University of Southern Queensland

Faculty of Engineering & Surveying

An Investigation And Quantitative Analysis Of The Impacts On Stream Flow And Fluvial Erosion Associated With Urbanisation Of A Small Catchment

A dissertation submitted by

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Abstract

The urbanisation of a catchment can have a significant impact on flow, flood and erosion processes. By modelling these processes in a rural and then a hypothetical urbanised catchment quantitative comparisons can be made on how the urbanisation process has impacted on stream flows, flood behaviour and erosion.

Hydraulic and hydrologic modelling are techniques frequently undertaken for a range of purposes including estimation of flood extents, development of flood mitigation plans and in determining the effects of hydraulic structures. Hydraulic modelling typically assume fixed cross-section geometries while in reality the processes of erosion and sediment transport results in changing channel geometries over time.

The results indicated that the urbanisation of a catchment has some dramatic effects on stream flow, flood and erosion processes. The RORB hydrologic model showed significant increases in peak flows and run-off volume and a reduction in lag time. The HEC-RAS hydraulic model showed significant increases in water surface elevations, shear stresses and flood extents. The channel enlargement modelling indicated a substantial increase in channel area was required to accommodate the increased urban flows.

The project has identified the importance of considering the impacts of development in long- term flood and hydraulic modelling as it cannot be assumed that channel geometries and peak flows are fixed particularly as development has been shown to accelerate fluvial erosion processes. The project has also indentified the need for further research to investigate the complex relationship between urbanization, flood behaviour and channel morphology.

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I certify that the ideas, designs and experimental work, results, analyses and conclusions set out in this dissertation are entirely my own effort, except where otherwise indicated and acknowledged.

I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

Julian Skipworth

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Acknowledgments

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Chapter 1

Introduction

Hydraulic and hydrologic modelling are techniques frequently undertaken for a range of purposes including estimation of flood levels, development of flood maps and to determine the effects of hydraulic structures. Hydrologic modelling can be used to determine the runoff that occurs following rainfall events while hydraulic modelling can calculate water surface elevations, flood levels and flow patterns. Flood mapping is a technique used to determine the extent of floods in a catchment and is used to define waterway corridors and setback zones for new developments to ensure they are not built in flood-prone areas. Development and urbanisation can have a significant impact on flow and flood patterns and may also impact on sediment transport and erosion processes. This study will address the impact of urbanisation on flow and flood behaviour in a catchment and the associated impacts on erosion and sediment transport leading to changes in channel geometry.

This study will attempt to quantify the hydraulic and hydrologic impacts during two design storms of different recurrence interval and compare these estimates in both the existing rural and a future hypothetical urbanised situation. The process of flood mapping and hydraulic modelling typically assumes a fixed geometry of water channels. In reality erosion and sediment transport are dynamic processes which can result in continuous changes in channel geometries and sediment characteristics. This study aims to quantify these geometry changes in the context of a developing catchment to establish how these changes could affect the accuracy of the hydraulic modelling and flood mapping process.

The focus of this project is the One Mile Creek catchment which located to the south of Wangaratta in North-East Victoria as shown in Figure 1.1. It is largely a rural catchment however it does contains areas of residential and commercial land use as the creek flows through the city of Wangaratta. The area of the catchment being studied in this project lies upstream of Wangaratta and so can be exclusively considered a rural catchment. The catchment lies in a temperate climatic zone with a mean average rainfall of 612 mm/year recorded at Wangaratta Airport which lies within the One Mile Creek catchment. The mean annual maximum temperature is 22.1°C while the mean annual minimum temperature is 7.5°C.

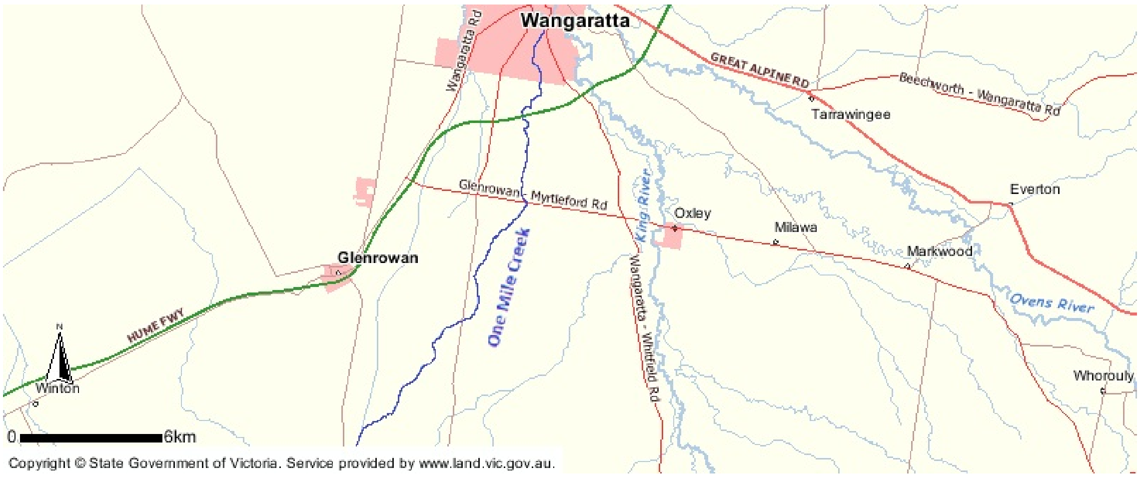

Figure 1.1: One Mile Creek Regional Map (Leopold 1968).

1.1 The Problem

The problem involves investigating the impacts of urbanisation in a small rural catchment in North-East Victoria. The problem involves analysing how flow and flood behaviour and channel erosion in the catchment would be affected if the catchment developed into an urban environment. In particular the study aims to quantify the magnitude of channel enlargement that would be occur if the catchment became urbanised thus providing an objective estimate as to how this process has been accelerated by the urban development. In addition the study will examine what impact urbanization will have on the extent of floods in the catchment.

1.2 Objectives

This study comprised of performing hydrologic, hydraulic and erosion modelling on a stream in a small catchment to analyse the impacts of urbanisation on the hydrology and hydraulics of the catchment and to estimate the amount erosion that may occur in response to the increased urban flows. The aims of this research were to quantify these impacts in a future urbanised catchment compared with the existing undeveloped, rural catchment. The research methodology is divided into three subparts hydrologic modelling of the catchment of both the rural and urbanised situations, hydraulic modelling of the catchment for both the rural and urbanised situations for 2 and 100 year ARI rainfall events and channel enlargement modelling to accommodate the increased urban flows.

In summary the objectives are:

1. To research existing literature on the impacts of urbanisation on the hydrology, hydraulics and geomorphology of rivers as well as background knowledge necessary to understand and complete the modelling tasks
2. To determine an appropriate geomorphic model for the selected catchment in North-East Victoria
3. To determine an appropriate hydraulic model for the selected catchment based on the selected geomorphic model
4. To determine an appropriate hydrologic model for the selected catchment based on the selected geomorphic and hydraulic models
5. To use the selected models to complete hydraulic and hydrologic modelling of 2-year and 100-year rainfall events
6. To define and overlay a future urbanised situation on the same catchment and repeat the modelling for of 2-year and 100-year rainfall events
7. To model the channel enlargement using both a bed erosion model and a bank erosion model for the stable catchment bankful event in order to accommodate the urban flows.

8. To quantitatively compare the results of modelling particularly with regards to the magnitude of channel erosion and extent of flooding in order to make some conclusions regarding the impacts on river morphology and stream flow due to urbanisation of a previously undeveloped catchment.

1.3 Overview of the Dissertation

This dissertation is organized as follows:

Chapter 2 is a summary of a review of literature relevant to this project.

Chapter 3 is a summary of the model selection process and parameters used in the models.

Chapter 4 contains the methodology.

Chapter 5 contains the results and discussion.

Chapter 6 concludes the conclusions and suggests some recommendations for further research.

Chapter 2

Literature Review

A literature review of topics relevant to this project was completed. Due to the nature of the project it was necessary to utilise a wide variety of sources and this included hydraulic and hydrologic texts, research papers, planning guidelines, planning schemes, software manuals and documents from relevant government bodies including water authorities and catchment management authorities. Due to the number of subject areas which are closely linked with this project and time constraints placed upon the author it was not possible to complete an in-depth literature review for each and every relevant topic. While the study was largely a modelling project the literature review was necessary to gain background knowledge on a number of key topics. These included:

- Impacts of urbanisation on catchment hydrology and hydraulics.
- Fluvial erosion and sediment transport processes.
- Research into appropriate models which had the capabilities to perform the required modelling.

2.1 Impact of Urbanisation on Catchment Hydrology and Hydraulics

Past research has concluded that streams impacted by urbanisation display considerably different flow, sediment and flood characteristics (Chin 2006, Kang & Marton 2006). The effects on flow characteristics include greater peak discharges, increased flood frequency and greater magnitude of flood discharges (Niezgoda & Johnson 2005, Brilly, Rusjan & Vidmar 2006, Chin 2006). The interaction between urbanisation and hydrological processes is complex but it is widely agreed that two of the most significant consequences are that a greater volume of runoff occurs from urban environments and that greater runoff velocities are attained (Leopold 1968). This is due to several factors including a greater proportion of impervious surfaces in the catchment and the effects of drainage infrastructure such as gutters and drains which lead to an increase in the conveyance of runoff (Brilly et al. 2006, Poff, allan, Bain, Karr, Prestegaard, Richter, Sparks & Stromberg 1997).

The fraction of impervious surface of a catchment is highly relevant to this study. The term fraction impervious refers to the proportion of the catchment which is an impervious surface and this is one of the primary mechanisms by which urbanisation affects stream flow (Kang & Marton 2006). Impervious surfaces by definition permit no rainfall to infiltrate through to the soil during a rainfall event and so virtually all precipitation will be dispersed as runoff. In the urban environment these impervious surfaces largely consist of rooftops and hard pavement surfaces such as roads and car parks. Impervious surfaces also contribute to the increased velocity of runoff as water will flow faster over such surfaces compared with natural surfaces such as soil and vegetated areas.

The increase in runoff velocity also leads directly to a reduction in lag time which further increases flood peaks. Lag time refers to the time between the centre of mass of the excess rainfall of a rainfall event and the peak of the resulting hydrograph (Bedient & Huber 2002). The increased lag time effectively means the mass of excess rainfall is moving through the catchment quicker and so will pass through the stream at a faster rate resulting in a greater peak. Figure 2.1 demonstrates these changes showing how the hydrograph will alter after urbanisation and thus impact on lag time and peak flows.

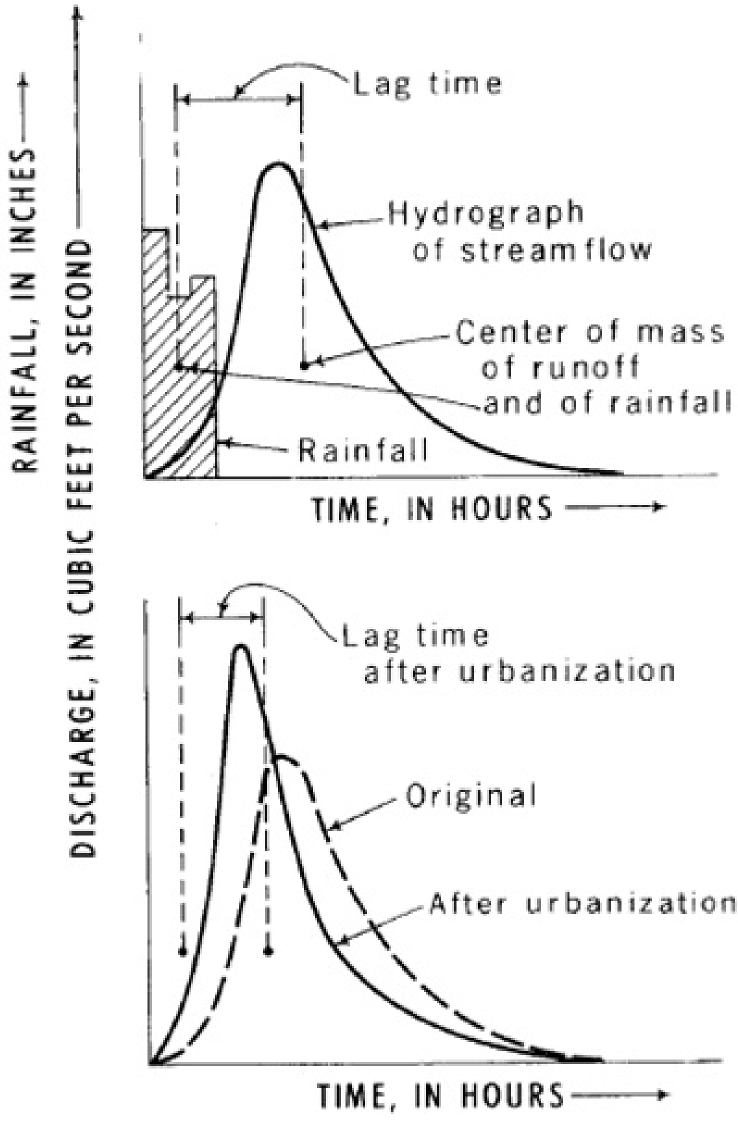

Figure 2.1: Hydrological impacts of urbanisation (Leopold 1968)

Time of Concentration is another factor which will be impacted by an urbanised environment and refers to the travel time for a water droplet from the most distant point in the catchment to the outlet (Ladson 2008). This is another characteristic used to predict the response of a catchment to a rainfall event and is useful to consider for a number of engineering applications including the building of infrastructure and flood risk. It has been shown that the time of concentration in an urbanised catchment is significantly less than in the pre-urbanised environment and this is closely tied in with the increased velocity of runoff and greater fraction impervious in the urbanised scenario (Chin 2006). In the hydrologic modelling conducted in this study it would be predicted that the time of concentration would be significantly quicker in the urbanised scenario than in the existing rural environment.

It has also been found that urbanised runoff processes have a greater impact on small urbanised catchments with small waterways and low flows than large urbanised catchments which contain large, high flow waterways (Brilly et al. 2006). This is of particular relevance to the catchment being studied in this project as it is a relatively small catchment with small channels operating with relatively small flows. Leopold (1968) described four significant hydrological changes that occur as a result of land-use changes such as urbanisation. Two of these are changes in peak flow and total runoff which have been discussed previously. The remaining two are changes in water quality and 'hydrologic amenities'. The changes in water quality in an urbanised environment are largely due to the addition of pollutants in runoff such as household rubbish, excess nutrients and leaked sewerage (Leopold 1968). Hydrologic Amenities refers to changes in the visual appearance of the stream and catchment. Fookes (2005) warns that in severe cases channels can actually change form from a meandering to a braided state. These changes are obviously of significant importance however they are not a focus of this study and will not be examined any further.

Chin (2006) collated past research on the effects of urbanisation on a range of characteristics including peak discharge, lag time and total runoff. This information was taken from studies on a number of catchments in Australian, the United Kingdom and the United States and a portion of these results are shown in Table 2.1. The results show an increase in peak discharge of between 132% and 6 times in the urbanised catchment compared with pre-urbanisation flows. Lag time was reduced to between 1/2 and 1/5 while total runoff was increased by up to four-fold during storm events.

While there is widespread agreement that urbanisation has significant impacts on stream flow and catchments it is also evident that the magnitude of these impacts can be quite variable and individual to a catchment or reach. The interaction is complex and there are a multitude of other factors which can be co-impacting on the catchment. The complex interaction means that categorically concluding that a particular change

Example hydrological changes caused by urbanization for selected areas of the U.S. and U.K.

Location	Peak discharge	Lag time	Floods (frequency)
Washington D.C.	+2–6× (80%)	–	+mean annual floods 1.8×
Long Island, New York	+123% direct runoff		
Santa Clara County, California			
Sacramento, California			
Jackson, Mississippi	+4.5× mean annual flood		
Pennsylvania	+2–3× mean annual Q est. (50% paved)	–	
Long Island, New York	+; at least 250%>than forested	−flood peak widths	
Detroit, Michigan	+3–4×	−1/5	
NE Exeter, Devon	+2x	−1/2	

Table 2.1: Summary of Past Research into the Hydrological Impacts of Urbanisation (Chin 2006)

in a catchment is attributable to a particular factor is not easy to achieve. Booth & Konrad (2002) noted that variability in stream flow patterns in catchments over a range of timeframes from hours to decades is common and may not necessarily be a result of human activity.

2.2 Channel Morphology and Fluvial Erosion Processes

One of the objectives of the project was to quantify the level of channel erosion that could occur in One Mile Creek as a result of urbanisation so it is important to gain an understanding of these processes and how they might be impacted by an urbanised environment. River morphology is a natural process and refers to the changes in river shape, bed depth and channel width over time largely due to sediment transport processes (Chang 1985). This process is a complex one and is influenced by a number of factors including sediment load and size, soil shear strength, flow characteristics, vegetation and the chemical makeup of the water and soil (Niezgoda & Johnson 2005, Osman & Thorne 1988*a*, Julien 1995). Figure 2.2 indicates that slope and sediment size are two of the important characteristic of a stream which can impact on bed degradation and aggradation. It can be seen that both increased stream slope and finer sediment will lead to increased bed degradation while a flat slope and coarse sediment will lead to bed aggradation. The One Mile Creek reach is very flat while the sediment size is neither significantly fine or coarse. Based on these two factors it could be concluded that One Mile Creek is not particularly prone to erosion in its natural state. It has also been observed that bedload sediment tends to coarsen with urbanisation in response to increased velocities and shear stresses leading to increased transportation of finer sediment.

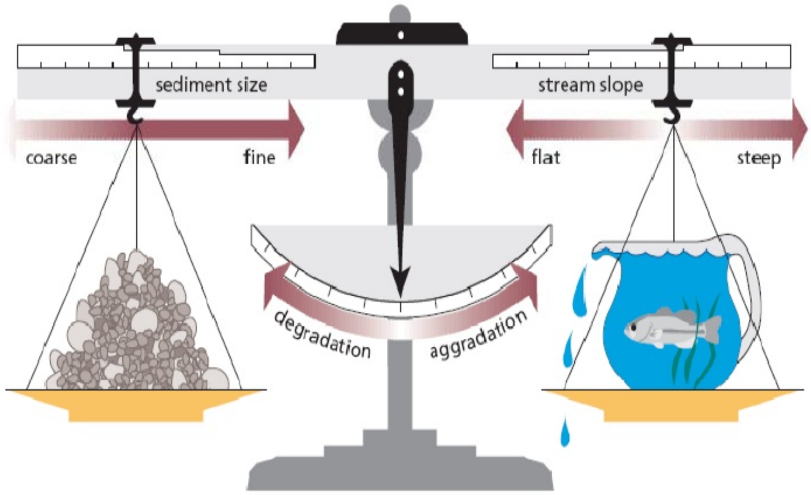

Figure 2.2: A pictorial representation of assessing stream response under different conditions (Lane 1955)

At a particle level erosion is caused by soil particles dislodging from the channel bank and bed surfaces. This will occur when the boundary shear stress of the channel flow exceeds the critical shear stress of the soil. Critical shear stress of soil is a function of a number of factors including soil composition, sediment size and sodium adsorption rate. Boundary shear stress is also a function of a number of factors including bed slope, flow velocity and hydraulic radius. Shear stress distribution will also vary around the channel boundary and depends on the shape of the channel and the ratio between width and depth (Hann 1982). With regards to the One Mile Creek project and making comparisons between an urbanised and non-urbanised scenario the primary factor which will change considerably will be the boundary shear stress as a result of changes to the flow characteristics. Increased velocity of flow is a known consequence of an urbanised catchment and this is will have a direct impact on the boundary shear stress potentially leading to accelerated channel erosion.

