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Flood Routing in Natural Channels Using Muskingum Methods

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safa taha elbashir

Flood Routing in Natural Channels Using Muskingum methods

“A dissertation submitted in partial fulfilment of the requirements for

the DIT’s Master of Engineering Computation”

by

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December, 2011

Declaration

I certify that this dissertation which I now submit for examination for the award of Master of Science in Engineering Computation, is entirely my own work and has not been taken from the work of others save and to the extent that such work has been cited and acknowledged within the text of my work.

This dissertation has not been submitted in whole or in part for an award in any other Institute or University.

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Signature __Safa Elbashir____________ Date _________________

Candidate

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Abstract

The accuracy of flood routing is an important subject for research in hydrology and hydraulics. Accurate information of the flood peak attenuation and the duration of the high water levels obtained by channel routing are of most importance in flood forecasting operations and flood protection works (Subramanya, 2008). This study implements two hydrological methods for channel routing, the basic Muskingum and the constant coefficient Muskingum-Cunge methods on the River Brosna, Co. Offaly in Ireland. Previous researches have reported the simplicity and applicability of these methods on most natural streams within certain limits. These limitations are encountered in the River Brosna where the available outflow data included a significant degree of error which makes it difficult to use for comparison and modelling purposes. Moreover, other factors influenced the implementation and the accuracy of these methods, in particular the backwater effects due to a weir located nearly four kilometres upstream the selected reach and the gradient of the channel which was very small (0.00047) to dampen the error in the routing procedure. This error is found to be greater when using a minimum time increment in the routing calculation. The results of this study showed that the hydrological methods failed to simulate the outflow hydrograph in the selected reach. Determining the models parameters was not possible by using the basic Muskingum method, whereas, the constant coefficient Muskingum-Cunge method calibrated some negative values for the attenuation, which contradicted the diffusivity of the flood wave and confirmed the significant effect of the weir located downstream the river. The conclusion is that an alternative method is needed to account for the factors that these methods neglect.

1. Introduction

1.1 Problem Statement

Flood routing is a technique for determining the flood hydrograph at a section of a river (See Chapter two) by utilizing the data of flood flow at one or more upstream sections. The accurate prediction of flood propagation is essential to take the necessary measures for protection and warning systems (Subramanya, 2008: p280). The study of the change in shape of a hydrograph as it travels down the channel using hydrological methods of flood routing is the topic of this study. The basic Muskingum and the constant coefficients Muskingum-Cunge methods are applied on the river Brosna, County Offaly-Ireland, particularly, in the reach between Ferbane and Moystown gauging stations.

Many studies have been performed by Ponce in 1981 which showed the consistency of the Muskingum-Cunge (constant coefficient) method to develop very similar outflow hydrographs for various selections of time interval and distance step (Merkel, 2002). This method is reported to work well for long river reaches and large drainage areas. However, more research is still needed to test this method on short reaches and small drainage areas which are the most common cases in reality for the application of channel routing methods (Bravo *et al.,* cited by Reid, 2009).

The worst scenario is involved when dealing with a small channel slope less than 0.001 and with a lack of good quality flow data which can be used for modelling and comparison purposes. These factors influenced the accuracy of the two methods and introduced sources of error in the comparison process.

1.2 Objectives

The objectives of this study are to assess the accuracy and reliability of the available flow data collected from the OPW for modelling, and to assess the application of the Muskingum and constant coefficient Muskingum-Cunge methods to this data. Chapter One has discussed the importance and efficiency of the routing models in the flood prediction process, and has introduced the Muskingum methods, their accuracy and limitations. Chapter Two describes the hydrograph, the base flow and base flow separation. The second chapter also describes flood routing in general discussing in detail the basic principles of unsteady flow as well as the hydraulic and hydrological methods. Chapter Three focusses on the Muskingum and Muskingum-Cunge methods with its two formulations, the constant coefficient and variable coefficient. The third chapter describes the numerical approaches for the two methods and the methodology used in parameter estimation, as well as detailing the characteristics of the two methods and their limitations. In Chapter Four there is a brief discussion of the data provided by the Office of Public Works (OPW), the methodology they adopt in both recording the water levels and estimating flows. This chapter includes an analysis of the flow data, the catchment location, gauge stations and the reach calculation. This is presented alongside the application of the two Muskingum methods on the available data. Chapter Five illustrates the results of the application of the two methods along with the analysis of these results. Finally, the conclusion and a recommendation for further study are all discussed in Chapter Six.

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2 *General principles of flood routing*

2.1 The Hydrograph

The term “hydrograph” refers to a graph showing changes in the discharge of a river over a period of time as shown in Figure 2.1. A hydrograph represents how a catchment responds to rainfall (Han, 2010: p77).

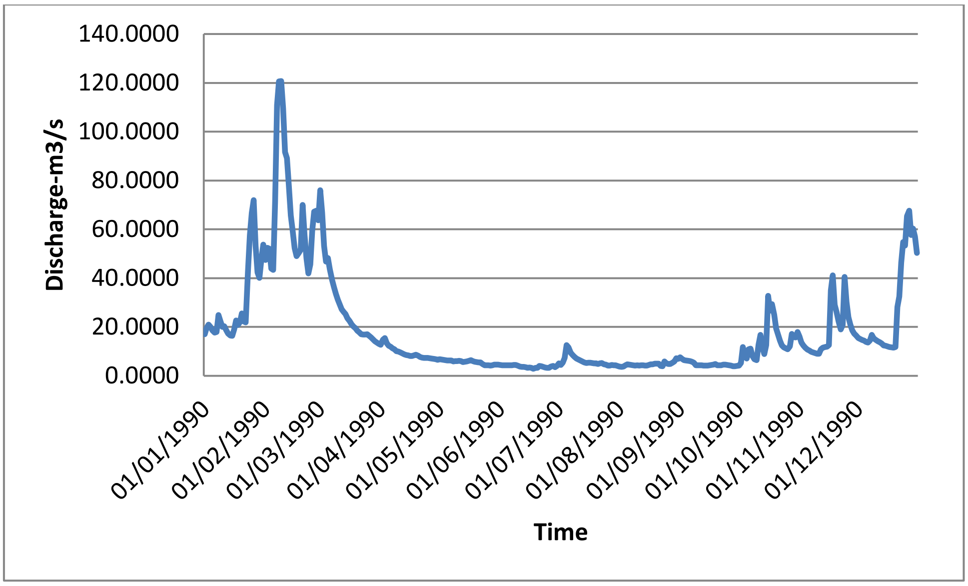


***Figure2.1** Hydrograph of the River Brosna, Ireland*

The volume of water that is formed directly from the rainfall is referred to as ‘Surface run-off’ or ‘Quick response’. Whereas, water that is supplied from groundwater sources is referred to as ‘Base flow’ and it does not generally respond quickly to the rainfall (Chadwick and Morfett, 1993: p296). As shown in Figure 2.2, a hydrograph has a rising limb, a recession limb and a peak flow. The division between the direct run- off and base flow is transitional, and various separation methods have been proposed to distinguish them (Han, 2000: p79).

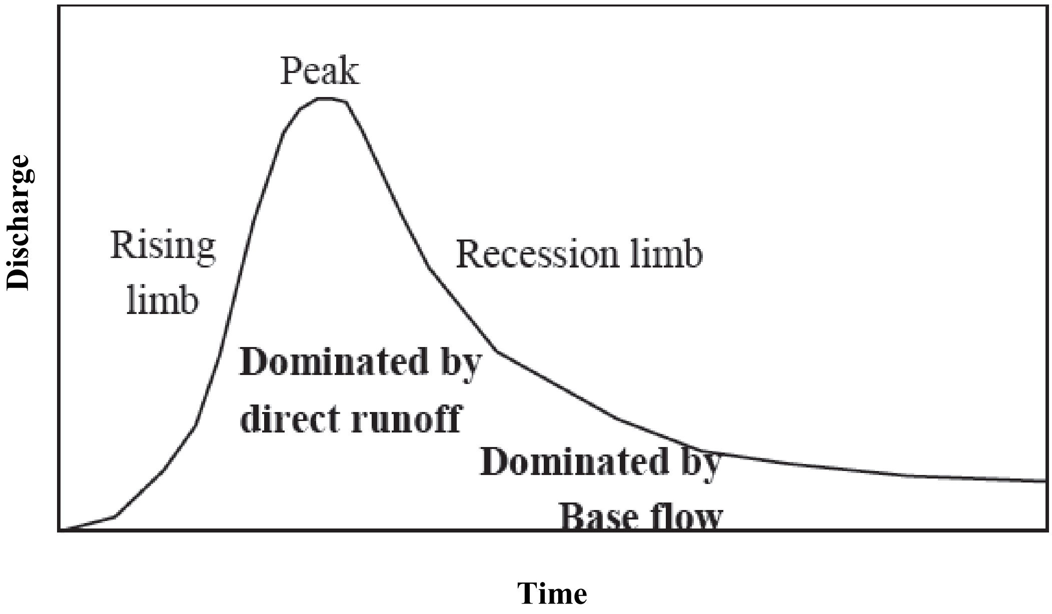


Figure2.2 *Hydrograph components (Han, 2000: p78)*

2.1.1 Base flow Separation

General methods are used in base flow separation, by obtaining a base flow signature from a record of stream run-off data. The two basic separation methods use graphical and filtering techniques. The graphical technique is based on determining the points of intersection between the base flow and the rising and falling limbs of the quick flow response. Filtering techniques on the other hand use the entire hydrograph data for deriving the base flow hydrograph (Connected Water, 2006).

2.1.1.1 Graphical Separation Methods

Graphical methods are generally used for plotting the base flow component of a flood hydrograph event; this includes finding the point of intersection of the base flow and the falling limb as illustrated in Figure 2.3 (page 6). Base flow refers to stream flow which is recorded after this point. Base flow continues until the start of a new hydrograph in the next significant rainfall event. Graphical procedures vary in complexity and they include:

- **An empirical relationship given in Equation 2.1** which is used to estimate the point along the falling limb (See Figure 2.3).The resulting straight line from this point separates the quick flow from base flow.

$$D = 0.827A^{0.2} \tag{2.1}$$

Where, D is the number of days between the storm crest and the end of quick flow, and A is the area of the catchment in square kilometres (Linsley *et al*., cited by Connected Water, 2006). The value of the constant (0.2) in this case depends on the geology and catchment characteristics.

- **The constant discharge method**: assumes that the base flow is constant throughout the storm hydrograph (Linsley *et al*., cited by Connected Water, 2006). The constant discharge is considered to be the minimum flow immediately prior to the rising limb.
- **The constant slope method**: is based on the link between the start of the rising limb and the inflection point on the falling limb. This method assumes an instant response in base flow to the rainfall event.
- **The concave method**: represents the initial decline in base flow during the rising limb by projecting the decrease in a hydrograph trend prior to the rainfall event to directly under the crest of the flood hydrograph (Linsley *et al*., cited by Connected Water, 2006). This projection point is then connected to the inflection point on the falling limb of a storm hydrograph to model the delayed increase in base flow.

The constant discharge method and the constant slope method are most commonly used in practice (Han, 2006: p82).

The three methods are illustrated in Figure 2.3.

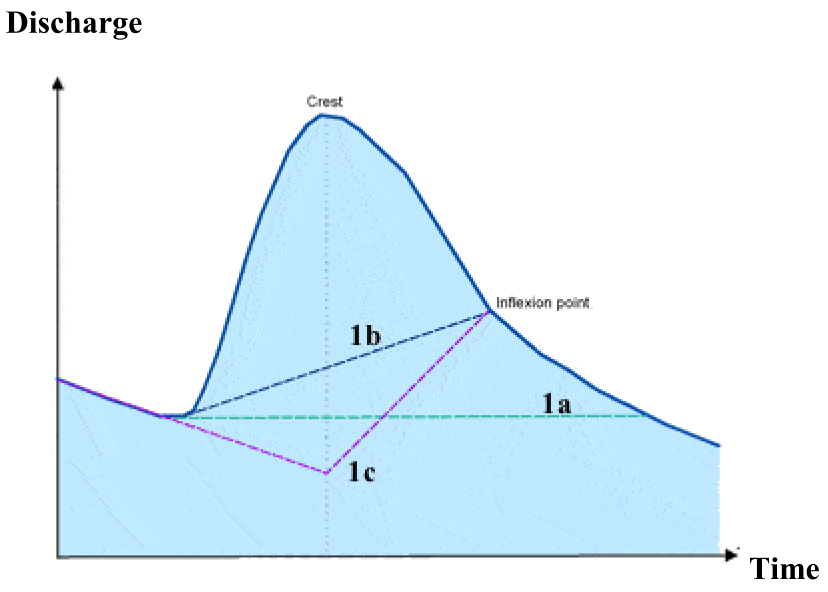


Figure 2.3 *Graphical base flow separation techniques including: (1a) constant discharge method, (1b) constant slope method and (1c) concave method. (Linsley et al., cited by Connected Water, 2006).*

2.1.1.2 Filtering Separation Methods

A second method for separating the base flow component is to use filtering procedures or data processing. These methods use an automated index, which is related to the base flow response of a catchment (Nathan and McMahon, cited by Connected Water, 2006). The base flow index (BFI) or reliability index gives the ratio of base flow to total flow computed from a hydrograph smoothing and separation procedure using daily discharges (Tallaksen, Van Lanen, 2004: P153). '*Other indices include the mean annual base flow volume and the long-term average daily base flow*' (Smakhtin, cited by Connected Water, 2006).

2.2 Definition of Flood Routing

Flood routing is a mathematical method used to predict changes in the magnitude and celerity of a flood wave when it propagates down rivers or through reservoirs. The peak flow and the overall shape of the flood wave change throughout its movement downstream (Fread and Linsley *et al.*, cited by Tewolde, 2005).

Two changes of the flood wave can be defined. 'Attenuation' describes the relative decrease in the magnitude of the peak discharge, and 'Translation' which refers to the delay in time of the peak discharge, based on the travel time of the water mass moving downstream. This idea has been supported in the work of USACE, Bedient and Huber, as cited by Heatherman (2008). These concepts are illustrated in Figure 2.4.

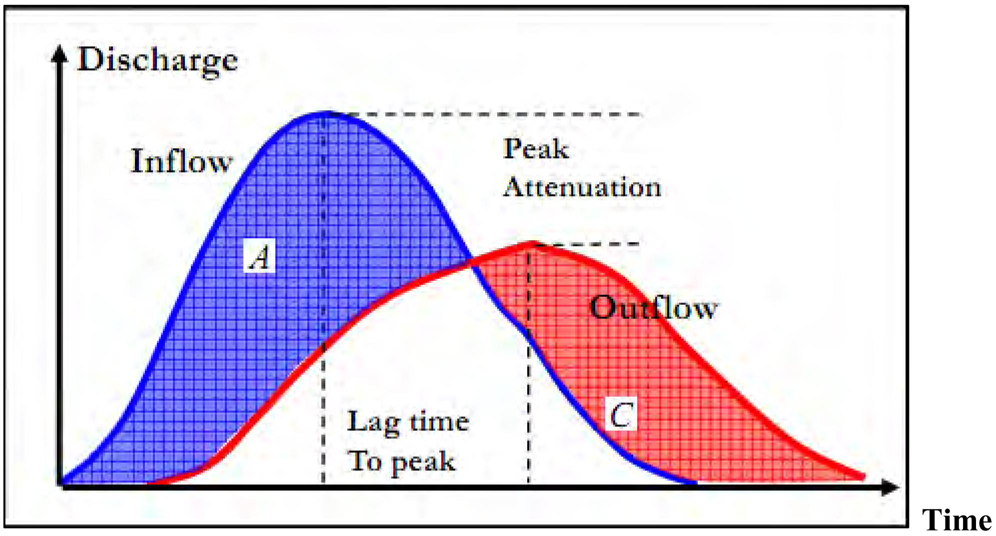


Figure2.4 *Flood routing hydrograph for natural channel (McKinney, 2008).*

The inflow hydrograph describes the flow of water at the upstream section of a river reach. In contrast, the water flows at the downstream end are defined by the outflow hydrograph. The two general broad categories of routing can be defined as Reservoir routing and Channel routing (Subramanya, 2008: p280). Generally, the two types of routing are designed to obtain the outflow hydrograph. However, a major difference is found-namely; that in reservoir routing the outflow hydrograph is determined over the spillway from the inflow hydrograph. Whereas in channel routing the outflow hydrograph is determined from a river reach (Chadwick and Morfett, 1993: p317).

2.3 Flow Classification

Flow in an open channel is sometimes referred to 'free-surface flow', where the water surface is exposed to the atmosphere. An open channel flow is said to be steady if the depth of flow at any specified location does not change with the time. In contrast, flow is unsteady if the depth of flow at a point varies with time. Furthermore, open channels can be classified as either prismatic, in which the shape of a channel cross-section and its bottom slope are constant with a relatively straight alignment, or non-prismatic, where the cross-section, the alignment, and the bottom slope change along the channel. An additional classification describes the nature of the flow in terms of uniformity. The flow is said to be uniform if the depth of flow is the same at every cross-section of the channel. When the depth is varied, then the flow is non-uniform or varied. This is the most common situation in open channels where the flows are either steady non-uniform or unsteady non-uniform flow (Chin, 2000: p138).

A non-uniform flow can be classified further into gradually varied and rapidly varied flows, depending on whether the variations along the channel are gradual or rapid (Akan, 2006: p10).

Rapidly varied flows are described by considerable accelerations in the vertical direction and by large curvatures in the wave profile. During rapidly varied flow, the pressure distribution in the water column departs from a hydrostatic distribution and discontinuities in the profile often emerge. In gradually varied flow by contrast, the vertical acceleration of the flow is negligible and the pressure distribution is hydrostatic (Chow, cited by Heatherman, 2008). The two types of flow are illustrated in Figure 2.5.

Flood routing problems can be categorized as gradually varied, unsteady flow which involves long gradual wave fronts. However, the initial stages of a dam breach are one exception when rapidly varied conditions dominate. Flood waves may also be described as ‘translatory waves’. This term refers to waves that propagate through an open channel where a significant movement of water mass downstream occurs. ‘Oscillatory waves’ on the other hand means that the water surface undulates, with very little net transport occurring (Chow, cited by Heatherman, 2008).

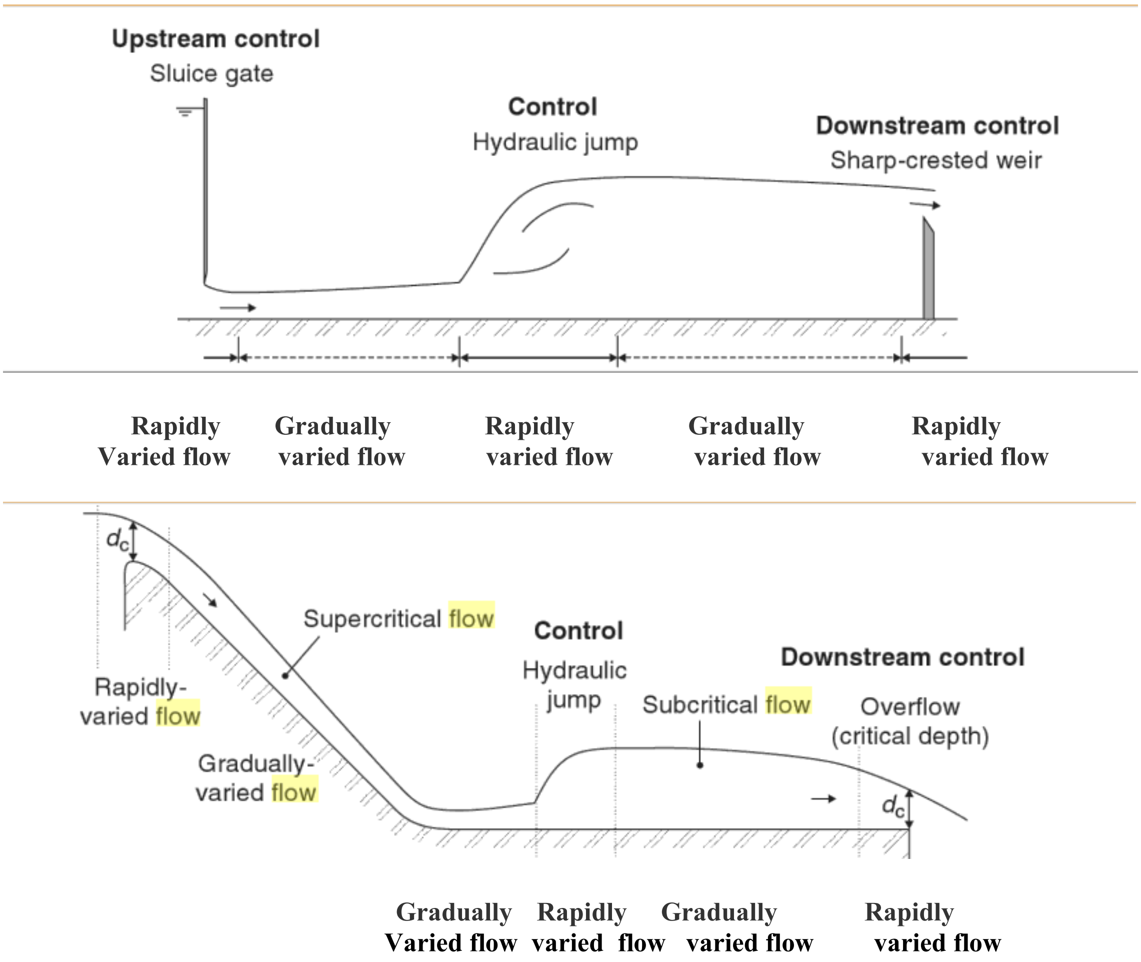


***Figure 2.5** Examples of non-uniform flows, (Chanson, 2004).*

2.3.1 The Mean Velocity

The mean velocity of flow can be derived from the well- known Manning equation for steady uniform flow as:

$V = \frac{1}{n} R^{\frac{2}{3}} (S^{\frac{1}{2}})_0$ In SI units (Boyd, Yoo, 1994: p196). (2.2)

From the equation above, the average velocity, (V in m/s) of a channel flow is related to three factors: the nature of the channel bed defined by the roughness coefficient (n), the ratio of the cross-sectional area of flow to the wetted perimeter of the channel bed, the hydraulic radius (R), and the slope of channel (S_0) (Boyd, Yoo, 1994: p196).

The assumption of the uniform flow is rarely achieved in reality. Despite this, Manning's equation is still widely used in modelling open channel flows.

The discharge in open channel flow (Q in m^3 /s), is the product of the cross-sectional area of flow (A in m^2) and the mean velocity (Boyd, Yoo, 1994: p196).This is shown in Equation 2.3 as follows:

$$Q = AV = \frac{1}{n} A R^{\frac{2}{3}} (S^{\frac{1}{2}})_0 \qquad (2.3)$$

The hydraulic radius in Equation 2.4 is computed by dividing the cross-sectional area of flow by the wetted perimeter.

$$R = \frac{A}{P} \qquad (2.4)$$

Where, A is the cross-sectional area of flow in (m^2) and P is the wetted perimeter in m.

The wetted perimeter is described as the distance along the channel bottom below the water surface (Boyd, Yoo, 1994: p196) this is illustrated in Figure 2.6.

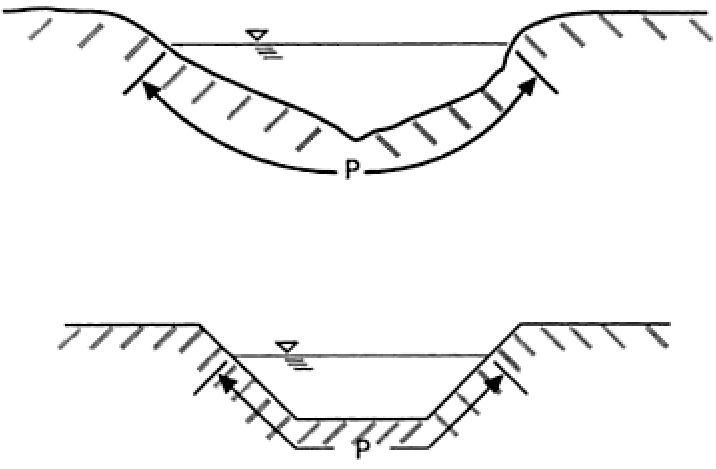


Figure 2.6 *Definition of wetted perimeter of open channel (Boyd, Yoo, 1994, p196).*

For a trapezoidal channel (See Figure 2.7), the wetted perimeter is determined as:

$$P = b + 2y_0\sqrt{1+z^2} \tag{2.5}$$

And the cross-sectional area is defined as:

$$A = (b + zy_0)y_0 \tag{2.6}$$

Where y_0 is the normal depth in m, z is the channel side slope in (m/m) and b is the channel bottom width in m.

A typical example of a trapezoidal channel is illustrated in Figure 2.7.

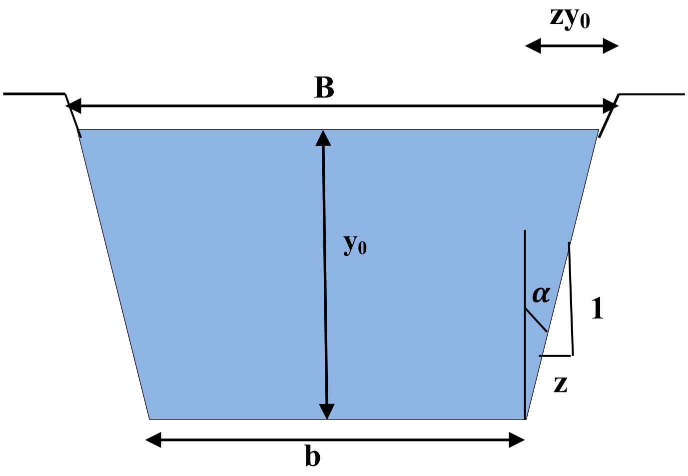


Figure 2.7 *Trapezoidal cross-section (Stonecyphe, 2010).*

2.3.2 The Normal Depth

The normal depth of flow y which is sometimes referred to as y_0 can be defined as the depth of uniform flow under a constant discharge. However, the normal depth can also be used to determine the mean velocity in cases of non-uniform flow in open channels. It can be calculated from Manning's equation or by tables contained in French, as cited by the American Society of Civil Engineers (1992).

The method of tables is based on the relationship:

$$\emptyset = \frac{Q_0 n}{b^{\frac{8}{3}}(S^{\frac{1}{2}})_0} \qquad (2.7)$$

Where:

$$\emptyset = f(\eta, m) \qquad (2.8)$$

And η is read from Table 2.1 in Appendix A as

$$\eta = \frac{y_0}{b} \qquad (2.9)$$

Q_0 is a reference discharge in (m^3/s) and m is the channel side slope in (m/m) which is referred to as z in this study.

Values of $\frac{y_0}{b}$ can be determined from the corresponding values of $\emptyset$ in Table 2.1 in Appendix A.

2.3.3 The Roughness Coefficient (n)

The roughness coefficient (n) for the Manning equation indicates the resistance of the channel bottom to flowing water. Table 2.2 in Appendix A lists the roughness coefficient for various open channel shapes. Values for the roughness coefficient (n) differ enormously depending on the channel's topography. For good maintained channels, smaller values for (n) are recommended. This value should be increased when dealing with poor maintained channels (Boyd and Yoo, 1994: pp.193-195).

2.3.4 Kinematic, Dynamic Wave Speed and Froude Number

Many studies have shown that the movement of the flood wave is described by the wave ‘celerity’ (Henderson, cited by Heatherman, 2008). In open channel flow, the dynamic celerity, c_d can be defined by the speed of a small disturbance in depth relative to the average velocity of flow. Waves must have low amplitudes, long periods and negligible losses of energy to travel at this velocity.

The equation for dynamic celerity is:

$$c_d = \sqrt{gy} \qquad \text{For a wide rectangular channel, or} \tag{2.10}$$

$$c_d = \sqrt{gD_m} \qquad \text{For channels in general} \tag{2.11}$$

Where, $$D_m = \frac{A}{T} \tag{2.12}$$

From the equations above, C_d is the dynamic celerity in (m/s), g is the acceleration due to gravity in (m/s^2), A is the cross-sectional area of flow in (m^2), T is the top width of free surface in m, y is the depth of flow in m and D is the hydraulic depth in m (Henderson, Chow, cited by Heatherman, 2008).

The flow regime is defined by the Froude Number (Fr) which relates the water velocity and wave velocity by Equation 2.13

$$Fr = \frac{V}{\sqrt{gy}} \tag{2.13}$$

When the water velocity is less than the wave velocity, the disturbances travel upstream and downstream, and the upstream water level are affected by downstream control. In this case the Froude number is less than 1 and the flow is subcritical. The second case occurs when the water velocity is greater than wave velocity. The disturbances now travel downstream only and this case is referred to as supercritical, hence, the Froude number is greater than 1. The third case represents critical flow, when the water velocity equals the wave velocity and the Froude number equals one (Chadwick and Morfett, 1993: p142).

While the dynamic waves (c_d) are characterised by higher velocities and quick attenuation, kinematic waves (c_k) on the other hand, move with much slower velocities. This characteristic describes any changes in the discharge and water surface elevation with time (Singh, 1996: p 492).The speed of the flood waves therefore, may be approximated by the speed of kinematic waves (c_k) (Lighthill and Witham, cited by Singh, 1996).

The characteristics of the two waves are illustrated in Figure 2.8.

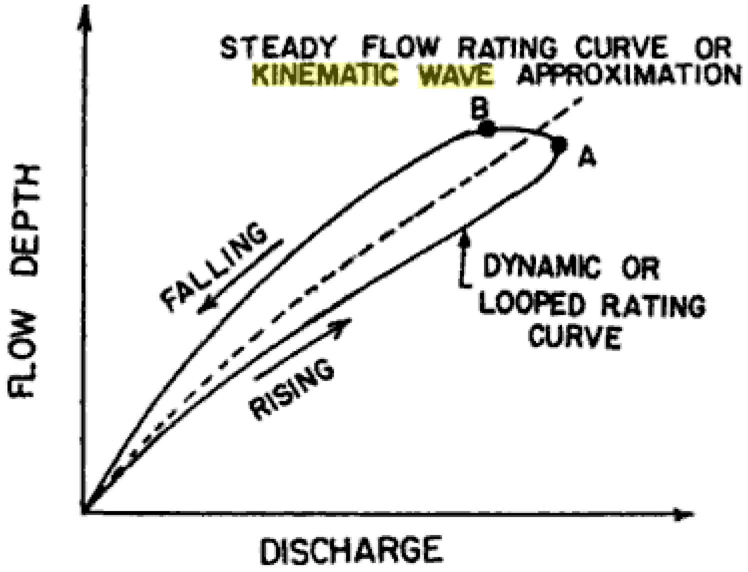


Figure 2.8 *Rating curves for kinematic and dynamic waves (Singh, 1996: p 492)*

Figure 2.8 above describes a rating curve, which is a relationship between the discharge and the corresponding stage (water depth). Details of rating curve estimation will be discussed in chapter 4.

It has been common to use the single variable (c) to refer to the kinematic wave celerity (c_k). Therefore, the expression which is used for the kinematic wave celerity is (c)

(Heatherman, 2008). The kinematic wave celerity may be defined as the slope of the discharge-area rating curve. However, it can be approximated by multiplying the average velocity by a factor (β). This factor may vary according to different channel shapes. Table 2.3 shows values of the factor (β) for various channel shapes.

Table 2.3 *factors for computing wave speed from average velocity (US Army Corps of Engineers, 2008: p341).*

Channel Shape	**Factor β=c/V**
Wide rectangular	1.67
Wide parabolic	1.44
Triangular	1.33
Natural channel	1.5

2.4 Distributed and Lumped models

Generally, routing models are classified as either lumped or distributed models. Lumped models consider composite parameters of the flow characteristics between the upstream and downstream sections in a channel. Hence, the flow hydrograph is calculated at the downstream section directly from a given flow hydrograph at the upstream section. In distributed models, more description of the flow characteristics is given by defining points in between the upstream and downstream sections of the channel. Flow routing using lumped parameter models is commonly called hydrological routing , and flow routing using distributed parameter models is called hydraulic routing (Chin, 2000: p387).

2.4.1 Hydraulic Methods

Hydraulic flow routing procedures are becoming popular for the purposes of flood routing. This is because hydraulic methods allow flow computation to be varied in both time and space (Mays and Tung, 2002: p 411).

Hydraulic methods employ the continuity equation together with the equation of motion of unsteady flow (Subramanya, 2009: p280).

The equation of motion for a flood wave is derived from the application of the momentum equation as:

$$S_f = S_0 - \frac{\mathrm{dy}}{\mathrm{dx}} - \frac{V}{g}\frac{dV}{dx} - \frac{1}{g}\frac{dV}{dt} \qquad (2.14)$$

Where,

V is the velocity of flow at any section in (m/s), S_0 is the channel bed slope and S_f is the slope of the energy line in (m/m) (Subramanya, 2009: p281).

And the one dimensional continuity equation is given by:

$$\frac{dQ}{dx} + \frac{dA}{dt} = 0 \qquad (2.15)$$

The one dimensional continuity and momentum equations mentioned above were first presented by Barre de Saint-Venant (1871), and they are commonly called the Saint Venant equations (Chin, 2000, p394).

If all of the terms in the momentum equation are neglected except for the friction slope (S_f) and bed slope (S_0), the kinematic wave equation simplifies to:

$$S_f = S_0 \qquad (2.16)$$

Where,

$$\frac{\mathrm{dy}}{\mathrm{dx}} = \frac{dV}{dx} = \frac{dV}{dt} = 0$$

The kinematic wave equation is sufficient for modelling flood waves on steep sloped rivers. When the pressure gradient term $\frac{dy}{dx}$ is considered, the diffusive wave equation is represented as:

$$S_f = S_0 - \frac{dy}{dx} \tag{2.17}$$

This term (pressure gradient) is very important for modelling wave propagation and storage effects within the channel for mild slopes and steeply rising and falling hydrographs. Most of the flood waves travelling in mild sloped river channels have some physical diffusion and are better simulated by a diffusive wave approximation equation (Boroughs, Craig and Zagona 2002: p3).

The full dynamic wave is used when all the terms of the momentum equation are considered. This is well suited in the case of a dam break (Boroughs, Craig and Zagona 2002: p3). The full dynamic equations afford a higher degree of accuracy when modelling flood situations, as they account for parameters such as backwater effects that other methods neglect. Solutions of hydraulic methods are more sophisticated, they use numerical models that employ high levels of computing which use implicit and explicit finite difference algorithms (Amein and Fang, cited by Chin, 2000), or they use the method of characteristics (Amein, cited by Chin, 2000). One of the recent models that are commonly used is the one dimensional HEC-RAS (Hydraulic Engineering Centre's -River Analysis System) to perform steady and unsteady flow river hydraulic calculations.

The shortcomings of these models are represented in the complexity of the methods which are used for solution. These often lead to a numerical instability and problems of convergence. Besides a long running time is needed for the solution which is costly and expensive. Other simplified methods were developed to assist in the calculation, mainly referred to as Hydrological methods. This view has been supported by Johnson (1999).

2.4.2 Hydrological Methods

Hydrological methods for channel routing use the principle of continuity equation to solve the mass balance of inflow, outflow and the volume of storage. These methods of routing require a storage-stage-discharge-relation to determine the outflow for each time step (Guo, 2006: p437). Hydrological methods involve numerical techniques that introduce translation or attenuation to an inflow hydrograph. (Heatherman, 2008: p13). The continuity equation is presented below as:

$$\frac{dS}{dt} = I_{(t)} - O_{(t)} \tag{2.18}$$

Where, S is the storage between the upstream and downstream sections in m^3.

t is the time in s, I (t) is the inflow at upstream section and O (t) is the outflow at downstream section in (m^3/s).

Over the finite interval of time between t and t+Δt, Equation 2.18 can be written in finite difference form as:

$$\frac{S_2 - S_1}{\Delta t} = \frac{I_1 + I_2}{2} - \frac{O_1 + O_2}{2} \tag{2.19}$$

Where the subscripts 1 and 2 refer to the values of the variables at times t and t+Δt respectively (Chin, 2000).

Two forms of Hydrological methods are presented. A simplified method based on the solution of continuity equation, known as the Muskingum method, and a similar method which begins with the continuity equation and includes the diffusion form of the momentum equation, known as the Muskingum-Cunge (Johnson, 1999). The derivation, characteristics and limitations of these methods will now be discussed in the next chapter.

3 Muskingum Methods

3.1 The Basic Muskingum method

The Muskingum method for flood routing was developed for the Muskingum Conservancy district (Ohio) flood control study in the 1930s (McCarthy, cited by Chin 2000) and is one of the most popular methods of hydrological routing for drainage channels with all types of rivers and streams (Ponce, cited by Chin, 2000). This method of routing approximates the storage volume in a channel by a combination of prism storage and wedge storage, as illustrated in Figure 3.1, for the case in which the inflow exceeds the outflow. When the water level recedes in the channel, a negative wave is produced due to outflow exceeding inflow.

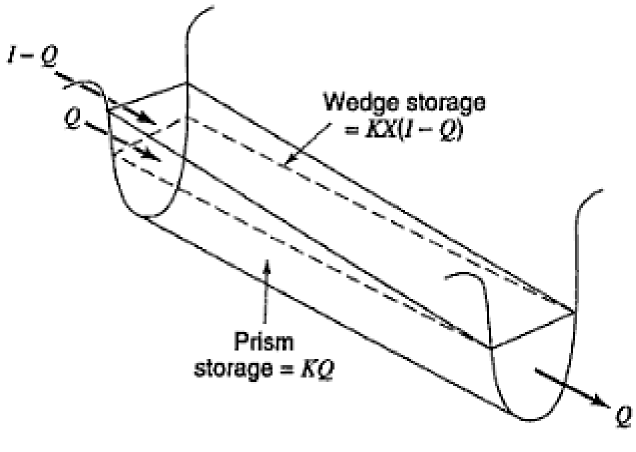


Figure 3.1 *Prism and wedge storage in a channel reach (Mays, 2009, p336).*

The prism storage is described as the volume of a constant cross-section that corresponds to uniform flow in a prismatic channel. With the movement of flow, wedge storage is generated (Chin, 2000: p390).

By assuming the flow area is directly proportional to the channel flow, the volume of prism storage can be described as:

$$KO \tag{3.1}$$

Where K is the travel time through the reach and O is the flow through the prism.

Hence, the wedge storage can be approximated by:

$$KX(I-O) \tag{3.2}$$

Where X is a weighting factor in the range $0 \leq X \leq 0.5$. A minimum value for X is 0, in the case of a reservoir. This is the situation where inflow has little or no effect on the storage. For equal weighting between inflow and outflow, translation with little or no attenuation is produced, and X=0.5. In natural streams, X takes more limited values, usually between 0 and 0.3, with a typical value near 0.2 (Chow *et al.,* cited by Chin 2000).

Johnson (1999) suggests that values of X between 0.4 and 0.5 may be calibrated for streams with little or no flood plain.

The total storage, S, between the inflow and outflow sections is therefore given by:

$$S = KO + KX(I-O) \tag{3.4}$$

Or

$$S = K[XI + (1-X)O] \tag{3.5}$$

By applying Equation 3.5 at time increments of Δt, the storage S in the channel between the inflow and outflow sections at times jΔt and (j+1) Δt can be written as:

$$S_j = K[XI_j + (1-\mathrm{X})O_j] \tag{3.6}$$

And

$$S_{j+1} = K[XI_{j+1} + (1 - \mathrm{X})O_{j+1}] \tag{3.7}$$

and the change in storage over the time interval Δt is therefore given by:

$$S_{j+1} - S_j = K\{[XI_{j+1} + (1 - \mathrm{X})O_{j+1}] - [XI_j + (1 - \mathrm{X})O_j]\} \tag{3.8}$$

The discretized form of the continuity equation, Equation (2.19) (See page 18), can be written as:

$$S_{j+1} - S_j = \frac{(I_j + I_{j+1})}{2}\, \Delta t - \frac{(O_j + O_{j+1})}{2} \Delta t \tag{3.9}$$

Combining Equations (3.8) and (3.9) yields the routing expression:

$$O_{j+1} = C_0\, I_{j+1} + C_1\, I_j + C_2\, O_j \tag{3.10}$$

Where, C_0, C_1 and C_2 are given by:

$$C_0 = \frac{\Delta\mathrm{t} + 2\mathrm{KX}}{\mathrm{m}} \tag{3.11}$$

$$C_1 = \frac{\Delta\mathrm{t} - 2\mathrm{KX}}{\mathrm{m}} \tag{3.12}$$

$$C_2 = \frac{2\mathrm{K}(1-\mathrm{X}) - \Delta\mathrm{t}}{\mathrm{m}} \tag{3.13}$$

Where $m = 2K(1 - X) + \Delta\mathrm{t}$ (3.14)

And $C_0 + C_1 + C_2 = 1$ (3.15)

The routing equation, Equation 3.10, is applied to a given inflow hydrograph, I_j (j=1, J), and initial outflow, O_1, to calculate the outflow hydrograph, O_j (j=2, J), at a downstream section. The constants in the routing equation, C_0, C_1, and C_2 are introduced in terms of the channel parameters K and X and the routing time step, Δt. Limiting the routing time step Δt within a reasonable range is very important to prevent instabilities in the routing procedure and also to prevent the negative value for coefficient C_1 (ASCE, cited by Chin, 2000).This is achieved by satisfying the condition given in Equation 3.16 below:

$$\Delta t \geq 2KX \tag{3.16}$$

A negative value of C_2 does not affect the flood-routed hydrographs (Viessman *et, al.,* cited by Tewolde, 2005). The routing time Δt should be kept smaller than 1/5 of the travel time of the flood peak through the reach. This view has been supported in the work of Gill, as cited by Tewolde (2005).

Many researchers have indicated that the theoretical stability of the numerical method is fulfilled if Equation 3.17 is satisfied (Wilson, Viessman *et al.,* cited by Tewolde, 2005).

$$2KX \leq \Delta t \leq 2K(1-X) \tag{3.17}$$

Another suggestion from Viessman and Lewis, as cited by Chin (2000) is that Δt should be assigned any convenient value between K/3 and K.

A number of studies have been carried out to analyse flood wave propagation, and the results have shown that the time taken for the centre of mass of the flood wave to travel from the upstream end of the reach to the downstream end is equal to K (Viessman *et al.,* cited by Tewolde, 2005).Thus, K can be easily estimated from the observed inflow and outflow data (Viessman *et al.,* Wilson, cited by Tewolde, 2005). Some factors that are related to a catchment may also play an important role in defining the travel time K. The surface geology, the soil type, the drainage pattern and the catchment shape may all have influences. This view has been supported in the work of Bauer and Midgley, as cited by Tewolde (2005).

3.1.1 Calibration of the Muskingum parameters

In the basic Muskingum method, K and X can be graphically estimated from the available inflow and outflow data of the reach of interest. Equation 3.5 shows that if S is plotted against XI+ (1-X) O, a straight line with a slope of K should result. Several values of X are tried; the value that gives the narrowest loop in the plotted relationship is taken as the correct X value and the slope of the plotted relationship is taken as the K value (Haan, Barfield and Hayes, 1994: p185). Figure 3.2 is an example showing that K is taken as the slope of the straight line of the narrowest loop when X=0.3 (Heggen, cited byTewolde, 2005).

