Quantification of Debris Potential and the Evolution of a Regional Culvert Blockage Model

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During flood events, materials that exist on the floodplain are mobilised by overland flow and by stream flow and transported downstream. Such materials are sourced from many parts of the floodplain, and consist of floating, non-floating and urban matter. As this material is mobilised and transported downstream towards structures, this material either passes through these structures, or it does not. When it does not pass through these structures, it causes a blockage of the structure and a subsequent modification of the hydraulic capacity of that structure.

This paper builds upon previous investigations and asks the question: What mechanisms exist within a particular catchment that trigger the mobilization and transportation of debris? This paper explores the factors behind debris availability, mobilisation and transportation, and draws relationships between characteristics of the catchment such as slope, land use, area etc, and recorded debris load, as evidenced by structure blockage patterns. This paper documents the development of a Regional Culvert Blockage Model based on the relationships found between features of a catchment and debris load/structure interaction. This paper also proposes an extrapolation of the Regional Culvert Blockage Model to a National Model and quantifies the additional work required to do so.

1. BACKGROUND

1.1. THE PROBLEM

During flood events, materials that exist on the floodplain can be mobilised by overland flow and by stream flow and transported downstream. Such materials are sourced from many parts of the floodplain. Forested areas can generate material such as trees, logs and leaf litter. Rural (cleared) areas can generate grass clippings such as hay, and fine sands from erosion processes on cleared land. Urban areas can generate domestic and commercial building materials and rubbish, including waste bins, cars and mattresses. The floodplain itself provides materials sourced from the underlying geology, such as boulders, cobbles and gravels.

As this material is mobilised and transported downstream it either passes through a hydraulic structure, or it does not. When it does not pass through these structures, it causes a blockage of the structure and a subsequent modification of the hydraulic capacity of that structure to convey flood water. 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 in the vicinity of the structure (Rigby and Silveri, 2001). The subsequent risk to life from structure blockage is considerable, as is the damage diverted flow can cause. The effects of blockage described above were observed throughout the suburbs of the northern Illawarra during a flood event on the evening of 17 August 1998.

1.2. CATCHMENT DESCRIPTION

The City of Wollongong is located some 70km south of Sydney, on an elongated narrow band of coastal land, confined by the Pacific Ocean to the east and Illawarra escarpment to the west (Rigby and Silveri, 2001).

The Illawarra escarpment forms a natural watershed boundary, with land to the west of the escarpment falling towards the west and the coastal strip draining to the east (Pacific Ocean). With the escarpment at about RL 600m AHD and a coastal strip only a few kilometers wide, the coastal streams are very steep and fast flowing, particularly in their upper reaches (Rigby and Silveri, 2001).

The time from peak of rainfall to peak of runoff, of these coastal streams, seldom exceeds 30 minutes. This short response time coupled with high rainfall intensities and high stream velocities, results in frequent, damaging flooding in the built up urban areas at the foot of the escarpment. With much of the lower slopes covered with talus, bed and bank erosion can be severe, leading to very high levels of debris in flooded streams. This has, in the past led to frequent blockages of culverts and bridges, particularly in the upper to middle reaches of these streams.

