Australian Rainfall & Runoff

Revision Projects

PROJECT 11

Blockage Guidelines For Culverts And Small Bridges

STAGE 3 REPORT

FEBRUARY 2015

Australian Government

ENGINEERS AUSTRALIA
Water Engineering

PROJECT 11: BLOCKAGE OF HYDRAULIC STRUCTURES
BLOCKAGE GUIDELINES FOR CULVERTS AND SMALL BRIDGES

STAGE 3

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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However, many of the practices recommended in the 1987 edition of AR&R are now becoming outdated, no longer representing the accepted views of professionals, both in terms of technique and approach to water management.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 Technical Committee for
ARR Research Projects

Dr James Ball
ARR 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

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1 INTRODUCTION

1.1 Background and Scope

Blockage can have a severe impact on the capacity of drainage systems, even though there are situations where significant blockage may not impact flood behaviour to any great extent. Determination of likely blockage levels and mechanisms, when simulating design flows, is therefore an important consideration in quantifying the potential impact of blockage of a particular structure on design flood behaviour.

This report provides guidance on the assessment of blockage in drainage systems to assist in drainage analysis and design for urban and rural catchments., While there are a range of locations and conditions where blockage of a drainage network may be a concern in hydraulic design, this guidance note concentrates specifically on blockage of cross drainage structures, in particular culverts and small bridges.

Blockage of drainage structures is a subject where a range of advice has been provided in different guidelines. Many drainage guidelines do not mention blockage at all, therefore blockage is ignored in many cases. In other situations, especially where there has been an observed blockage problem in historical flood events, blockage may be specified for extreme conditions. Other guidelines provide inconclusive advice.

In fact, the actual evidence for the impact of blockage on design flood events is very limited and the evidence for any clear quantitative design advice is lacking. This is the case internationally as well as in Australia.

This guideline is not a definitive approach, but is an attempt to provide an approach that allows a consistent analysis methodology, while not becoming too extreme in either direction since there are risks in either under- or over-estimating the influence of blockage. It draws heavily on the findings of an earlier report prepared by the ARR Project 11 team. Material upon which this guideline has been based are referenced in the Bibliography of this guideline and in the earlier project reports and papers released on the ARR website (www.arr.org.au).

It is expected that this guideline will be updated and revised as more information becomes available and designers gain experience in the assessment of blockage and how it affects the drainage system and calculated design flood behaviour.

1.2 Limitations of Procedure

This procedure has been developed to quantify the most likely blockage level and mechanism for a small bridge or culvert when impacted by sediment or debris laden floodwater. It has not been developed for and is not appropriate when considering the impact of what are known as hyperconcentrated flows, mudflows or debris flows, on blockage of a structure. Hyperconcentrated flows are typically defined by a solids content of 20% or more by volume (or about 40% by weight) of the water column. Mud and debris flows include even higher levels of solids. At these much higher levels of suspended or fully integrated solids, blockage levels are likely to be much higher than those assessed in accordance with this guideline. Care should be taken in the review of catchment conditions where bed grades are relatively steep (say > 3%), to confirm bed and banks would remain relatively stable, such that flows would remain in the sediment or debris laden category and not become hyperconcentrated during the event under consideration.

While this procedure includes consideration of the impact of non-floating (sediment) on blockage of a structure, it is restricted to the likely impact of such material arriving at the structure during a design event. It cannot reflect the impact of any pre-existing build-up of sediment on the subsequent blockage of a structure.

2 TYPES OF STRUCTURES AND DRAINAGE SYSTEMS

The types of structures or drainage elements affected by blockages can generally be grouped as follows:

(a) *Bridges and Culverts:* These cross drainage structures carry roads, railways, pipelines or other infrastructure across watercourses. These structures can be affected by a number of different types of blockage mechanisms, resulting in consequences including increased flood levels, changes to stream flow patterns, changes to erosion and deposition patterns in channels, and physical damage to the structure. Blockage of these structures is the subject of this guideline.

(b) *Drainage system inlets and pipes:* This includes components of urban drainage systems located within road reserves and urban overland flow paths. Frequently blockage of this type of system is generally less likely to cause the same extent of damage associated with blockage of bridges and culverts, but the consequences can still be serious from a traffic and safety perspective, and can cause serious inconvenience and nuisance. However in certain circumstances, in densely developed urban areas, pit blockage can cause significant monetary damage due to flooding of buildings upstream. While this type of blockage can be a significant nuisance, it is not covered in this guideline.

(c) *Open channels and waterways:* Blockage of natural and constructed waterways can occur at any location, typically as a result of large debris snagged against bank vegetation, or debris passing slowly down the channel. The consequences of such blockage are increased flood levels, diversion of surface flows and the possible relocation of the waterway channel as a result of severe bank erosion. Blockage of these structures is not covered in this guideline.

(d) *Overland flow paths:* This category covers various surface flow paths that are not normally recognised as drainage channels but do act to convey surface flows in larger events. Blockage of these flow paths can result from the deposition of sediment or the material blockage of structures built across the flow, such as property fences blocked by litter and grass clippings. Blockage of these structures is not covered in this guideline.

(e) *Weirs and dams:* Debris can cause blockage within the spillways of weirs and dams, especially where there is a significant constriction to the flow area. This could increase the water level in the storage, possibly threatening the security of the structure. The sudden release of large debris rafts from dam spillways can cause significant damage to downstream road crossings. Blockage of these structures is not covered in this guideline

3 FACTORS INFLUENCING BLOCKAGE

3.1 Generally

The factors that most influence the likely blockage of a bridge or culvert structure are;

- ***Debris Type and Dimensions*** - *Whether floating, non-floating or urban debris present in the source area and its size*
- ***Debris Availability*** – *The volume of debris available in the source area*
- ***Debris Mobility*** *– The ease with which available debris can be moved into the stream*
- ***Debris Transportability*** *– The ease with which the mobilised debris is transported once it enters the stream*
- ***Structure Interaction*** *– The resulting interaction between the transported debris and the bridge or culvert structure*
- ***Random Chance*** *– An unquantifiable but significant factor*

These various factors impacting debris movement and interaction with the structure are discussed further in the following sections.

3.2 Debris Type and Dimensions

3.2.1 Generally

All blockages that do occur arise from the arrival and build-up of debris at a structure. There are three different types of debris typically present in debris accumulated upstream of or within a blocked structure. This debris may be classified as floating (e.g. trees), non-floating or depositional (e.g. sediment) and urban (e.g. cars and other urban debris). Debris comprising natural materials is discussed in Sections 3.2.2 and 3,2.3 and urban debris in Section 3.2.4. A means of determining the relevant dimensions of the debris is set out in Section 4.4.1.

3.2.2 Floating Debris

Floating debris in rural or forested streams is generally vegetation of various types.

