Australian Rainfall & Runoff

Revision Projects

PROJECT 11

Blockage of Hydraulic Structures

P11/S1/007

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Australian Government

ENGINEERS AUSTRALIA
Water Engineering

AUSTRALIAN RAINFALL AND RUNOFF
REVISON PROJECT 11: BLOCKAGE OF HYDRAULIC STRUCTURES

STAGE 1 REPORT

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FOREWORD

AR&R Revision Process

Since its first publication in 1958, Australian Rainfall and Runoff (AR&R) has remained one of the most influential and widely used guidelines published by Engineers Australia (EA). The current edition, published in 1987, retained the same level of national and international acclaim as its predecessors.

With nationwide applicability, balancing the varied climates of Australia, the information and the approaches presented in Australian Rainfall and Runoff are essential for policy decisions and projects involving:

- infrastructure such as roads, rail, airports, bridges, dams, stormwater and sewer systems;
- town planning;
- mining;
- developing flood management plans for urban and rural communities;
- flood warnings and flood emergency management;
- operation of regulated river systems; and
- estimation of extreme flood levels.

However, many of the practices recommended in the 1987 edition of AR&R are now becoming outdated, no longer representing the accepted views of professionals, both in terms of technique and approach to water management. This fact, coupled with greater understanding of climate and climatic influences makes the securing of current and complete rainfall and streamflow data and expansion of focus from flood events to the full spectrum of flows and rainfall events, crucial to maintaining an adequate knowledge of the processes that govern Australian rainfall and streamflow in the broadest sense, allowing better management, policy and planning decisions to be made.

One of the major responsibilities of the National Committee on Water Engineering of Engineers Australia is the periodic revision of AR&R. A recent and significant development has been that the revision of AR&R has been identified as a priority in the Council of Australian Governments endorsed National Adaptation Framework for Climate Change.

The Federal Department of Climate Change announced in June 2008 $2 million of funding to assist in updating Australian Rainfall and Runoff (AR&R). The update will be completed in three stages over four years with current funding for the first stage. Further funding is still required for Stages 2 and 3. Twenty one revision projects will be undertaken with the aim of filling knowledge gaps. The 21 projects are to be undertaken over four years with ten projects commencing in Stage 1. The outcomes of the projects will assist the AR&R editorial team compiling and writing of the chapters of AR&R. Steering and Technical Committees have been established to assist the AR&R editorial team in guiding the projects to achieve desired outcomes.

Project 11: Blockage of Hydraulic Structures

There is considerable debate at present regarding appropriate advice on design blockages that should be assumed for various hydraulic structures in urban drainage systems. While a number of studies were undertaken in the Wollongong area in response to the widespread blockage of hydraulic structures during the 1998 flood that have developed criteria for the assessment of blockage for new hydraulic structures, these studies only relate to catchments whose characteristics are similar to those in the Wollongong area. Hence, there is a need to extend these previous studies and to extend their suitability so that appropriate guidance on design blockage for hydraulic structures can be developed for Australia.

For the purposes of this project, the term hydraulic structures refers to culverts and small bridges over drainage channels (rather than major bridge structures) and to inlet structures (i.e. pits) to urban drainage systems.

The aim of Project 11 is to provide design guidance on the blockage of structures during flood events. It is intended that these guidelines will incorporate the uncertainty associated with blockage so that appropriate risk management practices can be applied by users.

Mark Babister
Chair National Committee on Water Engineering

Dr James Ball
AR&R Editor

AR&R REVISION PROJECTS

The 21 AR&R revision projects are listed below :

ARR Project No.	Project Title	Starting Stage
1	Development of intensity-frequency-duration information across Australia	1
2	Spatial patterns of rainfall	2
3	Temporal pattern of rainfall	2
4	Continuous rainfall sequences at a point	1
5	Regional flood methods	1
6	Loss models for catchment simulation	2
7	Baseflow for catchment simulation	1
8	Use of continuous simulation for design flow determination	2
9	Urban drainage system hydraulics	1
10	Appropriate safety criteria for people	1
11	Blockage of hydraulic structures	1
12	Selection of an approach	2
13	Rational Method developments	1
14	Large to extreme floods in urban areas	3
15	Two-dimensional (2D) modelling in urban areas.	1
16	Storm patterns for use in design events	2
17	Channel loss models	2
18	Interaction of coastal processes and severe weather events	1
19	Selection of climate change boundary conditions	3
20	Risk assessment and design life	2
21	IT Delivery and Communication Strategies	2

AR&R Technical Committee:

PROJECT TEAM

Because of the limited research that has been undertaken in this field, and because of the difficulty in collection of actual data on blockage of hydraulic structures, this project was carried out using a panel of people who are experienced in the field and this expertise was combined to provide the basis of this report. It is recognised that there are other relevant experts and input from these people will be welcomed during Stage 2 of the process.

The panel of experts involved in the preparation of this report (who provided their time as inkind) includes the following:

- Bill Weeks, AR&R TC Project Manager, Queensland Department of Main Roads (Brisbane).
- Monique Retallick, WMAwater (Sydney).
- Michael Boyd, University of Wollongong (Wollongong).
- James Ball, AR&R Editor, University of Technology Sydney (Sydney).
- Ted Rigby, Rienco (Wollongong).
- Pas Silveri, Wollongong City Council (Wollongong).
- Anthony Barthelmess, Cardno Forbes Rigby (Wollongong).
- Paul Doherty, Melbourne Water (Melbourne).
- Bill Lipp, Department of Transport, Environment and Infrastructure (Adelaide).
- Grant Witheridge, Catchments & Creeks (Brisbane).
- Alastair Peddie, Newcastle City Council (Newcastle).
- George Kuczera, University of Newcastle (Newcastle).
- Karen Mckenzie, University of Newcastle (Newcastle).
- Geoff O’Loughlin, Anstad (Sydney).
- Bob Adamson, Brisbane City Council (Brisbane).
- Bob Keller, Monash University (Melbourne).

This report was independently reviewed by:

- Tony Ladson, SKM (Melbourne)

BACKGROUND

Blockage of hydraulic structures is an important issue in the design and management of drainage systems. Blockage is produced by a range of different processes and can reduce the capacity of drainage systems by partially or completely closing the drainage structure. Firstly blockage needs to be considered in the planning and design of drainage systems to ensure that the system can perform adequately if (or when) blockage occurs and allowance can be made for this effect when it does occur. Secondly appropriate procedures need to be developed to manage the risk of blockage in existing systems.

In both cases, consideration of different types of drainage systems, different catchment conditions (including differences from one event to another) and different flood conditions need to be considered. Drainage causes considerable damage and disruption and blockage contributes to the worsening of this damage.

This report comprises the deliverable for Stage 1 of the project. This stage outlines the issues involved in the process of blockage and the range of approaches that may be necessary to analyse and manage the process.

The project will continue with Stage 2, which will provide recommended design procedures for the assessment, analysis and management of drainage systems for blockage. Stage 2 will build on the current project following consultation and further investigations.

EXECUTIVE SUMMARY

Blockage in drainage systems can cause significant problems in some situations, increasing water levels, inundating neighbouring properties, overtopping roads or railways, damaging infrastructure and increasing maintenance costs.

Considering the importance of the problem, blockage has not been well studied and is not well documented in existing design guides such as Australian Rainfall & Runoff.

Blockage can be caused by a wide range of materials in waterways, with the issues and consequences varying depending on individual circumstances. Blockage is an issue for structures in both rural and urban catchments, though conditions and consequences may be different for these two catchment types.

Management of blockage needs to consider a number of issues, including causes, impacts, assessment and analysis methods and maintenance approaches.

This report provides the Stage 1 deliverable for the Engineers Australia project to develop guidelines for assessment and analysis of blockage and provides preliminary findings of the project. Following acceptance of this report and further consultation and review, the Stage 2 report will be prepared to provide design guidance and recommendations for the assessment, analysis and management of blockage for drainage systems throughout Australia.

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1. INTRODUCTION

1.1. BACKGROUND

Flooding is one of the most costly of natural disasters in Australia. As our population growth continues, and as we in turn urbanise catchments, we have a need to create structures over watercourses such as bridges and culverts, to enable ease of access over these areas of the floodplain. Urban areas need adequate drainage, utilising pits and pipes and other overland and underground drainage systems.

During flood events, materials that exist on the floodplains and urban areas can be mobilised and transported downstream by overland flow and by stream flow. Such materials are sourced from many parts of the floodplain. In forested areas, material such as trees, leaf litter and logs as well as sediment may be transported during flood events. Depending on specific conditions, large individual items and large amounts of material may be transported. In rural (cleared) areas, material that is transported includes grass clippings and fine sands. In urban areas, there may be wide range of material that may be transported such as garbage bins, cars, household rubbish and building materials. Depending on the catchment, channel and floodplain land uses, vegetation material similar to that noted above for rural catchments may also be transported. Floodplains generate materials representative of the catchment geology, such as boulders, cobbles and gravels. A range of finer sediment types can be sourced from all land uses.

As this material is mobilised and transported downstream it either passes through hydraulic structures that it encounters, or it does not. When it does not pass through a structure, it may cause a blockage of that structure and a subsequent modification of the hydraulic capacity of that structure. When severe, this blockage has the ability to divert flow to areas that are not usually subject to flooding, and can significantly alter flood levels and flow paths in the vicinity of the structure. The subsequent risk to life from structure blockage is considerable, as is the damage diverted flow can cause. Blockage is a concern at all scales of structures from minor inlets in urban drainage systems up to large culverts and bridges.

This report covers the major issues influencing blockage and provides the background for a review of the analysis, assessment and management of structure blockage that has not been previously documented in design guides such as *Australian Rainfall & Runoff.*

This report comprises Stage 1 of the project and sets the scene for subsequent investigations as part of Stage 2. The second stage will provide recommendations for assessment, design and management of blockage in drainage systems.

1.2. PROCESS

This report has been prepared by a committee with a range of interests and backgrounds relating to stream and structure blockages.

Since little published information exists on the subject, an important part of the data gathering component of the project was the collection and collation of the expertise of people and organisations who are responsible for drainage systems, and who have experienced problems with blockage. Identification of knowledgeable experts who could represent the wide range of conditions around Australia was therefore critical. A panel of experts was assembled as listed below.

These experts were consulted to obtain relevant data on blockage. The issues covered included the extent of the blockage problem in their area of practice, causes and impacts of blockage, methods of assessment and analysis and methods applied to minimise the problem. This process was planned to identify the current approaches that have been adopted, how widely they are used and to identify any specific concerns and issues with these practices.

The members of the “Australian Rainfall & Runoff” Project 11 Committee (Blockages) are:

- Bill Weeks, Queensland Department of Main Roads (Brisbane). Coordinator for the workshop and ARR Technical Committee representative.
- Monique Retallick, WMAwater (Sydney). Contributed input on drainage design and also represents the ARR Technical Committee.
- Michael Boyd, University of Wollongong (Wollongong). Represented Engineers Australia on the Technical Committee, and has done research on blockage.
- James Ball, University of Technology Sydney (Sydney), Editor of Australian Rainfall and Runoff and Chair of the Technical Committee.
- Ted Rigby, Rienco (Wollongong). Has done extensive reviews of the impacts of blockage following the floods in 1998 in Wollongong.
- Pas Silveri, Wollongong City Council (Wollongong). Has worked with Ted Rigby and has also developed guidelines for Wollongong.
- Anthony Barthelmess, Cardno Forbes Rigby (Wollongong). Has also worked on Wollongong issues and is currently completing a Masters thesis on "Factors affecting Culvert Blockage".
- Paul Doherty, Melbourne Water (Melbourne). Provided expertise on the operation and maintenance and field experience with blockage in urban areas.

- Bill Lipp, Department of Transport, Environment and Infrastructure (Adelaide). Provided experience in urban and rural areas of South Australia as well as experience for arid regions of Australia.
- Grant Witheridge, Catchments & Creeks (Brisbane). Has considerable experience with drainage design and erosion and sediment control work and has recently released the Queensland Urban Drainage Manual and the Best Practice Erosion and Sediment Control Manual.
- Alastair Peddie, Newcastle City Council (Newcastle). Carried out investigations following the floods in 2007.
- George Kuczera, University of Newcastle (Newcastle). Research interests in a range of drainage issues and member of the ARR Technical Committee.
- Karen Mckenzie, University of Newcastle (Newcastle). Student carrying out research with George Kuczera.
- Geoff O'Loughlin, Anstad (Sydney). Urban drainage expert with wide experience in all aspects of drainage.
- Bob Adamson, Brisbane City Council (Brisbane). Provided perspective on issues for Brisbane as well as generally for other urban centres.
- Bob Keller, Monash University (Melbourne). Hydraulic expert who provided information on hydraulic design issues.

Members of the committee contributed to a workshop held in Sydney on 5 March 2009. This workshop provided an opportunity for participants to present papers on individual topics and to discuss the outcomes from these presentations. This served to clarify the approach to be adopted in preparing the associated report, identified key issues for further investigation and provided material for an interim paper on the subject to be presented at the National Hydrology and Water Resources Symposium to be held in Newcastle in November 2009.

While there was some valuable information and experience shared at the workshop and during the preparation of this report, it was found (as expected) that there was quite limited published and quantitative data available on blockage and very limited guidance for planning, design and management.

This consultative approach to the preparation of this report was not that of a typical research project, but was considered most relevant because of the lack of previous research on the topic and the difficulty in carrying out such research.

1.3. DEFINITIONS

The definition of blockage is difficult to delineate accurately. However for this report, the definition has been developed in a broad sense to include the many facets of structure blockage experienced in Australia. Blockage refers to the presence of debris in drainage structures that prevent them from operating effectively.

The principal areas included in this report are as follows.

- *Major cross drainage structures.* These are bridges and culverts that carry roads, railways, pipelines or other infrastructure across water courses. These structures are sometimes large and can be affected by a number of different types of blockage phenomena. Where these structures are blocked, water can pond during flood events and severe impacts may be experienced.
- *Drainage system inlets.* These are a range of inlet structures for piped drainage systems and are generally located in streets and other urban areas to collect surface runoff. These inlets may be blocked in a number of different ways. This category of blockage is less likely to cause the serious damage that may result from the category above, but there may be serious inconvenience to traffic and the community.
- *Open channels and swales.* These structures convey flow in urban and rural areas, and may be blocked by several mechanisms, natural and constructed. Blockage of these may cause an increase in water level and a diversion of flow, and the impacts may be severe, depending on the quantity of flow that is conveyed. Debris blockage in waterways can also affect fish passage.
- *Overland flow paths.* In many locations, flow may be conveyed across floodplains in overland flow paths away from defined stream channels. These flow paths may not be immediately obvious as regions where flow is conveyed and development may occur in the area. In this case, flow may pond and then be diverted, sometimes with severe consequences. Blockage can result from a number of sources in this area. For example even a fence across an overland flow path may collect grass and other small items of debris, which can cause backup along the flow path.
- *Weirs and dams.* Floating debris may be caught on the spillways of weirs and dams, which may cause a risk to the structure or to the spillway or stream banks.

