WSUD:

WATER SENSITIVE URBAN DESIGN

BASIC PROCEDURES FOR 'SOURCE CONTROL' OF STORMWATER

A Handbook for Australian practice

STUDENT EDITION

John R Argue (Editor)

ABOUT THE AUSTRALIAN WATER ASSOCIATION (AWA)

The Australian Water Association is Australia's largest water focussed association. As a not-for-profit, independent organisation, AWA brings together individuals, water utilities, consultancies, businesses, educational and government entities who share an interest in ensuring the sustainable management of Australia's water resources. With such a broad-based, multi-disciplinary membership, it could be expected that there is a diversity of opinions on how best to achieve this goal.

While Australians as a whole are learning the importance of more efficient and effective use of scarce water resources, it is often a harder exercise to convey appreciation of aesthetic, restful qualities of a babbling brook, a reeded pond or a fountain in cities and towns where the natural experience of running water is far removed.

Water sensitive urban design attempts to merge the goals of valuing, managing, and using all urban water resources (roof runoff, stormwater, groundwater and wastewater) to create a sustainable urban environment where humans can connect with nature while living in the city. This can be achieved by combining the skills of planners; community groups; developers; social scientists; building and landscape architects; environmental scientists; hydrologists; hydrogeologists; and civil, water and environmental engineers, all of whom share goals for sustainable water management similar to AWA.

AWA is delighted to offer its support to encouraging the adoption of the practical ideas and concepts described in this handbook for the planning and design of modern water (and human) sensitive cities and towns.

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ABOUT THE STORMWATER INDUSTRY ASSOCIATION (SIA)

Traditional urban water practice, as established in all developed countries over the past 150 years, has been characterised by an almost unquestioned acceptance of the twin notions that a) all operations involved in urban water supply, sewerage and drainage could remain functionally separated, and b) that the most efficient systems would be the largest in scale.

About 20 years ago these concepts started to be seriously questioned. In fact, as investigations have continued and experience gained, it has become now widely accepted that it is likely to be the almost exact opposites of these twin notions that will finally prove to be the more sustainable position.

The SIA was established as an Australia-wide organisation to take a lead in the development of a new generation of more efficient urban water systems based on these 'opposite' notions and to assist in the parallel development of a range of industries for their planning, construction, operation and regulation. Stormwater was an obvious starting point, but the Association has always recognised the need to take a 'total water cycle' approach to urban water matters. The Association takes great pride in what it has achieved in the relatively short time since its inception and the great support it has received from the public in its endeavours.

The term Water Sensitive Urban Design not only links water and urban design together, as they most obviously must be (but often are not), but it also links them with the somewhat provocative word 'sensitive'. We want our cities to be more than just functional, we want them to be happy, healthy and beautiful also. Water is life and Water Sensitive Urban Design is a reminder to its practitioners to take heed of all human values when addressing water as a basic of city living.

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Cover Picture :

Roof gardens on apartment buildings in Woolloomooloo, N.S.W.

WSUD : **"Hold the rain where it falls!"**
(Photograph : Mandy Argue and Uwe Dombrowski)

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in collaboration with
Stormwater Industry Association and Australian Water Association

WATER SENSITIVE URBAN DESIGN : BASIC PROCEDURES FOR 'SOURCE CONTROL' OF STORMWATER

A HANDBOOK FOR AUSTRALIAN PRACTICE

STUDENT EDITION

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ISBN 1 920927 18 2

February, 2008

First printing : November, 2004
Second printing : April, 2005
Third printing : February, 2007
Fourth printing : February, 2008

FOREWORD

It is a great honour to have been asked to write the Foreword to this book. As a city planner and environmental designer, one of my strongest passions has been to find ways to use water as an integrating element to help develop more sustainable human settlements. In my searching for solutions to the challenge of creating more sustainable urban water systems I have benefited greatly from interactions with colleagues from different disciplines who share this passions. John Argue has been one of my valued collaborators in the task of translating Water Sensitive Urban Design from concept to reality.

The wisdom and insight presented in this, a very technical document, cannot be over-looked. The stormwater 'source control' approach to Water Sensitive Urban Design offered here is part of what can be recognised as a major shift in how we approach the planning, design and water infrastructure servicing of our cities and towns. The 'vision' of this approach is to find integrated solutions aligned with the ever-expanding quest of the sustainable cities movement, whether it be retrofitting old catchments or designing new settlements. This is not an insignificant challenge as our world becomes increasingly urbanised.

Fundamentally, the range of concepts, design approaches and technologies presented here, ask the designers to understand the site and its opportunities within a catchment repair context. In doing this, design solutions emerge that are site and catchment responsive. These solutions have a very simple starting point: a view that the rain that falls on our cities and towns is both a resource and something that needs to be managed with care to ensure that our urban water environments are protected and urban catchments are repaired.

The challenges of shifting to the Water Sensitive Urban Design approach presented in this book should not be under estimated. Our traditional urban water systems are designed and operate within complex and often conservative institutional, political and technical settings. In simple terms, Australians like their suburbs and like to keep their feet dry when it rains. Further, our urban development industry has become efficient at delivering that 'product' and local government, the owner of most of the stormwater facilities, is often conservative in its approach. But as communities begin to increasingly recognise the value and importance of water in urban environments, they are demanding that new systems and solutions be found.

While the barriers to innovation are significant, John Argue and his team have been able to capture the imagination of their clients and show through research, demonstration and evaluation that it is possible to find ways to help re-integrate our cities with 'place'. In doing this, the techniques and methods have been refined to assist designers to establish an urban hydrology that serves human needs as well as looking after ecological health.

As this research effort has been taken more and more into practice, the team has looked for ways to use these skills within trans-disciplinary teams. By seeking design solutions that integrate the skills of urban planning, ecological design, landscape and engineering, what has emerged are important 'case studies' of potentially far more sustainable patterns of human settlements. Water has helped to be an integrating element in the design process.

I know that this book fills a much-needed gap in the emerging practice of Water Sensitive Urban Design. I am confident that this contribution will have a significant and lasting influence on practitioners involved in designing, building and managing urban Australia, and probably beyond. The outcome will be better, more sustainable places to live that respect and celebrate 'place' and their associated water environments.

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September, 2004

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PREFACE

The seeds of this Handbook may be found in Chapter 3 of the ARRB publication, "Storm drainage design in small urban catchments" (Argue, 1986). But it was the fledgling research programme carried out in the late 1980s by staff and students of the former School of Civil Engineering (SA Institute of Technology, now University of South Australia) to find answers to many questions raised by 'Chapter 3', that provided the technical foundation and impetus for the present Handbook.

The early achievements of that programme, in particular the New Brompton Estate project, led in 1993 to creation of the Urban Water Resources Centre (UWRC), a research unit within the University of South Australia devoted to providing :

> *"…a focus for collaborative research, demonstration projects and education programmes aimed at improving the efficiency of urban water management while simultaneously increasing amenity and contributing to the achievement of ecologically sustainable development" (UWRC, 1993)*

When Professor Wolfgang Geiger, a leading environmental engineering researcher from Essen University, Germany, visited Adelaide in the early 1990s, he was impressed by local progress in stormwater management and proposed a jointly authored design Handbook based on the German ATV (Abwassertechnische Vereinigung EV) procedures, modified to suit Australian practice and conditions.

About the same time, a group of environmental planners, engineers and landscape architects in Perth coined the term **water-sensitive urban design (WSUD)** to describe their thinking about total water cycle management in the urban landscape. The overlap between this concept and the research being conducted in Adelaide in the domain of stormwater 'source control' was striking. Clearly, the proposed Argue/Geiger document would be a valuable sub-set within the broader WSUD context.

A major submission was made to provide research infrastructure to support the programme of basic and applied research and demonstration projects. This was called "Watermark 21" – urban water cycle technology for the new century – and submitted to the appropriate national grants agency. The application was not successful, however the project was pursued in modified form.

For reasons beyond the control of either Wolfgang or myself, the original design Handbook proposal did not eventuate; however, many hours of discussion and review of draft material did take place in Essen and in Adelaide throughout the 1990s. The material in the present Handbook as well as its overall philosophy were strongly influenced by these most productive interactions. During this period, UWRC operated as a self-funded unit, generously supported by the University of South Australia, solely in the domain of innovative water cycle management technology.

On occasions, the group produced concept designs for clients, sometimes it operated on projects in collaboration with government agency or council staff, and sometimes with local consulting engineers, architects or builders. These projects provided opportunities to convert 'in-house' research concepts and findings into operating systems and, in the process, confront and overcome the inevitable practical problems posed by 'real world' situations. The Handbook encapsulates the wealth of experience gained through these most valuable interactions.

WSUD has gained wide recognition in Australia since the late 1990s when experience with constructed (stormwater) wetlands in Perth, Adelaide, Canberra and Melbourne, and success achieved with urban ASR (aquifer storage/recovery) and stormwater-based water cycle schemes in Adelaide and Newcastle (Newcastle City Council and University of Newcastle) were reported at national and international conferences: the AMCORD document (Dept of Housing and Regional Development, 1995) also dates from this period. This led to new initiatives in Melbourne (CRC for Catchment Hydrology) and Brisbane (WBM Oceanics and Brisbane City Council) in particular. WAWA, NSW Dept of Housing, CSIRO, SIA along with Melbourne Water, Brisbane City Council, the Lower Hunter Central Coast regional councils and Upper Parramatta River Catchment Trust (Sydney WSUD capacity building program) have all made major contributions to the field in support of its technical base or case studies or promoting WSUD principles through professional gatherings and conferences.

These achievements and activities are part of the early adoption phase of a new and quite revolutionary technology – the 'paradigm shift' referred to by some of its contributors. However, the great bulk of urban development carried out across the nation does so with scant regard for WSUD and for the principles of sustainability upon which it is based.

- CBD and residential roofs are still being directly-connected to street drainage networks despite many alternative solutions being available;

- car parking areas are still being constructed with hotmix surfaces though porous/permeable paving systems are readily available;

- drainage in new residential sub-divisions is still being installed using impervious pipes and channels in circumstances where swales would bring both flood security and a 'softening' of the urban landscape.

The Handbook provides the "how to" tools to support the wider adoption of the technology through its presentation of approaches to solving everyday problems of small-scale stormwater management – flood control, pollution control and stormwater harvesting. The procedures are simple yet soundly based in theory and practice, set out for the most part in step-by-step format. Lessons learned from over 20 case study installations have been incorporated. Material contained in the Handbook has been trialled over the past six years in undergraduate and postgraduate classes at the University of South Australia and duly modified as a consequence of student review and comment.

WSUD is committed to sustainability. It provides an urgent call to our post-industrial urban society to reclaim the seasons, to celebrate the presence of rainfall and sensitively managed runoff in the built environment and, by so doing, to protect the community and, at the same time, promote amenity and restore treasured waterways and their biotic communities. It is no accident, I believe, that the 'Watermark' demonstration projects have – without exception – produced community values and attitudes to 'place' undreamed of by those involved in the technical process of their creation.

The indigenous peoples who inhabited our great continent for tens of thousands of years before European settlement and who lived in sustained harmony with its bounty and vicissitudes, lived in spiritual union with and showed profound reverence for the land, the water and its fauna and flora. The cultural and technological differences brought by the 'newcomers' have resulted in a wide range of environmental problems for our nation that non-indigenous Australians, in particular, are being called upon to solve as a matter of urgency.

WSUD has, unquestioningly, a significant role to play in this process : its end result could well be a new appreciation for community values within our urban concentrations, hand-in-hand with a reverence for the land and water and for our native fauna and flora.

Users of this Handbook are challenged to embrace this vision and to apply the document's procedures, guidelines and strategies not in a prescriptive way but, rather, to use them as building blocks for creating unique solutions that achieve not only their basic technical objectives but also goals of improved amenity – places of community harmony and spiritual enrichment – as well as increased quality of the natural environment.

John R. Argue
Adelaide
November, 2004

ACKNOWLEDGEMENTS

The story which lies behind the production of this Handbook – theory development, experimentation, case example installations, monitoring, class trialling, text development – has involved many contributors, all of whom have responded to the opportunities inherent in 'source control' of stormwater with energy and commitment. The base of that support has been firmly located in South Australia, but a handful of agencies and personnel outside SA have also provided significant input and encouragement.