Small floating debris, less than 150 mm long, can include small tree branches, sticks, leaves and refuse from yards such as litter and lawn clippings and all types of rural vegetation. This type of debris can also be introduced into a stream by earlier windstorms, bank erosion and land mass failures or from seasonal leaf falls. It is important to note that this material is available in both urban and rural catchments, and is usually available for transportation at any time.

Medium floating debris, typically between 150 mm and 3 m long, mainly consists of tree branches of various sizes. This material is usually introduced into the flow path by channel erosion undermining riparian vegetation or through wind gusts during storms. It can also be present as a result of the breakdown of larger floating debris.

Large floating debris, more than 3 m long, consists of logs or trees, typically from the same sources as for medium floating debris. 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. In small and intermediate size channels, this material is not easily transported and can easily become snagged mid-stream acting as a collection point for smaller material (i.e. a debris raft or log-jam). Whole trees can be retained within streams by being temporarily anchored either to the bed or banks of the stream. Large floating debris is usually transported during larger floods or prolonged periods of high river-stage where the floodplain is engaged and the ability of the debris to become snagged is reduced. This type of debris can cause significant problems for both culverts and bridge structures.

Small items of vegetation will usually pass through drainage structures during floods, while larger items may be caught in the structure. Once larger items are caught, this then allows smaller debris to collect on the structure.

3.2.3 Non-Floating Debris

Non-floating debris in rural or forested streams is usually sediment of all types.

Fine sediments (silt and sand) typically consist of particles ranging from 0.004 to 2 mm. The deposition of finer clay-sized particles is normally a concern in tidal areas, with lower flood surface gradients and velocities. This type of debris is either transported along the streambed as bed load or within the water column as suspended load. Such material is normally sourced from sheet and rill erosion, landslip and landmass failures and channel erosion. Yield rates for this material can be significantly influenced by the conditions of, and changes to, a catchment due to urbanisation and/or rural land use practices.

Gravels and cobbles consist of rock typically ranging in size from 2 to 63 mm and 63 to 200 mm respectively. The source of this material may be from gully formation, channel erosion, landslips or land mass failure although landslips and/or land mass failures of any size will likely create hyperconcentrated or even debris flows which are not covered by this guideline. Once mobilised, gravels and cobbles are primarily transported as bed load within high gradient streams. The deposition of cobbles can readily block the entrance of culverts or reduce the flow area under bridges.

Boulders comprise rocks greater than 200 mm. The source of boulders is mostly from gully and channel erosion, landslips and the displacement of rocks from channel stabilisation works. Like gravel and cobbles, this material is typically transported as bed load in high gradient streams. This material can readily block the entrance to a structure and/or cause damage to the structure from the force of impact/collision.

3.2.4 Urban Debris

Urbanisation of catchments introduces many different man-made materials that are less common in rural or forested catchments and which can cause structure blockage. These include fence palings, building materials, mattresses, garbage bins, shopping trolleys, fridges, large industrial containers and vehicles. Garbage bins can for example be easily washed down a street and into a stream or drainage structure, a situation made worse if a large rainfall event occurs on the same day as rubbish collection within the catchment, when bins are placed in streets for collection. Urban Debris can be floating or non-floating.

3.3 Debris Availability

In discussing debris availability and mobility, defining the source area is an important consideration. The source area is that area from which debris could be sourced during an event. In a small event it may be restricted to the immediate confines of the creek and its banks but in larger events will likely extend to the full extent of the floodplain and possibly the full extent of the upstream catchment area. As this procedure is used to initially establish debris potential in a 1% AEP event , the relevant source area will typically be limited to the 1% AEP flood extents. Steep sided tributaries and larger rills may however extend the source area beyond the limits of the 1% AEP flood.

The following factors affect the availability of debris material within a source area.

- *Potential for soil erosion: S*oil erosion exposes soil and rock particles, thus increasing their availability. The potential for soil erosion is dependent on a number of factors including soil erodibility, rainfall erosivity, surface slope length and gradient, vegetation cover and changes in catchment hydrology, this latter factor being often closely linked to the effects of urbanisation.

- *Local geology:* The geology of the debris source area, particularly the exposed geology of the watercourse, influences the availability of materials such as clay, silt, sand, gravel, rocks and boulders.
- *Source area:* Increasing the area supplying debris typically increases the quantity of available blockage material. It is noted however, that once blockage occurs at a given structure, the debris source area for the next downstream structure may be much less than that of the upstream structures source area.
- *Amount and type of vegetative cover:* Cover can vary from grasses and shrubs to thick forests and plantations as well as a variety of crops and agricultural uses. Increasing the cover density in the source area will typically increase the availability of debris. Some types of cover are also more prone to produce debris than others (eg Cora trees). The type of cover in the source area can also impact availability *Land clearing:* This is associated with both rural and urban land use practices. Deforestation and urbanisation can alter the long-term flow regime of streams and may lead to gully erosion and channel expansion.
- *Preceding wind and rainfall:* The occurrence of frequent flood events typically reduces the availability of debris in the source area, however, the occurrence of frequent windstorms will typically increases the quantity of debris available in the source area.
- *Urbanisation:* Such areas make available a wide range of debris typically influenced by the extent of flood inundation and proximity of such debris to the stream. In most circumstances this a manageable factor linked to town planning and drainage design.

3.4 Debris Mobility

The following factors affect the mobilisation of debris material within the catchment:

- *Rainfall erosivity:* Different regions experience a range of frequencies of rainfall intensity, and in general, those areas that experience more intense rainfall have a greater potential to mobilise debris than areas of lower rainfall intensity.
- *Soil erodibility:* This can vary from weathered rocks to cohesive clays, all soils have different abilities to become eroded, entrained and available for mobilisation.
- *Slope:* For sediment and boulder movement, there is a relationship between the mobilisation of such debris and the slope of the catchment, with respect to overbank areas where debris may be sourced and the stream channel which conveys the debris.
- *Storm duration:* The mobilisation of materials generally increases with increasing storm duration.
- *Vegetation cover:* Sparse vegetation cover can increase sediment mobility.

3.5 Debris Transportability

Once debris has been mobilised, it then needs to be transported down the stream if it is to present a hazard to downstream structures. Stream power, velocity, depth, presence of snags and bends and the overall dimensions of the water course play a large part in determining whether the mobilised debris lodges where it first enters the stream or is transported downstream to a receiving structure. There is a reasonably strong correlation between the waterway width and the maximum size of floating debris that a stream can transport. The event magnitude is also a major factor in controlling the quantity of debris transported. Rarer events produce deeper and faster floodwater able to transport large quantities and larger sizes of debris, smaller events may not be able to transport larger bridging material at all.

