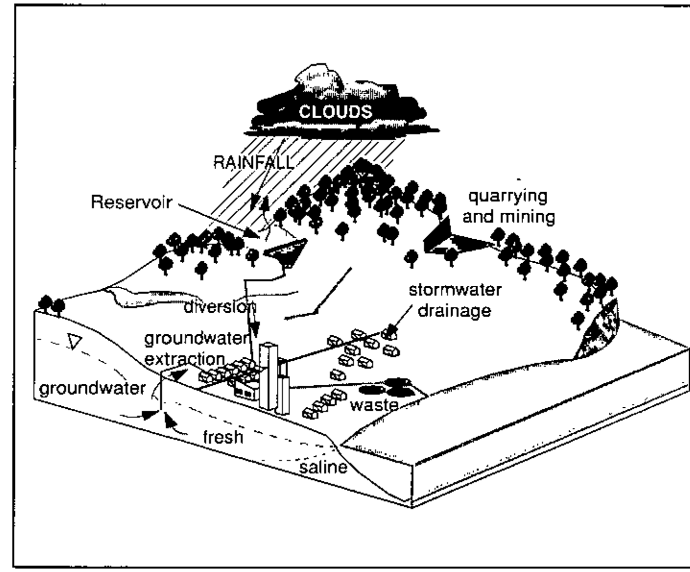


Figure 10: Human impact on natural water cycle

Reticulated water is used for household, commercial and industrial consumption and for watering of parks, lawns and gardens (Figure 11). Reticulated water not used for garden watering enters the sewerage system. Excessive outdoor water use contributes to stormwater levels. In urban areas not serviced with sewers, septic tanks are used to store and treat sewage. Septic tank effluent that filters through the soil may enter streams via groundwater.

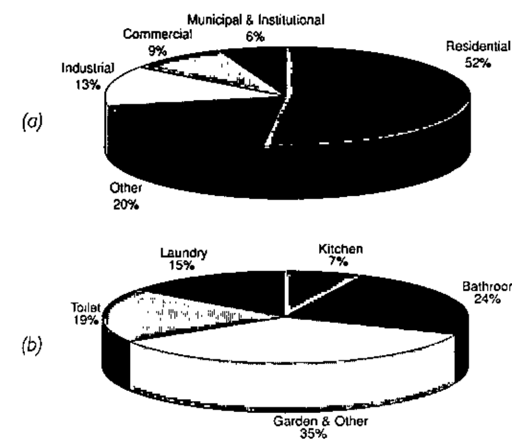


Figure 11: (a) Typical pattern of urban water consumption by land-use (b) Typical pattern of residential water consumption (All values are population-weighted means from Sydney, Canberra and Melbourne data analysed by the CRC).

Sources of pollution

Some contaminants may be carried long distances by wind and rain (distributed sources), while others affect nearby areas (local sources).

Distributed sources (Figure 12)

- ash and smoke from bush-fires
- sea-spray
- swamp gases
- wind-blown pollen, insects and micro-organisms
- dust from agricultural activities and roads
- dust, ash and emissions from industry (especially fossil-fuel dependent activity)
- agricultural herbicides, pesticides and fertilisers.