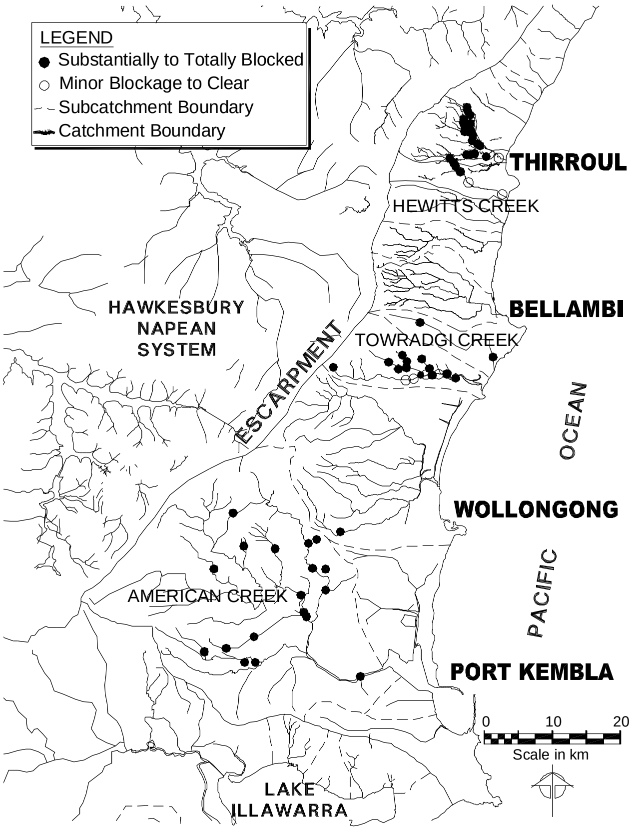

Figure 1 – Catchment Locality

Source: Rigby and Silveri, 2001.

1.3. 17 AUGUST 1998 STORM EVENT

After a week of sporadic heavy rainfall further heavy rainfall developed during the afternoon of the 17th August, intensifying to a peak around 7pm, leading to widespread flash flooding in the Northern Suburbs of Wollongong with extensive damage to property (Forbes Rigby, 2002). In general, rainfall intensities were highest around the Woonona/Bulli areas in the north, reducing rapidly to the south of the CBD of Wollongong (Rigby and Silveri 2001, Evans and Berwick 1998, Reinfelds and Nanson 2001).

Most low-lying areas and areas adjacent to streams in the Hewitts Creek catchment were significantly inundated during this event. One life was lost and approximately 1,000 houses were affected by flooding (Rigby and Silveri 2001). Tangible damage to private property was estimated at $50 million with public property damage at $25m (Forbes Rigby, 2002). During the event massive scouring occurred in the steeper reaches of most streams with major areas of deposition in the middle reaches (Rigby and Silveri 2001). Large quantities of vegetation were swept into streams from collapsing banks and some urban material and vegetation were swept into streams from overbank areas (Reinfelds and Nanson, 2001). The observed structure blockages were located in catchments hardest hit by the storm (Forbes Rigby, 2002).

The most significant recorded rainfall intensities occurred over a 3 to 6 hour period with some pluviometers recording intensities with an ARI in the order of 100 years. The highest 24 hour total up to 9 am on Tuesday 18 August 1998 of 445 mm was recorded at Mt Ousley (Forbes Rigby, 2002). See **Figure 2** showing an IFD plot of the storm event at Bulli Pass (northern-most extent of recorded blockage data).

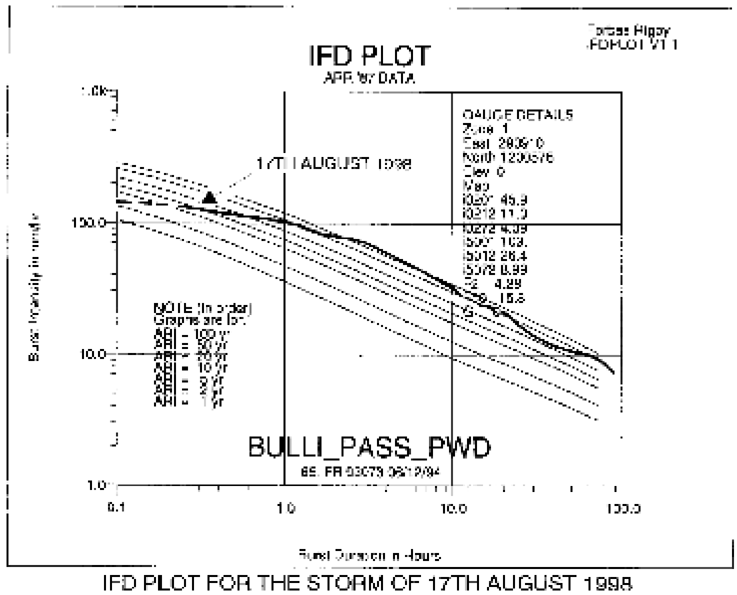

Figure 2 – IFD Plot for Storm of 17 August 1998
Note: IFD plot for Bulli Public Works Department Gauge.