3.6 Structure Interaction

The likelihood of blockage at a particular structure depends on whether or not debris is able to bridge across the structure's inlet or become trapped within the structure. As bridging occurs, the clear expanse of each opening reduces, thus increasing the likelihood of further bridging and further blockage by smaller or similar material. Smaller blockage matter is unlikely to cause full blockage of a structure without the presence of suitable larger bridging matter, the material that initially bridges across the opening or inlet of a structure. Bridging matter can be as small as leaves caught on a kerb inlet grate, or as large as logs, cars and shipping containers caught at a culvert inlet or on bridge piers.

Exposed services attached to the face of culverts or bridges or obstructing the culvert waterway opening can significantly increase the risk of blockage. Similarly, some through-culvert features introduced to improve fish passage can also collect and hold debris increasing the risk of internal blockage problems. Many other factors such as skew alignments, opening aspect ratios, opening height to overtopping height ratios, culvert hoods, sloping inlet walls and the smoothness of transitions can also modify the likely interaction between the arriving debris and the bridge or culvert structure

In urban drainage systems, any individual culvert in the system is not an individual structure, it is part of a system, generally with culverts and other structures in a series down the water course. As a consequence, upstream culverts are likely to collect a portion of the transported debris in the stream, reducing the quantity of debris that would otherwise reach the downstream culverts so the risk of blockage in these downstream structures is reduced.

Consideration of multiple structures is discussed further in Section 4.4.10.

3.7 Random Chance

While an unquantifiable factor, random chance plays a significant role in the blockage of structures. Antecedent conditions can in particular substantially alter the likely level of blockage at a structure. Recent floods can for example reduce the availability of debris but increase the transportability of debris of a particular size by cleaning out the waterway. Even the alignment of a limb approaching a structure can substantially alter its likelihood of being caught on the inlet and triggering a more substantial blockage. Blockage of a structure in any event of a particular magnitude will therefore vary in response to these random changes in behaviour, creating a distribution of blockage levels associated with such an event. This guideline attempts to quantify the average or most likely blockage level associated with a design event of a particular magnitude, as this presents an AEP neutral approach to simulation of the resulting flood surface.

4 ASSESEMENT OF DESIGN BLOCKAGE LEVELS

4.1 Overview

Blockage of cross drainage structures such as culverts and bridges could have an impact on the capacity of these structures and also on flood levels. Hydraulic analysis of these structures should therefore provide for some consideration of these impacts. This section describes a procedure for the inclusion of the impacts of blockage in analysis.

The design blockage is the blockage condition that is most likely to occur during a given design storm and needs to be an “average” of all potential blockage conditions to ensure that the calculated design flood levels reflect the defined probability. For example, an assumption of a higher than average level of blockage would lead to the calculated design flood level upstream of the structure being higher than would be appropriate for the defined probability. Downstream flood levels would be lower because of the additional flood storage created upstream of the structure. On the other hand, an assumed lower than average level of blockage would result in lower flood levels upstream and higher flood levels downstream. This is a similar concept to that of AEP neutrality used in various aspects of design flood event analysis. It is also noted that actual blockage levels vary greatly from event to event with a potential spread from “all clear” to “fully blocked” even in floods of comparable magnitude. Antecedent catchment conditions and pure chance are major factors in determining blockage levels in an actual event. The selected design blockage must aim for AEP neutrality (the concept of ensuring that the average recurrence interval of the design flood discharge is the same as the AEP of the design rainfall input) so design floods are appropriate for the particular circumstances. As with other similar aspects of design flood estimation, such as losses, each individual historical flood may have quite different amounts of blockage compared to the design event.

Flood mapping is an exercise in probabilities that involves the estimation of ‘average’ catchment conditions for various storm and flood frequencies to ensure that the rainfall of the defined probability produces a flood event of the same probability. In such work, *design blockage* conditions must be considered when predicting flood levels of a given frequency. In situations where the consequences of flooding (including the impact of blockage) are high, planning rules typically require design for a lower probability (rarer) event. An increase in the design event probability is typically adopted for planning purposes, when the consequences of flooding are low.

This guideline is based on a design event type analysis, where a flood of a defined flood probability is required. For Monte Carlo analysis of flood risk, a probability distribution of blockage is required, as an input. Considering the uncertainty in the assessment of blockage, analysis of probability distributions is even more difficult. This topic is discussed in a little more detail below in Section 5.3.The procedure presented in this guideline is based on a qualitative assessment of debris likely to reach a structure, and the likely interaction between that debris and the structure regarding its potential for blockage. It is based on the various papers prepared by Barthelmess, Rigby, Silveri and others.

The procedure initially involves a series of decisions leading to estimation of the likely magnitude of debris reaching a structure in a 1% AEP event and the most likely blockage level that would develop at the structure under consideration. Subsequent adjustments are then made to reflect the most likely design blockage levels in lesser or greater AEP events and to establish the associated most likely blockage mechanism. This procedure provides an AEP neutral approach to the assessment of an appropriate level of blockage for the simulation of design flood behaviour , but may not reflect specific conditions in an equivalent historical event. Such is the random nature of the many variables controlling blockage behaviour

4.2 Appropriate Investigation

It is important to recognise the impact that different levels of investigation can have on the confidence associated with any blockage estimate. Estimates based on aerial imagery alone cannot for example provide the level of confidence that would be obtained from a field visit to the site, specifically aimed at assessing the various factors influencing blockage levels at the site or likely blockage mechanisms.

Where the target structure/site is located in a particularly flood sensitive area and blockage of the structure could significantly impact flood behaviour in that area, then a high level of investigation is warranted. This should include a field inspection of the upstream catchment/source area to confirm the types of debris likely to reach the site, their availability, mobility and transportability together with the average size of the largest 10% of each debris type likely to reach the site. Any structures upstream of the target structure/site should be inspected and consideration given to their ability to trap debris reaching the target structure/site. Any photographs/records of past blockage material and extents should be used to validate the choice of L_{10} and debris type. Although seldom available, any photos/records of the blockage mechanism (Location – Type – Timing) that have been observed in past events will help to validate the chosen blockage mechanism to be used in the hydraulic model. However it must be stressed that it is the most likely (AEP neutral) blockage mechanism that is required, not the worst case scenario. Flood mapping, aerial photography, annual rainfall and rainfall IFD data, rainfall and soil erosivity maps, topographic maps, vegetation and soil maps should be consulted when available to further consolidate conclusions as to the types of debris likely to reach the site and the quantum of such debris.

Conversely, when the structure under consideration is in an area where changes in flood behaviour would have no significant consequences on safety, property damage or amenity, then an extensive investigation to support the blockage assessment process, as outlined above, may not be warranted. This decision should be documented..