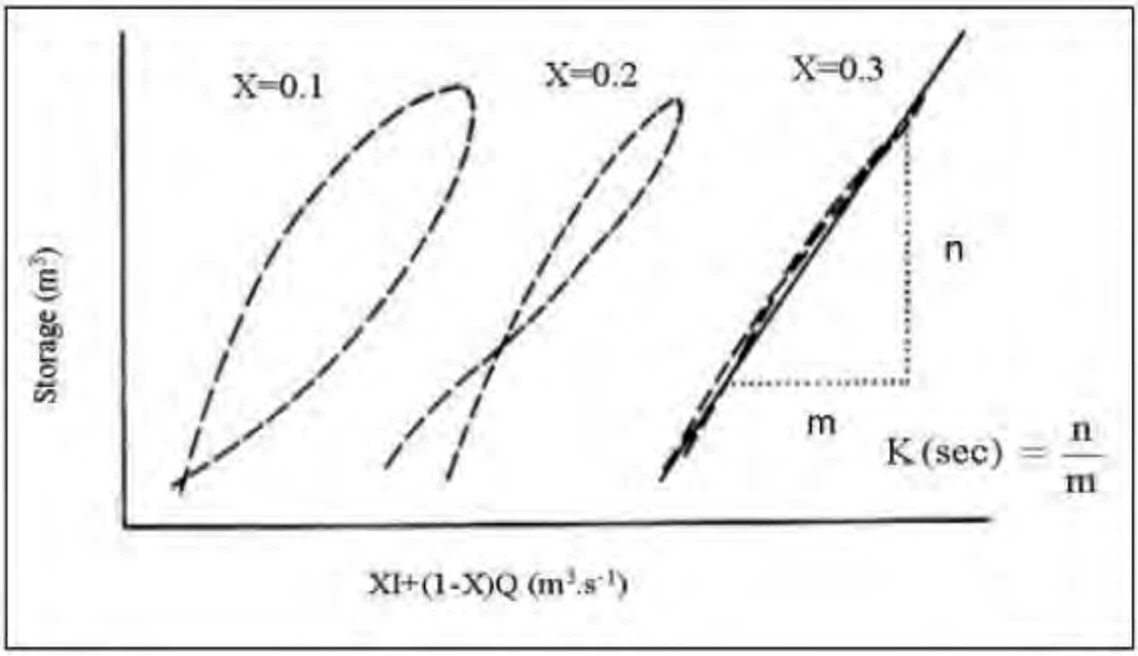


Figure 3.2 *River routing storage loops (after Wilson, cited by Tewolde, 2005).*

3.1.2 Criticism of the Muskingum method

The Muskingum method assumes a single stage-discharge relationship. This assumption causes an effect known as hysteresis, which may introduce errors into the storage calculation (Johnson, 1999). The hysteresis effect between reach storage and discharge is due to the different flood wave speeds during the rising and falling limb of the hydrograph. For the same river stage, the flood wave moves faster during the rising limb of the hydrograph. This phenomenon is illustrated in Figure 3.3; several stages for storage are represented in Figure 3.4, where the first stage shows the storage in the reach during the rising limb of a hydrograph, the second stage represents uniform flow, and the third stage illustrates the storage during the falling limb of the hydrograph.

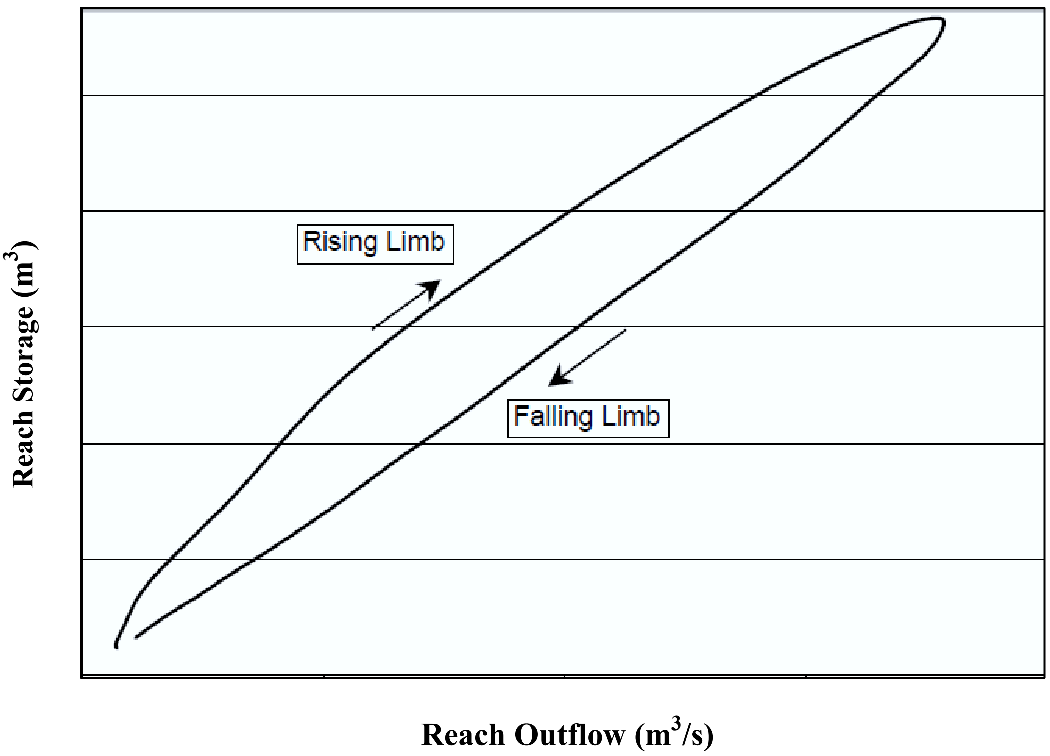


Figure 3.3 *Storage in a river reach versus reach outflow (Boroughs, Craig and Zagona, 2002: p4).*

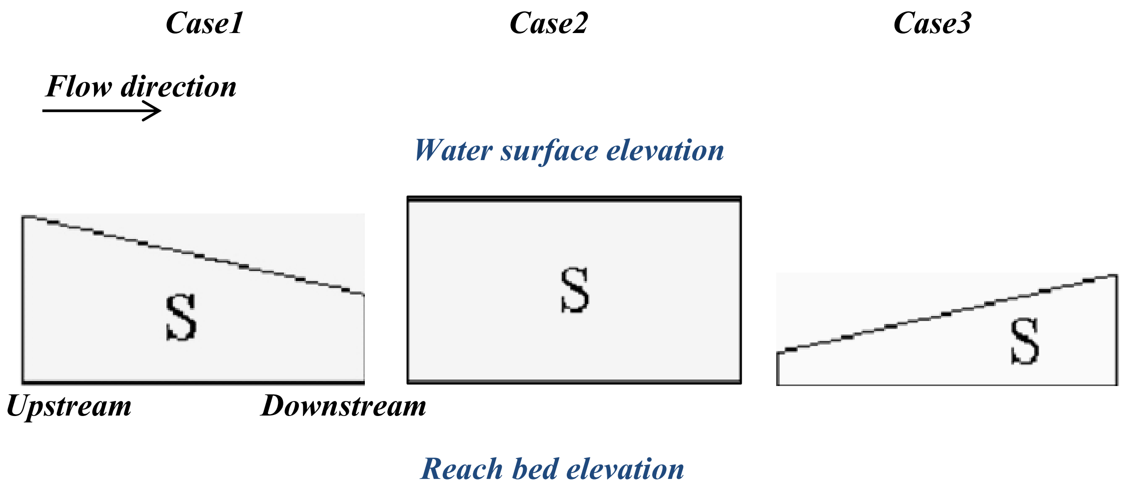


Figure 3.4 *Depiction of reach storage as a flood wave propagates downstream (Boroughs, Craig and Zagona, 2002: p4).*

In spite of its simplicity and its wide applicability, the Muskingum method has the shortcoming of producing a negative initial outflow which is commonly referred to as ‘dip’ or ‘reduced flow’ at the beginning of the routed hydrograph. This view has been supported in the work of Venetis and Dooge, cited by Perumal (1992). Additionally, the method is restricted to moderate to slow rising hydrographs being routed through mild to steep sloping channels (Johnson, 1999). This constraint restricts the Muskingum method even more by making the method not well suited for very mild sloping waterways where a looped stage-discharge rating may exist (Fread, Feng and Xiaofang, cited by Tewolde, 2000).

Finally, the Muskingum method also ignores variable backwater effects such as downstream dams, constrictions, bridges and tidal influences (Johnson, 1999).

In small catchments, where measured inflow and outflow hydrographs are not available, or where a significant uncertainty and errors are reported for the outflow data, modelling the flow using this method is quite a source of errors, and the Muskingum method fails to simulate the flow hydrograph using this type of data. In this situation, an alternative procedure developed by Cunge (1967) has received widespread acceptance. This is due to its ability to estimate the model parameters without the observed hydrograph.

3.2 The Muskingum-Cunge method

In the absence of observed flow data, the Muskingum-Cunge method may be used for parameter estimation. This concept is also applied when measured flow data are available, but with significant degree of uncertainty (Smithers and Caldecott, cited by Tewolde, 2005).

The Muskingum-Cunge parameters are calculated based on the flow and the channel characteristics (Ponce, cited by Tewolde 2005). This method involves the use of a finite difference scheme for solving the Muskingum equation, where the parameters in the Muskingum equation are determined based on the grid spacing for the finite difference scheme and the channel geometry characteristics (Boroughs, Craig and Zagona, 2002).

The Muskingum-Cunge has two formulations, which relate the estimation of the routing coefficients with the methods of mathematical solution. They include:

3.2.1 Constant coefficient method

In this formulation, the routing coefficients are computed based on a reference discharge. The solution of the routing equation, therefore, is based on these coefficients. The reference discharge could be the peak inflow or the average of the peak and the base flow. The basic characteristic of this formulation is that the volumes of water are equal at upstream and downstream ends of the reach. This formulation is considered to be an efficient direct solution technique (Merkel, 2002).

3.2.2 Variable coefficient method

The routing coefficients in this formulation are varying by time step to reflect the flow characteristics (mainly wave celerity, friction slope and top width) of the rising and receding flood wave. The variable coefficient formulation explicitly shows the differences in the flow speed and the variation in the cross-section at top width and flood plain for the channel. This gives a better simulation of the real outflow hydrograph compared to the constant coefficient formulation. The two solution techniques proposed by Ponce (1983) are the three points direct and the four point iterative procedures (Merkel, 2002).

Routing coefficients in the three point direct solution method are derived from three known discharges (inflow at the first and second time steps and outflow at the first time step). The four point iterative procedure estimates the outflow at the second time step based on the three known discharges. Iterations are needed to converge to the final discharge based on some error tolerance (Merkel, 2002: pp.2-7).

3.2.3 Selection of routing time and distance steps

As a result of many studies that have been performed by Ponce in 1981, a simulation of similar outflow hydrographs for various selections of Δx and Δt have been derived using the Muskingum-Cunge with the constant coefficient method. Within a reasonable range of Δt and Δx, the Muskingum-Cunge produces consistent results. This method selects Δx based on the desired value of Δt and other factors. This relationship is illustrated in Equation 3.18 as:

$$\Delta x \leq \frac{1}{2}\left\{c\Delta t + \frac{Q_0}{BS_0 c}\right\} \quad \text{(Ponce, cited by Merkel, 2002).} \qquad (3.18)$$

Where,

c is the wave celerity in (m/s), Q_0 is the reference discharge in (m3/s), B is the top width of the channel in (m) and S_0 is the channel bed slope (m/m).

The resulting value of Δx can be checked under the following conditions:

1- If the reach length L is shorter than Δx, the reach is treated as a single step.

2- If the value of Δx is less than 2/3 of the reach length, the reach is divided into steps. For example if there are two steps, the routing will be for two separate reaches instead of one reach. The routing equations are solved for the upstream half of the reach and the resulting outflow hydrograph is routed through the downstream half of the reach (Merkel, 2002: p7).

Ponce and Theurer, as cited by Garbrecht and Brunner (1991), showed that the use of a minimum time increment results in good routing hydrographs. The size used should be ranged from one day to five minutes. This limitation is shown to work well for previous simulations of drainage networks.

The routing time interval can be adjusted using the relationship shown in Figure 3.5 below:

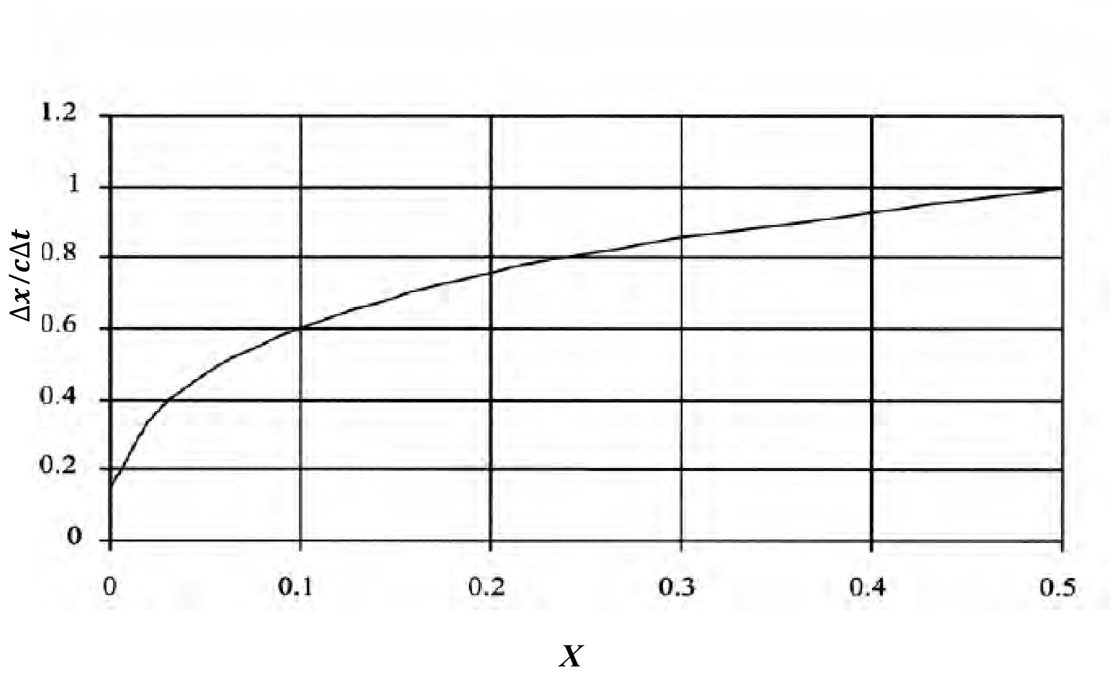


Figure 3.5 *Cunge curve (NERC, cited by Tewolde, 2005).*

Where,

$\Delta x/c\Delta t <$ Value of the curve derived from the X value.

For an adequate temporal resolution, Δt is chosen so that there is a minimum of five discretised points on the rising part of the inflow hydrograph (Ponce and Theurer, cited by US Army Corps of Engineers, 1991).

3.2.4 Derivation of the Muskingum-Cunge Equation

Cunge, as cited by Todini (2007) introduced a method with a formulation similar to the original Muskingum type formulation. However, the Cunge method accounted for the diffusive effect by transforming Equation 3.10 (page 22) from the original Muskingum formulation into a proper diffusion wave model. Cunge started from the following kinematic routing model:

$$\frac{\partial Q}{\partial t} + c\frac{\partial Q}{\partial x} = 0 \tag{3.19}$$

Where:

Q is the discharge in (m^3/s), x is the longitudinal coordinate in m, t is the time coordinates in s, and c is the wave celerity in (m/s).

Cunge then derived the following finite difference weighted approximations for the partial derivatives on a four point scheme:

$$\frac{\partial Q}{\partial t} \approx (X(Q^{i+1}{}_{j} - Q^{i}{}_{j}) + (1 - X)(Q^{i+1}{}_{j+1} - Q^{i}{}_{j+1}))/\Delta t \tag{3.20}$$

$$\frac{\partial Q}{\partial x} \approx (\beta(Q^{i+1}{}_{j+1} - Q^{i+1}{}_{j}) + (1 - \beta)(Q^{i}{}_{j+1} - Q^{i}{}_{j}))/\Delta x \tag{3.21}$$

Where,

$Q^{i+1}{}_{j+1} = Q\big((i+1)\Delta t, (j+1)\Delta x\big)$, $Q^{i+1}{}_{j} = \mathrm{Q}\big((i+1)\Delta t, j\Delta x\big)$,

$Q^{i}{}_{j+1} = Q(i\Delta t, (j+1)\Delta x)$ And $Q^{i}{}_{j} = Q(i\Delta t, j\Delta x)$

X ($0 \le X \le 1$) is the space weighting factor and β ($0 \le \beta \le 1$) is the time weighting factor. This approximation leads to the following first order approximation of the kinematic wave equation (Equation 3.19) as:

$$\frac{[X(Q^{i+1}\,j - Q^{i}\,j) + (1-X)(Q^{i+1}\,j{+}1 - Q^{i}\,j{+}1)]}{\Delta t} +$$

$$c\,\frac{[\beta(Q^{i+1}\,j{+}1 - Q^{i+1}\,j) + (1-\beta)(Q^{i}\,j{+}1 - Q^{i}\,j)]}{\Delta x} = 0 \tag{3.22}$$

This can be written as:

$$\frac{[X(Q^{i+1}\,j - Q^{i}\,j) + (1-X)(Q^{i+1}\,j{+}1 - Q^{i}\,j{+}1)]}{\Delta t} + \frac{c}{2}\,\frac{[(Q^{i+1}\,j{+}1 - Q^{i+1}\,j) + (Q^{i}\,j{+}1 - Q^{i}\,j)]}{\Delta x} = 0 \tag{3.23}$$

By assuming a time centred scheme $\left(\beta = \frac{1}{2}\right)$, Equation 3.23 after some algebraic manipulation can be transformed to:

$$Q^{i+1}j + 1 = C_0 Q^{i+1}j \ + C_1 Q^i j + C_2 Q^i j + 1 \qquad (3.24)$$

Where,

$$C_0 \ = \frac{2\Delta x.X + c\Delta t}{2\Delta x(1-X) + c\Delta t} \qquad (3.25)$$

$$C_1 = \frac{-2\Delta x.X + c\Delta t}{2\Delta x(1-X) + c\Delta t} \qquad (3.26)$$

$$C_2 \ = \frac{2\Delta x(1-X) - c\Delta t}{2\Delta x(1-X) + c\Delta t} \qquad (3.27)$$

Cunge also noted that by substituting for $K = \frac{\Delta x}{c}$, and by comparing with Equation 3.10:

$$O_{j+1} = Q^{i+1}j + 1, \ O_j = Q^i j + 1, \ I_{j+1} = Q^{i+1}j \ , \ \ I_j = Q^i j$$

Equation 3.24 becomes identical to Equation 3.10. However, a different interpretation of the two equations shows that Equation 3.24 represents the solution of a partial differential equation, while Equation 3.10 is the solution of an ordinary differential equation after integration of the continuity of mass equation in space.

A variable parameter formulation can be obtained from the discretisation of any explicit parabolic or hyperbolic scheme, by expanding the discharge Q in a Taylor series. Cunge (1969) showed that Equation 3.24 represents a first order approximation, with second order residual equal to zero, of the kinematic model given in Equation 3.19, and at the same time a linear approximation of the parabolic model of Equation 3.28 as:

$$\frac{\partial Q}{\partial t} + c\frac{\partial Q}{\partial x} - \frac{Q_0}{2BS_0}\frac{\partial^2 Q}{\partial x^2} = 0 \tag{3.28}$$

with a second order rounding error (also known as numerical diffusion), given by:

$$R = \frac{c\Delta x}{2}(1 - 2X)\frac{\partial^2 Q}{\partial x^2} + \cdots \tag{3.29}$$

In Equation 3.28, B in m is the surface width; S_0 in (m/m) is the bottom slope.

This result implies that Equation 3.23 can also be interpreted as the solution of the parabolic model given in Equation 3.28, provided that the following relation holds:

$$\frac{c\Delta x}{2}(1 - 2X) = \frac{Q_0}{2BS_0} \tag{3.30}$$

Therefore, by imposing the condition that the numerical diffusion equals the physical one, Cunge (1969) derived an expression for the X value as:

$$X = \frac{1}{2}\left(1 - \frac{Q_0}{c\Delta x BS_0}\right) \tag{3.31}$$

Where, X is a weighting factor varying between 0.0 and 0.5 (dimensionless). Q_0 is a reference discharge in (m^3/s), S_0 is the channel bottom slope in (m/m), c is the kinematic wave celerity in (m/s), Δx is the routing reach or sub-reach length in m and B is the water surface width in m.

Wilson and Ruffini, as cited by Tewolde (2005) defined the reference discharge as:

$$Q_0 = Q_b + 0.5\,(Q_p - Q_b) \tag{3.32}$$

Where,

Q_0 is the reference discharge in (m^3/s), Q_b is the base flow in (m^3/s), taken from the inflow hydrograph (See section 2.1.1.1 in chapter 2) and Q_p is the peak inflow in (m^3/s).

The base flow as suggested by Langbein and others (1947) is composed largely of groundwater effluent, and it is defined as the minimum inflow (Tewolde and Smithers, 2006).

K is the storage time constant for the river reach in seconds, which has a value close to the wave travel time within the river reach, it is estimated as:

$$K = \Delta x / c \tag{3.33}$$

Values of X in Equation 3.31 and K in Equation 3.33 are used in Equations 3.25 to 3.27 and updated at each time step to derive the Muskingum-Cunge approach. Ponce and Yevjevich, as cited by Todini (2007) presented the following expression for C_0, C_1 and C_2 as:

$$C_0 = \frac{-1+C+D}{1+C+D} \tag{3.34}$$

$$C_1 = \frac{1+C-D}{1+C+D} \tag{3.35}$$

$$C_2 = \frac{1-C+D}{1+C+D} \tag{3.36}$$

The ratio of physical and numerical diffusivities is derived in terms of the dimensionless “Courant number” (C); and “cell Reynolds number” (D), as:

$$C = \frac{c\Delta t}{\Delta x} \tag{3.37}$$

$$D = \frac{Q_0}{BS_0 c\Delta x} \tag{3.38}$$

In the case of variable parameter Muskingum-Cunge method, the parameters C and D are generally estimated at each time interval, as a function of a reference discharge Q_0 relevant to each computation section in which a river reach will be divided. By comparing Equations 3.11– 3.13 and Equations 3.34 – 3.36, the two original Muskingum parameters can be expressed as:

$$K = \frac{\Delta t}{C} \tag{3.39}$$

$$X = \frac{1-D}{2} \tag{3.40}$$

the two parameters derived in Equations 3.39 and 3.40 are estimated in every computation section of length Δx and at each time step Δt (Todini, 2007).

For simplicity, values for the Courant Number (C) and Reynolds Number (D) from Equations 3.39 and 3.40 can be substituted in Equations 3.34 - 3.36 to derive a final expression for the routing coefficients C_0, C_1 and C_2 as:

$$C_0 = \frac{\frac{\Delta t}{K} - 2X}{\frac{\Delta t}{K} + 2(1-X)} \tag{3.41}$$

$$C_1 = \frac{\frac{\Delta t}{K} + 2X}{\frac{\Delta t}{K} + 2(1-X)} \tag{3.42}$$

$$C_2 = \frac{2(1-X) - \frac{\Delta t}{K}}{\frac{\Delta t}{K} + 2(1-X)} \tag{3.43}$$

3.2.5 Acceptable Ranges for the "X" Parameter

Estimation of X parameter in the Muskingum method is agreed to be between 0 and 0.5 (Miller and Cunge, Weinmann and Laurenson, cited by Heatherman, 2008). However, keeping a positive value for X when using the Muskingum-Cunge places a lower limit on the size of distance step that can be used (Weinmann and Laurenson, cited by Heatherman, 2008). A new accuracy criteria suggested by Ponce and Theurer (1982) for time and distance steps showed that negative values of X caused no computational difficulties in a practical manner. It would indicate that the outflow contributes more to the channel storage than inflow and this occurred in cases where a significant backwater is evolved. An event which has not been simulated by the Muskingum-Cunge method. (Reid, 2009).

Recently, Szel and Gasper, as cited by Heatherman (2008) have reported that the concept of weighting parameters played no role in the Muskingum-Cunge and negative value for X may sometimes improve the stability and the accuracy of the solution.

3.2.6 Criticism of the Muskingum-Cunge method

Despite the wide applicability of the Muskingum-Cunge method on most of the flood wave simulations, the method does not account for variable backwater effects, in the same way as the Muskingum method (Johnson, 1999).

Although the constant coefficient method seems to work well for long river reaches and large drainage areas, more research is still needed to test this method on short reaches and small drainage areas; this is the most common case in reality for the application of channel routing methods (Bravo *et al.,* cited by Reid, 2009).

The variable parameter Muskingum-Cunge method has the defect of not satisfying the mass balance preservation, where the volume of water upstream does not equal to the volume of water downstream (Ponce and Changanti, cited by Reid, 2009). This is particularly the case when dealing with rapidly rising hydrographs in flat channels which have very mild slopes, less than 0.0002. The solution then diverges from a full unsteady flow (Brunner, cited by US Army Corps of Engineers, 1991). A number of studies have shown that the minimum time for a hydrograph to rise can maintain an error up to 10%. This error increases as the slope decreases (Tang *et al.,* cited by Johnson, 1999). The smaller the channel slopes are, the worse the cases will be when considering smaller time increments (Fenton, 2011).

In general cases, when the flood wave travels through the sub-reach in a time less than the computational interval Δt, computational instabilities may be encountered. Hence, the Courant Number as defined in section 3.2.4 (page 33) will be greater than one. To optimise the solution, the Courant Condition is used to fix the spatial and temporal steps so that Δt can be expressed as: $\Delta t \leq \Delta x / C$ (Johnson, 1999). Where, Δt and Δx are the temporal and spatial weighting factors and C is the Courant Number.

Barry and Bajracharya, as cited by Reid (2009) have found that the solution for the dispersion problem in the spatial and temporal steps can be achieved by using a value of 0.5 for the Courant Number.

Generally, the selection criteria for the routing models is influenced by some factors such as the required accuracy, the type and availability of data, the available computational facilities, the computational costs and the extent of flood wave information desired (NERC, Fread, cited by Tewolde, 2005). The analysis of the available flow data and their accuracy for modelling are discussed in the next chapter.

4 Flow Data Analysis and Application of the Muskingum methods

4.1 Hydrologic data

The hydrometric data applied in this research have been collected from the Office of Public Works (OPW, 2000)-Ireland. Types of these data include water levels and estimated flows. A brief description of the equipment and methodologies that have been used in collecting and processing the hydrometric data are presented in this chapter.

4.1.1 Water Level Recording

The general two equipment types used for water level recording are the autographic recorders and the data loggers (OPW, 2000). An autographic recorder provides a continuous trace of water level on weekly or monthly charts. This method depends on a pen movement on a spindle via a pulley and gearing mechanism. The water level trace on the charts is then digitised to present a ‘time-series’ of water level against time.

A data logger is a more commonly used method of recording water level. These devices are used by the OPW to digitally record the water level at set time intervals.

The recorded water level is referred to as water depth or ‘stage’ above a staff gauge zero level. This staff gauge helps the field technicians in the process of checking and validating the data recorded. In Ireland, the zero level of the staff gauges have been surveyed to either Poolbeg or Malin Head Ordnance Datum levels. These heights are added to the recorded levels (stage) to provide water levels to an Ordnance Datum.

As indicated by the Environmental Protection Agency EPA (2011), some periods have gaps in the recorded water level. These gaps are due to the equipment malfunction or it may be due to periods of no rating, unreliable rating and periods of channel maintenance and drainage works. Hence, a certain quality code is attached in Table (4.1) in Appendix B. This code must be taken into consideration when evaluating the data, particularly, peak or low water levels or flows. A gap in the water level record has a corresponding gap in the flow record.

4.1.2 Flow Estimation

River flow is not recorded continuously, but it is rather estimated from ratings (stage-discharge relationships) and the recorded water levels. As indicated in section 2.3.4 (page14), the rating is a relationship that equates a given water level to a given flow at a particular location. The procedure begins by measuring the velocity at a series of points across the river; this is known as the velocity-area method of measurement according to the British Standard of International Organization for Standardization (ISO748 / BS3680). The methodology used to calculate flow (discharge) for a particular level (stage) is to use a number of gaugings over a range of water levels. This can be achieved by deriving an equation for the best fit of line through the scatter of gaugings. Hence, flows are estimated using a direct extrapolation of the rating equation. This flow estimation can be classified further into daily mean flows, or flow duration statistics. Figure 4.1 shows an example of a best fit- rating curve for River Dodder in Ireland.

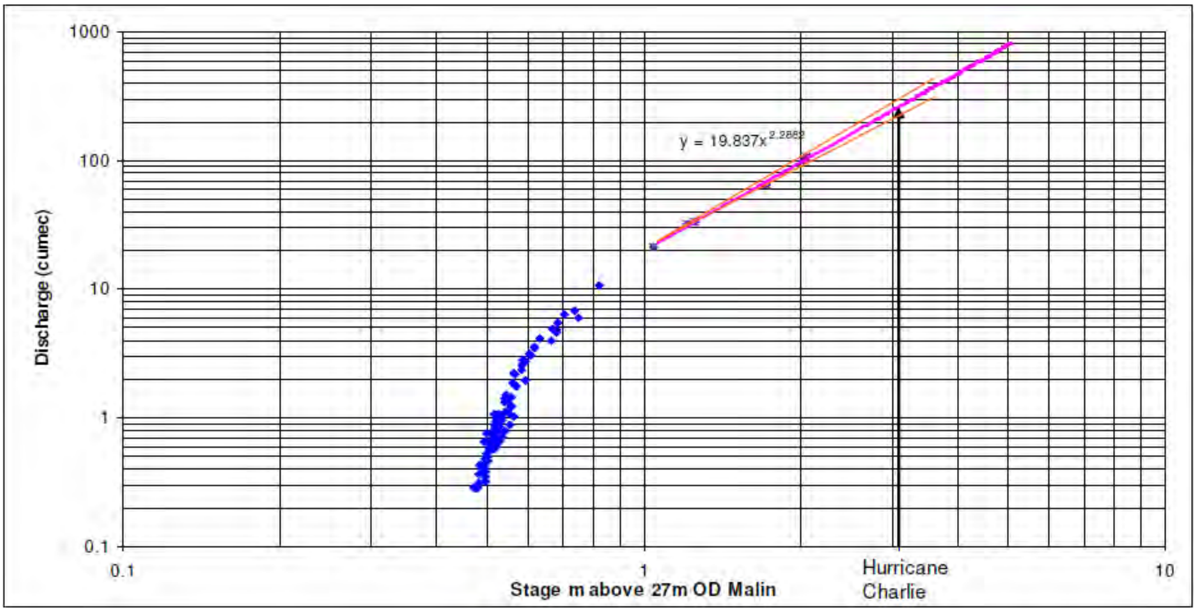


Figure 4.1 *Rating Data and best fit Rating Curve for River Dodder Flood Flows at Orwell Bridge (Station 09010) (Cawley, Fitzpatrick, Cunnane and Sheridan, 2005).*

The basic assumption in using the rating curve to estimate flow is that the relationship between stage and discharge remains constant in time. However, in reality, several factors can have significant effects such as, seasonal weed-growth, sedimentation, erosion, drainage and construction work in the channel or floodplain. These factors can backwater the monitoring sites, hence, they may affect the water level.

The flow data estimation using the rating curve method raised reliability issues with the use of these data for comparison and modelling purposes. As indicated by the OPW website, some available flow data may contain a considerable degree of error. This is due to the scatter in flow gaugings around the rating equation and changes of control in time.

4.1.3 Introduction to Quality Codes

Quality Codes represent an indicative measure of the reliability and confidence which are associated with the data provided. They are shown as a numeric or as a symbol, depending on the data formatting. The majority of the codes are not associated with any given confidence limits in terms of percentage, absolute value or standard error. Hence, codes should be used only as an indication of the reliability of the data. Table (4.1) in Appendix (B) describes Quality Codes for water level and estimated flow data used by the OPW.

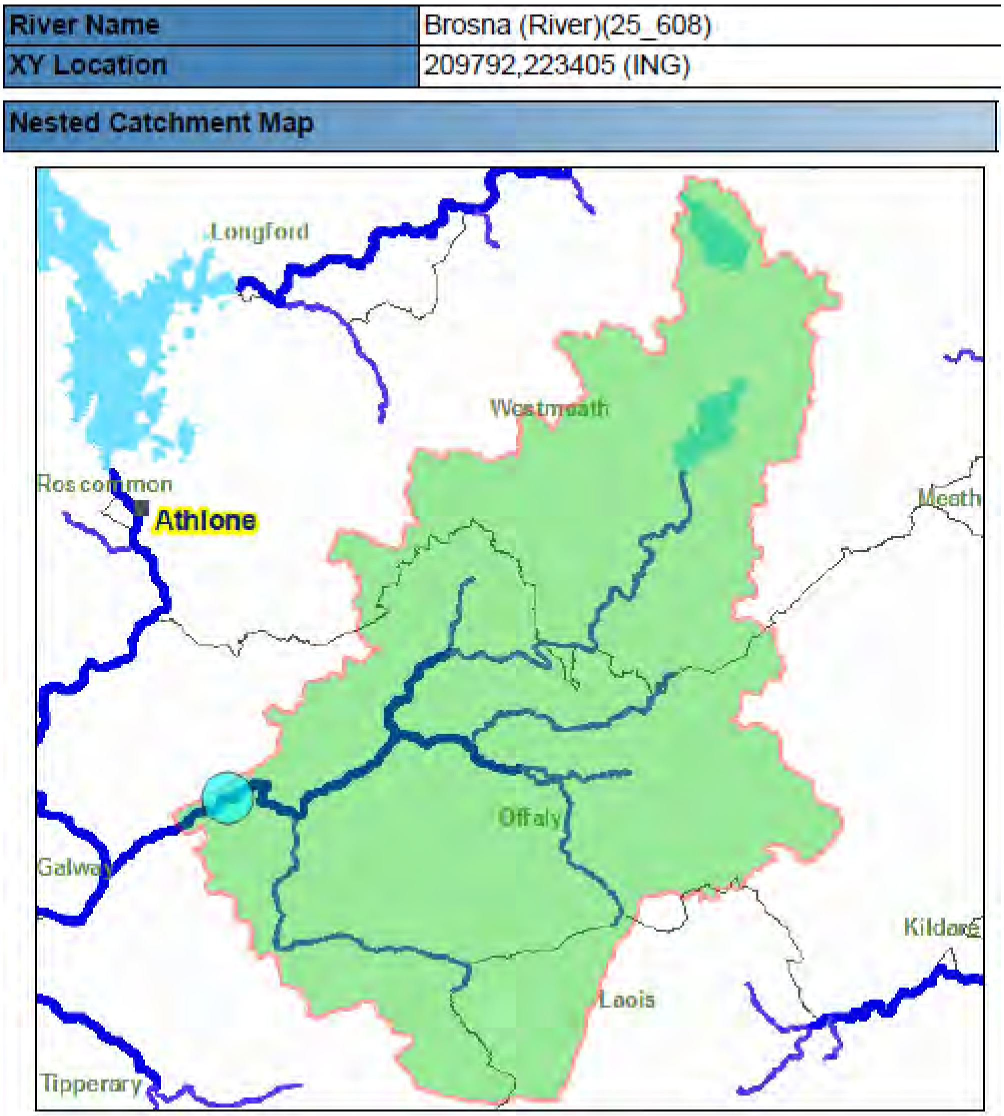
4.1.4 Case Study

The River Brosna

The river Brosna is a small river in Ireland which rises in Lough Owel, north of Mullingar town. It flows through county Westmeath and county Offaly in the South-West direction into Lough Enell (See map in Figure 4.2, page41). From Lough Enell the river flows into Kilbeggan where it powers the mill at Kilbeggan Distillery. The Brosna continues flowing southwest till it joins the Silver River east of Ferbane. From Ferbane it heads to Shannon Harbour where it joins the Shannon River (Wikipedia, 2011).

The land on both sides of the River's Canal has been subjected to OPW drainage schemes. Several works had been carried out under the Arterial Drainage Act, 1945, to reduce the risk of flooding on these lands (Westmeath County Council, 2010). Despite this, the river suffered a severe flood which occurred in Mullingar in November 1965. This flooding as reported by Cawley, Fitzpatrick, Cunnane and Sheridan (2005) is considered the worst flooding in the River Brosna in at least 50 years. Recently, the river also suffered from some pollution problems, caused by the discharge of untreated sewage in the Mullingar area during storm conditions (Wikipedia, 2011).

Around six gauging stations are located on the river Brosna. Beginning from the upstream end of the river to downstream, these gauging stations are: Culleen Fish Farm, Mullingar Pump HSE, Newell’s bridge, Pollagh, Ferbane and Moystown. Flow data for the last two gauging stations, Ferbane (Inflow) and Moystown (Outflow) has been selected for analysis and modelling in this study. Figures 4.2 and 4.3 illustrate the Brosna catchment and the location of the two gauging stations. No lateral inflow is found between the two locations.



River Name	Brosna (River)(25_608)
XY Location	209792,223405 (ING)

Nested Catchment Map

Figure 4.2 *Flow direction of the River Brosna in the South-West, where the two gauging sites are located in the blue circle (EPA, 2010).*

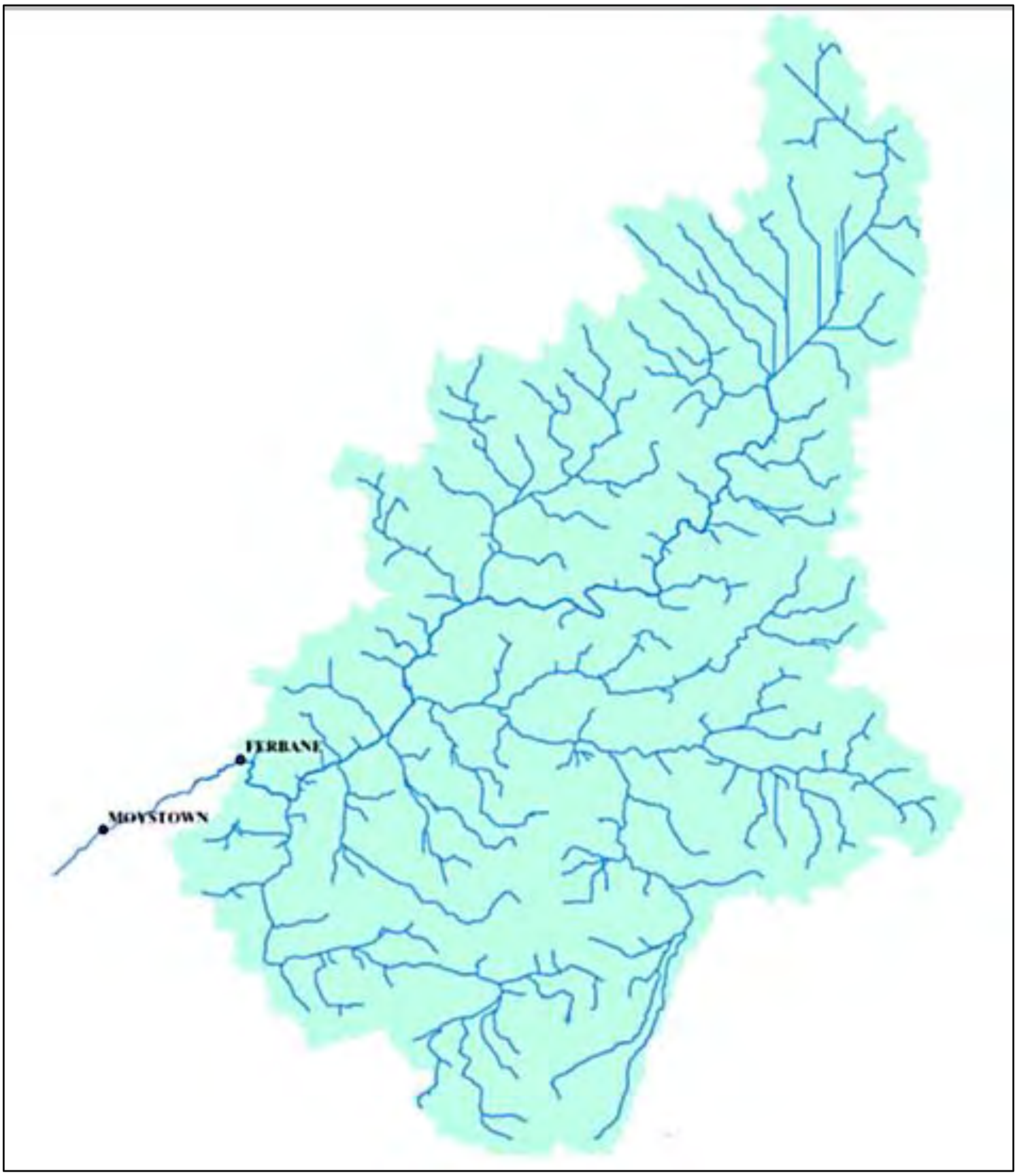


Figure 4.3 *The River Brosna Catchment including Ferbane and Moystown gauging stations (EPA, 2010).*

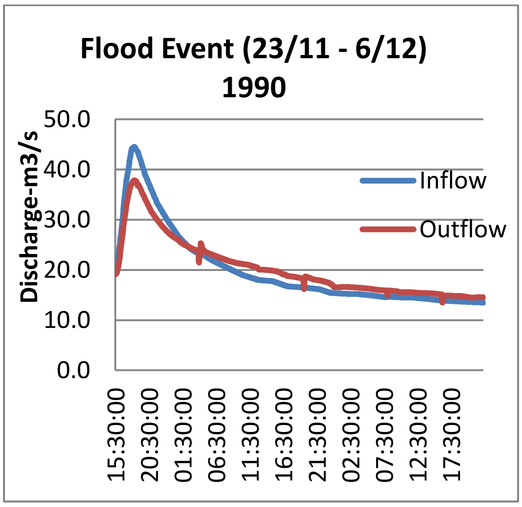
Details of the two gauging stations are shown in Table 4.2 on the following page.

Table 4.2 *Details of the gauging stations at the River Brosna (OPW, 2000).*

Station Name	Station No.	NGR	Catchment Area (km^2)	Catchment	Datum
Ferbane	25006	N11543	1207	Brosna	Poolbeg
Moystown	25011	N 046208	1227	Brosna	Poolbeg

According to the Quality Code classification, estimated flow data for the Ferbane gauging station is classified with the code of type (31), which means that the flow data contain an acceptable degree of error. Hence, they can be used for general purposes. In contrast, most of flow data for the Moystown gauging station contain a significant degree of error. Therefore, it is classified with type (B), which means that the use of these data for modelling purposes is limited with certain cautions. This is due to its poor quality rating curve which resulted in a shift occurring in the stage. This shift maybe caused by a significant backwater effect due to a weir transition downstream in the river (US Army Corps of Engineers, 2008). The weir is located in the Belmont area which is approximately 3.9 km from Ferbane (upstream). The small bed slope for the river Brosna is also responsible for increasing the shift in the stage (US Army Corps of Engineers, 2008).

In this study, the flow data of type (B) is classified further in terms of uncertainty to high, moderate and low, according to the number of errors estimated in days during the flood periods. For example, a hydrograph with high uncertainty is one which contains flow data of type B for all of the flood period. While a hydrograph with a moderate uncertainty is one that includes flow data of type B for nearly half of the flood period. The final hydrograph with low uncertainty is one that includes only a few days or hours of data type B. For this study, a number of flood events have been selected for analysis and modelling. The hydrographs chosen range from high to moderate and low flood events which occurred between 1990 and 1994. For adequate hydrograph shapes, a minimum time increment of 15 minutes has been used in analysis and modelling. Figures 4.4 – 4.21 as follow illustrate hydrographs for a selection of similar flood events on the Brosna River, each with its duration and peak flow.