First to be recognised is University of South Australia – the primary source of support – particularly during years 1993 to 1999 when the bulk of the intellectual base of the project was laid. Instrumental in securing and maintaining this support were Mr. Bob Taylor of Techsearch and Mr. Jim Mitkas who acted as Business Manager for UWRC throughout the period. Members of the UWRC Advisory Board under the Chairmanship of Mr. B. C. (‘Skip’) Tonkin, AO – Kathryn Bellette, Leon Broster, Don Bursill, Jason Kuchel, Bill Lipp, Dr. Kevin Mills, Dr. Dennis Mulcahy, Professor Stephen Priest – also rendered sterling service, encouragement and sound advice. In more recent time the support of Professors Robin King, Ian Davey, Patrick James and Bill Richards is acknowledged with gratitude.

Mr. Bill Lipp in his role as Manager, Stormwater Section of Transport SA, deserves a special ‘thank you’ for his role in forging links between UWRC and municipal agencies, and for finding funds to bring collaborative projects to fruition. Other government agencies who provided significant help to and encouragement of field projects included South Australian departments responsible for, in particular, water resources, stormwater pollution control and planning/environment : their departmental names have changed over the period, but never their support. In this connection Messrs Murray Hutchesson and Peter Hoey deserve special mention. The Torrens and Patawalonga Catchment Water Management Boards and General Manager Alan Ockenden and Technical Manager Keith Downard are also recognised in this context.

Projects organised collaboratively with SA municipal agencies provided opportunities to convert theory into field installations and, thereby, to learn from experience: the councils of Charles Sturt, Marion, Burnside, West Torrens, Holdfast Bay, Campbelltown, Salisbury, Mount Barker, Mitcham and Whyalla were active in these respects. Success in these ventures led to collaborative projects interstate with Newcastle City Council, Wingecarribee Shire, Upper Parramatta River Catchment Trust (Dr. Stephen Lees) and Baulkham Hills Council (NSW Stormwater Trust). Waitakere City, New Zealand, may be added to this list as an overseas collaborator.

Commonwealth government support is also acknowledged. Federal funds were provided through a *Coasts and Clean Seas* grant for a permeable paving project leading to some of the data on which Table 3.1 is based.

Support for two significant stormwater ‘source control’ installations came from an unexpected source – the Adelaide Diocese of the Anglican Church led by former Archbishop, Dr. Ian George AO. Those involved in bringing these projects to fruition included Archdeacon John Collas, the Reverends Peter Simmons, Barry Davis and Peter Miller and the parishioners of Warradale and Plympton.

The concept of bringing the detailed design knowledge gained from all of these initiatives into a manual or handbook of practice under the heading of Water Sensitive Urban Design owes its origins to Mr. John Wood, former Executive Director of the Stormwater Industry Association. John recognised the need for something more than ‘guideline’ information readily available at that time. SIA’s endorsement of the Handbook is due, largely, to representations made by Mr. Richard Clark, Chairman of the South Australian Chapter. Similar representations by Mr. Richard Marks within the ranks of Australian Water Association are also acknowledged with gratitude.

An early draft of the document was reviewed by some leading researchers and practitioners in the (Australian) field of urban drainage and ‘source control’ technology. These included Dr. Geoff O’Loughlin, Dr. Peter Coombes, Mr. Chris Tanner, Mr. Ian Rowbottom and Dr. Simon Beecham. Simon Beecham’s review, in particular, resulted in the inclusion of a most valuable introductory section (written by Simon) for Chapter 6 : his contribution will be appreciated by all users of the Handbook. Ms. Megan Flint’s input to Chapter 6 is also acknowledged.

There is a small army of supporters who have contributed their skills and encouragement to the Handbook project in a variety of ways. Particular thanks go to Cheryl and David Wilson for their skill in typing, formatting and in the graphics input to the final document; Carolyn Bellamy has handled administrative tasks associated with the Handbook with cheer and efficiency. Encouragement and contributions in many forms over the long period of the Handbook’s development have been provided by Kim Read, OAM, Mark Brindal, MP, Hon. David Wotton, Lyn

Parnell, Jay Hogan, Ken Schalk, Chris Tually, Clive Jenkins, Dr Peter Mitchell, Frank Smith, Dr. Phil Crawley, Dr. John Sabine, Rosalie Disney, Stephen West, Colin Pitman, Brian Taylor, Garry Moore, Sydney Wood and Rev. Tony Cox of the Green Worship Fellowship. Important, critical input to the Handbook came from undergraduate and post-graduate students of Urban Hydrology classes and Workshop participants at the University of South Australia since 1998.

Finally, there are the partners and families of the Principal Contributors – particularly Tina Pezzaniti and Jan Argue – who have maintained their belief in the value and importance of the Handbook project throughout its long gestation period. Their support, in no small measure, has contributed to the successful outcome of a project which, we trust, will lead to greater use of improved urban water management practices across the nation : we thank them sincerely for their patience and forbearing.

LAUNCH AND DEDICATION

The First Edition of the Handbook was launched by Hon. Dr. Don Hopgood, Chair, "Water Proofing Adelaide" Advisory Panel, at the Engineers Australia WSUD2004 "Cities as Catchments" Conference held 21 – 24 November, 2004, in Adelaide.

The Handbook was dedicated and commissioned by Reverends Barry Davis and Peter Miller in the Community Garden, Plympton Anglican Church, Adelaide, on Sunday 21 November, 2004.

FUTURE DIRECTIONS

It is the intention of the Principal Contributors to the Handbook to maintain the content of the document in as up-to-date form as possible. To this end, users are encouraged to provide information to UWRC on any aspects of the Handbook's procedures, guidelines or strategies which produce interesting or unexpected outcomes or which raise issues of limited application. This feedback should be addressed to :

cwss@unisa.edu.au

In time a Second Edition may be published taking account of such contributions. The Handbook should therefore be seen as a 'work in progress' and not a static once-and-for-all-time manual.

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ENDORSEMENTS

Australian Water Association : November, 2004
Stormwater Industry Association : November, 2004
Department of Water, Western Australia : January, 2008

AWARDS

Engineering Excellence – Engineering Reports
Engineers Australia, South Australia Division : 2005

Excellence in Stormwater Education
SIA National Awards : 2005

National Engineering Excellence Awards – Finalist
Engineers Australia : 2005

1. INTRODUCTION : SOME BASIC CONCEPTS

1.1 INTRODUCTION

The principles which govern the layout and detailing of storm drainage including site drainage as designed by leading practitioners has undergone greater change in the last 30 years than at any other period of similar length since wastewater collection and disposal technology (including stormwater) was introduced to Europe in the latter half of the 19th Century. For most of the 100 years prior to the 1960s, the philosophy of "collect and dispose of storm runoff as completely and as quickly as possible" dominated general practice throughout the developed world : its dire consequences are now being experienced in the older cities of Europe, UK and North America (Pearce, 2004). Little thought, if any, was given in that philosophy to :

- increased downstream flooding, and,
- pollution of receiving waterways.

The 1960s saw two significant changes in direction : the first was development of **detention** technology carried out at both individual premises and sub-division/catchment scales. The second change was the introduction of the major/minor philosophy for managing the bulk of storm runoff flows generated in urban landscapes (Wright-McLaughlin Engineers, 1969; Argue, 1986; I.E.Aust., 1987).

Australian practice has made wide use of detention basins in city-wide and municipal planning; on-site stormwater detention (OSD) has not been as universally accepted, but many Councils in Sydney and Melbourne as well as major cities such as Wollongong, Newcastle and Canberra, introduced OSD policies in the 1990s which apply, in particular, to cases of re-development (UPRCT, 2005).

1.2 DETENTION AND RETENTION OF STORM RUNOFF

1.2.1 Flood control

The primary goal of detention, whether practised at the scale of the individual residence or the suburb, is flood peak reduction achieved through temporary ponding. **Detention** refers to the holding of runoff for relatively short periods to reduce peak flow rates and later releasing it into natural or artificial watercourses to continue in the hydrological cycle as channel flow, evaporation, groundwater recharge, input to lakes and the ocean, etc. The volume of surface runoff involved in the temporary ponding process is relatively unchanged by it.

On-site stormwater retention (OSR) has been the logical next step in the progress of detention/retention technology. **Retention** refers to procedures and schemes whereby stormwater is held for relatively long periods causing it to continue in the urban water cycle via domestic use (in-house and outdoors), industrial uses and the natural processes of infiltration, percolation, evaporation, evapotranspiration, but not, usually, via direct discharge to natural or artificial watercourses (after Argue, 1986).

The differences between OSD and OSR are more than cosmetic with OSR installations being typically smaller (in volume) as the following illustration shows.

Consider a hypothetical, 60 lot sub-division in Parramatta, NSW, where each 'quarter-acre' block (1,000 m^2) with house (300 m^2 roof) and 150 m^2 paved area, illustrated in Figure 1.1, is re-developed for dual-occupancy (500 m^2 roof area, 300 m^2 paved area). Hydrological modelling using the 1-hour, ARI, Y = 100-years design storm, is carried out on the sub-division to determine :

1. Runoff hydrograph for ARI, Y = 100-years 1-hour storm on each (present development) site.

2. Runoff hydrograph for ARI, Y = 100-years 1-hour storm on each re-developed site.

3. What peak flow rate would occur at the downstream end of the sub-division (60 sites) in the ARI, Y = 100-years, 1-hour storm, **before** re-development?

4. What peak flow rate will occur at the downstream end of the sub-division (60 sites) in the ARI, Y =100-years, 1-hour storm, **after** re-development (without detention/retention measures)?

5. What SSR (site storage requirement) associated with an OSD device is needed on each re-developed site to ensure that the exit peak flow from the sub-division (60 sites) equals the exit peak flow before re-development?

6. What on-site volume of storage must be provided with an OSR device on each re-developed site to ensure that the exit peak flow from the sub-division (60 sites) equals the exit peak flow before re-development?

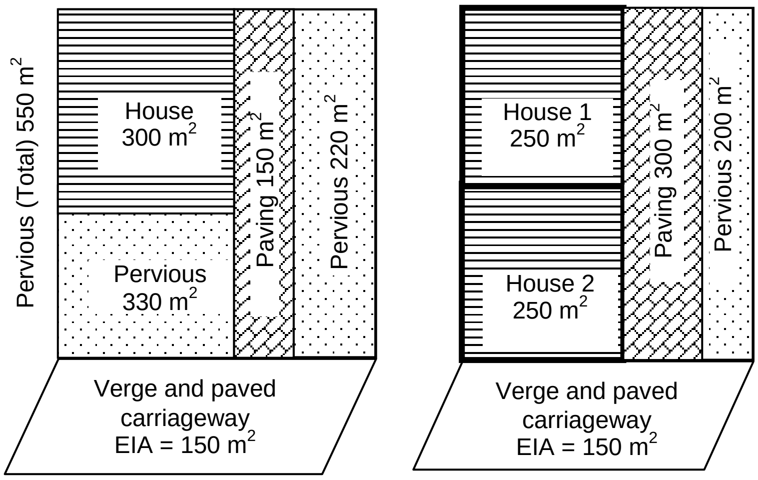


FIGURE 1.1 : Layouts of residential developed and re-developed allotments

Runoff hydrographs for the present and re-developed cases (items 1 and 2, above), are shown in Figure 1.2.1a. Hydrographs for the ARI, Y = 100-years storm applied to the 60 adjacent sites before and after re-development (items 3 and 4, above), are shown in Figure 1.2.2a.

The storage volume (SSR) required for an OSD device to achieve the required reduction in peak exit flow from the sub-division (illustrated in Figure 1.2.2a) is 28.2 m^3 per site (item 5, above). The volume of on-site storage required to achieve the same reduction using OSR devices is 18.3 m^3 per site (item 6, above). Additional graphical displays for the ARI, Y = 100-years 1-hour storm used in the illustration are included in Figure 1.2, in particular :

- hydrographs for re-developed site and re-developed site plus OSD device (Figure 1.2.1b);
- hydrographs for re-developed site and re-developed site plus OSR device (Figure 1.2.1c);
- hydrographs for 60 re-developed sites without and with OSD flood reduction (Figure 1.2.2b);
- hydrographs for 60 re-developed sites without and with OSR flood reduction (Figure 1.2.2c).