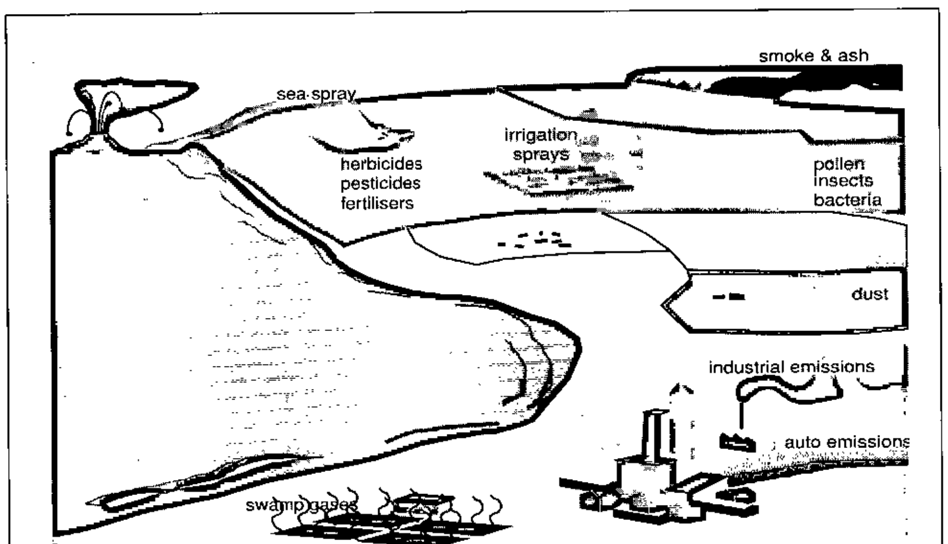


Figure 12: Distributed sources of urban stormwater pollution

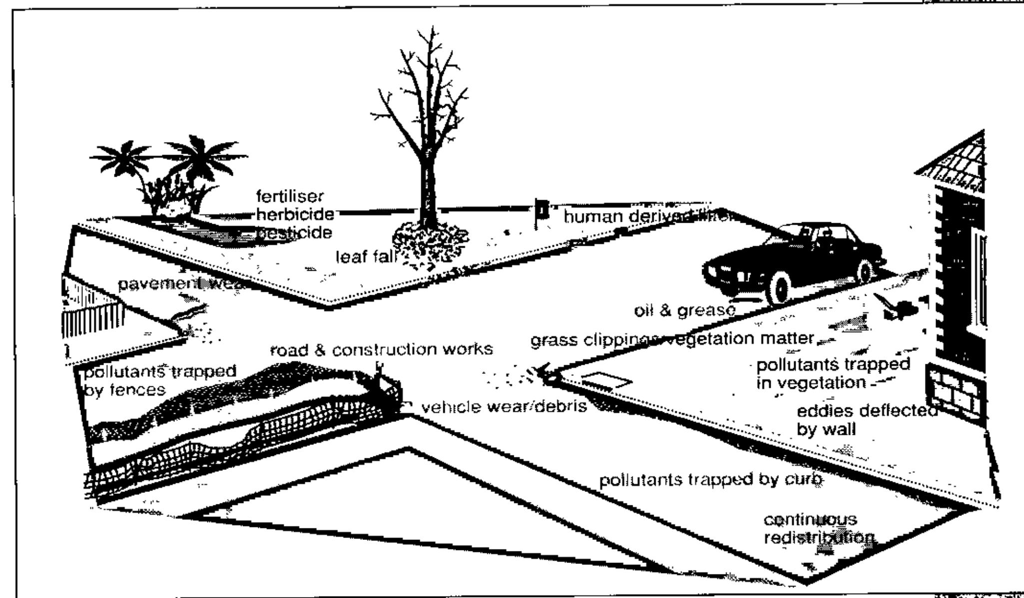


Figure 13: Local sources of urban stormwater pollution

Local sources (Figure 13)

- leaf-litter, grass clippings and other vegetation
- dog and other domesticated animal faeces
- herbicides, pesticides and fertilisers
- sewer overflows
- sewer outlets illegally connected to stormwater drainage
- septic tank leakage
- leakage and spillage of materials from vehicles and storage tanks and bins
- seepage from land-fill waste disposal sites
- waste-water from cleaning operations
- corrosion of roofing and other metallic materials
- industrial emissions
- vehicle emissions
- wear of vehicle components such as tyres and brakes
- wear of road surfaces
- erosion from construction activity and vegetation removal on slopes
- litter - plastic, foam and paper packaging, glass and metal containers, etc.

How stormwater becomes polluted

Based on the CRC's research findings and review of over 800 Australian and overseas studies, the process of stormwater contamination can be viewed as occurring in two phases – buildup and washoff (Figure 14).

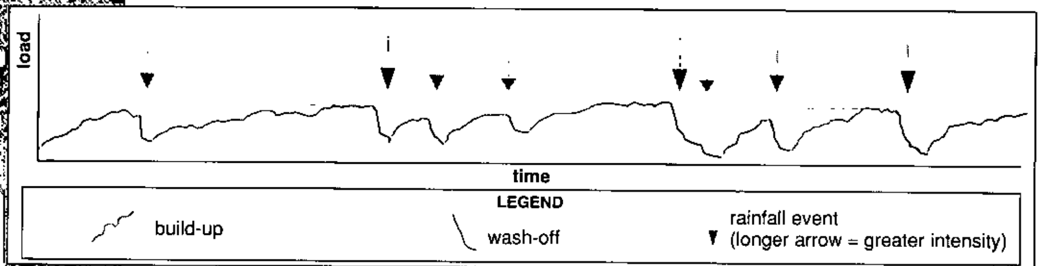


Figure 14: Typical pattern of pollutant load on catchment surfaces over time

Buildup is the accumulation of pollutants on pavements and other surfaces during dry weather. It can happen through:

- dry deposition or fallout (the settling of fine particles from the atmosphere)
- accumulation of fine particles and gross pollutants from local sources
- redistribution of surface pollutants by wind and traffic.

Pollutant loads tend to be high on roads because of vehicle and road wear, and because of deposition of pollutants originating further upslope. The total load of leaves and vegetation in particular can be substantial because of their larger surface areas.

The level of pollutant buildup depends on the rate of deposition; the length of the dry period; and any removal by redistribution, decomposition, street sweeping or washoff (Figure 15). Data and modelling studies by the CRC

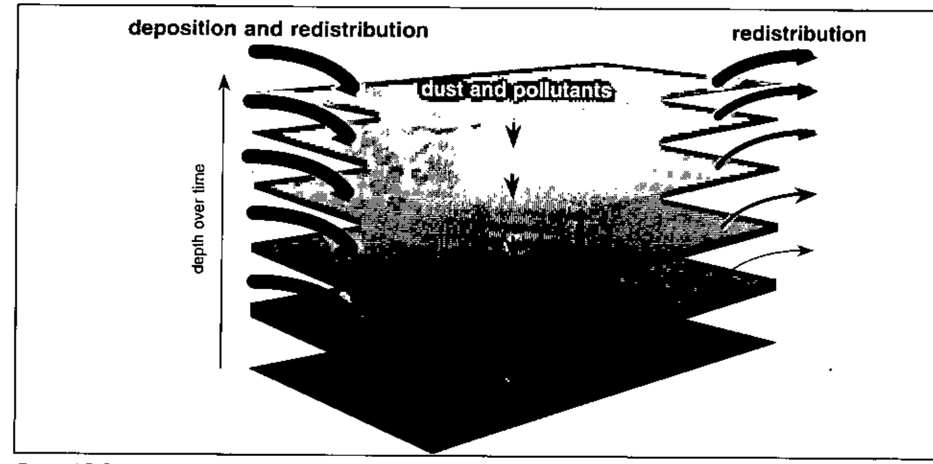


Figure 15: Dry-weather processes (dry deposition, buildup and redistribution)

and other research groups suggest that buildup increases with time and reaches an equilibrium. This is because the removal rate of surface pollutants increases as the buildup increases, and eventually equals the input rate.