The final decision as to what is an appropriate level of investigation must ultimately be the responsibility of the person making the assessment. It will vary greatly between sites and will to some extent be constrained by what information is available. Whatever the approach adopted, it is important that the level of investigation undertaken should be relevant to the importance of the assessment of blockage at the site and is documented, so that others relying on the assessment can be aware of the confidence limits attaching to that particular assessment.

4.3 Blockage History

The history of blockages in the drainage system is an important input to any risk based approach to blockage, and should always be explored in so far as available data permits. While the procedure outlined in this guideline provides a generic assessment of likely design blockage levels and mechanisms, local observations and history can be important in ensuring that this procedure results in reasonable answers. All available history should be sought from relevant local stakeholders, including residents, in assessing the reasonableness of blockage levels and mechanisms produced by this guideline.

In particular, if there has been no long term history of blockage at a particular structure and similar drainage structures in the catchment have not demonstrated blockage problems, blockage may not need to be considered, or a nominal allowance only may be appropriate in design.

4.4 Assessment Procedure

4.4.1 Debris Types and Dimensions

In using this procedure it is necessary to first assess the type of debris likely to arrive at the structure under review and the likely dimensions of that debris. Where more than one type of debris is present in quantity in the source area, the procedure will need to be repeated for each debris type to establish the debris type with the most impact on the performance of the blocked structure.

The types of debris available in their respective source areas will normally be readily apparent during a field visit or from aerial photographs, but relevant dimensions may be more difficult to assess.

The ratio of the opening width of structures (e.g. diameter or width of the culvert or bridge pier spacing) to the average length of the longer debris that could arrive at the site (termed here as L_{10}) is a well correlated guide to the likelihood that this material could bridge the openings of the structure and trigger a blockage. This L_{10} value is defined as the average length of the longest 10% of the debris reaching the site and should preferably be estimated from sampling of typical debris loads, If however, such data is not available, it should be determined from an inspection of debris on the floor of the source area, with due allowance for snagging and reduction in size during transportation.to the structure.

For debris of any particular type and size to reach the structure, the debris must;

- be available in the source area and,
- be able to be mobilised into the stream and not snagged by bank vegetation as it enters the stream, and,
- be delivered into a stream able to transport the debris from the source area down to the structure, without floating debris being snagged by bank vegetation or stream bends or constrictions, or without non-floating debris being deposited prior to reaching the structure as the stream grade and velocities reduce. For smaller more turbulent streams (less than say 6 m bank to bank) the width between banks of the stream through the source area will normally limit the size/length of larger floating debris to less than the stream width. The bed grade immediately upstream of the structure will normally limit the size of the larger non floating debris reaching the structure to that capable of being moved by the flow.

Any loose material and pockets of debris lying within or in close proximity to the channel are likely to be representative of the debris that could cause downstream blockage. A detailed inspection of the waterway upstream of the target structure, particularly after a flood, will assist with assessing the above factors and deriving a realistic value for L_{10}.

In an urban area the variety of available debris can be considerable with an equal variability in L_{10}. In the absence of a record of past debris accumulated at the structure, an L_{10} of at least 1.5m should be considered as many urban debris sources produce material of at least this length such as palings, stored timber, sulo bins and shopping trolleys.

4.4.2 Debris Availability

The availability of a particular type of debris (floating, non-floating or urban) in a source area limits the level of that particular debris that can be ultimately mobilised and transported to a structure. As noted in Section 4.4.1, there may be significant quantities of more than one type of debris present in the source area, requiring more than one type of debris to be assessed. The characteristics of high, medium and low availability are hard to quantify, so there is some judgment required in their evaluation. Table 1 describes typical source area characteristics and a corresponding ranking for the likely availability of a particular type of debris in that source area. It should be noted that the characteristics included are not exhaustive or presented in any particular order. Some will only be applicable in respect to certain debris types. They are provided to provoke thought about the factors that could be relevant to the level of availability. As this procedure is based on a 1% AEP flood (with later adjustment for other AEPs) the effective source area is that associated with a 1% AEP event.

Table 1: Debris Availability - *in source area of a particular type/size of debris*

Classification	Typical Source Area Characteristics (1% AEP Event)
High	• *Natural forested areas with thick vegetation and extensive canopy cover, difficult to walk through with considerable fallen limbs, leaves and high levels of floor litter.* • *Streams with boulder/cobble beds and steep bed slopes and steep banks showing signs of substantial past bed/bank movements.* • *Arid areas, where loose vegetation and exposed loose soils occur and vegetation is sparse.* • *Urban areas that are not well maintained and/or where old paling fences, sheds, cars and/or stored loose material etc., are present on the floodplain close to the water course.*
Medium	• *State forest areas with clear understory, grazing land with stands of trees.* • *Source areas generally falling between the High and Low categories.*
Low	• *Well maintained rural lands and paddocks with minimal outbuildings or stored materials in the source area.* • *Streams with moderate to flat slopes and stable bed and banks.* • *Arid areas where vegetation is deep rooted and soils are resistant to scour.* • *Urban areas that are well maintained with limited debris present in the source area*

4.4.3 Debris Mobility

The ability for debris to become mobilised from the source area into a stream has an effect on the amount of debris that can then be ultimately transported to a structure. Table 2 describes typical source area characteristics and a corresponding rank for the likely mobility of debris from the sorce area into receiving streams.

Table 2: Debris Mobility – *Ability of a particular type/size of debris to be moved into streams*

Classification	Typical Source Area Characteristics (1% AEP Event)
High	Steep source areas with fast response times and high annual rainfall and/or storm intensities and/or source areas subject to high rainfall intensities with sparse vegetation cover. Receiving streams that frequently overtop their banks. Main debris source areas close to streams
Medium	Source areas generally falling between the High and Low mobility categories.
Low	Low rainfall intensities and large, flat source areas. Receiving streams infrequently overtops their banks. Main debris source areas well away from streams

4.4.4 Debris Transportability

The ability for debris to be transported by a stream down to a structure has an effect on the amount of debris arriving at the structure. Table 3 describes typical stream characteristics and a corresponding rank for the likely transportability of debris.

Table 3: Debris Transportability - *Ability of a stream to transport debris down to the structure*

Transportability	Typical Transporting Stream Characteristics (1%AEP Event)
High	• Steep bed slopes (> 3%) and/or high stream velocity (V>2.5m/sec) • Deep stream relative to vertical debris dimension ($D > 0.5L_{10}$) • Wide stream relative to horizontal debris dimension.($W>L_{10}$) • Stream relatively straight and free of major constrictions or snag points. • High temporal variability in maximum stream flows.
Medium	Stream generally falling between High and Low categories.
Low	• Flat bed slopes (< 1%).and/or low stream velocity (V<1m/sec) • Shallow depth relative to vertical debris dimension ($D < 0.5L_{10}$) • Narrow stream relative to horizontal debris dimension ($W<L_{10}$) • Stream meanders with frequent constrictions/snag points. • Low temporal variability in maximum stream flows.