This illustration is little more than a 'skirmish' with the technical issues involved : Scott et al (1998) and Argue and Pezzaniti (2001) have explored the issue in much greater detail (see also Section 5.6). The re-development of 60 adjacent 'quarter-acre' lots is a most unlikely scenario, however, correct hydrological modelling of actual cases yields similar results.

Those seeking a logical rather than modelling explanation for the above outcome will find it in the fact that retention devices can withdraw some 20% – 30% of the flood wave from the drainage path. Comparison of Figures 1.2.2b and 1.2.2c reveals the benefits of this for downstream flood control.

1.2.2 Other comparisons and potential of stormwater on-site retention (OSR)

Cost : Accepting the outcome, above, as typical leads to the important conclusion that an OSR solution is likely to be the cheaper of the two options since the volume of storage required is less. But the cost advantage does not stop there. On-site retention devices (see Figures 1.3, 1.4 and 1.5) are simple and, in most circumstances, their depths are not limited – as OSD installations are – by street drainage invert levels. These advantages can result in significantly smaller capital outlays.

Single dwelling case

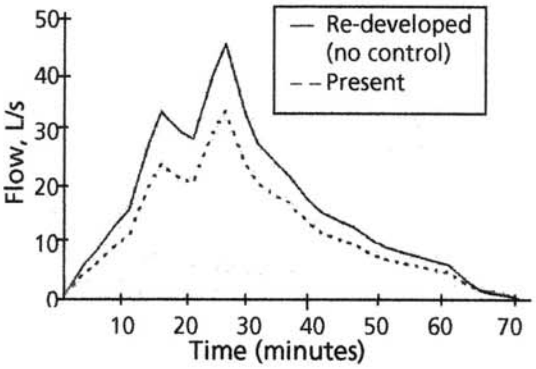


FIGURE 1.2.1(a) : Parramatta, N.S.W. Hydrographs for present and re-developed site 100-year ARI, 1-hour storm

60 dwellings case

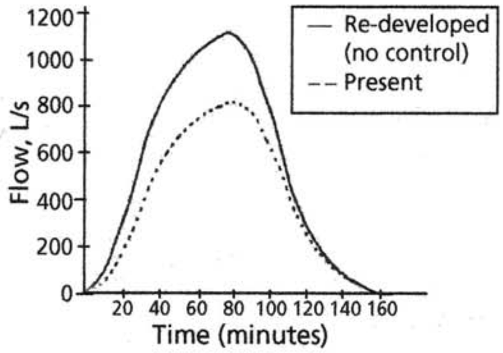


FIGURE 1.2.2(a) : 60 sites each lagged by 1 minute

USING ON-SITE DETENTION, OSD

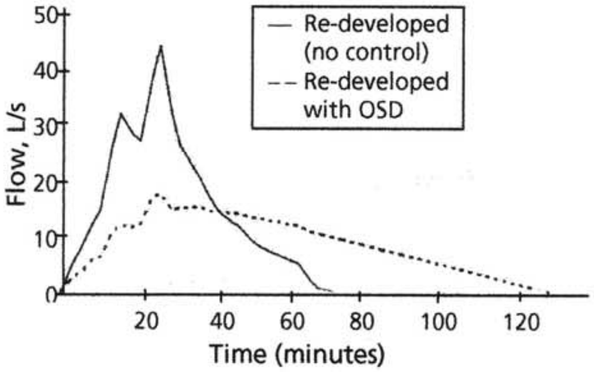


FIGURE 1.2.1(b) : Re-developed with possible OSD solution

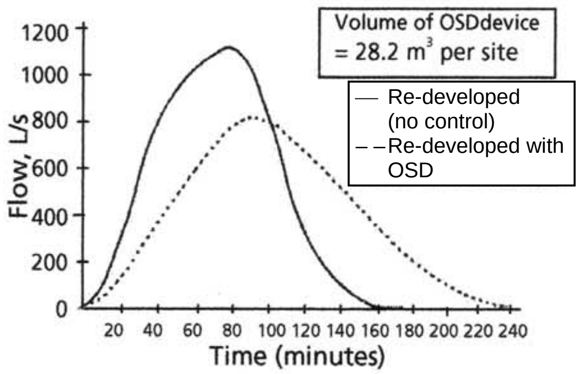


FIGURE 1.2.2(b) : 60 OSD sites each lagged by 1 minute

USING ON-SITE RETENTION, OSR

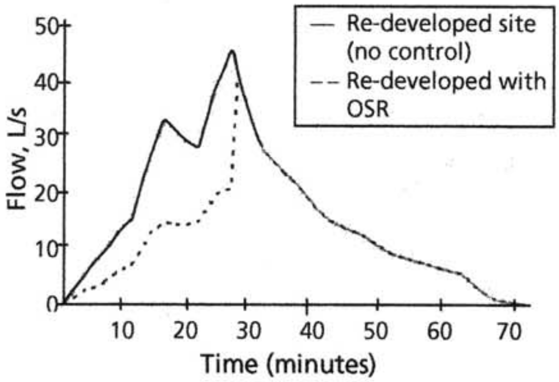


FIGURE 1.2.1(c) : Re-developed with possible OSR solution

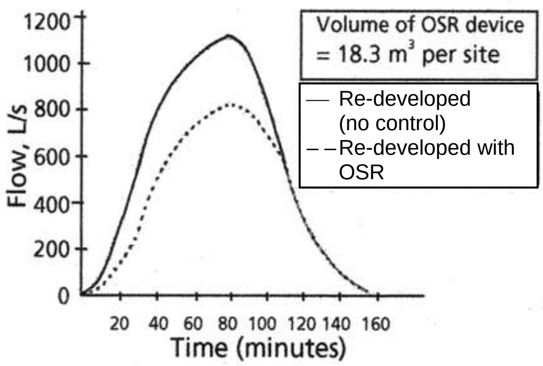


FIGURE 1.2.2(c) : 60 OSR sites each lagged by 1 minute

Furthermore, and provided the guidelines on treatment of runoff passing to OSR devices are carefully followed, maintenance can also be significantly less.

Environmental benefits : Stormwater retention involves, firstly, the holding of storm runoff, including pollution, on site: this certainly reduces the flow of **site** contaminants downstream, but it does not reduce pollution loads originating on urban roads and highways passing to receiving waters. Secondly, such run-off management involves on-site collection and use of stormwater from roofs and other relatively clean surfaces. The consequences of both of these aspects, acting together, is **greater** concentration of pollution in the general (reduced) runoff flow passing towards urban streams, rivers and the sea than would otherwise occur. Pollution treatment devices and systems – GPTs, wetlands, etc. – intercepting this flow can therefore be made **smaller** than installations needed to treat the whole stormwater flow.

Harvesting of stormwater : Harvesting can be considered under the following categories :

- Roof runoff collected in rainwater tanks can be used in domestic hot water systems and for toilet flushing, etc. Roof runoff can be cleaner than some town water supplies, and when used in storage hot water systems, overcomes the problem of contamination by *E.coli, cryptospiridium* or *giardia.*
- Soil moisture maintenance in the vicinity of "leaky" devices such as wells, gravel-filled trenches, etc.; this moisture promotes growth of grass, shrubs and trees.
- Recharge of aquifers with cleansed water using ASR (aquifer storage and recovery) technology: this can be retrieved for irrigation, toilet flushing or industrial uses.
- Environmental flows: when cleansed stormwater is injected into an aquifer with a steep groundwater hydraulic gradient, retrieval of the recharged water is virtually impossible; the injected flow usually emerges as percolation into a local urban stream, thereby enhancing the stream environment and its biotic community.

1.2.3 Detention technology : its role in contemporary stormwater management

The case for introducing retention technology into Australian practice presented above should not be interpreted as signalling an end to the use of OSD and its complete replacement by OSR in urban catchments. There are at least four sets of circumstances where detention technology may be preferred to OSR in contemporary stormwater management practice :

- Situations where soil types or topography are unsuited to OSR; where allotment sizes are too small to permit required clearance distances being observed; where groundwater is saline and shallow; etc. (see Section 3.8).
- Catchment management scenarios where maximum storm runoff yield is sought from the urban landscape together with control of peak flood flows : this is an aspect of stormwater harvesting achieved through downstream wetlands associated with aquifer storage and recovery (ASR) schemes (see Section 4.2.1).
- Catchment management situations where the primary objective – perhaps even the sole objective – is flood control. There is no doubt that the simplest way to reduce flood peak flows in an isolated catchment – to achieve a target outflow – is through the use of a 'bottom end' detention basin. Certainly, the identical effect can be achieved through the use of distributed retention installations, but this option is often unattractive to municipal agencies who prefer the centralised solution (see Section 5.6).
- Detention techniques can also be employed to provide environmental flows in urban waterways through the medium, perhaps, of 'slow-drainage' (see Section 5.1.5).

1.3 RETENTION-BASED STORMWATER MANAGEMENT : WATER-SENSITIVE URBAN DESIGN (WSUD)

1.3.1 Primary aims

There are three primary goals of retention-based stormwater management :

1. to reduce storm runoff in terms of both peak flow and volume;
2. to minimise pollution conveyance from urban catchments to downstream waterways and receiving waters; and;
3. to harvest and use storm runoff to replace mains water use including some potable but mainly ‘second quality’ applications.

The first two goals are well understood and universal; the third has sprung from the pressing needs of urban communities looking for alternatives to ‘big system’ infrastructures delivering a single water product whose quality exceeds the requirements of many applications.

It follows that stormwater management practices, where they are incorporated as fully as possible into appropriate urban landscapes, may reproduce hydrological behaviours bearing close resemblance to those of the original forested catchments they replaced. Such simulation studies as have been carried out lend support to this assertion.

This is an exciting concept for planners and developers to entertain, as it carries with it the possibility that minor drainage lines with their associated fauna and flora habitats, normally sacrificed in the wake of the urban sprawl, may well find co-habitation alongside sensitively-designed urban developments. This concept is reviewed in greater detail in Section 1.4.

This is the vision of contemporary stormwater management or **water-sensitive urban design**, the terminology first used in Perth to describe this approach (Whelans et al, 1994; Wackernagel and Rees, 1996; Beecham, 2003; Mouritz et al, 2003) : how can it be realised?

1.3.2 Site-dependent options and opportunities

Opportunities for using rainwater tanks and/or (enlarged) eave gutter systems to store roof runoff exist at all sites, but in-ground storage of runoff, other than in impermeable rainwater tanks, raises a number of site capability issues which depend on the following properties :

- permeability of the soil, measured by its hydraulic conductivity, k_h,
- nature of the soil in terms of its reaction to the temporary presence of water,
- geology of the site in terms of land slope, depth to bedrock, availability and types of aquifers and aquifer water quality,
- potentiometric gradient of water flowing through aquifers, where present.

Australian urban concentrations include a range of natural environments where interplay between these properties produces a number of zones whose capabilities vary from unlimited opportunities for storm run-off retention and retrieval for use, on the one hand, to total inability to apply this technology, on the other. There is a preponderance of the former over the latter.

Some guidance on the types of devices and systems which may be used, and site capabilities, is presented in the following sub-sections.

1.3.3 Runoff categories and treatment

There are two basic types of water-retaining installations which may be used in on-site systems: simple in-ground devices such as “leaky” wells, gravel-filled trenches or pipe/gravel trenches, as illustrated in Figure 1.3 (also, strong plastic ‘milk crate’ and other types of cells) : these devices drain by natural percolation into the surrounding soil. Alternatively, the same simple device can be fitted with a direct (unconfined aquifer) or bore connection to an underlying confined aquifer, if present (see Figure 1.4a). Wherever on-site stormwater retention is practised, certain general guidelines should be observed in the way it is controlled or managed prior to entering a device. The first of these relates to roof runoff, the second to ground-level surface runoff.