It has also been shown that urbanisation in the long-term can reduce the sediment input into local streams which can increase the rate of channel degradation due to there being a greater sediment transport capacity then sediment supply (Niezgoda & Johnson 2005). Wilcock (1971) concluded that the greatest factor contributing to long-term channel erosion and degradation is stream velocity. This further confirms the link between urbanisation and accelerated channel morphology. Booth (1991) also recognised that some streams can expand catastrophically due to urbanisation even in areas that previously had been little affected by flooding or erosion. Hammer (1972) identified that the increase in peak flows due to urbanisation is nearly always accompanied by the enlargement of stream channels. He went on to conclude that the largest urbanisation factor attributable to channel enlargement is impervious area which has been discussed previously with relation to peak flows and flow patterns. This further confirms the close links that exists between urbanisation, stream flow changes and channel erosion.

2.2.1 Channel Response to Urbanisation

Erosion takes the form of both lateral bank erosion and deepening of the channel bed or channel incision. In effect it could be seen as a buffer system whereby increased flow in a channel leads to increased shear stresses on the bed and banks. The channel responds by eroding and the resultant increase in channel depth and width allows better conveyance of the flows being transported. Hann (1982) explains that there are a multitude of factors which impact on channel erosion but nonetheless erosion of the channel will occur until equilibrium is reached. Booth (1991) describes the channel deepening or incision process as a loss of geomorphic balance between the erosive down cutting force of the water and the stabilising or resistance force of the steam bed related to factors such as sediment size and channel roughness. It seems evident that erosion will continue until the balance or equilibrium is restored between the eroding properties of the water and the stabilising forces of the channel. In the context of this study one of the purposes of the erosion model will be to model the erosion until equilibrium is restored.

Logic would suggest that in the long-term the stream response to urbanisation would be enlargement of the channel. While the literature shows that this is true in the long-term it has actually been found that an initial period of channel narrowing usually takes

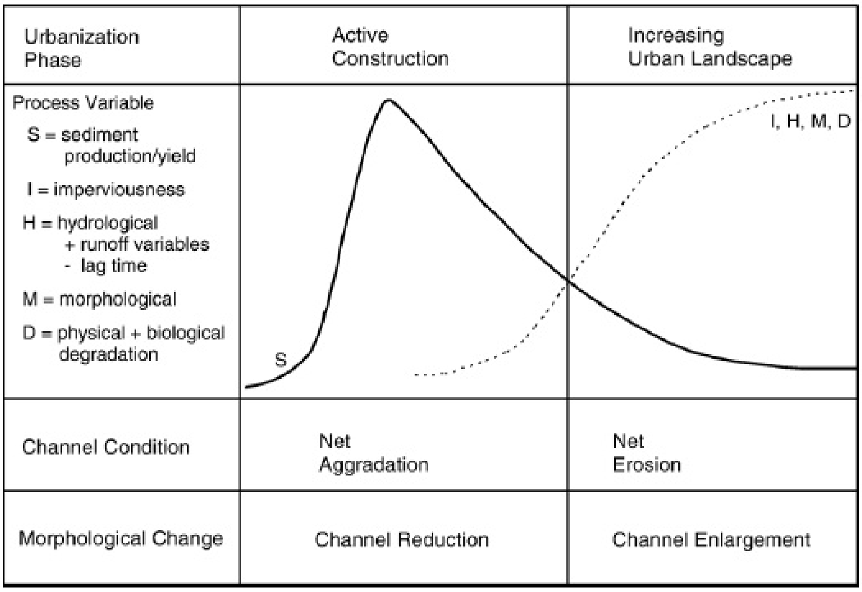

Figure 2.3: Stream response to urbanisation (Chin 2006)

place as shown in Figure 2.3. This is mainly due to the increased sediment load in the stream from erosion of bare surfaces associated with construction and new development in the catchment. In the long-term though once the catchment is developed, impervious surfaces will increase, sediment loads will reduce and net erosion will take place leading to channel enlargement. Some of the literature also suggests that the frequency of the bankful event in a stable channel is the dominant event which dictates the stream response when flow conditions change. It has been suggested that the channel will respond to the altered conditions by enlarging until the bankful conditions again occurs at that same frequency of event. This theory of equilibrium is the basis behind the erosion modelling used in this project.

Enlargement of a channel involves both bank and bed erosion however the relative contribution to the total channel enlargement is difficult to predict. Hammer (1972) concluded that there was no significant relationship between the ratio of width to depth and the degree of urbanization and that it tends to be a localised response. He also noted that there was no relationship between the width-to-depth ratio and the change in cross-sectional area caused by urbanization. In contrast, Osman & Thorne (1988*a*) concluded that a relationship does exist and that erosion in one direction can have a significant impact on erosion in the other direction. He explained that if channel beds are non-erodible this tends to lead to increased bed degradation while erodible banks

Impervious area <4 years old and unsewered street and house area	1.08
Area of houses fronting on sewered streets	
Houses 4–15 years old	3.36
Houses 15–30 years old*	4.15
Houses >30 years old†	1.08
Area of sewered streets	
Streets 4–15 years old	4.20
Streets 15–30 years old*	5.16
Streets >30 years old†	3.76
Other impervious area	
Area 4–15 years old	6.26
Area >15 years old	7.99

* Built after 1940.
† Built before 1940.

Table 2.2: Channel Enlargement Ratios from Impervious Land Uses (Hammer 1972)

results in less bed degradation as a result of decreasing hydraulic radius and increased sediment loads from the eroding banks.

It has been reported that the magnitude of channel enlargement has also been difficult to predict and varies widely (Chin 2006). Hammer (1972) is one of the few studies that has attempted to quantify channel enlargement and concluded that a mean enlargement ratio of 3.76 existed in sewered streets that were more than 30 years old. Table 2.2 outlines these findings. It is interesting to note the ratios seem to reduce after a period of 30 years however it is mentioned that in these older systems drainage facilities are likely to have been built poorly, underdesigned and to have deteriorated over the years.

Interestingly, other literature also indicates that clear patterns exists in the timing of channel enlargement. It has been noted that it typically takes a few years for a stream to begin responding to urbanised flows and that maximum change occurs anywhere between 5 and 30 years (Chin 2006, Kang & Marton 2006, Hammer 1972). It has also been observed that enlargement tends to stabilise after approximately 30 years. These are interesting points and suggest that when managing floodplains and developing catchments it would be worthwhile assessing where on this timeline a developed or developing catchment is situated and if an equilibrium has been reached.

2.3 One Mile Creek Catchment

Background knowledge of the One Mile Creek catchment was important to obtain so an understanding of it's characteristics and existing processes could be achieved. One Mile Creek catchment is located in North-East Victoria and the stream flows through the City of Wangaratta downstream of the area being investigated in this study. The One Mile Creek catchment is largely a rural catchment however it contains an area of residential and commercial land use as the creek flows through the city of Wangaratta. The area of the catchment being studied is approximately $45m^2$ and lies upstream of Wangaratta and so can be considered exclusively to be a rural catchment.

The Wangaratta Flood Mitigation Study (1996) was reviewed as part of the background reading for the project and One Mile Creek is mentioned numerously in this document as major flood events in the catchment can have significant impacts on residential areas in the City of Wangaratta. Major flood events have occurred as recently as September 2010 and threatened to inundate residential housing. It was noted that several mitigation measures have been implement including an artificial diversion channel out of One Mile Creek which diverts flow to Three Mile Creek in high flow events. Three Mile Creek flows around Wangaratta thus avoiding the impact of flood events to residential areas. For the purposes of modelling in this project this channel has been ignored and it is assumed that all flow will move through the One Mile Creek catchment.

2.4 Miscellaneous Background Knowledge

Further miscellaneous information was obtained to improve background knowledge related to the study. The Guidelines for Development on Flood-prone Areas (Melbourne Water 2008) provide some background information on requirements for developments with regards to flood consideration. The current Victorian standard is that the 100 year Average Recurrence Interval (ARI) flood level delineates areas which are suitable for development. While this study will compare water surface levels in an urbanised and pre-urbanised catchment it does not include flood mapping within its scope due to the limited resources available to the author. This would be a useful exercise to further identify the impacts of urbanisation on flood extents and the resulting ramifications for development.

The Wangaratta Planning Scheme (2009) was also consulted and advised that applications for development in the region including the One Mile Creek catchment need to be consistent with local floodplain development and management plans.

Chapter 3

Model Selection and Parameters

As part of the background research a range of models were researched to determine what would be the most appropriate for this project. The models each needed to allow the objectives of the project to be met and in addition needed to be accessible to the author. This chapter explains this process and goes on to outline the parameters used in each model.

3.1 Hydrology Model

There are a number of numerical and mathematical models which can be utilised to model the hydrology of a catchment. The required hydrologic output data for this study included peak flow values and hydrographs for 2 and 100 year rainfall events. The software capabilities and accessibility were the primary reasons for choosing the modelling software RORB for this project. RORB is a runoff and stream flow routing program which utilises a storage routing procedure to calculate the movement of excess rainfall through the catchment. The catchment is first divided into sub-areas and rainfall losses through factors such as infiltration are estimated leaving a volume of rainfall excess available to enter the stream flow. The excess is routed through the sub-area and then combined with other sub-areas as streams converge. The process continues until the catchment outlet is reached and an outlet hydrograph is obtained.

RORB is also freely available to download which was another reason for its selection due to the authors limited access to resources. The hydrologic modelling process for this project involved modelling both the existing rural catchment and a proposed urbanised catchment. To define the urbanised catchment a range of key characteristics were considered including the fraction of impervious surface described previously. White & Greer (2006) performed a similar analysis of an urbanised catchment to quantify the degree of urbanisation and this was useful to review in order to define the One Mile Creek urbanised catchment. While factors which might impact on water quality could be considered these are not a focus of this study and so do not need to be defined.

Land use is the single biggest factor which will impact on stream and erosion processes and defined the urbanised scenario in this study. A dramatic change in land use was used in this study in order to better demonstrate the hydraulic and geomorphic impacts. While this is a scenario that is unlikely to occur in the short-term future in the One Mile Creek catchment it is feasible that in decades and centuries to come such development could occur as regional growth accelerates in response to a growing population. The One Mile Creek urbanised scenario is defined in Table 3.1.

Table 3.1: One Mile Creek Future Urban Land Use

Level of Urbanisation	Proportion of Catchment %	Impervious Surface	Fraction Impervious Of Sub-Area
Commercial/Local Business	10	90	0.090
Urban Residential (High Density)	20	80	0.15
Urban Residential (Low Density)	70	50	0.35
Weighted Fraction Impervious			0.59

For the purposes of hydrologic modelling the resultant fraction impervious was treated as uniform across all sub-areas of the catchment. The modelling process in RORB initially involved development of a conceptual model which clearly defined sub-areas of the catchment (Ladson 2008). The sub-areas were based on the stream network and for this project was determined using a topographic map. Nodes were placed at the centre of each sub-area and these nodes were then connected by stream reaches. Further nodes were placed to represent stream junctions. The above process was achieved using the Graphical Editor in RORB. Other detail such as length of stream reaches and impervious area of sub-areas was also added.

Runoff routing in RORB functions similar to reservoir routing in that floods are attenuated and translated when moving through a stream reach just as they are through a reservoir (Ladson 2008). A storage-discharge relationship model is utilised and each stream reach in the conceptual model is treated as a conceptual storage. The storage discharge relationship for each of these storages has the form:

$$S = kQ^m \tag{3.1}$$

Where S is the storage (m^3), k is a dimensionless coefficient related to the travel time of the reach, Q is discharge from the storage (m^3/s) and m is a parameter that can usually be set at 0.8 in ungauged catchments.

The coefficient k is determined by the following:

$$k = k_c k_r \tag{3.2}$$

Where k_c is a coefficient applicable to the catchment and k_r is the relative delay time and is a ratio applicable to the individual reach.

To determine k_c for the model the following equation is used by RORB:

$$k_c = 2.2A^{0.5} \frac{Q_p}{2}^{0.8-m} \tag{3.3}$$

Where A is catchment area, Q_p is the hydrograph peak discharge and m is defined previously. This is an equation suggested by RORB and while considered to be not completely inaccurate it is the simplest method to determine the coefficient of ungauged catchments. While Q_p would be unknown when constructing the model a value of unity can be used when m is set at 0.8.

Another sub-model utilised by RORB and other runoff-routing model is loss modelling which in effect involves subtraction of rainfall losses from the rainfall hyetograph to produce rainfall-excess which is then routed through the catchment. Losses are largely due to soil infiltration, interception by vegetation and depression storage. The type of Loss Model can be selected in RORB however for this project an initial loss followed by a constant (continuing) loss rate was chosen for simplicity. The chosen initial and continuing loss rate for each catchment type are shown in Table 3.2.

Table 3.2: One Mile Creek Losses

Catchment	Initial Loss (mm)	Continuing Loss (mm)
Rural	15	2.5
Urban	10	1.7

These values were deemed appropriate based on information in the literature for design floods in South-Eastern Australia (Pilgrim 2001*a*, Laurenson, Mein & Nathan 2010). The differences between rural and urban values are largely attributable to the differences in impervious surface area as previously outlined.

3.2 Hydraulic Model

There are a number of numerical and mathematical models which can be utilised to model the hydraulics of a stream. HEC-RAS was deemed to be the most appropriate software for this project. The choice of model was determined by capabilities of the software and software accessibility. HEC-RAS is also freely available to download which was another reason for its selection due to the authors limited access to resources. In steady flow conditions HEC-RAS uses conservation of energy laws in a one dimensional environment. For unsteady flow HEC-RAS solves the Saint-Venant equation using an implicit, finite difference method. The Saint-Venant equations are a set of partial differential equations which link momentum and continuity equations and are used to solve flood routing and wave propagation situations (Stephenson & Meadows 1986). While an unsteady flow analysis was originally considered it was decided that a steady flow analysis was sufficient to meet the objectives of the project and is typically used in the industry for similar modelling tasks.

The required inputs for the HEC-RAS model include channel cross-section geometry, flood hydrographs, peak flow and Manning's roughness coefficient values (Dyhouse 2003). Surveyed cross-section geometry used in previous studies in the region was made available to the author for use in the project. This cross-section data was originally commissioned for the Wangaratta Flood Mitigation Study conducted in 1996 and was gathered by contracted surveyors. It is acknowledged that some changes are likely to have ocurred in the cross-section geometry since the data was surveyed in 1996. The locations of the individual cross-sections are shown in Figure 3.1. Flood hydrographs and peak flows were determined from the output of the hydrologic modelling section of the project. Manning's roughness coefficient values are a measure of hydraulic resistance and directly related to friction in a channel (Chadwick & Morfett 2004). For the purposes of this study it is necessary to rely on documented values from similar channels.

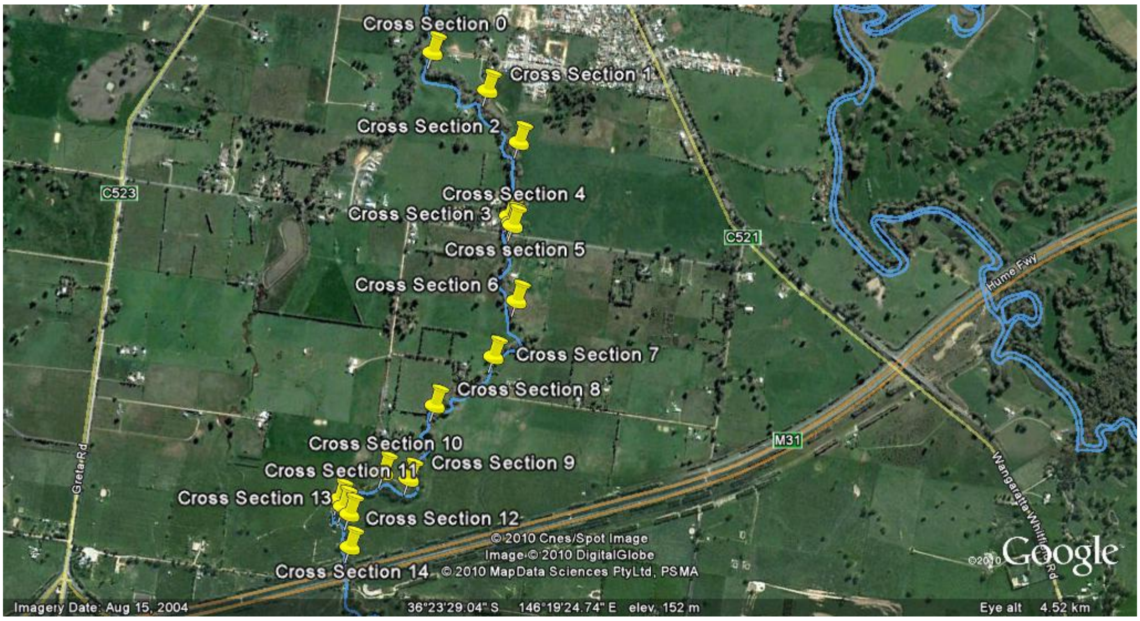

Figure 3.1: Location of One Mile Cross-Sections

Chow (1959) provides the most detailed guidance in the selection of Manning's roughness coefficients for natural channels. There are a number of factors to be considered when determining Mannings's n values. These include surface roughness, vegetation, channel irregularity and obstructions such as log jams and large woody debris. In completing this project field visits were made to the One Mile Creek catchment in order to assess these values. Based on these field visits and consultation of tables in Chow (1959) the selection of Manning's values was made and these were deemed to be the most accurate for the situations being modelled. Despite best efforts to accurately select a Manning's value it remains a relatively subjective assessment so a degree of inaccuracy is inherent in this process. The selection of Manning's roughness values for natural channels also tend to be less accurate than that for manmade channels while values will also vary according to time, season, vegetation levels and flow levels ((Chadwick & Morfett 2004, Chow 1959). Improvements in accuracy can be further achieved through calibration of a reach however this was not possible in this instance due to it being an ungauged catchment so no historical record of flow or flood data exists. Figure 3.2 shows a typical section of One Mile Creek. It can be seen that the stream is meandering with significant levels of vegetation and dead wood in and around the channel.

Figure 3.2: Photograph of typical section of One Mile Creek.

The Manning's roughness values were considered to be identical in both the urbanised and pre-urbanised situation. Cottingham, Gawne, Gigney, Koehn, Roberts, Stewardson & Vietz (2008) noted that empirical Manning's values remain constant despite the

Table 3.3: One Mile Creek Manning's Roughness Values

Reach	Description	Manning's Roughness (n)
One Mile Creek - In-Channel	earth, winding, some weeds, sluggish, not maintained	0.045
One Mile Creek - Overbank	Pasture, earth, sparse trees and scrub	0.06

discharge through the channel so in the event greater flows were discovered in the hydraulic modelling process for the urbanised environment a constant manning's value can be justified. Table 3.3 displays the Manning's Roughness Coefficients used through the reach and a short description of the characteristics used to determine the value.