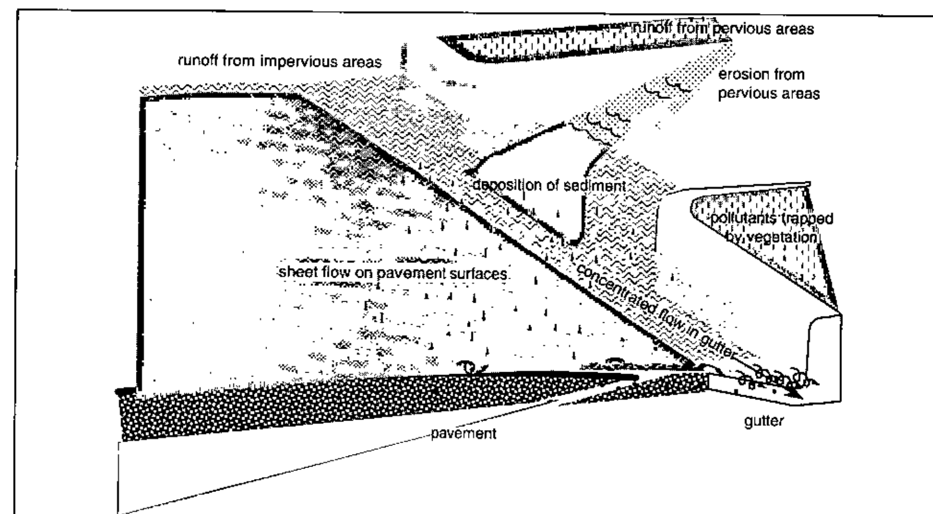


Figure 16: Wet-weather processes (wet deposition and washoff)

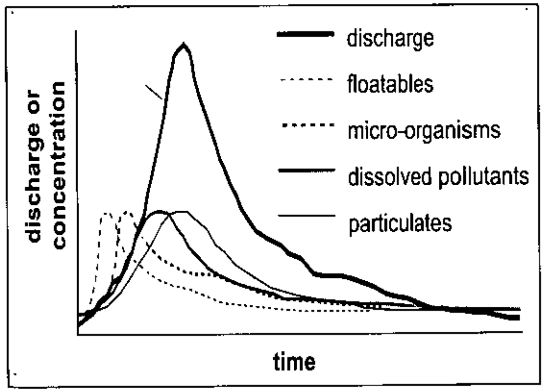


Figure 17: Hypothetical pollutant and flow hydrographs showing the first flush effect of pollutant removal (a hydrograph is a graphical representation of changes in water flow over time)

Washoff is the removal of accumulated pollutants by rainfall and runoff. During storms, turbulence created by falling raindrops and flowing water loosens particles, which become suspended in water and are carried into the drainage system. Pollutants washed out from the atmosphere by rainfall (wet deposition) can add to the load carried in the flow (Figure 16). The detailed mechanisms of washoff are still being studied, but measurements show that typically only a small proportion of the pollutant load on the surface becomes washoff in a single event.

Pollutant concentration often peaks before the peak in stormwater runoff, a process known as 'first flush'. The first flush effect is more detectable in smaller catchments and impervious areas. In larger catchments, the time taken for pollutants from different parts of the catchment to reach a given outlet can be quite different, resulting in a less detectable first flush.

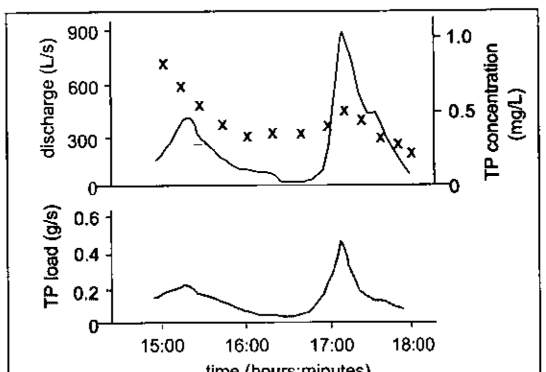


Figure 18: Hydrograph of phosphorus load (TP) for one storm event in 1994 from a 150-ha urban catchment monitored by the CRC in Coburg, Melbourne

Pollutographs – hydrographs of pollutant concentration during storm events – are different for different types of pollutants (Figure 17). Because less energy is required to keep them in suspension, peak levels of micro-organisms and dissolved pollutants usually occur before peaks in particulate pollutants.

Stormwater Monitoring

The total pollutant load washed off urban surfaces depends on the runoff volume and the concentration of a given contaminant (Figure 18). Within a catchment, the runoff volumes vary over a much larger range than the water quality concentration. Thus, most of the pollution in urban catchments is generated during heavy storms (Table 1). During a single storm, most of the pollutant load is transported during the higher discharges, even when first flush occurs (Figure 18).

Table 1: Runoff and total suspended solids (SS) loads for 1993 in two Sydney urban catchments

Catchment area (ha)	Runoff (ML)		SS (tonnes)	
	dry weather	wet weather	dry weather	wet weather
670	190	1,100	5	130
6000	1,400	2,400	16	320

Water-quality monitoring networks – Some water authorities take 'grab' samples from urban waterways periodically (usually monthly), and test them for different water quality parameters. This provides an indication of pollutant concentrations during dry weather (groundwater baseflow) conditions. Data from grab sampling can also be used to study long-term water-quality trends.


Collecting dry-weather water samples

But because most pollutants are transported during heavy storms, reliable estimates of pollutant loads can only be obtained by monitoring throughout several storms. Some authorities have now established automatic event sampling

Automatic sampler to monitor stormwater quality during storms

programs using a device programmed to collect stormwater samples throughout a storm. For more reliable estimates of storm-related pollution, more samples need to be collected during higher discharges.

Gross pollutants

The CRC's gross pollutant monitoring program has shown that:

- typical stormwater gross pollutant loads in Australian urban areas lie between 20 and 40 kilograms per hectare per year (kg/ha/year) of dry mass (equivalent to about 1.8 billion litter items per year in Melbourne)
- vegetative matter such as leaves, twigs and garden refuse accounts for about three-quarters of all stormwater gross pollutants
- commercial and industrial areas contribute the most human-derived material – mostly paper, plastics, food packaging, bottles and cans (Figure 19).