This report covers all of these categories and discusses the issues related to each and provides design guidelines considered appropriate.

Data on blockages is very difficult to obtain and there are several reasons for this. Blockage, even in a single location can be extremely variable. It may result from the accumulation of floating debris or non-floating debris. It may grow from a single piece of floating debris that becomes jammed in the inlet of a structure, with subsequent material building up on top of it resulting in full blockage of the structure. Structures may be partly or fully blocked and the degree of blockage may vary from the start to the end of a storm.

Further, the blockage itself is often removed soon after the event, and may sometimes even be removed by maintenance crews during the flood event. As well as removal by maintenance crews, debris may be dislodged naturally during and after flood events. The blockage may also vary during the flood event and there is inconclusive information about the times when blockage occurs, at the beginning, peak or end of the flood event for example.

Blockage affects infrastructure owned by local authorities or other organisations. Blockage is often the concern of the field staff of these organisations, and they may not have close contact with planning and design staff responsible for the implementation of policies. When the structure affected by blockage is owned by a government agency or other large organisation, there is often a significant separation between the owner, designer, asset manager and maintenance personnel. This separation can both compound the problems caused by blockage and adversely affect the design and maintenance processes.

This report contains information that has been based on the opinions and experience of the participants in this project. There is limited information published on the subject and a very limited amount of factual data that has been published. Therefore some of the information may be debated by others and therefore comment and additional information is sought to provide better and more complete data. Stage 2 of this project will collate additional information and use this to develop procedures for assessment of blockage. However the data presented at this stage can be regarded as interim information for discussion.

Because of the lack of publications in the field, formal references are difficult to provide and the text is based on the contributions of individuals.

1.4. EXISTING POLICIES AND GUIDELINES

Most Councils and other agencies such as road authorities in Australia incorporate some reference to blockage of grates and drainage lines in their drainage codes, but the broader impact of stream and structure blockages on flooding and flow diversions is not addressed. Other agencies such as the United States Army Corps of Engineers mention blockage as being important but do not discuss methods of defining limits or anticipated blockage conditions for designing such structures.

The 1986 NSW Floodplain Development Manual (appendix G3) discusses issues associated with the hydraulic modelling of flood surfaces but does not comment on the need for consideration of blockages or diversions in this process (Rigby et al, 2001). It has been standard practice in modelling floods in flood studies throughout Australia to assume all structures are clear (i.e. no blockage).

The 2001 NSW Floodplain Management Manual raises the need to consider blockages in design or analysis of major drainage systems, but for the most part repeats the 1986 manuals guidance on hydraulic analysis (Rigby et al., 2001).

Similarly the Queensland Urban Drainage Manual (QUDM - 1992 and 2007 editions) both note the issues related to blockage. This manual is widely used in Queensland, especially by local authorities and is commonly referenced in Council design guidelines. The guidance provided in QUDM though is general and simply states that allowance should be made for blockage when designing drainage systems. There are no clear design procedures or blockage allowance that can be applied, and the allowance is left to the individual to estimate a reasonable approach.

Along with Australian Rainfall and Runoff (IEAust, 1987) and the Queensland Urban Drainage Manual, Wollongong City Council's 1993 "Drainage Design Code" introduced the major/minor system concept and a requirement for consideration of blockage (Rigby et al., 2001). This policy required grates at 50% blockage and *"if the trunk drainage system is prone to blockage by debris, the effect of a minimum 50% blockage shall be investigated".*

Following on from the work of Rigby and Silveri (2001) Wollongong City Council developed a Conduit Blockage Policy (2002). This is one of the few well described and developed policies on blockage found in Australia. The policy's objective is *to more accurately predict flood behaviour in real events as a result of blockage of bridges and culverts across waterways.*

The policy applies to all watercourses including creeks, floodways and trunk drainage systems within the Wollongong City Council Local Government Area (LGA). The policy states that based on a detailed evaluation of flood behaviour during the major floods of 17 August 1998 and 24 October 1999 the following blockage factors are to be applied to structures across all watercourses when calculating design flood levels:

a) 100% blockage for structures with a major diagonal opening width of less than 6m.

b) 100% blockage for handrails over structures covered in (a) and for structures.

Based on a review of council guidelines for local authorities around Australia, no other councils had a blockage policy as well developed as that for Wollongong, though many councils and agencies mention that blockage should be considered in drainage designs. In Queensland for example, most councils specify that drainage designs should follow the guidelines in the Queensland Urban Drainage Manual, and do not include specific local authority guidelines.

Because the guidance provided by existing guidelines and manuals is incomplete, inconsistent and unclear, designers and managers of drainage infrastructure are unsure of the most appropriate approach to adopt for the treatment of blockage and it is therefore likely that designs may be making either insufficient or excessive allowance for blockage.

This project is therefore aimed at improving this current incomplete and inconsistent approach.

2. BLOCKAGE ISSUES

2.1. REGIONS OF BLOCKAGE

Blockage can cover a wide range of locations, which results in a number of different consequences. The locations where blockage can occur and the general types of blockage can be classified into five main categories. These categories are outlined here.

Cross drainage. In this case the structure concerned is a bridge or culvert that conveys a road, railway or pipeline across a drainage path including both natural and artificial channels. These water courses are the main means of flow conveyance. The cross drainage structure usually causes a constriction in the flow path, as well as obstructions such as bridge piers. Because these types of flow paths can convey significant amounts of flow, the flow velocities can be high and there is potential to convey floating and non-floating debris. Where the flow passes under or through the cross drainage structure, this debris may be collected and thereby reduce the flow capacity of the structure. Because of the importance of the flow path, this reduction in capacity of the drainage structure may cause upstream increases in water level or flow diversions as discussed further below. Management of this type of blockage includes design of the structures as well as management of the sources and movement of the blockage materials.

Drainage system inlets. Flow must enter piped drainage systems by inlets in the street or elsewhere in the drainage system. These inlets are designed to ensure that the inflow of debris is minimised and they must also be designed to ensure that pedestrians and vehicles, including bicycles, can cross the inlets safely. This means that the grating on the inlet must be constructed to reduce the ingress of any material transported in the surface drainage system before it enters the pipes. Because of this, the inlet is a point where debris may collect, thereby preventing water from entering the inlet. In this case, the blockage means that water remains on the surface and the piped drainage system does not operate at capacity. The water that cannot enter the piped system therefore ponds on the surface or continues to flow along the surface system. Generally the amount of flow carried in this type of system is less than that in the main flow paths noted above so the potential for damage may be less than that for cross drainage structures, but this ponding can usually be a disruption to traffic and a serious inconvenience but it can also cause diversion of flow and flood damage to property and infrastructure. There is a range of measures that can be used to manage this type of blockage, involving the design of the inlets and the production and movement of material that may cause the blockage. It must be noted that while debris blockage will reduce the inlet capacity of drainage systems, there are occasions where water may not enter these systems for other reasons, even when there is no debris effect.

Open channels and swales. In this case, the blockage occurs in channels but there is no cross drainage structure involved. The open channel may be natural or artificial. These more minor flow paths may usually be dry and only convey flow during flood events. Because of this they may include fences, minor structures or other constrictions to the flow, which can collect debris. These structures may include trash racks or other water quality structures, which are specifically designed to collect debris. Blockage in these locations can cause an increase in water level, which may inundate neighbouring infrastructure or may cause a diversion of flow. Management of this type of blockage requires that obstructions are controlled in the channels.

Overland flow paths. Overland flow paths are areas of floodplain or other parts of the catchment that convey flow only during major flood events. In many cases, they may not even be recognised as a flow path since they are not open channels as noted above. These flow paths may convey flow very rarely. Because of the infrequent flow, they may have different types of obstructions built over them. For example, there may be buildings on the flow path, where the smaller flows are carried by underground systems and the system for major flows may operate infrequently. In other cases, fences across the overland flow path can cause serious impacts on the often shallow flows that occur. These linear features like fences can be extensive and cause flow impacts over extensive areas. Blockage of overland flow paths cause increases in flood levels as well as flow diversions. Management of this type of blockage involves planning to ensure that the overland flow paths remain open to convey the major flood events, and there are no obstructions.

Weirs and dams. The spillways of weirs or dams provide a constriction to the flow path in a stream and therefore they will be a location where floating debris can accumulate and impact on the flood flow patterns in the water course.

2.2. DEBRIS TYPE

2.2.1. Overview

Blockages can result from a wide range of materials and sources as outlined in Table 2.1.

Table 2.1: Types and sources of debris

Type of debris	Typical sources of debris
Litter	General urban litter (e.g. cans, plastic bags, takeaway food containers)
	Litter originating from recreational, sporting and commercial areas
	Litter blown off building and construction sites
Leaves	Local trees as a result of strong winds, with an increases in autumn or when trees lose leaves
Grass	Cut grass washed from rural and urban properties
	Cut grass from the mowing of public open spaces
Garden mulch	Garden mulch from overland flow paths within urban areas
	Natural mulch from bushland areas
Reeds	Aquatic reeds from urban and rural creeks
Woody debris	Storm damage of trees and shrubs from urban areas
	Flood damage of riparian vegetation
Sediment	Building and construction sites
	Road surfacing material
	Erosion of gullies and watercourses
	Landslips in steep topography
Building material	Loose building material blown off building and construction sites
	Large debris resulting from flood damage of buildings
	Loose objects washed from residential and commercial properties
Cars	Cars and other vehicles swept down waterways by floodwaters
Miscellaneous debris	A wide range of material may be transported in water courses, especially in urban catchments, where many types of trash and other material may be available

The mechanics of blockages is generally based on four possible actions:

- settlement of materials, such as sediment, under favourable hydraulic conditions;
- the progressive accumulation of floating materials around the more closely spaced components of a structure or around previously trapped debris;
- individual or collective 'rafts' of similar materials caught or entangled on protruding or isolated objects—debris rafts can also become entrapped by bridge piers and culvert legs;

- larger floating materials trapped by either bridging across an opening, or wedged between the channel bed and a suspended object such as the culvert obvert—such blockages can be either progressive or pulse like depending on the material and transport mechanism.

The extent of blockage at a given location during any given flood typically depends on whether debris is able to 'bridge' across openings within the hydraulic structure, or not. As bridging occurs, the clear expanse of each opening reduces, thus increasing the likelihood of further bridging and further blockage by smaller or similar materials.

'Blockage matter' refers to the material that is likely to form the primary 'blockage', i.e. the material primarily causing the interference to hydraulic flow. Such material is unlikely to cause full blockage of a structure without the presence of suitable 'bridging matter'.

'Bridging matter' refers to the material of sufficient strength to 'bridge' across the opening (inlet) of a structure, and on which 'blockage matter' can collect, thus potentially resulting in the full blockage of all or part of the structure. Bridging matter can be as small as leaves caught on a debris screen up to logs, cars and mattresses caught at a culvert inlet.

The causes of structure blockage are based around a process of:

- Particular debris existing within a catchment. Such debris may consist of floating (i.e. trees) and non-floating (i.e. sediment) and urban (i.e. miscellaneous debris). This is described as 'debris availability' in this report.
- Processes occurring whereby the available debris is mobilised across overland areas, into and down streams. This is described as 'debris mobility' and 'debris transportation' in this report.
- Site specific aspects of each individual structure (such as inlet diameter, etc) that govern the propensity of a specific structure to block. This is termed 'structure interaction' in this report.

2.2.2. Debris Flow

Debris flows occur in a variety of geologic, geomorphic and climatic environments and there are a variety of conditions and factors that govern the mobility of a detached mass of earth and/or rock forming a debris flow (Flentje et al., 2001). The dominant factors in the triggering of a debris flow are centred around the catchment's geological and geomorphic aspects, as well as the hydrological conditions preceding the debris flow. Debris flow provides a supply of material to streams for further conveyance downstream, and thereby is an important consideration with regard to factors affecting structure blockage (Van Dine, 1996).

Figure 2.1 – Debris Flow

Bulli Pass, Wollongong, the morning after the August 1998 flood event (Source: SES)

Debris flows can have fatal consequences. There was the loss of two lives at Coledale, located in the northern suburbs of Wollongong adjacent to the Hewitts Creek catchment. On 30 April 1988 a natural slope and railway embankment failed after a significant rainfall event and developed into a debris flow that impacted on a house and killed a mother and child (Flentje et al., 2001).

During the storm of August 1998, a total of 148 sites were considered to be landslides and debris flows (Flentje et al., 2001). Of these 148 sites, 75 were reactivations of previously known landslides and 73 were new landslides. There were 14 debris flows out of which 10 occurred at new sites and 4 at existing sites.

2.2.3. Types of Debris

Floating Debris

Small Floating Debris. Small floating debris can include small limbs or sticks, leaves and refuse from backyards such as lawn clippings. This material can be easily transported by both stream and overland flow (USDOT, 2005). Therefore, it is possible that this type of material can be introduced into the stream from overland flow areas within the catchment, and then transported by the stream to structures. This type of debris can also come from trees and vegetation that are introduced into the stream due to earlier wind storms, bank erosion, landmass failures or from the loss of foliage during the changing of seasons

(USDOT 2005, Reinfelds and Nanson 2001). It is important to note then that this material is available in both urban and rural catchments, and it is available for transportation at any time.

Medium Floating Debris. Medium floating debris consists of tree limbs or large twigs. The source of this material comes from trees introduced into the stream by bank erosion or from wind gusts during the storm (USDOT, 2005). Vegetation within the channel, remnants of a previous flood, could also be a source of this type of debris (Rigby et al., 2002).

Figure 2.2 – Medium Floating Debris

Hewitts, Creek, Wollongong, after the August 1998 flood event (Forbes Rigby, 1999)

Large Floating Debris. Large floating debris consists of logs or trees, from the same sources as for Medium Floating Debris (USDOT, 2005). Transport and storage of this material depends on discharge, channel characteristics, the size of the drift pieces relative to the channel dimensions, and the hydraulic characteristics (depth and slope) of the system (Diehl 1997, Braudrick and Grant 2001). In small and intermediate size channels, this material is not easily transported and can easily become snagged, acting as a further 'snag' for smaller material. It is usually transported during larger floods or prolonged periods of high river stage (Diehl, 1997) where the floodplain is engaged and the debris's ability to become snagged is reduced. As alluded to above, once this size of debris is introduced into the main channel of small and intermediate size streams, it can form into a log-jam, which is a collection of debris formed around large, whole trees that may be anchored to the bed or banks at one or both ends (Diehl 1997, Wallerstein and Thorne 1996).