3.3 Erosion and Channel Enlargement Model

There are a number of numerical and mathematical models which can be utilised to model the erosion processes and morphology of a stream however the process is such a complex one with a multitude of impacting factors that the accuracy of the model as a predictor of real-life scenarios is going to be questionable. However, in this project the modelling allowed a comparison to be made between the urbanised and pre-urbanised scenarios which was the primary objective of the study. Many variables were constant across the two scenarios so while the results may not be an accurate predictor of future erosion in One Mile Creek or a true model of the catchment it did allow estimates to be made on how the erosion process is accelerated by an urbanised catchment.

A range of manual and computer numerical models of channel morphology were considered (Darby & Thorne 1996*a*, Osman & Thorne 1988*b*) however it was determined that largely due to accessibility and model capabilities that HEC-RAS was the most appropriate modelling software for this study. Other models were investigated but deemed not appropriate for the One Mile Creek catchment due to them being designed for certain conditions such as straight river reaches which are not appropriate for this project

(Darby & Thorne 1996*b*). HEC-RAS has the capability to simulate sediment transport processes and has components which can simulate moveable channel boundaries as a result of scour or deposition however it does require the availability of sediment data which was not available for this study. An alternative method for modelling the erosion in HEC-RAS was selected and is explained below.

Fluvial 12 was another software model that was considered. Fluvial 12 has the capability to model flow hydraulics, sediment transport as well as changes in channel geometry. It is an erodible-boundary model meaning it has the capability of modelling both the bed and lateral channel erosion processes. A trial version is freely available for download however the trial version is limited in the number of cross-sections which can be modelled. It also requires sediment data which was not available for this study. Osman & Thorne (1988*a*) proposed a method of calculating lateral erosion and bed degradation in erodible channels. The method can be used to determine bank geometry following erosion and may also be used to analyse bank stability. The model has some obvious weaknesses particularly with regards to its simplicity and also that it does not take into account the effect of vegetation. The Osman and Thorne method of calculating lateral erosion uses a series of steps and involves a number of characteristics including average shear stress, initial lateral bank erosion rate and ongoing rate of soil erosion. This method was used to give an indication of time for the modelled bed changes.

As outlined in the previous chapter it has been widely observed that channels will enlarge in response to increased flows and shear stresses related to urbanisation of a catchment. This enlargement is believed to continue until shear stresses reduce, increased flows have been accommodated and an equilibrium has been reached. Some of the literature identifies the bankful event in a stable channel as the dominant event which dictates channel morphology. It has been theorised that in altered conditions the channel will respond in such a way that the dominant frequency event again becomes the bankful event. This is the basis for the channel enlargement in this project. Channel cross-sections were manually enlarged to accommodate the increase flows until bankful conditions are restored. The initial step in this process was to determine what the dominant bankful event is in the existing rural catchment. It is assumed that the area of One Mile Creek being studied is stable and in a state of equilibrium with regards to channel morphology.

As discussed in the previous chapter the ratio of bed and bank erosion is extremely difficult to predict and depends on a range of factors such as sediment characteristics, soil cohesiveness and local geology. For this reason it was decided to use two models to enlarge the channels - one which involves a high degree of lateral bank erosion and a second model which involves a greater degree of bed erosion. In both models the enlargement process was dictated by shear stresses in that cross-sections with higher shear stresses were enlarged first as one might expect would occur in One Mile Creek.

Chapter 4

Methodology

The methodology involved sequentially completing the three different modelling processes as outlined below.

4.1 Hydrologic Modelling Using RORB

The hydrologic modelling involved the following steps:

1. Use of topographic maps of catchment to delineate sub-catchments and determine approximate areas of sub-catchment. Lengths of individual stream reaches were also determined.

2. Development of existing rural and future urbanised models of sub-catchments, stream reaches and junctions using Graphical Editor of RORB. This included input of parameters for impervious fractions and channel types as outlined previously.

3. Input of IFD Chart for One Mile Creek catchment using the Bureau of Meteorology IFD Tool

4. Running of the RORB model with Design Storms for 2 and 100 year ARI rainfall events for both rural and urbanised scenarios to determine peak hydrograph and

peak flows for these events.

5. Calculation of Peak Flows using the Rational Method and compared against the RORB Rural Model output

6. Comparisons made between the models with regards to peak flows, lag times and volume of runoff.

4.2 Hydraulic Modelling using HEC-RAS

The hydraulic modelling involved the following steps:

1. Input of channel cross-section data into HEC-RAS using geometry data file supplied.

2. Input of other parameters including Manning's roughness values as previously defined.

3. Use of topographic map and Google Earth to map cross-section locations and determine overbank distances

4. Input of inflow data and boundary conditions using the output of RORB hydrologic modelling.

5. Running of a Steady Flow Analysis for 2 and 100 year flood events for the three different models

6. Processing the data as appropriate and making comparisons of the results with regards to water levels, flood extents, shear stresses, flood widths and flood hazard.

4.3 Channel Enlargement Modelling using HEC-RAS

The Erosion and Channel Enlargement Modelling involved the following steps:

1. Determination of which annual recurrence interval and duration in the Rural Model leads to Bankful Conditions.

2. Running of RORB using the determined ARI and Duration event with the urban flow

3. Completion of an erosion channel enlargement process by manually enlarging cross-sections laterally until the increased flow have been accommodated and returned to bankful conditions. Shear stress values were used to guide the channel enlargement process.

4. Completion of a bed erosion channel enlargement process by enlarging cross-sections through deepening of the channel bed until the increased flows were accommodated and flow regime returned to bankful conditions. Shear stress values were used to guide the channel enlargement process.

5. Comparisons were made between the results particularly with regards to magnitude of enlargement required and change in shear stresses.

Chapter 5

Results and Discussion

5.1 RORB Results

The RORB results concurred with existing literature in that significantly increased peak flows and reduced lag times occurred in the urban models. A diagram of the catchment map including sub-areas can be found in Appendix C. Initial results showed substantially increased peak flows in the urban model sometimes ten times the rural model. After consideration it was felt that a channel consisting entirely of lined channels was probably not realistic particularly with modern trends in urban drainage design. For these reasons it was decided to develop a third model which contained the same fraction of impervious surface but retained the natural unlined channels of the rural model. This model will be referred to as the urban unlined model.

The initial step in the RORB modelling process was to determine what would be the critical duration for both the 2 year and 100 year ARI events that would lead to the greatest peak discharge. Modelling showed that for the 2 year ARI event the critical duration was a 2 hour event while for the 100 year ARI event it was of 1 hour duration. Figure 5.1 is a chart of the model for the 100 year ARI event used in determining the critical duration. The urban catchment was used so the maximum peak flow could be determined across the three models. It can be seen that the 1 hour event resulted in the greatest peak flow for this event.

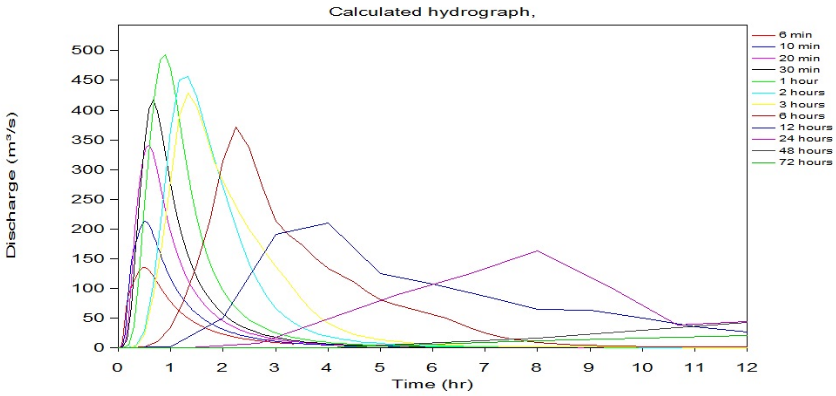

Figure 5.1: Critical Duration Hydrograph for Urban 100 YearARI Event

Figure 5.2 shows the hydrograph for the three models during the 2 year ARI event. The hydrograph broadly demonstrates that the urbanisation of the catchment has had a dramatic effect on the hydrology of the catchment with much greater peak flows in the urban models.

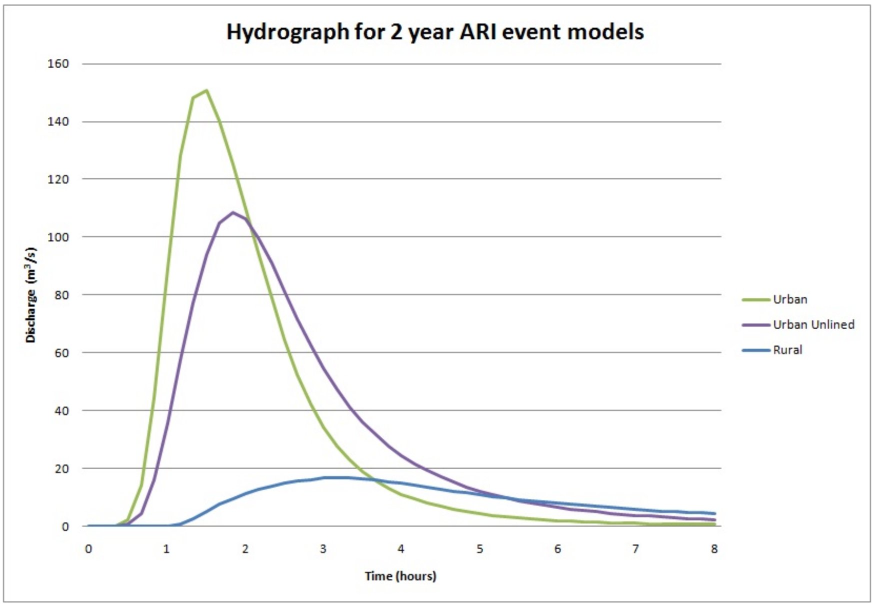

Figure 5.2: 2 Year ARI Event - Hydrograph of Three Models

It is also evident from Figure 5.2 that lag times are significantly reduced in the urban models. It can also be seen that there is a significant delay compared with the urban models before the hydrograph climbs which is indicative of the increased losses in the rural catchment meaning it takes longer for excess rainfall to occur leading to delay in runoff. Figure 5.3 shows the hydrograph for the 100 year ARI event and the results are similar but to a greater magnitude.

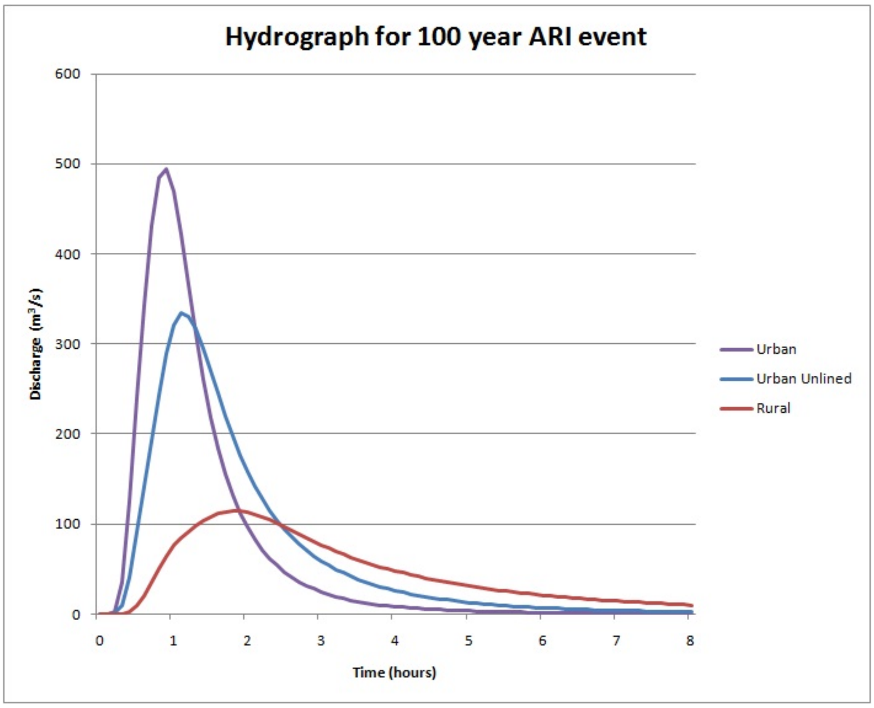

Figure 5.3: 100 Year ARI Event - Hydrograph of Three Models

In both Figure 5.2 and Figure 5.3 it can be seen that the hydrograph for the urban unlined model falls in between the other two models and suggests that the channel type has as much of an influence on the hydrograph as the fraction of impervious surface. The numerical output from the model is also worth noting and further demonstrates the impact that urbanisation has on the hydrology of the catchment. Table 5.1 shows the peak flows, runoff volume and lag times for the 100 year ARI event.

Rural, 1 hour, 100 year ARI	
Peak Discharge	114.9
Time to peak, h	1.8
Volume (m^3)	1.47E+06
Time to centroid (h)	3.69
Lag, c.m. to c.m. (h)	3.21
Lag to peak (h) 1.32	1.32

Urban Unlined, 1 hour, 100 year ARI	
Peak Discharge (m^3/s)	334
Time to peak, h	1.1
Volume (m^3)	2.02E+06
Time to centroid (h)	1.96
Lag, c.m. to c.m. (h)	1.55
Lag to peak (h) 1.32	0.689

Table 5.1: RORB Numerical Output of 100 Year ARI Event

It can be seen that the runoff volume is approximately a third greater in the urban unlined model than in the rural model. This indicates the fraction of impervious surface has led a significant greater volume of runoff. It also shows that lag time has been cut by around 50% in the urban model while peak flow has almost tripled. Table 5.2 displays the peak flows for each model and ARI event which have been used in the remainder of the modelling.

Table 5.2: RORB Peak Flows

Catchment	2 yr ARI Peak Flow (m^3/s)	100 yr ARI Peak Flow (m^3/s)
Rural	16.7	114.9
Urban Unlined	108.5	334
Urban	150.7	494

The peak flows for the rural catchment were verified against a Rational Method computation and flood events reported in the Wangaratta Floodplain Management Study. The Rational Method computations can be found in Appendix B. While there was some disparity between the Rational Method and model peak flows there was much greater similarity between the historical flood discharges and the model results. The 100 year ARI discharge for One Mile Creek was reported in the floodplain study as 160m^3/s while the model discharge for the rural catchment was found to be 114.9^3/s. It was deemed from these results that the model output discharges were sufficiently accurate for the purposes of the project. The project aims to make comparisons between the rural and hypothetical models so some level of disparity between the rural model and the physical catchment was considered acceptable and does not impact on the objectives of the project.

5.2 HEC-RAS Results

The results discussed in this section refer to HEC-RAS Modelling using the existing, fixed channel geometries. The results showed that urbanisation of the catchment has led to increased flow velocities, increased channel shear stresses, increased water levels and increased flood extents. Results of the water levels for each cross-section for the rural catchment can be found in Appendix D and cross-sections for the urban unlined channel are shown in Appendix E. A typical cross-section is shown in Figure D.5 and demonstrates the different in water level between the 2 and 100 year ARI events in the rural catchment.

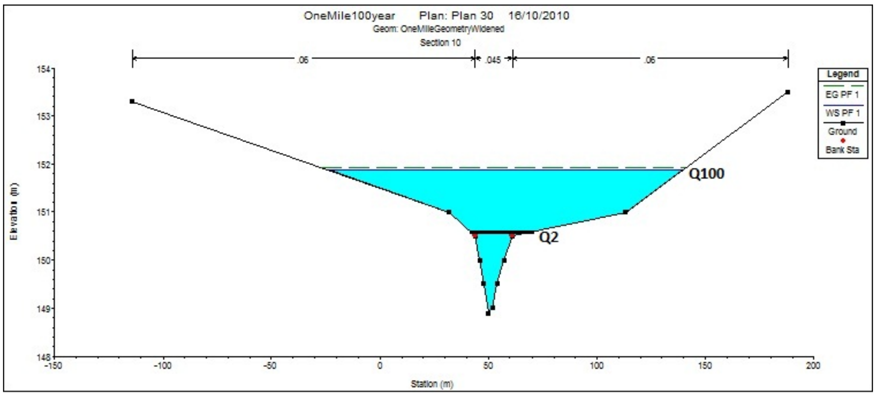

Figure 5.4: Typical Cross-Section - Rural Catchment

Figure 5.5 displays some key output for the 2 year ARI event. It can be seen that urbanisation has had a significant impact on discharge and flow velocity. The increase in discharge has been discussed earlier as this is the primary output from the RORB Model.

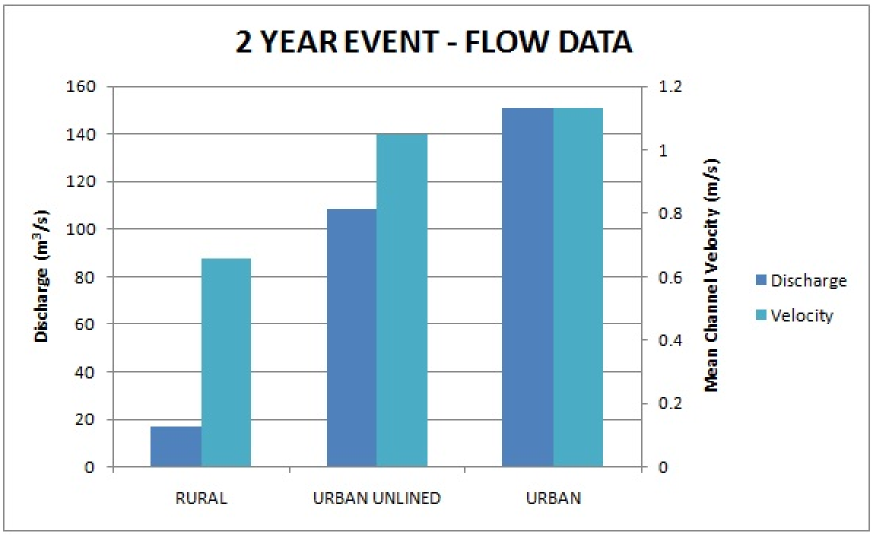

Figure 5.5: 2 Year ARI Event - Impacts on Discharge and Flow Velocity

The results from each cross-section were compiled into a spreadsheet so mean values could be determined along the channel length. The results show that mean channel flow velocity has increased from 0.658m/s in the rural model to 1.05m/s and 1.13m/s in the urban unlined and urban models respectively.

The results from the 100 year ARI event show similar increases. It can be seen in Figure 5.6 that mean channel flow velocity has increased from 1.06m/s in the rural model to 1.36m/s and 1.48m/s in the urban unlined and urban models respectively. These results agree with both the literature and logic and show some of the impacts that occur when greater discharges move through the reach.