This gross pollutant data also indicates that potential nutrient loads from vegetative matter in stormwater are one to two orders of magnitude lower than the loads measured in stormwater samples. Thus vegetative matter in stormwater is not a major source of nutrients compared to other sources. Nevertheless, because of its large volume, vegetative matter should be taken into account in the design of gross pollutant traps, and in controlling pipe blockage and habitat destruction.

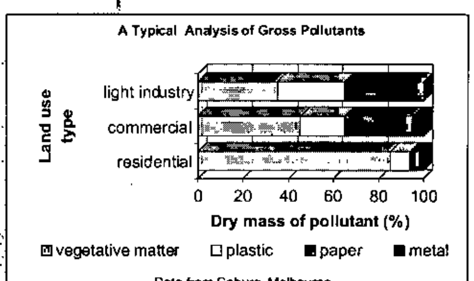
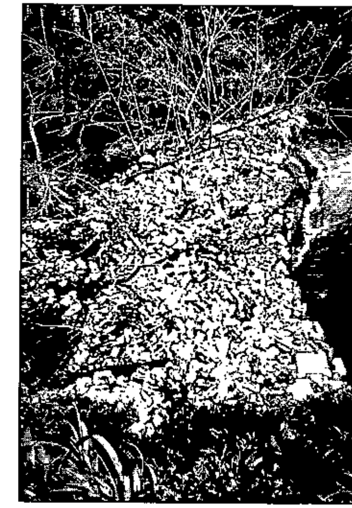


Figure 19: Typical composition of gross pollutants by land-use type (data from CRC monitoring study in Coburg, Melbourne)

The fate of stormwater pollutants

In an urban drainage system, water flow is concentrated in gutters, pipes and channels. Pollutants are transported in bottom sediments, as suspended particles or in solution (Figure 20).



Litter and tree debris in an urban creek

The rate of pollutant **transport** depends on water velocity and depth, and the degree of turbulence. Fine particulate and dissolved pollutants can become attached to sediments, or flocculate to form larger particles. Most of the pollutants in sediments are found on the smaller particles due to their greater surface area relative to larger particles. Pollutants attached to fine particles are easily carried because a small flow velocity is sufficient to mobilise them and keep them in suspension.

Storage basins (lakes, ponds and wetlands) in urban waterways reduce flow velocity and encourage sedimentation. The longer the water is detained, the more efficient the pollutant removal. Aquatic plants and

Vegetation and litter in gross pollutant 'trap"

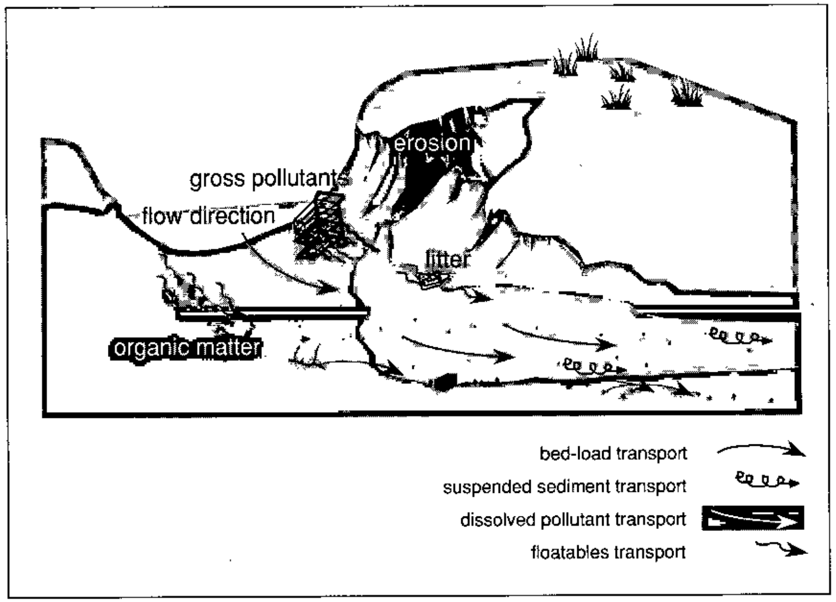


Figure 20: Transport of pollutants in urban catchments

micro-organisms in storage basins aid the pollutant removal process through physical filtration, stabilisation of sediments and biological removal (Figure 21).

The CRC's analysis of overseas and Australian data suggests that the three variables that best describe the pollutant removal performance of a pond or wetland are

- the concentration of pollutant entering the storage basin (input concentration)
- a design index that describes the basin characteristics (length/width ratio, number of cells, etc.)
- upflow rate, a parameter that takes into account annual runoff, storage area and catchment area.

For **particulate pollutants** like suspended solids, input concentration and upflow rate best explain the storage performance, while the design index is less important. It appears as if particulates can settle out almost anywhere, even under less favourable conditions. The removal performance is better for higher input concentrations because higher concentrations tend to include larger particles, which settle faster than fine particles. Under ideal conditions, the storage removal efficiency (the ratio of load retained to load entering a storage) of particulate pollutants can exceed 80 percent.