1.4. BLOCKAGES IN THE AUGUST 1998 FLOOD EVENT

Culvert blockage data recorded after the August 1998 event was collated by Rigby and Silveri (2001). The day after the storm, engineers from Wollongong City Council walked the creeks noting the extent of damage (Rigby et al, 2002). In some areas where data blockage was not recorded but flood levels were, a hydraulic model was used to back-calculate the blockage occurring during the flood event (Bewsher Consulting, 2003). For each culvert, the following data were collected:

- Type of material blocking opening and the land use upstream of the culvert
- Degree of blockage and the size and type of culvert
- Stream slope upstream of the culvert and the location of culvert on the catchment

Table 1 is an extract from the work of Rigby et al (2002) showing the culverts surveyed within the test catchments and their details.

Table 1 – Available Surveyed Blockage Data

Catchment	Total No. of Culverts	Culverts Surveyed	Total Number of Bridges	Bridges Surveyed
Hewitts Creek	20	20	7	7
Towradgi Creek	30	26	8	8
Allans Creek	76	76	16	16

The data supplied was in the form of an Excel spreadsheet and was filtered to only include the most accurate and complete data. The geographic location was recorded, along with all the other information described above. The information was then geo-coded by the author to enable the data to be spatially assessed in a GIS environment for further analysis.

2. RELATIONSHIP EXPLORATION

2.1. DEBRIS CLASSIFICATION

The characteristics of blockage materials vary within different parts of the catchment, and as such it is beneficial to have a classification system by which blockage material, or debris, can be identified and understood. Generally, and at a very broad level, there are three main categories of blockage material; Floating, Non-Floating and Urban. **Table 2** is the authors suggested classification of materials that cause culvert and bridge blockage, based around the USDOT (2005) paradigm and modified to suit Australian references and data.

Table 2 – Classification of Debris Material

Type	Description
Floating	
Small	Small floating debris can include small sticks, leaves and refuse from backyards such as lawn clippings. This material can be easily transported by both stream and overland flow (USDOT, 2005). This type of debris can also come from trees and vegetation that are introduced into the stream due to bank erosion, landslides or from the loss of foliage during the changing of seasons (USDOT 2005, Reinfelds and Nanson 2001). Rigby and Silveri (2001) also observe that such small floating debris is often mobilised in flood events within the Illawarra
Medium	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).
Large	Large floating debris consists of logs or trees, sourced by 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 channels, this material is not easily transported and can easily become snagged, acting as a further 'snag' for smaller material (Diehl 1997, Wallerstein and Thorne 1996).
Non-Floating	
Small	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, landslide 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).
Medium	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 landslides. Once mobilised this material is usually transported as both bed and suspended load within high gradient streams. Deposition of cobbles can readily block a culvert entrance or significantly reduce a bridge opening.
Large	This debris material is generally comprised of large rock ranging in size from 256 mm and above (USDOT, 2005). Boulders, in the Illawarra, are associated with steep streams and are transported as bed load. The source of the boulders is again from bed or bank erosion or

	landslides. 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 culvert and/or cause damage to the culvert from the forces of impact/collision.
Random / Urban	
All	Urbanisation of catchments introduces many 'random' man-made materials that can cause culvert blockage. For example, a garbage bin can easily be washed down a street and into a stream, 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 blocks a culvert inlet or a larger item (6m container) blocks a bridge span. Rigby and Silveri (2001) also observed that such debris is 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 or overbank flow from a rising stream, once it breaks its banks*. This highlights the random nature of blockage caused by urban debris, both in terms of the availability of the debris, and the complex way in which it is mobilised during flood events. **This paper does not address urban debris.**

This debris classification system is particularly useful as it not only classifies the materials observed to be blocking structures, it also classifies the material based on other important 'heads of consideration' when determining blockage potential. In other words, the nature of blockage material varies across a catchment, and the nature of each type of material affects blockage. For example, floating debris such as logs will block a structure in a different way (top down) than non-floating debris (bottom up). Further, urban material tends to arrive at a structure in a pulse like delivery (Rigby and Silveri, 2001) once a stream has broken its banks, whereas large non-floating debris (such as boulders) typically arrive near the peak of a flood event when stream power is highest.