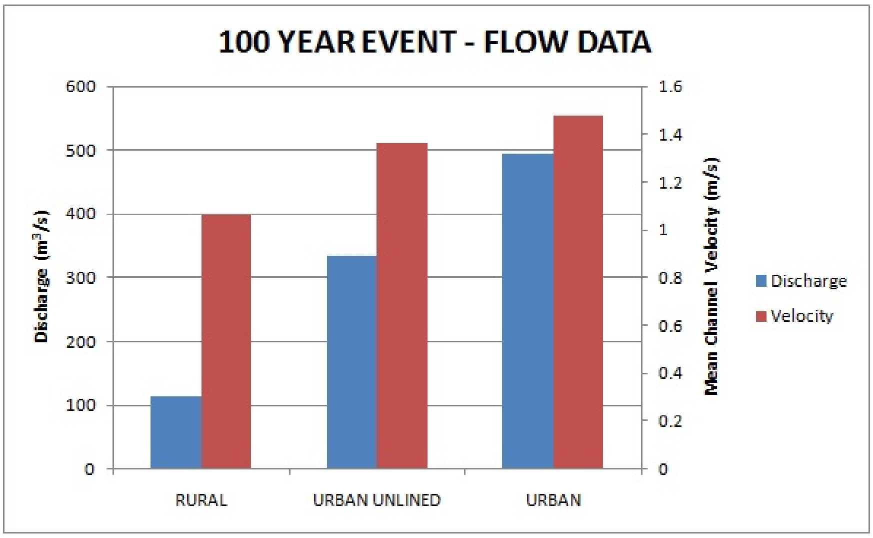

Figure 5.6: 100 Year ARI Event - Impacts on Discharge and Flow Velocity

The other significant area of interest in the HEC-RAS results was flood behaviour. This can be measured in several ways including flood widths, area of inundated land and flood hazard. Flood hazard is a basic measure used to assess the severity of a flood or the risk that is poses. It is determined simply by taking the product of mean channel depth and mean flow velocity. The resultant flood hazard gives an indication of severity and there are also charts which grade the flood severity according to the relative contribution of depth and velocity. It is generally agreed that a flood hazard of greater than 0.5 indicates a moderate to severe flood while greater than 1 indicates a severe to extreme flood. Figure 5.7 displays the results for Mean Flood Width and Flood Hazard for the 2 year ARI event.

The results show a Mean Flood Width of 56.2 metres for the rural model. This in itself is a substantial flood and may suggest that discharged and flood extents may be overestimated in this model however that does not stop useful comparisons being made between the different scenarios. This possible overestimation has been further confirmed subjectively through images of September 2010 flood events in One Mile Creek which

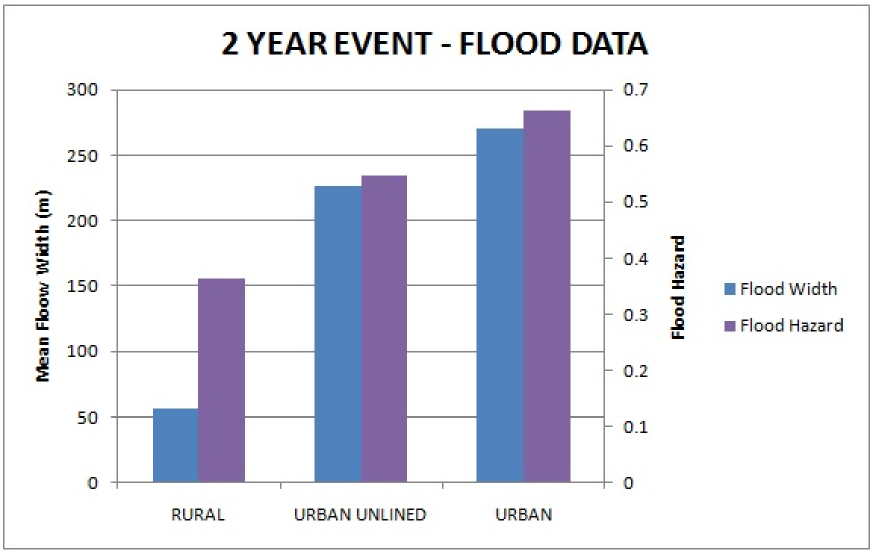

Figure 5.7: 2 Year ARI Event - Impacts on Flood Width and Flood Hazard

have been estimated at 15 year ARI floods but appear to have less flood extent than the results have shown in the 2 year ARI model. Images from the September 2010 floods can be seen in Appendix F. It is also important to note that local topography plays a role in flood behaviour as the wide, flat plains surrounding the channel lend themselves to greater flood extents. The urban and unlined mean flood widths for the 2 year ARI event were calculated to be 226m and 270m respectively. Again, these flood extents seem quite large for a 2 year event.

Figure 5.7 show that the flood hazard results for the 2 year ARI event show a mean of 0.36. This places the flood in the low-medium risk category. In the urban models however the mean hazard increases to 0.55 and 0.66 in the urban unlined and urban models respectively. This means the urbanisation of the catchment has increased the flood risk for the 2 year ARI event from a low-medium risk to a medium-high risk. This quantifying of flood risk is a useful tool and allows a greater appreciation of how urbanisation has affected the catchment particularly in terms of flood behaviour.

Figure 5.8 display the flood results for the 100 year ARI event and show similar results to the 2 year ARI event but to greater magnitudes. The mean flood with for the rural model was calculated to be 242m and increased to 473m and 580m for the urban unlined and urban models. These are obviously quite substantial floods with an approximate two-fold increase from the rural to urban scenario.

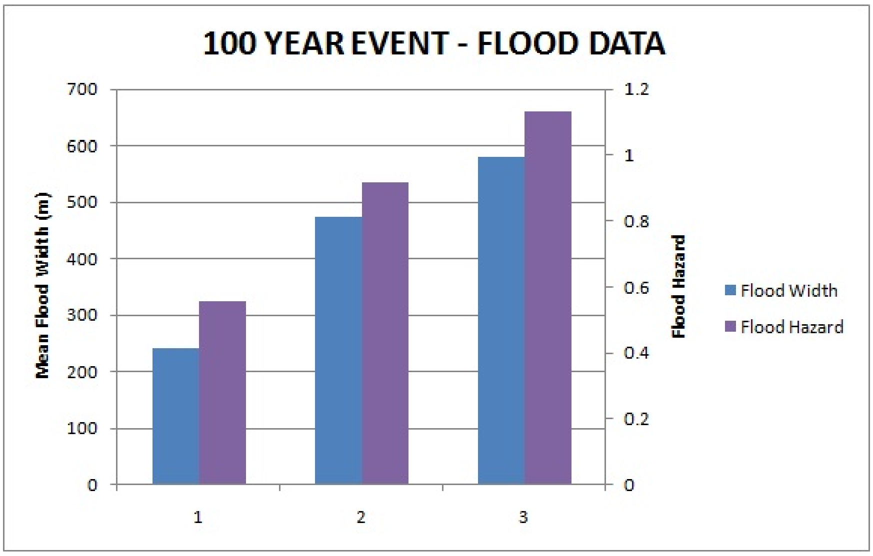

Figure 5.8: 100 Year ARI Event - Impacts on Flood Width and Flood Hazard

The Flood Hazard results in Figure 5.8 show the rural model to have a risk of 0.55 which places it in the moderate-severe category. The Flood Hazard result for the urban unlined model is 65% higher than this placing it almost in the extreme category of flood event. The urban model results on a flood hazard of 1.13 making it an extreme flood. This results further confirm the impact that urbanisation has on flood behaviour. It highlights the need for these impacts to be considered and gives some indication as to the consequences if mitigating strategies and structures are not implemented.

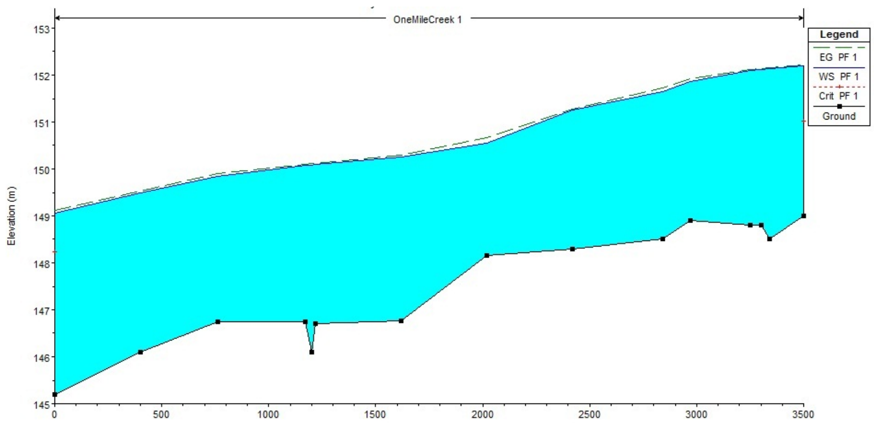

Figure 5.9: Longitudinal Profile - 100 Year ARI Event with Rural Flow

Another useful output from HEC-RAS are longitudinal profiles which help gain an understanding of the stream hydraulics through the length of the reach. Figure 5.9 displays the 100 ARI event longitudinal profile in the rural model. This diagram permits a greater understanding of the bed profile and correspondingly how the water surface elevation alters in response to the bed changes. The dotted line represents the energy line and it can be seen that there are two sections were the energy line is higher than the water surface level. This indicates areas where flow velocity has increased and so accordingly there is a greater degree of kinetic energy. It can be seen that these sections coincide with either a flattening or increasing height of the channel bed which concurs with hydraulics theory.

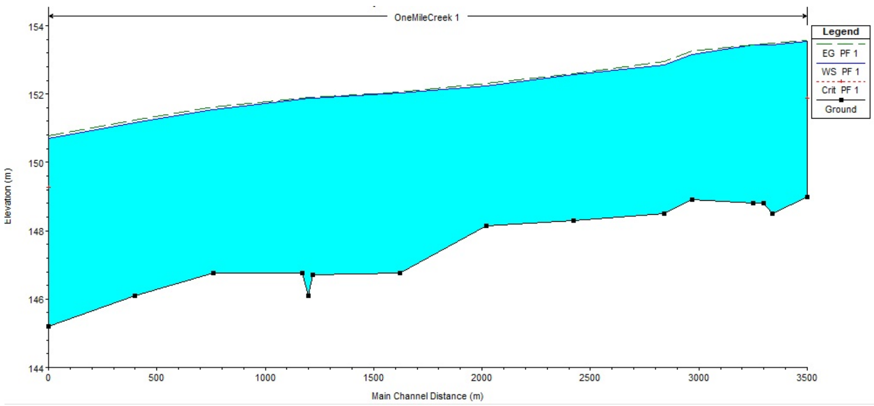

Figure 5.10: Longitudinal Profile - 100 Year ARI Event with Rural Flow

By comparing the longitudinal profile in Figure 5.9 to the profile for the urban model in Figure 5.10 it can be seen how urbanisation has had a significant impact on water surface levels through the reach. It is evident that the urban water level is approximately 1-1.5 metres higher than in the rural model. It can also be seen that this increase in profile has reduced the impact of the changes in bed profile and that the energy line and water surface level run largely parallel through the reach. The difference between the energy line and water surface profile seems slightly more throughout the reach which is indicative of the increased flow velocities in the urban model.

Another output that can give a good visual indicator of flow and flood behaviour in the reach is the xyz 3D Plot. Figure 5.10 displays this plot for the 100 year ARI event with rural flows. It is evident in this plot that flood levels have gone over bank level and are inundating significant areas of the floodplain which is to be expected based on the flood widths determined earlier.

The same plot for the 100 year ARI event but with the urban flows really shows how the flood extents are dramatically increased in the urban catchment. While the plot

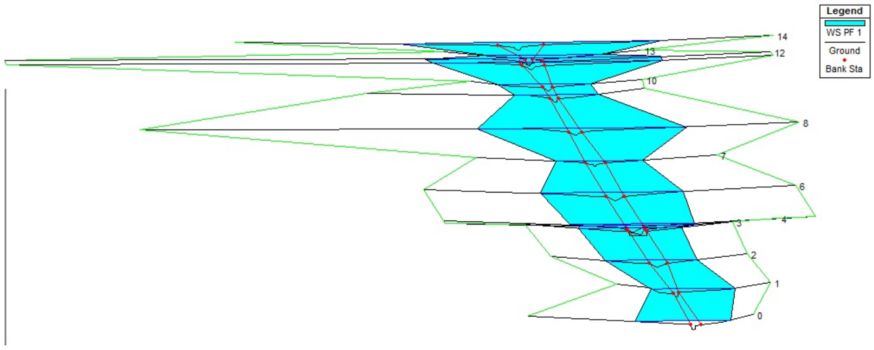

Figure 5.11: 3D Plot - 100 year ARI event with Rural Flow

does not contain a scale the different in inundated area between the rural and urban catchments is very clear.

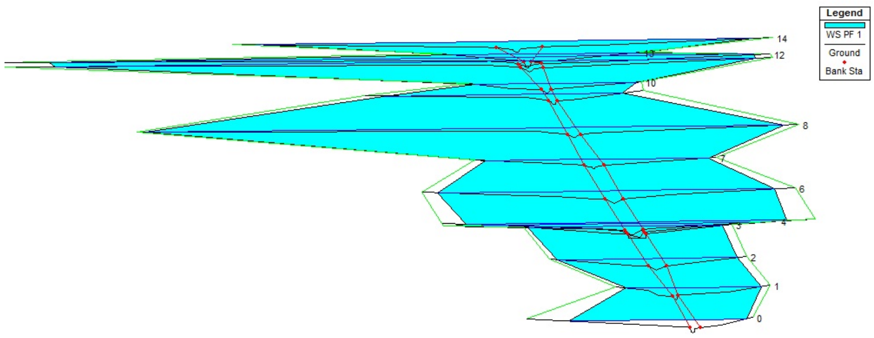

Figure 5.12: 3D Plot - 100 year ARI event with Urban Flow

The various types of results from the HEC-RAS model allow a good understanding of how urbanisation of the catchment has impacted on the hydraulics and flood behaviour of the channel. While some of the impacts such as discharge and velocity have been well documented in past research there is far less recorded information on the impacts of flood behaviour so these results give some initial and basic understanding of the gravity of these impacts. The results confirm that urbanisation leads to increased flow velocities, increased shear stresses, increased water levels and in this catchment quite substantial increases in flood extents. It seems clear that results of the magnitude of these impacts are quite particular to the One Mile Creek catchment and models which concurs with much of the literature that has concluded that these impacts are quite localised and individual. It has been noted that significant variations in impacts can even occur within a single reach making it difficult to take some specific conclusions from these results for use on other catchments.

5.3 Erosion and Channel Enlargement Results

The initial step in the channel enlargement process was to determine what would be a bankful event. Typically this tends to be approximately a 2 year ARI event although it can vary considerably. The existing results showed that the 2 year ARI event led to overbank conditions so a 1 year ARI event was trialled. Using the RORB model with a range of durations it was determined that the critical peak flow for the 1 year ARI was 8.5m^3/s. A steady flow analysis was run in HEC-RAS and it was observed that this led to bankful conditions through much of the reach. The urban peak flow for the same event was then determined in RORB and found to be 46m^3/s. Figure 5.13 displays a typical unmodified cross-section with the urban flow resulting in overbank flow conditions.

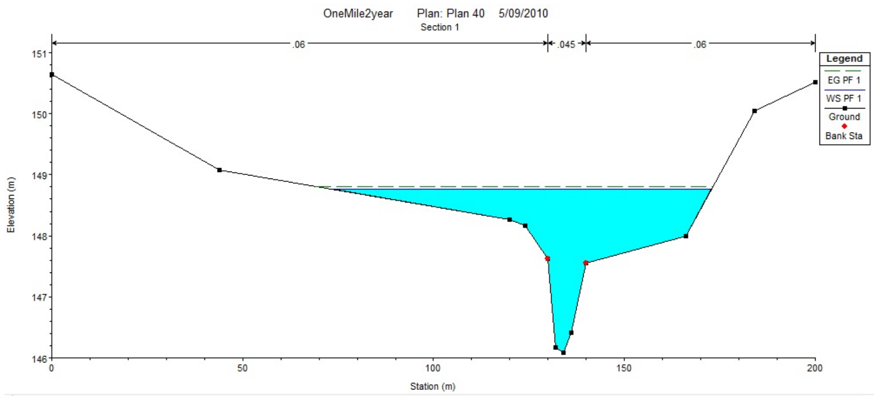

Figure 5.13: Unmodified Channel - Typical Cross-Section with 1yr ARI Urban Flow

The reach channels were then enlarged to accommodate the increased flow. As described earlier two enlargement processes were used. One involved a degree of lateral bank erosion while another involved a greater degree of bed erosion this leading to a deepening of the channel. The channels were enlarged using shear stresses to guide the process with the assumption that cross-sections experiencing higher shear stresses would be likely to erode first. The bank erosion process proved to be fairly straightforward and cross-sections were enlarged until the urban flows were accommodated. Figure 5.14 shows a typical modified cross-section from the bank erosion model and it can be see that the water level has returned to bank height. The results from the bank erosion model showed that a mean channel width increase of 16m was required to accommodate the increased flows.

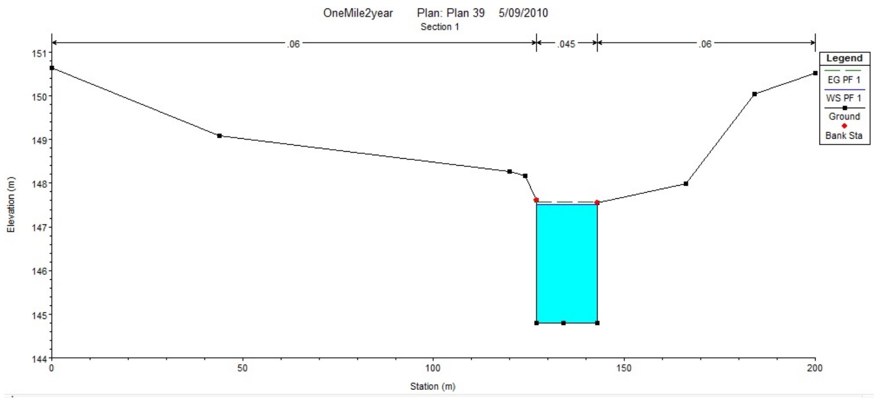

Figure 5.14: Bank Erosion Model - Typical Modified Cross-Section with 1 year ARI Urban Flow

The channel enlargement process using the bed erosion model was not as easy to achieve. The process proved very time-consuming and water levels were quite sensitive to changes in other cross-sections. This resulted in bankful conditions not being achieved as well as in the bank erosion model. The resultant cross-sections were considered to be the ones that led most closely to bankful conditions across the reach. Figure 5.15 displays a typical modified cross-section from the bed erosion model and it can be seen that the water level is slightly above bank height demonstrating some of the difficulties experienced in trying to achieve bankful conditions. The results from the bed erosion model showed that a mean channel depth increase of 0.55m was required to accommodate the increased flows.