It has been observed that it is not common for larger streams to store large floating debris within the channel, and during flood events, a larger stream will transport nearly all large floating debris entering the reach via its overbanks (Diehl, 1997). This type of debris causes a significant problem at bridge structures because of its size, shape, and tenacity for entrapment on bridge piers (USDOT, 2005).

Figure 2.3 – Large Floating Debris Collection

Chalmers Street, Wollongong after the August 1998 flood event (Forbes Rigby, 1999). Note this photo also shows some random debris

Non-Floating Debris

Sands and Gravels. This debris material consists of silt, sand, and fine gravel and ranges from 0.004 to 8 mm (USDOT, 2005). This type of debris is transported along the bed and in the water column above the bed as bed load and suspended load (USDOT, 2005). The source of this material is from sheet and rill erosion, landslip and landmass failure, and channel and bank erosion. Sediment yield rates for this material can be significantly influenced by the conditions of, and changes within, the catchment due to urbanisation or land use change (USDOT, 2005).

Figure 2.4 – Fine Debris Collection

Woodlands Creek, Wollongong, after the August 1998 flood event (Forbes Rigby, 1999)

Cobbles. This debris material consists of coarse gravel or rock ranging in size from 16 to 256 mm (USDOT, 2005). The source of this material may be from bed or bank erosion or land slip failures. Once mobilised this material is usually transported as both bed and suspended load within high gradient streams. Deposition of cobbles can readily block a structures entrance or significantly reduce a bridge opening.

Figure 2.5 – Coarse Debris Collection

Hewitts Cree, Wollongong (looking upstream from bridge in George St residence) after the August 1998 flood event (Forbes Rigby, 1999)

Boulders. This debris material is generally comprised of large rocks. Boulders are associated with steep streams and are transported as bed load. The source of the boulders is again from bed or bank erosion or land slip failures. Given its particle size relative to the opening diameter (or cross sectional area) of many urban drainage structures, this material can readily block the entrance to a structure and/or cause damage to the structure from the forces of impact/collision.

Figure 2.6 – Large Boulder Debris

Hewitts Creek, Wollongong, after the August 1998 flood event (Forbes Rigby, 1999)

Urban Debris

Urbanisation of catchments introduces many 'random' materials that can cause structure blockage. For example, a garbage bin can easily be washed down a street and into a stream or drainage structure such as a culvert, a situation made worse if a large rainfall event occurs on the same day as rubbish collection within a suburb. Rigby and Silveri (2001) also noted one off "special" circumstances whereby a mattress/wheel/drum/vehicle blocked a structure inlet or a larger item (6 m container) blocked a bridge span.

Rigby and Silveri (2001) also observed that such small floating debris is often mobilised via a pulse like delivery of urban refuse/building materials/fences/sheds and the like, swept into streams by over bank flow into the stream by overbank flow.

2.3. DEBRIS AVAILABILITY

2.3.1. Introduction

In terms of debris availability, the following factors affect the availability of debris material within the catchment:

- Potential for soil erosion. Soil erosion exposes soil and rock particles thus increasing their availability. The potential for soil erosion is dependent on a number of factors including soil erosivity, rainfall erosivity, slope length and gradient, vegetation cover and changes in catchment hydrology. The latter is often closely linked to the effects of urbanisation.
- Local geology. The geology of the catchment and particularly the exposed geology of the water course, influences the availability of materials such as clay, silt, sand, gravel, rocks and boulders.
- Catchment area. Increasing catchment area increases the quantity of available blockage material. However it is noted that once blockage occurs at a given structure within a given reach of a water course, there is often a reduced availability of blockage material for those structures located immediately downstream of the partially blocked structure.
- Amount and type of vegetative cover. This can vary from grasses and shrubs to thick forest or plantations. It can also include various types of crops and agricultural uses. Some types of cover are easily uprooted by overland flow and others are not. Some types are easily damaged by high winds producing considerable leaf and limb debris on the ground, ready to be washed away in subsequent flooding.
- Urban Areas. Such areas make available a wide range of debris such as garbage bins, mattresses, shopping trolleys, fences, outhouses, stored timber, cars, shipping containers, and a considerable range of other materials. Specifically the degree of flood inundation of urban areas influences the debris availability, thus making this a manageable factor linked to town planning and drainage design.
- Preceding Rainfall. If flood events are experienced regularly, this typically reduces the quantum of debris present in the catchment at the time of the flood under consideration and therefore the ‘availability’ of debris. Preceding wind storms may have the reverse effect, greatly increasing the quantum of debris ‘available’ within a catchment.

2.3.2. Landslip

Landslips are a potential source of sediment for streams in steep country throughout Australia. Slope stability depends on many factors such as flood and drainage behaviour, the underlying geology and the intensity and volume of rainfall. These factors may solely influence a landslip or combine together to produce a slope failure. Young (1978) has observed that in the Illawarra region of New South Wales while flood and drainage behaviour, underlying geology and slope material are significant contributions to potential landslips, runoff is a more crucial factor than rainfall.

This work was extended by Flentje (1998) who extended the Young (1978) data set to 328 landslides being mapped. This study also determined a percentage exceedance of antecedent rainfall which correlated with slope failure or with accelerated landslide movement. The study concluded that the timing and failure of a landslide correlated to antecedent rainfall periods of 90 and 120 days. This work is very important in understanding the link between antecedent rainfall conditions and slope stability (i.e. potential for debris flow and therefore the supply of material to cause structure blockage).

2.3.3. Land Use Surface Characteristics

Debris transport and blockage of drainage structures can occur in all types of catchments.

Land use affects the availability of debris or detritus material that could be mobilised to cause structure blockage. Urban catchments contain areas such as roads, footpaths, dwellings, car parks, offices, industrial areas amongst others. Urban catchments contain various sources of floating and non-floating debris, as well as ‘random’ urban debris described previously. As well as a greater amount of source material, the runoff response and flow velocities are generally higher in urban catchments compared to rural catchments and this contributes to a larger quantity of debris.

In rural catchments, the principal sources of blockage material are vegetation of all types as well as sediment. Non-urban land uses comprise two very different sub land uses, forested or natural catchments and rural catchments. Forested or natural catchments contain large areas of trees and under-storey shrub growth. Rural areas are known to be predominantly cleared land with short grass cover and are used for rural-residential living, agricultural purposes or grazing.

Land use affects the availability of debris or detritus material that could be mobilised to cause structure blockage. Urban catchments contain areas such as roads, footpaths, dwellings, car parks, offices, industrial areas amongst others. Whilst some urban areas contain parks and other “rural” land uses, urban areas usually have significant areas of impervious surfaces, which contribute significant runoff and export of contaminants including material that can block drainage structures. Depending on the particular catchment characteristics, there may or may not be a significant contribution for the rural portions of urban catchments.

2.3.4. Impacts of Preceding Rainfall

Very little is understood about the general effect that preceding rainfall has on the propensity of structures to block, but it can be significant. Frequent rainfall and flood events may clear debris from the catchment in smaller individual quantise and therefore the risk of major blockage may be reduced. On a short temporal scale, for example, if a given catchment experienced a 5 year ARI flood event, and then 3 days later received a 20 year flood event, the degree of blockage in the latter event would typically be reduced as the previous flood had (potentially) cleared the catchment of much of its available debris.

For example, in Brisbane, there were two significant storm events in November 2008. The first event was a major storm with high winds and hail as well as moderately heavy rainfall. This event stripped trees of leaves and branches and also caused damage to buildings and other structures. There was therefore a large amount of loose debris on the ground after the storm. Two days later, there was another storm. This second event did not cause the same extent of damage as the earlier storm, but there was very heavy rainfall. This rainfall moved significant debris into water courses causing significant blockage in many drainage structures. Figure 2.7 shows some debris caught on bridge railings in this event.

Figure 2.7 – Debris caught on bridge rails

Brisbane suburban creek – November 2008

2.3.5. Factors Affecting Mobility

In terms of debris mobility, the following factors affect the movement of debris material within the catchment:

- Rainfall Erosivity. Different areas of the country experience different intensities of rainfall, and in general, areas that experience more intense rainfall have a greater potential to mobilise debris than areas of lower rainfall intensity. This is however somewhat offset by the ‘cleansing’ nature of regular flooding in these high erosivity areas.
- Soil Erosivity. This can vary from weathered rocks to cohesive clays, all having different abilities to become eroded, entrained and ‘available’ to be mobilised.

- Slope. There is a relationship between the blockage of structures and the slope of the upstream catchment, both with respect to the overbank areas and the slope of the stream itself. Slope is also highly correlated with stream power, and as such slope is generally considered a suitable 'surrogate' for stream power.
- Storm duration. The mobilisation of materials generally increases with increasing storm duration.
- Debris Transportation. Data collected as part of this report shows a correlation between the size of debris and the potential for this material to be transported within the stream to downstream parts of the catchment.
- Structure Interaction. Data collected as part of this report shows that site specific structure features, such as the structure opening diameter, plays a key role in whether a structure will or will not block.

2.4. STRUCTURE INTERACTION

2.4.1. Introduction

Site specific features such as the structure opening diameter, plays a key role in whether a structure will block.

2.4.2. Inlet Pits

Inlet pits are critical parts of drainage systems, and collect the runoff from the streets and other parts of the urban catchment and convey these to the piped underground system. Because inlet pits must be well screened to ensure safely, these screens are an obvious point where debris can be collected. Because these screens are often quite fine, this debris can be small. Small debris can be conveyed by the relatively small flow rates in these systems, and will then be collected and can cause a high level of blockage. Since these drainage systems are usually in urban areas, the debris can include a wide range of small material, such as litter and cans. It can also include grass clippings and garden mulch all of which can totally block drainage inlets.

These structures are usually located on roads, and the blockage can be related to a range of issues.

All types of material that may occur naturally on the road surface or that may be placed or swept onto the road can be mobilised by quite small storm events. The most common material will be leaves and other small vegetation as well as general litter. Litter such as drink cans can be caught on the grates and then act to collect other smaller items to sometimes completely block the inlet. As well, there may be building material that is washed away from building sites and into the street. This material includes packaging and waste materials which may not be used in the building. As well during construction operations, sediment controls are placed around inlets to limit the movement of material into the underground drainage system. If a storm event occurs during the construction period, this "deliberate" acts to block entry of water into the drainage system. This sediment control material may also be abandoned at the end of construction and thereby remain as a blocking factor for some time into the future. Related to the placing of sediment controls, residents may sometimes deliberately or unknowingly place materials on the inlets and limit the inflow of water into the drainage system.

Figure 2.8: Ponding on street caused by blocked inlet pit

(Source: G O'Loughlin)

Figure 2.9: Leaves can completely block inlets

(Source: G O'Loughlin)

Figure 2.10: Litter in an inlet

(Source: G O'Loughlin)

Figure 2.11: Builders material and sediment controls can block culverts

(Source: G O'Loughlin)

Poor design may also work towards reducing the capacity of the drainage inlets. Work carried out after the completion of the drainage system may provide additional obstructions to the inlet capacity.

All of these factors are exacerbated by poor maintenance. Whenever any blockage occurs, it should be cleared as soon as possible to ensure that the system can operate effectively when the next rainfall event occurs. Because relatively small events can mobilise debris that affect inlet pits, this means that maintenance must be carried out frequently.

Figure 2.12: Vegetation growing in inlet indicates poor maintenance

(Source: G O'Loughlin)

2.4.3. Fences/Handrails/Guardrails

Cross drainage structures are often bridges and these will often have fences or guardrails. In some cases such as on road or rail bridges on major rivers where there is extensive debris transport and where the bridge is frequently overtopped, guard rails are not provided to allow for the risk of debris blockage. However most bridges will provide some sort of structure, which increases the depth of the bridge deck, and thereby increases the risk and extent of blockage. With increasing emphasis on safety of bridges, these structures have become more extensive and more solid. In some cases, the structures may be designed to “fail” during flood events or they may fail despite the design, and the extent of debris collection is reduced.

These types of structures however can be a serious impact on bridges and culverts and may significantly increase the risk and extent of blockage. The planning and design of these structures on cross drainage structures must be carefully considered to ensure that the impacts are accounted for correctly.

These structures, especially fences, may also affect blockage on channels and swales and overland flow paths. In these cases, the flow may be more shallow and occur less frequently than in the channels where there are cross drainage structures. Fences may cross the flow path and affect the usually shallow flow that occurs in these situations. Usually the fence will collect larger items of debris that are too large to pass through the structure and then this allows further material to collect until there is a significant degree of blockage.

Figure 2.13: Guardrails on a bridge can collect debris

Figure 2.14: Fences collect debris and block overland flow paths

2.4.4. Culverts

Culverts are locations in water courses where a constriction occurs and therefore where blockage of some type is likely to occur. As well as the constriction to the overall flow width, the walls of the culvert or the spacing between pipes are clear locations where debris can collect. Depending on the type of material transported, the catchment type and the configuration of the drainage structure, the blockage can be very variable.

It is intuitive to expect that the smaller the opening diameter of a structure inlet, the more prone to blockage it would be. Further, it would also be intuitive to expect that multiple openings (even multiple small openings) would be less prone to blockage than one single opening, because debris will be spread across several openings. Rigby et al (2002) found that in Hewitts Creek, after the flood event of August 1998, almost all structures with an opening of less than 6 m (measured diagonally) blocked 100% irrespective of nearly all other factors (such as land use and stream slope for example). It is recognised though that the event where this occurred was a significant one and may not be representative of other locations around Australia. The catchment conditions in Wollongong are also distinct and may not be entirely representative of other places in Australia, so while the conclusions of the studies in Wollongong are very valuable, extension of the findings to other parts of Australia may not be simple to apply.

Floating and non-floating debris can block different areas of the same structure, altering the hydraulic capacity of the structure.

It is difficult to confirm post flood whether floating debris caused a top down blockage during the flood, as floating debris can move after the flood has receded and may not be observed post flood in the location it was at the time of the peak of the blockage. As the flood surface increases during the rising limb of the hydrograph, floating debris is entrained and can begin to lodge on the upstream side of a culvert, and remains in place as additional floating debris arrives at the structure. As the flood subsides, the new accumulated debris usually floats down on top of the lowering flood surface until it sits on the bed or on the previous debris accumulation to form a reasonably solid mass (USDOT, 2005), sometimes covering the full waterway of the culvert in the process. Such a post flood appearance does not necessarily mean the culvert inlet was blocked (perhaps at all) at the flood peak.

Various types of blockage patterns exist at each structure. Some of the reasons for this can become detailed and site specific (such as wing-wall type, poor structure alignment to stream flow direction etc). However, there have been many documented examples of inlet blockage and other cases where both the inlet and barrel have become blocked (Rigby and Silveri, 2001). Further, the literature suggests that inlet and barrel blockage is predominantly caused by non-floating debris (Rigby and Silveri 2001, USDOT 2005), whereas inlet blockage while dominated by floating debris, can be caused by all forms of debris (Rigby and Silveri, 2001).