2.2. PREVIOUS RESEARCH INTO BLOCKAGE RELATIONSHIPS IN THE AUGUST 1998 FLOOD EVENT

The data (described in **Section 1.4**) was initially assessed for relationships by Davis (2001), who explored basic relationships between culvert blockage and the recorded field attributes, such as blockage material, immediate upstream slope, etc. Davis (2001) concluded that "*While a substantial amount of data has been presented in this thesis, it is difficult to form any definite conclusions from the unpredictable behaviour that the storm seemed to exhibit around these blocked culverts".*

Rigby and Silveri (2001) undertook a more substantive assessment delving deeper into the data and used a different approach to Davis (2001) to determine any relationships between observed culvert blockage and recorded factors. This was extended by Rigby et al (2002) with similar conclusions drawn. Reinfelds and Nanson (2001) focused on the geomorphic effects of the flood event, and also noted significant stream and structure blockages throughout the Wollongong region. Key outcomes of the Rigby and Silveri (2001) work are:

- Land use and stream slope are highly correlated with forest in the steeper foothills and urban development on the lesser slopes at the foot of the escarpment.
- Structures up to 6m diagonal opening were prone to block substantially almost irrespective of upstream slope, land use or debris type.
- Urban and mixed urban/forested catchments were equally prone to blockage
- Structures draining high slope (>3%) upstream areas were prone to substantial blockage.

- No clear correlation could be found between debris type and blockage levels although areas where bed and bank erosion was prevalent appear prone to full blockage.

2.3. CURRENT RESEARCH INTO BLOCKAGE RELATIONSHIPS IN THE AUGUST 1998 FLOOD EVENT

A co-author of this paper (Barthelmess) is currently finalizing a Master of Engineering thesis at the University of Wollongong titled 'Factors Affecting Culvert Blockage". This thesis provides an alternate assessment into the August 1998 recorded data, using spatial assessment techniques in GIS to assess relationship potential. Additional data sets were used to refine land use, slope and other factors relative to that previously available (as described in **Section 1.4**).

A key outcome of this research is a good bi-linear relationship between local slope and recorded blockage. For example, for all local slopes greater than 4%, all culverts blocked 100%. For slopes varying from 0% to 4%, the percent blocked of recorded culverts varies lineally from 0% to 100% blockage. The trend between a culverts percentage blocked and other factors such as land use and geology are not as strong as the relationship with slope.

In the August 1998 flood event, significant material was mobilised and transported to structures. As such, slope of the contributing catchment was found to be a good surrogate in a GIS/spatial assessment of the 'mobilisation and transportation factor' associated with debris load. Land use / vegetation (amongst others) were found to be a good surrogate for the 'availability factor'.

This 'debris availability' and 'debris mobility' concept is key to developing a regional spatial assessment of potential debris load and structure blockage patterns. This regional spatial model is further developed, based on the relationships that can currently be reasonably quantified, in **Section 3.2.**

2.4. BLOCKAGE CAUSATION OVERVIEW

Based on the work undertaken in Davis (2001), Rigby and Silveri (2001) and Rigby et al (2002) and the (to date) unpublished thesis of the co-author, the likelihood of structure blockage in the Illawarra is found to be highly influenced by:

- The availability 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. cars, mattresses). This is described as ***'debris availability'*** in this paper.
- Processes occurring whereby the available debris is mobilised across overland areas, into streams and along streams until it reaches a structure. This is described as ***'debris mobility'*** and ***'debris transportation'*** in this paper.
- 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 paper.