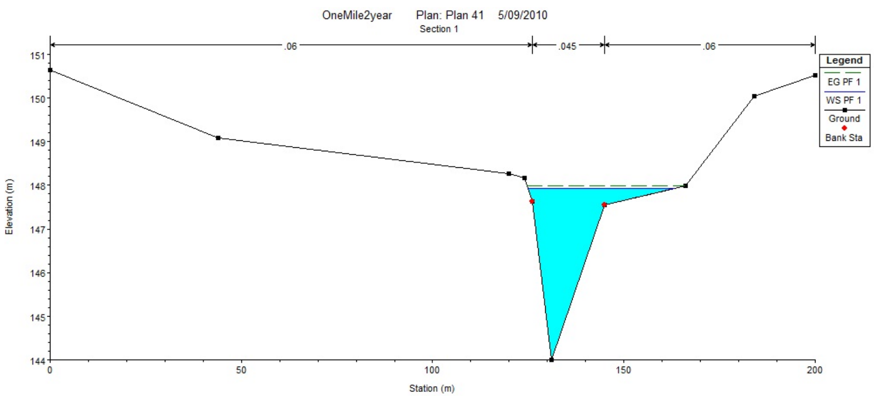

Figure 5.15: Bed Erosion Model - Typical Modified Cross-Section with 1 year ARU Urban Flow

Analysis of the results provided some interesting information regarding the magnitude of channel enlargement required to accommodate the increase flows and the associated impact on hydraulic characteristics such as shear stress. Figure 5.16 displays the mean results for channel enlargement and shear stress in the two models. The first series shows the mean channel area in the unmodified channel and this was found to be $20.7m^2$. In the bed erosion model this increased to $67.5m^2$ while the mean channel area in the bank erosion model was found to be $64.9m^2$. These results equate to a mean channel increase of 120.2% or an enlargement ratio of 2.2. This enlargement fell within some of the ranges identified in the literature.

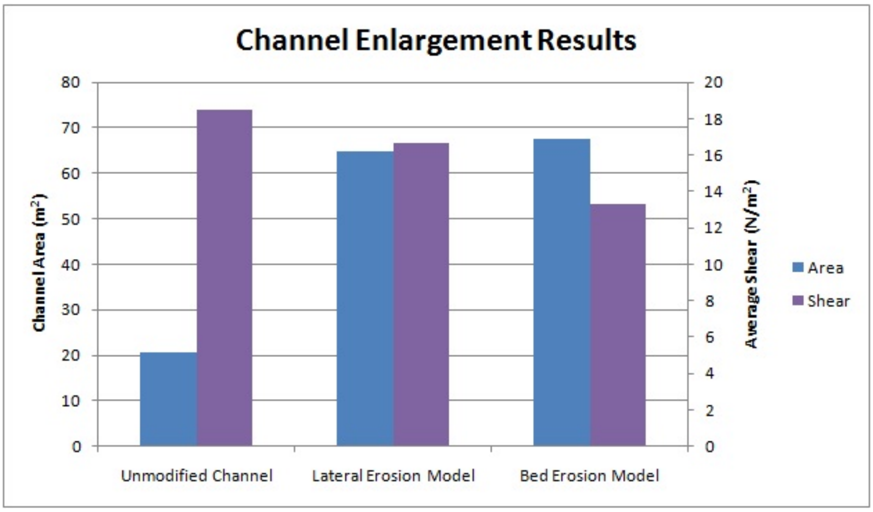

Figure 5.16: Channel Enlargement Results - Channel Area and Shear Stresses

The results of the mean channel shear stress is also worth noting. It was calculated that the unmodified channel with rural flows had a mean channel shear stress of 10.96N/m^2. With the increase to urban flows the shear stress increased to 18.52N/m^2 as a result of increased flow velocities. Figure 5.16 shows the reductions in shear stresses that occurred with each channel enlargement model. The resultant mean channel shear stresses were 13.28N/m^2 and 16.68N/m^2 for the bed erosion and bank erosion models respectively. The lower shear stress in the bed erosion model possibly suggests that the bed model geometry is a more efficient shape with regards to flow conveyance. It is evident that the shear stresses did not reduce back to the original unmodified channel levels following the enlargement process. One could conclude that, while the urban flows have been accommodated, continued enlargement is likely to occur until shear stresses have reduced to their original levels. This means the final stable channel size may be greater than the 2.2 enlargement ratio that was calculated.

The unmodified shear stress of 10.96N/m^2 is worth noting as it is considerably greater than some critical stress values reported for other streams in the region that ranged from 0.4 to 4.0m^2. Based on this it could be concluded that there is a significant differential between the critical and boundary shear stresses in One Mile Creek and that the channel may be undergoing a significant erosion process as a result. Closer analysis of the cross-section identifies that there is a single cross-section with a very high shear stress of 90N/m^2 which skews the mean considerably. The median shear stress value for the rural flow is 3.7N/m^2 and if this upper value is removed completely the mean adjusts to 5.3N/m^2 which is obviously much closer to the regional critical shear stress values.

The results indicate that channel geometries and peak flows for specific rainfall events can change significantly over time. This is in direct contrast to one of the assumptions frequently made in flood modelling and mapping tasks which is that geometries are assumed to be fixed. The results indicate that this may not be the case in developing catchments and this could cause significant inaccuracies in the flood mapping results. An example of this would be if a 100 year event peak flow increased significantly over time to the same magnitude as occurred in this project. Flood extents would increase accordingly and lead to the extent of the 100 year flood being considerably greater than previously thought. If the flood mapping is being used for the purposes of planning for new development this could have enormous ramifications for both the residents now living on the floodplain and the person who developed the flood map. This study has identified that changes in channel geometry and peak flows need to be considered in the context of a developing catchment and that it cannot be assumed that these characteristics are fixed.

This concept of changing peak flows and flood extents needs to be tied in with the channel enlargement processes discussed in this project. While it has been shown that flood extents can increase considerably in time if the channel enlarges accordingly these flood extents would presumably reduce as the increased flows are accommodated. Thus it could be predicted that these impacts are not necessarily permanent and may in fact reduce over time although the literature does suggest that stabilisation and equilibrium of a channel can take up to thirty years to occur. These are complex processes, however, and it is difficult to make clear predictions and conclusions. There is a clear need for further research to examine these relationships.

Chapter 6

Conclusions and Recommendations

This project has confirmed that urbanisation has a significant impact on the hydrology and hydraulics of a catchment which reflects the existing literature. The modelling has shown that urbanisation leads to several hydrologic changes including increased peak flows, reduced lag times and increased runoff volume. It has been identified that the fraction of impervious surface of a catchment and the type of drainage channels are the two main factors which differ in an urbanised catchment and lead directly to the altered runoff characteristics. While the nature of these impacts are widely agreed in the literature there is less evidence regarding the magnitude of these impacts. The results of this project showed variability in the changes in peak flows, lag times and runoff volumes varied between different models and rainfall events. It is likely that these changes are quite localised to the One Mile Creek catchment and model. This concurs with the existing literature which has concluded that the magnitude of these impacts varies considerably even in catchments that appear to have quite similar characteristics and levels of development.

The hydraulic modelling identified some significant impacts on flow and flood behaviour as a result of urbanisation. The increased peak flows associated with development of the catchment led to increased channel velocities and boundary shear stresses. It was also found that water levels and flood extents increased significantly in the urban models. While there is ample literature on the impacts on the hydrology of urbanised catchment there is substantially less information on how urbanisation impacts on flood behaviour.

The erosion modelling showed that a significant enlargement in the channel geometry is needed to accommodate the urban flows which was in the order of a 2.2 enlargement ratio compared with the unmodified channel. The modelling has also shown that this enlargement leads to an associated reduction in shear stresses through the channel reach although they did not reduce back to pre-urban levels. In terms of exactly how the channel will respond in terms of bed and bank erosion this was not as easy to determine and reflected some of the existing literature which suggests that it depends on a range of different factors and tends to be a very localised and individual response. Nevertheless, despite different approaches used in each model they showed a similar degree of channel enlargement was required to accommodate the increased flows.

in terms of the implications of these results there are several conclusions that can be made. The first is that the nature and magnitude of these impacts highlight the importance of good urban drainage design and implementing measures that can mitigate these changes. While it wasnt a focus of this project using principles such as Water Sensitive Urban Design can certainly reduce these impacts through a range of measures such as retaining unlined channels and encouraging stormwater harvesting. It is acknowledged that it is increasingly becoming the norm for councils to stipulate that peak flows from new developments are no greater than pre-development levels. This type of regulation is recommended to mitigate these unwanted impacts.

Another issue that has been addressed is the fact that cross-section geometries and flows for specific rainfall events are typically assumed to be fixed for the purposes of flood modelling and floodplain management. Clearly though in the case of developing catchments this is not always true and flows and channel geometries could change significantly over time. The likelihood of these changes may need to be assessed as flood extents and flows could go on to be very different in 50 or 100 years time depending on how the catchment develops. This has significant ramifications for long-term planning including the location of new developments and the delineation of flood corridors and buffer zones. Changes in geometry and peak flows may need to be factored into the modelling processes in developing catchments to ensure accuracy in the long-term.

This project has also discussed the notion that channels experiencing increased flow regimes will respond by enlarging until an equilibrium has been reached. The literature suggests that this response takes considerable time and that maximal channel morphology occurs between 5 and 30 years after development. This has implications for industry in that in channels undergoing enlargement may take a long period of time to stabilise and some of the literature suggests that measures to stabilise eroding channels are likely to fail until an equilibrium has been reached.

In conclusion this project has confirmed that urbanisation of a catchment can lead to significant impacts on the catchment hydrology, hydraulics and channel morphology. While the nature of these impacts are widely agreed in the literature it has been found that the magnitude of these impacts are quite varied and this was reflected in the results of this investigation. The project has also identified the need for further research into this area so that the impacts of urbanisation on the hydrology, hydraulics and fluvial erosion of a catchment can be better understood.

6.1 Achievement of Project Objectives

The following objectives have been addressed:

Research existing literature on the impacts of urbanisation on catchments Chapter 2 presented a summary of existing literature regarding the impactions of urbanisation on catchments.

Determine appropriate models and model parameters The process of selecting appropriate models was addressed in Chapter 3 and included a detailed description of the parameters used in each model.

Complete modelling of both 2 year and 100 year ARI rainfall events This objective was completed and the results are detailed in Chapter 5.

Repeat the modelling for the future urbanised catchments This objective was completed and the results are detailed in Chapter 5.

Quantitatively compare the results of modelling Detailed comparisons were made between the existing rural and future urban models and the results are detailed in Chapter 5.

6.2 Recommendations

This study has identified the need for further research into this area to see if the relationship between urbanisation and the associated impacts on catchments can be better understood. The project has also identified the need for further investigation into the relationships between urbanisation, flood behaviour and channel morphology. It has also been noted that while there is significant theoretical literature behind topics such as sediment transport, hydrology and open channel hydraulics there is far less literature on the application of these fields for some of the tasks mentioned in this project including flood modelling and predicting morphological changes. Further research into the application of this theory for such purposes would be valuable.

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Appendix A

Project Specification

University of Southern Queensland

FACULTY OF ENGINEERING AND SURVEYING

ENG 4111/4112 Research Project
PROJECT SPECIFICATION

FOR: **Julian Skipworth**

TOPIC: AN INVESTIGATION AND QUANTITATIVE ANALYSIS OF THE GEOMORPHIC AND STREAM FLOW IMPACTS ASSOCIATED WITH URBANISATION OF A SMALL CATCHMENT

SUPERVISORS: Dr. Ian Brodie, USQ
Julian Martin, Water Technology

PROJECT AIM: This project will investigate methods of modelling the geomorphic effects of urbanization in a small rural catchment in North-East Victoria and will include hydrologic, hydraulic and geomorphic modelling and a quantitative analysis of these geomorphic effects

PROGRAMME: **Issue A, 13 March 2010**

1. To research the impacts of urbanisation on the hydraulics and geomorphology of rivers
2. To research and determine an appropriate geomorphic model for the selected catchment in North-East Victoria
3. To research and determine an appropriate hydraulic model for the selected catchment based on the selected geomorphic model
4. To research and determine an appropriate hydrologic model for the selected catchment based on the selected geomorphic and hydraulic models
5. To use the selected models to complete hydraulic, hydrologic and geomorphic modelling of 2-year and 50-year rainfall events
6. To define and overlay a future urbanised situation on the same catchment and repeat the modelling for of 2-year and 50-year rainfall events
7. To quantitatively compare the modelling results in order to make some conclusions regarding the impacts on geomorphology and stream flow due to urbanisation of a previously undeveloped catchment.

As time permits:

8. To complete further modelling, mapping and comparisons for 20-year and 100-year events

AGREED:

___________________________ (Student) ____________________________(USQ Supervisor)

Date: ___/____/2010 Date: ___/____/2010

Examiner/Co-examiner:____

Figure A.1: Project Specification.

Appendix B

Rational Method Calculations

This Appendix contains the Rational Method Calculations used to verify RORB peak discharges. The calculations are shown below.

100 Year ARI Rational Method Calculation

Catchment Area = 44.71km^2

C_{10} = 0.11, FF_{100} = 1.3 (from AR & R)

$tc = 0.76 \times A^{0.38} = 3.22h$

$I_{3.22h,\,100y}$ = 22mm/h (Using One Mile IFD)

$C_{100} = C_{10} \times FF_{100} = 0.11 \times 1.3 = 0.143$

$Q_{100} = 0.278 C_{100} I_{3.22,100} A = 0.278 \times 0.143 \times 22 \times 44.71 = 39m^3/s$

2 Year ARI Rational Method Calculation

Catchment Area = 44.71km^2

C_{10} = 0.11, FF_2 = 0.75 (from AR & R)

$tc = 0.76 \times A^{0.38} = 3.22h$

$I_{3.22h,\,2y}$ = 9mm/h (Using One Mile IFD)

$C_2 = C_{10} \times FF_2 = 0.11 \times 0.75 = 0.0825$

$Q_2 = 0.278 C_2 I_{3.22,2} A = 0.278 \times 0.0825 \times 9 \times 44.71 = 9.2m^3/s$

Figure B.1: Rational Method Calculations

Appendix C

Catchment Sub-Area Map

A topographic map was used to map the catchment and delineate the sub-areas for the RORB Model. A representative map is shown below and demonstrates the sub-areas used in this process.

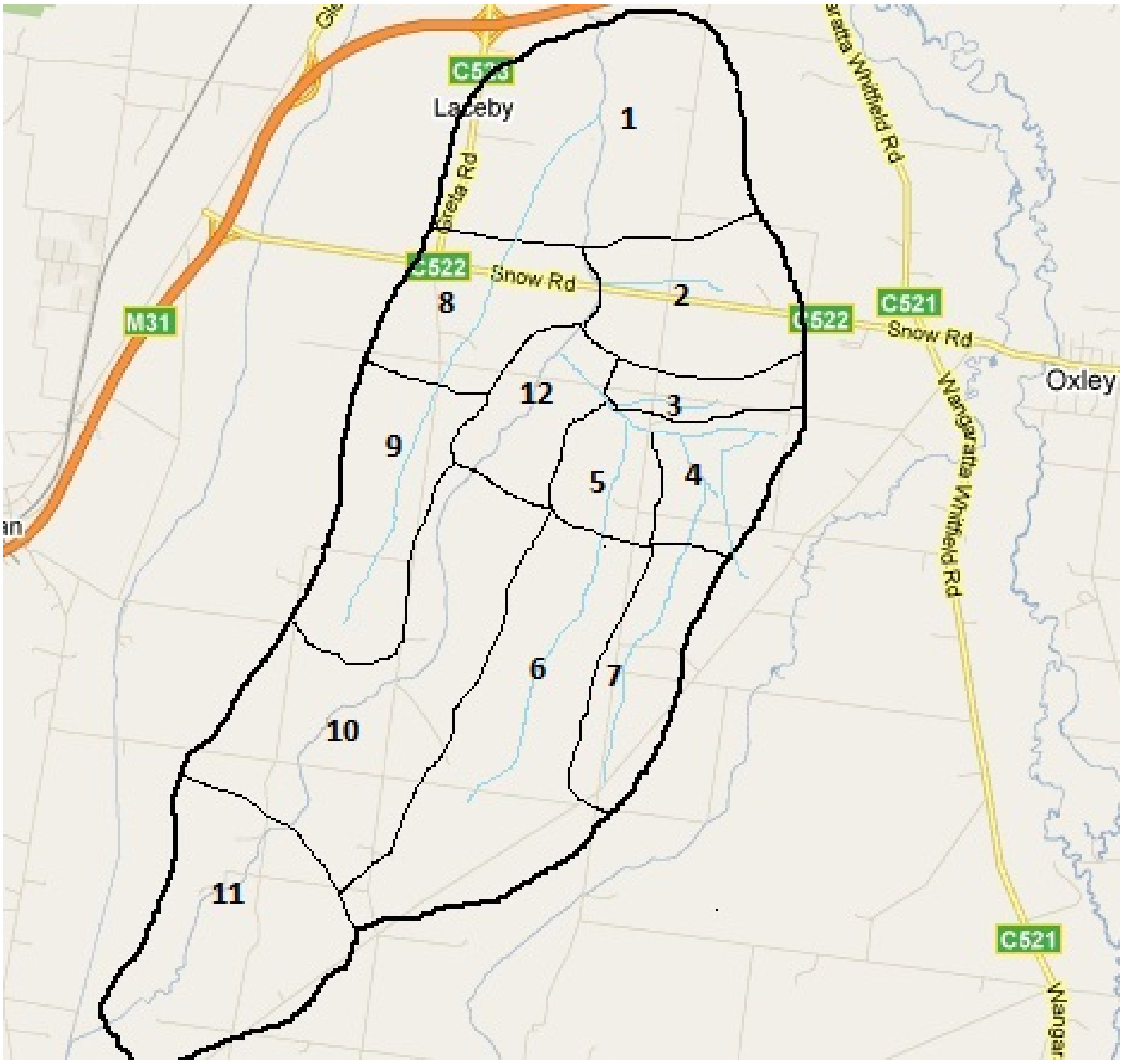

Figure C.1: Catchment Map for One Mile Creek including sub-areas

Appendix D

HEC-RAC Cross-Sections - Rural Catchment

The fifteen One Mile Creek cross-sections are displayed below with water levels for the 2 and 100 year events show for the rural catchment.