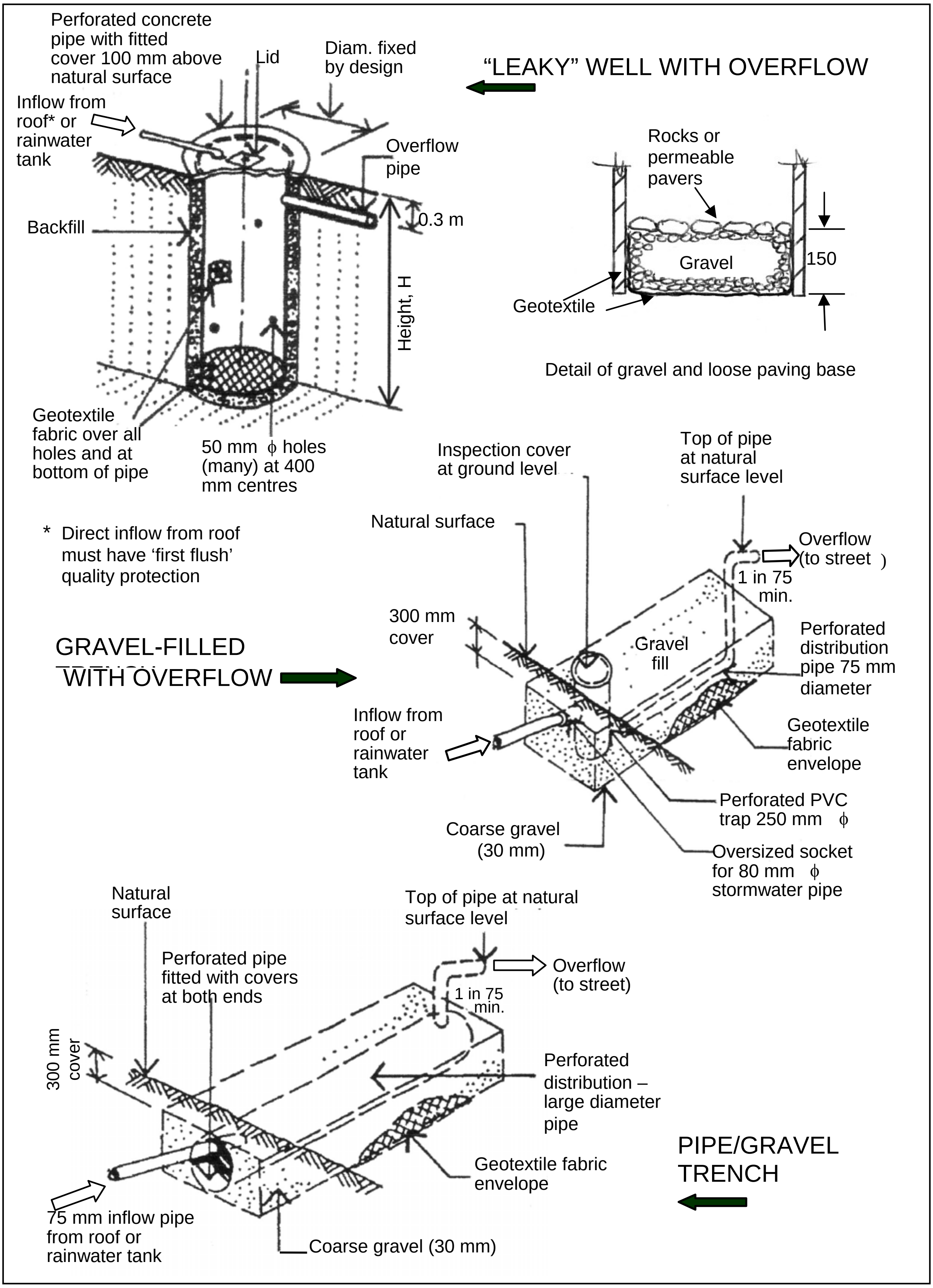
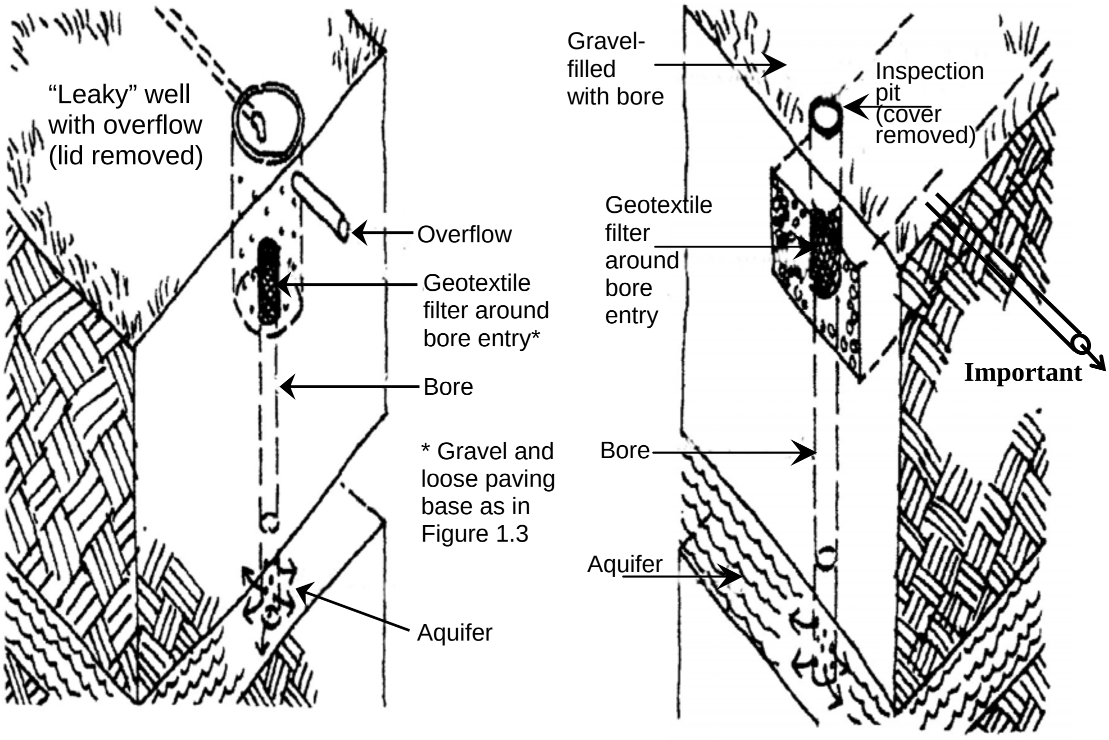
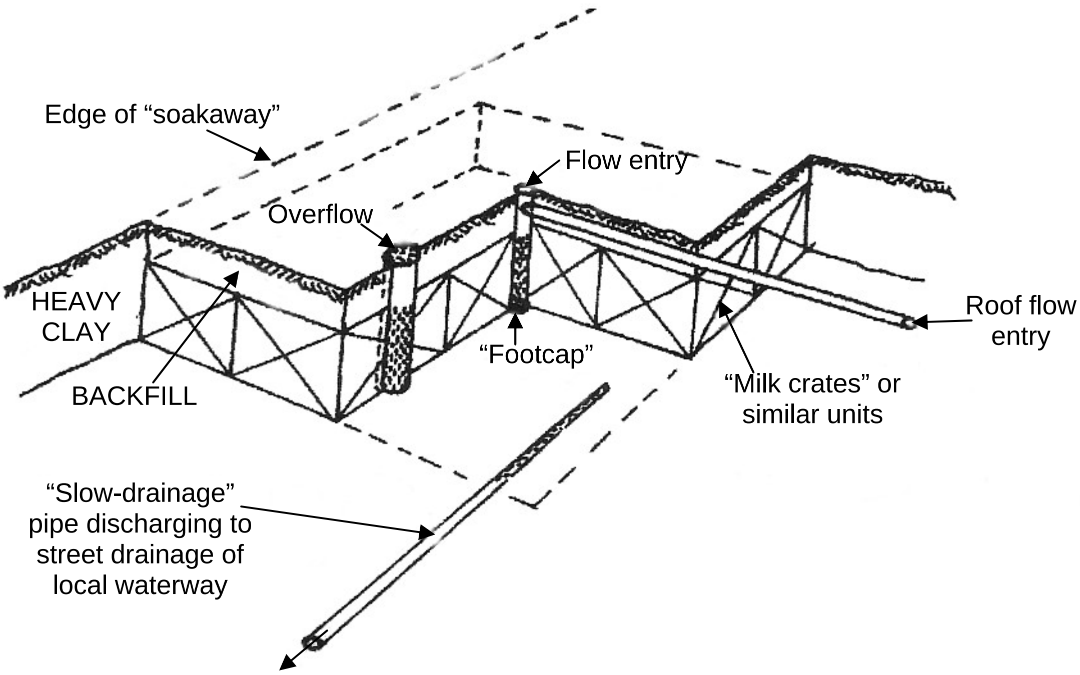


FIGURE 1.3 : 'Simple' devices for retaining stormwater



(a) Aquifer recharge from "leaky" devices : this technology has two main uses in water-sensitive urban design. The first is in stormwater harvesting, the second is to reduce device "emptying time" (see Procedure 4A, Chapter 5)



b) This illustration depicts the 'limit' of OSR technology in heavy clay soils where acceptable emptying time can only be achieved through the use of a slow-drainage pipe (see Procedure 4B and Section 5.4, Chapter 5)

FIGURE 1.4 : "Leaky" devices with aquifer access or 'slow-drainage' pipe to improve emptying performance

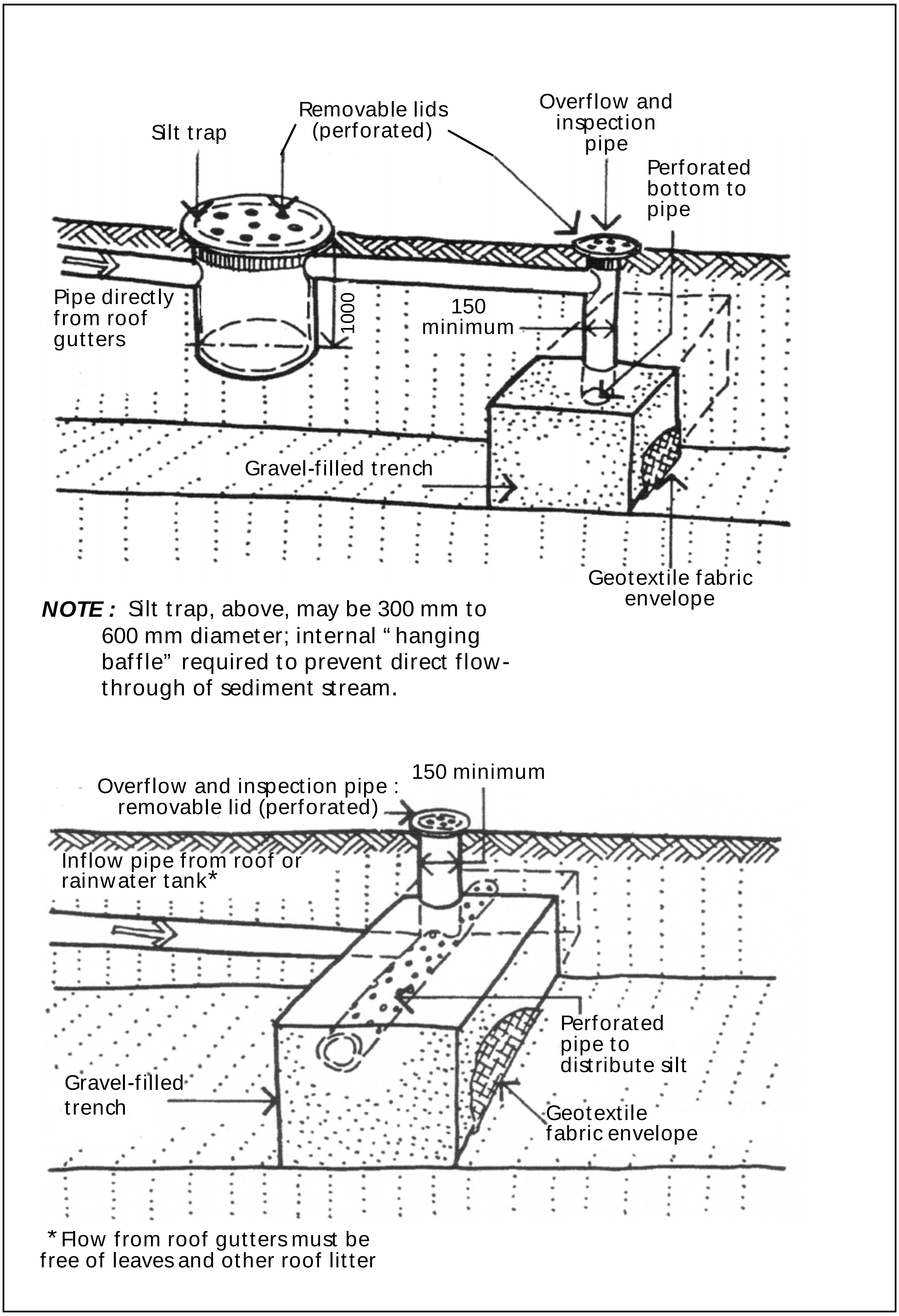


FIGURE 1.5 : Details of sediment management systems for roof (only) flows to gravel-filled trenches

Storm runoff from roofs, cleared of leaves and any other roof litter, may be passed into a rainwater tank(s) and the overflow piped directly to an in-ground device(s) of the type described above (Figures 1.3 or 1.4). Alternatively, roof runoff, cleared of roof litter and other gross pollutants may be passed **directly** to a "leaky" device, provided the entry details sketched in Figure 1.5 are observed. Some municipal and government housing agencies object to combined inspection/overflow pipes of the types illustrated in Figures 1.4 and 1.5 on two grounds :

- these elements may be responsible for perpetual 'damp spots' adjacent the overflows, and,
- these access points are vulnerable to environmental vandalism through the disposal of toxic (liquid) waste, for example sump oil.