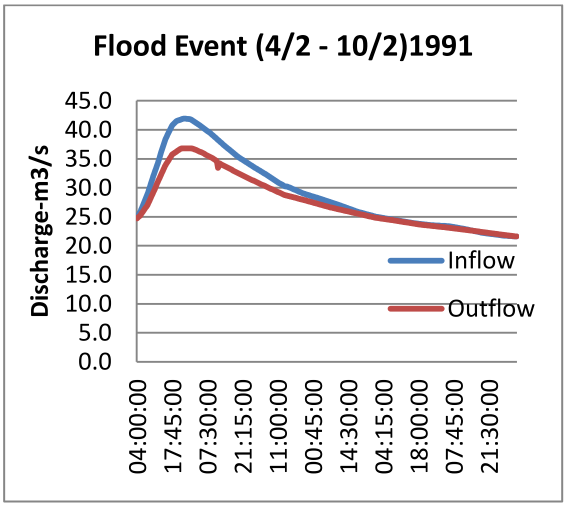


Figure 4.4

Q_{peak}=44.5607 m^3/s -14 days

Moderate Uncertainty

Figure 4.5

Q_{peak}= 41.9388 m^3/s – 7days

High Uncertainty

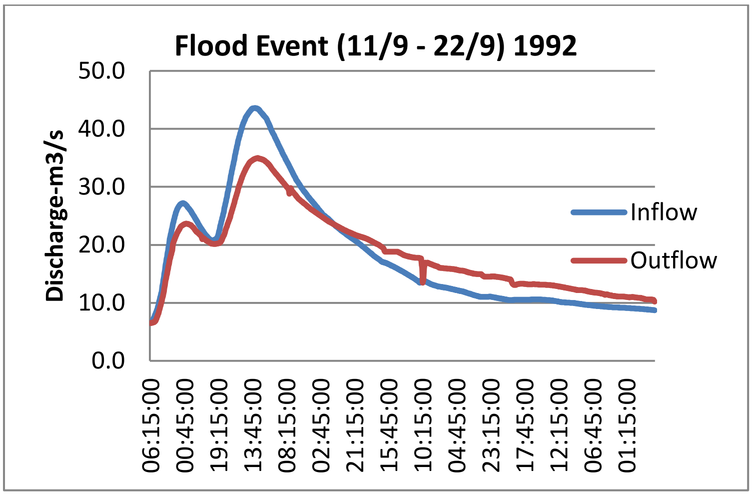


Figure 4.6

Q_{peak}= 43.6023 m^3/s – 12 days

Low Uncertainty

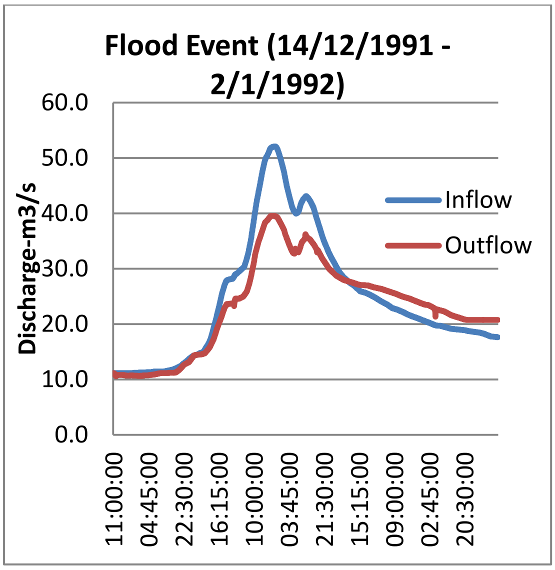


Figure 4.7

Q_{peak}= 52.0836 – 19 days

High Uncertainty

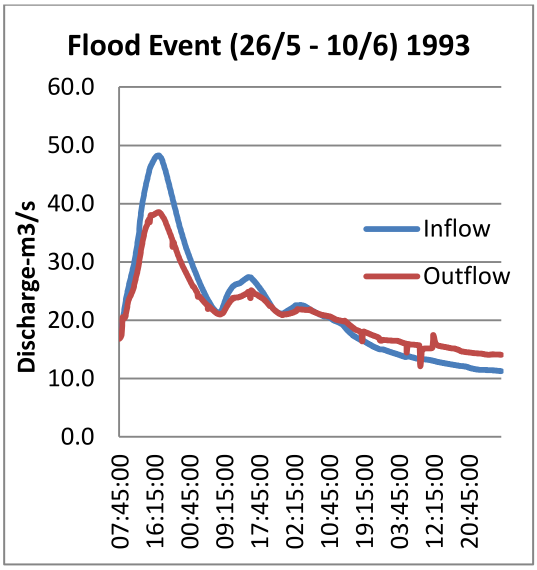


Figure 4.8

Q_{peak}= 48.2758 m^3/s – 16 days

High Uncertainty

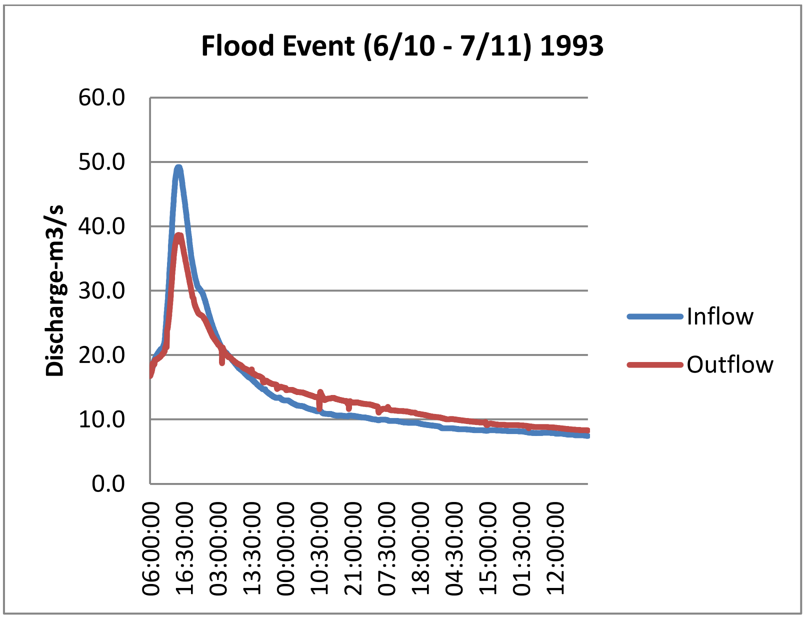


Figure 4.9

Q_{peak}= 49.2122 m^3/s – 31 days

Low Uncertainty

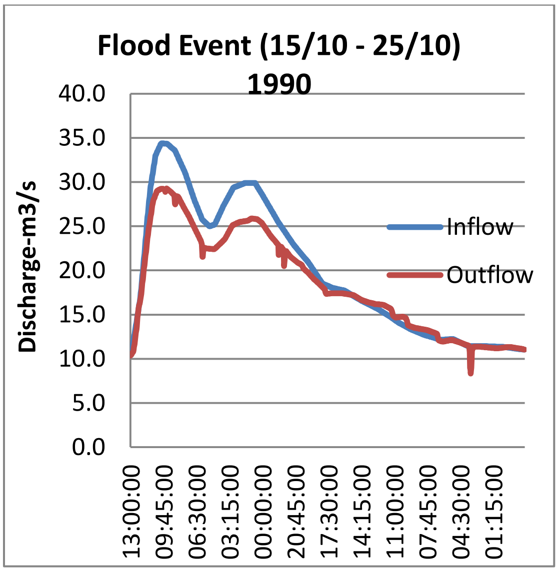


Figure 4.10

Q_{peak}= 34.3871 m^3/s – 10 days

Moderate Uncertainty

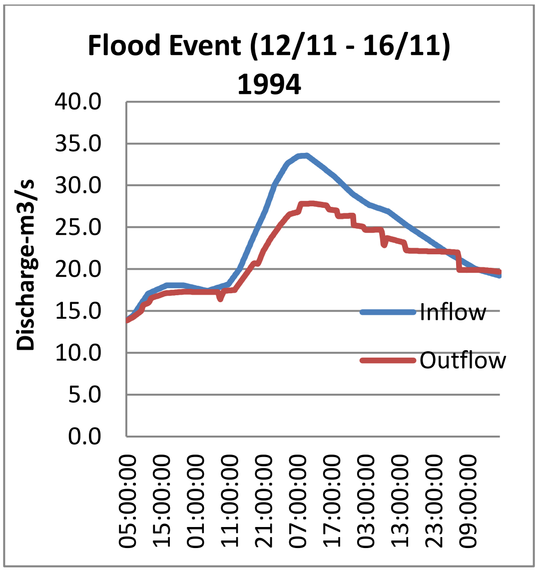


Figure 4.11

Q_{peak}= 33.5624 m^3/s – 5 days

High Uncertainty

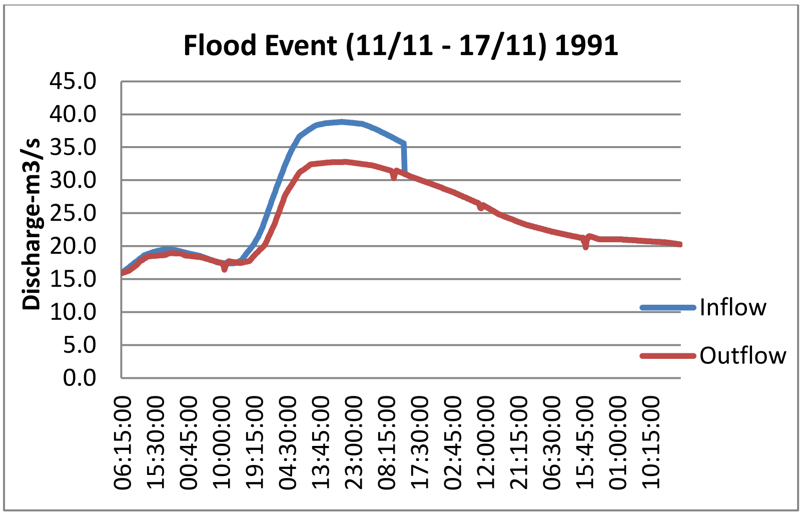


Figure 4.12

Q_{peak}= 38.8437 m^3/s – 7 days

High Uncertainty

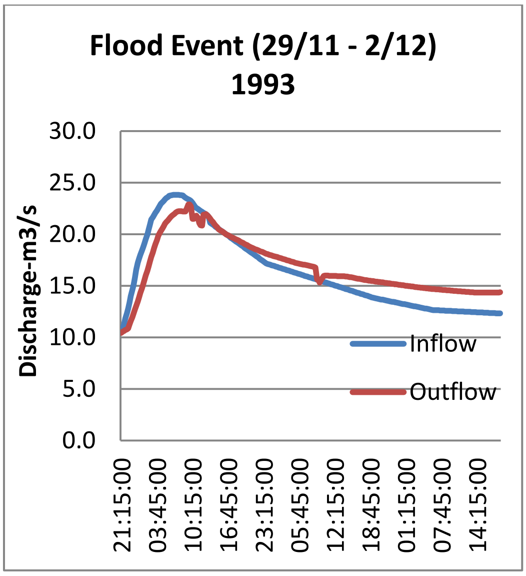


Figure 4.13

Q_{peak}= 23.8231 m^3/s – 4 days

Low Uncertainty

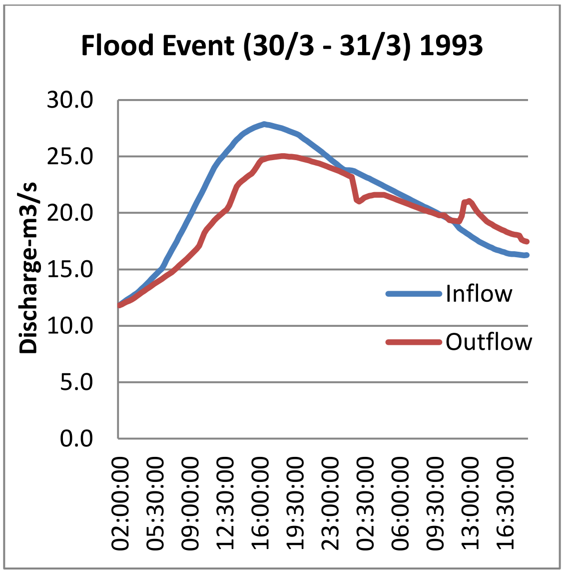


Figure 4.14

Q_{peak}= 27.8620 m^3/s – 1 day

Low Uncertainty

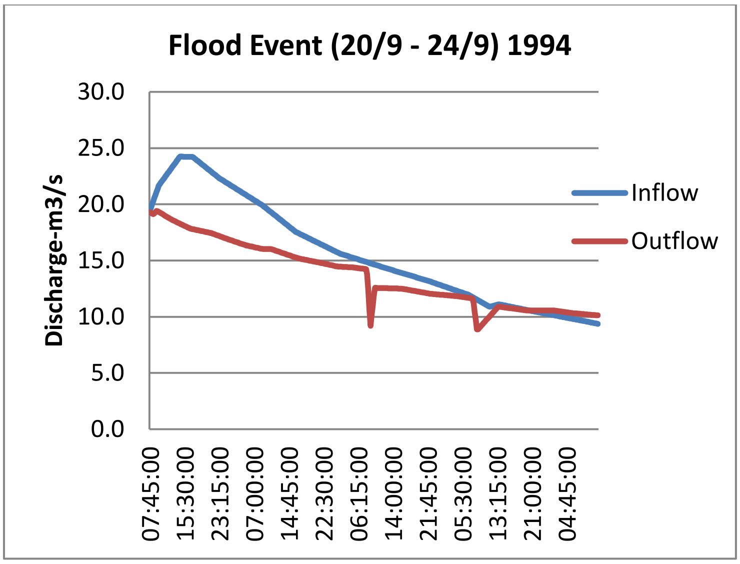


Figure 4.15

Q_{peak}= 24.2415 m^3/s – 5 days

Low Uncertainty

Maximum Floods

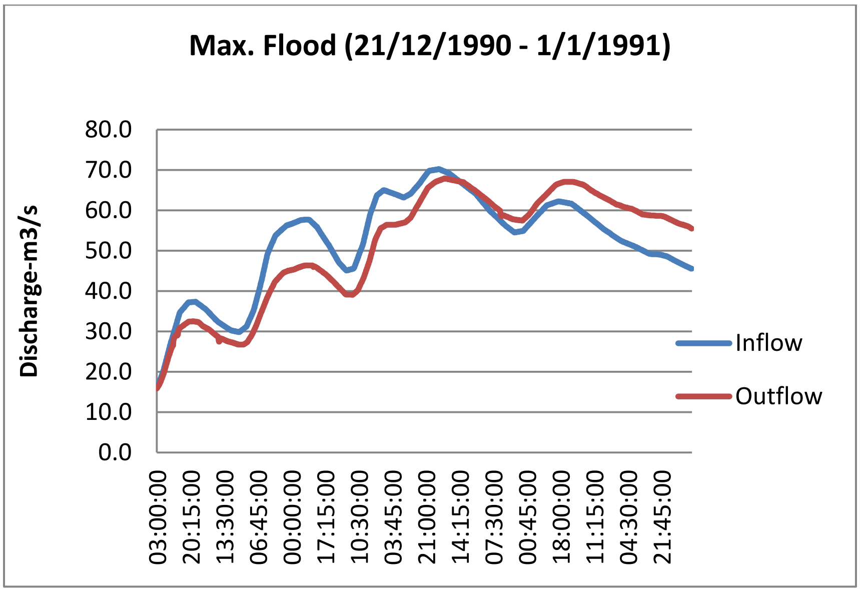


Figure 4.16

Q_{peak}= 70.2282 m^3/s – 12 days

High Uncertainty

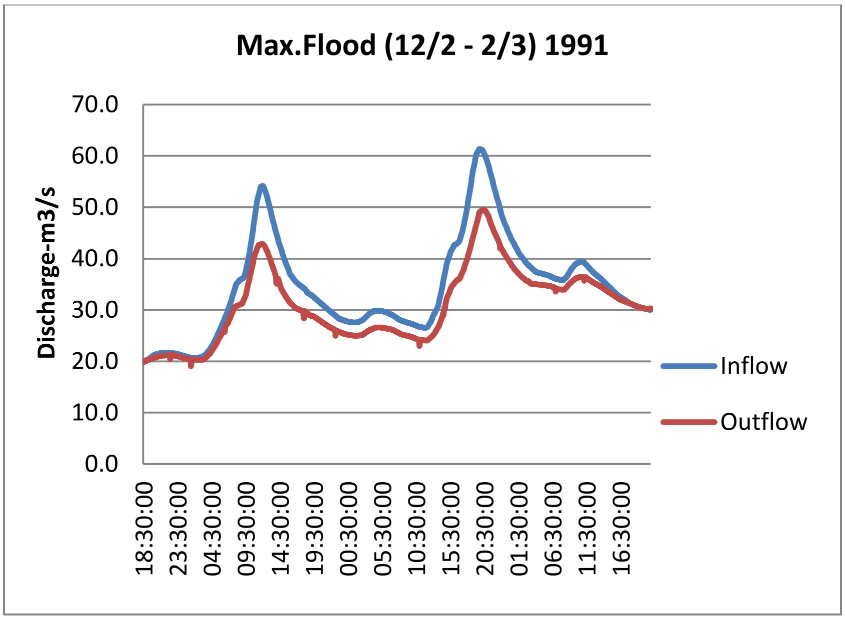
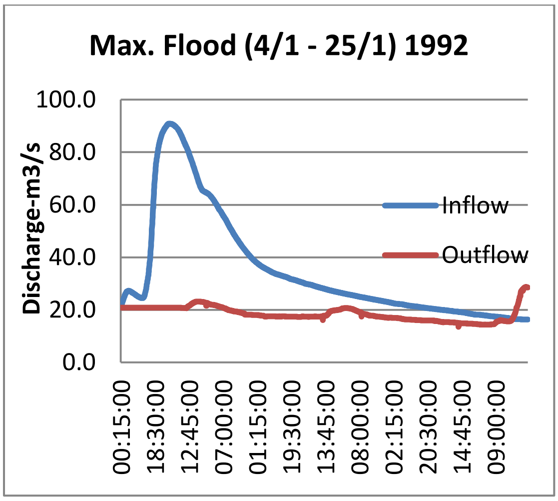


Figure 4.17

Q_{peak}= 61.3475 m^3/s – 18 days

Moderate Uncertainty



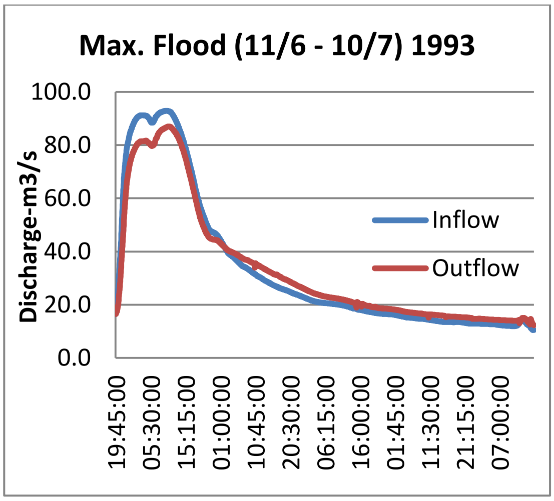


Figure 4.18

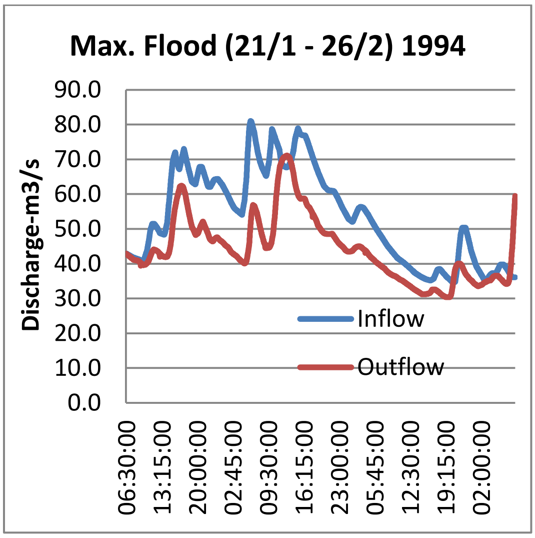
Q_{peak}= 90.9154 m^3/s – 22 days

High Uncertainty

Figure 4.19

Q_{peak}= 92.9465 m^3/s – 30 days

High Uncertainty



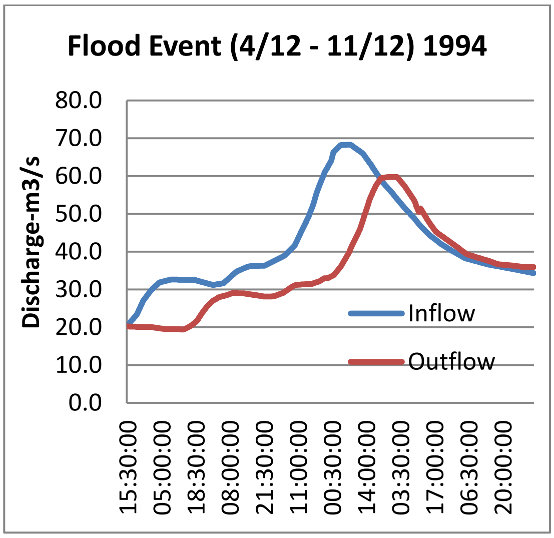


Figure 4.20

Q_{peak}= 81.0211 m^3/s – 37 days

High Uncertainty

Figure 4.21

Q_{peak}= 68.2972 m^3/s – 8 days

High Uncertainty

4.1.5 Flow Data Analysis

The hydrographs show that the flood periods ranged from a minimum of one day which was recorded in 1993 to a maximum of 37 days which were recorded in 1994. Their peak values were 23.8231m^3/s and 81.0211m^3/s respectively.

The general characteristics of the hydrographs shown are that the moderate and low floods occurred between September in the previous year and March in the following year. The only exception was in 1993 where a flood event occurred in May.

Figures 4.16- 4.20 illustrate the maximum flood hydrographs for each year. The maximum floods in the five selected years occurred between December in the previous year and February in the following year. Similar exception for the moderate flood events was also recorded in June, 1993 with a peak of 92.9465m^3/s.

In 1992, the outflow hydrograph shows a significant error in the flow data for Moystown gauging station. While the peak inflow was 90.9154 m^3/s recorded in the sixth of January, the outflow at that time was only a minimum or a base flow. Immediately after this period, the malfunction of the water level recorder resulted in missing flow data for the following three months.

The Figures indicate that in general the flood hydrographs are steeply rising. In contrast, however, the flood hydrographs illustrated in Figures 4.7, 4.11, 4.12, 4.13 and 4.21 are gradually rising. These last figures may possibly represent a good shape for the inflow hydrograph. Another observation is associated with the degree of uncertainty. The overall shape of the hydrographs with high and moderate uncertainty indicates that very little or no flood translation is found between the inflow and outflow peaks. In contrast, flood translation is found to be within a reasonable value for some hydrographs with low uncertainty. This is obvious when tabulating the flow data for some events. As the wave travel time K can be easily estimated from the observed data as indicated in section 3.1 (page23). For example, a hydrograph with low uncertainty such as the one in Figure 4.6 for a flood occurred in September 1992 with a peak of 43.6023m^3/s, the travel time taken for the flood wave to propagate from Ferbane to Moystown is tabulated as 75 minutes. Whereas, in some hydrographs with high and moderate uncertainty, illustrated in Figures 4.4 and 4.5 for flood events reported in November 1990 and February 1991 and their peaks are limited within the same range, their travel time is found to be -15 and 0 minutes respectively, which indicate the high error found in the outflow data. Another example is shown in the two flood hydrographs for the events of November and March 1993 which are illustrated in Figures 4.13 and 4.14. In the first figure the time taken for a flood wave to travel from the upstream to downstream is one hour (K=60 minutes) and in the second hydrograph the travel time K is tabulated as 1.75 hour (105 minutes). These indicate reasonable values for a flood translation, as this value increases with the increase of peak flow. The flood event for December 1994 as shown in Figure 4.21 is an exception. Despite including a high degree of uncertainty, the flood wave takes 15.5 hours to travel downstream the river.

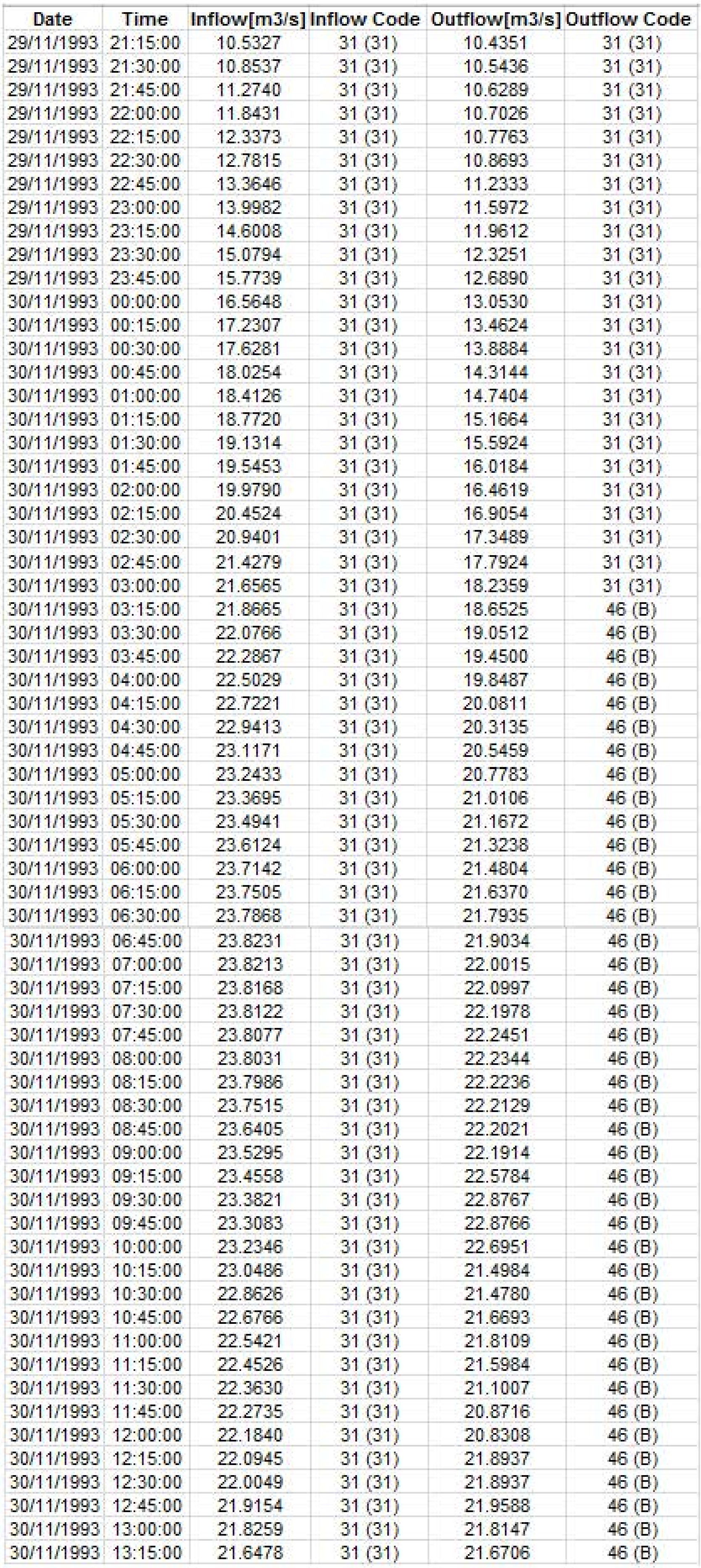
There are some cases where the shapes of the hydrographs fluctuate more. The inflow and outflow limbs rise and fall several times before they reach their peak values. This is clearly shown in Figures 4.16 and 4.20.

Most of the cases mentioned above differ from the ideal flood situation where the rising stage of the flood wave increases gradually until reaches its peak, and then the flood propagates downstream to reach its downstream peak at a later stage. Hence, the peak of the outflow lies outside the recession curve of the inflow hydrograph. The flood event of December 1994 which is illustrated in Figure 4.21 is a typical example of the ideal flood situation.

4.2 Application of the basic Muskingum method

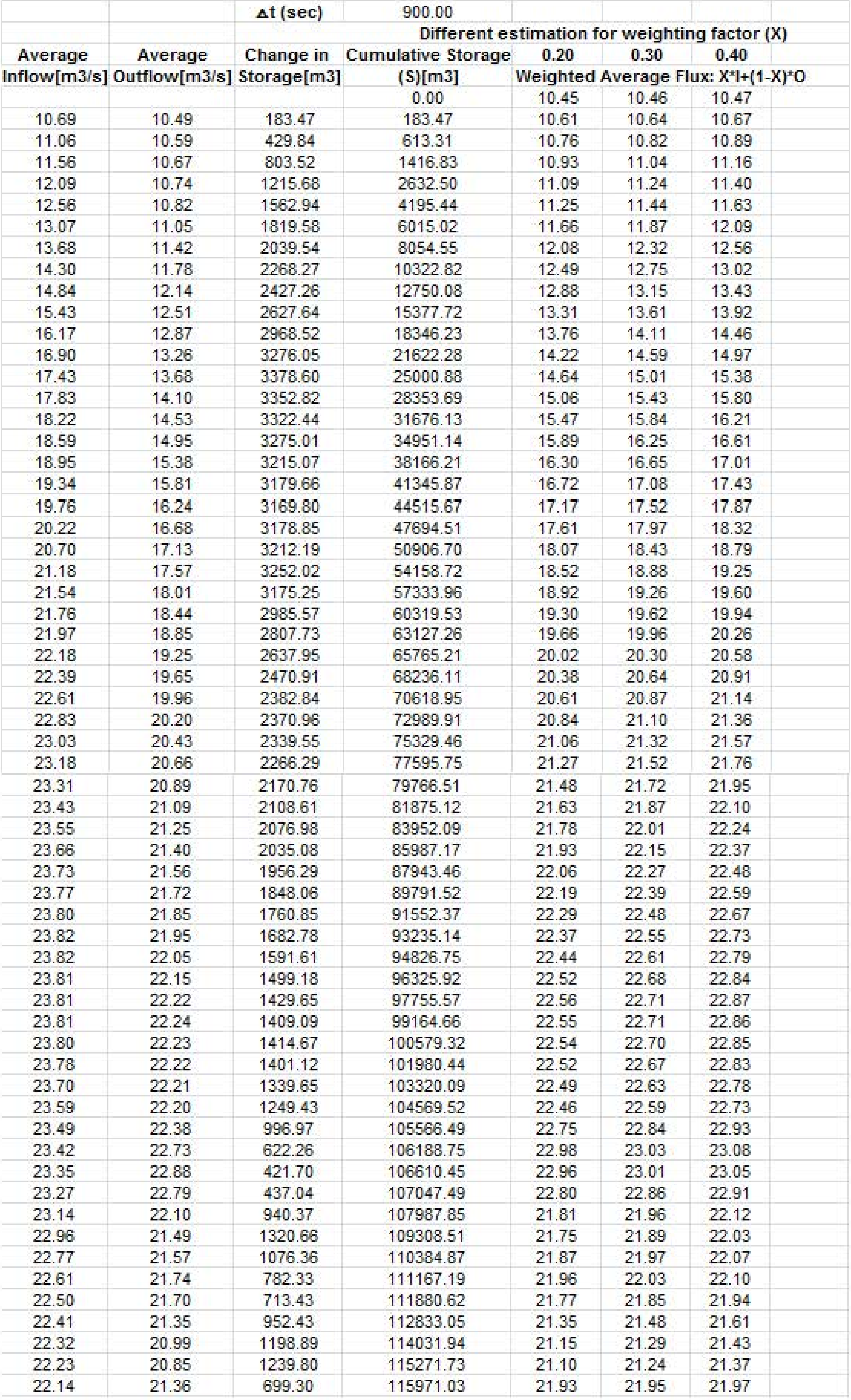
The assumption in the basic Muskingum method is that the initial storage in the system is zero. The available data for a series of flood events are inflow, outflow and a time increment Δt for every 15 minutes, or 900 seconds in the calculation. The first stage of the solution is to find the average inflow and outflow, starting from the second time step. Then to find the change in the reach storage (ΔS) which is the difference between the average inflow and outflow multiplied by the time increment Δt. Secondly, the cumulative volume of reach storage (S_{i+1}), where (i ranges from one to n) can be found by adding the storage at a previous time step (S_i) to the change in storage of the next time step (ΔS_{i+1}). Thirdly a value of X is chosen from 0.2 to 0.4 and the storage (S) is plotted against the weighted flux (X*I+ (1-X)*O). An Excel spread sheet was used to implement the numerical procedure. Table 4.4 shows a sample of the storage calculation with different values of X for a flood event which occurred in November 1993. The flood data for this event is first shown in Table 4.3. The two tables show the dates in the upper parts of the complete tables in the spread sheet.

Table 4.3 *illustrates some dates of the inflow and outflow for flood (29/11-2/12)1993.*

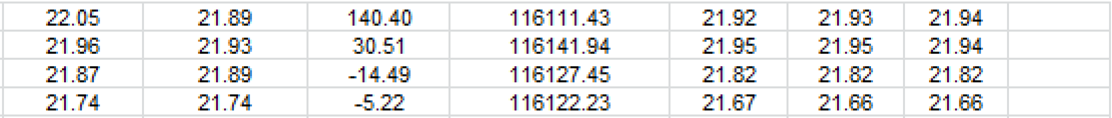


Date	Time	Inflow[m3/s]	Inflow Code	Outflow[m3/s]	Outflow Code
29/11/1993	21:15:00	10.5327	31 (31)	10.4351	31 (31)
29/11/1993	21:30:00	10.8537	31 (31)	10.5436	31 (31)
29/11/1993	21:45:00	11.2740	31 (31)	10.6289	31 (31)
29/11/1993	22:00:00	11.8431	31 (31)	10.7026	31 (31)
29/11/1993	22:15:00	12.3373	31 (31)	10.7763	31 (31)
29/11/1993	22:30:00	12.7815	31 (31)	10.8693	31 (31)
29/11/1993	22:45:00	13.3646	31 (31)	11.2333	31 (31)
29/11/1993	23:00:00	13.9982	31 (31)	11.5972	31 (31)
29/11/1993	23:15:00	14.6008	31 (31)	11.9612	31 (31)
29/11/1993	23:30:00	15.0794	31 (31)	12.3251	31 (31)
29/11/1993	23:45:00	15.7739	31 (31)	12.6890	31 (31)
30/11/1993	00:00:00	16.5648	31 (31)	13.0530	31 (31)
30/11/1993	00:15:00	17.2307	31 (31)	13.4624	31 (31)
30/11/1993	00:30:00	17.6281	31 (31)	13.8884	31 (31)
30/11/1993	00:45:00	18.0254	31 (31)	14.3144	31 (31)
30/11/1993	01:00:00	18.4126	31 (31)	14.7404	31 (31)
30/11/1993	01:15:00	18.7720	31 (31)	15.1664	31 (31)
30/11/1993	01:30:00	19.1314	31 (31)	15.5924	31 (31)
30/11/1993	01:45:00	19.5453	31 (31)	16.0184	31 (31)
30/11/1993	02:00:00	19.9790	31 (31)	16.4619	31 (31)
30/11/1993	02:15:00	20.4524	31 (31)	16.9054	31 (31)
30/11/1993	02:30:00	20.9401	31 (31)	17.3489	31 (31)
30/11/1993	02:45:00	21.4279	31 (31)	17.7924	31 (31)
30/11/1993	03:00:00	21.6565	31 (31)	18.2359	31 (31)
30/11/1993	03:15:00	21.8665	31 (31)	18.6525	46 (B)
30/11/1993	03:30:00	22.0766	31 (31)	19.0512	46 (B)
30/11/1993	03:45:00	22.2867	31 (31)	19.4500	46 (B)
30/11/1993	04:00:00	22.5029	31 (31)	19.8487	46 (B)
30/11/1993	04:15:00	22.7221	31 (31)	20.0811	46 (B)
30/11/1993	04:30:00	22.9413	31 (31)	20.3135	46 (B)
30/11/1993	04:45:00	23.1171	31 (31)	20.5459	46 (B)
30/11/1993	05:00:00	23.2433	31 (31)	20.7783	46 (B)
30/11/1993	05:15:00	23.3695	31 (31)	21.0106	46 (B)
30/11/1993	05:30:00	23.4941	31 (31)	21.1672	46 (B)
30/11/1993	05:45:00	23.6124	31 (31)	21.3238	46 (B)
30/11/1993	06:00:00	23.7142	31 (31)	21.4804	46 (B)
30/11/1993	06:15:00	23.7505	31 (31)	21.6370	46 (B)
30/11/1993	06:30:00	23.7868	31 (31)	21.7935	46 (B)
30/11/1993	06:45:00	23.8231	31 (31)	21.9034	46 (B)
30/11/1993	07:00:00	23.8213	31 (31)	22.0015	46 (B)
30/11/1993	07:15:00	23.8168	31 (31)	22.0997	46 (B)
30/11/1993	07:30:00	23.8122	31 (31)	22.1978	46 (B)
30/11/1993	07:45:00	23.8077	31 (31)	22.2451	46 (B)
30/11/1993	08:00:00	23.8031	31 (31)	22.2344	46 (B)
30/11/1993	08:15:00	23.7986	31 (31)	22.2236	46 (B)
30/11/1993	08:30:00	23.7515	31 (31)	22.2129	46 (B)
30/11/1993	08:45:00	23.6405	31 (31)	22.2021	46 (B)
30/11/1993	09:00:00	23.5295	31 (31)	22.1914	46 (B)
30/11/1993	09:15:00	23.4558	31 (31)	22.5784	46 (B)
30/11/1993	09:30:00	23.3821	31 (31)	22.8767	46 (B)
30/11/1993	09:45:00	23.3083	31 (31)	22.8766	46 (B)
30/11/1993	10:00:00	23.2346	31 (31)	22.6951	46 (B)
30/11/1993	10:15:00	23.0486	31 (31)	21.4984	46 (B)
30/11/1993	10:30:00	22.8626	31 (31)	21.4780	46 (B)
30/11/1993	10:45:00	22.6766	31 (31)	21.6693	46 (B)
30/11/1993	11:00:00	22.5421	31 (31)	21.8109	46 (B)
30/11/1993	11:15:00	22.4526	31 (31)	21.5984	46 (B)
30/11/1993	11:30:00	22.3630	31 (31)	21.1007	46 (B)
30/11/1993	11:45:00	22.2735	31 (31)	20.8716	46 (B)
30/11/1993	12:00:00	22.1840	31 (31)	20.8308	46 (B)
30/11/1993	12:15:00	22.0945	31 (31)	21.8937	46 (B)
30/11/1993	12:30:00	22.0049	31 (31)	21.8937	46 (B)
30/11/1993	12:45:00	21.9154	31 (31)	21.9588	46 (B)
30/11/1993	13:00:00	21.8259	31 (31)	21.8147	46 (B)
30/11/1993	13:15:00	21.6478	31 (31)	21.6706	46 (B)

Table 4.4 *Storage calculation using Muskingum method for flood event (29/11-2/12)93*



		Δt (sec)	900.00			
		Different estimation for weighting factor (X)				
Average	Average	Change in	Cumulative Storage	0.20	0.30	0.40
Inflow[m3/s]	Outflow[m3/s]	Storage[m3]	(S)[m3]	Weighted Average Flux: X*I+(1-X)*O		
			0.00	10.45	10.46	10.47
10.69	10.49	183.47	183.47	10.61	10.64	10.67
11.06	10.59	429.84	613.31	10.76	10.82	10.89
11.56	10.67	803.52	1416.83	10.93	11.04	11.16
12.09	10.74	1215.68	2632.50	11.09	11.24	11.40
12.56	10.82	1562.94	4195.44	11.25	11.44	11.63
13.07	11.05	1819.58	6015.02	11.66	11.87	12.09
13.68	11.42	2039.54	8054.55	12.08	12.32	12.56
14.30	11.78	2268.27	10322.82	12.49	12.75	13.02
14.84	12.14	2427.26	12750.08	12.88	13.15	13.43
15.43	12.51	2627.64	15377.72	13.31	13.61	13.92
16.17	12.87	2968.52	18346.23	13.76	14.11	14.46
16.90	13.26	3276.05	21622.28	14.22	14.59	14.97
17.43	13.68	3378.60	25000.88	14.64	15.01	15.38
17.83	14.10	3352.82	28353.69	15.06	15.43	15.80
18.22	14.53	3322.44	31676.13	15.47	15.84	16.21
18.59	14.95	3275.01	34951.14	15.89	16.25	16.61
18.95	15.38	3215.07	38166.21	16.30	16.65	17.01
19.34	15.81	3179.66	41345.87	16.72	17.08	17.43
19.76	16.24	3169.80	44515.67	17.17	17.52	17.87
20.22	16.68	3178.85	47694.51	17.61	17.97	18.32
20.70	17.13	3212.19	50906.70	18.07	18.43	18.79
21.18	17.57	3252.02	54158.72	18.52	18.88	19.25
21.54	18.01	3175.25	57333.96	18.92	19.26	19.60
21.76	18.44	2985.57	60319.53	19.30	19.62	19.94
21.97	18.85	2807.73	63127.26	19.66	19.96	20.26
22.18	19.25	2637.95	65765.21	20.02	20.30	20.58
22.39	19.65	2470.91	68236.11	20.38	20.64	20.91
22.61	19.96	2382.84	70618.95	20.61	20.87	21.14
22.83	20.20	2370.96	72989.91	20.84	21.10	21.36
23.03	20.43	2339.55	75329.46	21.06	21.32	21.57
23.18	20.66	2266.29	77595.75	21.27	21.52	21.76
23.31	20.89	2170.76	79766.51	21.48	21.72	21.95
23.43	21.09	2108.61	81875.12	21.63	21.87	22.10
23.55	21.25	2076.98	83952.09	21.78	22.01	22.24
23.66	21.40	2035.08	85987.17	21.93	22.15	22.37
23.73	21.56	1956.29	87943.46	22.06	22.27	22.48
23.77	21.72	1848.06	89791.52	22.19	22.39	22.59
23.80	21.85	1760.85	91552.37	22.29	22.48	22.67
23.82	21.95	1682.78	93235.14	22.37	22.55	22.73
23.82	22.05	1591.61	94826.75	22.44	22.61	22.79
23.81	22.15	1499.18	96325.92	22.52	22.68	22.84
23.81	22.22	1429.65	97755.57	22.56	22.71	22.87
23.81	22.24	1409.09	99164.66	22.55	22.71	22.86
23.80	22.23	1414.67	100579.32	22.54	22.70	22.85
23.78	22.22	1401.12	101980.44	22.52	22.67	22.83
23.70	22.21	1339.65	103320.09	22.49	22.63	22.78
23.59	22.20	1249.43	104569.52	22.46	22.59	22.73
23.49	22.38	996.97	105566.49	22.75	22.84	22.93
23.42	22.73	622.26	106188.75	22.98	23.03	23.08
23.35	22.88	421.70	106610.45	22.96	23.01	23.05
23.27	22.79	437.04	107047.49	22.80	22.86	22.91
23.14	22.10	940.37	107987.85	21.81	21.96	22.12
22.96	21.49	1320.66	109308.51	21.75	21.89	22.03
22.77	21.57	1076.36	110384.87	21.87	21.97	22.07
22.61	21.74	782.33	111167.19	21.96	22.03	22.10
22.50	21.70	713.43	111880.62	21.77	21.85	21.94
22.41	21.35	952.43	112833.05	21.35	21.48	21.61
22.32	20.99	1198.89	114031.94	21.15	21.29	21.43
22.23	20.85	1239.80	115271.73	21.10	21.24	21.37
22.14	21.36	699.30	115971.03	21.93	21.95	21.97



22.05	21.89	140.40	116111.43	21.92	21.93	21.94	
21.96	21.93	30.51	116141.94	21.95	21.95	21.94	
21.87	21.89	-14.49	116127.45	21.82	21.82	21.82	
21.74	21.74	-5.22	116122.23	21.67	21.66	21.66	

From Table 4.4 above, the last two negative values for the change in storage indicate that the outflow exceeded inflow. This occurred when the water leave storage after reach its peak. As indicated in Section 3.1, (page 20), a negative wedge storage is produced when the water level recedes in the channel during the falling limb of the hydrograph. These negative values are increasing in the lower part of the complete table. The numerical procedure which is shown here in Table 4.4 for this flood event was repeated for another flood event occurred in December1994 with the same range of X value, this flood event and its storage calculation are both illustrated in Tables 4.5 and 4.6 in Appendix B. Also the same procedure repeated for the rest of the flood events using only one value for the parameter X (0.2). Some of the results of these calculations are presented in the form of storage loops in Chapter Five together with an overall commentary of the results.