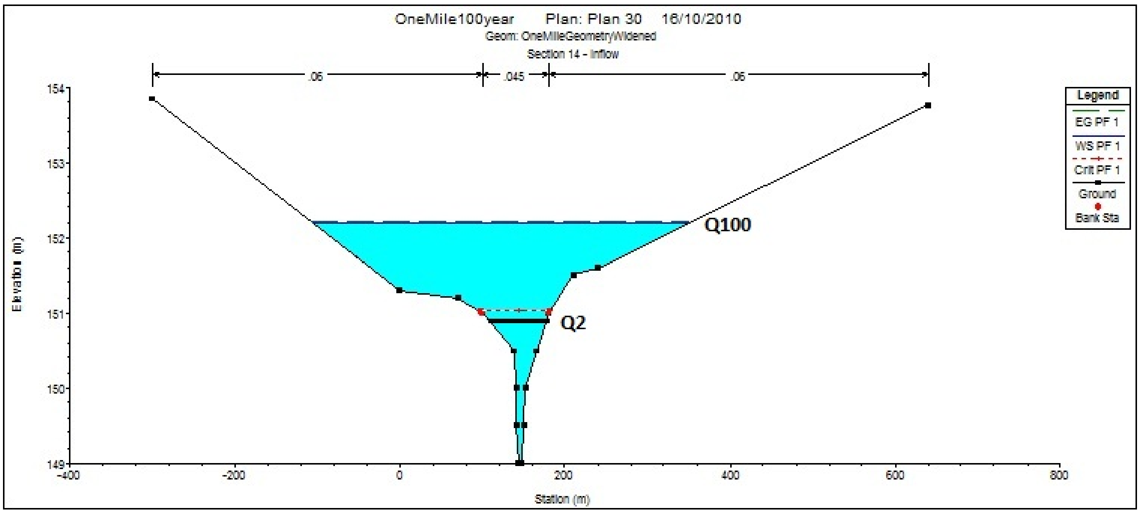

Figure D.1: Cross-Section 14 - Rural Catchment

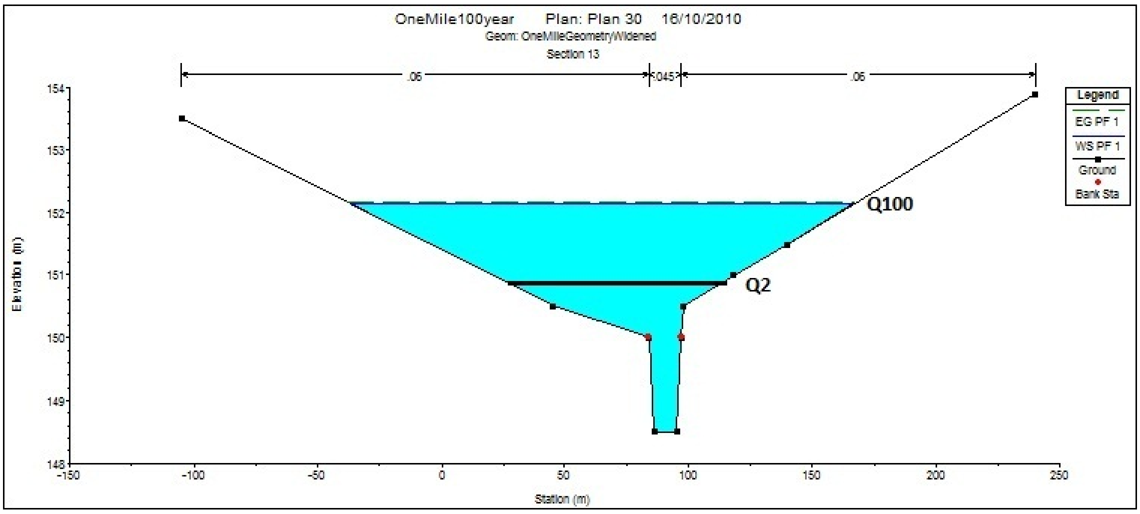

Figure D.2: Cross-Section 13 - Rural Catchment

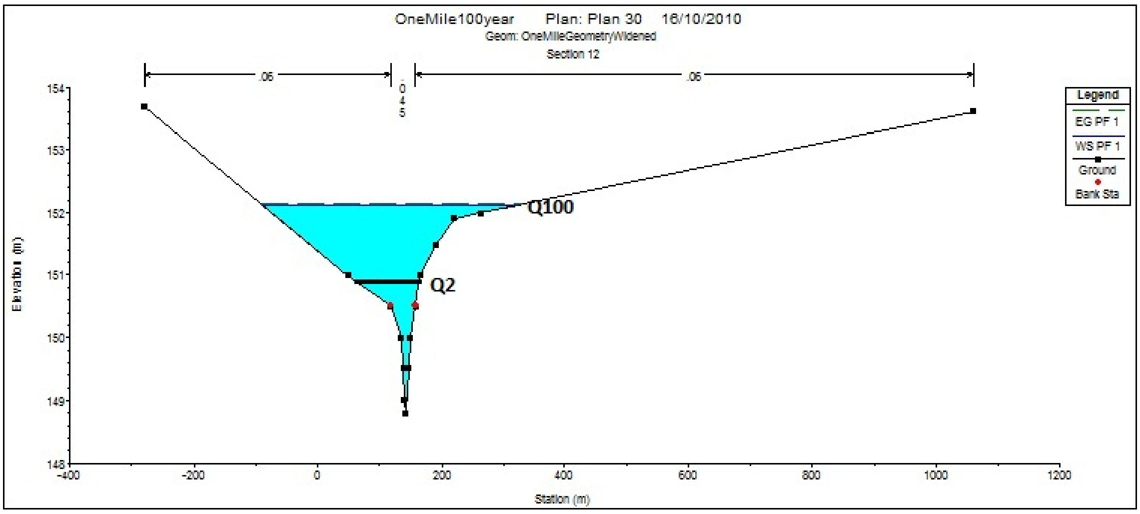

Figure D.3: Cross-Section 12 - Rural Catchment

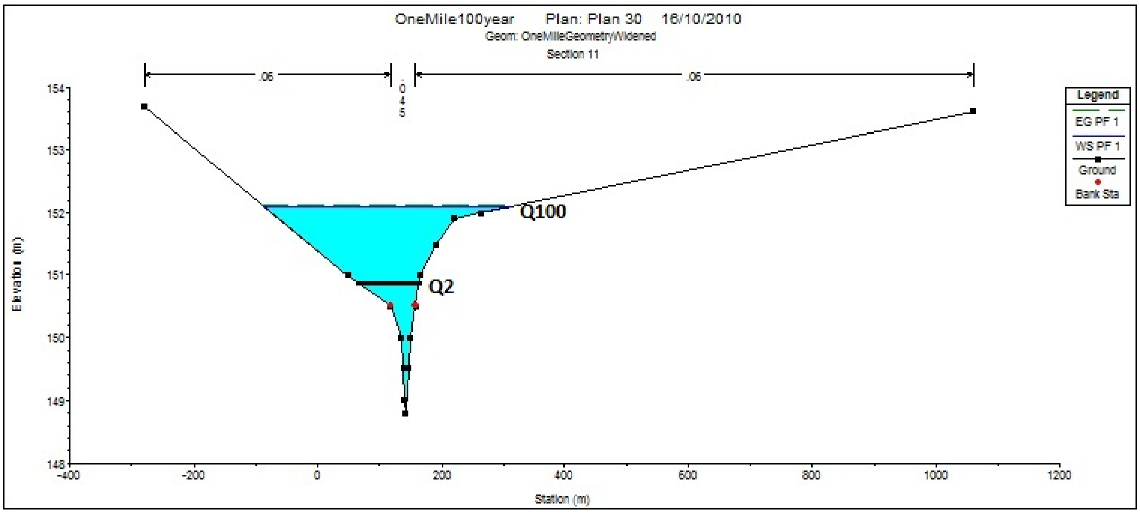

Figure D.4: Cross-Section 11 - Rural Catchment

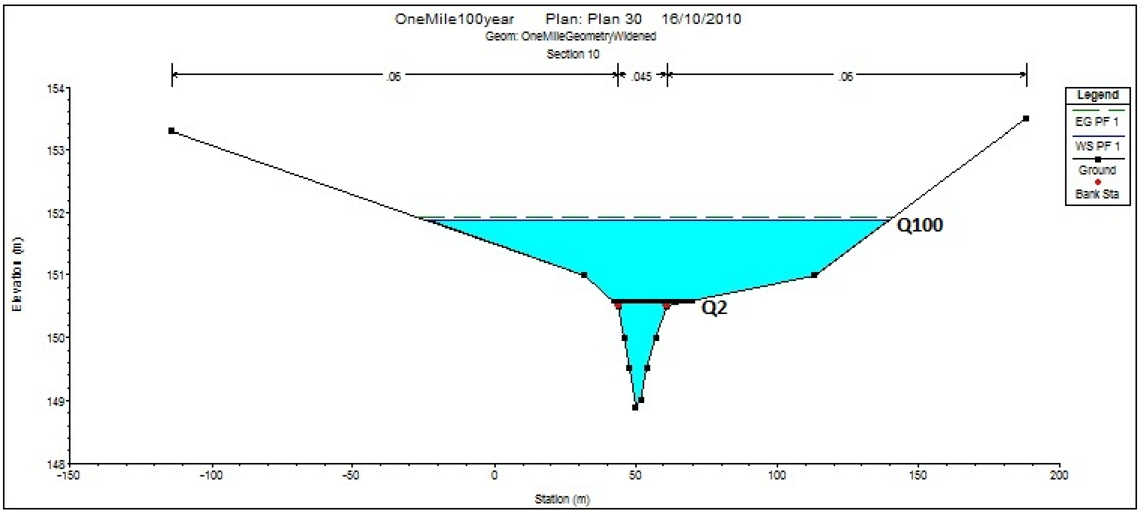

Figure D.5: Cross-Section 10 - Rural Catchment

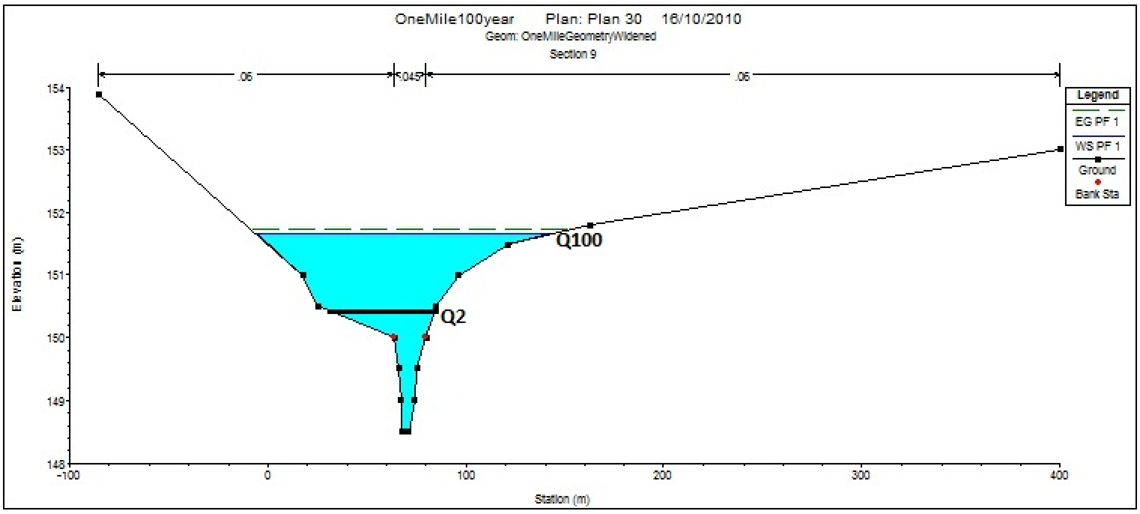

Figure D.6: Cross-Section 9 - Rural Catchment

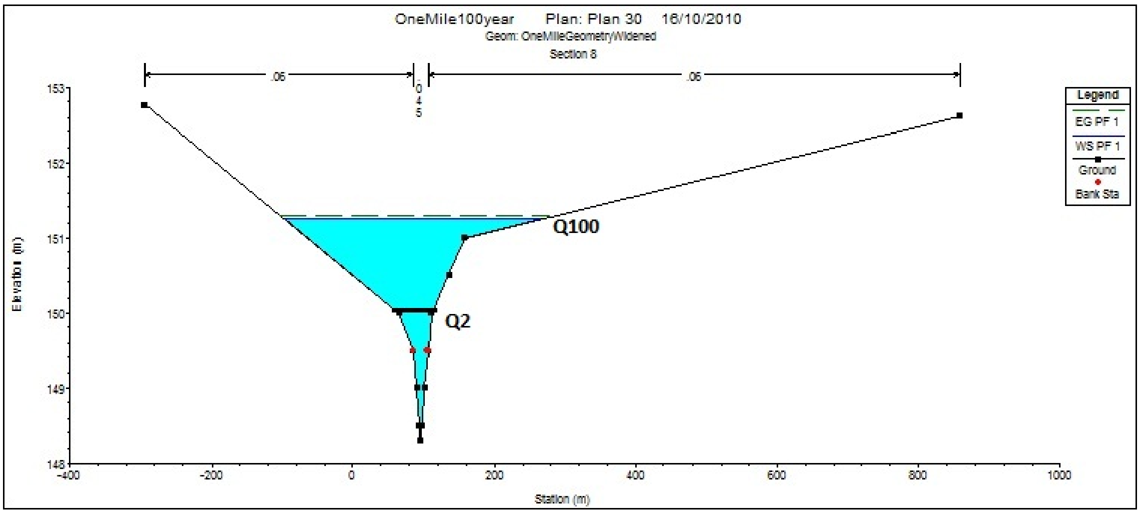

Figure D.7: Cross-Section 8 - Rural Catchment

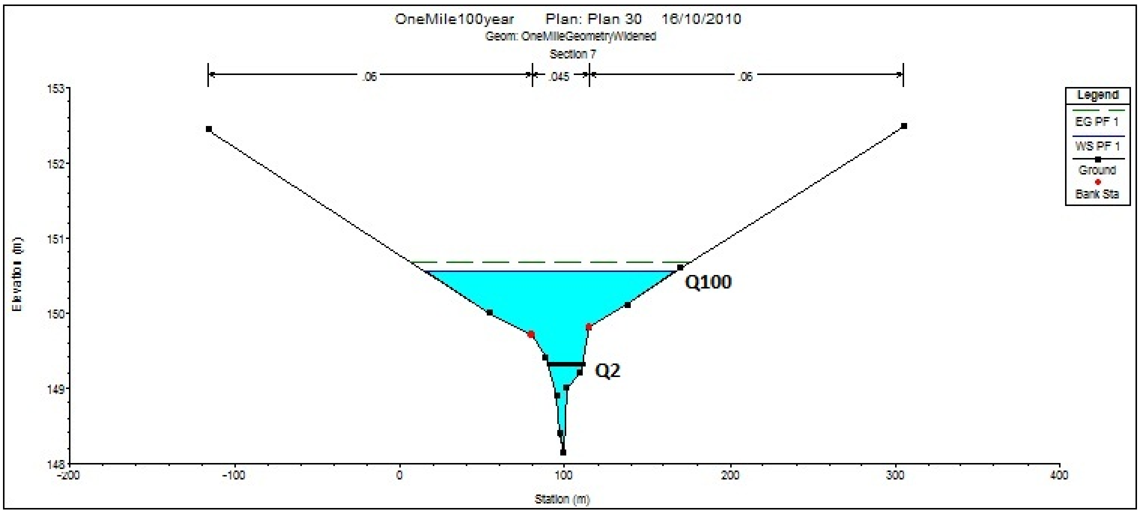

Figure D.8: Cross-Section 7 - Rural Catchment

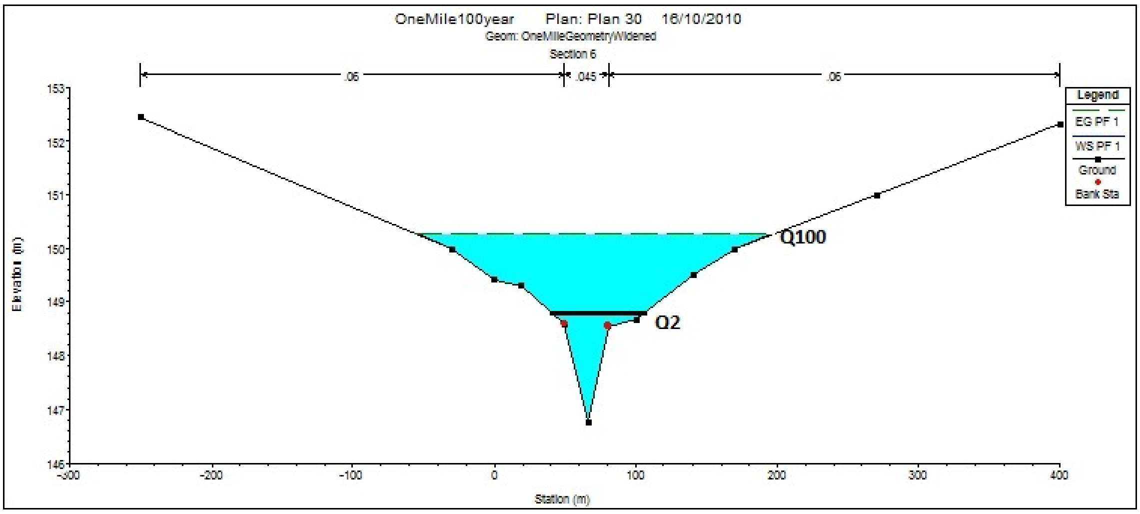

Figure D.9: Cross-Section 6 - Rural Catchment

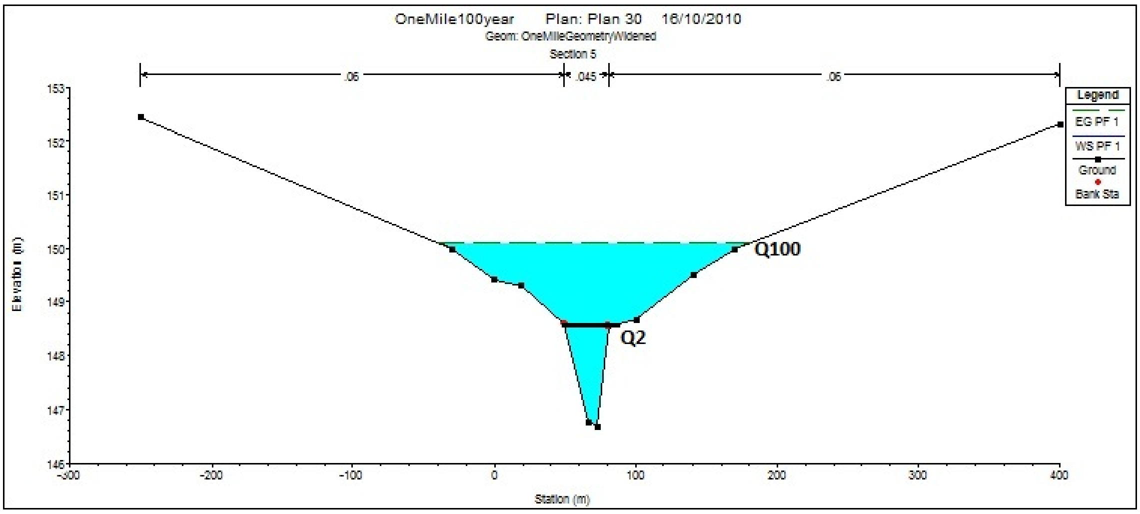

Figure D.10: Cross-Section 5 - Rural Catchment

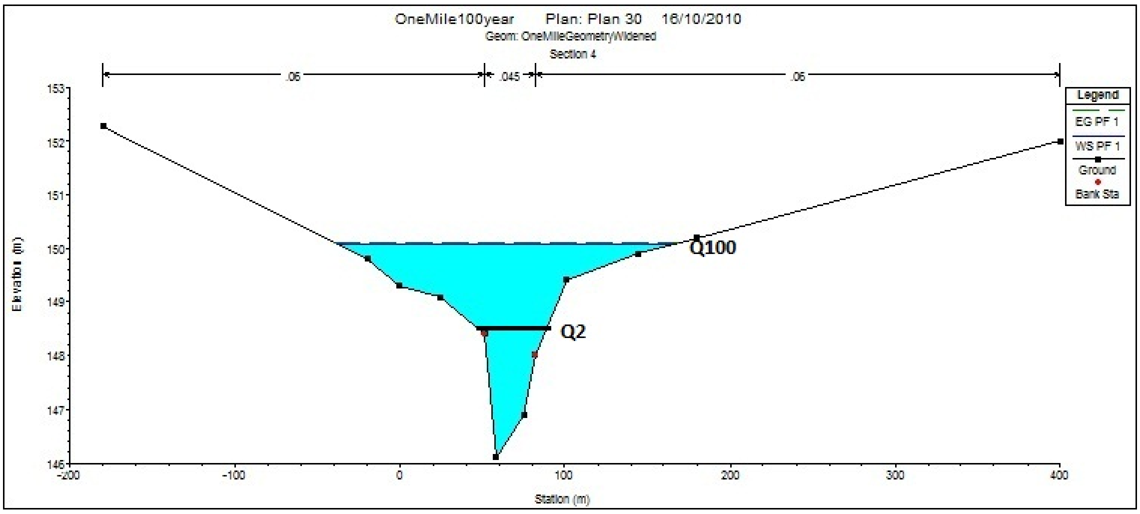

Figure D.11: Cross-Section 4 - Rural Catchment

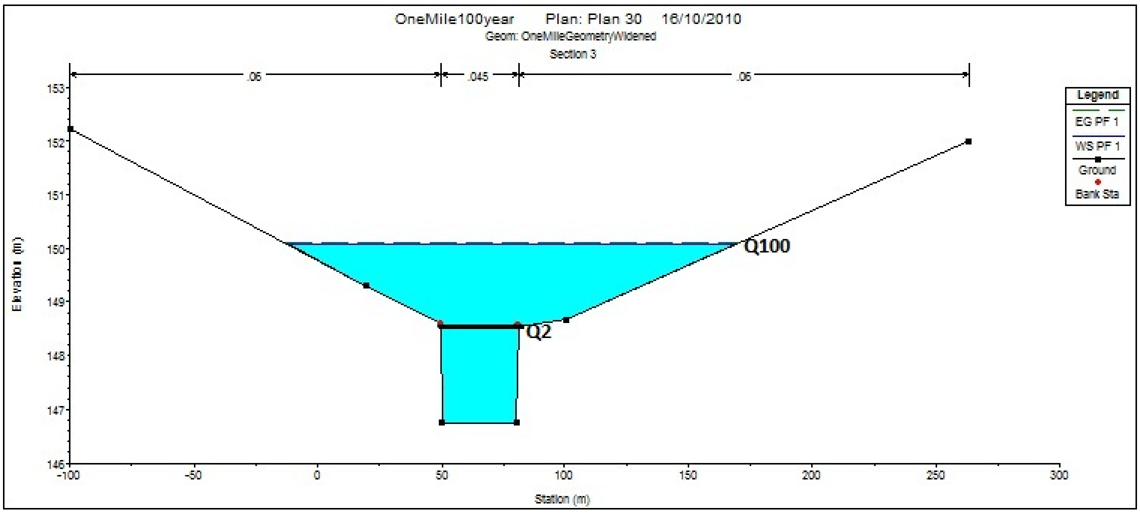

Figure D.12: Cross-Section 3 - Rural Catchment

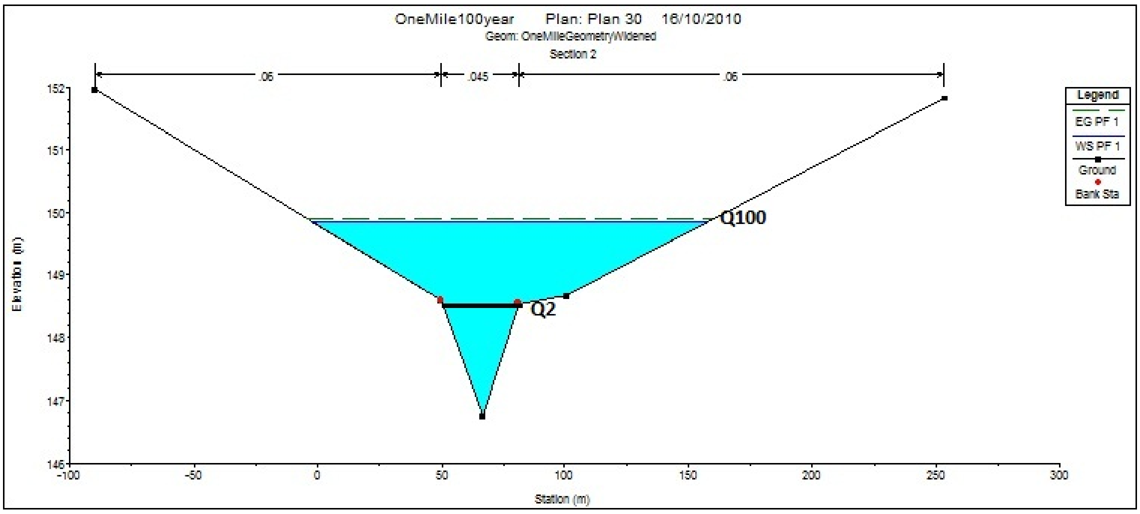

Figure D.13: Cross-Section 2 - Rural Catchment

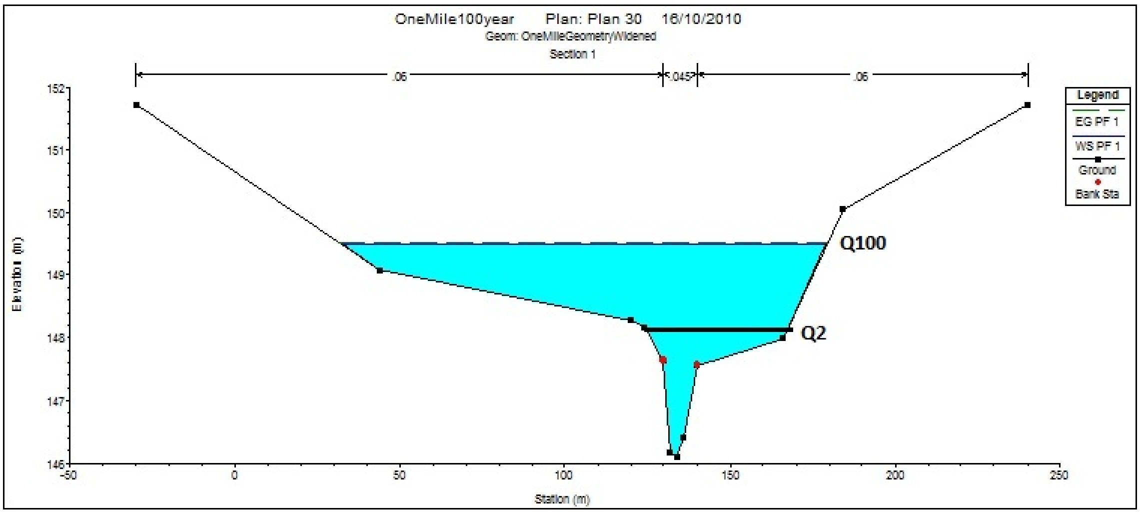

Figure D.14: Cross-Section 1 - Rural Catchment

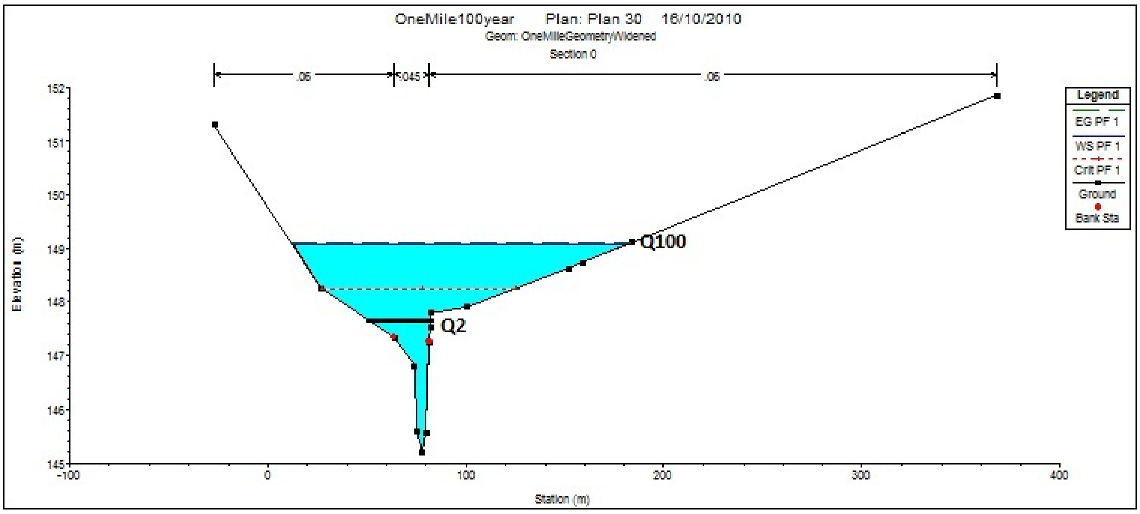

Figure D.15: Cross-Section 0 - Rural Catchment

Appendix E

HEC-RAC Cross-Sections - Urban Unlined Catchment

The fifteen One Mile Creek cross-sections are displayed below with water levels for the 2 and 100 year events shown for the urban unlined catchment.