The concern which forms the basis of the first objection can be largely dismissed but is reviewed in relation to four "soakaway" installations in Western Sydney in Section 5.5. However, the latter problem is particularly serious where direct access to aquifers is possible (as in Figure 1.4a). Where these valid concerns are felt, then appropriate action needs to be taken, such as locating devices in secure areas or incorporating the more formal overflows illustrated in Figure 1.3. This leads to the vital issue of sediment generation in urban catchments.

The most intensive investigation of the performance of infiltration facilities ever reported in the literature is the landmark study conducted in Maryland, U.S.A., in the late 1980s. The investigation followed legislative action by the State of Maryland requiring stormwater to be retained ('source control') on all developments and re-developments. The devices used to meet the requirements ranged from "leaky" wells to porous paving. Early indications of some poorly performing installations were followed by two surveys of randomly selected sites taken in the first six years of operation of the regulations. Some 200 devices/ installations were sampled: the results showed **failure** rates ranging from 40% for "leaky" wells to 85% for porous paving. Sedimentation of facilities was reported as the most frequent cause (Pensyl and Clement, 1987; Lindsay et al, 1991).

Recognition of sedimentation and its potential for damage to WSUD installations is, undoubtedly, a first step in avoiding the mistakes revealed by the Maryland study. Australian practitioners have N.S.W. Department of Housing (1998) to thank for its excellent Handbook "Managing urban stormwater : soils and construction (3rd Edition)", which includes procedures for calculating expected sediment loads for a wide range of field conditions (climate, soils, terrain, etc.) and practices for controlling sediment. The focus of the document is clearly on the construction phase of development/re-development.

The following data, based on North American literature (Wolman and Schick, 1962; Marsalek, 1992), are offered, not as a substitute for the N.S.W. Housing information, but simply to briefly convey the scale of the problem.

- **Atmospheric sediment :** The amount of sediment which can be expected to precipitate from the atmosphere onto the land surface in an urban catchment is at least 20 tonnes per km^2 per annum. This translates into 2 kg per annum per 100 m^2 of roof area;
- **Sediment supply from a fully-established suburb :** This ranges from 10 m^3 per km^2 per annum to 50 m^3 per km^2 per annum. The lower end of the range applies to high quality neighbourhoods where strategic action is taken to control sediment; the upper limit applies to neighbourhoods where no sediment control strategy is in place.
- **Sediment supply from suburb during construction phase :** This ranges from 7,000 m^3 per km^2 per annum to 20,000 m^3 per km^2 per annum. The observed sedimentation rate for small sites is even higher, and corresponds to 25 – 45 m^3 per 'quarter-acre' block (1,000 m^2) per annum. It follows that some 5 – 10 m^3 of sediment can be expected to enter neighbourhood drainage paths from each developed/re-developed 'quarter-acre' building site during construction.

This information shows quite close agreement with results calculated using the N.S.W. Housing RUSLE model (construction sites) : the model does not address the problem of sediment supply from fully-established suburbs. It may be concluded that a neighbourhood facility designed for sediment storage over a 50-year, fully-established 'lifespan', is likely to fill well before the construction phase of the sub-division is completed (Argue, 2000).

These considerations lead to the following advice relating to the storage of surface runoff from any (surface) paved areas :

Storm runoff from paved areas including courtyards, walkways, driveways, carriageways, car parks, etc. **should under no circumstances be passed directly to devices of the types illustrated in Figures 1.3 or 1.4.** Such runoff, where it originates on relatively small areas, must be prepared for entry by passing it slowly (‘creeping flow’) across at least six metres of grass (Bren et al, 1997) or through a gravel/sand or sand/loam filter at least 100 mm thick and covered with grass or suitable ground cover (see St. Elizabeth Church Car Park, Section 3.9). Surface runoff from urban components such as car parks or suburban-scale areas should be passed through, perhaps, a succession of devices/systems called a **treatment train** before it is suitable for entry into aquifers, urban waterways (freshwater or marine) or rivers (see Sections 2.9.3 and Parfitt Square, Section 3.9).

The problem of ‘construction phase’ versus ‘fully-established phase’ in terms of sediment supply and control should be recognised and suitable provision made. This may lead to a two-phase approach, the first involving sediment being stored and, possibly, regularly removed during the construction process. The second phase is that of long-term management of sediment over the development’s well-established lifespan.

Reference should be made here to the variety of techniques described in Chapter 2 of this document or other guideline publications, e.g. Whelans et al, 1994; CSIRO, 1999; and the N.S.W. “blue book” (N.S.W. Dept. of Housing, 1998 and later editions), IEAust (2003).

1.3.4 Soils : permeability and water-reactivity

The soil types and surface geological conditions present in most landscapes range from aeolian soils (dune sands) in coastal zones, alluvial soils and sandy clays in stream outwash areas to, generally, medium clays and heavy clays. (There are also many areas where soils of various types provide shallow cover over rock.) The hydraulic conductivities of these soils range from around 5×10^{-4} m/s (dune sands) to 1×10^{-8} m/s (heavy clays). There are also “constructed soils” whose permeabilities may range from that of sand to values smaller than 1×10^{-8} m/s. The influence which soil permeability has on the type of on-site stormwater retention practice employed is profound :

Deep, confined or unconfined sands (homogeneous) : These sands are capable of accepting, via suitably designed devices, all roof runoff generated in small-moderate storms without overflow. Hydraulic conductivities range upwards from a minimum of 5×10^{-5} m/s. Installations constructed in these soils should recognise seepage during storms in their design, which may take the forms illustrated in Figures 1.3 and 1.5. The phenomenon of soil “heave” is not observed in unconfined sandy soils so water-retaining devices can be placed as close as 1.0 m from footings and property boundaries; a clearance of 2.0 m should be incorporated where sand is associated with a mantle of sandy clay. Infiltration or ‘dry’ ponds are well-suited to sandy soils.

Sandy clays (homogeneous) : The hydraulic conductivity of these soils ranges from 1×10^{-5} to 5×10^{-5} m/s; seepage “loss” from installations during storms is small but should, nevertheless, be taken into account in design. Devices used for on-site retention of stormwater in sandy clay soils can be of the types illustrated in Figures 1.3 and 1.5, where the soil mass is deep and homogeneous. In situations where the sandy clay covers a useable aquifer, installations of the types illustrated in Figures 1.4a may be used. Some “heave” may be expected in these soils: in-ground devices should show clearances to footings and property boundaries of not less than 2.0 m. Infiltration or ‘dry’ ponds are well-suited to sandy soils.

Medium clay soils (homogeneous) : The range of hydraulic conductivity values exhibited by these soils is 1×10^{-6} to 1×10^{-5} m/s. Seepage loss from installations during storms is therefore likely to be very small so that in-ground devices need to provide storage for almost the full design runoff volume, without overflow: trench-shaped installations are appropriate for these soils. Significant soil “heave” is characteristic of these clays: devices retaining water in these soils should therefore be placed at least 4.0 m from building footings and property boundaries. Installations of the types illustrated in Figures 1.3 and 1.5 may be used where the soil mass is deep and homogeneous. In situations where the clay covers a useable aquifer, installations of the types illustrated in Figure 1.4a may be used. Infiltration or ‘dry’ ponds constructed in these soils are not effective unless provided with a “soakaway” sub-structure.

Heavy clay soils (homogeneous) : These soils show hydraulic conductivity values in the range 1×10^{-8} to 1×10^{-6} m/s. Seepage "loss" from installations during storms is insignificant. Although success can be achieved using simple systems of the types illustrated in Figure 1.3, the most suitable shape is that of the "soakaway", i.e. a shallow mattress with large plan area (see Figure 1.4b). Trenches constructed in these soils tend to have long emptying times (20 days or more); acceptable emptying times – one, two or three days – following moderate-large storms can often be achieved with some form of slow drainage. This may take the form of that provided by aquifer access or, in hilly terrain, a small diameter connection to a local stormwater main or to an urban waterway (see Figure 1.4b and Procedures 4A and 4B, Chapter 5). Soil "heave" similar in magnitude or greater than that observed in medium clay soils can be expected in these soils : clearance distances to footings and boundaries should therefore be not less than 5.0 m. Infiltration or 'dry' ponds constructed in these soils are not effective unless provided with a "soakaway" sub-structure possibly, also, with 'slow-drainage' assistance (see Procedure 4, Chapter 5).

Non-homogeneity : The properties, recommendations and guidelines set out above for the various naturally-occurring soil masses – sands to heavy clays – are all qualified as "…deep and homogeneous...". The inconsistency of soils is well recognised in the literature of soil mechanics, in particular, differences in the permeability of a soil in the vertical and horizontal directions. Practitioners should be aware of such variability and seek advice from a geotechnical specialist as to how such soil conditions at the site of a project might affect detailed design.

Another aspect of non-homogeneity of soil at a site arises from the presence of sand/loam backfilling of service trenches for sewage and stormwater pipes, landlines, cabling, etc. Potential damage to footings as a consequence of these components creating unexpected pathways for retained water should be carefully considered and appropriate preventative action taken.

Constructed clay soils : There is a further class of soils encountered in stormwater management practice – those laid down according to specifications meeting the requirements of engineering design. These range from deep-filling of previously excavated sites to mantles constructed over landfill. Typical requirements call for heavy clay in layers 150 mm thick at optimum moisture content and rolled. The hydraulic conductivity of the resulting soil matrix is likely to fall within the range 1×10^{-10} to 1×10^{-8} m/s. These soils are virtually impervious; "soakaway" installations are preferred, or on-site retention devices of the types illustrated in Figures 1.3 and 1.5, but acceptable emptying – one, two or three days – following moderate-large storms requires some form of low-level drainage. This may take the form of that provided by aquifer access or, in hilly terrain, a small diameter connection to a local stormwater main or to an urban waterway (see Figure 1.4 and Procedures 4A and 4B, Chapter 5). Except where the engineering properties of such soil masses are known to be non-reactive, constructed soils may be expected to exhibit "heave": clearance distances to footings and boundaries should therefore be not less than 5.0 m.

Sites with rock or shallow soil cover over rock : It has long been held that the presence of rock at a site precludes the use of techniques involving the retention and subsequent disposal, on site, of storm runoff. While this still holds true for site conditions where the rock is completely or nearly impervious, such as unweathered basalt, granite or shale, recent research has discovered rock cases – in particular, sandstone – which show similar permeabilities to "medium clay", i.e. hydraulic conductivity values in the range 1×10^{-6} m/s to 1×10^{-5} m/s, and therefore suitable for OSR technology. The first reported results indicating this outcome were obtained in Adelaide, South Australia (van der Werf et al, 1999); these have been confirmed in tests conducted in Parramatta and Hornsby, NSW, (Argue, 2001). The presence of rock renders the possibility of footings disturbance most unlikely, however, the potential for "heave" to occur in the clay mantle, where this is present, should be recognised and a clearance distance of 2 m would seem to be a wise precaution in these circumstances.