4.3 Application of the Muskingum-Cunge method

4.3.1 Reach Characteristics

The Brosna river reach between Ferbane and Moystown has been selected for modelling as already discussed. Data for the reach was collected from the Mullingar maintenance office-OPW and are illustrated in Table 4.7 as follows:

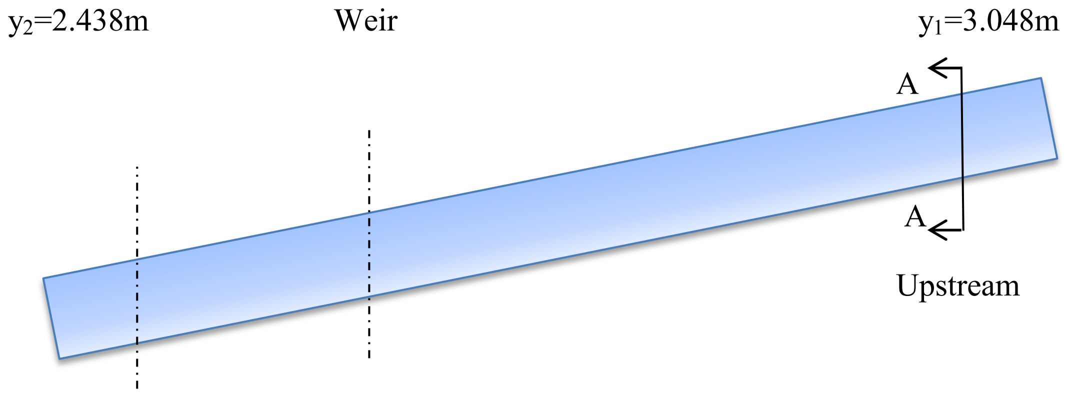
Table 4.7 *River Brosna reach characteristics.*

Length (L) m	**Bed width(b)m**	**Side slope(z)**	**Water depth(y)m**	**Average Bed slope (S_0)**
8000	22.86	1.25	3.048 (upstream)	0.00047
			2.4384 (downstream)	

The river reach is approximately 8km long and a sharp crested weir is located 3.93km from the upstream section of the river. The channel bed is lined with mostly gravel and large boulders. Hence, the roughness coefficient (n) is estimated from Table 2.2 in Appendix A to be 0.04.

The Brosna River has a trapezoidal cross-section with no recent floodplain (Cassidy, 2011). Due to the weir transition downstream the river, a cross-section which is located at the upstream end is only considered in modelling.

Figure 4.22 illustrates both the lateral profile and the cross-section for the river reach.



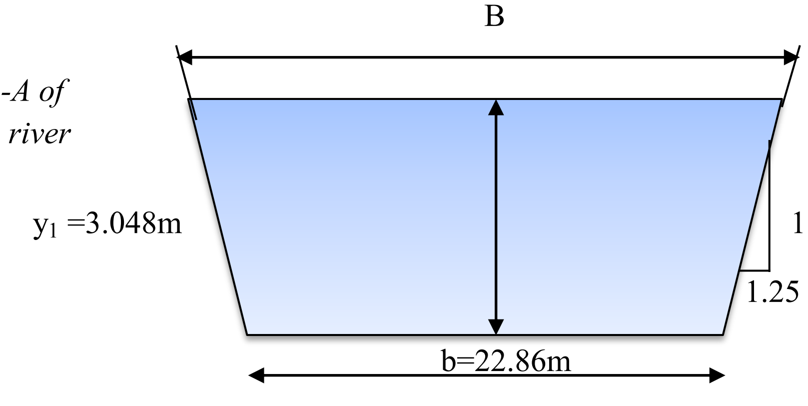


Figure 4.22 *Section A-A of the upstream end of the river reach.*

The nature of the flow in the river Brosna is non-uniform, gradually varied unsteady flow.

To determine the regime of flow upstream of the channel, Equation 2.13 in Section 2.3.4 (page13) is used to calculate the Froude Number as:

$$Fr = \frac{V}{\sqrt{gy_1}}$$

Where, V is the average velocity in (m/s) which can be defined from Equation 2.2 in Section 2.3.1 (page10), y_1 is depth of flow upstream in m and $g = 9.81 m/s^2$.

In channel routing where a non-uniform flow is the case, the average velocity can be determined using a reference discharge and the channel cross-sectional area in the relationship:

$$V = \frac{Q_0}{(b+zy_0)y_0} \quad \text{(Subramanya, 2008).}$$

To determine the normal depth y_0, a reference discharge is selected for a maximum flood event which occurred in January 1992 and can be calculated from Equation 3.32 in Section 3.2.4 (page32).

The minimum discharge is selected from the inflow hydrograph in Table 4.8 (page 60) as:

$Q_b = 16.3508 m^3/s$

And the peak discharge was

$Q_p = 90.9154 m^3/s$

From Equation 3.32 the reference discharge was calculated as:

$Q_0 = 53.6331 m^3/s$

With the known values of reference discharge (Q_0), Manning roughness coefficient (n), Channel bed width and bottom slope, the value of Φ can be determined from Equation 2.7 as

$$\emptyset = \frac{53.6331 \times 0.04}{22.86^{\frac{8}{3}} \times 0.00047^{0.5}} = 0.0235$$

Upon consulting Table 2.1 in Appendix A with the above value and with z=1.25 (see Figure 4.22 on page 56), the value for $\frac{y_0}{b} \approx 0.08$, hence, y_0 =1.83m.

The area of flow can then be obtained from Equation 2.6 in Section 2.3.1 (page11).

A= (22.86+1.25*1.83)*1.83= 46.02m^2

Hence, $V = \frac{53.6331}{46.02} = 1.165\ m/s$

Therefore, Fr = 0.21 < 1

This indicates that the channel has a mild slope and the flow is characterised as gradually varied subcritical flow.

The wave celerity (c) can be obtained from the relationship c=β*V as mentioned previously in Section 2.3.4 (page15).

For Natural channels, β is selected from Table 2.3 to be 1.5

Therefore, c=1.5*1.165= 1.748m/s

The mean surface width of the channel (B) =22.86+2*1.25*1.83 = 27.44m (see Figure 4.22 on page 56).

The normal depth, the average velocity and wave celerity are recalculated for two selected events, November 1993 and December 1994 based on the reference discharge for each event. The results of these calculations are shown in Table 4.13a (page 67).

4.3.2 Calibration of the Muskingum-Cunge parameters

Three flood events for January1992, November1993 and December1994 have been selected for calibration and different time increments Δt are tried. The reason for choosing the event of January 1992 is to correct the outflow hydrograph shape which is clearly not accurate as shown in Figure 4.18 (page 49). The flood event of November 1993 is considered to include reliable flow data compared to other hydrographs, while the flood event of December 1994 has been selected as it has a good hydrograph shape. The constant coefficient Muskingum-Cunge method is used where the routing parameters K and X are estimated from the reach characteristics and the flood hydrograph.

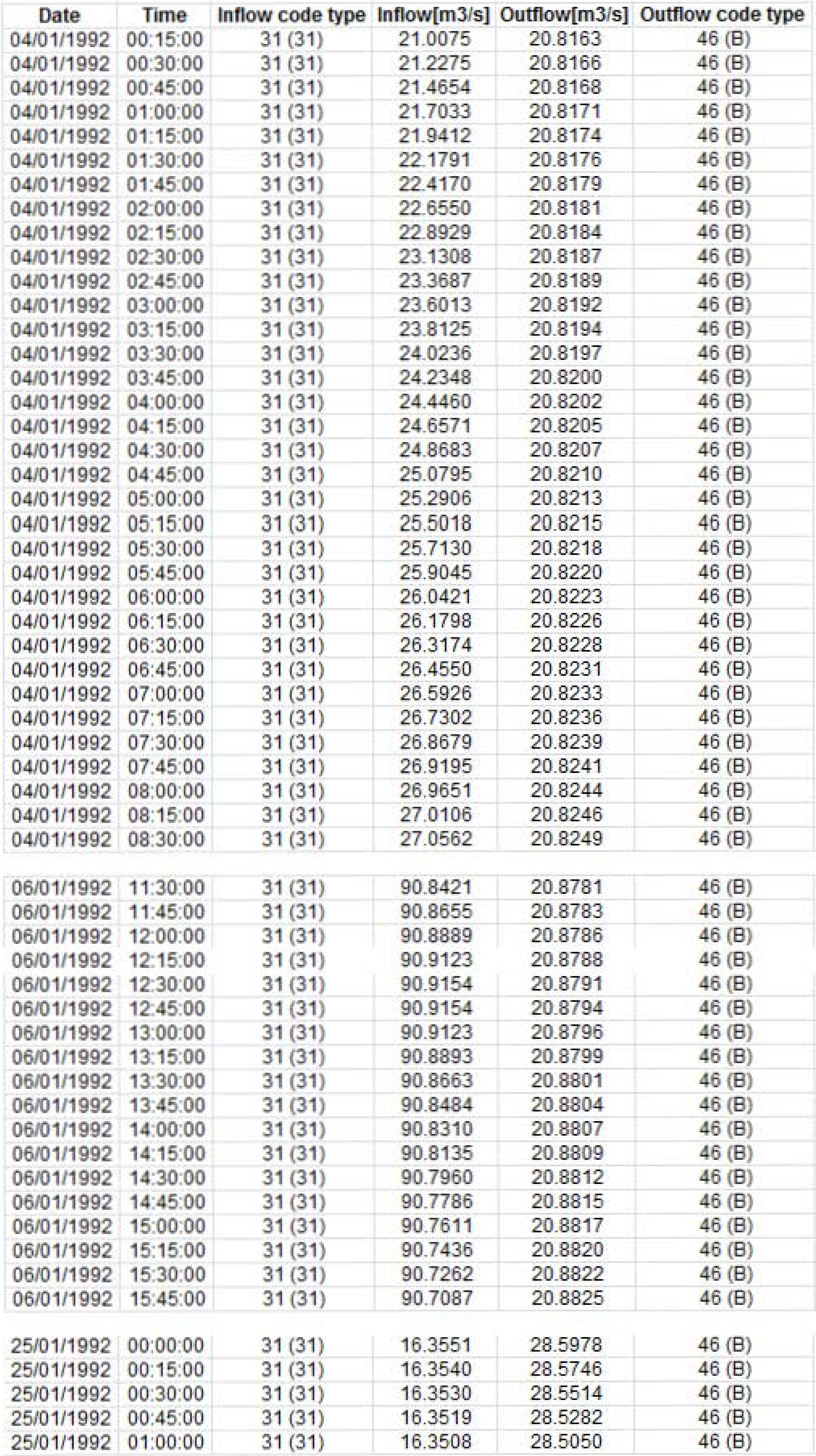
4.3.2.1 Flood event – 4th of January 1992

Some of the flood data for event (4/1 – 25/1)1992 is shown in Table 4.8 on page 60.

By tabulating the inflow data for the selected period, the time taken to peak is 60.5 hours. As discussed in Section 3.1 (page23) the time increment Δt is defined by the relationship: $\Delta t < \frac{60.5}{5}$.

Hence, $\Delta t \ < 12.1\ hours.$

Table 4.8 *Some dates of flood event (4/1 – 25/1)1992*



Date	Time	Inflow code type	Inflow[m3/s]	Outflow[m3/s]	Outflow code type
04/01/1992	00:15:00	31 (31)	21.0075	20.8163	46 (B)
04/01/1992	00:30:00	31 (31)	21.2275	20.8166	46 (B)
04/01/1992	00:45:00	31 (31)	21.4654	20.8168	46 (B)
04/01/1992	01:00:00	31 (31)	21.7033	20.8171	46 (B)
04/01/1992	01:15:00	31 (31)	21.9412	20.8174	46 (B)
04/01/1992	01:30:00	31 (31)	22.1791	20.8176	46 (B)
04/01/1992	01:45:00	31 (31)	22.4170	20.8179	46 (B)
04/01/1992	02:00:00	31 (31)	22.6550	20.8181	46 (B)
04/01/1992	02:15:00	31 (31)	22.8929	20.8184	46 (B)
04/01/1992	02:30:00	31 (31)	23.1308	20.8187	46 (B)
04/01/1992	02:45:00	31 (31)	23.3687	20.8189	46 (B)
04/01/1992	03:00:00	31 (31)	23.6013	20.8192	46 (B)
04/01/1992	03:15:00	31 (31)	23.8125	20.8194	46 (B)
04/01/1992	03:30:00	31 (31)	24.0236	20.8197	46 (B)
04/01/1992	03:45:00	31 (31)	24.2348	20.8200	46 (B)
04/01/1992	04:00:00	31 (31)	24.4460	20.8202	46 (B)
04/01/1992	04:15:00	31 (31)	24.6571	20.8205	46 (B)
04/01/1992	04:30:00	31 (31)	24.8683	20.8207	46 (B)
04/01/1992	04:45:00	31 (31)	25.0795	20.8210	46 (B)
04/01/1992	05:00:00	31 (31)	25.2906	20.8213	46 (B)
04/01/1992	05:15:00	31 (31)	25.5018	20.8215	46 (B)
04/01/1992	05:30:00	31 (31)	25.7130	20.8218	46 (B)
04/01/1992	05:45:00	31 (31)	25.9045	20.8220	46 (B)
04/01/1992	06:00:00	31 (31)	26.0421	20.8223	46 (B)
04/01/1992	06:15:00	31 (31)	26.1798	20.8226	46 (B)
04/01/1992	06:30:00	31 (31)	26.3174	20.8228	46 (B)
04/01/1992	06:45:00	31 (31)	26.4550	20.8231	46 (B)
04/01/1992	07:00:00	31 (31)	26.5926	20.8233	46 (B)
04/01/1992	07:15:00	31 (31)	26.7302	20.8236	46 (B)
04/01/1992	07:30:00	31 (31)	26.8679	20.8239	46 (B)
04/01/1992	07:45:00	31 (31)	26.9195	20.8241	46 (B)
04/01/1992	08:00:00	31 (31)	26.9651	20.8244	46 (B)
04/01/1992	08:15:00	31 (31)	27.0106	20.8246	46 (B)
04/01/1992	08:30:00	31 (31)	27.0562	20.8249	46 (B)
06/01/1992	11:30:00	31 (31)	90.8421	20.8781	46 (B)
06/01/1992	11:45:00	31 (31)	90.8655	20.8783	46 (B)
06/01/1992	12:00:00	31 (31)	90.8889	20.8786	46 (B)
06/01/1992	12:15:00	31 (31)	90.9123	20.8788	46 (B)
06/01/1992	12:30:00	31 (31)	90.9154	20.8791	46 (B)
06/01/1992	12:45:00	31 (31)	90.9154	20.8794	46 (B)
06/01/1992	13:00:00	31 (31)	90.9123	20.8796	46 (B)
06/01/1992	13:15:00	31 (31)	90.8893	20.8799	46 (B)
06/01/1992	13:30:00	31 (31)	90.8663	20.8801	46 (B)
06/01/1992	13:45:00	31 (31)	90.8484	20.8804	46 (B)
06/01/1992	14:00:00	31 (31)	90.8310	20.8807	46 (B)
06/01/1992	14:15:00	31 (31)	90.8135	20.8809	46 (B)
06/01/1992	14:30:00	31 (31)	90.7960	20.8812	46 (B)
06/01/1992	14:45:00	31 (31)	90.7786	20.8815	46 (B)
06/01/1992	15:00:00	31 (31)	90.7611	20.8817	46 (B)
06/01/1992	15:15:00	31 (31)	90.7436	20.8820	46 (B)
06/01/1992	15:30:00	31 (31)	90.7262	20.8822	46 (B)
06/01/1992	15:45:00	31 (31)	90.7087	20.8825	46 (B)
25/01/1992	00:00:00	31 (31)	16.3551	28.5978	46 (B)
25/01/1992	00:15:00	31 (31)	16.3540	28.5746	46 (B)
25/01/1992	00:30:00	31 (31)	16.3530	28.5514	46 (B)
25/01/1992	00:45:00	31 (31)	16.3519	28.5282	46 (B)
25/01/1992	01:00:00	31 (31)	16.3508	28.5050	46 (B)

- ***First implementation***

A minimum time increment Δt is selected to be 0.25 hours

The reference discharge as calculated in page 57 is given by:

$Q_0 = 53.6331 m^3/s$

The routing reach length Δx therefore, is determined from Equation3.18 on page 28 as

$$\Delta x \leq \frac{1}{2}\left(1.748 \times 0.25 \times 60 \times 60 + \frac{53.6331}{27.44 \times 0.00047 \times 1.748}\right)$$

Hence, $\Delta x \leq 1976.1$m which is less than 2/3 the reach length L (8000m) as indicated in Section 3.2.3 (page 28), therefore the reach is divided into eight sub-reaches.

So, Δx is selected to be1000m.

Then the value of Δx is substituted in Equation 3.31 in Section 3.2.4 (page32) to estimate the Muskingum-Cunge weighting parameter X as:

$$X = \frac{1}{2}\left(1 - \frac{53.6331}{27.44 \times 0.00047 \times 1.748 \times 1000}\right)$$

So, $X = -0.69$

The travel time for a flood wave is estimated from Equation 3.33 (page 33) as:

K= $1000/1.748$

Hence, K= 572.1 sec.

So the time taken by a flood wave to travel downstream is (572.1/3600) = 0.16 hours.

By substituting the known values for X, K and Δt in Equations 3.41, 3.42 and 3.43 on page 34, the coefficients of the Muskingum–Cunge method can now be determined as:

$$C_0 = \frac{\frac{0.25}{0.16} - 2 \times -0.69}{\frac{0.25}{0.16} + 2 \times 1.69} = 0.595$$

$$C_1 = \frac{\frac{0.25}{0.16} + 2 \times -0.69}{\frac{0.25}{0.16} + 2 \times 1.69} = 0.037$$

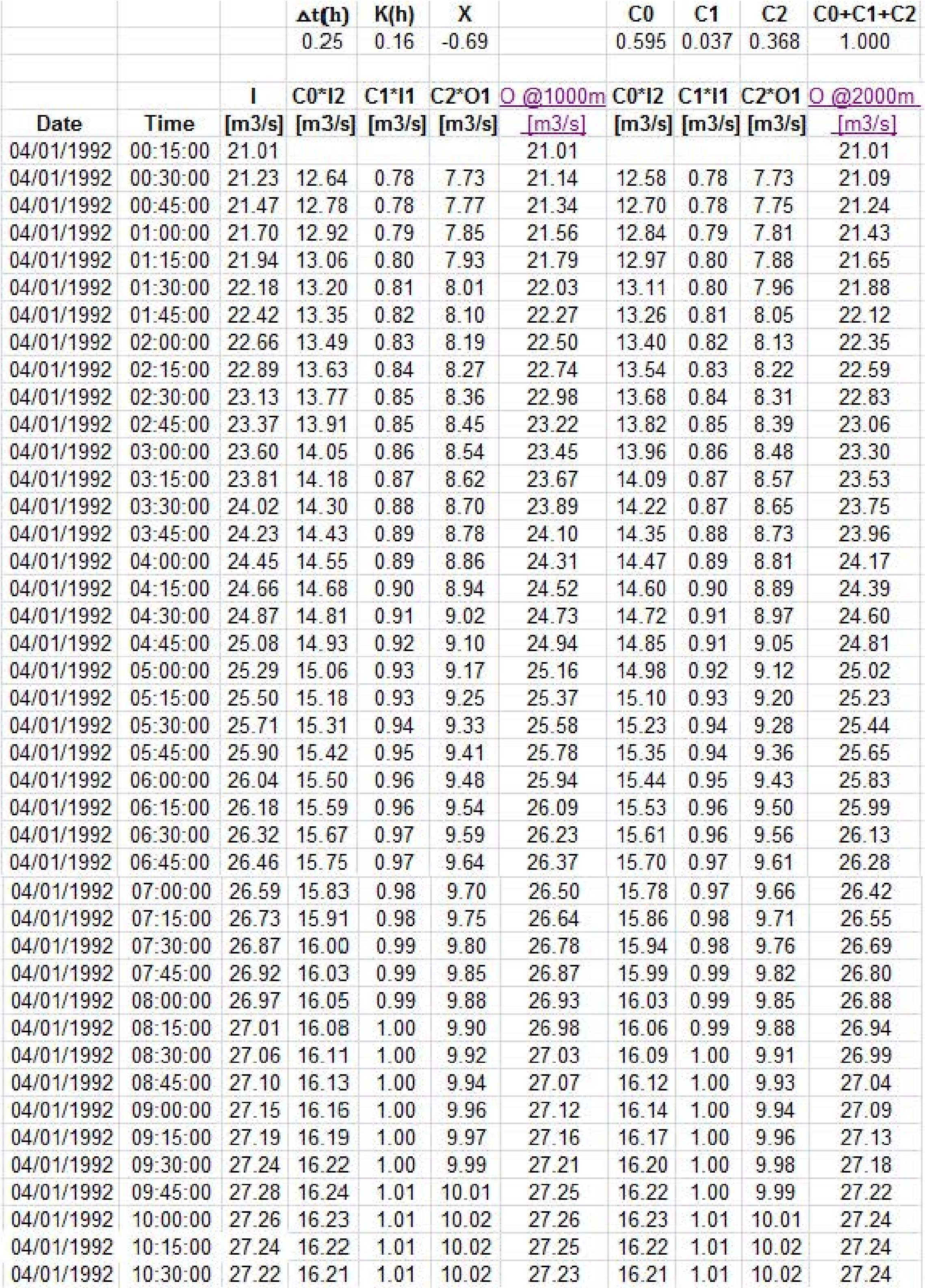
$$C_2 = \frac{2 \times 1.69 - \frac{0.25}{0.16}}{\frac{0.25}{0.16} + 2 \times 1.69} = 0.368$$

0.595+0.037+0.368 =1

The check ($C_0 + C_1 + C_2 = 1$) is verified.

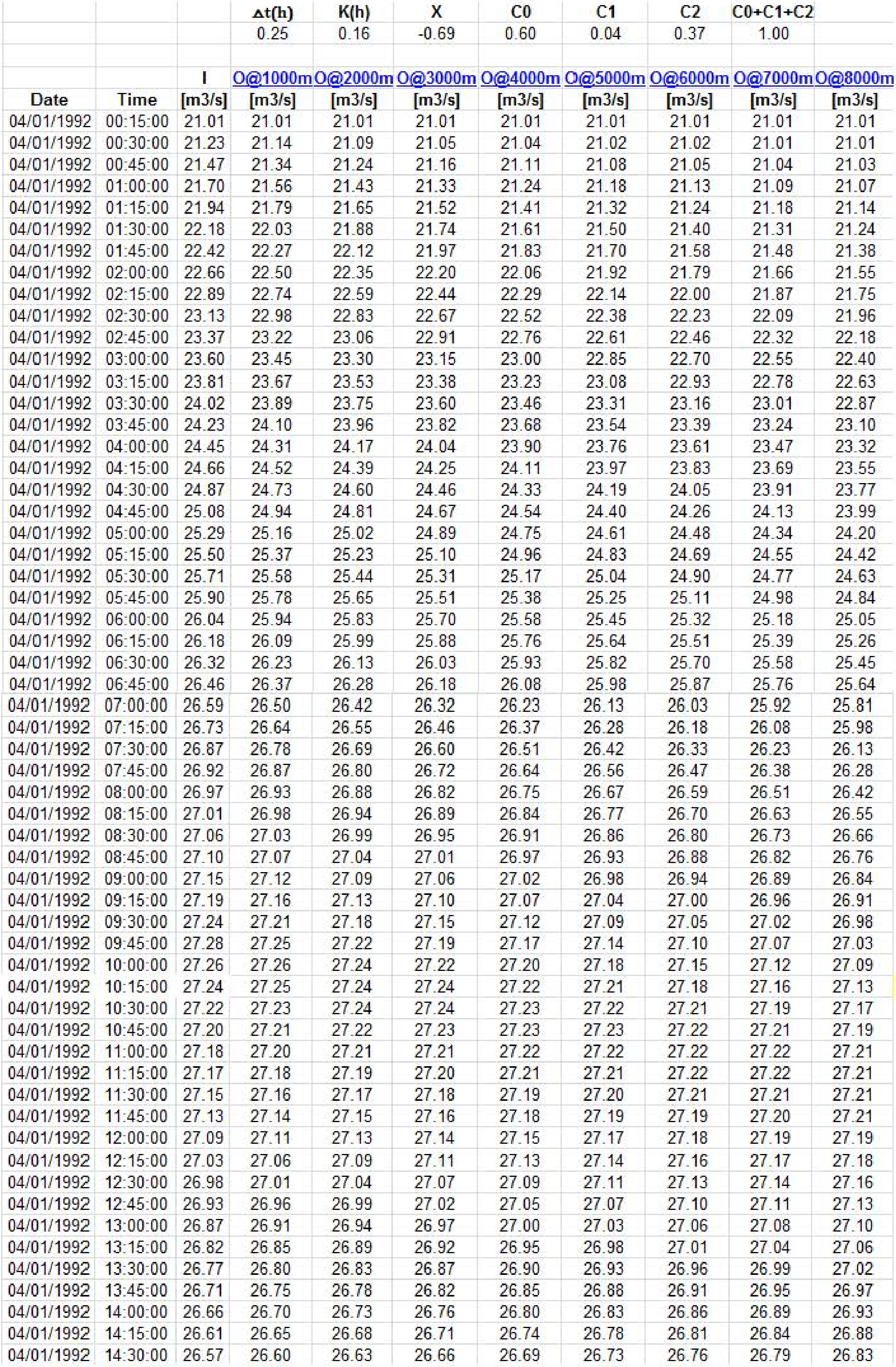
Hence, the outflow now can be computed using the Muskingum-Cunge routing equation, Equation 3.24 in Section 3.2.4 (page 31) with an Excel program for a 0.25 hour time increment. Some of the results of routing calculation are illustrated in Table 4.9 on page63. The procedure performed in Table 4.9 is repeated for every1000m and the resulting calculation is shown in Table 4.10 on page64.

Table 4.9 *Some of the results of the constant coefficient Muskingum-Cunge calculation for the outflow at 1000m and 2000m for flood event (4/1 - 25/1)1992, Δt=0.25h.*



			Δt(h)	K(h)	X		C0	C1	C2	C0+C1+C2
			0.25	0.16	-0.69		0.595	0.037	0.368	1.000
		I	C0*I2	C1*I1	C2*O1	O @1000m	C0*I2	C1*I1	C2*O1	O @2000m
Date	Time	[m3/s]	[m3/s]	[m3/s]	[m3/s]	[m3/s]	[m3/s]	[m3/s]	[m3/s]	[m3/s]
04/01/1992	00:15:00	21.01				21.01				21.01
04/01/1992	00:30:00	21.23	12.64	0.78	7.73	21.14	12.58	0.78	7.73	21.09
04/01/1992	00:45:00	21.47	12.78	0.78	7.77	21.34	12.70	0.78	7.75	21.24
04/01/1992	01:00:00	21.70	12.92	0.79	7.85	21.56	12.84	0.79	7.81	21.43
04/01/1992	01:15:00	21.94	13.06	0.80	7.93	21.79	12.97	0.80	7.88	21.65
04/01/1992	01:30:00	22.18	13.20	0.81	8.01	22.03	13.11	0.80	7.96	21.88
04/01/1992	01:45:00	22.42	13.35	0.82	8.10	22.27	13.26	0.81	8.05	22.12
04/01/1992	02:00:00	22.66	13.49	0.83	8.19	22.50	13.40	0.82	8.13	22.35
04/01/1992	02:15:00	22.89	13.63	0.84	8.27	22.74	13.54	0.83	8.22	22.59
04/01/1992	02:30:00	23.13	13.77	0.85	8.36	22.98	13.68	0.84	8.31	22.83
04/01/1992	02:45:00	23.37	13.91	0.85	8.45	23.22	13.82	0.85	8.39	23.06
04/01/1992	03:00:00	23.60	14.05	0.86	8.54	23.45	13.96	0.86	8.48	23.30
04/01/1992	03:15:00	23.81	14.18	0.87	8.62	23.67	14.09	0.87	8.57	23.53
04/01/1992	03:30:00	24.02	14.30	0.88	8.70	23.89	14.22	0.87	8.65	23.75
04/01/1992	03:45:00	24.23	14.43	0.89	8.78	24.10	14.35	0.88	8.73	23.96
04/01/1992	04:00:00	24.45	14.55	0.89	8.86	24.31	14.47	0.89	8.81	24.17
04/01/1992	04:15:00	24.66	14.68	0.90	8.94	24.52	14.60	0.90	8.89	24.39
04/01/1992	04:30:00	24.87	14.81	0.91	9.02	24.73	14.72	0.91	8.97	24.60
04/01/1992	04:45:00	25.08	14.93	0.92	9.10	24.94	14.85	0.91	9.05	24.81
04/01/1992	05:00:00	25.29	15.06	0.93	9.17	25.16	14.98	0.92	9.12	25.02
04/01/1992	05:15:00	25.50	15.18	0.93	9.25	25.37	15.10	0.93	9.20	25.23
04/01/1992	05:30:00	25.71	15.31	0.94	9.33	25.58	15.23	0.94	9.28	25.44
04/01/1992	05:45:00	25.90	15.42	0.95	9.41	25.78	15.35	0.94	9.36	25.65
04/01/1992	06:00:00	26.04	15.50	0.96	9.48	25.94	15.44	0.95	9.43	25.83
04/01/1992	06:15:00	26.18	15.59	0.96	9.54	26.09	15.53	0.96	9.50	25.99
04/01/1992	06:30:00	26.32	15.67	0.97	9.59	26.23	15.61	0.96	9.56	26.13
04/01/1992	06:45:00	26.46	15.75	0.97	9.64	26.37	15.70	0.97	9.61	26.28
04/01/1992	07:00:00	26.59	15.83	0.98	9.70	26.50	15.78	0.97	9.66	26.42
04/01/1992	07:15:00	26.73	15.91	0.98	9.75	26.64	15.86	0.98	9.71	26.55
04/01/1992	07:30:00	26.87	16.00	0.99	9.80	26.78	15.94	0.98	9.76	26.69
04/01/1992	07:45:00	26.92	16.03	0.99	9.85	26.87	15.99	0.99	9.82	26.80
04/01/1992	08:00:00	26.97	16.05	0.99	9.88	26.93	16.03	0.99	9.85	26.88
04/01/1992	08:15:00	27.01	16.08	1.00	9.90	26.98	16.06	0.99	9.88	26.94
04/01/1992	08:30:00	27.06	16.11	1.00	9.92	27.03	16.09	1.00	9.91	26.99
04/01/1992	08:45:00	27.10	16.13	1.00	9.94	27.07	16.12	1.00	9.93	27.04
04/01/1992	09:00:00	27.15	16.16	1.00	9.96	27.12	16.14	1.00	9.94	27.09
04/01/1992	09:15:00	27.19	16.19	1.00	9.97	27.16	16.17	1.00	9.96	27.13
04/01/1992	09:30:00	27.24	16.22	1.00	9.99	27.21	16.20	1.00	9.98	27.18
04/01/1992	09:45:00	27.28	16.24	1.01	10.01	27.25	16.22	1.00	9.99	27.22
04/01/1992	10:00:00	27.26	16.23	1.01	10.02	27.26	16.23	1.01	10.01	27.24
04/01/1992	10:15:00	27.24	16.22	1.01	10.02	27.25	16.22	1.01	10.02	27.24
04/01/1992	10:30:00	27.22	16.21	1.01	10.02	27.23	16.21	1.01	10.02	27.24

Table 4.10 *Some of the results of the constant coefficient Muskingum-Cunge outflows for flood event (4/1-25/1)1992 with*$\Delta x = 1000m$ *and* Δt*=0.25h.*



			Δt(h)	K(h)	X	C0	C1	C2	C0+C1+C2	
			0.25	0.16	-0.69	0.60	0.04	0.37	1.00	
		I	O@1000m	O@2000m	O@3000m	O@4000m	O@5000m	O@6000m	O@7000m	O@8000m
Date	Time	[m3/s]	[m3/s]	[m3/s]	[m3/s]	[m3/s]	[m3/s]	[m3/s]	[m3/s]	[m3/s]
04/01/1992	00:15:00	21.01	21.01	21.01	21.01	21.01	21.01	21.01	21.01	21.01
04/01/1992	00:30:00	21.23	21.14	21.09	21.05	21.04	21.02	21.02	21.01	21.01
04/01/1992	00:45:00	21.47	21.34	21.24	21.16	21.11	21.08	21.05	21.04	21.03
04/01/1992	01:00:00	21.70	21.56	21.43	21.33	21.24	21.18	21.13	21.09	21.07
04/01/1992	01:15:00	21.94	21.79	21.65	21.52	21.41	21.32	21.24	21.18	21.14
04/01/1992	01:30:00	22.18	22.03	21.88	21.74	21.61	21.50	21.40	21.31	21.24
04/01/1992	01:45:00	22.42	22.27	22.12	21.97	21.83	21.70	21.58	21.48	21.38
04/01/1992	02:00:00	22.66	22.50	22.35	22.20	22.06	21.92	21.79	21.66	21.55
04/01/1992	02:15:00	22.89	22.74	22.59	22.44	22.29	22.14	22.00	21.87	21.75
04/01/1992	02:30:00	23.13	22.98	22.83	22.67	22.52	22.38	22.23	22.09	21.96
04/01/1992	02:45:00	23.37	23.22	23.06	22.91	22.76	22.61	22.46	22.32	22.18
04/01/1992	03:00:00	23.60	23.45	23.30	23.15	23.00	22.85	22.70	22.55	22.40
04/01/1992	03:15:00	23.81	23.67	23.53	23.38	23.23	23.08	22.93	22.78	22.63
04/01/1992	03:30:00	24.02	23.89	23.75	23.60	23.46	23.31	23.16	23.01	22.87
04/01/1992	03:45:00	24.23	24.10	23.96	23.82	23.68	23.54	23.39	23.24	23.10
04/01/1992	04:00:00	24.45	24.31	24.17	24.04	23.90	23.76	23.61	23.47	23.32
04/01/1992	04:15:00	24.66	24.52	24.39	24.25	24.11	23.97	23.83	23.69	23.55
04/01/1992	04:30:00	24.87	24.73	24.60	24.46	24.33	24.19	24.05	23.91	23.77
04/01/1992	04:45:00	25.08	24.94	24.81	24.67	24.54	24.40	24.26	24.13	23.99
04/01/1992	05:00:00	25.29	25.16	25.02	24.89	24.75	24.61	24.48	24.34	24.20
04/01/1992	05:15:00	25.50	25.37	25.23	25.10	24.96	24.83	24.69	24.55	24.42
04/01/1992	05:30:00	25.71	25.58	25.44	25.31	25.17	25.04	24.90	24.77	24.63
04/01/1992	05:45:00	25.90	25.78	25.65	25.51	25.38	25.25	25.11	24.98	24.84
04/01/1992	06:00:00	26.04	25.94	25.83	25.70	25.58	25.45	25.32	25.18	25.05
04/01/1992	06:15:00	26.18	26.09	25.99	25.88	25.76	25.64	25.51	25.39	25.26
04/01/1992	06:30:00	26.32	26.23	26.13	26.03	25.93	25.82	25.70	25.58	25.45
04/01/1992	06:45:00	26.46	26.37	26.28	26.18	26.08	25.98	25.87	25.76	25.64
04/01/1992	07:00:00	26.59	26.50	26.42	26.32	26.23	26.13	26.03	25.92	25.81
04/01/1992	07:15:00	26.73	26.64	26.55	26.46	26.37	26.28	26.18	26.08	25.98
04/01/1992	07:30:00	26.87	26.78	26.69	26.60	26.51	26.42	26.33	26.23	26.13
04/01/1992	07:45:00	26.92	26.87	26.80	26.72	26.64	26.56	26.47	26.38	26.28
04/01/1992	08:00:00	26.97	26.93	26.88	26.82	26.75	26.67	26.59	26.51	26.42
04/01/1992	08:15:00	27.01	26.98	26.94	26.89	26.84	26.77	26.70	26.63	26.55
04/01/1992	08:30:00	27.06	27.03	26.99	26.95	26.91	26.86	26.80	26.73	26.66
04/01/1992	08:45:00	27.10	27.07	27.04	27.01	26.97	26.93	26.88	26.82	26.76
04/01/1992	09:00:00	27.15	27.12	27.09	27.06	27.02	26.98	26.94	26.89	26.84
04/01/1992	09:15:00	27.19	27.16	27.13	27.10	27.07	27.04	27.00	26.96	26.91
04/01/1992	09:30:00	27.24	27.21	27.18	27.15	27.12	27.09	27.05	27.02	26.98
04/01/1992	09:45:00	27.28	27.25	27.22	27.19	27.17	27.14	27.10	27.07	27.03
04/01/1992	10:00:00	27.26	27.26	27.24	27.22	27.20	27.18	27.15	27.12	27.09
04/01/1992	10:15:00	27.24	27.25	27.24	27.24	27.22	27.21	27.18	27.16	27.13
04/01/1992	10:30:00	27.22	27.23	27.24	27.24	27.23	27.22	27.21	27.19	27.17
04/01/1992	10:45:00	27.20	27.21	27.22	27.23	27.23	27.23	27.22	27.21	27.19
04/01/1992	11:00:00	27.18	27.20	27.21	27.21	27.22	27.22	27.22	27.22	27.21
04/01/1992	11:15:00	27.17	27.18	27.19	27.20	27.21	27.21	27.22	27.22	27.21
04/01/1992	11:30:00	27.15	27.16	27.17	27.18	27.19	27.20	27.21	27.21	27.21
04/01/1992	11:45:00	27.13	27.14	27.15	27.16	27.18	27.19	27.19	27.20	27.21
04/01/1992	12:00:00	27.09	27.11	27.13	27.14	27.15	27.17	27.18	27.19	27.19
04/01/1992	12:15:00	27.03	27.06	27.09	27.11	27.13	27.14	27.16	27.17	27.18
04/01/1992	12:30:00	26.98	27.01	27.04	27.07	27.09	27.11	27.13	27.14	27.16
04/01/1992	12:45:00	26.93	26.96	26.99	27.02	27.05	27.07	27.10	27.11	27.13
04/01/1992	13:00:00	26.87	26.91	26.94	26.97	27.00	27.03	27.06	27.08	27.10
04/01/1992	13:15:00	26.82	26.85	26.89	26.92	26.95	26.98	27.01	27.04	27.06
04/01/1992	13:30:00	26.77	26.80	26.83	26.87	26.90	26.93	26.96	26.99	27.02
04/01/1992	13:45:00	26.71	26.75	26.78	26.82	26.85	26.88	26.91	26.95	26.97
04/01/1992	14:00:00	26.66	26.70	26.73	26.76	26.80	26.83	26.86	26.89	26.93
04/01/1992	14:15:00	26.61	26.65	26.68	26.71	26.74	26.78	26.81	26.84	26.88
04/01/1992	14:30:00	26.57	26.60	26.63	26.66	26.69	26.73	26.76	26.79	26.83

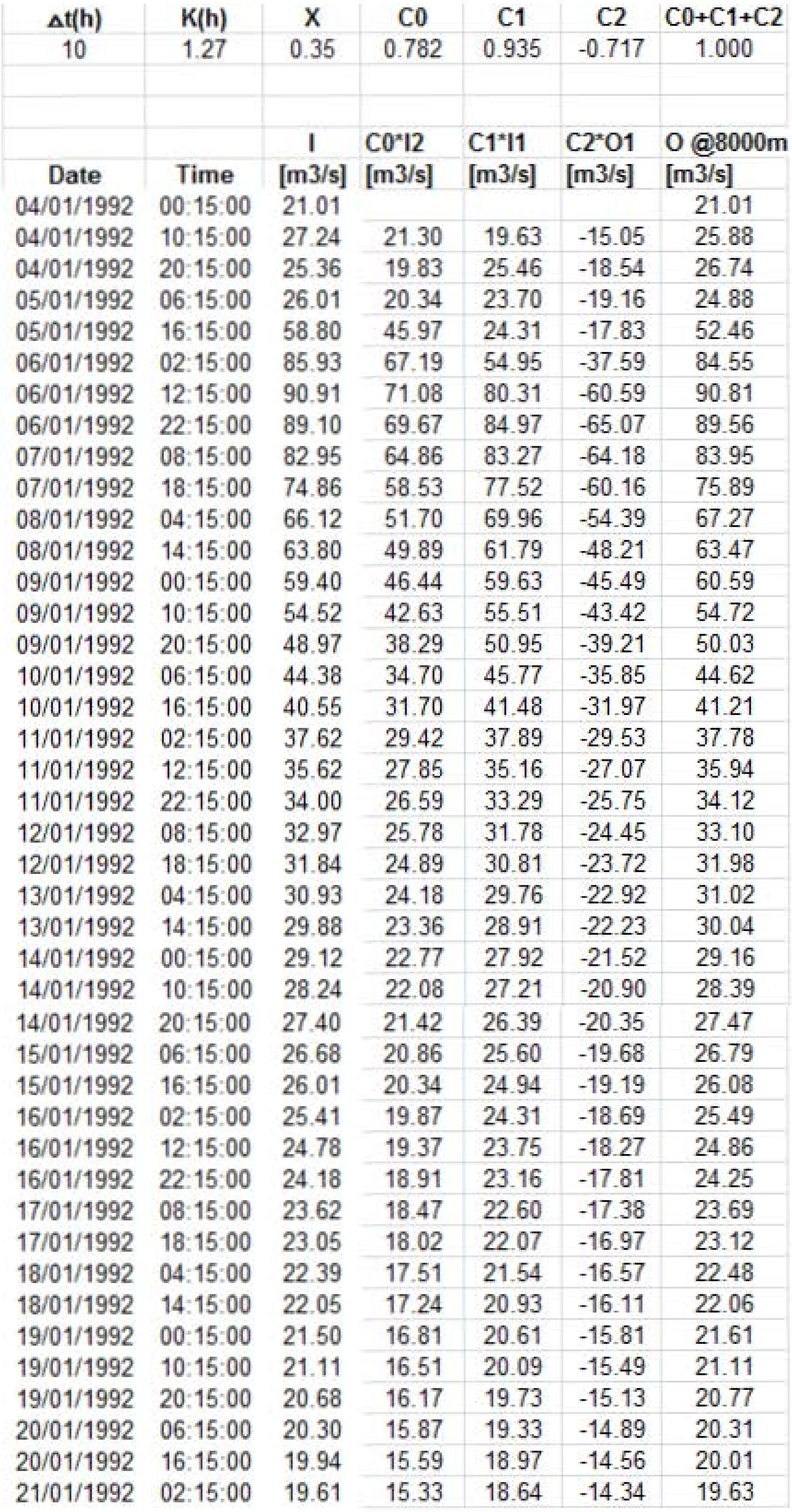
- ***Second Implementation***

In the second implementation a bigger value for the time increment was chosen, which was less than 12.1 hours, so Δt was chosen to be 10 hours. The same calculation is performed to derive Δx and the routing coefficients. The routing distance Δx is calculated to be$\leq 31{,}464m$, where this value is greater than 2/3 of reach length. The value of Δx therefore is chosen to equal the reach length which is 8000m. Therefore, X is calculated using Equation 3.31 to be 0.35 and K is calculated using Equation 3.33 as 1.27 hours. Hence, the routing coefficients are calculated using Equations 3.41, 3.42 and 3.43 (page 34) to be $C_0 = 0.782$, $C_1 = 0.935$ and $C_2 = -0.717$

$0.782 + 0.935 - 0.717 = 1$ Which satisfy the criterion ($C_0 + C_1 + C_2 = 1$).