Figure 2.15 – Example of Partial Inlet and Barrel Blockage

Lachlan Street culvert, Wollongong, on the main arm of Hewitts Creek (Forbes Rigby, 1999)

2.4.5. Bridges

Debris blockage of bridges is generally less of a concern compared to culverts simply because the waterway opening is usually larger and less susceptible to full debris blockage. However bridges, especially their abutments and foundations, can be more susceptible to structural damage than culverts. Severe debris blockage can cause local variations in flow velocity resulting in significant bed scour, undermining of abutment foundations and exposure of bridge pier foundations.

Non-floating debris such as silts, sands, gravels and boulders can be deposited under the bridge in locations where there is a change in bed gradient and sediment tends to deposit. In some cases, the sedimentation may have a severe impact on the performance of the bridge. This effect usually builds slowly and may even totally block the waterway area of the bridge over a long period of time.

Floating debris, especially vegetation is a more frequent occurrence and one that may threaten the safety of the bridge during flood events. Usually, this process begins with a large floating object such as a tree that has been displaced by bank slumping floats onto the bridge and becomes wedged under the deck or between piers. This then acts to collect other smaller pieces of debris and ultimately a large waterway area is lost. While vegetation is the most common type of floating debris that affects bridges, other materials may also be a concern. For example boats may be washed from their moorings and wedge on the bridge, and then they act similarly to the tree trunks referred to above. In addition to their impact on the bridge’s waterway, drag on these floating rafts of debris can exert very substantial forces on the bridge superstructure, leading at times to structural failure of the bridge.

Figure 2.16 – Floating debris on a bridge

Source – Queensland Department of Main Roads

Figure 2.17 – Sedimentation under a bridge

Source – Queensland Department of Main Roads

2.4.6. Weirs and dams

Weirs and dams provide a constriction to flow paths where water flows through a spillway. Floating debris can be caught across the spillway. The risk of this type of blockage increases for more narrow spillways and for larger items of floating debris such as large tree branches or trunks. When a large item is caught, it forms a barrier that can then collect smaller items such as smaller branches or leaves and the whole opening can be closed.

When the spillway is blocked, this causes increased ponding in the storage of the dam or weir and this could even cause a risk of overtopping of the dam embankment. Spillway gates can increase the risk.

2.4.7. Open channels and overland flow paths

Open channels and overland flow paths are different from the other types of structures mentioned here. These types of drainage paths may be blocked by floating or non-floating material in a “natural” situation. However it is more likely that these flow paths may be blocked by various types of construction. It may be sometimes difficult to identify where major flows occur if the flow directions change depending on the conditions. In these cases, the construction may be accidental and planners and local property owners may not even be aware that there is a problem until a major flood event occurs, which may be many years after the construction has occurred.

This type of blockage can cause increased ponding of water upstream and may also cause significant diversion of flows.

2.5. TIMING OF BLOCKAGES WITHIN A FLOOD EVENT

During a storm event, it is not well known when each of the debris types (i.e. floating or non-floating) will block a structure. For example, the timing of a blockage in an outlet of a detention basin can be most important, as it can significantly impact peak flood discharge through or over a structure and/or flood levels upstream of the structure (Rigby and Silveri, 2001). A blockage early on in a storm event will likely cause any available storage in the structure to fill prior to the peak, reducing the ability of the storage to attenuate peak flows during the main ‘burst’ (Rigby and Silveri, 2001).

This issue of timing is further complicated by the percentage of blockage occurring at a structure, and by the blockage material. For example, fine sediment and small to medium floating debris could be mobilised during most of the duration of a given flood event, but would generally pass through structures and be deposited on the falling limb of the hydrograph. Conversely, boulders may only be mobilised for a short time during rare, large flood events with high stream power, and are therefore likely to block structures around the peak of a flood event when stream power is highest. In an urban area it is most likely that blockage occurs shortly after sufficient depth of overbank flow occurs upstream of the structure to wash material into the stream and structure.

3. IMPACTS OF BLOCKAGE

3.1. OVERVIEW

3.1.1. General

As well as increasing flood risk by lowering conveyance of drainage structures and changing flow paths, blockages can of course cause damage to the affected hydraulic structure, but often more importantly, these blockages can cause damage to unattached public and private assets as well as cause increased safety risks to both the public and maintenance personnel. Table 3.1 outlines typical impacts likely to arise from the blockage of various hydraulic structures.

Table 3.1 – Likely impacts of blockages of various hydraulic structures

Hydraulic structure	Typical impacts
On-site detention systems	• Increased maintenance requirements of outlet structure • Increased frequency and severity of overland flow through property
Overland flow paths	• Increased property flooding • Damage to property fences
Stormwater inlets (kerb and field inlets)	• Increased overland flow down roads and associated safety risks • Flooding of roads and intersections • Property flooding and damage resulting from bypass flows
Stormwater pipes	• As above for stormwater inlets • High inspection and maintenance costs
Stormwater outlets, including surcharge chambers	• As above for stormwater inlets • Structural damage to outlet screens • High cost associated with de-silting coastal outlets
Detention/retention basins	• Safety risk to maintenance personnel during post-storm maintenance • Increased property flooding due to the failure of the structure to fill or de-water in accordance with desired operational performance • Structural damage to outlet structure
Fishways	• Restrictions to fish passage during period of blockage • Potential long-term changes to upstream aquatic habitats
Waterway bridges, culverts and causeways	• Flooding and damage to adjacent properties caused by overtopping and bypass flows • Safety risk to maintenance personnel during post-storm maintenance • Cost of post-storm debris removal • Structural damage to pedestrian safety fencing and handrails • Cost of debris removal from handrails and traffic barriers • Bed erosion resulting from debris collection around bridge piers • Restrictions to fish passage even during period of minor bed-level debris blockage • Blockages in causeways, particularly rural causeways, can result in long-term changes to upstream water levels, resulting in the creation of aquatic habitats, and the creation of instream water storages (feeding irrigation pumps), that can attract environmental/community values.

Assessing the impacts of blockages requires consideration of the following issues on a site-by-site basis:

- variations in the risk of blockage for different storm probabilities or ARI;
- likely degree of blockage at individual structures, and the likely extend of such blockages across the catchment;
- hydraulic consequences of various degrees of blockage (i.e. changes in flood levels and channel discharge due to inter-catchment flow exchange, and/or changes in flood storage);
- potential impacts on the catchment, community assets, and public safety;
- environmental impacts such as interference to fish passage.

When considering the potential impact of debris blockage on major waterway structures such as bridges and culverts, appropriate analysis (modelling) and assessment should be made of:

- the consequences of blockages in excess of that assumed during the minor/major design events;
- the consequences of flow in excess of the nominated major storm;
- the likelihood and consequences of structural damage resulting from blockages;
- the relative elevation of property floor levels (residential or commercial) upstream and adjacent to the culvert;
- the potential path/s of bypass and overtopping flows (e.g. overland flows that may pass through downstream properties before re-entering the waterway channel, and flows that may exit the waterway and enter an adjacent roadway, such as shown in Figure 3.1).

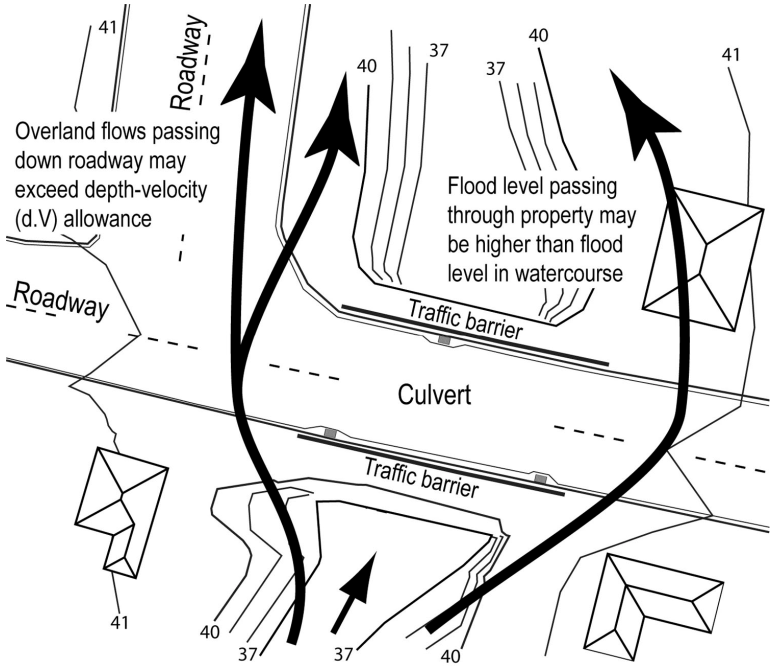

Figure 3.1 – Example flow path of overtopping flows

When assessing the potential effects of debris blockage, or flows in excess of the design flow, consideration should at least be given to at the following:

- potential for floor level flooding, especially flood level flooding that results from only minor changes in the 'design' conditions of the waterway structure;
- potential adverse affects on both the 'value' and 'use' of adjacent land;
- potential, unrepairable property damage (e.g. damage to historical sites, or severe erosion that threatens the structural integrity of public and private assets).

3.2. RISK ASSESSMENT

In order for blockages to occur the following triggers are usually required:

- a source of blockage material;
- a trigger for the initial displacement of such material;
- a means of providing transportation of the material to the hydraulic structure.
- a structure that would have difficulty in passing the transported debris

It is the combination of the potential quantity of blockage material within the catchment, and the triggers for the initial displacement of this material that ultimately influences the quantity of material entering a drainage line, overland flow path or waterway. Therefore, a large quantity of catchment vegetation does **not** necessarily result in a high risk of blockage if there are no triggers for the initial displacement of the organic matter. Such triggers would include strong winds and active erosion of the waterway channel and/or riparian zones.

In a similar way, in an urban area for example, a car park full of cars is not necessarily a potential source of culvert-blocking debris unless floodwaters either reach sufficient elevation to cause the cars to float, or sufficient shear stress to move the cars towards deep water. Different sources of material become apparent at different flood levels and flow velocities, that is for different probabilities of flooding. In the car park, smaller floods may not affect parked cars, but smaller items of debris may move and block smaller components of the drainage system before the cars begin to float.

The ‘source’ of blockage material strongly relates to land use and catchment management activities within the catchment. The ‘triggers for initial displacement’ usually relates to the severity of winds, channel shear stress, and elevation of floodwaters across the floodplains. The latter two factors are closely linked to hydraulic factors of the flood and flow patterns, which are related to the average recurrence interval (ARI) of the flood. The ‘method of transportation’ of material also closely links to the ARI of the flood, but can also relate to other catchment properties such as the slope of the catchment, especially in relation to the transportation of large rock and boulders.

Table 3.2 provides an overview of key risk assessment factors likely to influence the quantity, initial displacement, and transportation of various blockage materials.

The severity of blockage at a given structure is likely to be influenced by the following factors:

- potential quantity of blockage material;
- severity of the storm (wind, rain or flood level) to cause the initial displacement and transportation of the blockage material;
- opportunities for such materials to collect at, or within, a structure—typically relating to the design of the structure and the hydraulic gradient;
- potential quantity of material of sufficient size and strength to ‘bridge’ across the opening, thus increasing the opportunity for further blockages—typically related to the size of the structure and the availability of suitable ‘bridging’ material;
- degree of blockage prior to commencement of a given storm—typically related to recent storm history and the frequency of maintenance.

Table 3.2 – Risk assessment factors associated with various blockage materials

Blockage material	Risk assessment factors		
	Quantity	**Initial displacement**	**Transportation**
Leaves	Degree of tree cover Density and location of deciduous trees Frequency of street sweeping	Severity of winds Seasonal factors relating to leaf fall from deciduous trees	ARI of storm relative to the structure (i.e. critical storm duration at location of structure)
Grass and garden mulch	Percentage grass cover Collection of grass clipping following mowing	Shear stress of overland flow	ARI of storm relative to the structure (i.e. critical storm duration at location of structure)
Reeds and other aquatic vegetation	Regional factors relating to growth opportunities, including annual rainfall and canopy cover of the upstream waterway	Shear stress of in-bank flow Frequency of bankfull flows	ARI of storm relative to the structure (i.e. critical storm duration at location of structure)
Woody matter	Density of riparian tree cover	Severity of winds Stability of waterway channel (often related to changes in catchment hydrology) ARI of flood event Whether the flood event is sufficiently large to uproot trees	ARI of storm relative to the structure (i.e. critical storm duration at location of structure)
Litter	Land use (sporting, recreational and commercial) Degree of building activities Regional factors Frequency of street sweeping	Severity of winds Shear stress of overland flow	ARI of storm relative to the structure (i.e. critical storm duration at location of structure)
Building debris	Extent and control of building activities Land use (commercial)	Severity of winds Shear stress of overland flow	ARI of storm relative to the structure (i.e. critical storm duration at location of structure)
Sediment	Extent and control of building and construction activities Geology of watercourse Degree of sediment control measures	ARI of flood event Stability of waterway channel (often related to changes in catchment hydrology)	ARI of storm relative to the structure (i.e. critical storm duration at location of structure)
Rocks and boulders	Geology of watercourse Gradient of watercourse Stream power	ARI of flood event Stability of waterway channel (including natural channel migration)	Gradient of watercourse Shear stress of flood flow, typically related to the ARI of storm
Flood debris and cars	Land use (car parks) Population (car) density Density of buildings within floodplain	Severity of overbank flooding Depth of flooding Velocity of flood flows	ARI of storm relative to the structure (i.e. critical storm duration at location of structure)

3.3. HYDRAULIC IMPACTS

3.3.1. Introduction

Hydraulic issues are related to all of the related impacts of blockage on the drainage system and these specific technical issues are described initially.

Drainage structures are designed to convey water, both floods and low flows, and blockage of the structure reduces this capacity. The major impact of this reduced capacity is an increase in flood level upstream of the structure which may inundate infrastructure or cause other damage or nuisance. In some cases, the increase in flood level may be significant. If the blockage affects low flows, the increase in water level may be relatively low, but water will tend to pond for long periods of time, which may be an environmental concern.

When the capacity of the structure is reduced by blockage, the flow velocity through the remaining open portion of the structure is increased by the higher upstream water level, which may also be a concern. At the point where the structure is totally blocked, the upstream water levels will be increased to an even greater extent. The higher flow velocity and more concentrated flow can cause scour of the water course or can cause structural damage to other features or infrastructure. Changes in flow velocity can also be an environmental concern if it increases the risk of scour at the structure or reduces the capacity of the structure for transfer of fish or other aquatic fauna.