Water-reactivity and 'clearance' : The clearance distances recommended above are a direct consequence of the potential for damage to footings, particularly domestic foundations, posed by soil "heave" (or swelling) near water-retaining devices draining "naturally", i.e. without hydraulic assistance of the types illustrated in Figure 1.4. The recommendations are based on observations made at field installations in Adelaide, South Australia. These show maximum "heave" of 30 mm, approximately 2 m from the edges of devices constructed in the most water-reactive soils : swelling decreases to near zero at the extremity of the stated clearance distance.

A feasible alternative to observing clearance requirements is to ensure that OSR devices located in soils with high "heave" potential are designed to empty rapidly. It is inconceivable for the soil surrounding a gravel-filled trench, for example, to develop its full swelling potential if the device is "dry" one, two or even three days after filling. Figure 1.4 illustrates ways in which accelerated emptying can be achieved to take advantage of this phenomenon : Procedures 4A and 4B (Chapter 5) provide the design approach needed to meet this objective. With 'accelerated' emptying in place, it is suggested that devices could be located at, say, **half** the recommended distances from footings and property boundaries given above. In cases where even the modest seepage outflow into the parent soil that this suggestion entails is unacceptable, then the flood management benefits of OSR practice can still be realised through use of *extended detention*, as explained in Section 5.1.5. A storage device with impermeable boundaries and a **slow drainage** outlet would be needed.

Soils : a final word : The OSR devices of interest introduced in Section 1.3.3, namely "leaky" wells, trenches and "soakaways" of various types can be employed in all soil categories described in Section 1.3.4. However, the manner in which they perform their retention function – either using simple systems (illustrated in Figures 1.3 and 1.5) or through accelerated emptying between successive storms using systems of the types illustrated in Figure 1.4 – represent major concerns for the designer. It suffices at this stage of the Introduction merely to draw to the reader's attention the range of soils for which simple solutions are possible, and those requiring more complex design approaches.

The point of changeover from the former to the latter is set at :

$$\text{hydraulic conductivity, } k_h = 1.0 \times 10^{-6} \text{ m/s.}$$

It will be noted (see above) that this value separates medium clay soils from those described as heavy. Further discussion of the issues raised here, and solutions, are set out in Chapter 5.

1.3.5 Aquifer water quality, potentiometric gradients and use

The qualities of water in Quaternary, Tertiary and fractured rock aquifers vary greatly with useable waters ranging from near tap water standard (less than 1,000 mg/L) to 5,000 mg/L (in Adelaide). [There are, also, groundwaters with salinities ranging up to greater than that of seawater (35,000 mg/L)]. It is recommended that no direct, potable use of these waters be considered in metropolitan areas.

Second quality, direct use of much of these resources is possible in industrial processes, such as cooling, washing-down operations and in toilet flushing, but the ambient salinity of most of it provides limited opportunity for use in long-term irrigation for house gardens. This opportunity can be significantly expanded through recharge using cleansed stormwater : localised mixing to sweeten saline waters, with subsequent retrieval, has the potential to lift the scope for employing this technology to much of these resources.

There are, however, many regions with limited opportunity for application of aquifer storage/recovery (ASR) technology : in these regions, natural waters are either far too saline to achieve irrigation-standard quality through mixing, or their potentiometric gradients are too steep. ASR technology may still be employed in the former of these cases, however, where a salt-tolerant use of the retrieved water is proposed, e.g. irrigation of special (salt-tolerant) plants and grasses, industrial applications, toilet flushing, etc.

The relationship between cleansed stormwater recharge, mixing and use is further complicated by localised gradients of the potentiometric surface. In locations where gradients are flat and ambient quality is better than 2,000 mg/L, storm runoff injected in the 'wet' season will be recoverable in the 'dry' season, providing potential for use in irrigation. [In Northern Australia (see Figure 3.8), the wet season is summer; the corresponding season in Southern Australia is winter. Dry seasons are winter in Northern Australia and summer in Southern Australia.]. There are other locations which have ambient water quality around 2000 mg/L, but steep potentiometric gradients : it is not possible to retrieve cleansed storm runoff recharged at these sites. This is because water injected in wet periods will have travelled too far downstream before the arrival of the following dry periods.

The above considerations should not be interpreted as meaning that aquifer recharge using stormwater is feasible only at those sites where recovery is advantageous, e.g. in irrigation. One of the main benefits of recharge of Quaternary, Tertiary and fractured rock aquifers using cleansed stormwater is provision of environmental flows in urban creeks and streams. This point is revisited in the Aquifer Recharge/Retrieval Protocol section, below.

1.3.6 Bores : extraction rates and recharge rates

Bore extraction rates vary from less than 0.5 L/s to 4.0 L/s (Quaternary aquifers) or greater per bore (Adelaide experience). These values represent long-duration extraction rates and are conservative when considered for short-term uses such as irrigation and other domestic and industrial/commercial purposes. It is recommended that site tests using an extraction bore and a second bore as observation well, be conducted as part of the exploratory process needed to establish an ASR system.

There is a rule-of-thumb link between extraction and recharge rates advised by Pavelic et al (1992) : the recharge rate is 0.5 times the extraction rate. This, again, is based on long-term performance and may therefore be considered conservative for the short-term periods of recharge likely to occur on most rainy days. Site testing of recharge capability is recommended in the early stages of project feasibility investigation.

1.3.7 Aquifer recharge/retrieval protocol

Broadly, two groundwater regimes in which recharge using cleansed stormwater may take place should be recognised. The first is where potentiometric gradients are ‘flat’ and groundwater movement is very slow (around 20 m per year). The second is where potentiometric gradients are steep and groundwater movement is relatively rapid, e.g. 300 m per annum.

In the regime of flat potentiometric gradients, it is essential that recharge and retrieval of groundwater be balanced on an annual basis : this ensures continued equilibrium of local potentiometric levels and also, sustainability of the resource. South Australian practice in this regard is to limit extractions in ASR schemes to “…not exceeding 80% of the volume artificially recharged…” (Northern Adelaide and Barossa CWMB, 2000). Even with such a management strategy in place, “mounding” of recharge water in unconfined aquifers, particularly where sandy soils are involved, can cause problems with foundations, flooding of cellars, salt damp, and ingress of groundwater into sewers. Severe mounding of highly saline groundwater can lead to surface salinisation – a consequence which must be avoided at all costs (see Section 3.8).

There are many ways in which the balance referred to above can be achieved. In cases of recharge using roof runoff at a large factory site, for example, or stormwater cleansed and collected from a large car park, the quantity involved is likely to justify, on economic grounds, installation of retrieval systems replacing mains water use in irrigation or certain factory processes such as cooling, washing-down, etc.

At the level of the domestic dwelling, such a recharge/retrieval system, while technically possible, is rarely economical. Encouragement of on-site retention of storm runoff in predominantly residential sectors of cities, however, can benefit local Councils who can maintain the required equilibrium of local potentiometric levels by extracting water for irrigation, thereby saving on mains water use.

In locations where potentiometric gradients are steep, usually in foothills or hilly terrain, on-site aquifer storage/recovery **of injected water** cannot be practised because of rapid movement of recharge downstream from injection sites. This does not preclude the use of aquifer-connected bore systems of the types illustrated in Figure 1.4a, but water injected into such systems is most likely to outflow ultimately into local creeks and urban streams. These are certainly not wasted flows : on the contrary, they represent most valuable contributions to achieving one important element of the vision for stormwater management referred to earlier (Section 1.3.1), namely, environmental flows and the return of urban drainage lines and associated fauna and flora to their natural state (see also Section 1.4). Great care needs to be exercised, however, in pursuing the strategy outlined here to ensure that injected flows do not create hazard or nuisance for developments between injection sites and the urban creeks (see Section 3.8).

A form of ASR (aquifer storage/recovery) is possible in locations where potentiometric gradients are steep, but, unlike conventional ASR schemes, the water withdrawn is different from the injected flow. In these cases, ambient aquifer water is extracted – matched in terms of quantity and quality to an appropriate use – and an equivalent (or 20% greater) quantity of cleansed water is injected, on an annual basis, meeting the requirements of the Protocol.

1.3.8 OSR and site capability

The capability of a site to retain stormwater and the constraints which must be observed in applying appropriate retention practices, depend on the site properties reviewed in the previous Sections. Their application to actual situations is illustrated, for the case of Adelaide's Patawalonga Catchment, in Figure 1.6 and for **two** of the zones in Table 1.1.

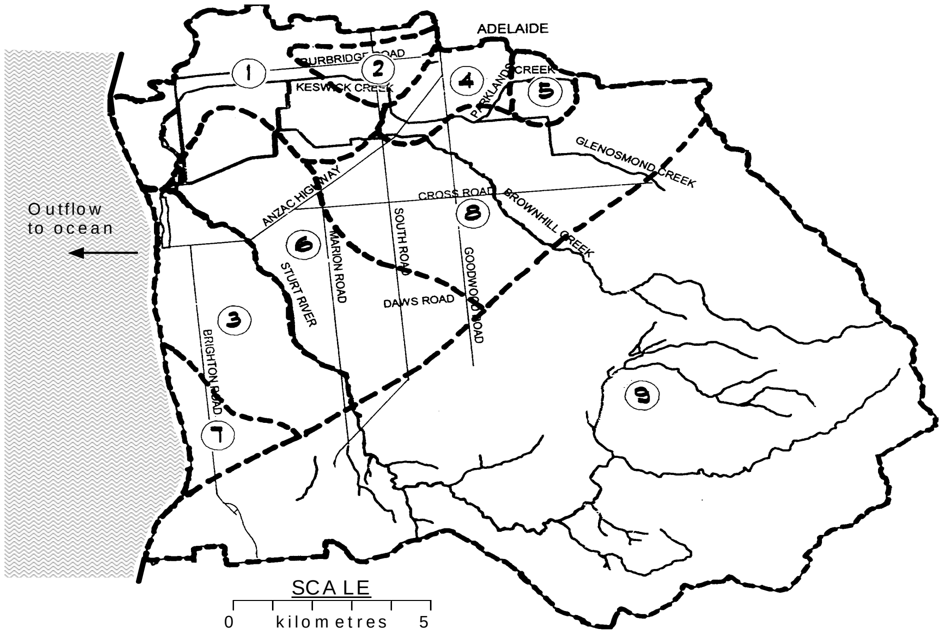


FIGURE 1.6 : Nine stormwater management zones of the Patawalonga Catchment (B C Tonkin, 1996)

TABLE 1.1
PATAWALONGA CATCHMENT ZONE GUIDELINES ON STORMWATER MANAGEMENT

PROPERTY	ZONE 1	-	ZONE 3	-
Soil Type	Alluvial soils, aeolian (dune) sands, some clay	-	Red-brown earths and podzolic soils north of Diagonal Road	-
Soil permeability	Hydraulic Conductivity: 5×10^{-5} m/s	-	Hydraulic Conductivity: 1×10^{-6} m/s, and 1×10^{-5} m/s	-
Clearances	Not less than 1.0 m to footings and boundaries	-	Not less than 4.0 m to footings and boundaries	-
Bores : • Aquifer depths	Mainly 2 – 4 m, some deeper inland	-	Variable: 4.0 m to 10.0 m	-
• Water quality	Variable: salinity 500 – 3,000 mg/L	-	Variable: salinity 1,000 – 3,000 mg/L	-
• Extraction rate	Variable: 0.5 L/s to 4.0 L/s per bore	-	Variable: 0.5 L/s to 4.0 L/s per bore	-
• Recharge rate	Half extraction rate	-	Half extraction rate	-
Stormwater option	Simple devices or devices with bores (Figures 1.3, 1.4 and 1.5) may be used in all zones. See comment below			
Advised use	Variable: irrigation, industrial, toilet flushing, etc., depending on location	-	Variable: irrigation, industrial, toilet flushing, etc., depending on location	-
Recharge/ retrieval protocol	Recharge/retrieval to be balanced on single allotment basis or within local collective system.	-	Recharge/retrieval to be balanced on single allotment basis or within local collective system.	-
Comments	The coastal sector of the zone is unconfined sand; inland sands may be covered by sandy-clay mantle (confined aquifers). Highly saline, deep clay patches should be avoided.	-	Potentiometric gradients, generally, suitable for above practices. Exception is foothills sector at southern extremity of zone where gradients are steep. Direct ASR is not feasible, but annual injection/extraction (80% requirement)* is acceptable option. Devices with bores support environmental flows in local streams.	-

* See Northern Adelaide and Barossa CWMB (2000).