The value of Δt is checked again using Figure 3.5 (page 29) so that $\frac{\Delta x}{c\Delta t} < 0.9$ which gives $\Delta t > 1.41$ hour. This indicates that the value used for Δt satisfies the check. By using the Excel program, the routing calculation is performed in 10 hour time step as illustrated in Table 4.11 as follows:

Table 4.11 *Some of the results of the routing calculation using the constant coefficient Muskingum-Cunge method for the flood event (4/1 – 25/1)1992, Δt=10h.*



Δt(h)	K(h)	X	C0	C1	C2	C0+C1+C2
10	1.27	0.35	0.782	0.935	-0.717	1.000
		I	C0*I2	C1*I1	C2*O1	O @8000m
Date	Time	[m3/s]	[m3/s]	[m3/s]	[m3/s]	[m3/s]
04/01/1992	00:15:00	21.01				21.01
04/01/1992	10:15:00	27.24	21.30	19.63	-15.05	25.88
04/01/1992	20:15:00	25.36	19.83	25.46	-18.54	26.74
05/01/1992	06:15:00	26.01	20.34	23.70	-19.16	24.88
05/01/1992	16:15:00	58.80	45.97	24.31	-17.83	52.46
06/01/1992	02:15:00	85.93	67.19	54.95	-37.59	84.55
06/01/1992	12:15:00	90.91	71.08	80.31	-60.59	90.81
06/01/1992	22:15:00	89.10	69.67	84.97	-65.07	89.56
07/01/1992	08:15:00	82.95	64.86	83.27	-64.18	83.95
07/01/1992	18:15:00	74.86	58.53	77.52	-60.16	75.89
08/01/1992	04:15:00	66.12	51.70	69.96	-54.39	67.27
08/01/1992	14:15:00	63.80	49.89	61.79	-48.21	63.47
09/01/1992	00:15:00	59.40	46.44	59.63	-45.49	60.59
09/01/1992	10:15:00	54.52	42.63	55.51	-43.42	54.72
09/01/1992	20:15:00	48.97	38.29	50.95	-39.21	50.03
10/01/1992	06:15:00	44.38	34.70	45.77	-35.85	44.62
10/01/1992	16:15:00	40.55	31.70	41.48	-31.97	41.21
11/01/1992	02:15:00	37.62	29.42	37.89	-29.53	37.78
11/01/1992	12:15:00	35.62	27.85	35.16	-27.07	35.94
11/01/1992	22:15:00	34.00	26.59	33.29	-25.75	34.12
12/01/1992	08:15:00	32.97	25.78	31.78	-24.45	33.10
12/01/1992	18:15:00	31.84	24.89	30.81	-23.72	31.98
13/01/1992	04:15:00	30.93	24.18	29.76	-22.92	31.02
13/01/1992	14:15:00	29.88	23.36	28.91	-22.23	30.04
14/01/1992	00:15:00	29.12	22.77	27.92	-21.52	29.16
14/01/1992	10:15:00	28.24	22.08	27.21	-20.90	28.39
14/01/1992	20:15:00	27.40	21.42	26.39	-20.35	27.47
15/01/1992	06:15:00	26.68	20.86	25.60	-19.68	26.79
15/01/1992	16:15:00	26.01	20.34	24.94	-19.19	26.08
16/01/1992	02:15:00	25.41	19.87	24.31	-18.69	25.49
16/01/1992	12:15:00	24.78	19.37	23.75	-18.27	24.86
16/01/1992	22:15:00	24.18	18.91	23.16	-17.81	24.25
17/01/1992	08:15:00	23.62	18.47	22.60	-17.38	23.69
17/01/1992	18:15:00	23.05	18.02	22.07	-16.97	23.12
18/01/1992	04:15:00	22.39	17.51	21.54	-16.57	22.48
18/01/1992	14:15:00	22.05	17.24	20.93	-16.11	22.06
19/01/1992	00:15:00	21.50	16.81	20.61	-15.81	21.61
19/01/1992	10:15:00	21.11	16.51	20.09	-15.49	21.11
19/01/1992	20:15:00	20.68	16.17	19.73	-15.13	20.77
20/01/1992	06:15:00	20.30	15.87	19.33	-14.89	20.31
20/01/1992	16:15:00	19.94	15.59	18.97	-14.56	20.01
21/01/1992	02:15:00	19.61	15.33	18.64	-14.34	19.63

The same calculations steps performed for the flood event 4th of January 1992 are also applied to the two flood events which occurred on the 29th of November 1993 and the 4th of December 1994. The resulting calculations of the reference discharge, top width, cross-sectional area, the average velocity and wave celerity are summarised in Table 4.13, and the resulting routing calculations are summarized in Table 4.13a as follow:

Table 4.12 *Hydraulic parameters of the cross-sectional area for the three events.*

Flood event	Q_0 (m^3/s)	B (m)	A (m^2)	$V_{average}$(m/s)	c (m/s)
Jan-1992	53.6331	27.44	46.02	1.165	1.748
Nov-1993	17.1779	25.145	24.027	0.783	1.175
Dec-1994	44.2947	27.148	50.235	1.033	1.549

Table 4.13a *Summary of the routing calculations for the three flood events using different values of* Δt.

Flood Event	Time to peak(h)	Q_0(m^3/s)	Δt (h)	Δx(m)	X	K(h)	C_0	C_1	C_2
Jan-1992	60.5	53.6331	0.25 10	1000 8000	-0.69 0.35	0.16 1.27	0.595 0.782	0.037 0.935	0.368 -0.717
Nov-1993	9.5	17.1779	0.25 1.5	1000 2000	-0.12 0.29	0.24 0.71	0.391 0.434	0.244 0.762	0.365 -0.196
Dec-1994	87.25	44.2947	0.25 16	1000 8000	-0.62 0.36	0.18 1.43	0.569 0.840	0.034 0.955	0.398 -0.795

Table 4.13b *Suggested criterion by Wilson and Viessman for different values of* Δt.

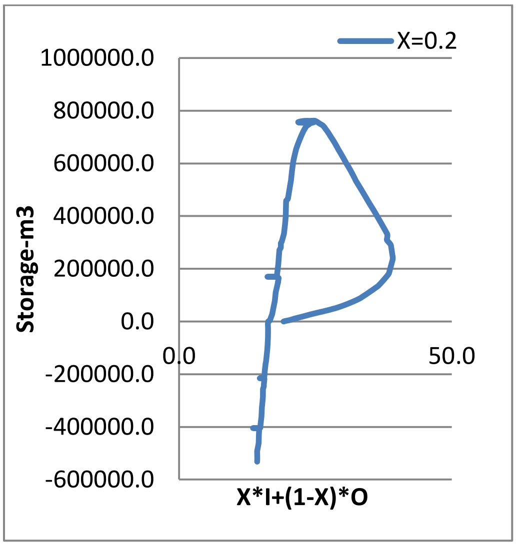
Flood Event	X	K	Δt (h)	$2KX \leq \Delta t \leq 2K(1-X)$
Jan-1992	-0.69	0.16	0.25	$-0.22 < 0.25 < 0.54$
	0.35	1.27	10	$0.89 < 10 < 1.65$
Nov-1993	-0.12	0.24	0.25	$-0.06 < 0.25 < 0.54$
	0.29	0.71	1.5	$0.41 < 1.5 < 1$
Dec-1994	-0.62	0.18	0.25	$-0.22 < 0.25 < 0.58$
	0.36	1.43	16	$1.03 < 16 < 1.83$

The results of using both the Muskingum and the Muskingum-Cunge methods for the series of flood events will be presented and discussed in the next chapter.

5 Presentation and Discussion of Results

5.1 Results of the basic Muskingum method application

By applying the storage calculation on a number of flood events that have been previously analysed in chapter 4, the resulting graphs for the storage loops are illustrated in the figures which follow:



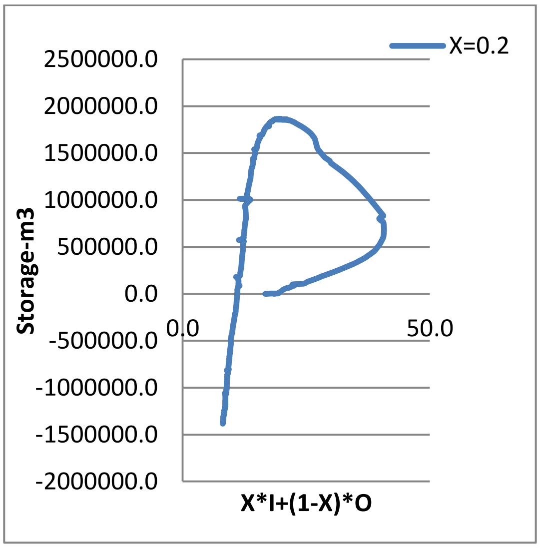
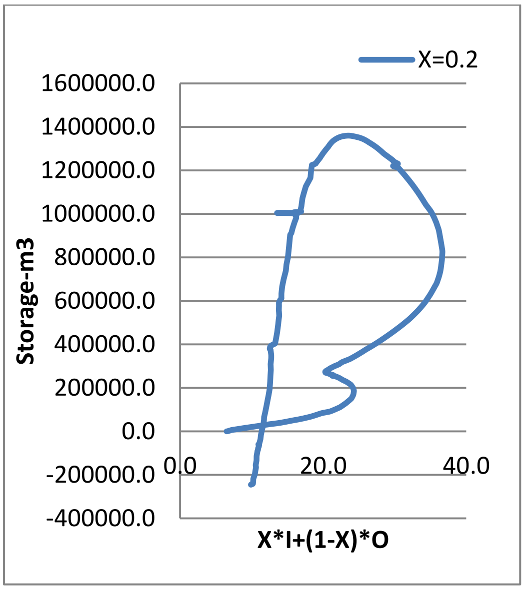


Figure 5.1 *Event (23/11- 6/12)1990*

Moderate Uncertainty

Figure 5.2 *Event (6/10 - 7/11)1993*

Low Uncertainty



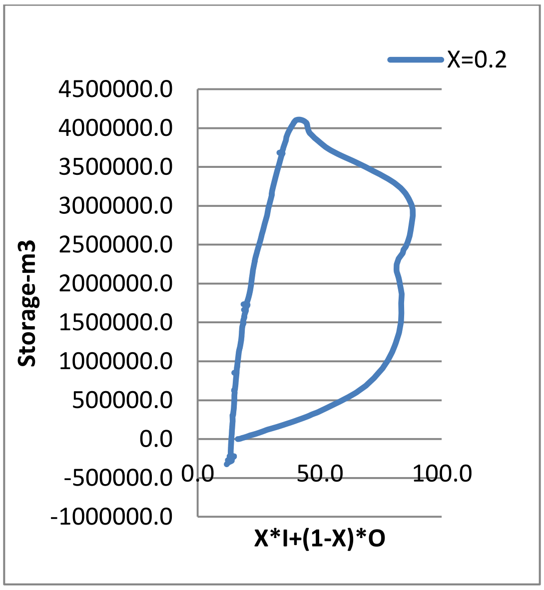


Figure 5.3 *Event (11/9 – 22/9)1992*

Low Uncertainty

Figure 5.4 *Event (11/6 – 10/7)1993*

High Uncertainty

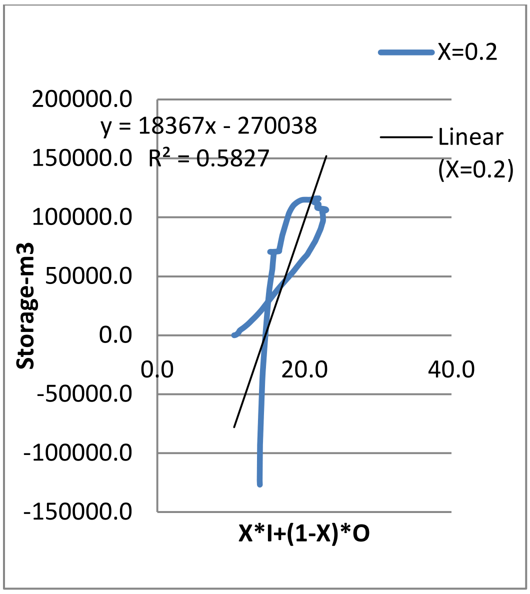


Figure 5.5a *Event (29/11 – 2/12)1993*

Low Uncertainty

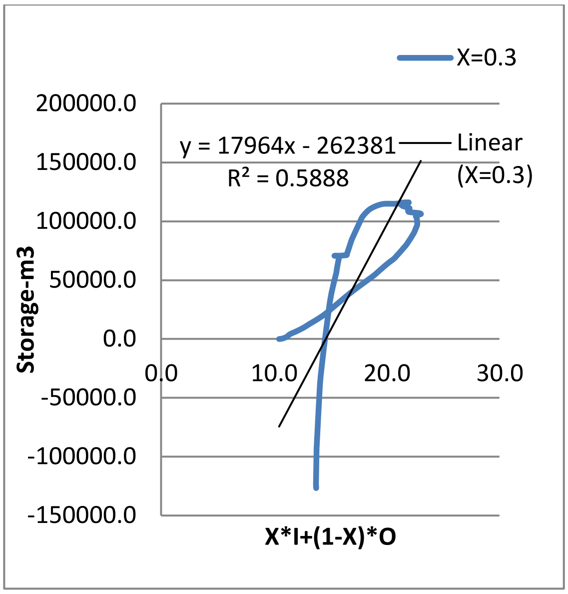


Figure 5.5b *Event (29/11 – 2/12)1993*

Low Uncertainty

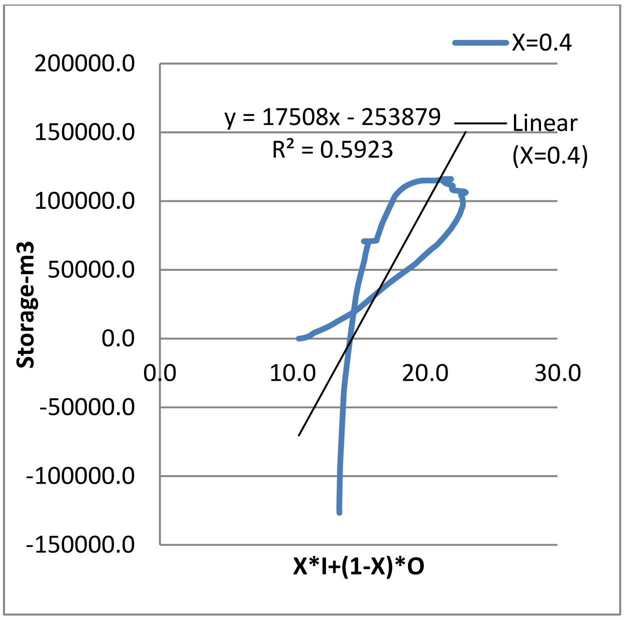


Figure 5.5c *Event (29/11- 2/12)1993*

Low Uncertainty

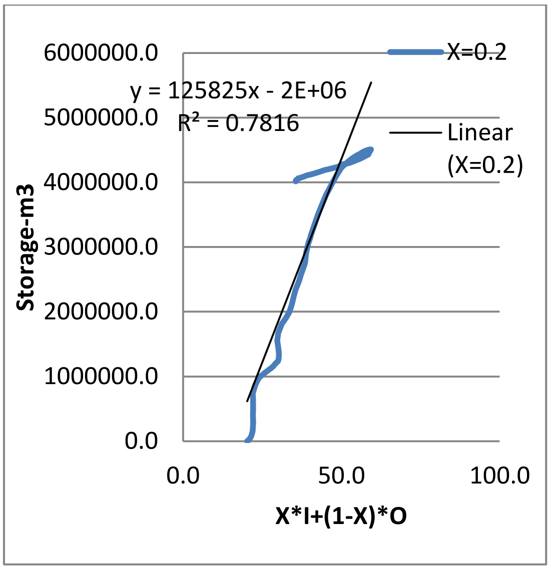


Figure 5.6a *Event (4/12 - 11/12)1994*

High Uncertainty

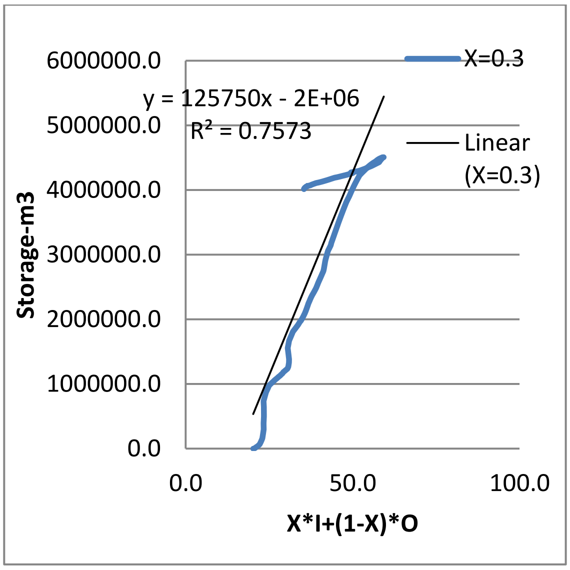


Figure 5.6b *Event (4/12 – 11/12)1994*

High Uncertainty

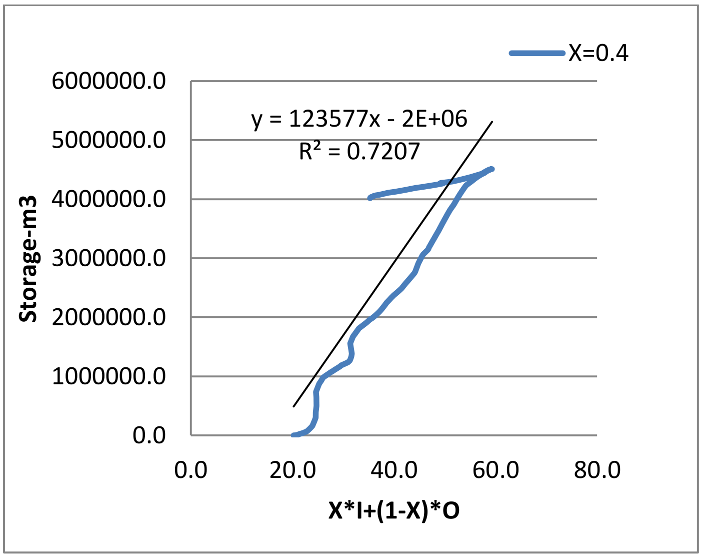
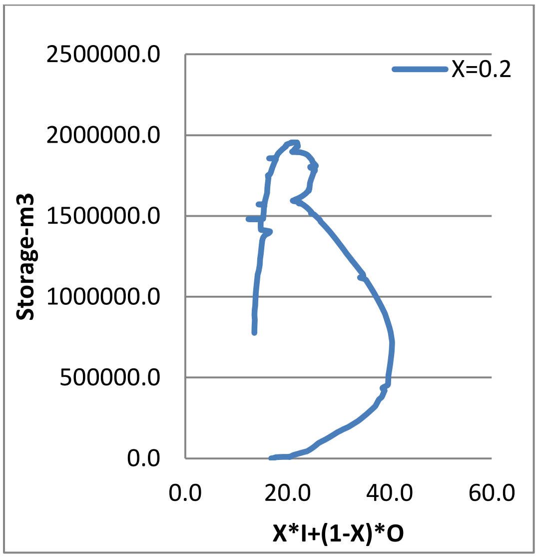


Figure 5.6c *Event (4/12 – 11/12)1994*

High Uncertainty



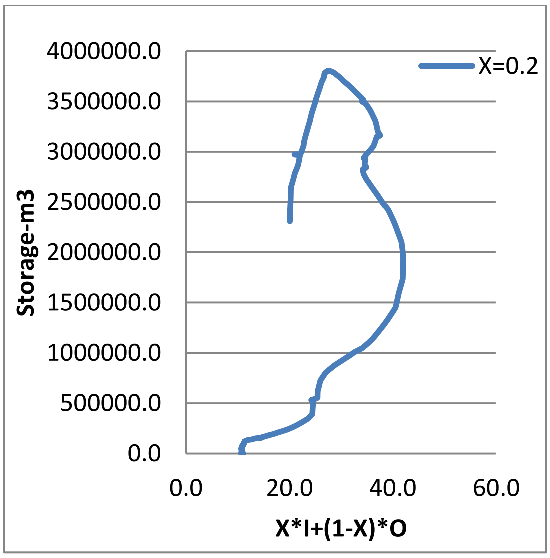
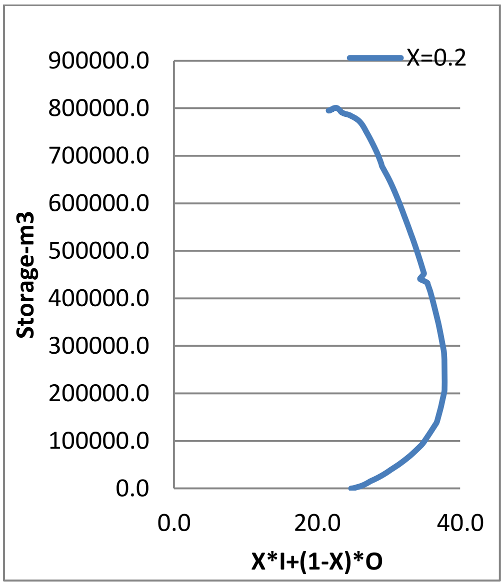


Figure 5.7 *Event (26/5 – 10/6)1993*

High Uncertainty

Figure 5.8 *Event (14/12/1991-2/1/1992)*

High Uncertainty



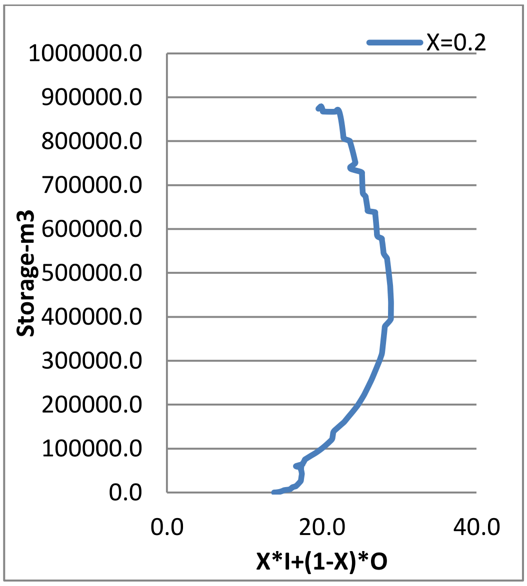


Figure 5.9 *Event (4/2 – 10/2)1991*

High Uncertainty

Figure 5.10 *Event (12/11 – 16/11)1994*

High Uncertainty

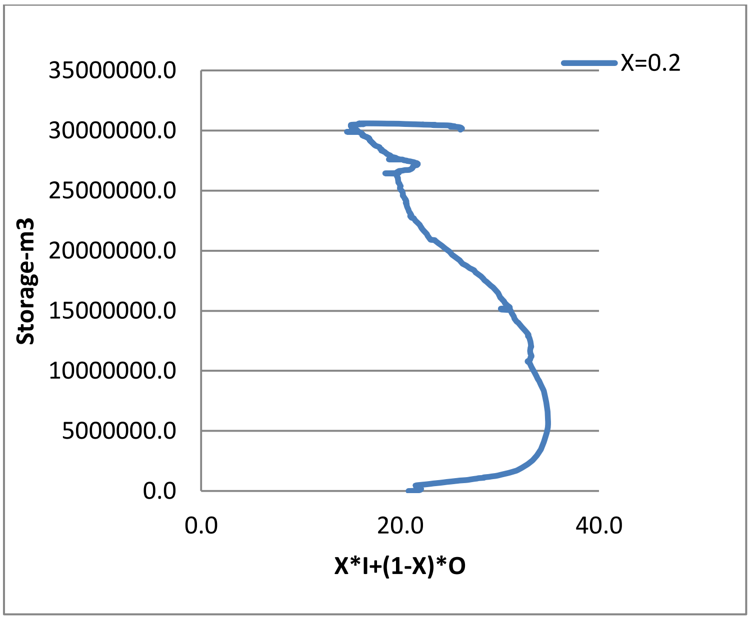


Figure 5.11 *Event (4/1 – 25/1)1992*

High Uncertainty

In the figures above a value of X=0.2 is tried for all the flood events and three values for X (0.2, 0.3 and 0.4) are tried for two flood events in November1993 and December 1994. The resulting graphs show that no storage loop is approaching a straight line shape, however, the graphs for the events of November1993 and December1994 in Figures 5.5 and 5.6 look far better compared to other graphs. Table 5.1 illustrates the values for the parameters X and K which are calibrated from the two flood events.

Table 5.1 *Values of the estimated parameters using the basic Muskingum method for events of November1993 and December1994.*

Date of flood	Figure	X	K (h)
29/11/1993	5.5a 5.5b 5.5c	0.2 0.3 0.4	5.1 5 4.9
4/12/1994	5.6a 5.6b 5.6c	0.2 0.3 0.4	34.96 34.93 34.33

5.2 Results of Muskingum-Cunge application

By applying the constant coefficient Muskingum-Cunge method on the three events for January1992, November1993 and December1994, the resulting graphs are illustrated in the figures which follow:

5.2.1 Flood Event of January 1992

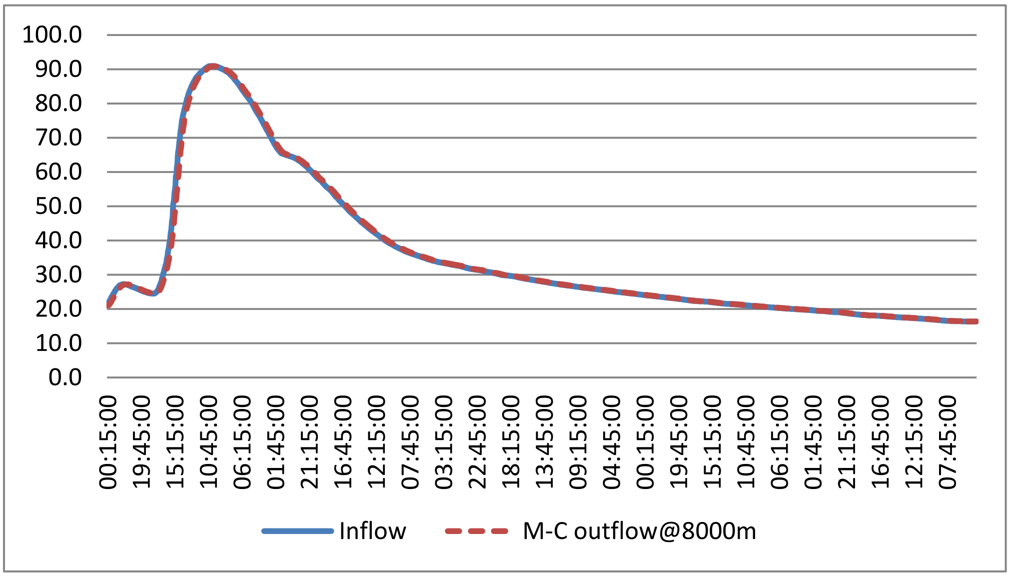


Figure 5.12 *Event (4/1 – 25/1)1992,* $\Delta t = 0.25h$.

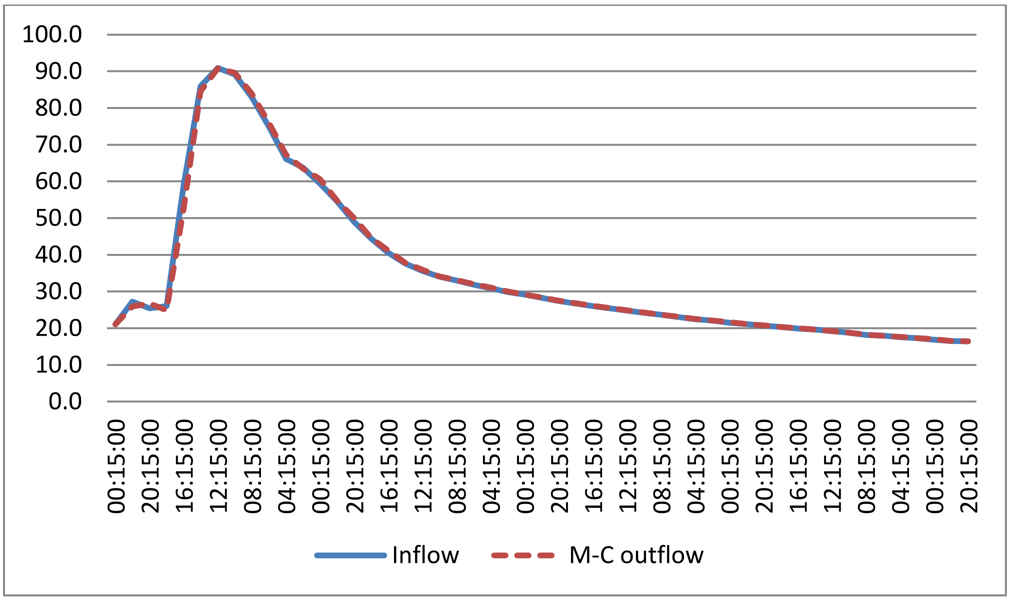


Figure 5.13 *Event (4/1- 25/1)1992,* $\Delta t = 10h$.

From the figures shown above, Figures 5.12 and 5.13, Muskingum-Cunge outflow (M-C) is nearly located in the zone of the inflow hydrograph. This is clearly shown in Figure 5.12 where the smaller time increment of 0.25 hour is used. The observed outflow hydrograph for this event was only a base flow as illustrated in Figure 4.18 in Chapter four (page49), which indicates a considerable degree of error and means that the comparison with the computed outflow is not possible.

5.2.2 Flood Event of November 1993

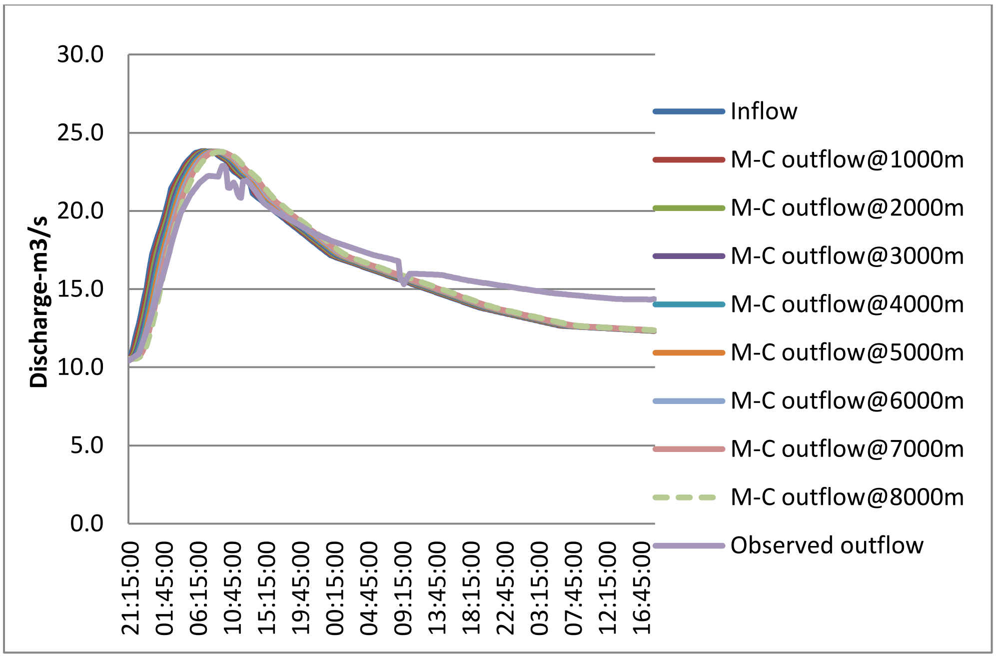


Figure 5.14 *Event (29/11 – 2/12)1993,* $\Delta t = 0.25h$

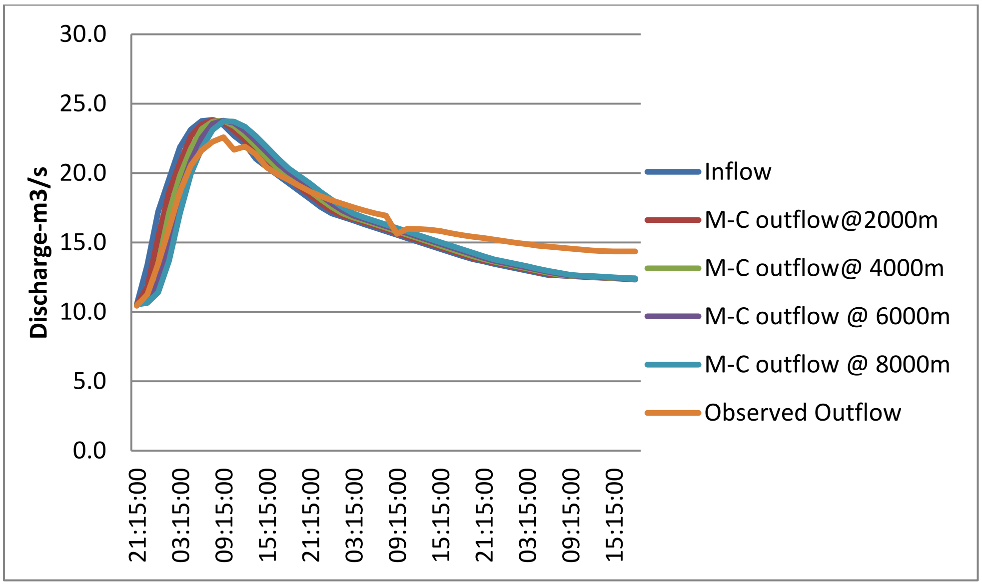


Figure 5.15 *Event (29/11 – 2/12)1993,* $\Delta t = 1.5h$

The two figures above, Figures 5.14 and 5.15 show that the computed outflow is closer to the observed one with a time increment of 1.5 hours.

5.2.3 Flood Event of December 1994

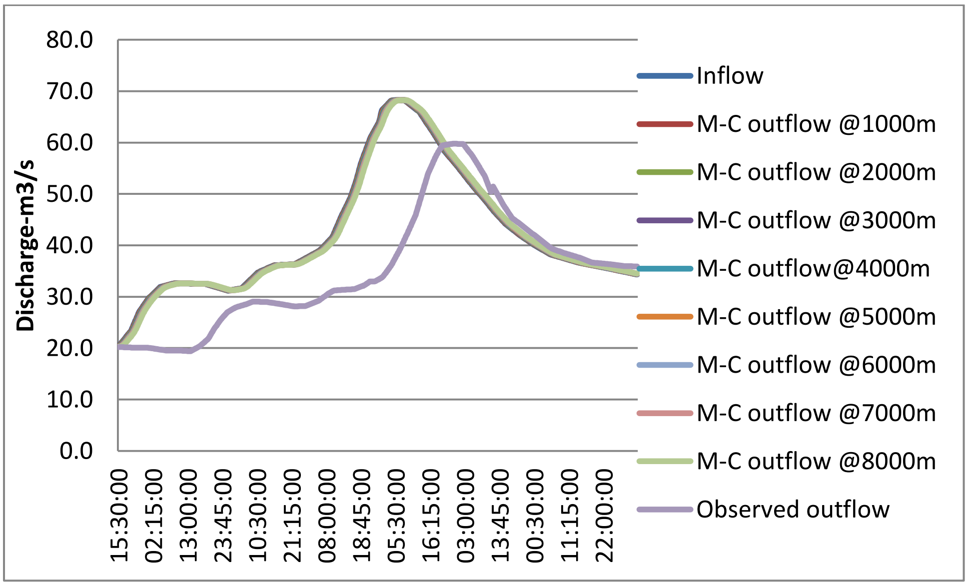


Figure 5.16 *Event (4/12 – 11/12)1994,* $\Delta t = 0.25h$

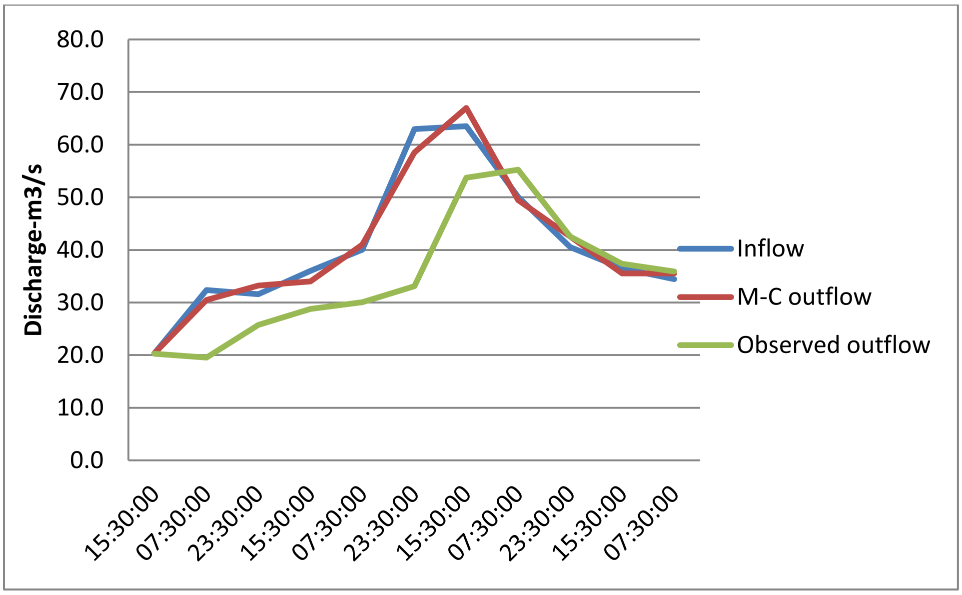


Figure 5.17 *Event (4/12 – 11/12)1994,* $\Delta t = 16h$.

Figures 5.16 and 5.17 show a noticeable change in the shape of computed outflow hydrograph with the change of the time increment from 0.25 hours to 16 hours.

5.3 Analysis of the Results

The figures illustrated in Sections 5.1 and 5.2 indicate that the storage calculation resulted in different loop shapes which are far removed from approximating a straight line. These differences are compounded due to the unreliability of flow data for each flood event. Although, the overall shape of the hydrographs does not take on a narrow looped shape, the hydrographs which are classified with low and moderate uncertainties have closed looped shapes. This is shown in Figures 5.1, 5.2, 5.3 and 5.5 respectively. Whereas, the hydrographs which are classified with high uncertainties tended to have open looped shapes, as shown in Figures 5.7 to 5.11. The flood event of June 1993 in Figure 5.4 is an exception, although it does contain a high degree of uncertainty, the storage relationship has a closed loop shape. Moreover, a similar pattern in the storage looped shapes can be observed in Figures 5.1 and 5.2 for the hydrographs that are more steeply rising. The two flood events for November 1990 with a peak of 49.2122m^3/s and October 1993 with a peak of 44.5607m^3/s as illustrated in Figures 4.4 and 4.9 (pages 44-45) are two examples of this situation.

Generally, the graphs indicate that for low, moderate and high uncertainty, varying the value of X does not have a big impact on the looped shapes. This concept is applied on two flood events, in November 1993 and December 1994, where values for X=0.2, 0.3 and 0.4 are tried as illustrated in Figures 5.5a - 5.6c.

The travel time K is defined as the slope of the line as indicated in Section 3.1.1 (page23). For the flood of November1993, K takes the values of 5.1 hours, 5 hours and 4.9 hours respectively as shown in Table 5.1 on page 73. These values differ from the actual travel time for the flood which is tabulated from Table 4.3 on page 53 to be 1 hour. The method of tabulation is determined by counting the hours between the peak inflow which was 23.8231m^3/s and the peak outflow which was 22.2451m^3/s in Table 4.3. In the second event for December 1994, the slope of the line for the graphs shown in Figures 5.6a-5.6c with values of X=0.2, 0.3 and 0.4 are calculated to be 34.96, 34.93 and 34.33 hours respectively, as shown in Table 5.1 on page 73. Whereas the actual travel time K is tabulated from the flow data in Table 4.5 in Appendix B to be 15.5 hours. The tabulation was also performed by counting the time from a peak of 68.2972m^3/s of the inflow data to the peak of 59.7790m^3/s of the outflow data in Table 4.5.

The flood hydrograph of December 1994 was considered to have a good shape as shown in Figure 4.21 (page 49). Despite this, the model parameters (K and X) using this method are not well estimated, due to the differences between the actual and the estimated values for these parameters.

In other situations, the storage loop diverges from a closed loop shape due to the significant error in the outflow estimation. This is the case for the flood event of January1992 as illustrated in Figure 5.11.

The figures illustrated above indicate that the basic Muskingum method failed to calibrate the model parameters K and X for the flood events on the Brosna River. This is due to the high degree of error in the estimated outflow and the fact that most of the hydrographs are steeply rising.

By applying the Muskingum-Cunge method for the flood event of January1992 with a minimum routing time increment of 0.25 hour, the resulting hydrograph showed that dividing the reach length into sub-reaches with a distance Δx does not make a noticeable change in the hydrograph shape. The resulting Muskingum-Cunge outflow which is computed at every 1000m is very close to the inflow with a little flood translation of 0.16 hours as calculated in Table 4.9 on page 63. This is illustrated in Figure 5.12 (page74). By increasing the time increment to 10 hours, the flood wave translation increased to around eight times the value in the first figure with the smaller time increment. However, very little attenuation has occurred as shown in Figure 5.13.

The resulting figures for the flood event of November1993 indicate that the outflow hydrograph is better simulated with the bigger time increment than with the small one. By using Δt=1.5h the sum of errors squared was 78.87, while by using Δt=0.25h the sum of the squares of the error increased to 427.8. In Figure 5.14, a minimum value of Δt is chosen to be 0.25 hour. Hence, the computed outflows hydrographs are closer to the inflow hydrograph. Where, the attenuation was very small with a value of -0.12 (See Table 4.13a on page 67 and a translation of 0.24 hours. The negative value of X confirms the existence of a weir downstream the river, which has significantly affected the outflow hydrograph as indicated in Section 3.2.5(page 34).

In Figure 5.15, Δt is chosen to be 1.5 hours where the computed outflow hydrograph is approaching from the position of the outflow of a normal flood wave. The attenuation and translation have increased to 0.29 and 0.71 hours respectively. The fifteen hours error in the data of Code B for the actual outflow hydrograph affected the peak shape badly. The sum of the errors squared increased as the time increment decreased.

It is important to remember that the Muskingum-Cunge outflow has been compared with the observed outflow for this flood event for the reason that the hydrograph of this event is not steeply rising, and the flow data is relatively reliable, although, numerical instability is an issue when using a bigger time increment. It is also evident that varying the distance step did not make a big difference in the routing procedure.

The resulting hydrographs of the Muskingum-Cunge simulation for the flood event in December 1994 as shown in Figures 5.16 and 5.17 indicate that the computed outflow for a 16 hours' time increment is better simulated than the outflow computed for only 0.25 hours. The attenuation increased from -0.62 in the first figure to 0.36 in the second one. And the translation time increased from 0.18 hour to 1.43 hour.

Problems of numerical dispersion occur when using the larger time increment which exceeds the limit described in Equation 3.17 (page 23). This is encountered in Figures 5.13, 5.15 and 5.17. In Figure 5.17 where a period in the rising part of the outflow hydrograph exceeds the inflow at 15:30:00 on the 8th of December 1994. The inflow and the computed outflow reached their peak values at the same time, which means that the travel time K is less than Δt.