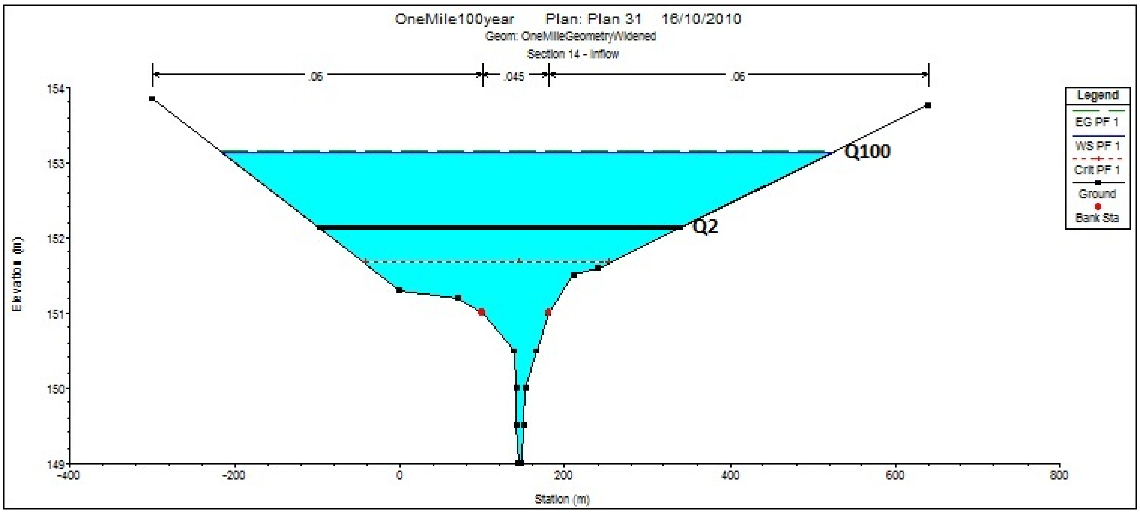

Figure E.1: Cross-Section 14 - Urban Unlined Catchment

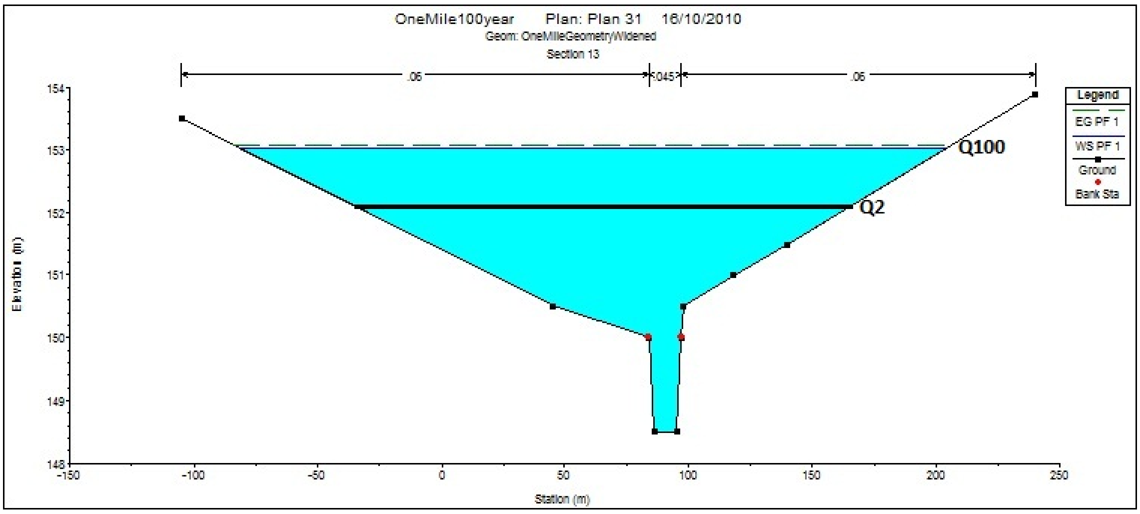

Figure E.2: Cross-Section 13 - Urban Unlined Catchment

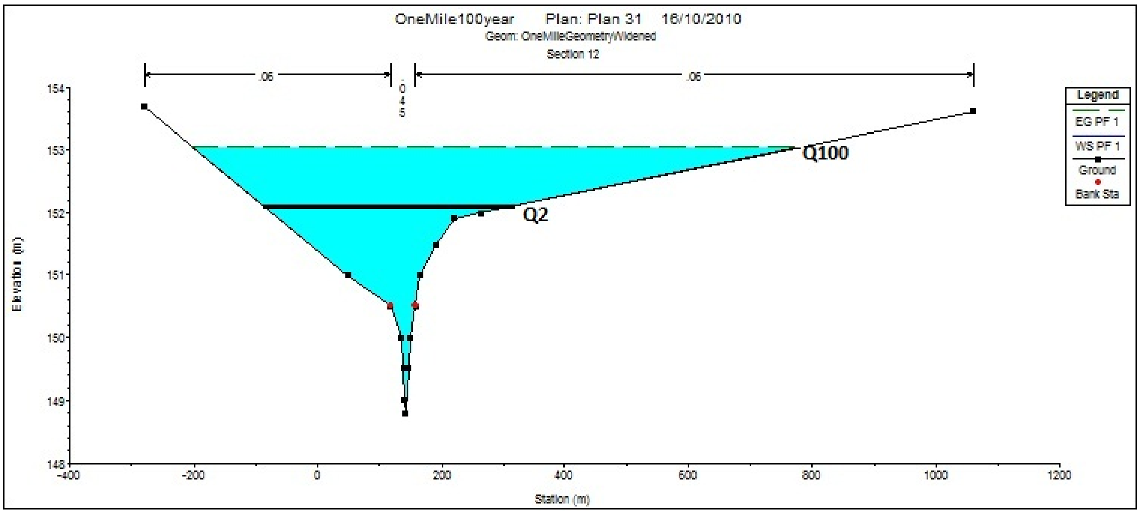

Figure E.3: Cross-Section 12 - Urban Unlined Catchment

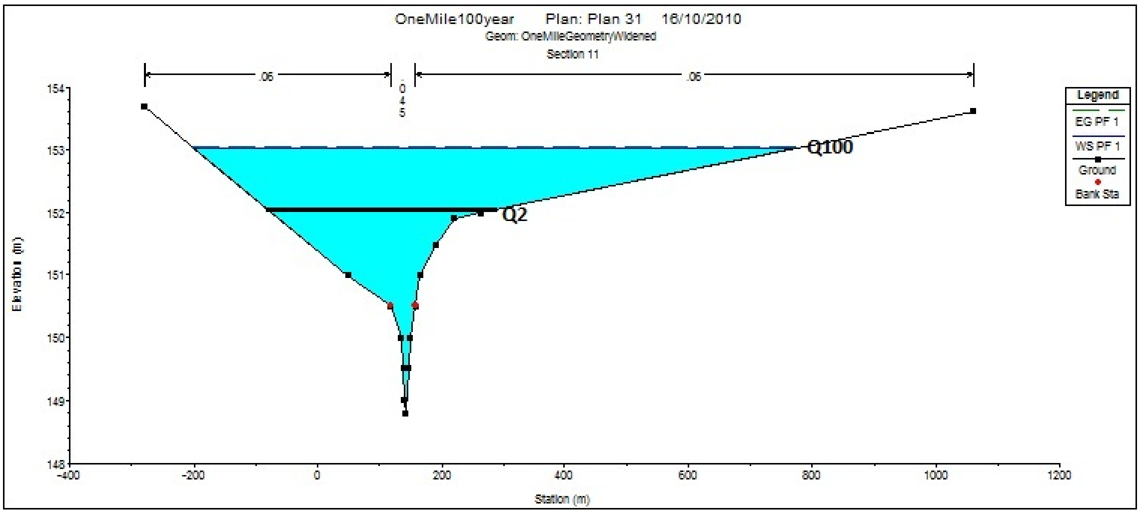

Figure E.4: Cross-Section 11 - Urban Unlined Catchment

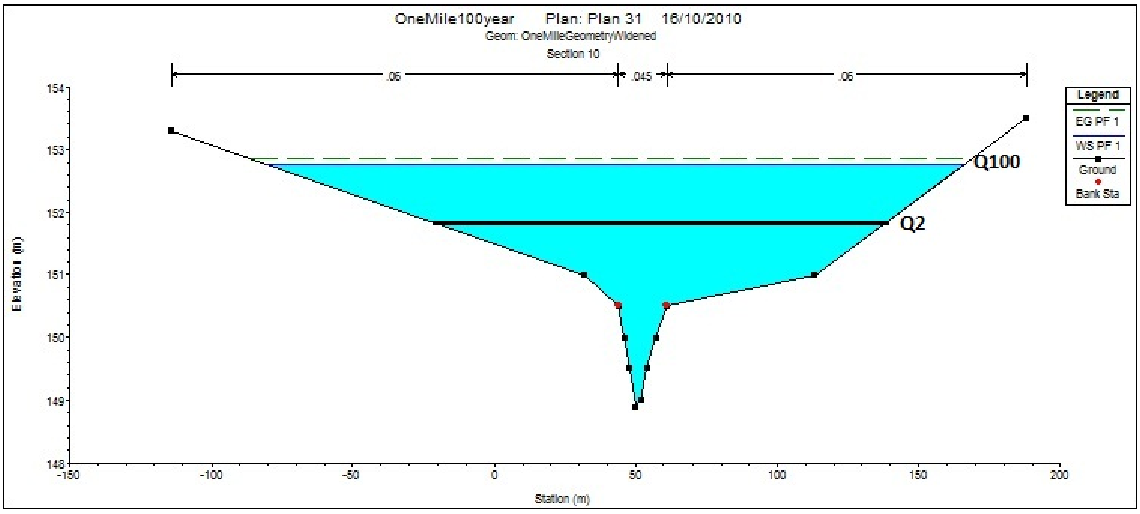

Figure E.5: Cross-Section 10 - Urban Unlined Catchment

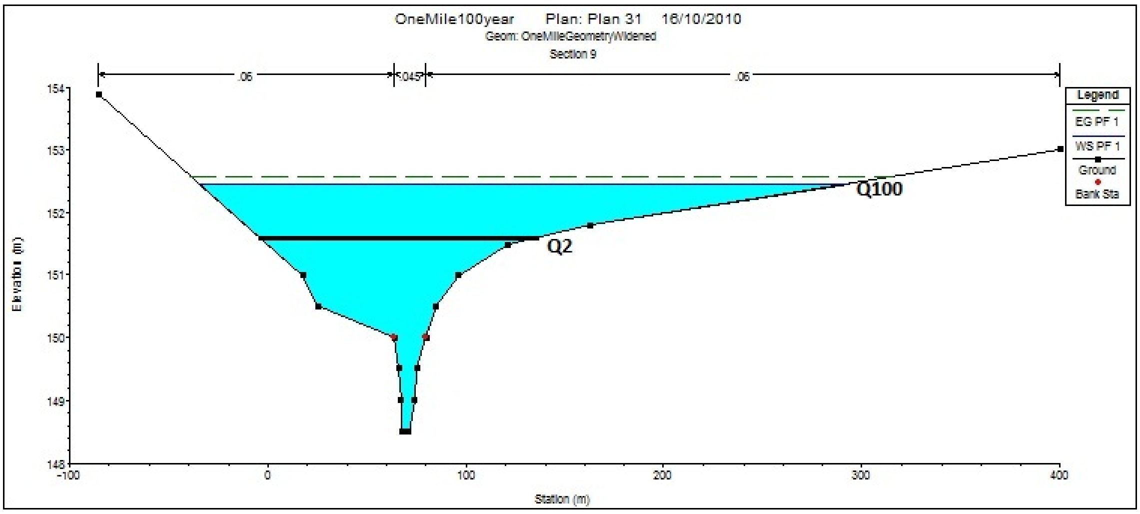

Figure E.6: Cross-Section 9 - Urban Unlined Catchment

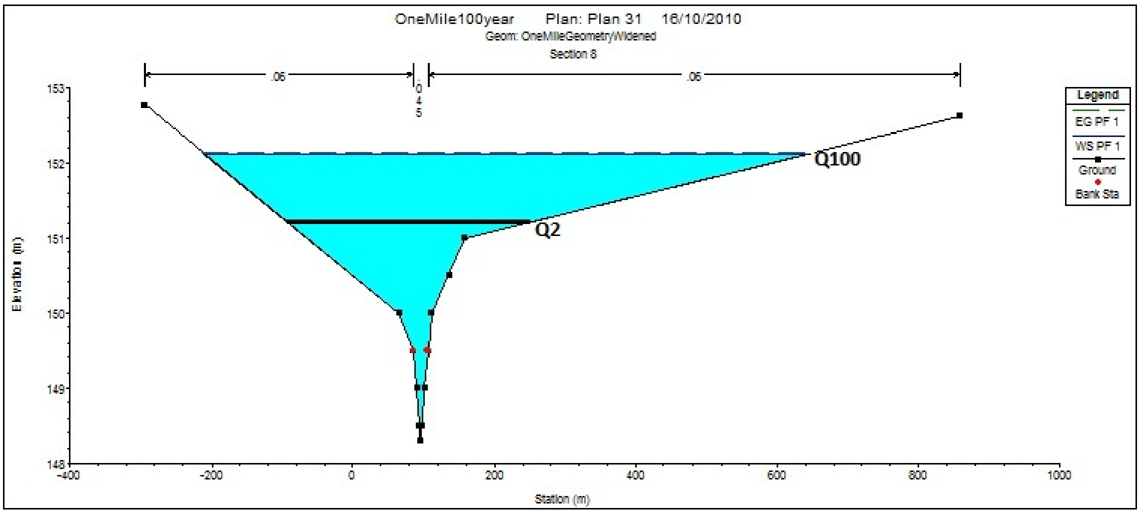

Figure E.7: Cross-Section 8 - Urban Unlined Catchment

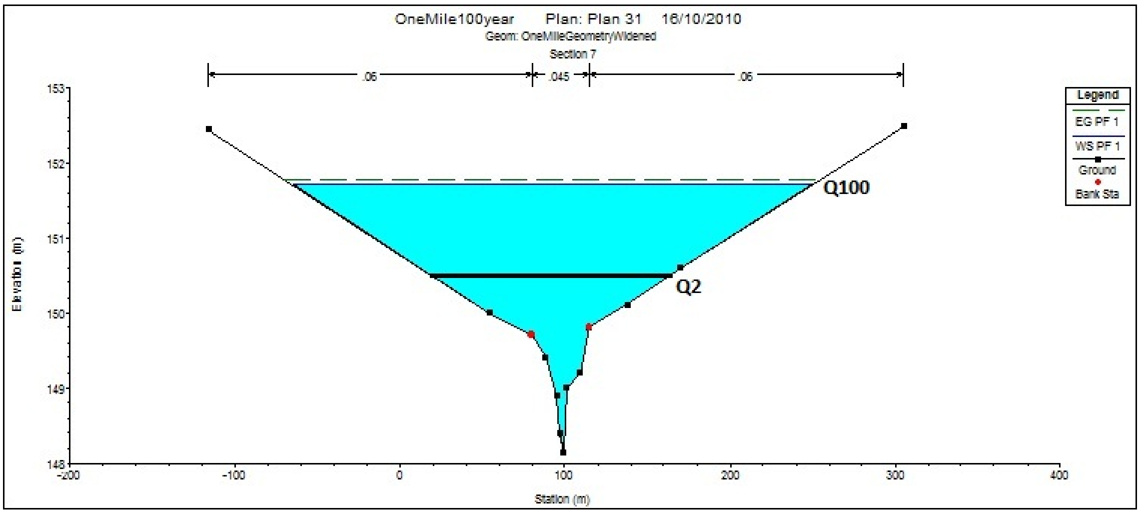

Figure E.8: Cross-Section 7 - Urban Unlined Catchment

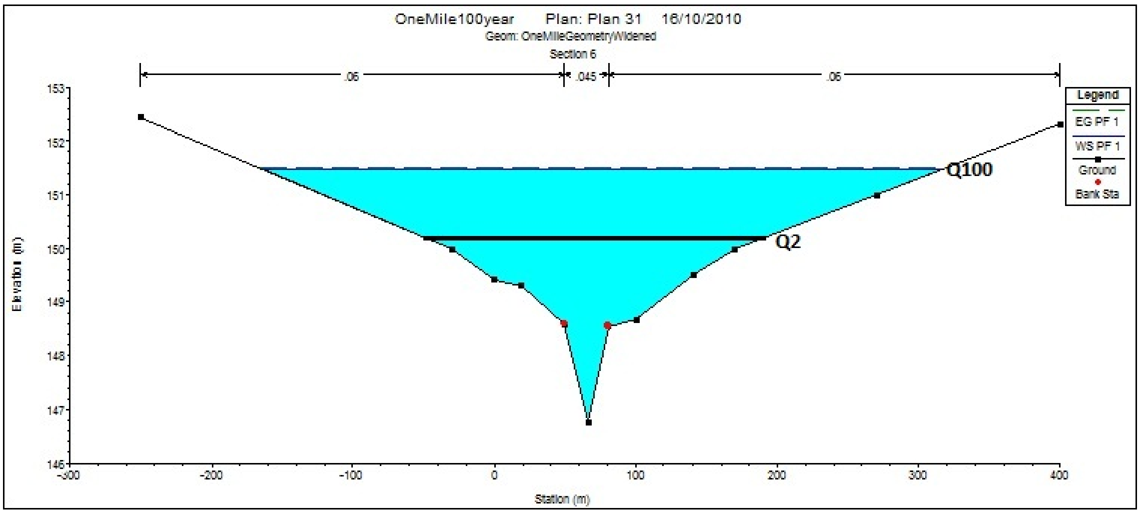

Figure E.9: Cross-Section 6 - Urban Unlined Catchment