1.4 WSUD – STORMWATER 'SOURCE CONTROL' : THE VISION AND ITS LIMITATIONS

1.4.1 Conventional urbanisation : typical consequences in a natural, coastal catchment

In its wild state, the natural (coastal) catchment is a system of drainage paths, creeks and streams well matched to the rainfall/runoff processes operating in that basin. Generally, less than 20% of storm rainfall is discharged from it as (annual) *surface* runoff. There is a second stream of flow from the natural catchment, that delivered by aquifers into creeks and waterways as 'base flow', long after the causative rainfall event. The *quantity* of discharge involved in this outflow is comparable to that delivered as surface runoff, but its exit into a local receiving domain or to the ocean takes place over a time scale measured, perhaps, in weeks, months, years or even decades (see Figure 1.7).

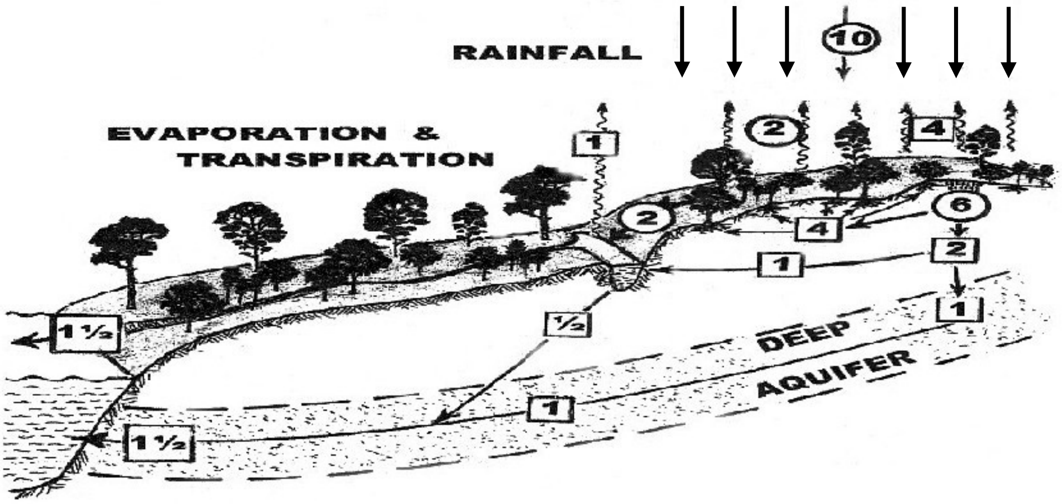


Figure 1.7 : Destiny of 10 units of *annual* rainfall input to a temperate zone, coastal forest catchment (notional values only)

The elements illustrated in Figure 1.7 present a 'notional' account of the fate of 10 units of **a**verage **a**nnual **r**ainfall **i**nput (**AARI,** shown circled) to a coastal forest catchment. The 'first contact' process is that of **interception** (including stemflow), which accounts for some 2 units (shown circled) of AARI: this stored water is temporarily retained before passing from the catchment as evaporation. 2 units (shown circled) become surface runoff passing over the forest floor to enter ponds, small channels and streams. The remaining 6 units (shown circled) are infiltrated into the forest floor where two-thirds of it - 4 units (shown 'boxed') - is intercepted by tree roots and transpires; the 2 units (shown 'boxed') **not** taken up by tree roots is divided evenly between seepage to streams and lakes (1 unit, 'boxed') and percolation to deep aquifers (1 unit, 'boxed'). H**alf** of the surface runoff originating on the forest floor i.e. 1 unit, 'boxed', evaporates in streams, ponds and lakes. A half unit ('boxed') of seepage passes from ponds and forest streams into the deep aquifer where it joins the aquifer stream – total 1½ units ('boxed') discharged to the a local receiving domain or the ocean. Surface runoff flow to the ocean also equals 1½ units ('boxed').

There are **two** sets of conditions that determine the 'nature' of a natural catchment waterway in terms of *cross section shape* and *ecosystem regime*, and **one** (set) which is responsible for delivering *effluent water quality*. These are, respectively :

natural stream <u>morphology</u>: the drainage paths of any forest basin have evolved over eons to establish waterway **shapes** which reflect, individually, their catchment area/shape and terrain (bed slope, soil, vegetation, etc) and their response to regional climate. The flow which exerts greatest influence on establishing waterway dimensions is that of **'bankfull' flow** or some variant of it (Gippel, 2002; Doyle et al, 2007);

catchment average annual <u>yield</u>: this parameter, considered for any particular stream, is influenced by the same properties as determine stream *morphology* – area/shape of catchment, terrain and climate – and also the catchment's response to frequent storm inputs – the **'low flow'** regime. The characteristics of this regime determine the stream's ecological state (Smakhtin, 2001; Lee et al, 2007);

effluent <u>water quality</u>: the primeval forest catchment provides home territory to a wide range of indigenous fauna and flora – including human – as well as temporary accommodation for migratory species. All of these elements lose 'body products' of one type or another – faeces, body fluids, feathers, skin, leaves, bark, branches etc – and, with death, experience decay. The catchment manages this pollution load using a wide range of natural 'treatment train' processes. Furthermore, the quality of effluent that results, while not pristine, nevertheless represents a level that contemporary best practice is ready to accept as the **benchmark for receiving waters** (Millis, 2003).

The scenario described here is represented in Figure 1.8a with a main stream providing capacity through its flood plain for the conveyance of all (surface) flood flows and base flows, as well as support for stream-associated indigenous fauna and flora in a plethora of biotic communities and riverine environments. The (natural) catchment exhibits a number of processes, apart from surface runoff and aquifer outflow recognised by the hydrologist – interception, detention, evaporation, transpiration, infiltration, percolation, soil moisture illustrated in Figure 1.7 – all of which can be sub-summed under the broad heading of storage/loss within the catchment or **retention** (of incident rainfall).

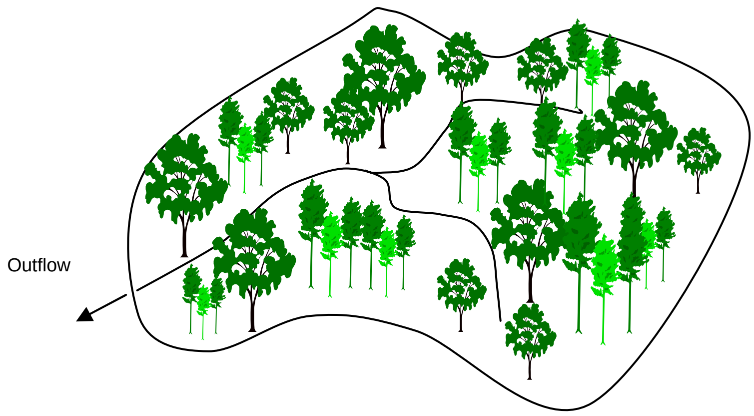
A further, important characteristic of natural catchments and one intimately linked with retention, is that of response or **'lag' time** which is the delay evident between the period of rainfall input and the appearance of a portion of it as a surface runoff *flood wave* at the point of catchment discharge. This is a direct consequence of the surface-retardation/loss processes listed above – interception and detention in particular – which results in delayed passage of water flow through the catchment media of trees, understorey, forest floor humus, natural obstacles, surface depressions, etc. A high proportion of incident rainfall is retained in the catchment initially as soil moisture: the ultimate destiny of this component (of incident rainfall) can be take-up by forest vegetation roots leading to transpiration, or alternatively, deep percolation into aquifer strata and, hence, base flow supply to local streams (see Figure 1.7).

The first impact of development upon such a balanced system is usually the clearing of land for agriculture. This leads to change in the type of vegetation cover, e.g. from forest to grassland or crop, leading to slightly increased flood peak flows with attendant increased scour and erosion. Pollution loads – fertilisers, pesticides, etc. – originating in the catchment and carried in streams may be high depending on the type of agricultural activity involved (Lloyd et al, 2004).

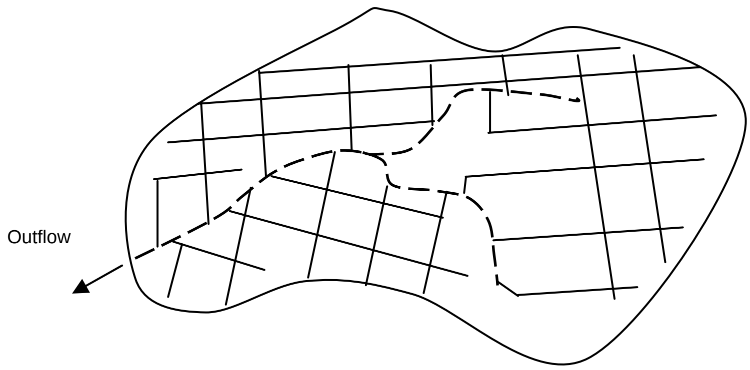
In the next phase of development – the conversion of agricultural land to low density urban landscape – a significant portion of the land is covered by impervious surface integral with the street drainage network and formal drainage channels. Some natural streams or portions of original waterways may be preserved in this stage of development. Greater surface runoff than observed in the pre-development catchment is characteristic of such catchments: this is universally recognised. What is often less appreciated is the effect that the presence of connected paved area has on catchment 'lag' time, referred to above. These two impacts – paved surfacing and *reduced* 'lag' time – account for, between them, the significant increases noted in flood runoff peaks compared to pre-development levels of (surface) outflow.

In what can be recognised as a further stage of urbanisation – 'over-development' **-** typically between 40% and 70% or more of the entire catchment is covered by roofs/paving or other relatively impervious surfaces, and runoff is conveyed rapidly by stormwater pipes and channels from points of origin in the catchment to its main stream(s). The natural creek branches are modified – straightened – and their original alignments used as the basis for a string of concrete pipes and channels, often contained within narrow municipal drainage easements (in some Australian jurisdictions, even this appreciation of the flood plain is absent) and development allowed to encroach, frequently, right to the boundaries of these easements. This process has two well-recognised consequences :

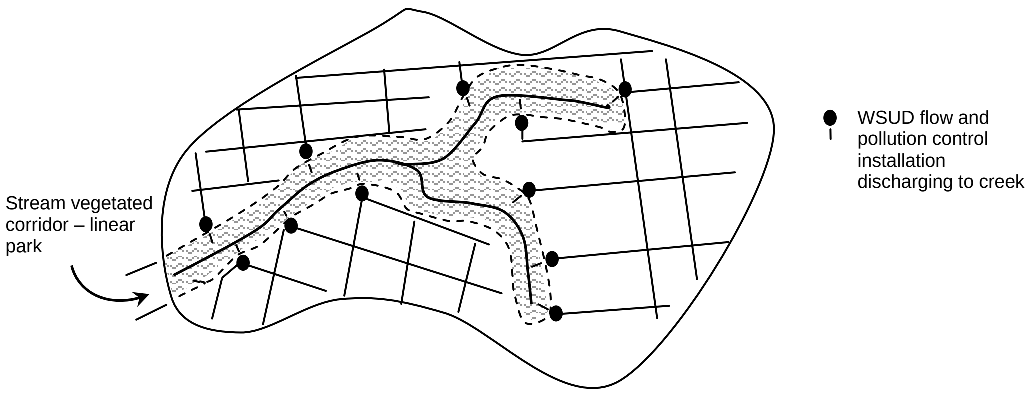
- greater surface runoff generated than occurred in the original, natural catchment; and,
- greatly reduced response (or 'lag') time, compared with that of the original catchment.



(a) Natural or substantially natural catchment



(b) Fully developed catchment with 'hard' flow paths and drainage lines



(c) Developed catchment with natural stream: WSUD in action

FIGURE 1.8 : Three stream scenarios as development proceeds in a natural catchment

In the case of over-developed catchments, riparian property owners in the valley "bottom lands" are likely to experience frequent inundation by floodwaters carrying high silt loads and high levels of coliform, phosphorous, nitrogen, heavy metals and petroleum hydrocarbons. Furthermore, because of rapid removal of stormwater from the urban landscape and consequent limited infiltration occurring during runoff events, supplementary irrigation is commonly undertaken to compensate for low soil moisture levels. Any remaining portions of natural streams and waterways of the valley may dry up completely during the low rainfall months (Southern and Central Australia) and members of their (stream) biotic communities which require year-round flow for their survival may vanish (after Argue, 1986; see King, 2003). This scenario is represented in Figure 1.8b.