From the Figures shown, it is clearly evident that the Muskingum-Cunge method is not well suited to model the outflow hydrograph in this instance. For the reason that the channel bed slope is not steep enough to dampen the error in the routing procedure, and some inflow hydrographs such as the flood hydrograph of January1992 are steeply rising. This is due to several factors which affected the flood hydrograph shape and made it steeply rising. For instance, most of the river bed is lined with large boulders and gravel, and this reduces the infiltration and means that run-off occurred quickly. Also the many maintenance and drainage works that had been carried out on the river Brosna as indicated in Section 4.1.4 (page 40) throughout the last decades may be another reason for making the surface run-off move quickly. This is apart from other factors that may influence the hydrograph shape such as the land use, urbanisation - Impermeable road surfaces, sloping roofs, guttering and underground drainage systems which transfer water very quickly to rivers (MRoden, 2000).

6 Conclusions

6.1 Conclusion

Flood routing using hydrological methods implemented in both the Muskingum and the Muskingum-Cunge have been presented for flood events between 1990 and 1994 on the River Brosna in Ireland. Despite the simplicity of these methods and their wide applicability on most natural channels, their use is limited to certain conditions. The analysis has shown that both methods failed to simulate the outflow hydrograph in the river Brosna due to several factors. The main factors are: (1) most of the hydrographs are steeply rising and (2) the channel has a very mild slope (0.00047). These are in addition to other factors that are associated with the reliability of the hydrometric data including the recorded water level and the outflow data which affected the hydrographs' shape and made the comparison between the inflow and outflow hydrographs difficult.

Moreover, the weir transition has a significant effect on the outflow hydrograph. By influencing the flow in Moystown and making the outflow contribute more to channel storage than the inflow as indicted in Section 3.2.5 (page 34). This has resulted in a negative attenuation in some cases, which contradicted the diffusivity that the Muskingum-Cunge method accounts for.

It is recognised that using a smaller time increment in the routing procedure results in a stable solution which satisfies the check suggested by Wilson and Viessman in Equation 3.17 (page 23). Conversely, this check is not valid for the hydrographs with a bigger time increment as shown in Table 4.13b on page 67 for flood events of January1992 with Δt=10 hours, November1993 with Δt=1.5 hours and December1994 with Δt=16 hours. The numerical stability criterion suggested by Wilson and Viessman seems to work well with other channel conditions which have steep slopes and are not affected by a significant backwater. Lettenmaier and Wood, as cited by Maidment (1992) recommend limiting the Muskingum methods to rivers without significant backwater effects and with slopes greater than 0.05.

Recently, a paper published in 2011 by Fenton has discussed the accuracy of the Muskingum-Cunge method for flood routing. Fenton indicated that the Muskingum-Cunge method is not accurate for streams with gentle slopes and where the time variation is more rapid. The smaller the channel slopes are, the worse the cases will be when considering smaller time increments.

A number of studies have shown that the minimum time for a hydrograph to rise can maintain an error of up to 10%. This error increases as the slope decreases (Tang *et al.,* cited by Johnson, 1999).

The analysis of the results showed that the flood wave translation, K, is very small. As indicated in Section 3.1 (page23), some factors that are related to a catchment may also play an important role in defining the travel time K. The surface geology, the soil type, the drainage pattern and the catchment shape may all have influences.

The analysis of the results also showed that the Muskingum-Cunge has calibrated values for the model parameters (K and X) for some flood events, for January1992, November1993 and December1994. Despite this, the model cannot be applied on all the events which are selected for this study due to the reasons mentioned above. This makes the validation not possible to evaluate the model performance, visually and statistically. The only the case considered is for the flood event of November1993 for the reason of a small degree of error in the outflow data, and its flood hydrograph was not steeply rising. The sum of errors squared between the computed outflow and the observed one is shown to be greater when using a smaller time increment.

The method of the rating curve for flow data estimation raised reliability issues with the use of these data for modelling, where some periods have gaps in the recorded water level. These gaps are due to the equipment malfunction or it may be due to periods of no rating, unreliable rating and periods of channel maintenance and drainage works. Hence, a gap in the water level has a corresponding gap in the flow record.

All of these issues are encountered when used hydrological methods to model the reach between Ferbane and Moystown at the River Brosna. An alternative method is needed to facilitate solutions for some problems discussed above.

6.2 Recommendations for future work

For cases similar to River Brosna, one suggestion is to use a full dynamic solution implemented in computer programs which use finite difference techniques. These techniques rely less on the previous flood data and they account for variable backwater effects as well as other factors used to determine the transportation of sediment along the waterway which can influence the outflow hydrograph. One of these models is the one dimensional HEC-RAS (Hydrologic Engineering Centre's - River Analysis System) model to perform steady and unsteady flow river hydraulic calculations. Other packages are also available such as MIKE11, TR20 hydrologic model for Natural Resources Conservation Service (NRCS) Technical Release 20**,** FLO-2D SOFTWARE and National Weather Service FLDWAV Computer Program.

Another suggestion is to perform a numerical sensitivity and physical parameter sensitivity for the model used. Based on the Courant condition which puts limits on the time and distance variation, Δt andΔx, a sensitivity of each case study flood routing modelling to input discharge statistics could be calculated.

Different structures of artificial neural networks (ANNs) may be used to compute the sensitivity of river flood routing to the number of previous time steps discharge which are effective in modelling accuracy.

Since a reference discharge has been used to calibrate the parameter X for the Muskingum-Cunge model, another suggestion is to use a peak discharge instead of the reference discharge to facilitate a comparison between the computed outflow hydrographs using the two discharges.

Due to the unavailability of flow data for most of the gauging stations on the River Brosna, radar altimetry could be used to measure the surface water level. This technique has an accuracy of within two centimetres and is available in near-real time.

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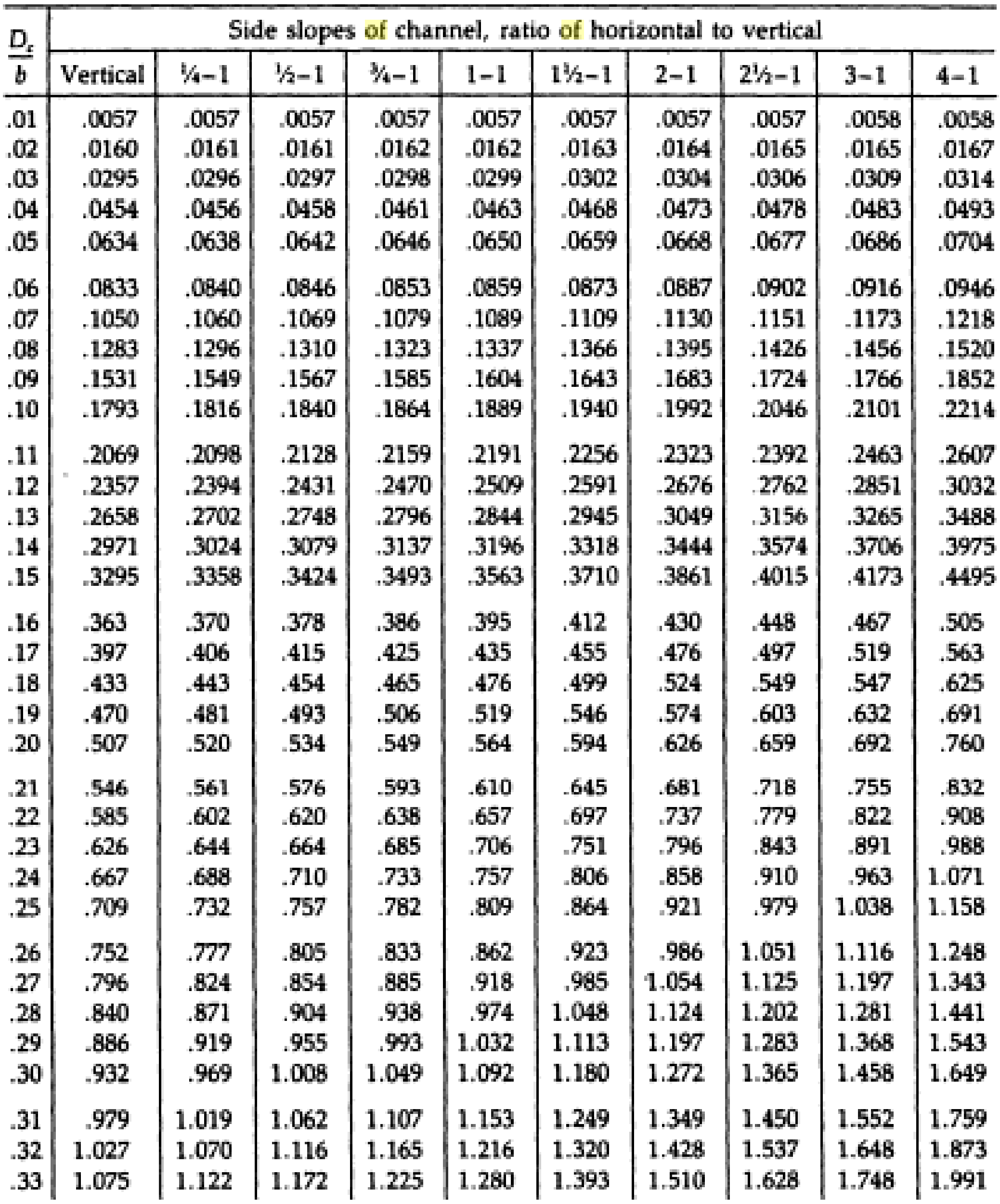
Appendices

Appendix A

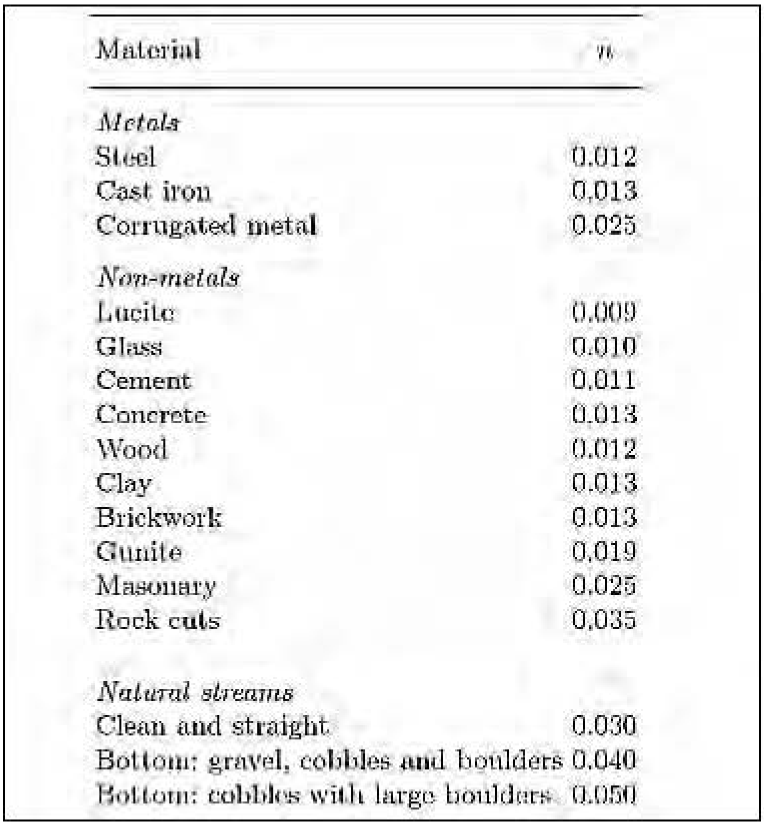
Table 2.1 *Values of Φ in formula* $\emptyset = \frac{Q_0 n}{b^{\frac{8}{3}}(S^{\frac{1}{2}})_0}$ *for trapezoidal channels*

(Batter and King, cited by American Society of Civil Engineers, 1992, p135).



$\frac{D_c}{b}$	Side slopes of channel, ratio of horizontal to vertical									
	Vertical	¼–1	½–1	¾–1	1–1	1½–1	2–1	2½–1	3–1	4–1
.01	.0057	.0057	.0057	.0057	.0057	.0057	.0057	.0057	.0058	.0058
.02	.0160	.0161	.0161	.0162	.0162	.0163	.0164	.0165	.0165	.0167
.03	.0295	.0296	.0297	.0298	.0299	.0302	.0304	.0306	.0309	.0314
.04	.0454	.0456	.0458	.0461	.0463	.0468	.0473	.0478	.0483	.0493
.05	.0634	.0638	.0642	.0646	.0650	.0659	.0668	.0677	.0686	.0704
.06	.0833	.0840	.0846	.0853	.0859	.0873	.0887	.0902	.0916	.0946
.07	.1050	.1060	.1069	.1079	.1089	.1109	.1130	.1151	.1173	.1218
.08	.1283	.1296	.1310	.1323	.1337	.1366	.1395	.1426	.1456	.1520
.09	.1531	.1549	.1567	.1585	.1604	.1643	.1683	.1724	.1766	.1852
.10	.1793	.1816	.1840	.1864	.1889	.1940	.1992	.2046	.2101	.2214
.11	.2069	.2098	.2128	.2159	.2191	.2256	.2323	.2392	.2463	.2607
.12	.2357	.2394	.2431	.2470	.2509	.2591	.2676	.2762	.2851	.3032
.13	.2658	.2702	.2748	.2796	.2844	.2945	.3049	.3156	.3265	.3488
.14	.2971	.3024	.3079	.3137	.3196	.3318	.3444	.3574	.3706	.3975
.15	.3295	.3358	.3424	.3493	.3563	.3710	.3861	.4015	.4173	.4495
.16	.363	.370	.378	.386	.395	.412	.430	.448	.467	.505
.17	.397	.406	.415	.425	.435	.455	.476	.497	.519	.563
.18	.433	.443	.454	.465	.476	.499	.524	.549	.547	.625
.19	.470	.481	.493	.506	.519	.546	.574	.603	.632	.691
.20	.507	.520	.534	.549	.564	.594	.626	.659	.692	.760
.21	.546	.561	.576	.593	.610	.645	.681	.718	.755	.832
.22	.585	.602	.620	.638	.657	.697	.737	.779	.822	.908
.23	.626	.644	.664	.685	.706	.751	.796	.843	.891	.988
.24	.667	.688	.710	.733	.757	.806	.858	.910	.963	1.071
.25	.709	.732	.757	.782	.809	.864	.921	.979	1.038	1.158
.26	.752	.777	.805	.833	.862	.923	.986	1.051	1.116	1.248
.27	.796	.824	.854	.885	.918	.985	1.054	1.125	1.197	1.343
.28	.840	.871	.904	.938	.974	1.048	1.124	1.202	1.281	1.441
.29	.886	.919	.955	.993	1.032	1.113	1.197	1.283	1.368	1.543
.30	.932	.969	1.008	1.049	1.092	1.180	1.272	1.365	1.458	1.649
.31	.979	1.019	1.062	1.107	1.153	1.249	1.349	1.450	1.552	1.759
.32	1.027	1.070	1.116	1.165	1.216	1.320	1.428	1.537	1.648	1.873
.33	1.075	1.122	1.172	1.225	1.280	1.393	1.510	1.628	1.748	1.991

Table 2.2 *Typical values of Roughness Coefficient (n) (Chow, cited by Chaudhry, 2008).*



Material	n
Metals	
Steel	0.012
Cast iron	0,013
Corrugated metal	0.025
Non-metals	
Lucite	0.009
Glass	0.010
Cement	0,011
Concrete	0.013
Wood	0.012
Clay	0.013
Brickwork	0.013
Gunite	0,019
Masonary	0.025
Rock cuts	0,035
Natural streams	
Clean and straight	0.030
Bottom: gravel, cobbles and boulders	0.040
Bottom: cobbles with large boulders	0.050

Appendix B

Table 4.1 *Quality Codes for water level and estimated flow data (OPW, 2000).*

Code	Symbol	Description
WATER LEVEL DATA		
1	*	Unchecked digitised water level data – Data is provisional only and must be used with caution
31		Inspected water level data – Data may contain some error, but has been approved for general use
32	C	As per Code 31, but where the digitised water level data has been corrected
99	*	Unchecked imported water level data – Data is provisional only and must be used with caution
145	<	Data is below prescribed data range and must only be used with caution
146	>	Data is above prescribed data range and must only be used with caution
150	I	Partial statistic – Data has been derived from records that are incomplete and do not necessarily represent the true value
101	!	Unreliable water level data – Data is suspected of being erroneous or is artificially affected (e.g., during drainage works) and must only be used with caution
>150	Various	Data is not available as it is missing, erroneous or of unacceptable quality
ESTIMATED FLOW DATA		
31		Flow data estimated using a rating curve that it is considered to be of **good** quality and inspected water level data – Data may contain some error, but is considered to be of acceptable quality for general use
32	C	As per Code 31, but using water level data of Code 32
36	F	Flow data estimated using a rating curve that it is considered to be of **fair** quality and inspected or corrected water level data – Data may contain a fair degree of error and should therefore be treated with some caution
46	B	Flow data estimated using a rating curve that it is considered to be of **poor** quality and inspected or corrected water level data – Data may contain a significant degree of error and should therefore be used for indicative purposes only
56	X	Flow data estimated using an extrapolated rating curve (see Section 3.2) and inspected or corrected water level data – Reliability of data is unknown and it should therefore be treated with caution
99	*	Flow data that has been estimated using unchecked water level data – Data is provisional only and must be used with caution
101	!	Flow data that has been estimated using unreliable water level data – Data is suspected of being erroneous and must only be used with caution

145	<	Data is below prescribed data range and must only be used with caution
146	>	Data is above prescribed data range and must only be used with caution
150	I	Partial statistic – Data has been derived from records that are incomplete and do not necessarily represent the true value
>150	Various	Data is not available as it is missing, erroneous or of unacceptable quality

Table 4.5 *Flood Event (4/12 – 11/12)1994*

Date	Time	Inflow code type	Inflow[m3/s]	Outflow[m3/s]	Outflow code type
04/12/1994	15:30:00	31 (31)	20.29	20.23	46 (B)
04/12/1994	15:45:00	31 (31)	20.49	20.23	46 (B)
04/12/1994	16:00:00	31 (31)	20.68	20.22	46 (B)
04/12/1994	16:15:00	31 (31)	20.88	20.21	46 (B)
04/12/1994	16:30:00	31 (31)	21.07	20.20	46 (B)
04/12/1994	16:45:00	31 (31)	21.26	20.20	46 (B)
04/12/1994	17:00:00	31 (31)	21.46	20.19	46 (B)
04/12/1994	17:15:00	31 (31)	21.65	20.18	46 (B)
04/12/1994	17:30:00	31 (31)	21.85	20.17	46 (B)
04/12/1994	17:45:00	31 (31)	22.04	20.17	46 (B)
04/12/1994	18:00:00	31 (31)	22.24	20.16	46 (B)
04/12/1994	18:15:00	31 (31)	22.43	20.15	46 (B)
04/12/1994	18:30:00	31 (31)	22.63	20.14	46 (B)
04/12/1994	18:45:00	31 (31)	22.82	20.14	46 (B)
04/12/1994	19:00:00	31 (31)	23.02	20.13	46 (B)
04/12/1994	19:15:00	31 (31)	23.21	20.12	46 (B)
04/12/1994	19:30:00	31 (31)	23.45	20.12	46 (B)
04/12/1994	19:45:00	31 (31)	23.82	20.11	46 (B)
04/12/1994	20:00:00	31 (31)	24.19	20.11	46 (B)
04/12/1994	20:15:00	31 (31)	24.55	20.11	46 (B)
04/12/1994	20:30:00	31 (31)	24.92	20.10	46 (B)
04/12/1994	20:45:00	31 (31)	25.29	20.10	46 (B)
04/12/1994	21:00:00	31 (31)	25.66	20.10	46 (B)
04/12/1994	21:15:00	31 (31)	26.03	20.10	46 (B)
04/12/1994	21:30:00	31 (31)	26.39	20.09	46 (B)
04/12/1994	21:45:00	31 (31)	26.76	20.09	46 (B)
04/12/1994	22:00:00	31 (31)	27.09	20.09	46 (B)
04/12/1994	22:15:00	31 (31)	27.32	20.09	46 (B)
04/12/1994	22:30:00	31 (31)	27.54	20.08	46 (B)
04/12/1994	22:45:00	31 (31)	27.77	20.08	46 (B)
04/12/1994	23:00:00	31 (31)	27.99	20.08	46 (B)
04/12/1994	23:15:00	31 (31)	28.22	20.07	46 (B)
04/12/1994	23:30:00	31 (31)	28.44	20.07	46 (B)
04/12/1994	23:45:00	31 (31)	28.67	20.07	46 (B)
05/12/1994	00:00:00	31 (31)	28.89	20.07	46 (B)
05/12/1994	00:15:00	31 (31)	29.12	20.06	46 (B)
05/12/1994	00:30:00	31 (31)	29.34	20.06	46 (B)
05/12/1994	00:45:00	31 (31)	29.57	20.06	46 (B)
05/12/1994	01:00:00	31 (31)	29.77	20.06	46 (B)
05/12/1994	01:15:00	31 (31)	29.92	20.03	46 (B)
05/12/1994	01:30:00	31 (31)	30.07	20.01	46 (B)
05/12/1994	01:45:00	31 (31)	30.22	19.98	46 (B)
05/12/1994	02:00:00	31 (31)	30.38	19.96	46 (B)
05/12/1994	02:15:00	31 (31)	30.53	19.94	46 (B)
05/12/1994	02:30:00	31 (31)	30.68	19.91	46 (B)
05/12/1994	02:45:00	31 (31)	30.83	19.89	46 (B)
05/12/1994	03:00:00	31 (31)	30.98	19.87	46 (B)
05/12/1994	03:15:00	31 (31)	31.13	19.84	46 (B)
05/12/1994	03:30:00	31 (31)	31.28	19.82	46 (B)
05/12/1994	03:45:00	31 (31)	31.44	19.79	46 (B)
05/12/1994	04:00:00	31 (31)	31.59	19.77	46 (B)
05/12/1994	04:15:00	31 (31)	31.74	19.75	46 (B)

05/12/1994	04:30:00	31 (31)	31.89	19.72	46 (B)
05/12/1994	04:45:00	31 (31)	31.94	19.70	46 (B)
05/12/1994	05:00:00	31 (31)	31.98	19.68	46 (B)
05/12/1994	05:15:00	31 (31)	32.02	19.65	46 (B)
05/12/1994	05:30:00	31 (31)	32.06	19.63	46 (B)
05/12/1994	05:45:00	31 (31)	32.10	19.60	46 (B)
05/12/1994	06:00:00	31 (31)	32.14	19.58	46 (B)
05/12/1994	06:15:00	31 (31)	32.19	19.56	46 (B)
05/12/1994	06:30:00	31 (31)	32.23	19.53	46 (B)
05/12/1994	06:45:00	31 (31)	32.27	19.52	31 (31)
05/12/1994	07:00:00	31 (31)	32.31	19.52	31 (31)
05/12/1994	07:15:00	31 (31)	32.35	19.52	31 (31)
05/12/1994	07:30:00	31 (31)	32.39	19.52	31 (31)
05/12/1994	07:45:00	31 (31)	32.43	19.52	31 (31)
05/12/1994	08:00:00	31 (31)	32.47	19.52	31 (31)
05/12/1994	08:15:00	31 (31)	32.52	19.52	31 (31)
05/12/1994	08:30:00	31 (31)	32.56	19.51	31 (31)
05/12/1994	08:45:00	31 (31)	32.60	19.51	31 (31)
05/12/1994	09:00:00	31 (31)	32.61	19.51	31 (31)
05/12/1994	09:15:00	31 (31)	32.61	19.51	31 (31)
05/12/1994	09:30:00	31 (31)	32.61	19.51	31 (31)
05/12/1994	09:45:00	31 (31)	32.61	19.51	31 (31)
05/12/1994	10:00:00	31 (31)	32.60	19.51	31 (31)
05/12/1994	10:15:00	31 (31)	32.60	19.50	31 (31)
05/12/1994	10:30:00	31 (31)	32.60	19.50	31 (31)
05/12/1994	10:45:00	31 (31)	32.60	19.50	31 (31)
05/12/1994	11:00:00	31 (31)	32.59	19.50	31 (31)
05/12/1994	11:15:00	31 (31)	32.59	19.50	31 (31)
05/12/1994	11:30:00	31 (31)	32.59	19.50	31 (31)
05/12/1994	11:45:00	31 (31)	32.58	19.50	31 (31)
05/12/1994	12:00:00	31 (31)	32.58	19.49	31 (31)
05/12/1994	12:15:00	31 (31)	32.58	19.48	31 (31)
05/12/1994	12:30:00	31 (31)	32.58	19.46	31 (31)
05/12/1994	12:45:00	31 (31)	32.57	19.45	31 (31)
05/12/1994	13:00:00	31 (31)	32.57	19.43	31 (31)
05/12/1994	13:15:00	31 (31)	32.57	19.42	31 (31)
05/12/1994	13:30:00	31 (31)	32.57	19.40	31 (31)
05/12/1994	13:45:00	31 (31)	32.56	19.39	31 (31)
05/12/1994	14:00:00	31 (31)	32.56	19.41	46 (B)
05/12/1994	14:15:00	31 (31)	32.56	19.50	46 (B)
05/12/1994	14:30:00	31 (31)	32.56	19.59	46 (B)
05/12/1994	14:45:00	31 (31)	32.55	19.68	46 (B)
05/12/1994	15:00:00	31 (31)	32.55	19.77	46 (B)
05/12/1994	15:15:00	31 (31)	32.55	19.85	46 (B)
05/12/1994	15:30:00	31 (31)	32.55	19.94	46 (B)
05/12/1994	15:45:00	31 (31)	32.54	20.03	46 (B)
05/12/1994	16:00:00	31 (31)	32.54	20.12	46 (B)
05/12/1994	16:15:00	31 (31)	32.54	20.21	46 (B)
05/12/1994	16:30:00	31 (31)	32.54	20.30	46 (B)
05/12/1994	16:45:00	31 (31)	32.53	20.38	46 (B)
05/12/1994	17:00:00	31 (31)	32.53	20.49	46 (B)
05/12/1994	17:15:00	31 (31)	32.53	20.63	46 (B)
05/12/1994	17:30:00	31 (31)	32.53	20.76	46 (B)
05/12/1994	17:45:00	31 (31)	32.52	20.90	46 (B)
05/12/1994	18:00:00	31 (31)	32.52	21.04	46 (B)
05/12/1994	18:15:00	31 (31)	32.52	21.17	46 (B)

05/12/1994	18:30:00	31 (31)	32.49	21.31	46 (B)
05/12/1994	18:45:00	31 (31)	32.45	21.45	46 (B)
05/12/1994	19:00:00	31 (31)	32.40	21.59	46 (B)
05/12/1994	19:15:00	31 (31)	32.35	21.72	46 (B)
05/12/1994	19:30:00	31 (31)	32.31	21.90	46 (B)
05/12/1994	19:45:00	31 (31)	32.26	22.16	46 (B)
05/12/1994	20:00:00	31 (31)	32.21	22.42	46 (B)
05/12/1994	20:15:00	31 (31)	32.17	22.69	46 (B)
05/12/1994	20:30:00	31 (31)	32.12	22.95	46 (B)
05/12/1994	20:45:00	31 (31)	32.07	23.21	46 (B)
05/12/1994	21:00:00	31 (31)	32.03	23.48	46 (B)
05/12/1994	21:15:00	31 (31)	31.98	23.74	46 (B)
05/12/1994	21:30:00	31 (31)	31.93	23.96	46 (B)
05/12/1994	21:45:00	31 (31)	31.89	24.19	46 (B)
05/12/1994	22:00:00	31 (31)	31.84	24.41	46 (B)
05/12/1994	22:15:00	31 (31)	31.80	24.63	46 (B)
05/12/1994	22:30:00	31 (31)	31.75	24.86	46 (B)
05/12/1994	22:45:00	31 (31)	31.70	25.08	46 (B)
05/12/1994	23:00:00	31 (31)	31.66	25.30	46 (B)
05/12/1994	23:15:00	31 (31)	31.61	25.53	46 (B)
05/12/1994	23:30:00	31 (31)	31.56	25.71	46 (B)
05/12/1994	23:45:00	31 (31)	31.52	25.88	46 (B)
06/12/1994	00:00:00	31 (31)	31.47	26.05	46 (B)
06/12/1994	00:15:00	31 (31)	31.42	26.22	46 (B)
06/12/1994	00:30:00	31 (31)	31.38	26.39	46 (B)
06/12/1994	00:45:00	31 (31)	31.33	26.56	46 (B)
06/12/1994	01:00:00	31 (31)	31.29	26.74	46 (B)
06/12/1994	01:15:00	31 (31)	31.24	26.91	46 (B)
06/12/1994	01:30:00	31 (31)	31.19	27.05	46 (B)
06/12/1994	01:45:00	31 (31)	31.21	27.14	46 (B)
06/12/1994	02:00:00	31 (31)	31.24	27.23	46 (B)
06/12/1994	02:15:00	31 (31)	31.27	27.32	46 (B)
06/12/1994	02:30:00	31 (31)	31.29	27.41	46 (B)
06/12/1994	02:45:00	31 (31)	31.32	27.50	46 (B)
06/12/1994	03:00:00	31 (31)	31.35	27.59	46 (B)
06/12/1994	03:15:00	31 (31)	31.37	27.68	46 (B)
06/12/1994	03:30:00	31 (31)	31.40	27.77	46 (B)
06/12/1994	03:45:00	31 (31)	31.43	27.86	46 (B)
06/12/1994	04:00:00	31 (31)	31.46	27.94	46 (B)
06/12/1994	04:15:00	31 (31)	31.48	28.00	46 (B)
06/12/1994	04:30:00	31 (31)	31.51	28.05	46 (B)
06/12/1994	04:45:00	31 (31)	31.54	28.09	46 (B)
06/12/1994	05:00:00	31 (31)	31.56	28.14	46 (B)
06/12/1994	05:15:00	31 (31)	31.59	28.19	46 (B)
06/12/1994	05:30:00	31 (31)	31.62	28.23	46 (B)
06/12/1994	05:45:00	31 (31)	31.65	28.28	46 (B)
06/12/1994	06:00:00	31 (31)	31.80	28.33	46 (B)
06/12/1994	06:15:00	31 (31)	31.95	28.37	46 (B)
06/12/1994	06:30:00	31 (31)	32.11	28.42	46 (B)
06/12/1994	06:45:00	31 (31)	32.26	28.47	46 (B)
06/12/1994	07:00:00	31 (31)	32.41	28.51	46 (B)
06/12/1994	07:15:00	31 (31)	32.56	28.56	46 (B)
06/12/1994	07:30:00	31 (31)	32.71	28.61	46 (B)
06/12/1994	07:45:00	31 (31)	32.86	28.66	46 (B)
06/12/1994	08:00:00	31 (31)	33.02	28.73	46 (B)
06/12/1994	08:15:00	31 (31)	33.17	28.80	46 (B)

06/12/1994	08:30:00	31 (31)	33.32	28.87	46 (B)
06/12/1994	08:45:00	31 (31)	33.47	28.94	46 (B)
06/12/1994	09:00:00	31 (31)	33.62	29.01	46 (B)
06/12/1994	09:15:00	31 (31)	33.77	29.06	46 (B)
06/12/1994	09:30:00	31 (31)	33.93	29.06	46 (B)
06/12/1994	09:45:00	31 (31)	34.08	29.05	46 (B)
06/12/1994	10:00:00	31 (31)	34.23	29.05	46 (B)
06/12/1994	10:15:00	31 (31)	34.38	29.04	46 (B)
06/12/1994	10:30:00	31 (31)	34.53	29.04	46 (B)
06/12/1994	10:45:00	31 (31)	34.68	29.03	46 (B)
06/12/1994	11:00:00	31 (31)	34.79	29.03	46 (B)
06/12/1994	11:15:00	31 (31)	34.86	29.02	46 (B)
06/12/1994	11:30:00	31 (31)	34.93	29.02	46 (B)
06/12/1994	11:45:00	31 (31)	35.00	29.01	46 (B)
06/12/1994	12:00:00	31 (31)	35.07	29.01	46 (B)
06/12/1994	12:15:00	31 (31)	35.14	29.00	46 (B)
06/12/1994	12:30:00	31 (31)	35.21	28.99	46 (B)
06/12/1994	12:45:00	31 (31)	35.28	28.99	46 (B)
06/12/1994	13:00:00	31 (31)	35.35	28.98	46 (B)
06/12/1994	13:15:00	31 (31)	35.42	28.98	46 (B)
06/12/1994	13:30:00	31 (31)	35.48	28.97	46 (B)
06/12/1994	13:45:00	31 (31)	35.55	28.97	46 (B)
06/12/1994	14:00:00	31 (31)	35.62	28.94	46 (B)
06/12/1994	14:15:00	31 (31)	35.69	28.92	46 (B)
06/12/1994	14:30:00	31 (31)	35.76	28.89	46 (B)
06/12/1994	14:45:00	31 (31)	35.83	28.87	46 (B)
06/12/1994	15:00:00	31 (31)	35.90	28.84	46 (B)
06/12/1994	15:15:00	31 (31)	35.97	28.82	46 (B)
06/12/1994	15:30:00	31 (31)	36.04	28.80	46 (B)
06/12/1994	15:45:00	31 (31)	36.11	28.77	46 (B)
06/12/1994	16:00:00	31 (31)	36.13	28.75	46 (B)
06/12/1994	16:15:00	31 (31)	36.14	28.72	46 (B)
06/12/1994	16:30:00	31 (31)	36.14	28.70	46 (B)
06/12/1994	16:45:00	31 (31)	36.15	28.67	46 (B)
06/12/1994	17:00:00	31 (31)	36.16	28.65	46 (B)
06/12/1994	17:15:00	31 (31)	36.16	28.62	46 (B)
06/12/1994	17:30:00	31 (31)	36.17	28.60	46 (B)
06/12/1994	17:45:00	31 (31)	36.18	28.57	46 (B)
06/12/1994	18:00:00	31 (31)	36.19	28.55	46 (B)
06/12/1994	18:15:00	31 (31)	36.19	28.52	46 (B)
06/12/1994	18:30:00	31 (31)	36.20	28.50	46 (B)
06/12/1994	18:45:00	31 (31)	36.21	28.47	46 (B)
06/12/1994	19:00:00	31 (31)	36.21	28.45	46 (B)
06/12/1994	19:15:00	31 (31)	36.22	28.42	46 (B)
06/12/1994	19:30:00	31 (31)	36.23	28.39	46 (B)
06/12/1994	19:45:00	31 (31)	36.23	28.36	46 (B)
06/12/1994	20:00:00	31 (31)	36.24	28.34	46 (B)
06/12/1994	20:15:00	31 (31)	36.25	28.31	46 (B)
06/12/1994	20:30:00	31 (31)	36.25	28.28	46 (B)
06/12/1994	20:45:00	31 (31)	36.26	28.26	46 (B)
06/12/1994	21:00:00	31 (31)	36.27	28.23	46 (B)
06/12/1994	21:15:00	31 (31)	36.27	28.20	46 (B)
06/12/1994	21:30:00	31 (31)	36.28	28.18	46 (B)
06/12/1994	21:45:00	31 (31)	36.29	28.15	46 (B)
06/12/1994	22:00:00	31 (31)	36.29	28.12	46 (B)
06/12/1994	22:15:00	31 (31)	36.35	28.13	46 (B)

06/12/1994	22:30:00	31 (31)	36.44	28.13	46 (B)
06/12/1994	22:45:00	31 (31)	36.52	28.14	46 (B)
06/12/1994	23:00:00	31 (31)	36.61	28.14	46 (B)
06/12/1994	23:15:00	31 (31)	36.69	28.15	46 (B)
06/12/1994	23:30:00	31 (31)	36.78	28.15	46 (B)
06/12/1994	23:45:00	31 (31)	36.86	28.16	46 (B)
07/12/1994	00:00:00	31 (31)	36.95	28.16	46 (B)
07/12/1994	00:15:00	31 (31)	37.04	28.16	46 (B)
07/12/1994	00:30:00	31 (31)	37.12	28.17	46 (B)
07/12/1994	00:45:00	31 (31)	37.21	28.17	46 (B)
07/12/1994	01:00:00	31 (31)	37.29	28.18	46 (B)
07/12/1994	01:15:00	31 (31)	37.38	28.18	46 (B)
07/12/1994	01:30:00	31 (31)	37.46	28.19	46 (B)
07/12/1994	01:45:00	31 (31)	37.55	28.22	46 (B)
07/12/1994	02:00:00	31 (31)	37.63	28.28	46 (B)
07/12/1994	02:15:00	31 (31)	37.72	28.34	46 (B)
07/12/1994	02:30:00	31 (31)	37.81	28.41	46 (B)
07/12/1994	02:45:00	31 (31)	37.89	28.47	46 (B)
07/12/1994	03:00:00	31 (31)	37.98	28.53	46 (B)
07/12/1994	03:15:00	31 (31)	38.06	28.60	46 (B)
07/12/1994	03:30:00	31 (31)	38.15	28.66	46 (B)
07/12/1994	03:45:00	31 (31)	38.23	28.72	46 (B)
07/12/1994	04:00:00	31 (31)	38.32	28.79	46 (B)
07/12/1994	04:15:00	31 (31)	38.40	28.85	46 (B)
07/12/1994	04:30:00	31 (31)	38.49	28.91	46 (B)
07/12/1994	04:45:00	31 (31)	38.57	28.98	46 (B)
07/12/1994	05:00:00	31 (31)	38.66	29.04	46 (B)
07/12/1994	05:15:00	31 (31)	38.75	29.10	46 (B)
07/12/1994	05:30:00	31 (31)	38.83	29.17	46 (B)
07/12/1994	05:45:00	31 (31)	38.92	29.26	46 (B)
07/12/1994	06:00:00	31 (31)	39.02	29.37	46 (B)
07/12/1994	06:15:00	31 (31)	39.18	29.49	46 (B)
07/12/1994	06:30:00	31 (31)	39.35	29.61	46 (B)
07/12/1994	06:45:00	31 (31)	39.51	29.72	46 (B)
07/12/1994	07:00:00	31 (31)	39.68	29.84	46 (B)
07/12/1994	07:15:00	31 (31)	39.84	29.95	46 (B)
07/12/1994	07:30:00	31 (31)	40.00	30.07	46 (B)
07/12/1994	07:45:00	31 (31)	40.17	30.18	46 (B)
07/12/1994	08:00:00	31 (31)	40.33	30.30	46 (B)
07/12/1994	08:15:00	31 (31)	40.50	30.42	46 (B)
07/12/1994	08:30:00	31 (31)	40.66	30.53	46 (B)
07/12/1994	08:45:00	31 (31)	40.83	30.64	46 (B)
07/12/1994	09:00:00	31 (31)	40.99	30.73	46 (B)
07/12/1994	09:15:00	31 (31)	41.15	30.81	46 (B)
07/12/1994	09:30:00	31 (31)	41.32	30.90	46 (B)
07/12/1994	09:45:00	31 (31)	41.48	30.99	46 (B)
07/12/1994	10:00:00	31 (31)	41.71	31.08	46 (B)
07/12/1994	10:15:00	31 (31)	42.08	31.16	46 (B)
07/12/1994	10:30:00	31 (31)	42.44	31.21	46 (B)
07/12/1994	10:45:00	31 (31)	42.80	31.22	46 (B)
07/12/1994	11:00:00	31 (31)	43.16	31.24	46 (B)
07/12/1994	11:15:00	31 (31)	43.53	31.25	46 (B)
07/12/1994	11:30:00	31 (31)	43.89	31.26	46 (B)
07/12/1994	11:45:00	31 (31)	44.25	31.28	46 (B)
07/12/1994	12:00:00	31 (31)	44.61	31.29	46 (B)
07/12/1994	12:15:00	31 (31)	44.97	31.30	46 (B)

07/12/1994	12:30:00	31 (31)	45.34	31.31	46 (B)
07/12/1994	12:45:00	31 (31)	45.70	31.33	46 (B)
07/12/1994	13:00:00	31 (31)	46.05	31.34	46 (B)
07/12/1994	13:15:00	31 (31)	46.37	31.35	46 (B)
07/12/1994	13:30:00	31 (31)	46.70	31.36	46 (B)
07/12/1994	13:45:00	31 (31)	47.02	31.37	46 (B)
07/12/1994	14:00:00	31 (31)	47.34	31.38	46 (B)
07/12/1994	14:15:00	31 (31)	47.66	31.39	46 (B)
07/12/1994	14:30:00	31 (31)	47.99	31.40	46 (B)
07/12/1994	14:45:00	31 (31)	48.31	31.41	46 (B)
07/12/1994	15:00:00	31 (31)	48.63	31.42	46 (B)
07/12/1994	15:15:00	31 (31)	48.95	31.42	46 (B)
07/12/1994	15:30:00	31 (31)	49.28	31.43	46 (B)
07/12/1994	15:45:00	31 (31)	49.73	31.44	46 (B)
07/12/1994	16:00:00	31 (31)	50.19	31.45	46 (B)
07/12/1994	16:15:00	31 (31)	50.64	31.46	46 (B)
07/12/1994	16:30:00	31 (31)	51.09	31.46	46 (B)
07/12/1994	16:45:00	31 (31)	51.54	31.48	46 (B)
07/12/1994	17:00:00	31 (31)	51.99	31.54	46 (B)
07/12/1994	17:15:00	31 (31)	52.44	31.60	46 (B)
07/12/1994	17:30:00	31 (31)	53.00	31.66	46 (B)
07/12/1994	17:45:00	31 (31)	53.58	31.72	46 (B)
07/12/1994	18:00:00	31 (31)	54.16	31.78	46 (B)
07/12/1994	18:15:00	31 (31)	54.73	31.83	46 (B)
07/12/1994	18:30:00	31 (31)	55.31	31.89	46 (B)
07/12/1994	18:45:00	31 (31)	55.86	31.95	46 (B)
07/12/1994	19:00:00	31 (31)	56.29	32.01	46 (B)
07/12/1994	19:15:00	31 (31)	56.73	32.07	46 (B)
07/12/1994	19:30:00	31 (31)	57.16	32.13	46 (B)
07/12/1994	19:45:00	31 (31)	57.59	32.20	46 (B)
07/12/1994	20:00:00	31 (31)	58.03	32.31	46 (B)
07/12/1994	20:15:00	31 (31)	58.46	32.41	46 (B)
07/12/1994	20:30:00	31 (31)	58.89	32.52	46 (B)
07/12/1994	20:45:00	31 (31)	59.33	32.62	46 (B)
07/12/1994	21:00:00	31 (31)	59.76	32.73	46 (B)
07/12/1994	21:15:00	31 (31)	60.19	32.84	46 (B)
07/12/1994	21:30:00	31 (31)	60.62	32.94	46 (B)
07/12/1994	21:45:00	31 (31)	61.04	32.95	46 (B)
07/12/1994	22:00:00	31 (31)	61.31	32.95	46 (B)
07/12/1994	22:15:00	31 (31)	61.59	32.96	46 (B)
07/12/1994	22:30:00	31 (31)	61.87	32.96	46 (B)
07/12/1994	22:45:00	31 (31)	62.14	32.97	46 (B)
07/12/1994	23:00:00	31 (31)	62.42	32.97	46 (B)
07/12/1994	23:15:00	31 (31)	62.70	33.02	46 (B)
07/12/1994	23:30:00	31 (31)	62.97	33.11	46 (B)
07/12/1994	23:45:00	31 (31)	63.25	33.20	46 (B)
08/12/1994	00:00:00	31 (31)	63.53	33.28	46 (B)
08/12/1994	00:15:00	31 (31)	63.81	33.37	46 (B)
08/12/1994	00:30:00	31 (31)	64.19	33.45	46 (B)
08/12/1994	00:45:00	31 (31)	64.88	33.54	46 (B)
08/12/1994	01:00:00	31 (31)	65.57	33.63	46 (B)
08/12/1994	01:15:00	31 (31)	66.25	33.71	46 (B)
08/12/1994	01:30:00	31 (31)	66.45	33.82	46 (B)
08/12/1994	01:45:00	31 (31)	66.62	34.03	46 (B)
08/12/1994	02:00:00	31 (31)	66.78	34.24	46 (B)
08/12/1994	02:15:00	31 (31)	66.95	34.46	46 (B)