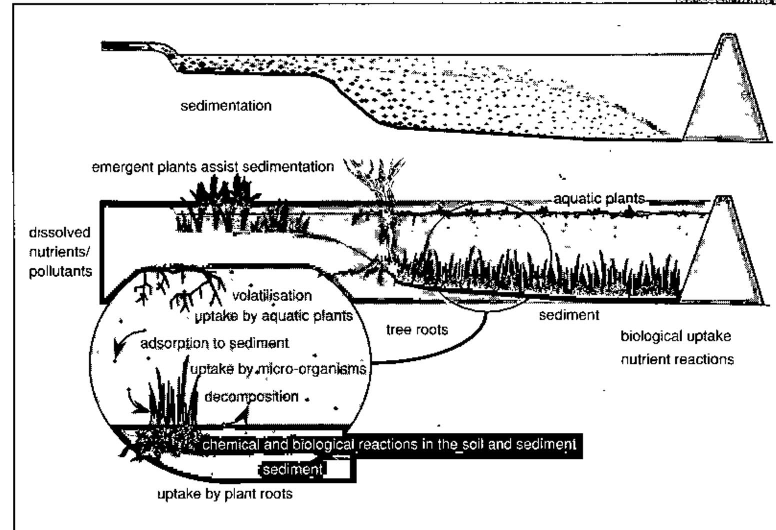


Figure 21: Storage and treatment of pollutants in water bodies

By way of contrast, the design index is very important for removal of **dissolved pollutants.** Storages with poor design practice give little removal of total phosphorus, and negligible removal of total nitrogen. However, with good design practice, storage removal efficiency of total phosphorous and total nitrogen of up to 70 percent is achievable.

An urban pond

ESTIMATING URBAN RUNOFF AND POLLUTANT LOADS

By understanding stormwater runoff and pollution processes, catchment managers can determine the best methods and sites for treatment, and thus control pollution levels in urban waterways and receiving waters.

Urban runoff and pollutant loads can be estimated by

- simple computations
- analysis of data from a good storm-event monitoring program
- an appropriate runoff and water-quality model.

The method selected will depend on management objectives and data availability. The following section presents methods that can be used to estimate runoff and pollutant loads over different time scales, and for different objectives and data availability.

ESTIMATING AVERAGE ANNUAL VALUES

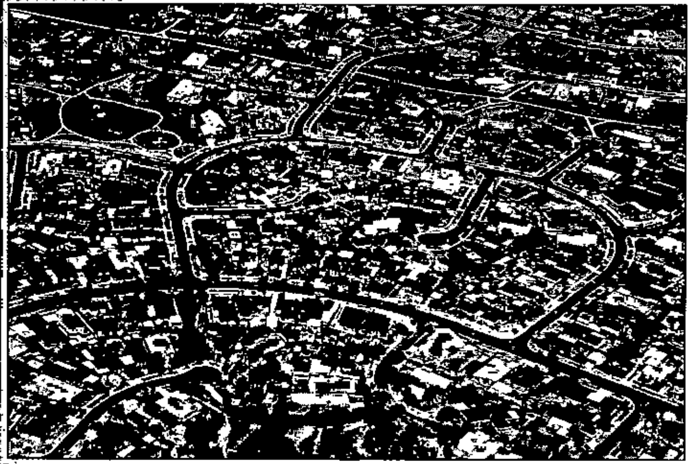


Figure 22: Aerial photos can be used to estimate the fraction impervious area

Average long-term runoff and pollutant loads can be estimated from rainfall data and from simple information about the catchment. These estimates provide an indication of the long-term inputs to - and environmental sustainability of - the receiving waters.

The key variables in estimating average **long-term runoff** are the fraction imperviousness (proportion of the catchment that is impervious) and the runoff coefficient (proportion of rainfall that becomes runoff).

Impervious area is defined here as impervious surfaces (pavements, roads and roofs) that are directly connected to drains. Almost all the rain that falls on the impervious area runs into drains; thus the runoff coefficient for the impervious area is almost 100 percent. Runoff coefficients for pervious areas in Australian urban catchments are typically between 5 and 40 percent. The total runoff is the sum of runoff from the impervious and pervious areas.

The following example shows the difference in average annual runoff between urban and rural catchments:

Average annual rainfall = 1200 mm
runoff coefficient = 1.0 for impervious areas and = 0.2 for pervious areas

Urban catchment in Brisbane	*Rural catchment near Brisbane*
fraction impervious = 0.5	**fraction impervious** =0.0
impervious area runoff = 0.5 x 1.0 x 1200 = 600 mm	**impervious area runoff** =0 mm
pervious area runoff = (1 - 0.5) x 0.2 x 1200 = 120 mm	**previous area runoff** = 1.0 x 0.2 x 1200 = 240
total runoff = 600 + 120 = **720 mm** (excluding outdoor water use)	**total runoff** =0+240=**240 mm**

The fraction of impervious surface in developed urban areas is typically between 0.2 and 0.7. It can be determined from:

- experience and local knowledge
- aerial photographs (Figure 22)
- a rainfall-runoff plot of small events (Figure 23)

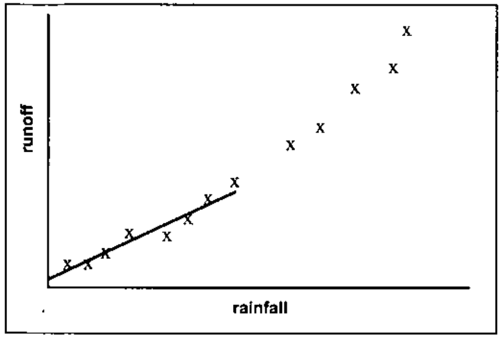


Figure 23: Estimating the fraction of impervious surface from a rainfall-runoff plot

The average **long-term pollutant load** of an area can be estimated as:

pollutant load = runoff x EMC

Event mean concentration (EMC) is defined as pollutant load washed off by a storm event divided by the event runoff volume. It can be estimated by monitoring pollutant concentration and discharge over a storm event (see section on stormwater monitoring). Even within one catchment, EMCs of different storms can be very different. In most studies, the EMCs of different storms are averaged to provide the EMC value for the catchment. The EMC, rather than dry weather or overall mean concentration, is used because most of the loads are transported by the big events.