The potential hazard to pedestrians and traffic is increased when there is additional flow overtopping roads or when flow velocities are increased.

The changes in water level and flow velocity may cause a change in the flow path and new flow paths may be developed, at least temporarily. These altered flow paths can have severe community impacts if they affect property.

3.3.2. Flow Diversions

In major storms it is not uncommon for structures to back up flow to the point that an overland flow path develops, causing flows contained within one stream to divert away from their previous alignment. This diverted flow may eventually return to the same stream or discharge into an adjacent stream. Blockages have the potential to increase both the frequency of occurrence and magnitude of such diverted flows (Rigby and Silveri, 2001). Even small blockages can create diversions that would not exist (even in major events) and can considerably change flood behaviour (Rigby and Silveri, 2001).

Further impacts of structure blockage, relating to the diversion of flow, were documented by Rigby and Silveri (2001), who found that after the August 1998 storm in Wollongong, the blockage of structures and subsequent diversion of flows to adjacent streams were highly significant factors in contributing to flood damages. Such blockages were observed to modify flood discharges and profiles in many of the streams studied. An important aspect relating to risk to human life noted by Rigby and Silveri (2001) was a lack of appreciation of the community of where flow would divert once a structure blocked. As these new flow areas were not considered during the design of the suburb or building, a blockage event creates many areas of unexpected high risk and consequential damage. An example of flow diversions and cross catchment diversions occurring due to culvert blockage can be seen below in Figure 3.2.

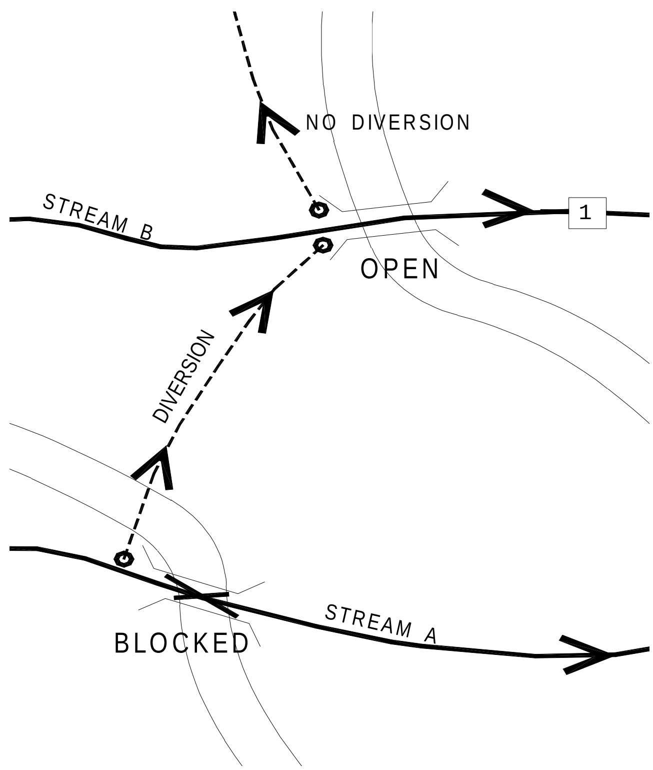

Figure 3.2 – Stream Diversions Occurring from Blockage

Note: Flow at location 1 is maximised in a scenario where the Stream B culvert is 'open' and the Stream A culvert is blocked causing a diversion of flow (Rigby and Silveri, 2001)

The following table describes the impacts of blockages on the 1% AEP flood flows within the Hewitts and Woodlands Creeks in Wollongong. This table has been extracted from Forbes Rigby (2002a) and describes the peak flows at Location 1 on Figure 3.3, with and without the actual blockages that occurred in the flood event of 17 August 1998.

Table 3.3 – 1% AEP Stream Diversions in Hewitts Creek

Source: Forbes Rigby, 2002a

Description	Flows Without Blockage (m^3/s)	Flows With Blockage (m^3/s)
Location '1' downstream of railway bridge in Hewitts Creek (Stream 'B')	91.8	117.7
Diversion from Steam 'A' to Stream 'B'	23.8	44.9

For the 1% AEP flood event, the flow diversion from Woodlands Creek (Stream A) to Hewitts Creek (Stream B) was some 80% higher when the culvert in Woodlands Creek blocked. This was much more than the community was anticipating, which is similar to that experienced at flow diversion locations during the 2007 Newcastle floods.

Such stream diversions cause many problems, of which an important aspect is the classification of flood prone land. The NSW Government's Flood Prone Land Policy states that all land subject to flooding in the PMF event is deemed 'flood prone'. When large diversions occur through culvert blockage, land that may never have experienced a flood previously, can become 'flood prone land'. The flow-on effects for property insurances and land values are considerable.

3.3.3. Depth and Velocity

The depth and velocity of flood flows are altered by blockage of components of the drainage system. These changes may cause damage to property or the environment and may cause flood flows in portions of the catchment that are normally free of flood waters.

Specifically blockage that reduces the capacity of drainage structures will cause an increase in flood level on the upstream side of structures, which will increase the depth of water in possibly a large extent of channel and floodplain. This increased flood level on the upstream side of structures will thereby increase the velocity through the structure, which will increase the risk of scour and will also cause other environmental concerns such as the reduced capacity of the culvert to allow fish to swim through the culvert.

A particular example of specific impacts was described by Haines and Thyer (2008) in Newcastle.

Given the steep nature of the upper catchment areas, flooding within most Newcastle suburbs lasted less than one hour. Again, this is very similar to Illawarra flood behaviour. In some areas, such as Newcastle West, flooding was exacerbated by significant blockages, with many smaller structures blocked by vehicles washed into the open drains or shipping containers blocking main drainage channels (Haines and Thyer, 2008). Blockages were also reported as a result of storm debris generated by the combination of gale force winds and rain resulting in the mobilisation of damaged trees, recyclable and garbage wheelie bins and color-bond fencing panels (Haines and Thyer, 2008).

Haines and Thyer (2008) stated that one of the main differences between the predicted 100 year ARI model results and the actual flood levels could be explained by the local influences of blockages within the stormwater channels. Substantial channel blockage was reported as a result of storm debris (the combination of gale force winds and rain resulted in significant tree damage), recyclable and garbage wheelie bins, colorbond fencing panels, and even cars (see Figure 3.3). Haines and Thyer (2008) note that the most substantial blockage occurred at the downstream end of Cottage Creek, wherein shipping containers from an adjacent construction site had become lodged within the culverts under the rail embankment.

Based on post-flood computer modelling, Haines and Thyer (2008) found that the impact of this particular blockage was shown to be in the order of 1 m vertically, having widespread consequences throughout the Newcastle West business area, and backwater flooding along the Cottage Creek drainage system. Haines and Thyer (2008) observed that this inundation persisted for hours following the event, as the culvert blockage inhibited post-flood drainage. This is similar to the August 1998 blockages in the Illawarra.

Figure 3.3 – Vehicles Blocking a Culvert Inlet

Photo from the Newcastle Storm of 8 June 2007. Photo reproduced from Haines and Thyer (2008).

3.4. GEOMORPHOLOGY

Geomorphic impacts may be critical and can cause serious impacts on stream channels, affecting the environment and properties. In many cases potential geomorphic impacts are not identified before a flood event occurs, their existence only becoming apparent when a new path develops and a new channel is eroded along this new path. Without remediation works, the altered flow paths may become permanent.

Many of the geomorphic impacts may be relatively temporary and minor, but there may be significant impacts at times, but there may be critical impacts in some circumstances.

It is often said that streams are the conveyor belts of catchments, transferring sediment from the upstream to the downstream end of a catchment. It is therefore prudent to consider the roles stream play in delivering debris to culverts to allow blockage to occur, and to understand their capacity to influence blockage patterns across a catchment.

The supply of floating debris to a stream and its ability to convey that debris downstream has been well studied within Australia (Brookes 1999(a), Abbe et al., 2003) although very little is known about what triggers this movement of material (Braudrick and Grant, 2001). This latter research addressed this issue by developing a physical-based model that predicts the flow conditions required to move and deposit wood. This model was rigorously tested in a series of flume experiments, finding that it could accurately predict when wood moves and where it is likely to end up once it starts moving, based on the flow conditions and log dimensions. This work is of great relevance to structure blockage in Australia. Braudrick and Grant (2001) found that large woody debris movement is dependent on the diameter of the log and its orientation in large rivers (where log length is less than channel width). Log length, often reported as the most important factor in determining its movement, was not a factor in channels where the width is larger than the log length. Braudrick and Grant (2001) attribute this to the importance of banks and vegetation on inhibiting log movement, further supposing that logs are often at least partially lodged on the banks or on other logs, which anchors it and increases the force required for entrainment.

Gregory et al (2002) also investigated wood's ability to become mobile, transported and retained in fluvial systems, as a function of wood characteristics and dynamics. This work illustrated how wood accumulations were more profound in 'small' and 'medium' channels. 'Large' channel woody deposits created subsequent sediment accumulations took smaller forms such as scroll bars and islands. Wood accumulations of 'small' and 'medium' rivers were stored closer to the source in comparison to 'large' rivers. Montgomery and Piegay (2003) also found that widely spreading hardwoods are more likely to form snags and then accumulate in large log jams, while coniferous wood debris is more readily transported resulting in local concentrations and log jams spread along the river system.

An increasing ratio of wood length to channel size increases the possibility of wood becoming jammed or trapped (Gregory et al, 2002). Increasing wood diameter (related to tree species and age), decreases the rivers ability to transport wood down stream, as diameter is related to density which in turn is a contributing factor in buoyancy. Buoyancy is also related to the woods living status, as un-decayed logs are heavier than decayed. Hence, wood which has been freshly detached from vegetation will require more energy to be transported in a river system in comparison to dead wood (Gregory et al, 2002). Tree species also delineate the shape of the wood, and straight wood is less likely to be jammed (Gregory et al, 2002).

The role that this floating woody debris plays in the shape of a channel is also understood. The Cann River on the south coast of NSW experienced a 360% increase in channel depth, a 240% increase in channel slope, a 700% increase in channel capacity and an increase of up to 150 times in the rate of lateral migration due to vegetation removal from the floodplain and channel since European settlement (Brookes et.al, 2003).

Brookes et al (2003) experimented with the reintroduction of woody debris into the Williams River in NSW, which had disappeared since European settlement time via the implementation of de-snagging programs and active removal by land owners. Woody debris was added to the system at strategic locations resulting in a marked increase in sediment retention within the study reach. Abbe et al (2003) also noted similar results. It is clear that the impact of snag removal on blockage potential is enormous.

The underlying geology can play an important part in the rivers potential to deliver sediment. Fryirs (undated found that in the Bega River's up-land streams, the sediment available to the catchment is relatively stable, and minimal. Due to the physical alterations of the landscape from agricultural practices and development, it was shown that the capacity of these reaches to manage the increased sediment flow within the catchment was disrupted. Fryirs (undated) found that this was most likely due to actions such as clearing of vegetation which enhanced erosion and thus increasing volume of sediment being entered into the system. Removal of riparian vegetation, initiating bank erosion and collapse of these escarpment base accumulation zones for sediment was also a factor.

Back to back events or preceding rainfall has been discussed previously as potentially having a significant impact on blockage. Whilst this issue may affect blockage from a hydrologic perspective, it is also known to affect stream and floodplain geomorphology. Nanson (1986) states that sedimentation and stripping rates on floodplains appear episodic – either from one large (rare) flood, or several smaller magnitude flood closely spaced together. In other words, it is not necessarily a large flood that might cause large volumes of floodplain stripping.

3.5. STRUCTURAL

Structural impacts may occur if drainage structures or other infrastructure located in the flow paths are affected. These can range from temporary poor performance up to complete destruction of the infrastructure.

Structural damage can occur in any event during flooding, but blockage of structures may exacerbate damage. The structural damage may occur during the event or may not become apparent until after the flood has receded and loads are placed on the structure again.

Structural design of bridges makes provision for the impact of debris accumulation on the decks. However this allowance is an arbitrary quantity specified in the bridge design codes and does not provide for particular differences in different regions or for different catchment conditions. It would be valuable to allow a better estimate of the risk to the structural safety of the bridge by having better estimates of the amount of blockage to be expected, especially in cases where extensive blockage is possible.

As well as bridges, there are many other drainage structures, where there is no guidance for structural design and good analysis of the risk to these structures would be valuable.

3.6. ECONOMIC

Financial impacts are usually very important and are able to be measured more accurately than some of the other impacts which are difficult to define quantitatively.

Financial impacts include increased damages, or inconvenience. The additional flooding or diverted flows may cause these additional costs. Even if there is no clear physical damage, the costs of inconvenience or nuisance may be important.

Floods are the most costly of all natural disasters in Australia, in terms of damage to infrastructure and possessions (Gentle et al., 2001). The additional impacts of blockage during a flood can exacerbate the already costly impacts of flooding, from both a risk to property and risk to life perspective (Nichols et al, 2008). It is interesting to note that whilst floods are the most costly in terms of financial loss, bushfires continue to be the most costly natural disaster in terms of loss of life and injury (Gentle et al., 2001). While flooding is a significant natural disaster risk, the costs of other risks (such as the annual costs of motor vehicle death and injuries) are greater.

On September 16, 2001, Typhoon Nari resulted in severe flooding in the Keelung River basin in Taiwan. More than 1,000 shipping containers were swept by the rising water from the floodplain into the river, blocking 14 bridges (Lee et al, 2006). A severe overbank flow due to this blockage occurred at the Ba-Tu Railway Bridge, and the overbank flow then passed through a railway tunnel and inundated Keelung City, resulting in significant damage (Lee et al, 2006).

The impacts of blockage can be very costly. Padgett et al (2008) found that the overall cost to repair or replace 44 bridges damaged during Hurricane Katrina is estimated at over $1 billion (USD). Damage was found to be directly attributable to debris impact and accumulation, where storm surge caused by the hurricane was not an issue. In Thirroul, the storm of August 1998 caused $75 million (AUD) of property damage (Forbes Rigby, 2002a) of which a significant proportion can be attributed to culvert blockage.

An example of the impact of debris accumulation on bridges, and subsequent structural failure, is evidenced in Figure 3.4.

Figure 3.4 – Debris Accumulation Bridge Failure

U.S. Department of Transportation Federal Highway Administration (DOTFHA) Hydraulic Engineering Circular No. 9 Third Edition (2005). Photo also shows structural failure.

3.7. SOCIAL

As well as the obvious financial costs associated with flooding, which can be at least partially attributed to blockage of structures, there are social impacts. These are the actual damages as well as the mental impacts on residents and businesses that are affected by flooding. These social impacts are often critical and blockage may be a serious contributing factor. Often because blockage causes flooding in locations or at a depth that may not be expected, the impacts may be greater than would be the case for flooding from the usual sources.