08/12/1994	02:30:00	31 (31)	67.12	34.67	46 (B)
08/12/1994	02:45:00	31 (31)	67.28	34.89	46 (B)
08/12/1994	03:00:00	31 (31)	67.45	35.10	46 (B)
08/12/1994	03:15:00	31 (31)	67.61	35.31	46 (B)
08/12/1994	03:30:00	31 (31)	67.78	35.53	46 (B)
08/12/1994	03:45:00	31 (31)	67.94	35.74	46 (B)
08/12/1994	04:00:00	31 (31)	68.11	35.96	46 (B)
08/12/1994	04:15:00	31 (31)	68.21	36.19	46 (B)
08/12/1994	04:30:00	31 (31)	68.22	36.48	46 (B)
08/12/1994	04:45:00	31 (31)	68.22	36.77	46 (B)
08/12/1994	05:00:00	31 (31)	68.23	37.05	46 (B)
08/12/1994	05:15:00	31 (31)	68.23	37.34	46 (B)
08/12/1994	05:30:00	31 (31)	68.24	37.63	46 (B)
08/12/1994	05:45:00	31 (31)	68.24	37.92	46 (B)
08/12/1994	06:00:00	31 (31)	68.25	38.21	46 (B)
08/12/1994	06:15:00	31 (31)	68.26	38.49	46 (B)
08/12/1994	06:30:00	31 (31)	68.26	38.78	46 (B)
08/12/1994	06:45:00	31 (31)	68.27	39.07	46 (B)
08/12/1994	07:00:00	31 (31)	68.27	39.36	46 (B)
08/12/1994	07:15:00	31 (31)	68.28	39.67	46 (B)
08/12/1994	07:30:00	31 (31)	68.29	40.01	46 (B)
08/12/1994	07:45:00	31 (31)	68.29	40.36	46 (B)
08/12/1994	08:00:00	31 (31)	68.30	40.70	46 (B)
08/12/1994	08:15:00	31 (31)	68.22	41.05	46 (B)
08/12/1994	08:30:00	31 (31)	68.10	41.39	46 (B)
08/12/1994	08:45:00	31 (31)	67.98	41.74	46 (B)
08/12/1994	09:00:00	31 (31)	67.86	42.08	46 (B)
08/12/1994	09:15:00	31 (31)	67.74	42.43	46 (B)
08/12/1994	09:30:00	31 (31)	67.62	42.77	46 (B)
08/12/1994	09:45:00	31 (31)	67.49	43.12	46 (B)
08/12/1994	10:00:00	31 (31)	67.37	43.47	46 (B)
08/12/1994	10:15:00	31 (31)	67.25	43.82	46 (B)
08/12/1994	10:30:00	31 (31)	67.13	44.17	46 (B)
08/12/1994	10:45:00	31 (31)	67.01	44.52	46 (B)
08/12/1994	11:00:00	31 (31)	66.89	44.86	46 (B)
08/12/1994	11:15:00	31 (31)	66.77	45.21	46 (B)
08/12/1994	11:30:00	31 (31)	66.65	45.56	46 (B)
08/12/1994	11:45:00	31 (31)	66.53	45.91	46 (B)
08/12/1994	12:00:00	31 (31)	66.41	46.42	46 (B)
08/12/1994	12:15:00	31 (31)	66.29	46.94	46 (B)
08/12/1994	12:30:00	31 (31)	66.17	47.46	46 (B)
08/12/1994	12:45:00	31 (31)	66.05	47.98	46 (B)
08/12/1994	13:00:00	31 (31)	65.87	48.51	46 (B)
08/12/1994	13:15:00	31 (31)	65.63	49.03	46 (B)
08/12/1994	13:30:00	31 (31)	65.40	49.55	46 (B)
08/12/1994	13:45:00	31 (31)	65.16	50.07	46 (B)
08/12/1994	14:00:00	31 (31)	64.92	50.59	46 (B)
08/12/1994	14:15:00	31 (31)	64.69	51.11	46 (B)
08/12/1994	14:30:00	31 (31)	64.45	51.63	46 (B)
08/12/1994	14:45:00	31 (31)	64.21	52.14	46 (B)
08/12/1994	15:00:00	31 (31)	63.97	52.66	46 (B)
08/12/1994	15:15:00	31 (31)	63.74	53.18	46 (B)
08/12/1994	15:30:00	31 (31)	63.50	53.69	46 (B)
08/12/1994	15:45:00	31 (31)	63.26	54.19	46 (B)
08/12/1994	16:00:00	31 (31)	63.02	54.54	46 (B)
08/12/1994	16:15:00	31 (31)	62.79	54.89	46 (B)

08/12/1994	16:30:00	31 (31)	62.55	55.24	46 (B)
08/12/1994	16:45:00	31 (31)	62.31	55.58	46 (B)
08/12/1994	17:00:00	31 (31)	62.07	55.93	46 (B)
08/12/1994	17:15:00	31 (31)	61.84	56.28	46 (B)
08/12/1994	17:30:00	31 (31)	61.60	56.63	46 (B)
08/12/1994	17:45:00	31 (31)	61.36	56.98	46 (B)
08/12/1994	18:00:00	31 (31)	61.11	57.33	46 (B)
08/12/1994	18:15:00	31 (31)	60.85	57.63	46 (B)
08/12/1994	18:30:00	31 (31)	60.60	57.89	46 (B)
08/12/1994	18:45:00	31 (31)	60.34	58.15	46 (B)
08/12/1994	19:00:00	31 (31)	60.09	58.41	46 (B)
08/12/1994	19:15:00	31 (31)	59.84	58.67	46 (B)
08/12/1994	19:30:00	31 (31)	59.58	58.93	46 (B)
08/12/1994	19:45:00	31 (31)	59.33	59.18	46 (B)
08/12/1994	20:00:00	31 (31)	59.07	59.44	46 (B)
08/12/1994	20:15:00	31 (31)	58.82	59.48	46 (B)
08/12/1994	20:30:00	31 (31)	58.56	59.51	46 (B)
08/12/1994	20:45:00	31 (31)	58.32	59.53	46 (B)
08/12/1994	21:00:00	31 (31)	58.13	59.55	46 (B)
08/12/1994	21:15:00	31 (31)	57.94	59.58	46 (B)
08/12/1994	21:30:00	31 (31)	57.76	59.60	46 (B)
08/12/1994	21:45:00	31 (31)	57.57	59.63	46 (B)
08/12/1994	22:00:00	31 (31)	57.38	59.65	46 (B)
08/12/1994	22:15:00	31 (31)	57.19	59.67	46 (B)
08/12/1994	22:30:00	31 (31)	57.01	59.70	46 (B)
08/12/1994	22:45:00	31 (31)	56.82	59.72	46 (B)
08/12/1994	23:00:00	31 (31)	56.63	59.74	46 (B)
08/12/1994	23:15:00	31 (31)	56.44	59.77	46 (B)
08/12/1994	23:30:00	31 (31)	56.26	59.78	46 (B)
08/12/1994	23:45:00	31 (31)	56.07	59.77	46 (B)
09/12/1994	00:00:00	31 (31)	55.88	59.77	46 (B)
09/12/1994	00:15:00	31 (31)	55.69	59.76	46 (B)
09/12/1994	00:30:00	31 (31)	55.50	59.76	46 (B)
09/12/1994	00:45:00	31 (31)	55.30	59.75	46 (B)
09/12/1994	01:00:00	31 (31)	55.10	59.75	46 (B)
09/12/1994	01:15:00	31 (31)	54.90	59.74	46 (B)
09/12/1994	01:30:00	31 (31)	54.71	59.74	46 (B)
09/12/1994	01:45:00	31 (31)	54.51	59.73	46 (B)
09/12/1994	02:00:00	31 (31)	54.31	59.73	46 (B)
09/12/1994	02:15:00	31 (31)	54.11	59.72	46 (B)
09/12/1994	02:30:00	31 (31)	53.91	59.72	46 (B)
09/12/1994	02:45:00	31 (31)	53.71	59.53	46 (B)
09/12/1994	03:00:00	31 (31)	53.52	59.32	46 (B)
09/12/1994	03:15:00	31 (31)	53.32	59.12	46 (B)
09/12/1994	03:30:00	31 (31)	53.12	58.92	46 (B)
09/12/1994	03:45:00	31 (31)	52.92	58.71	46 (B)
09/12/1994	04:00:00	31 (31)	52.72	58.51	46 (B)
09/12/1994	04:15:00	31 (31)	52.52	58.31	46 (B)
09/12/1994	04:30:00	31 (31)	52.33	58.11	46 (B)
09/12/1994	04:45:00	31 (31)	52.13	57.90	46 (B)
09/12/1994	05:00:00	31 (31)	51.93	57.70	46 (B)
09/12/1994	05:15:00	31 (31)	51.73	57.50	46 (B)
09/12/1994	05:30:00	31 (31)	51.53	57.26	46 (B)
09/12/1994	05:45:00	31 (31)	51.33	57.00	46 (B)
09/12/1994	06:00:00	31 (31)	51.14	56.75	46 (B)
09/12/1994	06:15:00	31 (31)	50.96	56.49	46 (B)

09/12/1994	06:30:00	31 (31)	50.78	56.24	46 (B)
09/12/1994	06:45:00	31 (31)	50.59	55.98	46 (B)
09/12/1994	07:00:00	31 (31)	50.41	55.73	46 (B)
09/12/1994	07:15:00	31 (31)	50.23	55.47	46 (B)
09/12/1994	07:30:00	31 (31)	50.05	55.22	46 (B)
09/12/1994	07:45:00	31 (31)	49.87	54.96	46 (B)
09/12/1994	08:00:00	31 (31)	49.68	54.71	46 (B)
09/12/1994	08:15:00	31 (31)	49.50	54.45	46 (B)
09/12/1994	08:30:00	31 (31)	49.32	54.19	46 (B)
09/12/1994	08:45:00	31 (31)	49.14	53.94	46 (B)
09/12/1994	09:00:00	31 (31)	48.96	53.68	46 (B)
09/12/1994	09:15:00	31 (31)	48.78	53.43	46 (B)
09/12/1994	09:30:00	31 (31)	48.59	53.03	46 (B)
09/12/1994	09:45:00	31 (31)	48.41	52.62	46 (B)
09/12/1994	10:00:00	31 (31)	48.22	52.21	46 (B)
09/12/1994	10:15:00	31 (31)	48.01	51.81	46 (B)
09/12/1994	10:30:00	31 (31)	47.81	51.40	46 (B)
09/12/1994	10:45:00	31 (31)	47.61	50.99	46 (B)
09/12/1994	11:00:00	31 (31)	47.41	50.58	46 (B)
09/12/1994	11:15:00	31 (31)	47.20	50.48	46 (B)
09/12/1994	11:30:00	31 (31)	47.00	51.00	46 (B)
09/12/1994	11:45:00	31 (31)	46.80	51.47	46 (B)
09/12/1994	12:00:00	31 (31)	46.62	51.19	46 (B)
09/12/1994	12:15:00	31 (31)	46.45	50.91	46 (B)
09/12/1994	12:30:00	31 (31)	46.28	50.63	46 (B)
09/12/1994	12:45:00	31 (31)	46.11	50.35	46 (B)
09/12/1994	13:00:00	31 (31)	45.94	50.07	46 (B)
09/12/1994	13:15:00	31 (31)	45.77	49.78	46 (B)
09/12/1994	13:30:00	31 (31)	45.60	49.50	46 (B)
09/12/1994	13:45:00	31 (31)	45.44	49.22	46 (B)
09/12/1994	14:00:00	31 (31)	45.27	48.94	46 (B)
09/12/1994	14:15:00	31 (31)	45.10	48.66	46 (B)
09/12/1994	14:30:00	31 (31)	44.93	48.38	46 (B)
09/12/1994	14:45:00	31 (31)	44.76	48.10	46 (B)
09/12/1994	15:00:00	31 (31)	44.59	47.84	46 (B)
09/12/1994	15:15:00	31 (31)	44.42	47.60	46 (B)
09/12/1994	15:30:00	31 (31)	44.26	47.37	46 (B)
09/12/1994	15:45:00	31 (31)	44.13	47.13	46 (B)
09/12/1994	16:00:00	31 (31)	44.01	46.89	46 (B)
09/12/1994	16:15:00	31 (31)	43.88	46.66	46 (B)
09/12/1994	16:30:00	31 (31)	43.76	46.42	46 (B)
09/12/1994	16:45:00	31 (31)	43.63	46.18	46 (B)
09/12/1994	17:00:00	31 (31)	43.50	45.94	46 (B)
09/12/1994	17:15:00	31 (31)	43.38	45.71	46 (B)
09/12/1994	17:30:00	31 (31)	43.25	45.47	46 (B)
09/12/1994	17:45:00	31 (31)	43.12	45.27	46 (B)
09/12/1994	18:00:00	31 (31)	43.00	45.16	46 (B)
09/12/1994	18:15:00	31 (31)	42.87	45.04	46 (B)
09/12/1994	18:30:00	31 (31)	42.75	44.92	46 (B)
09/12/1994	18:45:00	31 (31)	42.62	44.80	46 (B)
09/12/1994	19:00:00	31 (31)	42.49	44.69	46 (B)
09/12/1994	19:15:00	31 (31)	42.37	44.57	46 (B)
09/12/1994	19:30:00	31 (31)	42.24	44.45	46 (B)
09/12/1994	19:45:00	31 (31)	42.11	44.34	46 (B)
09/12/1994	20:00:00	31 (31)	41.99	44.22	46 (B)
09/12/1994	20:15:00	31 (31)	41.88	44.10	46 (B)

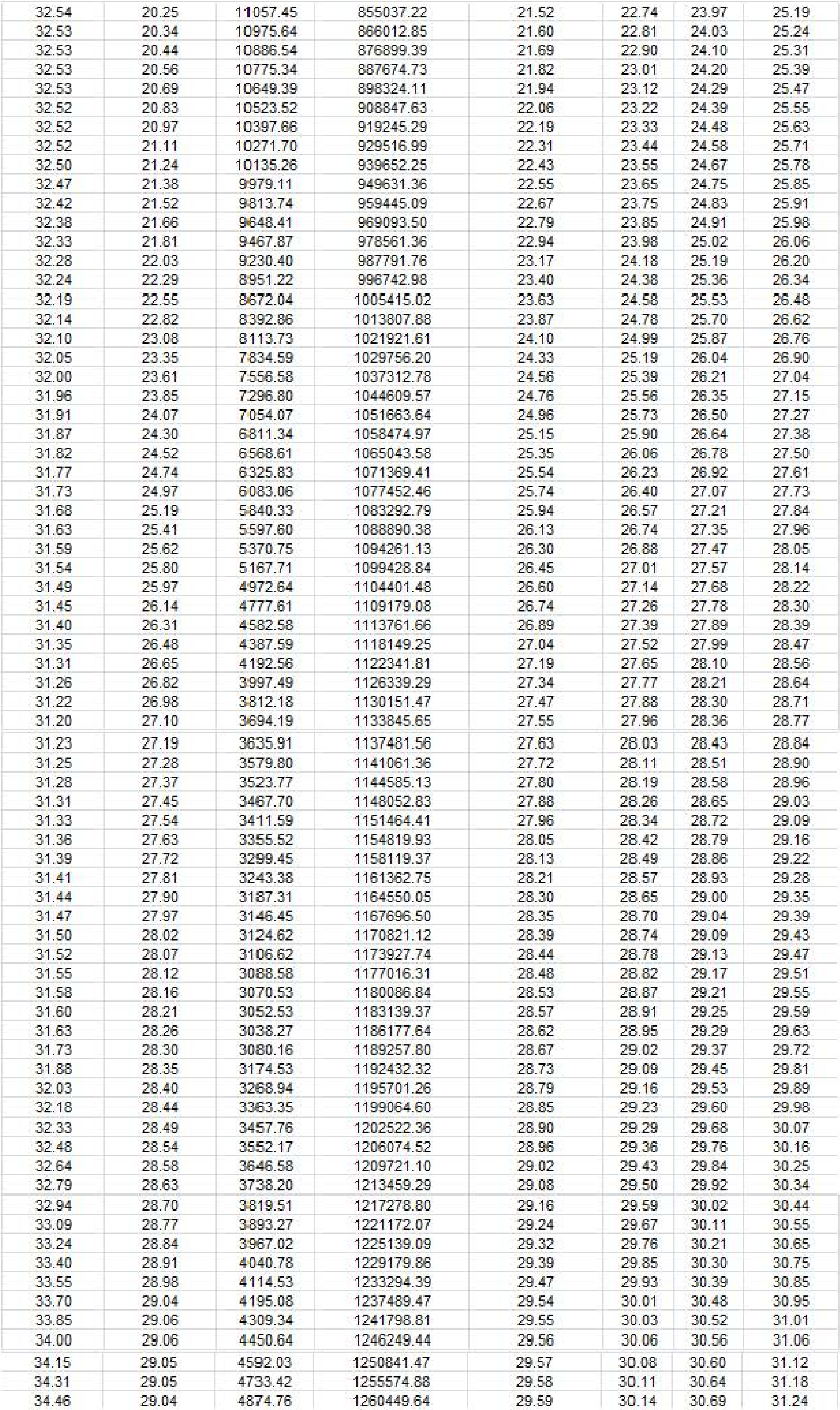
09/12/1994	20:30:00	31 (31)	41.78	43.98	46 (B)
09/12/1994	20:45:00	31 (31)	41.67	43.87	46 (B)
09/12/1994	21:00:00	31 (31)	41.56	43.75	46 (B)
09/12/1994	21:15:00	31 (31)	41.46	43.62	46 (B)
09/12/1994	21:30:00	31 (31)	41.35	43.50	46 (B)
09/12/1994	21:45:00	31 (31)	41.25	43.38	46 (B)
09/12/1994	22:00:00	31 (31)	41.14	43.25	46 (B)
09/12/1994	22:15:00	31 (31)	41.04	43.13	46 (B)
09/12/1994	22:30:00	31 (31)	40.93	43.01	46 (B)
09/12/1994	22:45:00	31 (31)	40.82	42.89	46 (B)
09/12/1994	23:00:00	31 (31)	40.72	42.76	46 (B)
09/12/1994	23:15:00	31 (31)	40.61	42.64	46 (B)
09/12/1994	23:30:00	31 (31)	40.51	42.52	46 (B)
09/12/1994	23:45:00	31 (31)	40.40	42.39	46 (B)
10/12/1994	00:00:00	31 (31)	40.30	42.27	46 (B)
10/12/1994	00:15:00	31 (31)	40.19	42.15	46 (B)
10/12/1994	00:30:00	31 (31)	40.09	42.03	46 (B)
10/12/1994	00:45:00	31 (31)	40.00	41.91	46 (B)
10/12/1994	01:00:00	31 (31)	39.90	41.79	46 (B)
10/12/1994	01:15:00	31 (31)	39.81	41.67	46 (B)
10/12/1994	01:30:00	31 (31)	39.72	41.54	46 (B)
10/12/1994	01:45:00	31 (31)	39.63	41.42	46 (B)
10/12/1994	02:00:00	31 (31)	39.53	41.30	46 (B)
10/12/1994	02:15:00	31 (31)	39.44	41.18	46 (B)
10/12/1994	02:30:00	31 (31)	39.35	41.06	46 (B)
10/12/1994	02:45:00	31 (31)	39.25	40.94	46 (B)
10/12/1994	03:00:00	31 (31)	39.16	40.82	46 (B)
10/12/1994	03:15:00	31 (31)	39.07	40.70	46 (B)
10/12/1994	03:30:00	31 (31)	38.98	40.57	46 (B)
10/12/1994	03:45:00	31 (31)	38.88	40.45	46 (B)
10/12/1994	04:00:00	31 (31)	38.79	40.33	46 (B)
10/12/1994	04:15:00	31 (31)	38.70	40.21	46 (B)
10/12/1994	04:30:00	31 (31)	38.60	40.09	46 (B)
10/12/1994	04:45:00	31 (31)	38.51	39.96	46 (B)
10/12/1994	05:00:00	31 (31)	38.42	39.84	46 (B)
10/12/1994	05:15:00	31 (31)	38.33	39.72	46 (B)
10/12/1994	05:30:00	31 (31)	38.25	39.60	46 (B)
10/12/1994	05:45:00	31 (31)	38.20	39.48	46 (B)
10/12/1994	06:00:00	31 (31)	38.16	39.35	46 (B)
10/12/1994	06:15:00	31 (31)	38.11	39.30	46 (B)
10/12/1994	06:30:00	31 (31)	38.07	39.24	46 (B)
10/12/1994	06:45:00	31 (31)	38.02	39.19	46 (B)
10/12/1994	07:00:00	31 (31)	37.97	39.13	46 (B)
10/12/1994	07:15:00	31 (31)	37.93	39.08	46 (B)
10/12/1994	07:30:00	31 (31)	37.88	39.02	46 (B)
10/12/1994	07:45:00	31 (31)	37.84	38.97	46 (B)
10/12/1994	08:00:00	31 (31)	37.79	38.91	46 (B)
10/12/1994	08:15:00	31 (31)	37.75	38.86	46 (B)
10/12/1994	08:30:00	31 (31)	37.70	38.80	46 (B)
10/12/1994	08:45:00	31 (31)	37.65	38.75	46 (B)
10/12/1994	09:00:00	31 (31)	37.61	38.69	46 (B)
10/12/1994	09:15:00	31 (31)	37.56	38.64	46 (B)
10/12/1994	09:30:00	31 (31)	37.52	38.58	46 (B)
10/12/1994	09:45:00	31 (31)	37.47	38.53	46 (B)
10/12/1994	10:00:00	31 (31)	37.43	38.47	46 (B)
10/12/1994	10:15:00	31 (31)	37.38	38.42	46 (B)

10/12/1994	10:30:00	31 (31)	37.33	38.37	46 (B)
10/12/1994	10:45:00	31 (31)	37.29	38.32	46 (B)
10/12/1994	11:00:00	31 (31)	37.24	38.28	46 (B)
10/12/1994	11:15:00	31 (31)	37.20	38.23	46 (B)
10/12/1994	11:30:00	31 (31)	37.15	38.18	46 (B)
10/12/1994	11:45:00	31 (31)	37.10	38.14	46 (B)
10/12/1994	12:00:00	31 (31)	37.06	38.09	46 (B)
10/12/1994	12:15:00	31 (31)	37.01	38.04	46 (B)
10/12/1994	12:30:00	31 (31)	36.97	38.00	46 (B)
10/12/1994	12:45:00	31 (31)	36.92	37.95	46 (B)
10/12/1994	13:00:00	31 (31)	36.88	37.90	46 (B)
10/12/1994	13:15:00	31 (31)	36.83	37.86	46 (B)
10/12/1994	13:30:00	31 (31)	36.78	37.81	46 (B)
10/12/1994	13:45:00	31 (31)	36.74	37.76	46 (B)
10/12/1994	14:00:00	31 (31)	36.69	37.71	46 (B)
10/12/1994	14:15:00	31 (31)	36.65	37.67	46 (B)
10/12/1994	14:30:00	31 (31)	36.61	37.62	46 (B)
10/12/1994	14:45:00	31 (31)	36.58	37.57	46 (B)
10/12/1994	15:00:00	31 (31)	36.55	37.51	46 (B)
10/12/1994	15:15:00	31 (31)	36.52	37.45	46 (B)
10/12/1994	15:30:00	31 (31)	36.49	37.38	46 (B)
10/12/1994	15:45:00	31 (31)	36.46	37.32	46 (B)
10/12/1994	16:00:00	31 (31)	36.43	37.25	46 (B)
10/12/1994	16:15:00	31 (31)	36.40	37.19	46 (B)
10/12/1994	16:30:00	31 (31)	36.37	37.12	46 (B)
10/12/1994	16:45:00	31 (31)	36.34	37.06	46 (B)
10/12/1994	17:00:00	31 (31)	36.31	37.00	46 (B)
10/12/1994	17:15:00	31 (31)	36.28	36.93	46 (B)
10/12/1994	17:30:00	31 (31)	36.24	36.87	46 (B)
10/12/1994	17:45:00	31 (31)	36.21	36.80	46 (B)
10/12/1994	18:00:00	31 (31)	36.18	36.74	46 (B)
10/12/1994	18:15:00	31 (31)	36.15	36.67	46 (B)
10/12/1994	18:30:00	31 (31)	36.12	36.65	46 (B)
10/12/1994	18:45:00	31 (31)	36.09	36.64	46 (B)
10/12/1994	19:00:00	31 (31)	36.06	36.62	46 (B)
10/12/1994	19:15:00	31 (31)	36.03	36.61	46 (B)
10/12/1994	19:30:00	31 (31)	36.00	36.59	46 (B)
10/12/1994	19:45:00	31 (31)	35.97	36.58	46 (B)
10/12/1994	20:00:00	31 (31)	35.94	36.56	46 (B)
10/12/1994	20:15:00	31 (31)	35.91	36.55	46 (B)
10/12/1994	20:30:00	31 (31)	35.88	36.53	46 (B)
10/12/1994	20:45:00	31 (31)	35.85	36.52	46 (B)
10/12/1994	21:00:00	31 (31)	35.82	36.51	46 (B)
10/12/1994	21:15:00	31 (31)	35.79	36.49	46 (B)
10/12/1994	21:30:00	31 (31)	35.75	36.48	46 (B)
10/12/1994	21:45:00	31 (31)	35.72	36.46	46 (B)
10/12/1994	22:00:00	31 (31)	35.69	36.45	46 (B)
10/12/1994	22:15:00	31 (31)	35.66	36.43	46 (B)
10/12/1994	22:30:00	31 (31)	35.63	36.42	46 (B)
10/12/1994	22:45:00	31 (31)	35.60	36.40	46 (B)
10/12/1994	23:00:00	31 (31)	35.57	36.39	46 (B)
10/12/1994	23:15:00	31 (31)	35.54	36.37	46 (B)
10/12/1994	23:30:00	31 (31)	35.51	36.36	46 (B)
10/12/1994	23:45:00	31 (31)	35.48	36.34	46 (B)
11/12/1994	00:00:00	31 (31)	35.44	36.33	46 (B)
11/12/1994	00:15:00	31 (31)	35.41	36.31	46 (B)

11/12/1994	00:30:00	31 (31)	35.38	36.29	46 (B)
11/12/1994	00:45:00	31 (31)	35.35	36.27	46 (B)
11/12/1994	01:00:00	31 (31)	35.31	36.25	46 (B)
11/12/1994	01:15:00	31 (31)	35.28	36.23	46 (B)
11/12/1994	01:30:00	31 (31)	35.25	36.21	46 (B)
11/12/1994	01:45:00	31 (31)	35.21	36.18	46 (B)
11/12/1994	02:00:00	31 (31)	35.18	36.16	46 (B)
11/12/1994	02:15:00	31 (31)	35.15	36.14	46 (B)
11/12/1994	02:30:00	31 (31)	35.12	36.12	46 (B)
11/12/1994	02:45:00	31 (31)	35.08	36.10	46 (B)
11/12/1994	03:00:00	31 (31)	35.05	36.08	46 (B)
11/12/1994	03:15:00	31 (31)	35.02	36.06	46 (B)
11/12/1994	03:30:00	31 (31)	34.98	36.04	46 (B)
11/12/1994	03:45:00	31 (31)	34.95	36.01	46 (B)
11/12/1994	04:00:00	31 (31)	34.92	35.99	46 (B)
11/12/1994	04:15:00	31 (31)	34.89	35.97	46 (B)
11/12/1994	04:30:00	31 (31)	34.85	35.95	46 (B)
11/12/1994	04:45:00	31 (31)	34.82	35.94	46 (B)
11/12/1994	05:00:00	31 (31)	34.79	35.94	46 (B)
11/12/1994	05:15:00	31 (31)	34.75	35.94	46 (B)
11/12/1994	05:30:00	31 (31)	34.72	35.93	46 (B)
11/12/1994	05:45:00	31 (31)	34.69	35.93	46 (B)
11/12/1994	06:00:00	31 (31)	34.66	35.93	46 (B)
11/12/1994	06:15:00	31 (31)	34.62	35.93	46 (B)
11/12/1994	06:30:00	31 (31)	34.59	35.93	46 (B)
11/12/1994	06:45:00	31 (31)	34.56	35.93	46 (B)
11/12/1994	07:00:00	31 (31)	34.53	35.92	46 (B)
11/12/1994	07:15:00	31 (31)	34.49	35.92	46 (B)
11/12/1994	07:30:00	31 (31)	34.46	35.92	46 (B)
11/12/1994	07:45:00	31 (31)	34.43	35.92	46 (B)
11/12/1994	08:00:00	31 (31)	34.39	35.92	46 (B)
11/12/1994	08:15:00	31 (31)	34.36	35.92	46 (B)
11/12/1994	08:30:00	31 (31)	34.36	35.92	46 (B)

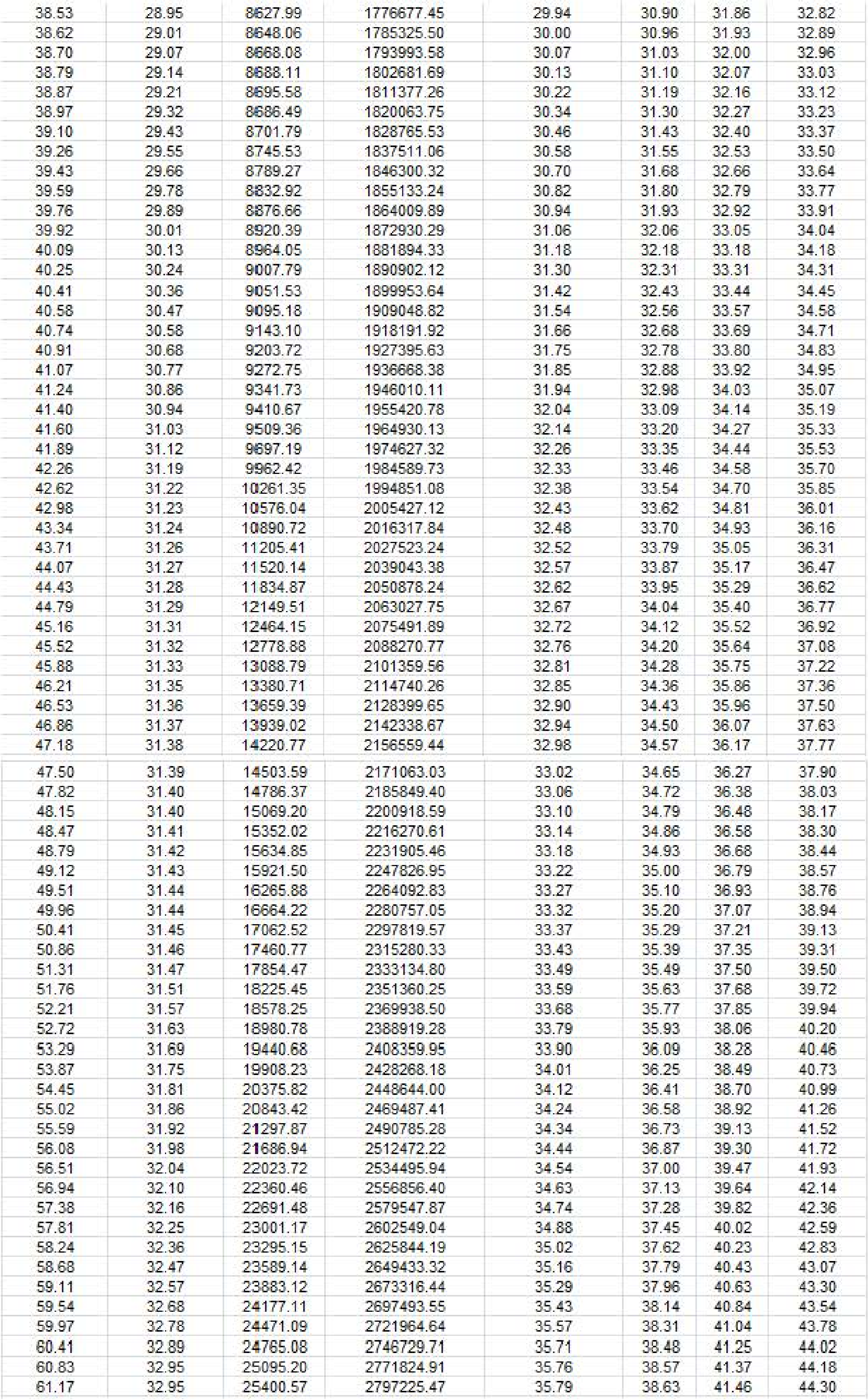
Table 4.6 *Storage calculation using the Muskingum method for flood event (4/12 – 11/12)1994.*

		Δt (sec)	900.00				
				Different estimation for weighting factor (X)			
Average Inflow[m3/s]	**Average Outflow[m3/s]**	**Change in Storage[m3]**	**Cumulative Storage (S)[m3]**	**0.10**	**0.20**	**0.30**	**0.40**
				Weighted Average Flux: X*I+(1-X)*O			
			0.00	20.24	20.25	20.25	20.26
20.39	20.23	143.14	143.14	20.25	20.28	20.30	20.33
20.58	20.22	324.90	468.04	20.27	20.31	20.36	20.40
20.78	20.22	506.70	974.74	20.28	20.34	20.41	20.48
20.97	20.21	688.50	1663.24	20.29	20.38	20.46	20.55
21.17	20.20	870.30	2533.55	20.30	20.41	20.52	20.62
21.36	20.19	1052.10	3585.65	20.32	20.44	20.57	20.70
21.56	20.19	1233.90	4819.55	20.33	20.48	20.62	20.77
21.75	20.18	1415.70	6235.25	20.34	20.51	20.68	20.84
21.95	20.17	1597.46	7832.70	20.35	20.54	20.73	20.92
22.14	20.16	1779.21	9611.91	20.37	20.57	20.78	20.99
22.33	20.16	1961.06	11572.97	20.38	20.61	20.84	21.06
22.53	20.15	2142.90	13715.87	20.39	20.64	20.89	21.14
22.72	20.14	2324.70	16040.57	20.41	20.67	20.94	21.21
22.92	20.13	2506.50	18547.07	20.42	20.71	21.00	21.28
23.11	20.13	2688.30	21235.37	20.43	20.74	21.05	21.36
23.33	20.12	2890.58	24125.94	20.45	20.78	21.12	21.45
23.63	20.11	3168.72	27294.66	20.48	20.85	21.22	21.59
24.00	20.11	3502.22	30796.88	20.52	20.92	21.33	21.74
24.37	20.11	3835.71	34632.59	20.55	21.00	21.44	21.89
24.74	20.11	4169.16	38801.75	20.59	21.07	21.55	22.03
25.11	20.10	4502.61	43304.36	20.62	21.14	21.66	22.18
25.47	20.10	4836.15	48140.51	20.65	21.21	21.77	22.32
25.84	20.10	5169.65	53310.15	20.69	21.28	21.87	22.47
26.21	20.09	5503.14	58813.29	20.72	21.35	21.98	22.61
26.58	20.09	5836.59	64649.88	20.76	21.42	22.09	22.76
26.93	20.09	6152.94	70802.82	20.79	21.49	22.19	22.89
27.20	20.09	6405.21	77208.03	20.81	21.53	22.25	22.98
27.43	20.08	6610.41	83818.44	20.83	21.57	22.32	23.07
27.65	20.08	6815.61	90634.05	20.85	21.62	22.39	23.15
27.88	20.08	7020.77	97654.82	20.87	21.66	22.45	23.24
28.10	20.08	7225.92	104880.74	20.89	21.70	22.52	23.33
28.33	20.07	7431.12	112311.86	20.91	21.75	22.58	23.42
28.56	20.07	7636.32	119948.18	20.93	21.79	22.65	23.51
28.78	20.07	7841.52	127789.70	20.95	21.83	22.71	23.60
29.01	20.07	8046.72	135836.42	20.97	21.88	22.78	23.69
29.23	20.06	8251.92	144088.34	20.99	21.92	22.85	23.77
29.46	20.06	8457.12	152545.46	21.01	21.96	22.91	23.86
29.67	20.06	8651.21	161196.66	21.03	22.00	22.97	23.94
29.85	20.04	8821.49	170018.15	21.02	22.01	23.00	23.99
30.00	20.02	8979.12	178997.27	21.01	22.02	23.03	24.03
30.15	20.00	9136.71	188133.98	21.01	22.03	23.06	24.08
30.30	19.97	9294.30	197428.28	21.00	22.04	23.09	24.13
30.45	19.95	9451.94	206880.21	21.00	22.06	23.11	24.17
30.60	19.93	9609.57	216489.78	20.99	22.07	23.14	24.22
30.75	19.90	9767.16	226256.94	20.98	22.08	23.17	24.27
30.91	19.88	9924.75	236181.69	20.98	22.09	23.20	24.31
31.06	19.85	10082.39	246264.08	20.97	22.10	23.23	24.36
31.21	19.83	10239.98	256504.05	20.97	22.11	23.26	24.40
31.36	19.81	10397.57	266901.62	20.96	22.12	23.29	24.45
31.51	19.78	10555.20	277456.82	20.95	22.13	23.32	24.50
31.66	19.76	10712.79	288169.61	20.95	22.15	23.34	24.54
31.81	19.74	10870.34	299039.94	20.94	22.16	23.37	24.59
31.91	19.71	10981.71	310021.65	20.92	22.15	23.37	24.60
31.96	19.69	11043.54	321065.19	20.91	22.14	23.37	24.60
32.00	19.66	11102.04	332167.23	20.89	22.13	23.36	24.60
32.04	19.64	11160.54	343327.77	20.87	22.12	23.36	24.60
32.08	19.62	11219.04	354546.81	20.85	22.10	23.35	24.60
32.12	19.59	11277.54	365824.35	20.84	22.09	23.35	24.61
32.16	19.57	11336.09	377160.44	20.82	22.08	23.35	24.61
32.21	19.55	11394.59	388555.02	20.80	22.07	23.34	24.61
32.25	19.53	11447.01	400002.03	20.80	22.07	23.35	24.62



32.54	20.25	11057.45	855037.22	21.52	22.74	23.97	25.19
32.53	20.34	10975.64	866012.85	21.60	22.81	24.03	25.24
32.53	20.44	10886.54	876899.39	21.69	22.90	24.10	25.31
32.53	20.56	10775.34	887674.73	21.82	23.01	24.20	25.39
32.53	20.69	10649.39	898324.11	21.94	23.12	24.29	25.47
32.52	20.83	10523.52	908847.63	22.06	23.22	24.39	25.55
32.52	20.97	10397.66	919245.29	22.19	23.33	24.48	25.63
32.52	21.11	10271.70	929516.99	22.31	23.44	24.58	25.71
32.50	21.24	10135.26	939652.25	22.43	23.55	24.67	25.78
32.47	21.38	9979.11	949631.36	22.55	23.65	24.75	25.85
32.42	21.52	9813.74	959445.09	22.67	23.75	24.83	25.91
32.38	21.66	9648.41	969093.50	22.79	23.85	24.91	25.98
32.33	21.81	9467.87	978561.36	22.94	23.98	25.02	26.06
32.28	22.03	9230.40	987791.76	23.17	24.18	25.19	26.20
32.24	22.29	8951.22	996742.98	23.40	24.38	25.36	26.34
32.19	22.55	8672.04	1005415.02	23.63	24.58	25.53	26.48
32.14	22.82	8392.86	1013807.88	23.87	24.78	25.70	26.62
32.10	23.08	8113.73	1021921.61	24.10	24.99	25.87	26.76
32.05	23.35	7834.59	1029756.20	24.33	25.19	26.04	26.90
32.00	23.61	7556.58	1037312.78	24.56	25.39	26.21	27.04
31.96	23.85	7296.80	1044609.57	24.76	25.56	26.35	27.15
31.91	24.07	7054.07	1051663.64	24.96	25.73	26.50	27.27
31.87	24.30	6811.34	1058474.97	25.15	25.90	26.64	27.38
31.82	24.52	6568.61	1065043.58	25.35	26.06	26.78	27.50
31.77	24.74	6325.83	1071369.41	25.54	26.23	26.92	27.61
31.73	24.97	6083.06	1077452.46	25.74	26.40	27.07	27.73
31.68	25.19	5840.33	1083292.79	25.94	26.57	27.21	27.84
31.63	25.41	5597.60	1088890.38	26.13	26.74	27.35	27.96
31.59	25.62	5370.75	1094261.13	26.30	26.88	27.47	28.05
31.54	25.80	5167.71	1099428.84	26.45	27.01	27.57	28.14
31.49	25.97	4972.64	1104401.48	26.60	27.14	27.68	28.22
31.45	26.14	4777.61	1109179.08	26.74	27.26	27.78	28.30
31.40	26.31	4582.58	1113761.66	26.89	27.39	27.89	28.39
31.35	26.48	4387.59	1118149.25	27.04	27.52	27.99	28.47
31.31	26.65	4192.56	1122341.81	27.19	27.65	28.10	28.56
31.26	26.82	3997.49	1126339.29	27.34	27.77	28.21	28.64
31.22	26.98	3812.18	1130151.47	27.47	27.88	28.30	28.71
31.20	27.10	3694.19	1133845.65	27.55	27.96	28.36	28.77
31.23	27.19	3635.91	1137481.56	27.63	28.03	28.43	28.84
31.25	27.28	3579.80	1141061.36	27.72	28.11	28.51	28.90
31.28	27.37	3523.77	1144585.13	27.80	28.19	28.58	28.96
31.31	27.45	3467.70	1148052.83	27.88	28.26	28.65	29.03
31.33	27.54	3411.59	1151464.41	27.96	28.34	28.72	29.09
31.36	27.63	3355.52	1154819.93	28.05	28.42	28.79	29.16
31.39	27.72	3299.45	1158119.37	28.13	28.49	28.86	29.22
31.41	27.81	3243.38	1161362.75	28.21	28.57	28.93	29.28
31.44	27.90	3187.31	1164550.05	28.30	28.65	29.00	29.35
31.47	27.97	3146.45	1167696.50	28.35	28.70	29.04	29.39
31.50	28.02	3124.62	1170821.12	28.39	28.74	29.09	29.43
31.52	28.07	3106.62	1173927.74	28.44	28.78	29.13	29.47
31.55	28.12	3088.58	1177016.31	28.48	28.82	29.17	29.51
31.58	28.16	3070.53	1180086.84	28.53	28.87	29.21	29.55
31.60	28.21	3052.53	1183139.37	28.57	28.91	29.25	29.59
31.63	28.26	3038.27	1186177.64	28.62	28.95	29.29	29.63
31.73	28.30	3080.16	1189257.80	28.67	29.02	29.37	29.72
31.88	28.35	3174.53	1192432.32	28.73	29.09	29.45	29.81
32.03	28.40	3268.94	1195701.26	28.79	29.16	29.53	29.89
32.18	28.44	3363.35	1199064.60	28.85	29.23	29.60	29.98
32.33	28.49	3457.76	1202522.36	28.90	29.29	29.68	30.07
32.48	28.54	3552.17	1206074.52	28.96	29.36	29.76	30.16
32.64	28.58	3646.58	1209721.10	29.02	29.43	29.84	30.25
32.79	28.63	3738.20	1213459.29	29.08	29.50	29.92	30.34
32.94	28.70	3819.51	1217278.80	29.16	29.59	30.02	30.44
33.09	28.77	3893.27	1221172.07	29.24	29.67	30.11	30.55
33.24	28.84	3967.02	1225139.09	29.32	29.76	30.21	30.65
33.40	28.91	4040.78	1229179.86	29.39	29.85	30.30	30.75
33.55	28.98	4114.53	1233294.39	29.47	29.93	30.39	30.85
33.70	29.04	4195.08	1237489.47	29.54	30.01	30.48	30.95
33.85	29.06	4309.34	1241798.81	29.55	30.03	30.52	31.01
34.00	29.06	4450.64	1246249.44	29.56	30.06	30.56	31.06
34.15	29.05	4592.03	1250841.47	29.57	30.08	30.60	31.12
34.31	29.05	4733.42	1255574.88	29.58	30.11	30.64	31.18
34.46	29.04	4874.76	1260449.64	29.59	30.14	30.69	31.24