In terms of ***debris availability***, the following factors have been found to affect the availability of debris material within the catchment, viz:

a) Soil Erosivity. This can vary from weathered rocks to cohesive clays, all having different abilities to become eroded, entrained and 'available' to be mobilised. This is considered a suitable spatial surrogate for 'non-floating' debris availability.

b) 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. This is considered a suitable spatial surrogate for 'floating' debris availability.

c) Urban Areas. Such areas make available a wide range of different debris such as garbage bins, mattresses, shipping containers, and other materials. This is considered a suitable spatial surrogate for 'Urban/Random' debris availability.

d) Preceding Rainfall. If storm events are experienced regularly, this typically reduces the quantum of debris 'available' in the catchment. Preceding wind storms may have the reverse effect, greatly increasing the quantum of debris 'available' within a catchment.

In terms of ***debris mobility***, the following factors have been found to affect the movement of debris material within the catchment, viz:

e) Rainfall Intensity. Different areas 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.

f) Slope. Data analysed (as described in **Sections 2.2 & 2.3**) show a strong correlation between the blockage of structures and the slope of the contributing catchment. Slope is also highly correlated with stream power, and as discussed previously, is considered a suitable spatial 'surrogate' for stream power.

In terms of ***structure interaction***, the opening diameter, for the Illawarra dataset, was the overwhelming distinguishing factor contributing to whether or not debris that arrived at a structure caused the blockage of that structure. Based on this, a Structure Interaction assessment was also required such that the site specific features of each structure could be recognised.

Once the above three key causes of structure blockage were identified, a spatial model could be developed to predict the likelihood of culvert blockage in the future.

3. REGIONAL DEBRIS POTENTIAL MODEL

3.1. CURRENT REGIONAL ASSESSMENT PROCEDURE

Following on from the work of Rigby and Silveri (2001) Wollongong City Council developed a Conduit Blockage Policy (2002). 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, floodway's and trunk drainage systems within the Wollongong City Council Local Government Area (LGA). The policy states that the following blockage factors are to be applied to structures across all watercourses when calculating design flood levels:

- 100% blockage for structures with a major diagonal opening width of <6m
- 25% bottom up blockage for structures with a major diagonal opening width of >6m. For bridge structures involving piers or bracing, the major diagonal length is defined as the clear diagonal opening between piers/bracing, not the width of the channel at the cross-section.
- 100% blockage for handrails over structures covered in (i) and for structures

3.2. EXTENDED REGIONAL ASSESSMENT PROCEDURE

A combination of the inherent potential of a catchment to generate and mobilise debris, and the site specific details of the structure determines how the structure should be modelled for design events. The authors propose an extended process (based on that described in **Section 3.2**) to assess the potential for culvert blockage. In order to determine the debris potential present within a particular catchment, several factors relating to the structure itself and the catchment need to be quantified.

Culvert Blockage is a combination of Debris Availability, Debris Mobility/Transportation and Structure Interaction.

Given the above, the authors proposed the following methodology for quantifying each of the factors that contribute to culvert blockage such that a 'model' can be developed to predict blockage.

3.2.1. Quantification of Debris Availability and Debris Mobility

Datasets were obtained by the CSIRO and the University of Wollongong that represented items (a) to (f) in **Section 2.4**, such that a Regional Debris Potential Map could be created. A GIS model was developed to account for all of the factors (unweighted) contributing to debris availability and debris mobility described in **Section 2.4** except preceding rainfall, as this was approximately equal for all of the recorded data locations. The results forms a Regional Debris Potential Map which can be categorised into 3 'risk' areas reflecting the high, moderate and low debris potential areas within the region (see **Figure 3**).

3.2.2. Quantification of Structure Interaction

The following table was produced based on the recorded blockage data for the Illawarra. For the catchments whose average debris potential (determined from the Debris Potential Map) is 'High', the proposed blockage condition for design purposes is the same as the current blockage assessment procedure (i.e. < 6m diagonal width = 100% culvert blockage). Based on the author's assessment of recorded data and observations within the Illawarra after flood events, an extended range of blockage conditions where debris potential is not high has been developed (see **Table 2**).