Where blockage occurs on inlets to urban drainage systems, water can pond on roads and produce a hazard to traffic and pedestrians, even if the actual financial damage is minor. In these cases, there is a risk of injury or even death in addition to inconvenience, so the social consequences may be major.

From a risk to human life perspective, flooding fatalities in this country fall well behind other natural disasters, and are orders of magnitude behind the 'background' risk we face every day. The current national road toll puts the rate of fatalities at 9.3 per 100,000 people annually, down from as high as 30.4 per 100,000 people in 1970 (ARC, 2006).

3.8. ENVIRONMENTAL

Blockage and the resultant changes in flow patterns can also affect the environment in one of several ways. Blockage may cause ponding in flow paths close to the inlets of drainage systems or culverts. This ponding may persist for long periods of time and may therefore cause health concerns by providing breeding areas for insects.

The increased flow velocities downstream when the flow occurs through a constricted opening may cause scour damage to the channel. Drainage structures are often important transfer routes for aquatic and terrestrial fauna. Fish in particular need to swim along flow paths and if these are blocked, this transfer is adversely affected.

Riffles and pools in watercourses can also become inundated with sediment, destroying any low flow habitat afforded by the pools and riffles.

4. HYDRAULIC ANALYSIS

The entrance loss and energy loss coefficient for a culvert experiencing partial debris blockage while operation under outlet control conditions are provided by Equations 4.1 and 4.2.

$$\Delta H_e = K_e \left(\frac{V_o^{\,2}}{2g} \right) \qquad \text{(Equation 4.1)}$$

where:

ΔH_e = energy loss at entrance of culvert (m)

K_e = energy loss coefficient relative to culvert-full velocity head

V_o = flow velocity of downstream culvert flowing full (m/s)

g = acceleration due to gravity (m/s^2)

$$K_e = \left(\left(\frac{1 + K_c^{\,1/2}}{BR} \right) - 1 \right)^2 \qquad \text{(Equation 4.2)}$$

where:

K_c = energy loss coefficient relative to downstream culvert-full velocity head for a culvert without debris blockages

= 0.5 for square edge culvert entrances

= 0.2 for rounded (radius = 1/12 diameter) entrance

BR = blockage ratio, being the ratio of free space cross-sectional area at the cell entrance (i.e. excluding area of blockage) to the downstream full pipe area

The ratio of culvert cell discharge with partial blockage to cell discharge without blockage for a culvert operating under inlet control conditions is provided by Equation 4.3 and Table 4.1.

$$BF = (BR)^{5/4} \qquad \text{(Equation 4.3)}$$

where:

BF = ratio of discharge with blockage to discharge without blockage

Table 4.1 – Percentage flow reduction capacity of culvert under inlet control conditions

Blockage %	0	10	20	30	40	50	60	70	80	90	100
Ratio (BR)	1.00	0.90	0.80	0.70	0.60	0.50	0.40	0.30	0.20	0.10	0.00
Factor (BF)	1.00	0.88	0.76	0.64	0.53	0.42	0.32	0.22	0.13	0.06	0.00

Table 4.1 demonstrates that for a road culvert operating under inlet control conditions, the reduction in hydraulic capacity (BF) is slightly greater than the adopted reduction in flow area (BR) associated with the inlet blockage.

Case A: Screen upstream of pipe/culvert inlet (Figure 4.1)

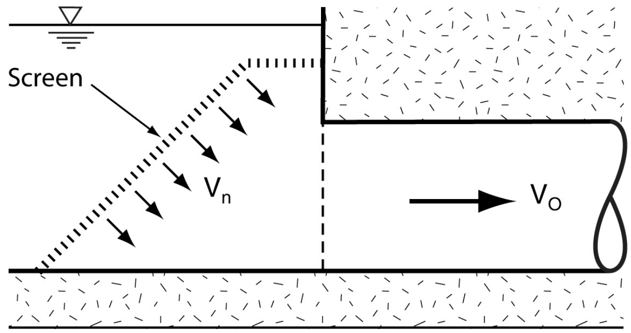

Figure 4.1 – Inlet screen mounted away from the inlet

Energy loss (ΔH_e) consists of screen loss (with blockage) plus pipe entry loss (no blockage).

$$\Delta H_e = K_t * \left(\frac{V_n^2}{2g}\right) + K_c\left(\frac{V_o^2}{2g}\right) \qquad \text{(Equation 4.4)}$$

where:

ΔH_e = total energy loss of combined screen and pipe/culvert entry (m)

K_t* = trash rack/screen loss coefficient relative to through velocity head (Equation 4.5) based on a screen with assumed blockage (i.e. the area ratio (A_r) takes into consideration loss of flow area caused by both the screen bars and the debris blockage)

V_n = average flow velocity through screen with blockage considered (m/s)

g = acceleration due to gravity (m/s^2)

K_c = entry loss coefficient for a 'clean' culvert (i.e. without blockages), and excluding losses caused by screen

V_o = average flow velocity within the pipe/culvert downstream of the entrance (pipe flowing full) (m/s)

$$K_t * = 2.45A_r - A_r^2 \qquad \text{(Equation 4.5)}$$

where:

A_r = reduction in flow area from screens

Case B: Screen located at pipe/culvert inlet (Figure 4.2)

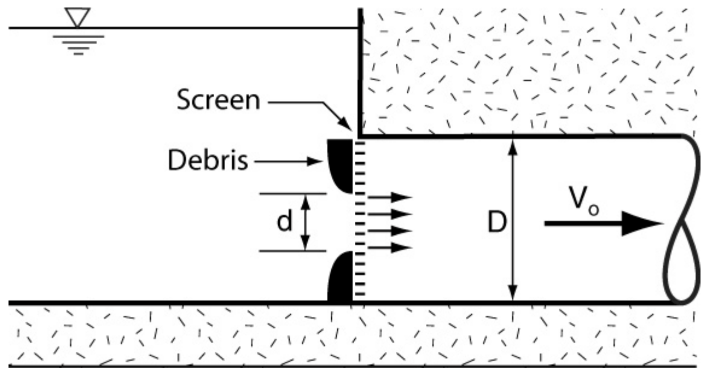

Figure 4.2 – Inlet screen mounted close to the inlet

If the screen is bolted directly to the face of the inlet headwall, or where flow immediately downstream of the screen is confined within a conduit with a cross sectional area approximately equal to the gross area of the screen, then the head loss for the screen cannot be considered separately from the pipe entry loss.

Total energy loss (ΔH_e) for the combined screen and pipe/culvert entry may be determined from Equation 4.6.

$$\Delta H_e = K_e\left(\frac{V_o^{\,2}}{2g}\right) \qquad \text{(Equation 4.6)}$$

where:

$$K_e = \left(\left(\frac{1 + K_c^{\,1/2}}{BR}\right) - 1\right)^2 + \frac{BR(2.45\,A_r - A_r^{\,2})}{(1 - A_r)^2} \qquad \text{(Equation 4.7)}$$

and:

ΔH_e = combined energy loss of pipe/culvert exit including effects of screen (m)

K_e = combined entry loss coefficient based on downstream pipe-full velocity head

BR = blockage ratio, being the ratio of the gross area of the screen not affected by debris blockage, to the internal flow area of pipe/culvert downstream of the screen

A_r = area ratio = A_b/A = $1 - A_n/A$

A_b = surface area of 'clean' screen bars excluding debris blockage (m^2)

A_n = net flow area through 'clean' screen (i.e. excluding bars)

A = gross flow area of the bar screen, $A = A_b + A_n = A_o$ (m^2)

A_o = internal flow area of pipe/culvert downstream of screen (m^2)

In effect, Equation 4.7 determines the energy loss coefficient for a partially blocked pipe/culvert entrance (first part of equation), plus a loss component for that portion of the screen that is assumed not to be experiencing any blockage effect (second part of equation).

Values of the combined entry loss coefficient are provided in Table 4.2 for a range of area blockage ratios (BR) and bar screen area ratios (A_r) based on a 'no screen, no blockage' entry loss coefficient (K_c) of 0.5.

Table 4.2: Combined entry loss coefficient for area blockage ratios and screen area ratios

Blockage ratio (BR)	Trash rack/safety screen bar area ratio (A_r) for a 'clean' screen						
	No screen	0.01	0.02	0.05	0.1	0.15	0.2
1.00	0.50 [1]	0.52	0.55	0.63	0.79	0.98	1.20
0.90	0.80	0.83	0.85	0.92	1.07	1.23	1.44
0.80	1.29	1.31	1.33	1.39	1.52	1.67	1.85
0.70	2.07	2.09	2.11	2.16	2.27	2.40	2.56
0.60	3.40	3.42	3.44	3.48	3.58	3.69	3.83
0.50	5.83	5.84	5.85	5.89	5.97	6.07	6.18
0.40	10.7	10.7	10.7	10.7	10.8	10.9	11.0
0.30	22.0	22.0	22.0	22.0	22.1	22.1	22.2
0.20	57.0	57.0	57.0	57.0	57.0	57.0	57.0
0.10	260	260	260	260	260	260	260

All energy loss coefficients are based on an assumed 'no screen, no debris' entrance loss coefficient of 0.5

Case C: 'Clean' screen located at pipe/culvert outlet (Figure 4.2)

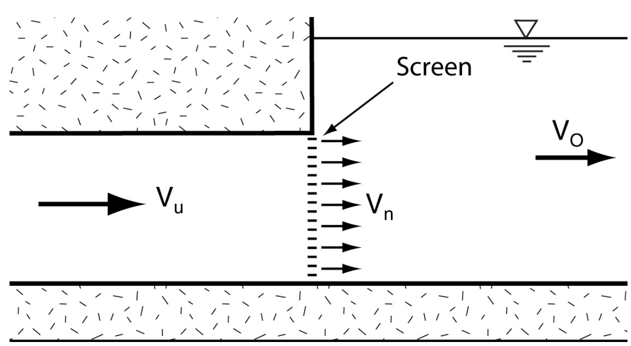

Figure 4.2 – Outlet screen with minimal blockage

Energy loss (ΔH_{exit}) consists of screen loss plus normal exit loss component.

$$\Delta H_{exit} = K_t\left(\frac{V_u^2}{2g}\right) + K_{exit}\left[\left(\frac{V_u^2}{2g}\right) - \left(\frac{V_o^2}{2g}\right)\right] \qquad \text{(Equation 4.8)}$$

where:

ΔH_{exit} = combined energy loss of pipe/culvert exit including effects of screen (m)

K_t = energy loss coefficient for 'clean' screen determined from Equation 4.9

V_u = average full-pipe flow velocity upstream of screen (m/s)

K_{exit} = exit loss coefficient that would exist for the 'no screen' case (Table 4.3)

V_o = average flow velocity well downstream of the outlet and screen (m/s)

$$K_t = \frac{2.45A_r - A_r^2}{(1 - A_r)^2} \qquad \text{(Equation 4.9)}$$

Exit loss coefficient, K_{exit} may be determined from Table 4.3.

Table 4.3 – Pipe/culvert exit loss coefficients (H_{exit})

'No screen' exit loss coefficient (K_{exit})	Outlet conditions
1.0	Flow expansion occurs in four directions, above, below, left and right of the pipe/culvert exit
	Typical case exists when significant bed scour occurs immediately downstream of the exit during the design storm
0.7	Flow expansion occurs in three directions, above, left and right of the pipe/culvert exit, but not along the channel bed
	Typical case exists when a stabilised outlet scour pad exists that prevents bed scour at the pipe/culvert exit
0.5	Flow expansion occurs in two directions, left and right of the pipe/culvert exit, but not along the channel bed, and the downstream water level is approximately equal to the pipe/culvert obvert level
	Typical case exists when a stabilised outlet scour pad exists that prevents bed scour at the pipe/culvert exit, and the downstream water level is approximately equal to the pipe/culvert obvert level
0.3	Flow expansion occurs in one direction only, above the pipe/culvert obvert, but not along the channel bed or banks
	Typical case exists when the pipe/culvert discharges into a concrete channel that has a channel width equal to the pipe/culvert width

Case D: Partially blocked screen located at pipe/culvert outlet (Figure 4.3)

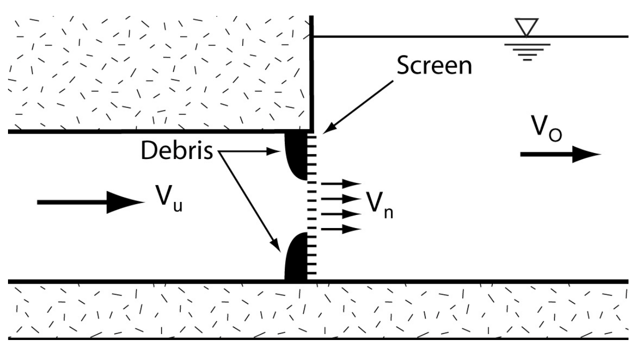

Figure 5 – Partially blocked outlet screen

Energy loss (ΔH_{exit}) consists of an exit loss component plus screen loss.

$$\Delta H_{exit} = K_{exit}\left(\frac{V_u}{2g}\right) \qquad \text{(Equation 4.10)}$$

$$K_{exit} = \left(\frac{1}{BR.C_c} - \frac{V_o}{V_u}\right)^2 + \frac{BR(2.45A_r - A_r^{\ 2})}{(1-A_r)^2} \qquad \text{(Equation 4.11)}$$

where:

$$C_c = 1 - (0.1446 - 0.058BR - 0.0866BR^2)^{1/2} \qquad \text{(Equation 4.12)}$$

and:

ΔH_{exit} = combined energy loss of pipe/culvert exit including effects of screen (m)

K_{exit} = combined exit loss coefficient based on upstream pipe-full velocity head

BR = blockage ratio, being the ratio of the gross area of the screen not affected by debris blockage, to the internal flow area of pipe/culvert upstream of the screen

C_c = coefficient of contraction at orifice vena contracta (from Equation 4.12)

A_r = area ratio = A_b/A = $1 - A_n/A$

A_b = surface area of 'clean' screen bars excluding debris blockage (m^2)

A_n = net flow area through 'clean' screen (i.e. excluding bars)

A = gross flow area of the bar screen, $A = A_b + A_n = A_u$ (m^2)

A_u = internal flow area of pipe/culvert upstream of screen (m^2)

Values of the coefficient of contraction are presented in Table 4.4 for a range of blockage ratios.