The EMC depends on catchment and climate characteristics, and can vary by more than an order of magnitude between catchments. A good event monitoring program is thus essential where accurate estimates of pollutant loads are required. In the absence of data, the range of values presented earlier in this report, in the discussion of different pollutants, can be used as a guide to calculate rough estimates of pollutant loads.

Typical errors in estimating long-term pollutant loads are as follows:

- no monitoring - 100 to more than 1000 percent
- some periodic monitoring - 50 to more than 500 percent
- detailed event monitoring - 20 to 100 percent

Using the earlier example of an urban catchment in Brisbane, we can estimate the average annual pollutant load:

---

catchment area = 150 ha

average annual runoff = 420 mm

420 x 150 = 630 megalitres (ML)

mean EMC for total phosphorus (TP) for urban area (from literature, see Figure 4)

= 0.4 mg/L

Average annual TP load = 630 x 0.4 = 252 kg

(correct units must be used throughout)

Modelling daily runoff and pollutant loads

Computer models are used to:

- estimate runoff quantity and quality for short time-scales (daily, weekly or monthly)
- determine seasonal and spatial characteristics of urban runoff quality
- study the impact of land-use change, such as urban development
- provide inputs to water-quality management models.

Figure 24 illustrates a **conceptual daily rainfall-runoff model** developed by the CRC for urban catchments. The model uses daily rainfall, climate and outdoor water-use data to continuously estimate daily runoff. It represents an urban catchment as a number of interconnected storages,

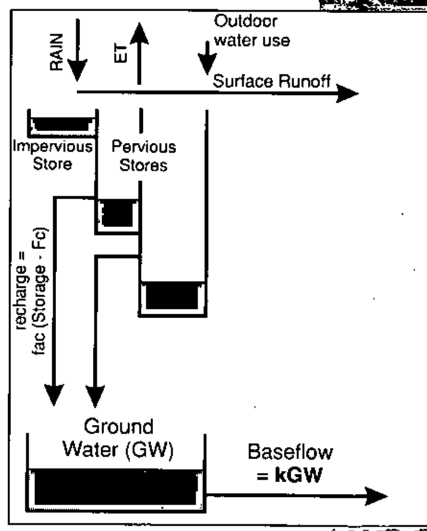
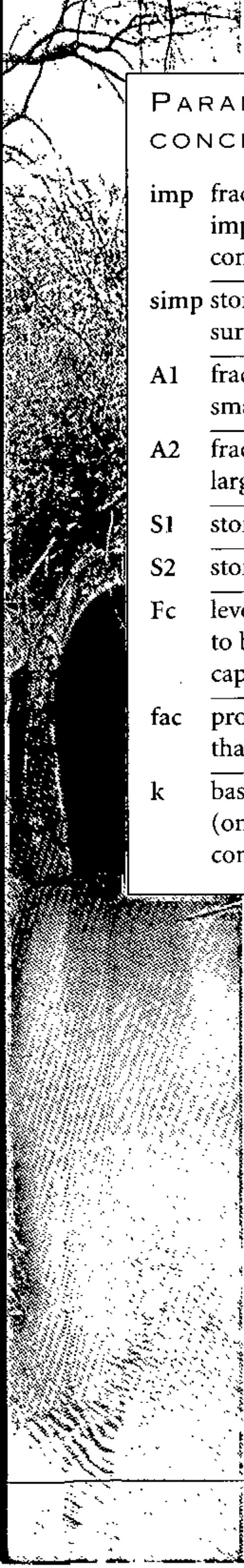


Figure 24: Example of a conceptual daily rainfall-runoff model for urban catchments



Parameter list for the conceptual model

imp	fraction of catchment with impervious surfaces directly connected to drains
simp	storage capacity of impervious surfaces
A1	fraction of pervious areas with the smaller storage capacity
A2	fraction of pervious areas with the larger storage capacity
S1	storage capacity of A1
S2	storage capacity of A2
Fc	level above which gravity drainage to baseflow store can occur (field capacity)
fac	proportion of 'storage minus Fc' that drains to baseflow store
k	baseflow store depletion parameter (one minus daily recession constant)

with mathematical functions used to describe the movement of water into, between, and out of them. Such a conceptual model attempts to mimic the actual physical processes, sometimes by using empirical equations to represent the processes.

In this model, the impervious (imp) area (impervious surfaces directly connected to drains) and pervious area (remaining parts of the catchment) are modelled separately. For the impervious area, after rainfall has exceeded a small threshold (simp), all the rainfall becomes surface runoff.

The pervious area is modelled as two separate parts (A1 and A2) with different storage capacities (S1 and S2) related to 'effective' soil depth. The first has a smaller storage capacity and represents parts of the catchment which saturate quickly. The second represents the remainder of the catchment with a greater soil storage capacity. Surface runoff occurs when either storage capacity is exceeded, that is, when saturation occurs.

Water from the pervious soil stores recharges to the baseflow (groundwater) store when the storage exceeds the 'field capacity'. Recharge is calculated as a parameter (which mimics hydraulic conductivity) times the amount the storage exceeds field capacity. Baseflow is simulated using a linear recession. Evapotranspiration (ET) depends on the amount of water in the soil stores

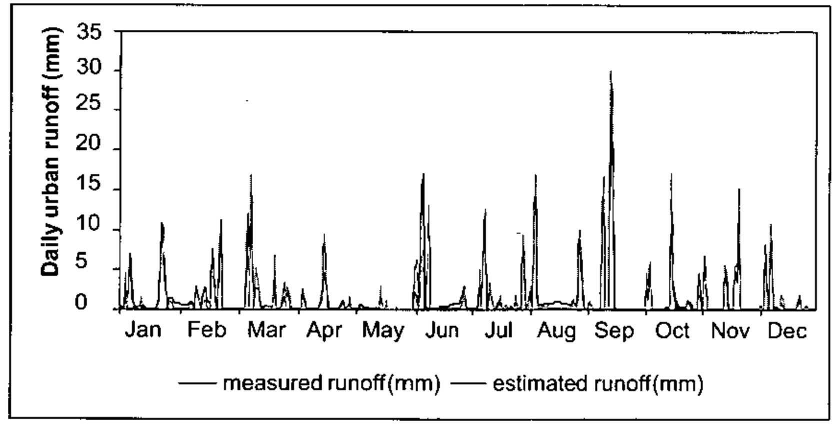


Figure 25: Example showing hydrograph of recorded monthly runoff and hydrograph simulated by the model

and the potential rate, which is weather/climate dependent. This model thus estimates the two components of runoff (surface runoff and baseflow) using eight parameters.