Table 2 – Structure Interaction

Upstream Catchment Conditions	Culvert Blockage Condition	
Debris Potential	**Full Blockage**	**Partial Blockage**
High	If <= 6000mm diag	If >6000 @ 25%
Moderate	If <= 2400mm diag	If >2400 @ 15%
Low	If <= 1200mm diag	If >1200 @ 10%

3.2.3. Proposed Blockage Assessment Procedure

The first factor in the assessment procedure can be determined from the 'debris potential' map. Once the debris potential within the contributing catchment has been determined, the structure interaction details can be assessed against the information provided in **Table 2**. Once the 'debris potential' and the 'Structure Interaction' are determined, the designer can proceed with the design or assessment of the structure blockage in accordance with this guideline.

For example, when designing a new culvert or upgrading an existing culvert, the design engineer would firstly determine the debris potential of the contributing catchment from the 'debris potential' map (**Figure 3**). He/she would then determine the 'Structure Interaction' values for **Table 2**, and this would provide the design engineer with the appropriate blockage conditions required for analysis. This is a more realistic approach than a 'blanket' 100% blockage of culverts < 6m diagonal width across the whole LGA, and is made possible by the more spatially orientated assessments of the base data undertaken by the authors.

3.3. REGIONAL DEBRIS POTENTIAL (AVAILABILITY & MOBILITY)

Figure 3 shows an extract of the Regional Debris Potential Map in the northern Illawarra catchment of Hewitt's Creek. The map has predicted areas of High, Moderate and Low Debris potential in all of the sub-catchments that make up Hewitt's Creek. It is important to note that whilst all culverts with recorded blockage were located within urban areas (shown 'grey' in **Figure 3**) the material causing blockage of these culverts was not urban material. Generally, the material causing the blockage was the material that had been sourced, mobilised and transported from the High and Moderate Debris Potential zones upstream of the site.