4.4.5 Debris Potential

Where reliable long term data is available on the quantity and type of debris typically present at a structure, this should be used to directly quantify the debris potential at the structure. Where such data is not available, the potential quantity of debris reaching a structure at a site from a contributing source area in a 1% AEP event can be estimated from Table 4. If there is a significant quantity of more than one type of debris in the source area that could induce blockage, this will require more than one type of debris to be assessed.

Table 4: 1% AEP Debris Potential

Classification	Combinations of the Above (any order)
High	HHH or HHM
Medium	MMM or HML or HMM or HLL
Low	LLL or MML or MLL

4.4.6 Adjustment for AEP

Observation of debris conveyed in streams strongly suggests a correlation between an event's magnitude and debris potential at a site. This is accommodated in Table 5 as follows.

Table 5: AEP Adjusted Debris Potential

Event AEP	(1% AEP) Debris Potential at Structure		
	High	**M**edium	**L**ow
AEP > 5% (Frequent)	**M**edium	**L**ow	**L**ow
AEP 5% - AEP 0.5%	**H**igh	**M**edium	**L**ow
AEP < 0.5% (Rare)	**H**igh	**H**igh	**M**edium

4.4.7 Design Blockage Level

Inlet Blockage (Floating or Non Floating)

In conjunction with the quantity of debris likely to arrive at the site, Table 6 provides an estimate of the 'most likely' inlet blockage level should a blockage form from floating or non-floating debris bridging the inlet.

Table 6: Most Likely Inlet Blockage Levels - B_{DES}%

Control Dimension Inlet Clear Width W m	AEP Adjusted Debris Potential At Structure		
	High	**Medium**	**Low**
W < L_{10}	100%	50%	25%
W ≥ L_{10}≤ 3*L_{10}	20%	10%	0%
W> 3*L_{10}	10%	0%	0%

Barrel Blockage (Non Floating)

An alternative blockage mechanism is however possible for non-floating material (typically sediment) when this material progressively arrives and is deposited at the inlet and in the barrel or waterway of the structure. This typically leads to a bottom up blockage of both the barrel and inlet to the structure. Blockage in this form can arise because velocities through the structure fall below the level required to maintain the material in motion or, in extreme cases, because the depth of sediment in the bed load is sufficient to overwhelm the inlet, leading to sediment with little water completely blocking the inlet and filling a substantial proportion of the barrel of the structure.

Table 7a classifies the likelihood of deposition in the barrel or waterway based on sediment size and velocity through the structure. Using this likelihood of deposition Table 7b then combines the likelihood of deposition with the debris potential to provide a most likely depositional barrel or waterway blockage level for the structure.

TABLE 7a: Likelihood of Sediment Being Deposited in Barrel/Waterway (HML)

Peak Velocity Through Structure (m/sec)	Mean Sediment Size Present				
	Clay/Silt 0.001 to 0.04 mm	Sand 0.04 to 2 mm	Gravel 2 to 63 mm	Cobbles 63 to 200 mm	Boulders >200 mm
>= 3	L	L	L	L	M
1.0 to < 3.0	L	L	L	M	M
0.5 to < 1.0	L	L	L	M	H
0.1 to < 0.5	L	L	M	H	H
< 0.1	L	M	H	H	H

Based on Hjulstrom's diagram as modified by Sundborg

.

TABLE 7b: Most Likely Depositional Blockage Levels – B_{DES}%

Likelihood that Deposition will Occur (Table 6a)	AEP Adjusted Non Floating Debris Potential (Sediment) at Structure		
	High	Medium	Low
High	100%	60%	25%
Medium	60%	40%	15%
Low	25%	15%	0%

It is noted that Table 7b (blockage caused by non-floating debris) is to be read in conjunction with Table 6 (blockage caused by floating debris) and the blockage mechanism creating the worst impact on flood behaviour should be used in design.

While the above tables provide a means of estimating a realistic value for the magnitude of a likely (AEP neutral) blockage, they do not address the other characteristics required to properly describe the blockage mechanism (viz the blockage type, location and timing) and its impact on the hydraulics of flow through the structure. These issues are discussed further in Section 5.

4.4.8 Minimum Opening Height Considerations

Consideration of likely inlet blockage levels as presented in Table 6 assumes that the greatest dimension (length) of debris relative to the structures opening width is the dominant factor influencing inlet blockages. All debris however has three dimensions and a lesser dimension, such as the debris height, could also trigger vertical bridging across the opening height if the structure's opening height was substantially less than the structures opening width. In the absence of detail data on likely debris geometry, it is recommended that structures be designed with a clear opening height of at least one third their width to reflect the assumptions inherent in this procedure. In an existing structure where the opening height is less than one third of the opening width, it is recommended that analysis be based on the likely vertical dimension of the debris and the vertical opening height of the structure in lieu of the likely debris length and horizontal opening width. Unless data is available to support the choice of L_{10} (vertically), it should be taken as not less than one half of the assessed debris L_{10} (length).

4.4.9 Blockage of Multi Cell/Span Structures

Limited observation of blockages at multi cell culverts or multi span bridges suggests that all cells/spans often do not block to the same extent. The main factors influencing this variability appear to be the main stream approach alignment and location relative to the multiple culverts or spans and the relative width of flow carrying debris to the total opening width. These two factors are somewhat related as they both influence the uniformity of presentation of debris, carried by the flow, to the individual cells or spans.

Where the main stream width is considerably less than the total structure width, it is likely that more debris will be delivered to and accumulate at or in the cells/spans falling within the main stream width, than at the cells/spans located on the adjacent floodplains. This may however not be the case when the mainstream flow is only a small proportion of the total flow reaching the structure. In such cases the presentation of debris to the multiple cells/spans may become more uniform resulting in more consistent levels of blockage.

As an initial guide it is suggested that, where the width of that part of the approach flow that is capable of transporting the debris under consideration, is comparable with or greater than the total width of the structure, then the assessed B_{DES} be applied uniformly to all cells/spans.

Where the width of that part of the approach flow that is capable of transporting the debris under consideration is significantly less than the total width of the structure, then the culverts/spans within the effective transport width be assessed as blocked to B_{DES} and those outside of that zone be reduced to half B_{DES}. Measurements of observed distributions are however essentially non-existent at this time. More information, to permit refinement of guidelines for blockage of multiple spans/cells, is needed.

4.4.10 Assessment of Multiple Structures

It is fundamental to the consideration of the interaction between multiple culverts that any individual culvert/bridge could be 'all clear' or 'guideline blocked' in a design event.