Table 4.4 – Coefficient of contraction for partially blocked outlet screen (Equation 4.12)

BR	0.00	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00
C_c	0.620	0.629	0.640	0.654	0.672	0.693	0.720	0.752	0.793	0.851	1.000

Case E: Screen located well downstream of pipe/culvert outlet (Figure 4.4)

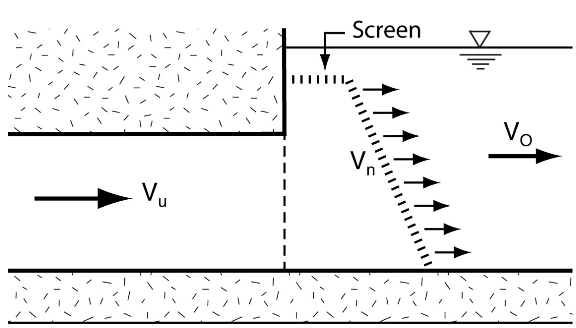

Figure 6 – Outlet screen mounted away from the outlet

This arrangement is the most hydraulically complex of the five conditions (Cases A to E). The appropriate analysis of such flow conditions required an appreciation of complex three-dimensional hydraulics. As such, the following analytical procedure may not be appropriate in all circumstances.

Energy loss (ΔH_{exit}) consists of screen loss plus normal exit loss component.

$$\Delta H_{exit} = K_t * \left(\frac{V_n^{\,2}}{2g}\right) + K_{exit}\left[\left(\frac{V_u^{\,2}}{2g}\right) - \left(\frac{V_o^{\,2}}{2g}\right)\right] \qquad \text{(Equation 4.13)}$$

where:

ΔH_{exit} = combined energy loss of pipe/culvert exit including effects of screen (m)

K_t* = energy loss coefficient for ‘clean’ screen determined from Equation 4.5

V_n = average flow velocity through screen with blockage considered (m/s)

K_{exit} = exit loss coefficient that would exist for the ‘no screen’ case (Table 4.3)

V_u = average full-pipe flow velocity upstream of the outlet (m/s)

V_o = average flow velocity well downstream of the screen (m/s)

Note: when determining the average flow velocity through the screen (V_n) it will be necessary to consider the effects of jet expansion from the pipe/culvert outlet. If the screen is heavily blocked with debris, then jet expansion from the outlet may not be relevant, and flow may simply pass evenly through any part of the screen not blocked by debris.

5. MANAGEMENT OF BLOCKAGE

5.1. INTRODUCTION

There are a number of different approaches that can be adopted for management of blockage in drainage structures and this section of the report has comments on some of these issues.

5.2. DESIGN CONSIDERATIONS

5.2.1. Introduction

The likelihood and impacts of blockages can in some cases be reduced through appropriate planning and design of hydraulic structures. The following section outlines a range of recommendations that should be given appropriate consideration during the planning and design of hydraulic structures.

5.2.2. All hydraulic structures

In all structures, it is important that consideration should be given to maintenance procedures, even without an allowance for blockage. However because blockage increases the requirement for maintenance, it is especially important when considering this factor. Appropriate consideration must therefore be given to how maintenance personnel gain safe access for inspection and maintenance purposes, including safe machinery access to remove debris blockages.

5.2.3. Urban drainage system form and layout

Drainage systems are usually designed on the assumption that blockage does not occur or is minimal, though in some areas, blockage may be considered in drainage planning and design. However, consideration of the potential for blockage in the planning of the urban drainage system can very significantly reduce the risk associated with such blockages. All of the issues discussed in this section are a concern for drainage systems even when blockage has not yet occured, but are a greater issue if blockage occurs regularly and restricts the capacity of the system.

Diverting major overland flows away from their natural flow path is generally **not** recommended as it can result in significant property damage during storms in excess of the design major storm, or when unexpected debris blockage of the drainage system occurs.

It should not be assumed that an overland flow path passing under a residential property fence will be maintained in proper working order. These systems can result in excessive damage when floods larger than the design flood occur, but blockage can result in major damage even for relatively small events. Drainage systems that rely on regular maintenance should ideally be restricted to land managed by a body corporate or government agency.

If overland flow paths are located within residential properties, then consideration must be given to the likely impacts of the transportation of organic matter (including grass clippings and garden mulch) and other stored materials from the property. Specifically, consideration should be given to the potential hydraulic and water quality impacts on the downstream drainage system and receiving waters.

Special care must be taken in the design of overland flow paths at locations where noise control fencing or other structures are required. Specifically, reference is made here to the conflicting needs to minimise gaps within control noise fencing, and to design of under-fence flow paths in a manner that will minimise potential debris blockage of the overland flow path. This is a particular issue in the case of swales or overland flow paths, but can also be a problem where the noise control fencing is on a road with a cross drainage structure.

5.2.4. Major drainage system

The procedures for planning and design of the major drainage system should:

- account for the flow conveyed in the underground minor drainage system, and for the consequences of malfunctions or blockages within that system; and
- demonstrate that it is possible to design and construct an inlet system for the minor drainage network that can operate under appropriate levels of debris blockage, otherwise appropriate adjustments need to be made to the design discharge of the major drainage system in accordance with (a) above.

The design of major underground pipe systems with no overland flow component should be strongly discouraged, and should only be adopted where overland flow is either impracticable or unacceptable. Prior to adopting a major underground pipe system that does not incorporate an overland flow component, the planner/designer should consider the following:

- consideration of how design flows can enter the underground drainage system under expected blockage conditions;
- the potential effects of flows in excess of the design flow, including the consequences of the Probable Maximum Flood (PMF);
- the management of potential debris blockages, including likelihood of pre and post storm maintenance;
- the effects of debris blockages in excess of that allowed for in (i) above.

When assessing the potential effects of debris blockage, or flows in excess of the design flow, consideration should at least be given to at the following:

- potential for floor level flooding;
- potential adverse affects on the 'value' and 'use' of adjacent land;
- potential unrepairable property damage (e.g. damage to historical sites, or severe erosion that threatens the structural integrity of major structures).

5.2.5. Stormwater inlets

Stormwater inlets are especially prone to blockage and there are several ways that this can be managed and analysed.

To avoid confusion within the industry, inflow capacity (design) charts for kerb inlets should reflect the theoretical or measured capacity of the inlet, to which appropriate blockage factors should be applied. The effects of blockage should **not** be included within these design charts.

Particular considerations are as follows.

- At a sag, the capacity of a combination inlet (kerb inlet with grate) should be taken to be the theoretical capacity of the kerb opening with 100% blockage of the grate.
- On a continuous grade the capacity of a combination inlet should be taken to be 90% of the combined theoretical capacity of the grate plus kerb opening.
- The impacts of debris blockage can be delayed, if not reduced, through the adoption of 3-dimensional 'dome' screens on field inlets instead of the more traditional horizontal screens. These types of screens are only possible in suitable locations where safety concerns can be satisfied.
- The concrete lip formed around field (drop) inlets should have sufficient width to minimise the risk of grass growing over the grate, or causing blockage of the grate.

5.2.6. Stormwater outlets

Stormwater outlets are another area of concern and consideration of these structures is needed.

Consideration should be given to the likely impact of sand/sediment blockages of tidal outlets, and the appropriate design of such outlet to minimise these impacts, including consideration of the following:

(i) Elevating the outlet may reduce the risk of sand blockage and allow maintenance inspection of the pipe; however, aesthetic considerations may require the outlet be located below low tide level.

(ii) Use of flapgates or similar to prevent the intrusion of salt water and/or sediment into the pipe. The flapgate may need to be located within the first access chamber set back from the beach to protect its operation from vandalism, wave attack, debris and sand blockage. However, in some cases it may be preferable for the flapgate to be located at the end of the pipe for ease of maintenance.

- To minimise sedimentation within the pipe, a minimum 1 year ARI flow velocity of 1.2m/s is desirable.
- Stormwater outlets discharging to grass-lined swales/channels should have an invert level at least 50mm above the design invert of the grass surface, or as appropriate, to allow for normal grass growth without causing blockage of the outlet, or water to pond within the pipe.
- Stormwater outlets discharging to open channels should consider the likelihood of blockage of the outlet by heavy reed growth within the channel. Where appropriate, consideration may need to be given to the inclusion of an elevated, dry, bypass channel that is not susceptible to reed growth. Typically, reed growth is not expected to cause significant backwater problems when the discharging pipe has a diameter of 1200mm or greater.
- Prior to incorporating a surcharge chamber into a drainage line, the following should be considered:

(i) potential surcharge of the upstream system and resulting flooding problems caused by blockage of the outlet screen;

(ii) safe maintenance access to allow removal of debris trapped within the surcharge chamber.

5.2.7. Detention/retention basins

Detention or retention basins are an important component of many drainage or flood mitigation systems, and blockage of either piped or spillway outflows could reduce the effectiveness of the structure or could even threaten the safety of the structure itself. A number of measures in these basins are appropriate to reduce the risk.

- Detention/retention basin outlet structures should be protected against expected debris blockages, and appropriately designed to minimise safety risks to persons swept toward the outlet structure during flood events.
- The degree of protection must relate to the consequences of failure caused by such blockages, and the estimated frequency of blockage.

- Consideration should also be given to the consequences of a fully blocked low-level outlet structure during the designated minor storm.
- Best results are often achieved when the debris control trash racks are separated from the safety control screens. This allows both the trash rack and safety screen to be designed for the optimum location, size and bar spacing.
- Debris screens typically incorporate two critical design features: restriction of debris entry into the conduit, and prevention of the total collapse of the debris screen while under heavy debris loading so that the water storage can continue to drain post flood. It is noted that the total collapse of a screen into the conduit can cause blockages that are very difficult for maintenance personnel to repair, often requiring the basin to be fully de-watered (pumped dry) prior to commencement of maintenance activities.
- The design of debris screens must take appropriate consideration of the maintenance equipment likely to be available to the asset owner.
- Trash racks should be large enough that their partial blockage will not adversely restrict flows reaching the outlet control device. Typically the trash rack area should be at least ten times larger than the control outlet orifice.
- The use of inclined vertical bar rack is most effective for the lower stage outlets. Such rack designs allow the removal of accumulated debris with a rake while standing on top of the structure. Cage type racks or racks with horizontal members generally inhibit this type of debris removal.
- The spacing of trash rack bars must be proportioned to the size of the smallest outlet protected. This may require the use of a separate, close bar-spaced rack in front of the smaller outlets.
- To facilitate removal of accumulated debris and sediment from around the outlet structure, the trash racks should have hinged connections wherever practicable.
- To avoid sediment blockage and sediment entrainment into the lowest staged water quality outlet, the outlet chamber (i.e. the chamber invert between the flow control orifice and the entrance to the primary outflow pipe) should be recessed below the lowest outlet a distance at least equal to the diameter of the outlet.
- Wherever practicable, trash racks and bar screens should be designed to shed debris and assist the egress of persons trapped in the basin. Guidelines on the design of trash racks and bar screens that allow the egress of persons are provided by the Queensland Department of Natural Resources (2007).

On-site detention (OSD) systems

- Best self-cleaning effects are created when the length of the pit containing the outlet control orifice and debris screen (measured from the screen to the rear wall) is made only just large enough to incorporate the inlet pipe (entering tangential to the screen).
- The available screen area should be as large as possible in order to prevent blockage.
- The inflow pipe should enter the pit at 90 degrees to the direction of outflow through the orifice and tangential to the screen.
- Self-cleaning is improved if surface inflow (inflow via screened drip pit) falls directly onto an inclined, vertically slotted, screen.

5.2.8. Watercourse crossings

As a general guideline, many references indicate that the minimum size of all cross drainage culverts should be 375 mm diameter for pipes and 375 mm height for box culverts. For culverts highly susceptible to sedimentation it is generally advisable to avoid culvert cell dimension of 600 to 900 mm and this standard is commonly applied in many rural areas. Pipes less than 600 mm can be mechanically cleaned with water jets. Pipes greater than 900 mm can be manually cleaned. To minimise the potential for 100% debris blockage of a culvert, the minimum desirable cell height is 3 m, and the minimum desirable cell width is 5 m. These sizes are significantly smaller than the dimensions recommended for Wollongong, where a minimum dimension of 6 m has been suggested.

These conflicting recommendations show the uncertainty in the assessment of the risk of blockage. In some drainage systems and cross drainage structures, the smaller widely adopted minimum dimensions may be quite acceptable. In other locations such as Wollongong, these sizes may be significantly smaller than the necessary size. Wollongong does however show an extreme risk and the flood event that precipitated the Council guidelines was an extreme event. In Wollongong, the city is located at the base of a steep mountain range, where high flow velocities can gather sediment and vegetation as well as any other loose material. The main cross drainage structures are then located on flat sections of the stream channels just below the steep slopes, the natural locations where debris is likely to be deposited.

Therefore recommendations of minimum sizes for cross drainage structures should make allowance for specific localised risk factors, perhaps with an allowance for uncertainty. The difficult problem is to determine a suitable method for calculating the minimum dimension for cross drainage structures that provide for an acceptable risk while ensuring a minimum structure size to account for the wide range of different conditions.

The smaller sizes indicated above may be generally suitable for regions where the risk is relatively low, but with an increased guideline value for regions where the risk is assessed as greater. Determination of an appropriate guideline will be a difficult problem.

To minimise the effects of debris blockage, and to minimise the risk of a person drowning if swept through the culvert, all reasonable and practicable measures should be taken to maximise the height of the culvert, even if this results in the culvert's hydraulic capacity exceeding the design standard.

The risk of debris blockage can also be reduced by using single-cell culverts, or in the case of floodplain culverts, spacing individual culvert cells such that they effectively operate as single-cell culverts without a common wall (leg).

A viable alternative to increased culvert capacity (in response to the effects of debris blockage) may be to lengthen the roadway area (i.e. the effective causeway weir length) subject to overflow.

Impacts on fish passage by debris blockage must be considered within critical fish habitats.

One means of maintaining the hydraulic capacity of culverts in high debris streams is to construct debris deflector walls (1V:2H) as shown in Figure 4.1. The purpose of these walls is to allow the debris raft to rise with the flood, thus maintaining a relatively clear flow path under the debris.

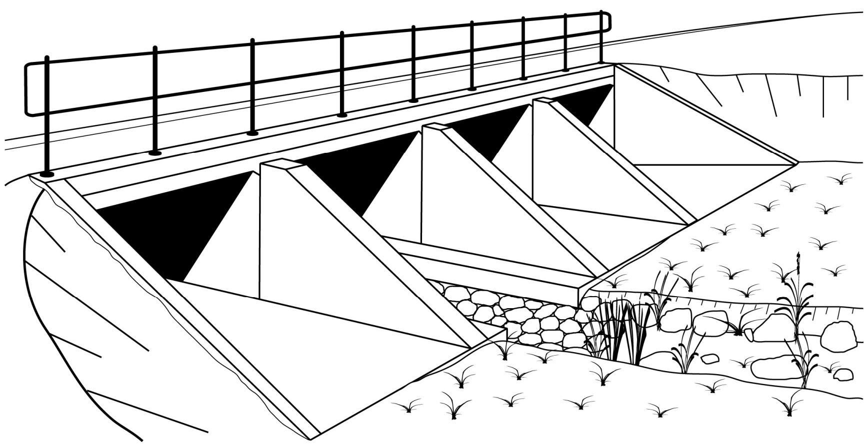

Figure 4.1 – Culvert Inlet with debris deflector walls

Sedimentation within culverts may be managed using one or more of the following activities:

- formation of an instream sedimentation pond upstream of the culvert;
- formation of a multi-cell culvert with variable invert levels such that the profile of the base slab simulates the *natural* cross section of the channel;
- installation of *sediment training walls* on the culvert inlet (Figures 4.2 and 4.3). Sediment training walls reduce the risk of sedimentation of the outer cells by restricting minor flows to just one or two cells.