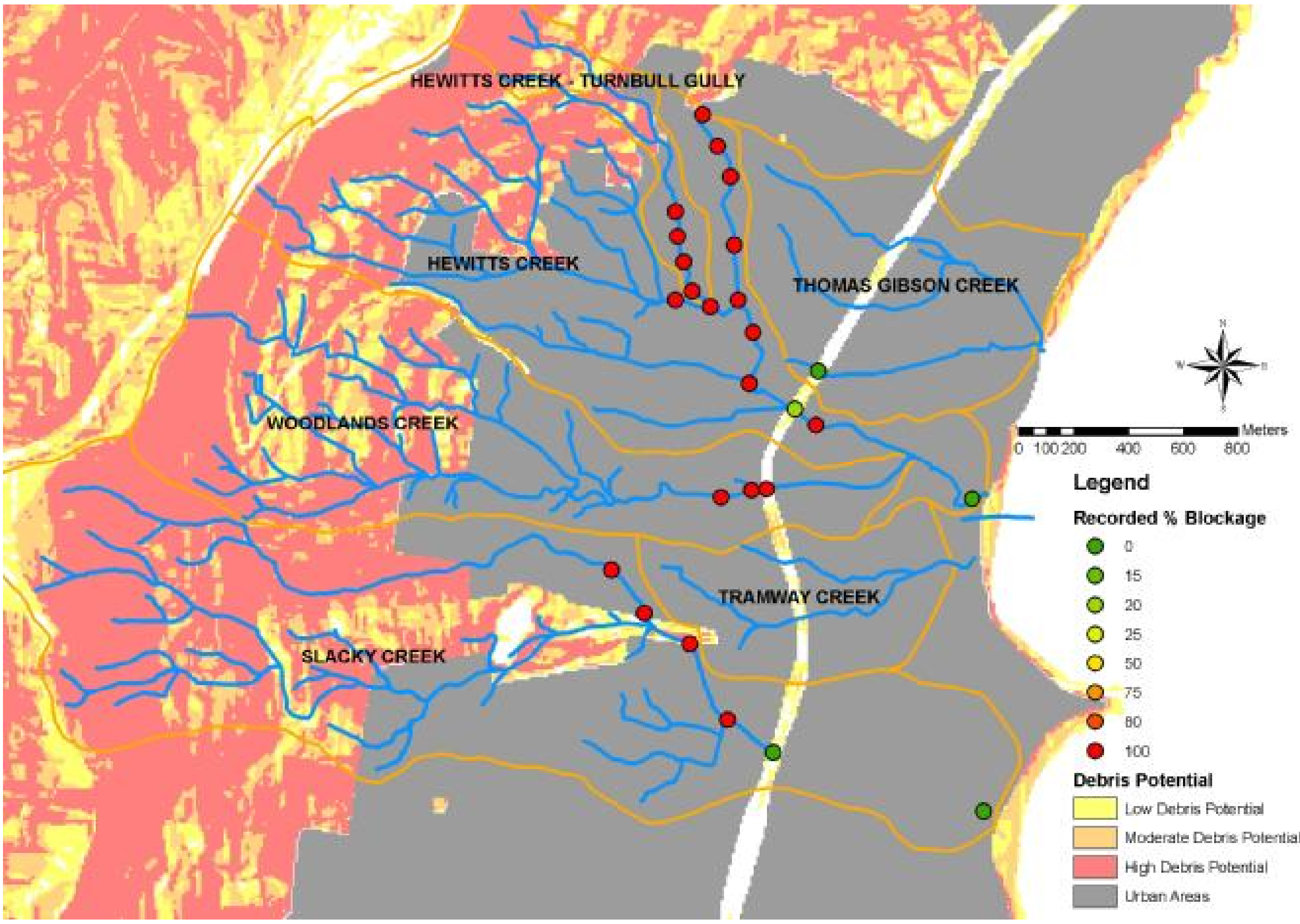

Figure 3 – Regional Debris Potential Map Example

The Regional Debris Potential Map (**Figure 3**), and the Structure Interaction values (**Table 2**) combine together to create the Regional Culvert Blockage Model.

3.4. REGIONAL CULVERT BLOCKAGE MODEL VERIFICATION

In order to convert the 'debris potential' into a predicted percentage of blockage for a given location, the 'Structure Interaction' values need to be taken into account (i.e. to make the model complete). For each culvert location where blockage was recorded, the debris potential of the contributing catchment was determined using GIS. Then, based on **Table 2**, the structure interaction values were used to assess what the percent blockage would be at the culvert, based on the models predictions. These predictions were assessed against the actual recorded blockage, and the following results were obtained.

Table 3 – Model Verification / Validation

Model Results	Percent Error in Recorded Blockage vs Modelled (Predicted) Blockage
65% of sample	0 % error
20% of sample	25 % error
2% of sample	50 % error
8% of sample	75 % error
5% of sample	100 % error

As evidenced in **Table 3**, the model is achieving either the exact result, or a result within one blockage increment (25%) 85% of the time across the entire regional dataset. This verifies that the Regional Culvert Blockage Model produces results that relate well to the recorded blockage patterns (i.e. a direct result of debris availability, mobility and structure interaction). The standard deviation on the error values is 27%, which is a solid model result considering the nature of structure blockages which can be significantly affected by random processes.

3.5. FURTHER WORK REQUIRED / REGIONAL LIMITATIONS

The relationships that are developed in this paper are based around one particular storm event in the Illawarra. The climatic conditions (such as annual rainfall totals, rainfall intensity, orographic effects of the Illawarra Escarpment etc) are different in other parts of NSW and Australia. Whilst the recorded culvert locations show significant variation in geo-physical features (such as land use and slope) they are still all within one small area of NSW.

Further, the data is based around the availability and mobility of natural materials, and does not include the effects of urban material. Further work is required in order to integrate the impacts of urban debris into the present model. Notwithstanding these limitations, the Regional Culvert Blockage Model does provide a good representation of mainstream debris movement within the Illawarra.

4. MODELLING STRUCTURE BLOCKAGE – TOWARDS A NATIONAL PROCESS

4.1. NATIONAL DEBRIS POTENTIAL MAP

Based on datasets obtained by the CSIRO (for all factors listed in **Section 2.4**) at a national scale (1km grid DEM), but including all of the factors affecting debris availability and debris mobility, a preliminary National Debris Potential Map was produced in accordance with the procedure for producing the Regional Debris Potential Map. The weightings of the individual factors were all equal, and the map is shown at **Figure 4**.