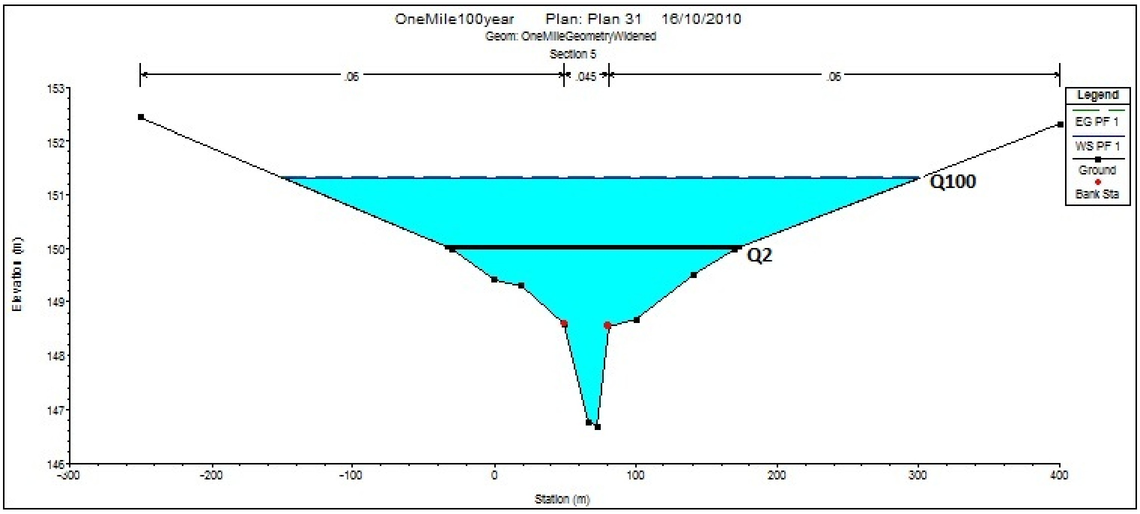

Figure E.10: Cross-Section 5 - Urban Unlined Catchment

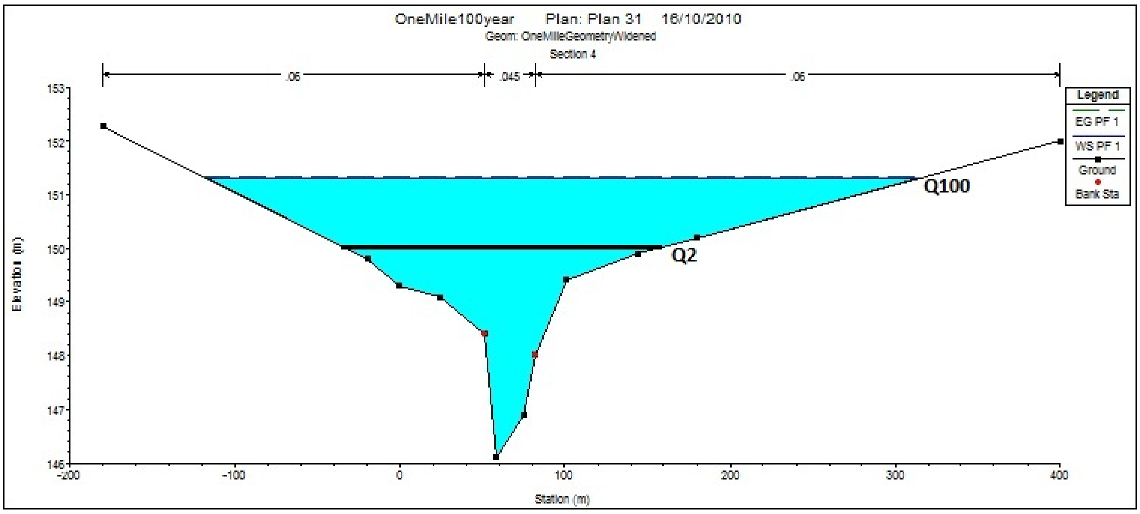

Figure E.11: Cross-Section 4 - Urban Unlined Catchment

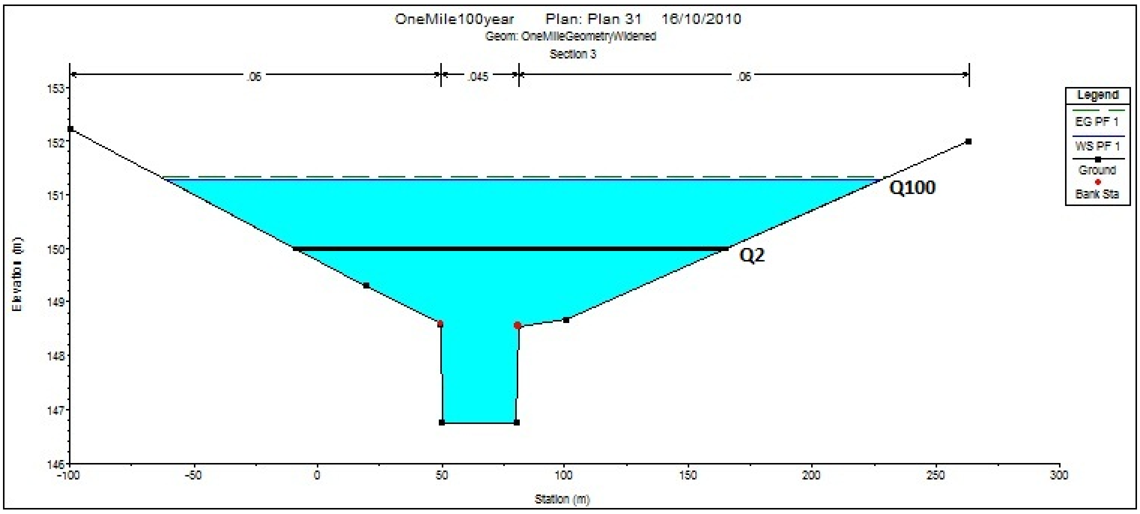

Figure E.12: Cross-Section 3 - Urban Unlined Catchment

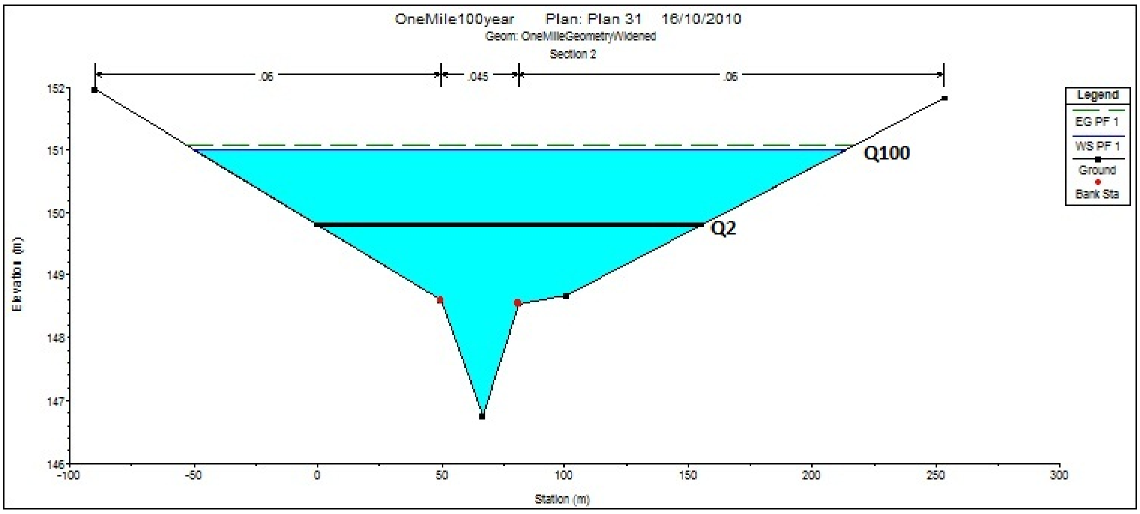

Figure E.13: Cross-Section 2 - Urban Unlined Catchment

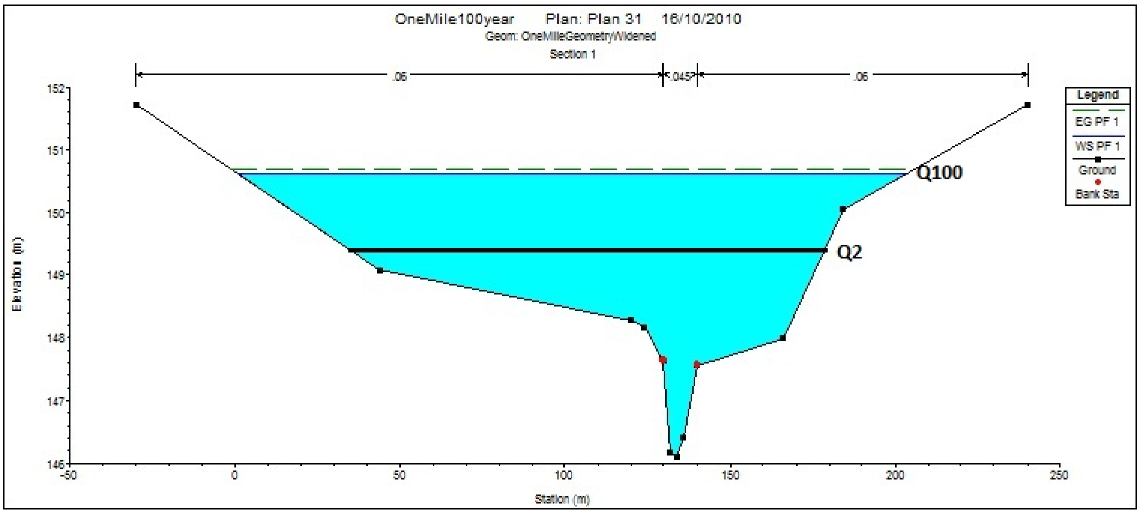

Figure E.14: Cross-Section 1 - Urban Unlined Catchment

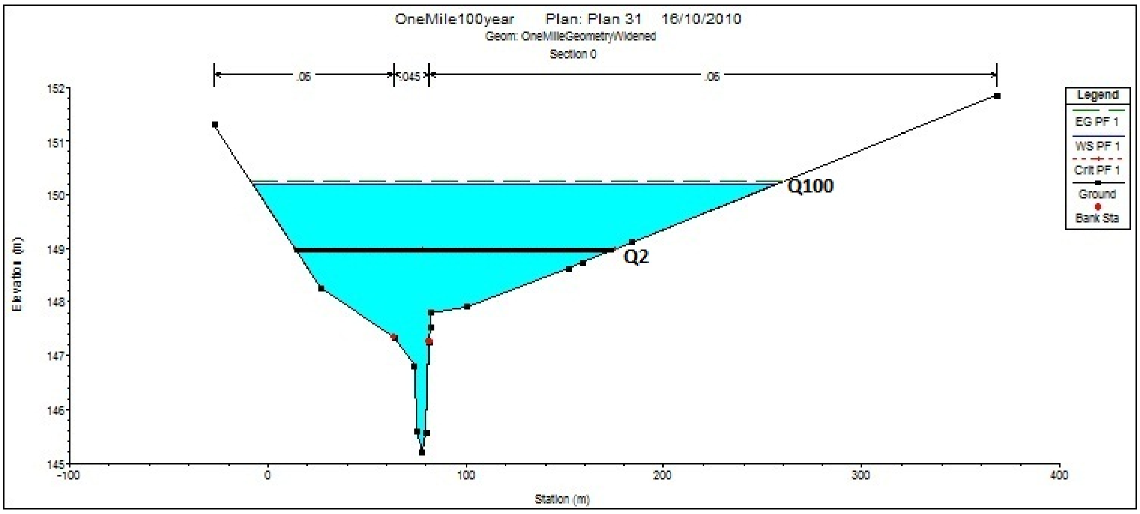

Figure E.15: Cross-Section 0 - Urban Unlined Catchment

Appendix F

Photos of One Mile Creek Flooding (September 2010)

Figure F.1: Flooding along One Mile Creek

Figure F.2: Flooding along One Mile Creek

Figure F.3: Flooding along One Mile Creek

Figure F.4: Flooding at One Mile Creek Diversion Channel