The question then arises as to what are the 'likely' AEP neutral combinations of blockage that could occur across a catchment. Clearly an 'all clear' (Bdes=0) global solution is possible in any event and even probable in lesser events. In these lesser events the single site Bdes is probably also low so the change in catchment floods behaviour between different mixes of sites with Bdes>0 and Bdes=0 may not be great. In larger events however substantial differences in flood behaviour can be created from different mixes of 'all clear' and Bdes structures across the catchment. Simple math shows that n independent sites with two choices for blockage presents 2^n combinations. A catchment with 6 interacting culverts therefore could involve 64 possible blockage scenarios. In analysing these mixes it is therefore critical both with respect to AEP neutrality and computation time that only likely combinations are considered. Seldom will all structures be responding in a truly independent manner. There is unfortunately no pre-prepared solution for this problem – all catchments will be different. While not a truly AEP neutral approach, modelling all structures 'all clear' and 'guideline blocked' ensures individual structure impacts are properly simulated in the envelope solution together with the all-clear impacts. If these scenarios are then augmented with 'likely' mixtures of clear and guideline blocked structures, the resulting flood surface envelope should reasonably represent the likely envelope flood surface levels that could be reached at any site in the catchment. It should be noted however that in any single historic event of a given AEP, the recorded flood surface will likely only reach the envelope levels at some locations (due to the variability in actual historic blockages).

As previously noted, where there are multiple structures on a contiguous water course, the debris availability will normally reduce downstream since debris will be captured by the upstream structures. Therefore for downstream structures, the debris availability, as defined in Table 1 will normally be reduced.

4.4.11 Risk Based Assessment of Blockages

In general, the consequences of a flood event of given probability will be used to establish risk in an area or at a site and this level of risk will in turn be used to establish the appropriate event AEP to be used as the planning event for that particular area or site. What this approach does not reflect is the relative uncertainty in all of the various parameters influencing design flood estimation. With even the most careful approach to the selection of parameters like design rainfall intensity, rainfall temporal patterns, stream roughness or most likely blockage levels, there is a significant likelihood that error in the assessment of these parameters may in turn lead to errors in the predicted design flood behaviour

In an event based approach to modelling it is therefore prudent to undertake various sensitivity runs to quantify how reasonable variation in the chosen parameters could affect the model's results. Where such an analysis generates significant changes in the flood surface, it indicates that the parameter creating that change needs very careful review to confirm that the value selected was as appropriate as available data permits. A sensitivity analysis of alternate reasonable blockage levels and mechanisms is therefore strongly recommended for design or analysis involving blockages. It is recommended that the sensitivity to such a variation in design blockage levels be incorporated into analysis by considering both an 'all clear' and blocked at twice the calculated guideline blocked level (max 100%) scenarios, to identify sites where flood behaviour upstream or downstream of the structure is particularly sensitive to the adopted design blockage level. Where such a site is identified, all inputs into the assessment process should be carefully reviewed to confirm the adopted design blockage level before proceeding with design or analysis based on that level.

As blockage of a structure with significant upstream available flood storage can lead to a reduction in flood flow and levels downstream of the structure, effectively protecting downstream properties, it is important to review the all clear analysis to see if the all clear scenario results in significantly increased flows downstream of the structure. If this is found to be the case then the all clear and guideline blocked results should be enveloped for design flood estimation purposes.

In reviewing risk, inclusion of blockage in a Monte Carlo analysis is a valuable means of quantifying the impact of blockage on uncertainly in the flood assessment process. A distribution of blockage values is however needed for Monte Carlo analysis. Considering the uncertainty inherent in the factors influencing blockage levels and the lack of data in respect to the variation of blockage levels over time, it is however difficult to determine a suitable distribution. What little has been done on this distribution suggests that the probability distribution is likely to be dual peaked with the 'all clear' and 'most likely' values ranking higher than adjacent values. Much more data is however needed before these characteristics can be confirmed.

4.5 All Clear

This is the condition where there is no allowance for blockage, and the hydraulic analysis assumes that the structure flows freely.

This condition should be considered as referenced above as an important sensitivity case, since the all clear condition will reduce the upstream flood level and may increase flood levels downstream depending on the storage and flood immunity of the structure being considered.

Secondly, and perhaps more importantly, as referenced in Section 4.3, blockage may not need to be considered at all or may need consideration as a nominal allowance, if there is no history of blockage at this site or at similar neighbouring sites, especially if there is low risk of damage or disruption caused when blockage is neglected.

5 HYDRAULIC ANALYSIS OF BLOCKED STRUCTURES

5.1 Generally

Where blockages have historically been included in analysis or design, they have often been applied as a reduction factor to the all-clear flow through the structure. This is a simple and rapid means of making some allowance for blockage and in the absence of information on likely blockage mechanisms and extents can provide an answer commensurate with the associated uncertainty in such an approach.

This guideline enhances our understanding of likely design blockage mechanisms at a structure by quantifying likely blockage levels at a structure based on assessable catchment and structure parameters and understanding the blockage mechanism that will likely develop at the structure. Given this information, a more deliberate approach to hydraulic analysis of design blockages is now available, although most current hydraulic modelling software currently lacks the functionality to simulate the blockage mechanisms described in this document. It is hoped that this functionality will however be made available in the more capable software packages, in use in Australia, in the not too distant future.

5.2 Blockage Types

As previously noted, a blockage mechanism can be described by its type, its location and its timing and extents. With respect to type, there are three types of blockages that could occur.

A top down blockage occurs, when a floating debris raft builds up at the entrance to a structure, obstructing the inlet. This is a very dynamic type of blockage with the raft volume and elevation varying over time. These changes occur in response to both the flow rate and the difference between debris being added and lost from the raft as the blockage develops. On the flood recession this material may settle to fully block the inlet even though the inlet may have been only partly blocked by the raft at the flow peak. While rarely available, the temporal history of such a blockage, in an historic event, can be an important factor in realistically reproducing the actual flood behaviour at the blocked structure. While top down blockages are common in heavily vegetated areas, realistic simulation of this form of blockage is very complex.

A bottom up blockage occurs, when non floating material is deposited at the inlet and/or in the barrel or waterway of the structure. This also is a dynamic type of blockage with sediment being both added and removed from the blockage as time passes. Because of the dynamic nature of this process, the debris apparent at the conclusion of the event may have little relationship to the debris level at any point in time during the event. As with the top down blockage, the temporal history of blockage in an historic event can be important in realistically reproducing actual flood behaviour during the event. Bottom up blockages are relatively common in steep lightly vegetated catchments with unstable stream banks or easily eroded stream beds. As the geometry of a bottom up blockage does not directly vary with flood stage (as in a top down blockage), hydraulic analysis of a bottom up blockage is more straightforward.