4.2. NATIONAL STRUCTURE INTERACTION

A structure interaction table would need to be developed based upon an assessment of a larger dataset of culvert sizes and recorded blockage patterns. To date this larger dataset is not available.

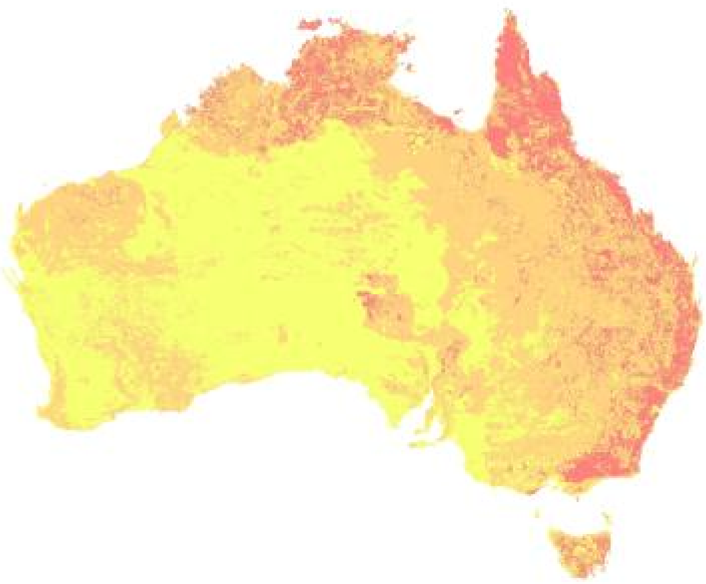

Figure 4 – National Debris Potential Map Example

Note: Red areas denote High Debris Potential, Orange areas denote Moderate Debris Potential, Yellow areas denote Low Debris Potential.

4.3. NATIONAL CULVERT BLOCKAGE MODEL

A National Culvert Blockage Model could be developed based upon the finalisation of the models components as described in **Sections 4.1 & 4.2**. This would allow for a culvert blockage assessment to be undertaken anywhere in Australia commensurate with the prevailing conditions attributable to that location.

4.4. FURTHER WORK REQUIRED / NATIONAL LIMITATIONS

More recorded blockage data is required to validate the model. The authors are desperate for such additional data and anyone who reads this paper and has any data is urged to contact the authors. It is also not known how Climate Change, and its projected increases in rainfall volume and intensity, will affect the debris potential within a catchment. This would require further investigations prior to a National Debris Potential Map being finalised.

The effects of preceding rainfall need to be taken into account in the national assessment. Preceding rainfall is likely to be very different spatially across the country, and as such a measure of the 'frequency of rainfall' needs development. Such an assessment would include an assessment of the total annual rainfall, and its distribution across the 12 months. This would help assess whether a region experiences smaller storms more often (i.e. tropical areas such as Darwin), or rarer but larger events (i.e. SE NSW coast).

Both the Regional Culvert Blockage Model, and proposed National Culvert Blockage Model, assess the debris potential from natural catchments. It does not, at this time, integrate the debris load derived from urban land uses. Additional work needs to be undertaken to integrate this so that the blockage of structures that are deeply contained within urban areas can also be predicted.

5. CONCLUDING COMMENTS

1. Debris load can be segregated into three categories; Floating, Non-Floating and Urban Debris, each having different physical characteristics and different structure blockage characteristics;
2. The local slope surrounding a structure is highly (bi-lineally) correlated with the percentage of blockage recorded in the August 1998 flood event in the Illawarra;
3. This paper, based on a spatially orientated assessment of the factors affecting structure blockage, proposes an alternate approach to the Wollongong region's current assessment paradigm;
4. A Regional Culvert Blockage Model has been developed that specifies the suggested blockage conditions required for any design/assessment/modelling of that culvert.
5. This paper acknowledges that the impacts of urban debris are complicated and can be 'random' by very nature of the land use and the materials thereon. Further work, and more data, is required to gain a better understanding of the impacts of urban debris generation;
6. This paper also discusses the extrapolation of the Regional Culvert Blockage Model to a national model, and quantifies the aspects affecting structure blockage requiring more investigation, prior to the national model being finalised.

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