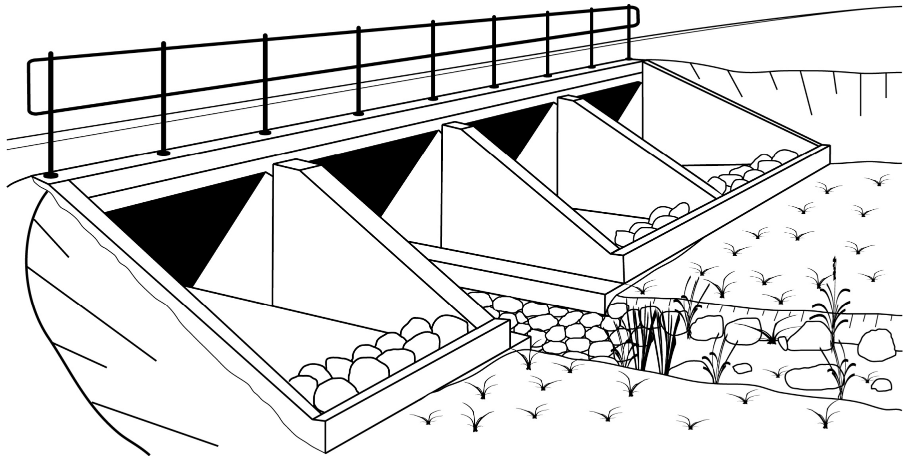

Figure 4.2 – Sediment training walls incorporated with debris deflector walls

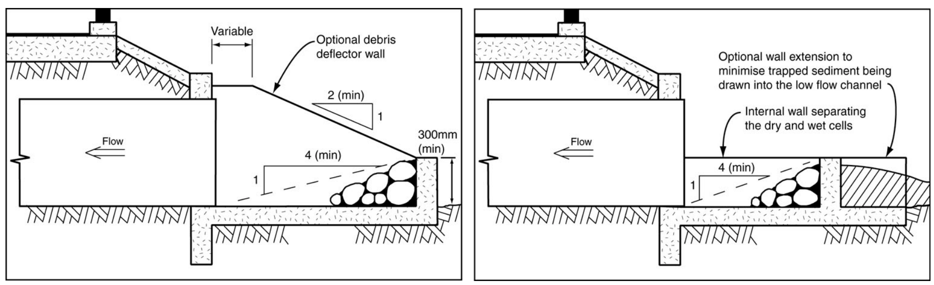

Figure 4.3 – Various arrangements of sediment training walls with (left) and without (right) a debris deflector wall

5.2.9. Maintenance for cross drainage structures

The likelihood and impacts of blockages can in some cases be reduced through appropriate maintenance of hydraulic structures.

The following section outlines a range of recommendation relating to the maintenance of hydraulic structures.

The selective maintenance clearing of riparian vegetation upstream or downstream of a bridge or culvert must be assessed on a case-by-case basis; however, is likely to be warranted in the following situations:

(i) the hydraulic and/or environmental benefits have been clearly demonstrated by past clearing operations;

(ii) woody vegetation is restricting flood flows from leaving the upstream floodplain and entering the bridge or culvert;

(iii) woody vegetation is restricting the flow of floodwaters exiting the bridge or culvert from entering into the downstream floodplain;

(iv) woody or inflexible vegetation is growing within an area defined by one culvert/bridge width upstream of the bridge or culvert (Figure 4.4);

(v) the vegetation is considered noxious or damaging to the ecological integrity of the downstream watercourse.

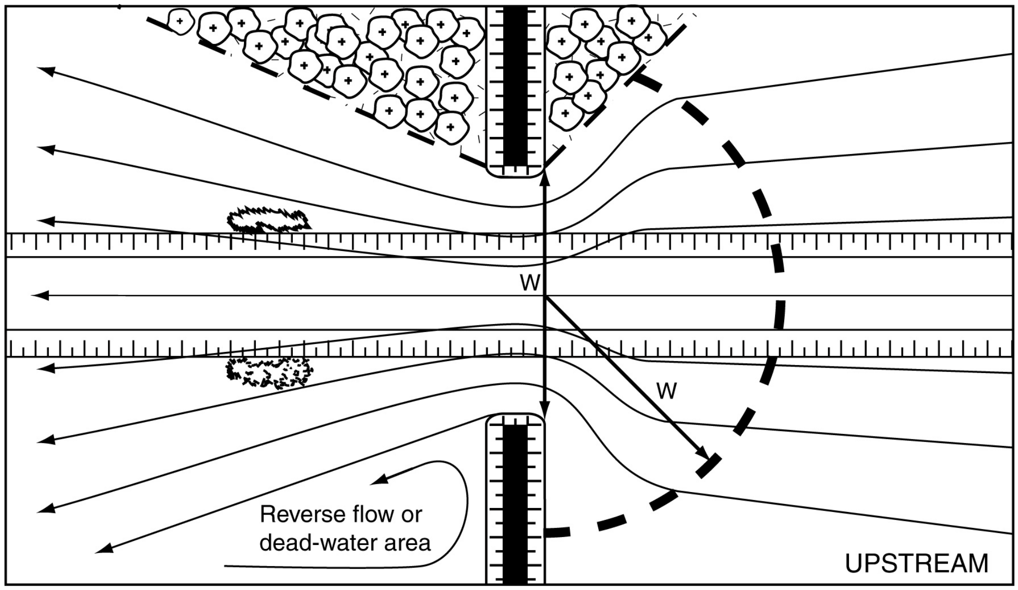

Figure 4.4 – Critical inflow control zone

In critical fish habitats, the prompt removal of bed-level debris blockage can be essential in maintaining essential fish passage along the waterway. Such debris blockages may appear insignificant from a hydraulic (flood control) perspective, but can be critical in the sustainable management of aquatic habitats.

5.2.10. Weirs and dams

Management of blockage for dams and weirs needs to consider each situation individually since every location will have its own unique features. Generally it is necessary to review the specific risk factors for each location and consider the appropriate measures.

Where blockage of spillways occurs, maintenance must be implemented quickly to ensure the safety of the structure.

5.2.11. Overland flow paths and open channels

Management of these drainage systems requires a planning process to ensure that the drainage system is well understood and future works on the floodplain do not cause a risk increase for the system.

5.3. DEBRIS REDUCTION PROGRAMS

While debris reduction programmes may be difficult to implement, the reduction of the source of blockage material is an excellent means of reducing the damage and inconvenience caused by blockage of hydraulic structures. This can be implemented in catchment management plans that include specific measures to reduce the sourcing of problem debris.

Debris reduction programmes can be implemented in conjunction with community awareness programmes.

5.4. DEBRIS CONTROL STRUCTURES

Debris control structures are structural measures provided in a watercourse or immediately upstream of critical structures to collect debris before it reaches the structure and causes problems. These can be.

- fences, posts or rails providing a much larger "interception area" for debris than a pipe or culvert entrance.
- storages or dry basins in which boulders or other debris can collect as on the Hobart Rivulet.
- diversion structures designed to provide safe bypass of debris or water.

These structures can be a part of a water quality management plan for a catchment.

5.5. MAINTENANCE OPTIONS

5.5.1. Introduction

As demonstrated throughout this report, blockage can have a range of important impacts on drainage systems. Maintenance is a way of reducing this impact and maintaining the system to an acceptable standard.

Maintenance is necessary to reduce the impact of blockages in stormwater drainage. When designing for maintenance the essential criteria are the following;

- Whole of life costs.
- Physical access.
- Legal access.
- Workplace health and safety issues.
- Frequency and trigger points for maintenance.
- Unintended risks to children and others.
- Design to be replaced.
- Local environment.

5.5.2. Whole of life costs

When comparing alternatives for structures, whole of life costs must be compared rather than just the initial costs. Whole of life costs include maintenance and replacement cost over the anticipated life of the structure.

5.5.3. Physical access

Access to the structure must be provided for maintenance purposes, access must provide for the most efficient way of maintaining the structure. This may include all-weather roads or tracks to access the structure with trucks, bob cats or other equipment to maintain the structure and remove material. The grade and width of access tracks must be appropriate for the equipment used and the likely conditions it is used in.

5.5.4. Legal access

Local authorities require the legal right to access waterway structures and maintain them. This can be achieved by appropriate easements that will include drainage easements and access easements from the public road.

5.5.5. Workplace health and safety

An understanding of workplace health and safety laws and the reasons for them is essential when designing for maintenance. The laws restrict the size and weight of grates, height of access walkways, depths of manholes etc. A maintenance plan will be rendered inoperable if it contravenes the Workplace Health and Safety Act.

5.5.6. Frequency and trigger points for maintenance

A maintenance plan should be developed at design stage, to guide those maintaining the structure, regarding both the essential and desirable works that must be done. The timing and frequency of the maintenance work is an important part of the maintenance plan. The plan will help estimate the cost the anticipated maintenance.

5.5.7. Unintended risks to children and others

Waterways attract children and waterway structures can challenge children, this must be taken into account when designing storm water structures. The location off the structures, the anticipated age of the children, the likelihood of adult supervision, and the possible consequences of an accident are other factors to take into account when considering the maintenance of waterway structures with respect to children.

5.5.8. Replacement of structures

Structures consist of elements that have a limited life. The appropriate replacement of the structure or parts of it must be taken into account at the design stage. The structure must be able to be replaced in the future without causing inordinate disruption and expense.

5.5.9. Design to reduce maintenance costs

Typical examples include the following:

- *Mangrove areas.* Widen concrete aprons and maintenance access to culverts to prevent mangroves growing back and blocking structures.
- *Natural Channels.* Design "natural" channels to include sensitivity check with Manning's "n" of 0.15 to allow for future planned and unplanned re-vegetation.
- *Vegetated catchments.* Trap debris at a more appropriate upstream location where it will cause less damage and/or it is easier to collect or divert debris with appropriate structures
- *Tidal areas*. Sacrificial depth (eg 150mm) for silting in channels, culverts etc.
- *Low bikeway bridges.* Collapsible handrails
- *Tide gates.* Install in manhole and not at outfall
- *Pipes, culverts and so on.* Minimum sizes of pipes, culverts, inlets and other structures.

Field inlets are a common source of blockage for storm water drainage systems. Inlets should be designed for both low flows and high flows. The most effective are designed to take flow from any direction, ie all sides and the top, a sloping surface such as a dome allows the pit to still function effectively with floating debris, is structurally stronger, safer and is easier to maintain than a flat inlet.

5.6. STRUCTURE MODIFICATIONS

Structures can be modified to allow debris that potentially causes blockage to be directed through the structure with a reduced risk of blockage. These modifications can include improved inlet performance or an increase in the size of the structure.

5.7. COMMUNITY AWARENESS

Education and awareness programmes can be implemented in conjunction with planning procedures to ensure that the community is aware of the risk and consequences of debris movement in watercourses and can take active measures to reduce the availability and risk of movement of debris.

While this approach would seem to be a possibility, such a programme would be very difficult to implement and would need to be every well targeted to be effective.

6. CONCLUSIONS AND RECOMMENDATIONS

6.1. OVERVIEW

Blockage has been identified as an important aspect of drainage planning and design, but one which is little understood and often poorly managed. Blockage can has significant impacts on the drainage system and can lead to costly and sometimes dangerous impacts on the community.

This report has drawn together experts in the field from a number of agencies around Australia and developed an understanding of current issues and procedures. While efforts have been made to include representatives of different industry sectors and geographical regions, it is recognised that there are gaps in this coverage. This means that the conclusions of this report are subject to further refinement as further coverage is incorporated.

Considering the significance and impacts of blockage, it has been surprising that the available data has been so limited and the adopted procedures so variable.

This report provides a background review of many of the issues that are needed for the assessment and design flor blockage of hydraulic structures. There are extensions of this work that will provide a more comprehensive coverage of the issues and will also provide design guidance for application of the findings.

This additional work will be carried out as Stage 2 of this project and will include the following aspects.

Publicise this report. The findings of this report will be published in technical forums and this will inform others of the progress and invited further contributions. This report will be presented at technical presentations during the second half of 2009 to invite these further contributions.

Gather more data. This project has made an effort to gather data and has made an effort to contact relevant agencies around Australia to find individuals and organisations that can be of assistance. While many individuals have been identified and they have contributed, it is likely there are others who may be able to provide additional information. The distribution and discussion of this report will hopefully locate some of these people, and they will be able to assist in the following stages.

Review further policies. Councils and other agencies have polices as part of their engineering guidelines to assist in the appropriate management of blockage in drainage systems. Some of these policies have been reviewed as part of the preparation of this report, but the review has been far from complete. Further research is proposed to collect additional information and determine if there is any agreement on the types of policies that are adopted and applied. A part of this review will be to assess the effectiveness of these policies and of any monitoring that has been carried out.

Prepare recommended procedures. The ultimate outcome of this project is to consolidate all of the findings and to make recommendations on procedures that can be adopted for planning and design of drainage systems throughout Australia. Following the completion of this comprehensive project, the recommendations should draw on the best and most complete data from throughout Australia and then should result in consistent and logical application of blockage allowances for all drainage designs.

6.2. FURTHER INVESTIGATIONS

The principal objective of this project is to provide appropriate recommendations for parameters to be used in the planning, design and management of blockage in drainage structures. This Stage 1 report has outlined the issues concerned in a qualitative manner, and has given descriptions of the range of conditions that must be considered and well as a description of a number of case particular conditions that were known to the members of the committee that has prepared this report.

Stage 2 of the project will be more difficult and will provide the numerical guidelines that need to be applied to the problem.

Because of the lack of currently available exact quantitative guidelines and the expected wide variation for different geographical regions and catchment types, these guidelines will need to be developed based on experience and judgement of the committee members and other input. Even after the Stage 2 report has been published, there will be additional material that will become known and this will necessitate changes to the guidelines. Because of the current poorly developed knowledge in the field, the guidelines in the Stage 2 report will be subject to further development and revision, though they will be a considerable advance on the very limited guidance that is currently available.

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