1.4.2 WSUD: planning for urbanisation in a natural or predominantly natural catchment

Where the opportunity presents itself to plan the course of urbanisation in an undeveloped or partly-developed catchment, perhaps on the outskirts of a metropolis, then WSUD techniques can be employed to manage storm runoff in a truly water-sensitive manner. The primary principle upon which such planning must be based is for :

> Stormwater generated on each site in the developed catchment – *above that occurring on the same site in the natural catchment* – to be fully **retained** for at least the duration of the **lag time** determined for the natural catchment. [This is referred to as the **regime-in-balance** strategy in later text, Section 4.2; *lag time* is the delay evident between the period of *excess* rainfall input to a catchment and its appearance as a surface runoff flood wave at the point of catchment discharge.]

The presence of pollutants of various types in the urban landscape – sediment, phosphorous, nitrogen, hydrocarbon – of course, must also be taken into account in the planning process, but the requirements of this aspect can be integrated into on-site stormwater management practices and/or into 'final filter' installations discharging to the urban streams.

Stormwater 'source control' retention may be provided by :

- Roof gardens, 'green' roofs and roof water (raintanks or similar) storages.
- Surface infiltration at permeable surfaces including porous/permeable paving.
- Storage/percolation in "leaky" underground devices.
- Above-ground or underground storages or "leaky" devices with aquifer access and no recovery of water entering aquifers.
- Above-ground or underground storages or "leaky" devices with slow-drainage disposal (typically, 24 hours or longer emptying) to the stormwater drainage path or to a local waterway.
- ASR schemes providing recovered water available for various surface uses.

Application of this approach is illustrated in Figure 1.8c : it manifests itself in a developed catchment whose hydrological behaviour, in terms of surface runoff and underground seepage/aquifer processes, resembles that of the original basin or sub-catchment in its undeveloped state. It follows that the central drainage paths – where these processes have been applied – can exhibit not only hydraulic and hydrological similarity to the original waterways, but also, similarity of ecosystem behaviour – vegetation and habitats.

Some overseas practices, notably those of North America (Stephens et al, 2002; Gilliard, 2004) and UK (CIRIA, 2001), attempt to reproduce in their sensitively designed urban catchments the same runoff hydrographs as observed in or attributed to the original (natural) catchments, in *all incident storms – small, medium and large.* The quest for this goal introduces yet another parameter of importance, that of storm magnitude linked to a flood wave frequency indicator – "once in 2 years", "once in 10 years", "once in 100 years", etc., called **average recurrence interval or ARI**. Success in achieving true hydrograph correspondence between the natural and developed catchments through the full range of ARIs is certainly an ideal and worthy objective, but one whose attainment in real world circumstances must be viewed with scepticism.

A practical compromise on this issue which delivers an 'acceptable' rather than ideal outcome is to base similarity of natural and developed catchment surface runoff performance on the selection of a 'representative' or *design storm* which combines the 'lag' time derived for the natural catchment with an adopted ARI of 'median' proportions – for example, "once in 5 years", "once in 10 years", "once in 20 years", etc.

It follows that 'enlightened', WSUD development can be achieved in a natural catchment provided there is :

- **retention** of all (surface) runoff *above that occurring in the (previously) natural catchment*;
- maintenance of the **same 'lag' time** estimated for the natural catchment;

- recognition of the need for pollution control installations 'at-source' and/or at waterway entry points, and,
- an appropriate **ARI** adopted leading to 'acceptable' runoff similarity (natural/developed catchments).

Realisation of these characteristics in the engineering of developed catchment infrastructure has the potential to deliver urbanisation outcomes that preserve natural waterway drainage paths along with their associated riverine and terrestrial environments and habitats in a practically sustainable manner. The second and fourth items in the above list, combined, form the basis of the **critical design storm** (see Section 4.2.3).

A major problem which the planner/designer must face in implementing schemes resulting from the above considerations, is that of sediment control during the construction phase of development. As explained in Section 1.3.3, it is possible – without due care – for a suburban water-sensitive installation designed for, say, 50 years service in 'fully-established' mode, to be filled with sediment before the construction operation has been completed (Argue, 2000). A two-phase solution to this problem may be called for : sediment storage/removal during and upon completion of construction, followed by long-term sediment management during the operating life of the development.

1.4.3 Retrofitting WSUD practices into an over-developed urban catchment

Opportunities for carrying out the type of development described in Section 1.4.2 are not the most common experience. It is more usual for a high level of urban development to have occurred, possibly to the extent referred to in Section 1.1, that is, serious flooding of catchment 'bottom lands' as well as pollution loads having significant impacts on downstream urban creeks and waterways including estuaries and marine foreshores. It is in these circumstances that WSUD practice (stormwater 'source control') meets its greatest opportunities and challenges.

The task of remediating an over-developed catchment calls for a two-step approach :

STEP 1 : Apply practices throughout the landscape aimed at **retaining** *as much surface runoff as possible* from every element of development or re-development taking place in the catchment; this process should be integrated with a strategy to incorporate pollution control installations within all modified sites and/or at points of discharge to urban waterways; and,

STEP 2 : restore the natural drainage path, as closely as practicable, to its pre-development state.

The process of **retention** (STEP 1) in the present case differs significantly from its counterpart in the natural catchment development process outlined above. Here, it is not sufficient to retain only the storm runoff **excess** (above that of the natural catchment) on a *site-by-site basis*, because development/re-development of sites occurs only on an opportunistic rather than 'planned' basis. It is therefore imperative that as much surface runoff as practicable be retained (for, at least, the duration of the critical design storm) in every development/re-development situation that arises in order to 'make up' for the numerous sites where no remedial action *in the short term* is likely. [This is referred to in later text as the **yield-minimum** strategy, Section 4.2.]

The greatest difficulty encountered by the practitioner attempting to implement this approach relates to established roadways. Techniques exist which can, given total community commitment, lead to retention measures being retrofitted into other urban classifications – residential (individual dwellings, housing clusters, high-rise apartment blocks), industrial sites, commercial/sporting complexes, etc. – as required by 'enlightened' re-development. However, retrofitting retention technology into an established roadway – short of complete or substantial reconstruction using permeable paving – presents, usually, insurmountable difficulties (including cost).

There are other components of the urban form in addition to roadways which may present similar difficulties, for example, sealed car park areas, multi-storey car parks, commercial/industrial estates, etc, where opportunities to modify existing building layouts to incorporate required stormwater retaining installations are severely limited. Or the cost of installations, were they to be constructed, may be prohibitive.

In circumstances such as these, it is possible to achieve the overall objectives of WSUD (stormwater ‘source control’), by a combination of **full retention** (retention of *all* surface runoff) in those components where this is possible, and **limited** retention in others. The process by which STEP 1 is implemented in an over-developed catchment has much the same basic profile as its earlier counterpart, and is :

- **retain** *as much (surface) runoff as possible* at each development/re-development site;
- employ (in design) the same catchment-wide **‘lag’ time** determined for the original catchment;
- recognise the need for pollution control installations ‘at-source’ and/or at waterway entry points, and,
- adopt an appropriate flood **ARI** for the catchment reflecting the consensus interests of its stakeholders.

The case for remediating an over-developed catchment through application of these actions as a first step, together with continuation of the process to embrace STEP 2 (restoration of the natural drainage path), requires high levels of commitment, patience and funding which should not be underestimated by any community setting out to “correct the errors of the past” (see Chandler, 2001). The ultimate outcome of such commitment is transformation of the catchment – illustrated in Figure 1.8b – towards the situation depicted in Figure 1.8c.

1.4.4 The problem of ‘oversizing’

It is tempting to interpret the suggestion made in Section 1.4.3 as meaning that ‘catch up’ retention capacity – by installing **above-full** retention – can be incorporated into all new developments/re-developments, allowing past failure (to install adequate retention capacity) to be corrected rapidly and progressively as development proceeds. Such **oversizing**, that is, the provision of greater capacity than called for at individual installations, must be avoided : **no greater capacity than that required to store all runoff generated at a site in the *critical design storm* (see Section 1.4.2) should be provided.**

A strategy based on correctly-sized installations, applied consistently to all new development/re-development cases in an overdeveloped catchment can, in time, deliver the ultimate overall goal, namely, runoff (volume) in the design storm event equal to that generated in the catchment before development – the **regime-in-balance** strategy referred to in Section 1.4.2. Catchment managers need to be patient, however, as steady progress is made towards this goal and not use ‘oversizing’ to achieve it in a compressed time scale.

1.4.5 WSUD – stormwater ‘source control’ : the limitations

It will be apparent from all that has been discussed in the course of Chapter 1, that stormwater ‘source control’ installations can be divided, broadly, into two main groups :

- above-ground or in-ground sealed systems; and,
- in-ground, including at-surface, “leaky” devices.

Opportunities for using the former are virtually inexhaustible and include rooftop rainwater storages, roof gardens, “green” roofs, enlarged gutter (eave) rainwater collectors, above-ground rainwater tanks and in-ground, sealed rainwater tanks. However, limitations must be recognised with certain classes of in-ground, “leaky” systems whose presence in unsuitable locations can lead to damage of buildings, in particular, domestic footings set in water-reactive soils, and situations where percolation from “leaky” systems will exacerbate problems associated with high or potentially rising groundwater. Problems of particular severity can arise where, in the latter case, the groundwater is highly saline. A more extensive discussion of such limitations may be found in Section 3.8.

Any review of limitations to the use of in-ground “leaky” retention practices must address the issue of soil permeability : it is widely held that locations where the permeabilities of soils are low to very low must be precluded from retention technology. Certainly, simple systems draining naturally (see Figure 1.3) cannot be successfully employed in such circumstances. But the techniques illustrated in Figure 1.4 open the way for on-site stormwater retention/detention – with, perhaps, 24-hour or longer emptying time incorporated into the design – in virtually the entire range of soil environments.

2. DEVICES AND SYSTEMS USED IN STORMWATER MANAGEMENT

2.1 INTRODUCTION AND DIRECTORY

This Chapter provides brief descriptions of a number of devices, systems and facilities used primarily in stormwater quality management : it is not comprehensive but intended, mainly, as an introduction to the field. There are numerous well-recognised publications in the pollution control domain, some produced in Australia, which describe various systems in great depth (e.g. Schueler et al, 1987; Ferguson, 1994; Debo and Reese, 2003; NSW EPA, 1999; CSIRO, 1999; CIRIA, 2001; Ontario Ministry of the Environment, 2003, France, 2003; Engineers Australia, 2005; Melbourne Water, 2005; Dept of Water WA, 2007). Practitioners requiring detailed information should consult these more comprehensive sources as well as information on commercially available devices and products obtainable from manufacturers' brochures and industry websites.

a. Selection **b. Hydrological design** **c. Other design and option issues**

2.2 ROOF SYSTEMS

2.3 "LEAKY" WELLS AND INFILTRATION TRENCHES (see Chapter 5)

2.4 FILTER STRIPS

2.5 POROUS AND PERMEABLE PAVEMENTS

2.5.1 Porous pavements

2.5.2 Permeable pavements

2.6 SWALES AND BIO-RETENTION SWALES

2.7 TRASH RACKS, BASKETS AND BOOMS

2.8 CATCH BASINS AND "SOAK PITS"

2.8.1 Catch basins

2.8.2 "Soak pits"

2.9 WATER QUALITY IMPROVEMENT STRUCTURES

2.9.1 Water quality inlets

2.9.2 Oil/grit separators

2.9.3 Fine sediment removal/retention device

2.10 "FIRST FLUSH" TANK – PARTITIONING AND "FIRST FLUSH" STORMWATER RUNOFF

2.11 INFILTRATION BASINS

2.12 EXTENDED DETENTION BASINS

2.13 WET DETENTION BASINS

2.14 CONSTRUCTED WETLANDS

[These sections omitted from the 2-Day Workshop Edition]