The parameter values are usually determined by calibrating the model output against measured data (Figure 25). During model calibration, the parameter values are chosen so that the runoff simulated by the model matches the recorded runoff as closely as possible.

The **daily pollutant load** is frequently estimated using either of these two equations :

load = surface runoff x EMC + baseflow x dry-weather concentration

load = a x runoff ^{b}

CRC research suggests that - with sufficient data - the power relationship (Figure 26) leads to better estimates of pollutant load than the constant concentration approach.

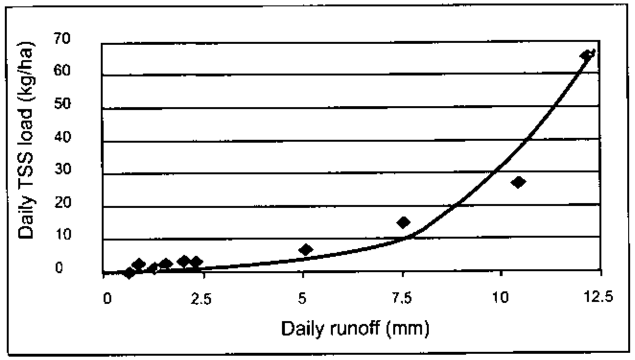


Figure 26: Power relationship between daily pollutant load (TSS=total suspended solids) and daily runoff (data from a Sydney catchment)

A more complete model would adopt a load-accounting method, in which dry-weather accumulation on impervious surfaces and pollutant contribution from rainfall are also simulated. However, at present, the lack of water-quality data does not justify the use of such a detailed approach.

Using models

Common applications of urban-runoff and pollutant-load models include the following.

Characterising urban runoff quantity and quality from an extensive monitoring program

Adequate monitoring of rainfall, climate, outdoor water use, runoff, dry-weather pollutant concentration and event water quality would allow reliable optimisation of model parameters. Once calibrated, a model can be used to describe the characteristics of runoff and pollutant load, and to estimate runoff and pollutant load from simple data (rainfall and climate) after the monitoring program is terminated.

Estimating runoff and pollutant loads from unmonitored areas

Runoff and pollutant loads for ungauged catchments are frequently estimated using model parameter values determined from monitored

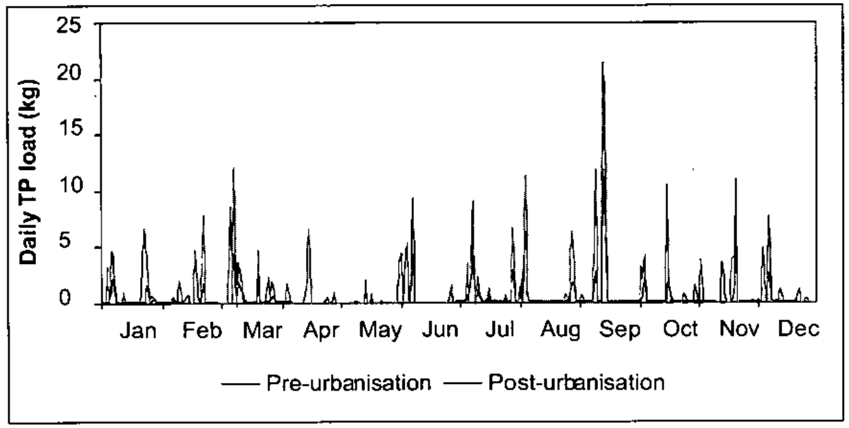


Figure 27: Daily total phosphorus (TP) load hydrographs for Sydney catchment simulated by the model for pre- and post-urban conditions

catchments that resemble the ungauged catchment. Because of the large variability in the physical processes - and thus parameter values – the model simulations must be interpreted cautiously.

Predicting the impact of urban development

The potential impact of urban development can be studied by running a model with parameters that reflect pre-urban and urban conditions. Figures 27 and 28 and Table 2 summarise results simulated by a CRC model of pre-urban and urban conditions, using data from a 180-ha Sydney catchment. The fraction imperviousness used is 0.5 for urban conditions and 0.0 for pre-urban conditions. The soil storages for urban conditions are assumed to be 80 percent that of pre-urban conditions. The same values are used for all other parameters.

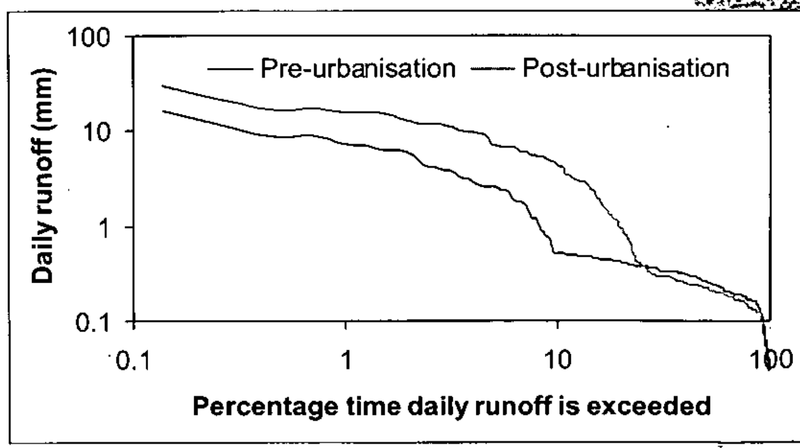


Figure 28

	Pre-urban	Urban
Water inputs (mm)		
rainfall	982	982
outdoor use	0	100
Runoff (mm)		
impervious area	0	342
pervious area	218	164
baseflow	17	91
total runoff	335	597
Phosphorus load (kg)		
impervious area	0	244
pervious area	155	117
baseflow	42	32
total load	197	393

Table 2: Input data and annual runoff and phosphorus loads simulated by the model for pre-urban and urban conditions.