A porous plug blockage typically occurs when larger vegetative debris (often rapidly) bridges across the inlet of the structure covering the entire inlet but with sufficient porosity to allow some flow through the plug. It typically arises from a rapid bank or slope collapse, releasing a substantial pulse of vegetation and sediment into the stream. Unlike a top down or bottom up blockage, the porosity of this plug will likely only diminish as the event continues, with ever finer material being trapped on the bridging material that triggered the initial blockage. As blockage geometry does not vary with flood stage (as in a top down blockage), hydraulic analysis of a porous plug blockage is also more straightforward.

5.3 Blockage Mechanisms

While the number of possible blockage mechanisms is considerable, there appears to be a strong correlation between the dominant debris type arriving at a structure and the blockage mechanism it triggers. This correlation forms the basis of Table 8 where the blockages ‘most likely' location, timing and extents are described. It should be noted that this table is based heavily on limited observations and should be updated as further data becomes available.

Progressive floating raft inlet blockages are assumed in this guideline to significantly impact flow through the structure only after the flow peaks (being mostly clear at higher flows as the raft lifts clear of the inlet and possibly overtops the structure. Pulse like blockages of floating material at an inlet mostly arise from vegetation injected into the stream from collapsing banks, as floodwater rise or from litter swept off the floodplain as streams overtop their banks. Neither of the above blockages is likely to create a significant barrel/waterway or outlet blockage although non floating debris, if present in any quantity can build up under the raft at the inlet and in the barrel, particularly as the flood recedes. It should be noted that factoring of all clear flow will not necessarily provide a good estimate of the impact of either of these mechanism as both are inlet control mechanisms and the all clear structure could be operating under strong outlet control.

Non floating material reaching a culvert or bridge will mostly build up progressively but can occur as a pulse of debris in streams with unstable banks. Typically, non-floating material (sediment) will build up throughout the structure (inlet, barrel and outlet) as increasing flows mobilise ever increasing amounts of bed and bank material. Material will be continuously lost from the accumulated debris mass, but the rate of supply is likely to exceed the rate at which material passes on downstream, at least while flows are increasing and new material is being mobilised.

These observations and assumptions on the likely type, location and timing of a blockage are summarised in Table 8 In this table, the following designations are used to describe the timing of key trigger points in the blockage process.

$\mathbf{T_{OTB/SA}}$ Is the time when flow that first overtops the stream's banks in the source area reaches the structure.

$\mathbf{T_{OT/F\ \&\ OT/L}}$ Are the times when flow first and last overtops the structure.

$\mathbf{T_{P}}$ Is the time at which the upstream water level peaks at the structure.

$\mathbf{T_{OBV/FL}}$ Is the time on the falling limb when the upstream water level drops back to the obvert level of the structure.

Table 8 Likely Blockage Timing and Extents

DOMINANT SOURCE MATERIAL	DELIVERY & TYPE	LIKELY BLOCKAGE LOCATIONS & TIMINGS			
		Inlet	Barrel	Outlet	Handrails[4]
FLOATING	Progressive Top Down	**0** @ $\mathbf{T_P}$ to B_{DES} @$\mathbf{T_{OBV/FL}}$	Unlikely	Unlikely[2]	B_{DES} @ $\mathbf{T_{0T/F}}$ to B_{DES} @ $\mathbf{T_{0T/L}}$
	Pulse[1] Porous Plug	B_{DES} @ $\mathbf{T_{OTB/SA}}$	N.A.	N.A.	B_{DES} @ $\mathbf{T_{0T/F}}$ to B_{DES} @ $\mathbf{T_{0T/L}}$
NON FLOATING	Progressive Bottom Up	**0** @ $\mathbf{T_{OTB/SA}}$ to B_{DES} at T_P	$\mathbf{T_{OTB/SA}}$ to B_{DES} at T_P	$\mathbf{T_{OTB/SA}}$ to B_{DES} at T_P	Unlikely
	Pulse[1] Porous Plug	Unlikely[3]	N.A.	N.A.	Unlikely

1. Pulse blockages are more likely in systems subject to irregular flooding and/or streams with unstable banks

2. Unlikely - but could become likely if inlet is open and outlet grated.

3. Unlikely – but could become likely if upstream bed/banks unstable and/or prone to scour

4. B_{DES} is for the handrail geometry and will normally be much higher than for the culvert/bridge waterway as L_{10} is likely to be much greater than the horizontal opening width/spacing of the balusters. In modelling Bdes can be assumed at t=0 as the model will not apply handrail blockages until flow reaches the level of the handrails.

As previously noted in Section 5.2, modelling the hydraulics of a progressively accumulating floating raft is quite complex as the blockage is not fixed in regard to its own geometry or in relation to the structure's opening geometry. While applying a blockage progressively from T_P to $T_{OBV/FL}$ provides a reasonable approximation of when a floating blockage most impacts flow through a culvert or bridge that overtops, it does not sensibly reflect behaviour when floodwater carrying floating debris does not reach the obvert of the structure. In the absence of any better information it is recommended that a progressive top down blockage by floating debris that does not reach the structures obvert be initiated at $T_{OTB/SA}$ and ramped up to B_{DES} at T_P. It should also be noted that a floating raft creates a top down blockage only as a consequence of the projection of floating debris below its water surface Relative to the structures opening height this projection will lift on the rising limb and fall on the falling limb creating a quite variable level of blockage of the structure itself during the event. Under such circumstances, blockage levels of the structure will be controlled by both the water depth and projection of the raft below the water level. Detailed simulation of such a process is however considered beyond the scope of this document. This guideline assumes that a top down blockage will be simplistically modelled by lowering the obvert of the structure over the tabulated time to then reflect the tabulated blockage level. Where the consequences of this form of blockage are high, and more realistic simulation is deemed necessary, it may be necessary to develop a site specific procedure. More information on this process can be found in Parola (2000), US DOTFHA (2005) and USGS (2013),

While the temporal pattern of a structure's blockage when it blocks prior to the flood peak in a system with little flood storage will have minimal impact on downstream peak flows or upstream peak flood levels, it can substantially alter the duration that upstream flood levels are above a target (floor or structure overtopping) level. In a system with significant flood storage, the timing of a structure's blockage can significantly alter upstream peak flood level, downstream peak discharge and overtopping duration. Consideration of the temporal pattern of a blockage can therefore be extremely important in realistically simulating the hydraulic impact of a blockage.

In establishing the key timings referred to in Table 8, it will normally be necessary to first run a simulation with estimated blockage levels and timings in place.

In an historic event, hydraulic analysis will need to reflect (as far as available data permits) the actual blockage mechanism that developed at the structure during the event. It should be noted that this may vary significantly from what this guideline provides as the 'most likely' blockage scenario for the structure, such is the impact of near random chance on the many parameters influencing actual blockages. However, where data for multiple historic events is available and blockages appear to consistently differ from these guidelines recommendations, further investigation is warranted, with historic data, if of reasonable quality, being given precedence.

6 MANAGEMENT OF BLOCKAGE

6.1 Design Considerations

Even though floodway crossings can be subject to blockage issues, by far the greatest attention is given to the management of blockages at culvert and bridge crossings.

To minimise the adverse impacts of debris blockages on bridges the following design considerations should be given appropriate consideration:

- Minimise the number of in-stream piers.
- Minimise the exposure of services (i.e. water supply pipelines) on the upstream side of the bridge, and/or minimise the likelihood of debris being captured on exposed services.

To minimise the effects of debris blockage on culverts the following design consideration should be noted:

- Take all reasonable and practicable measures to maximise the clear height of the culvert, even if this results in the culvert hydraulic capacity exceeding the design standard. This minimises the likelihood of debris being caught between the water surface and obvert, and also minimises the risk of a person drowning if swept through the culvert (i.e. the culvert is more likely to be operating in a partially full condition).
- 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 (Photos 1 and 2).

Photo 1: Series of floodplain culverts

Photo 2: Floodplain culvert

- 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 3 and Photo 3. The purpose of these walls is to allow the debris that normally collects around the central leg to rise with the flood, thus maintaining a relatively clear flow path under the debris. Following the flood peak, the bulk of the debris rests at the top of the deflector wall allowing easier removal (Photo 4).

Photo 3: Debris deflector walls

Photo 4: Post flood collection of debris on top of deflector walls

- Sedimentation problems within culverts may be managed using one or more of the following activities:
  - Formation of an in-stream sedimentation pond or trap 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 (Photo 5).
  - Installation of *sediment training walls* on the culvert inlet (Figure 3 and Photo 6). Sediment training walls reduce the risk of sedimentation of the outer cells by restricting minor flows to just one or two cells.

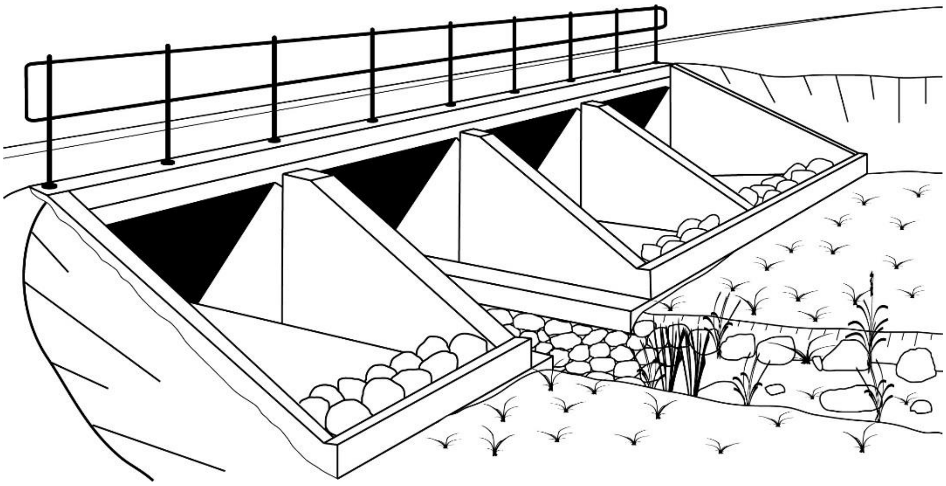

Figure 4: Sediment training walls incorporated with debris deflector walls (Catchments & Creeks Pty Ltd)

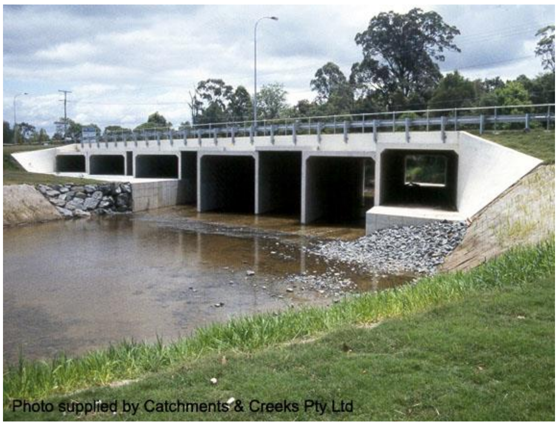

Photo 5: Multi-cell culvert with different invert levels

Photo 6: Debris deflector walls and sediment training wall added to existing culvert

- Where space allows, a viable alternative to increased culvert capacity (in response to the effects of debris blockage) may be to lengthen the roadway subject to overflow (i.e. the effective causeway weir length).
- Where high levels of floating debris are present and frequently become trapped on hand rails, collapsible hand rails may be considered. Such systems typically include pins or bolts designed to fail when water becomes backed up by the handrails and therefore require ongoing maintenance. If to be used as traffic barriers, the downstream rail fixing can be problematic. They can however limit rises in floodwater levels upstream of the structure.

6.2 Retro-fitting existing structures

Structures can be modified to allow debris to be directed through the structure with a reduced risk of blockage. These modifications can include improved inlet performance through the use of debris deflection walls and/or sediment training walls (Photo 4) or an increase in the size of the structure.

6.3 Debris control structures

Debris control structures or traps are structural measures provided in a watercourse i upstream of critical structures to collect debris before it reaches the structure and causes problems. These can be (a) fences, posts or rails providing a much larger 'interception area' for debris than a pipe or culvert entrance, (b) storages or dry basins in which boulders or other debris can collect, or (c) diversion structures designed to provide safe bypass of debris or water. Such structures can occasionally be incorporated into a water quality management plan for a catchment.

Where debris control structures or at-source control measures have been implemented, these should be incorporated into the assessment of the drainage system, which could mean a reduction in the allowance that needs to be made for blockage. Ongoing maintenance is however fundamental to the successful operation of these measures, Unless a deliberate maintenance program is in place and has been demonstrated to work, it would not be prudent to lower design blockage levels.as a consequence of such works.

Care should also be taken to ensure that the hydraulic impact of the debris control structure does not itself aggravate flooding in the system.

7 CONCLUSION

The inclusion of blockage in the analysis of hydraulic structures in drainage systems is an important consideration in the realistic simulation of flood behaviour. The impact of blockage is however a complex and difficult problem to analyse.. It is important to ensure that the estimate of blockage used in analysis is AEP neutral and not over or under-estimated as this can influence the performance of the total system. This guideline has presented an approach to the assessment of design blockage that has been developed in consultation with Australian experts and provides a consistent and logical approach to assist in the effective planning and design of drainage systems. Future investigation will refine this approach.

For further information on the background to this guideline, readers are referred to the following bibliography.

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