Modelling processes during storm events

Storm event models are used to:

- characterise discharge (hydrograph) and pollutant concentration (pollutograph) over storm runoff events
- estimate total runoff volumes and pollutant loads generated by storm events.

Event runoff models operate on very short time steps – as short as one minute or less – and use theoretical hydrologic equations to simulate processes such as infiltration, overland flow, pipe routing and pipe overflow.

Most **event water-quality models** adopt the buildup-washoff approach, simulating pollutant buildup during dry weather and pollutant washoff during storms (Figure 29). The CRC review and modelling studies have shown that buildup increases to an equilibrium level and that the surface pollutant load is typically very high compared with washoff load in any single storm event. Washoff is therefore rarely limited by the surface load, suggesting that a detailed simulation of buildup is not necessary for modelling washoff.

In modelling washoff, water quality models typically assume that the pollutant availability on the catchment surface decreases exponentially with time. Further studies are needed to explain pollutant washoff, but CRC research and modelling investigations suggest that washoff is an overland flow phenomenon, and is strongly associated with rainfall intensity. Thus, it is possible that washoff can be estimated as a simple function of rainfall intensity over short time intervals.

Event models are generally complex and use many parameters to describe the processes governing water and pollutant movement. They are used mainly for design and operational purposes – for example, control options for storage and high rate pollutant/sewage treatment. Event models are rarely required for management because the water-quality response of many receiving waters is insensitive to short-term variations. Even when

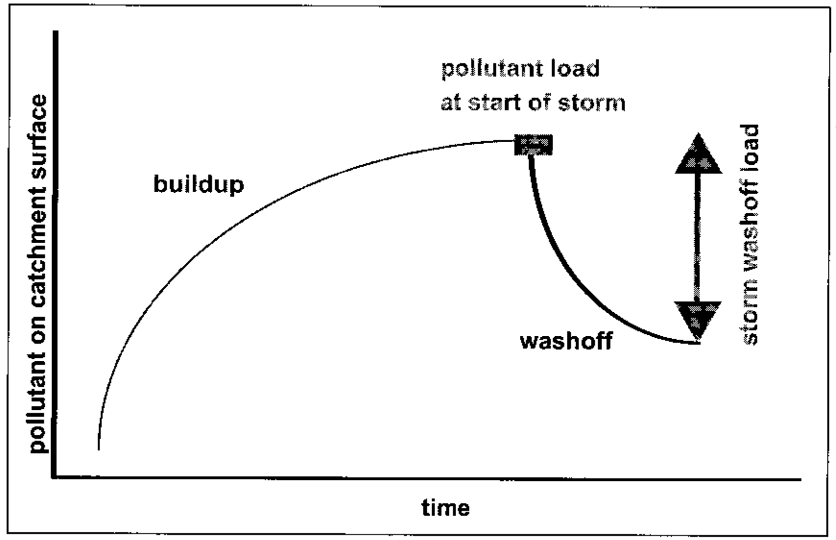
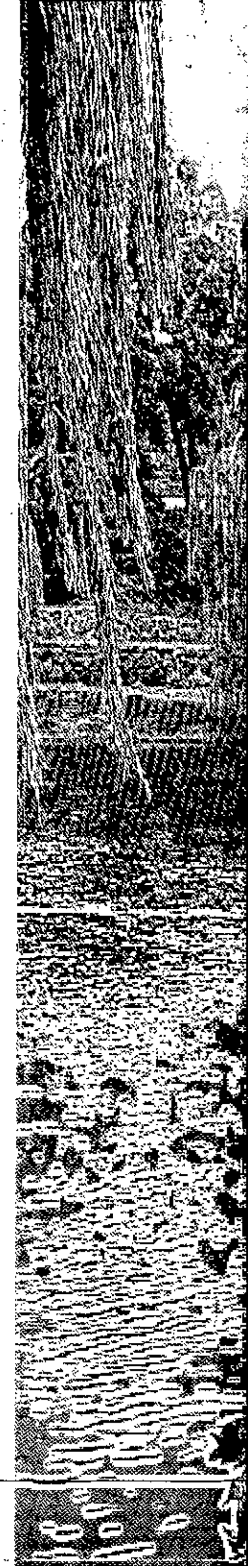


Figure 29: Modelling dry weather pollutant buildup and washoff during storms

event pollutographs are required – for example, when considering concentrations of toxic pollutants – they are difficult to simulate reliably.

Estimates of peak discharge rates are needed for urban drainage design. The use of simple methods outlined in flood and hydraulic design handbooks, instead of complex event models, is usually sufficient. Total pollutant loads generated by storm events are sometimes needed to evaluate water quality management options. In the absence of reliable data, estimates from complex event models are no better than estimates calculated using simple regression equations - for example, concentration times runoff, or load expressed as a function of climate/weather and catchment characteristics.

NOTE: There is no substitute for measured data. Computer models are simply tools used to aid studies and to interpolate and describe the measured data. Simulations from models should always be interpreted with caution, keeping in mind modelling constraints and management objectives.



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