34.61	29.04	5016.11	1265465.75	29.60	30.16	30.73	31.29
34.74	29.03	5137.70	1270603.44	29.60	30.18	30.76	31.33
34.83	29.02	5222.16	1275825.60	29.61	30.19	30.77	31.36
34.90	29.02	5289.30	1281114.90	29.61	30.20	30.79	31.38
34.97	29.01	5356.44	1286471.34	29.61	30.21	30.81	31.41
35.03	29.01	5423.63	1291894.97	29.61	30.22	30.82	31.43
35.10	29.00	5490.81	1297385.78	29.61	30.23	30.84	31.46
35.17	29.00	5557.95	1302943.73	29.62	30.24	30.86	31.48
35.24	28.99	5625.14	1308568.86	29.62	30.25	30.88	31.50
35.31	28.99	5692.32	1314261.18	29.62	30.26	30.89	31.53
35.38	28.98	5759.46	1320020.64	29.62	30.27	30.91	31.55
35.45	28.98	5826.60	1325847.24	29.62	30.28	30.93	31.58
35.52	28.97	5893.79	1331741.03	29.63	30.29	30.94	31.60
35.59	28.96	5969.61	1337710.64	29.61	30.28	30.95	31.62
35.66	28.93	6054.12	1343764.76	29.60	30.27	30.95	31.63
35.73	28.91	6138.63	1349903.39	29.58	30.27	30.95	31.64
35.80	28.88	6223.14	1356126.53	29.57	30.26	30.96	31.65
35.87	28.86	6307.65	1362434.18	29.55	30.26	30.96	31.67
35.93	28.83	6392.16	1368826.34	29.53	30.25	30.96	31.68
36.00	28.81	6476.72	1375303.05	29.52	30.24	30.97	31.69
36.07	28.78	6561.23	1381864.28	29.50	30.24	30.97	31.71
36.12	28.76	6625.08	1388489.36	29.48	30.22	30.96	31.70
36.13	28.73	6660.81	1395150.17	29.46	30.20	30.95	31.69
36.14	28.71	6689.03	1401839.19	29.44	30.19	30.93	31.68
36.15	28.68	6717.24	1408556.43	29.42	30.17	30.92	31.66
36.15	28.66	6745.50	1415301.93	29.40	30.15	30.90	31.65
36.16	28.64	6773.76	1422075.69	29.38	30.13	30.89	31.64
36.17	28.61	6801.98	1428877.67	29.36	30.11	30.87	31.63
36.17	28.59	6830.19	1435707.86	29.33	30.09	30.85	31.62
36.18	28.56	6858.41	1442566.26	29.31	30.08	30.84	31.60
36.19	28.54	6886.62	1449452.88	29.29	30.06	30.82	31.59
36.20	28.51	6915.33	1456368.21	29.27	30.04	30.81	31.58
36.20	28.49	6945.03	1463313.24	29.25	30.02	30.79	31.57
36.21	28.46	6975.18	1470288.42	29.22	30.00	30.78	31.55
36.22	28.43	7005.29	1477293.71	29.20	29.98	30.76	31.54
36.22	28.40	7035.39	1484329.10	29.17	29.96	30.74	31.53
36.23	28.38	7065.50	1491394.59	29.15	29.94	30.72	31.51
36.24	28.35	7095.60	1498490.19	29.13	29.92	30.71	31.50
36.24	28.32	7125.71	1505615.90	29.10	29.90	30.69	31.48
36.25	28.30	7155.86	1512771.75	29.08	29.88	30.67	31.47
36.26	28.27	7185.96	1519957.71	29.06	29.86	30.66	31.46
36.26	28.24	7216.07	1527173.78	29.03	29.84	30.64	31.44
36.27	28.22	7246.17	1534419.95	29.01	29.82	30.62	31.43
36.28	28.19	7276.28	1541696.22	28.99	29.80	30.61	31.42
36.28	28.16	7306.38	1549002.60	28.96	29.78	30.59	31.40
36.29	28.14	7336.53	1556339.13	28.94	29.76	30.57	31.39
36.32	28.13	7376.27	1563715.40	28.95	29.77	30.60	31.42
36.39	28.13	7437.38	1571152.77	28.96	29.79	30.62	31.45
36.48	28.14	7510.32	1578663.09	28.98	29.81	30.65	31.49
36.57	28.14	7583.27	1586246.36	28.99	29.84	30.68	31.53
36.65	28.14	7656.21	1593902.57	29.00	29.86	30.71	31.57
36.74	28.15	7729.16	1601631.72	29.01	29.88	30.74	31.60
36.82	28.15	7802.10	1609433.82	29.03	29.90	30.77	31.64
36.91	28.16	7875.05	1617308.87	29.04	29.92	30.80	31.68
36.99	28.16	7947.99	1625256.86	29.05	29.94	30.83	31.71
37.08	28.17	8020.94	1633277.79	29.06	29.96	30.85	31.75
37.16	28.17	8093.88	1641371.67	29.08	29.98	30.88	31.79
37.25	28.18	8166.83	1649538.50	29.09	30.00	30.91	31.82
37.33	28.18	8239.77	1657778.27	29.10	30.02	30.94	31.86
37.42	28.18	8312.72	1666090.98	29.11	30.04	30.97	31.90
37.51	28.20	8373.33	1674464.31	29.15	30.08	31.02	31.95
37.59	28.25	8407.49	1682871.80	29.22	30.15	31.09	32.02
37.68	28.31	8427.56	1691299.35	29.28	30.22	31.16	32.09
37.76	28.38	8447.63	1699746.98	29.35	30.29	31.23	32.17
37.85	28.44	8467.65	1708214.63	29.41	30.36	31.30	32.24
37.93	28.50	8487.68	1716702.30	29.48	30.42	31.37	32.31
38.02	28.57	8507.75	1725210.05	29.54	30.49	31.44	32.38
38.10	28.63	8527.82	1733737.86	29.61	30.56	31.51	32.46
38.19	28.69	8547.84	1742285.70	29.67	30.63	31.58	32.53
38.28	28.76	8567.87	1750853.57	29.74	30.69	31.65	32.60
38.36	28.82	8587.94	1759441.50	29.81	30.76	31.72	32.67
38.45	28.88	8607.96	1768049.46	29.87	30.83	31.79	32.74



38.53	28.95	8627.99	1776677.45	29.94	30.90	31.86	32.82
38.62	29.01	8648.06	1785325.50	30.00	30.96	31.93	32.89
38.70	29.07	8668.08	1793993.58	30.07	31.03	32.00	32.96
38.79	29.14	8688.11	1802681.69	30.13	31.10	32.07	33.03
38.87	29.21	8695.58	1811377.26	30.22	31.19	32.16	33.12
38.97	29.32	8686.49	1820063.75	30.34	31.30	32.27	33.23
39.10	29.43	8701.79	1828765.53	30.46	31.43	32.40	33.37
39.26	29.55	8745.53	1837511.06	30.58	31.55	32.53	33.50
39.43	29.66	8789.27	1846300.32	30.70	31.68	32.66	33.64
39.59	29.78	8832.92	1855133.24	30.82	31.80	32.79	33.77
39.76	29.89	8876.66	1864009.89	30.94	31.93	32.92	33.91
39.92	30.01	8920.39	1872930.29	31.06	32.06	33.05	34.04
40.09	30.13	8964.05	1881894.33	31.18	32.18	33.18	34.18
40.25	30.24	9007.79	1890902.12	31.30	32.31	33.31	34.31
40.41	30.36	9051.53	1899953.64	31.42	32.43	33.44	34.45
40.58	30.47	9095.18	1909048.82	31.54	32.56	33.57	34.58
40.74	30.58	9143.10	1918191.92	31.66	32.68	33.69	34.71
40.91	30.68	9203.72	1927395.63	31.75	32.78	33.80	34.83
41.07	30.77	9272.75	1936668.38	31.85	32.88	33.92	34.95
41.24	30.86	9341.73	1946010.11	31.94	32.98	34.03	35.07
41.40	30.94	9410.67	1955420.78	32.04	33.09	34.14	35.19
41.60	31.03	9509.36	1964930.13	32.14	33.20	34.27	35.33
41.89	31.12	9697.19	1974627.32	32.26	33.35	34.44	35.53
42.26	31.19	9962.42	1984589.73	32.33	33.46	34.58	35.70
42.62	31.22	10261.35	1994851.08	32.38	33.54	34.70	35.85
42.98	31.23	10576.04	2005427.12	32.43	33.62	34.81	36.01
43.34	31.24	10890.72	2016317.84	32.48	33.70	34.93	36.16
43.71	31.26	11205.41	2027523.24	32.52	33.79	35.05	36.31
44.07	31.27	11520.14	2039043.38	32.57	33.87	35.17	36.47
44.43	31.28	11834.87	2050878.24	32.62	33.95	35.29	36.62
44.79	31.29	12149.51	2063027.75	32.67	34.04	35.40	36.77
45.16	31.31	12464.15	2075491.89	32.72	34.12	35.52	36.92
45.52	31.32	12778.88	2088270.77	32.76	34.20	35.64	37.08
45.88	31.33	13088.79	2101359.56	32.81	34.28	35.75	37.22
46.21	31.35	13380.71	2114740.26	32.85	34.36	35.86	37.36
46.53	31.36	13659.39	2128399.65	32.90	34.43	35.96	37.50
46.86	31.37	13939.02	2142338.67	32.94	34.50	36.07	37.63
47.18	31.38	14220.77	2156559.44	32.98	34.57	36.17	37.77
47.50	31.39	14503.59	2171063.03	33.02	34.65	36.27	37.90
47.82	31.40	14786.37	2185849.40	33.06	34.72	36.38	38.03
48.15	31.40	15069.20	2200918.59	33.10	34.79	36.48	38.17
48.47	31.41	15352.02	2216270.61	33.14	34.86	36.58	38.30
48.79	31.42	15634.85	2231905.46	33.18	34.93	36.68	38.44
49.12	31.43	15921.50	2247826.95	33.22	35.00	36.79	38.57
49.51	31.44	16265.88	2264092.83	33.27	35.10	36.93	38.76
49.96	31.44	16664.22	2280757.05	33.32	35.20	37.07	38.94
50.41	31.45	17062.52	2297819.57	33.37	35.29	37.21	39.13
50.86	31.46	17460.77	2315280.33	33.43	35.39	37.35	39.31
51.31	31.47	17854.47	2333134.80	33.49	35.49	37.50	39.50
51.76	31.51	18225.45	2351360.25	33.59	35.63	37.68	39.72
52.21	31.57	18578.25	2369938.50	33.68	35.77	37.85	39.94
52.72	31.63	18980.78	2388919.28	33.79	35.93	38.06	40.20
53.29	31.69	19440.68	2408359.95	33.90	36.09	38.28	40.46
53.87	31.75	19908.23	2428268.18	34.01	36.25	38.49	40.73
54.45	31.81	20375.82	2448644.00	34.12	36.41	38.70	40.99
55.02	31.86	20843.42	2469487.41	34.24	36.58	38.92	41.26
55.59	31.92	21297.87	2490785.28	34.34	36.73	39.13	41.52
56.08	31.98	21686.94	2512472.22	34.44	36.87	39.30	41.72
56.51	32.04	22023.72	2534495.94	34.54	37.00	39.47	41.93
56.94	32.10	22360.46	2556856.40	34.63	37.13	39.64	42.14
57.38	32.16	22691.48	2579547.87	34.74	37.28	39.82	42.36
57.81	32.25	23001.17	2602549.04	34.88	37.45	40.02	42.59
58.24	32.36	23295.15	2625844.19	35.02	37.62	40.23	42.83
58.68	32.47	23589.14	2649433.32	35.16	37.79	40.43	43.07
59.11	32.57	23883.12	2673316.44	35.29	37.96	40.63	43.30
59.54	32.68	24177.11	2697493.55	35.43	38.14	40.84	43.54
59.97	32.78	24471.09	2721964.64	35.57	38.31	41.04	43.78
60.41	32.89	24765.08	2746729.71	35.71	38.48	41.25	44.02
60.83	32.95	25095.20	2771824.91	35.76	38.57	41.37	44.18
61.17	32.95	25400.57	2797225.47	35.79	38.63	41.46	44.30

61.45	32.96	25645.10	2822870.57	35.82	38.69	41.55	44.41
61.73	32.96	25889.63	2848760.19	35.85	38.74	41.64	44.53
62.00	32.97	26134.16	2874894.35	35.89	38.80	41.72	44.64
62.28	32.97	26378.73	2901273.08	35.92	38.86	41.81	44.75
62.56	33.00	26603.82	2927876.90	35.99	38.96	41.93	44.89
62.84	33.07	26792.42	2954669.31	36.10	39.08	42.07	45.06
63.11	33.15	26964.00	2981633.31	36.20	39.21	42.21	45.22
63.39	33.24	27135.54	3008768.85	36.31	39.33	42.36	45.38
63.67	33.33	27307.17	3036076.02	36.41	39.46	42.50	45.54
64.00	33.41	27528.03	3063604.05	36.53	39.60	42.68	45.75
64.54	33.50	27933.57	3091537.62	36.67	39.81	42.94	46.08
65.22	33.58	28474.56	3120012.18	36.82	40.01	43.21	46.40
65.91	33.67	29015.51	3149027.69	36.97	40.22	43.48	46.73
66.35	33.76	29329.65	3178357.34	37.08	40.34	43.61	46.87
66.54	33.92	29351.52	3207708.86	37.29	40.55	43.81	47.07
66.70	34.14	29307.96	3237016.82	37.50	40.75	44.01	47.26
66.87	34.35	29264.40	3266281.22	37.71	40.96	44.21	47.46
67.03	34.57	29220.80	3295502.01	37.92	41.16	44.41	47.65
67.20	34.78	29177.19	3324679.20	38.13	41.37	44.60	47.84
67.36	34.99	29133.63	3353812.83	38.33	41.57	44.80	48.04
67.53	35.21	29090.07	3382902.90	38.54	41.77	45.00	48.23
67.69	35.42	29046.51	3411949.41	38.75	41.98	45.20	48.43
67.86	35.63	29002.95	3440952.36	38.96	42.18	45.40	48.62
68.03	35.85	28959.39	3469911.75	39.17	42.39	45.60	48.82
68.16	36.07	28878.21	3498789.96	39.39	42.59	45.80	49.00
68.21	36.33	28691.78	3527481.74	39.65	42.83	46.00	49.17
68.22	36.62	28437.75	3555919.49	39.91	43.06	46.20	49.35
68.22	36.91	28183.77	3584103.26	40.17	43.29	46.41	49.52
68.23	37.20	27929.75	3612033.00	40.43	43.52	46.61	49.70
68.24	37.49	27675.72	3639708.72	40.69	43.75	46.81	49.87
68.24	37.77	27421.74	3667130.46	40.95	43.98	47.02	50.05
68.25	38.06	27167.72	3694298.18	41.21	44.21	47.22	50.22
68.25	38.35	26913.69	3721211.87	41.47	44.45	47.42	50.40
68.26	38.64	26659.67	3747871.53	41.73	44.68	47.63	50.57
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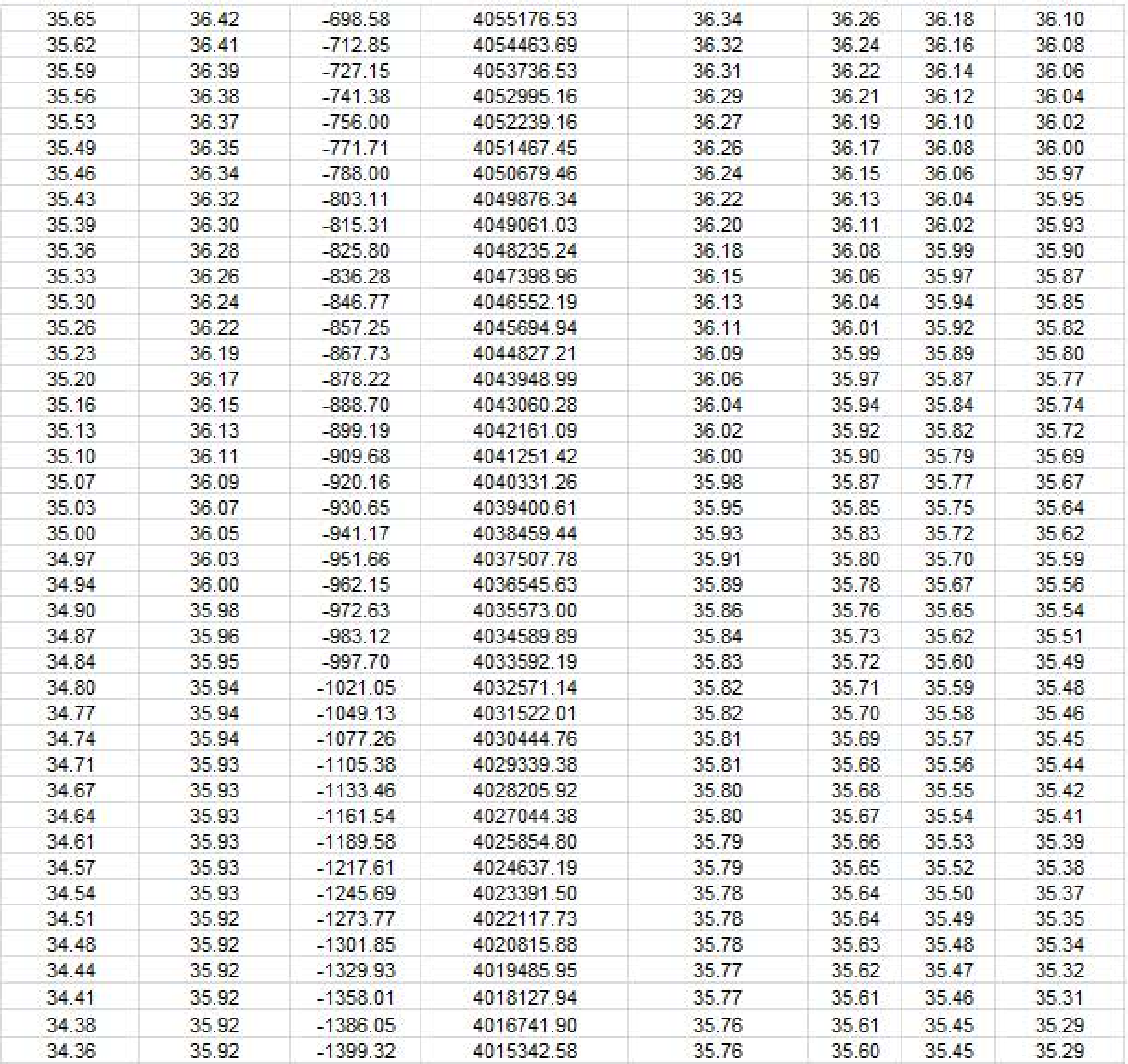
68.28	39.51	25887.56	3826316.52	42.53	45.39	48.25	51.11
68.28	39.84	25597.85	3851914.37	42.84	45.67	48.49	51.32
68.29	40.19	25292.84	3877207.20	43.15	45.94	48.74	51.53
68.29	40.53	24987.83	3902195.03	43.46	46.22	48.98	51.74
68.26	40.87	24644.88	3926839.91	43.76	46.48	49.20	51.92
68.16	41.22	24245.06	3951084.96	44.06	46.73	49.40	52.07
68.04	41.56	23826.24	3974911.20	44.36	46.98	49.61	52.23
67.92	41.91	23407.43	3998318.63	44.66	47.24	49.81	52.39
67.80	42.25	22988.66	4021307.28	44.96	47.49	50.02	52.55
67.68	42.60	22569.44	4043876.72	45.26	47.74	50.22	52.71
67.56	42.95	22148.37	4066025.09	45.56	48.00	50.43	52.87
67.43	43.29	21725.87	4087750.95	45.86	48.25	50.64	53.03
67.31	43.64	21303.27	4109054.22	46.16	48.51	50.85	53.19
67.19	43.99	20880.72	4129934.94	46.46	48.76	51.06	53.35
67.07	44.34	20458.22	4150393.16	46.77	49.02	51.26	53.51
66.95	44.69	20035.67	4170428.82	47.07	49.27	51.47	53.68
66.83	45.04	19613.12	4190041.94	47.37	49.53	51.68	53.84
66.71	45.39	19190.61	4209232.55	47.67	49.78	51.89	54.00
66.59	45.74	18768.06	4228000.61	47.97	50.03	52.10	54.16
66.47	46.17	18273.06	4246273.67	48.42	50.42	52.42	54.42
66.35	46.68	17700.57	4263974.24	48.88	50.81	52.75	54.68
66.23	47.20	17122.86	4281097.10	49.33	51.20	53.07	54.95
66.11	47.72	16545.15	4297642.25	49.79	51.60	53.40	55.21
65.96	48.25	15942.96	4313585.21	50.24	51.98	53.72	55.45
65.75	48.77	15288.17	4328873.37	50.69	52.35	54.01	55.67
65.52	49.29	14605.43	4343478.80	51.13	52.72	54.30	55.89
65.28	49.81	13922.69	4357401.48	51.58	53.09	54.60	56.11
65.04	50.33	13239.95	4370641.43	52.02	53.46	54.89	56.32
64.80	50.85	12558.83	4383200.25	52.47	53.82	55.18	56.54
64.57	51.37	11879.55	4395079.80	52.91	54.19	55.47	56.75
64.33	51.88	11200.59	4406280.39	53.35	54.56	55.76	56.97
64.09	52.40	10521.63	4416802.02	53.79	54.92	56.05	57.19
63.85	52.92	9842.62	4426644.65	54.23	55.29	56.34	57.40
63.62	53.44	9163.67	4435808.31	54.67	55.65	56.64	57.62
63.38	53.94	8494.79	4444303.10	55.10	56.00	56.91	57.82

63.14	54.36	7901.55	4452204.65	55.39	56.23	57.08	57.93
62.91	54.71	7373.97	4459578.62	55.68	56.47	57.26	58.05
62.67	55.06	6846.39	4466425.01	55.97	56.70	57.43	58.16
62.43	55.41	6318.81	4472743.82	56.26	56.93	57.60	58.28
62.19	55.76	5791.23	4478535.05	56.55	57.16	57.78	58.39
61.96	56.11	5263.65	4483798.70	56.84	57.39	57.95	58.50
61.72	56.46	4736.07	4488534.77	57.13	57.62	58.12	58.62
61.48	56.81	4207.46	4492742.22	57.42	57.86	58.29	58.73
61.23	57.15	3671.33	4496413.55	57.71	58.08	58.46	58.84
60.98	57.48	3150.18	4499563.73	57.95	58.27	58.60	58.92
60.72	57.76	2669.36	4502233.08	58.16	58.43	58.70	58.97
60.47	58.02	2207.39	4504440.47	58.37	58.59	58.81	59.03
60.22	58.28	1745.46	4506185.93	58.57	58.74	58.91	59.08
59.96	58.54	1283.49	4507469.42	58.78	58.90	59.02	59.13
59.71	58.80	821.52	4508290.94	58.99	59.06	59.12	59.19
59.45	59.05	359.55	4508650.49	59.20	59.21	59.23	59.24
59.20	59.31	-102.42	4508548.07	59.41	59.37	59.33	59.30
58.95	59.46	-465.52	4508082.54	59.42	59.35	59.28	59.22
58.69	59.49	-722.74	4507359.80	59.41	59.32	59.22	59.13
58.44	59.52	-968.94	4506390.86	59.41	59.29	59.17	59.05
58.23	59.54	-1185.21	4505205.65	59.41	59.27	59.13	58.99
58.04	59.57	-1375.47	4503830.18	59.41	59.25	59.09	58.92
57.85	59.59	-1565.73	4502264.45	59.42	59.23	59.05	58.86
57.66	59.61	-1756.04	4500508.41	59.42	59.21	59.01	58.80
57.48	59.64	-1946.34	4498562.07	59.42	59.20	58.97	58.74
57.29	59.66	-2136.60	4496425.47	59.43	59.18	58.93	58.68
57.10	59.69	-2326.86	4494098.61	59.43	59.16	58.89	58.62
56.91	59.71	-2517.12	4491581.49	59.43	59.14	58.85	58.56
56.72	59.73	-2707.38	4488874.11	59.43	59.12	58.81	58.50
56.54	59.76	-2897.64	4485976.47	59.44	59.10	58.77	58.44
56.35	59.77	-3081.83	4482894.65	59.43	59.07	58.72	58.37
56.16	59.78	-3253.01	4479641.64	59.40	59.03	58.66	58.29
55.97	59.77	-3417.26	4476224.39	59.38	58.99	58.60	58.21
55.79	59.77	-3581.46	4472642.93	59.36	58.95	58.54	58.14
55.60	59.76	-3748.23	4468894.70	59.33	58.91	58.48	58.05
55.40	59.76	-3919.91	4464974.79	59.31	58.86	58.42	57.97
55.20	59.75	-4093.88	4460880.92	59.28	58.82	58.35	57.89
55.00	59.75	-4267.80	4456613.12	59.26	58.78	58.29	57.81
54.81	59.74	-4441.68	4452171.44	59.23	58.73	58.23	57.73
54.61	59.74	-4615.61	4447555.83	59.21	58.69	58.17	57.64
54.41	59.73	-4789.58	4442766.26	59.19	58.64	58.10	57.56
54.21	59.73	-4963.50	4437802.76	59.16	58.60	58.04	57.48
54.01	59.72	-5137.43	4432665.33	59.14	58.56	57.98	57.40
53.81	59.62	-5228.19	4427437.14	58.95	58.36	57.78	57.20
53.62	59.43	-5229.81	4422207.33	58.74	58.16	57.58	57.00
53.42	59.22	-5225.49	4416981.84	58.54	57.96	57.38	56.80
53.22	59.02	-5221.22	4411760.63	58.34	57.76	57.18	56.60
53.02	58.82	-5216.90	4406543.73	58.14	57.56	56.98	56.40
52.82	58.61	-5212.53	4401331.20	57.93	57.35	56.77	56.20
52.62	58.41	-5208.26	4396122.95	57.73	57.15	56.57	55.99
52.42	58.21	-5203.98	4390918.97	57.53	56.95	56.37	55.79
52.23	58.00	-5199.62	4385719.35	57.32	56.75	56.17	55.59
52.03	57.80	-5195.30	4380524.06	57.12	56.55	55.97	55.39
51.83	57.60	-5191.02	4375333.04	56.92	56.34	55.77	55.19
51.63	57.38	-5171.09	4370161.95	56.69	56.11	55.54	54.97
51.43	57.13	-5127.66	4365034.29	56.44	55.87	55.30	54.74
51.24	56.88	-5074.97	4359959.33	56.19	55.63	55.06	54.50
51.05	56.62	-5014.85	4354944.48	55.94	55.39	54.83	54.28
50.87	56.36	-4948.70	4349995.79	55.69	55.14	54.60	54.05
50.68	56.11	-4882.59	4345113.20	55.44	54.90	54.37	53.83
50.50	55.85	-4816.49	4340296.71	55.19	54.66	54.13	53.60
50.32	55.60	-4750.38	4335546.33	54.95	54.42	53.90	53.37
50.14	55.34	-4684.28	4330862.06	54.70	54.18	53.67	53.15
49.96	55.09	-4618.13	4326243.93	54.45	53.94	53.43	52.92
49.78	54.83	-4552.02	4321691.91	54.20	53.70	53.20	52.70
49.59	54.58	-4485.91	4317206.00	53.96	53.46	52.97	52.47
49.41	54.32	-4419.77	4312786.23	53.71	53.22	52.73	52.25
49.23	54.07	-4353.66	4308432.57	53.46	52.98	52.50	52.02
49.05	53.81	-4287.51	4304145.06	53.21	52.74	52.27	51.79
48.87	53.56	-4221.36	4299923.70	52.96	52.50	52.03	51.57
48.68	53.23	-4090.86	4295832.84	52.59	52.14	51.70	51.26
48.50	52.83	-3891.38	4291941.47	52.20	51.78	51.36	50.94

48.31	52.42	-3694.05	4288247.42	51.81	51.41	51.01	50.61
48.11	52.01	-3505.77	4284741.65	51.43	51.05	50.67	50.29
47.91	51.60	-3319.92	4281421.73	51.04	50.68	50.32	49.96
47.71	51.19	-3134.16	4278287.57	50.65	50.31	49.97	49.64
47.51	50.78	-2948.31	4275339.26	50.26	49.94	49.63	49.31
47.31	50.53	-2902.01	4272437.25	50.15	49.83	49.50	49.17
47.10	50.74	-3274.43	4269162.83	50.60	50.20	49.80	49.40
46.90	51.24	-3901.86	4265260.97	51.00	50.54	50.07	49.60
46.71	51.33	-4158.95	4261102.02	50.73	50.28	49.82	49.36
46.53	51.05	-4063.86	4257038.16	50.46	50.02	49.57	49.13
46.37	50.77	-3962.88	4253075.28	50.19	49.76	49.32	48.89
46.20	50.49	-3861.90	4249213.38	49.92	49.50	49.08	48.65
46.03	50.21	-3760.88	4245452.51	49.65	49.24	48.83	48.42
45.86	49.92	-3659.85	4241792.66	49.38	48.98	48.58	48.18
45.69	49.64	-3558.87	4238233.79	49.11	48.72	48.33	47.94
45.52	49.36	-3457.89	4234775.90	48.84	48.46	48.09	47.71
45.35	49.08	-3356.87	4231419.03	48.57	48.21	47.84	47.47
45.18	48.80	-3255.84	4228163.19	48.30	47.95	47.59	47.23
45.01	48.52	-3154.86	4225008.33	48.03	47.69	47.34	47.00
44.84	48.24	-3053.84	4221954.50	47.76	47.43	47.10	46.76
44.68	47.97	-2964.69	4218989.81	47.52	47.19	46.87	46.54
44.51	47.72	-2895.44	4216094.37	47.29	46.97	46.65	46.33
44.34	47.49	-2830.28	4213264.10	47.06	46.75	46.44	46.12
44.20	47.25	-2745.90	4210518.20	46.83	46.53	46.23	45.93
44.07	47.01	-2646.14	4207872.06	46.60	46.32	46.03	45.74
43.95	46.77	-2546.37	4205325.69	46.38	46.10	45.82	45.55
43.82	46.54	-2446.65	4202879.04	46.15	45.89	45.62	45.35
43.69	46.30	-2346.88	4200532.16	45.93	45.67	45.42	45.16
43.57	46.06	-2247.12	4198285.04	45.70	45.46	45.21	44.97
43.44	45.83	-2147.40	4196137.64	45.47	45.24	45.01	44.78
43.31	45.59	-2047.64	4194090.00	45.25	45.03	44.80	44.58
43.19	45.37	-1965.82	4192124.18	45.06	44.84	44.63	44.41
43.06	45.21	-1938.02	4190186.16	44.94	44.72	44.51	44.29
42.94	45.10	-1946.25	4188239.91	44.82	44.61	44.39	44.17
42.81	44.98	-1954.53	4186285.38	44.70	44.49	44.27	44.05
42.68	44.86	-1962.81	4184322.57	44.59	44.37	44.15	43.93
42.56	44.75	-1971.05	4182351.53	44.47	44.25	44.03	43.81
42.43	44.63	-1979.28	4180372.25	44.35	44.13	43.91	43.69
42.30	44.51	-1987.56	4178384.69	44.23	44.01	43.79	43.57
42.18	44.39	-1995.80	4176388.89	44.11	43.89	43.67	43.45
42.05	44.28	-2004.03	4174384.86	44.00	43.77	43.55	43.33
41.93	44.16	-2003.67	4172381.19	43.88	43.66	43.44	43.21
41.83	44.04	-1994.00	4170387.20	43.76	43.54	43.32	43.10
41.72	43.93	-1983.69	4168403.51	43.65	43.43	43.21	42.99
41.62	43.81	-1971.81	4166431.70	43.53	43.31	43.09	42.87
41.51	43.69	-1957.23	4164474.47	43.41	43.19	42.97	42.76
41.41	43.56	-1941.57	4162532.90	43.29	43.07	42.86	42.64
41.30	43.44	-1925.96	4160606.94	43.16	42.95	42.74	42.53
41.19	43.32	-1910.34	4158696.60	43.04	42.83	42.62	42.41
41.09	43.19	-1894.73	4156801.88	42.92	42.71	42.50	42.29
40.98	43.07	-1879.16	4154922.72	42.80	42.59	42.39	42.18
40.88	42.95	-1863.54	4153059.18	42.68	42.47	42.27	42.06
40.77	42.82	-1847.93	4151211.26	42.56	42.35	42.15	41.94
40.67	42.70	-1832.31	4149378.95	42.44	42.23	42.03	41.83
40.56	42.58	-1816.70	4147562.25	42.32	42.11	41.91	41.71
40.45	42.46	-1801.08	4145761.17	42.19	42.00	41.80	41.60
40.35	42.33	-1785.47	4143975.71	42.07	41.88	41.68	41.48
40.24	42.21	-1770.80	4142204.91	41.95	41.76	41.56	41.37
40.14	42.09	-1754.73	4140450.18	41.83	41.64	41.45	41.25
40.04	41.97	-1732.86	4138717.32	41.72	41.53	41.33	41.14
39.95	41.85	-1707.48	4137009.84	41.60	41.41	41.22	41.03
39.86	41.73	-1682.15	4135327.70	41.48	41.29	41.11	40.92
39.76	41.61	-1656.77	4133670.93	41.36	41.18	41.00	40.81
39.67	41.48	-1631.39	4132039.55	41.24	41.06	40.88	40.70
39.58	41.36	-1606.05	4130433.50	41.13	40.95	40.77	40.59
39.49	41.24	-1580.67	4128852.83	41.01	40.83	40.66	40.48
39.39	41.12	-1555.34	4127297.49	40.89	40.72	40.55	40.38
39.30	41.00	-1529.96	4125767.54	40.77	40.60	40.43	40.27
39.21	40.88	-1504.08	4124263.46	40.65	40.49	40.32	40.16
39.11	40.76	-1477.80	4122785.66	40.53	40.37	40.21	40.04
39.02	40.63	-1451.52	4121334.14	40.41	40.25	40.09	39.93
38.93	40.51	-1425.24	4119908.90	40.30	40.14	39.98	39.82
38.84	40.39	-1399.01	4118509.89	40.18	40.02	39.87	39.71

38.74	40.27	-1372.77	4117137.12	40.06	39.91	39.75	39.60
38.65	40.15	-1346.45	4115790.68	39.94	39.79	39.64	39.49
38.56	40.03	-1320.12	4114470.56	39.82	39.67	39.53	39.38
38.47	39.90	-1293.89	4113176.67	39.70	39.56	39.42	39.27
38.37	39.78	-1267.65	4111909.02	39.58	39.44	39.30	39.16
38.29	39.66	-1234.31	4110674.72	39.46	39.33	39.19	39.06
38.23	39.54	-1179.81	4109494.91	39.35	39.22	39.09	38.97
38.18	39.42	-1111.19	4108383.72	39.23	39.11	39.00	38.88
38.13	39.33	-1072.62	4107311.10	39.18	39.06	38.94	38.82
38.09	39.27	-1064.16	4106246.94	39.13	39.01	38.89	38.77
38.04	39.22	-1055.61	4105191.33	39.07	38.95	38.84	38.72
38.00	39.16	-1047.06	4104144.27	39.02	38.90	38.79	38.67
37.95	39.11	-1038.56	4103105.72	38.96	38.85	38.73	38.62
37.91	39.05	-1030.01	4102075.71	38.91	38.79	38.68	38.57
37.86	39.00	-1021.46	4101054.26	38.85	38.74	38.63	38.52
37.81	38.94	-1012.95	4100041.31	38.80	38.69	38.58	38.46
37.77	38.88	-1004.40	4099036.91	38.75	38.63	38.52	38.41
37.72	38.83	-995.85	4098041.06	38.69	38.58	38.47	38.36
37.68	38.77	-987.35	4097053.71	38.64	38.53	38.42	38.31
37.63	38.72	-978.80	4096074.92	38.58	38.47	38.37	38.26
37.59	38.66	-970.24	4095104.67	38.53	38.42	38.31	38.21
37.54	38.61	-961.74	4094142.93	38.47	38.37	38.26	38.16
37.49	38.55	-953.19	4093189.74	38.42	38.31	38.21	38.10
37.45	38.50	-944.64	4092245.10	38.37	38.26	38.16	38.05
37.40	38.44	-937.89	4091307.21	38.31	38.21	38.11	38.00
37.36	38.40	-934.83	4090372.38	38.27	38.16	38.06	37.96
37.31	38.35	-933.75	4089438.63	38.22	38.12	38.01	37.91
37.27	38.30	-932.72	4088505.92	38.17	38.07	37.97	37.86
37.22	38.25	-931.64	4087574.28	38.13	38.02	37.92	37.82
37.17	38.21	-930.55	4086643.73	38.08	37.98	37.87	37.77
37.13	38.16	-929.57	4085714.16	38.03	37.93	37.83	37.72
37.08	38.11	-928.49	4084785.68	37.99	37.88	37.78	37.68
37.04	38.07	-927.41	4083858.27	37.94	37.84	37.73	37.63
36.99	38.02	-926.37	4082931.90	37.89	37.79	37.69	37.58
36.94	37.97	-925.29	4082006.61	37.85	37.74	37.64	37.54
36.90	37.93	-924.21	4081082.40	37.80	37.70	37.59	37.49
36.85	37.88	-923.13	4080159.27	37.75	37.65	37.55	37.45
36.81	37.83	-922.09	4079237.18	37.71	37.60	37.50	37.40
36.76	37.79	-921.06	4078316.12	37.66	37.56	37.45	37.35
36.72	37.74	-919.98	4077396.14	37.61	37.51	37.41	37.31
36.67	37.69	-918.90	4076477.24	37.57	37.46	37.36	37.26
36.63	37.64	-913.32	4075563.92	37.52	37.42	37.32	37.22
36.60	37.60	-900.95	4074662.97	37.47	37.38	37.28	37.18
36.57	37.54	-879.39	4073783.58	37.42	37.32	37.22	37.13
36.54	37.48	-849.96	4072933.62	37.35	37.26	37.17	37.08
36.50	37.42	-819.50	4072114.13	37.29	37.20	37.11	37.03
36.47	37.35	-788.94	4071325.19	37.23	37.15	37.06	36.97
36.44	37.29	-758.43	4070566.76	37.17	37.09	37.01	36.92
36.41	37.22	-727.96	4069838.79	37.11	37.03	36.95	36.87
36.38	37.16	-697.46	4069141.34	37.05	36.97	36.90	36.82
36.35	37.09	-666.99	4068474.35	36.99	36.92	36.84	36.77
36.32	37.03	-636.53	4067837.82	36.93	36.86	36.79	36.72
36.29	36.96	-606.01	4067231.81	36.87	36.80	36.73	36.67
36.26	36.90	-575.50	4066656.30	36.80	36.74	36.68	36.62
36.23	36.83	-545.04	4066111.26	36.74	36.68	36.63	36.57
36.20	36.77	-514.58	4065596.69	36.68	36.63	36.57	36.52
36.17	36.71	-484.06	4065112.62	36.62	36.57	36.52	36.47
36.14	36.66	-472.99	4064639.63	36.60	36.55	36.49	36.44
36.11	36.64	-484.33	4064155.29	36.58	36.53	36.47	36.42
36.08	36.63	-498.60	4063656.69	36.57	36.51	36.45	36.40
36.05	36.62	-512.87	4063143.83	36.55	36.49	36.43	36.38
36.02	36.60	-527.18	4062616.65	36.53	36.47	36.42	36.36
35.98	36.59	-541.44	4062075.21	36.52	36.46	36.40	36.33
35.95	36.57	-555.70	4061519.51	36.50	36.44	36.38	36.31
35.92	36.56	-570.02	4060949.49	36.49	36.42	36.36	36.29
35.89	36.54	-584.32	4060365.17	36.47	36.40	36.34	36.27
35.86	36.53	-598.59	4059766.58	36.45	36.39	36.32	36.25
35.83	36.51	-612.85	4059153.72	36.44	36.37	36.30	36.23
35.80	36.50	-627.17	4058526.56	36.42	36.35	36.28	36.21
35.77	36.48	-641.43	4057885.13	36.40	36.33	36.26	36.19
35.74	36.47	-655.69	4057229.43	36.39	36.31	36.24	36.17
35.71	36.45	-670.01	4056559.43	36.37	36.30	36.22	36.15
35.68	36.44	-684.32	4055875.11	36.35	36.28	36.20	36.12



35.65	36.42	-698.58	4055176.53	36.34	36.26	36.18	36.10
35.62	36.41	-712.85	4054463.69	36.32	36.24	36.16	36.08
35.59	36.39	-727.15	4053736.53	36.31	36.22	36.14	36.06
35.56	36.38	-741.38	4052995.16	36.29	36.21	36.12	36.04
35.53	36.37	-756.00	4052239.16	36.27	36.19	36.10	36.02
35.49	36.35	-771.71	4051467.45	36.26	36.17	36.08	36.00
35.46	36.34	-788.00	4050679.46	36.24	36.15	36.06	35.97
35.43	36.32	-803.11	4049876.34	36.22	36.13	36.04	35.95
35.39	36.30	-815.31	4049061.03	36.20	36.11	36.02	35.93
35.36	36.28	-825.80	4048235.24	36.18	36.08	35.99	35.90
35.33	36.26	-836.28	4047398.96	36.15	36.06	35.97	35.87
35.30	36.24	-846.77	4046552.19	36.13	36.04	35.94	35.85
35.26	36.22	-857.25	4045694.94	36.11	36.01	35.92	35.82
35.23	36.19	-867.73	4044827.21	36.09	35.99	35.89	35.80
35.20	36.17	-878.22	4043948.99	36.06	35.97	35.87	35.77
35.16	36.15	-888.70	4043060.28	36.04	35.94	35.84	35.74
35.13	36.13	-899.19	4042161.09	36.02	35.92	35.82	35.72
35.10	36.11	-909.68	4041251.42	36.00	35.90	35.79	35.69
35.07	36.09	-920.16	4040331.26	35.98	35.87	35.77	35.67
35.03	36.07	-930.65	4039400.61	35.95	35.85	35.75	35.64
35.00	36.05	-941.17	4038459.44	35.93	35.83	35.72	35.62
34.97	36.03	-951.66	4037507.78	35.91	35.80	35.70	35.59
34.94	36.00	-962.15	4036545.63	35.89	35.78	35.67	35.56
34.90	35.98	-972.63	4035573.00	35.86	35.76	35.65	35.54
34.87	35.96	-983.12	4034589.89	35.84	35.73	35.62	35.51
34.84	35.95	-997.70	4033592.19	35.83	35.72	35.60	35.49
34.80	35.94	-1021.05	4032571.14	35.82	35.71	35.59	35.48
34.77	35.94	-1049.13	4031522.01	35.82	35.70	35.58	35.46
34.74	35.94	-1077.26	4030444.76	35.81	35.69	35.57	35.45
34.71	35.93	-1105.38	4029339.38	35.81	35.68	35.56	35.44
34.67	35.93	-1133.46	4028205.92	35.80	35.68	35.55	35.42
34.64	35.93	-1161.54	4027044.38	35.80	35.67	35.54	35.41
34.61	35.93	-1189.58	4025854.80	35.79	35.66	35.53	35.39
34.57	35.93	-1217.61	4024637.19	35.79	35.65	35.52	35.38
34.54	35.93	-1245.69	4023391.50	35.78	35.64	35.50	35.37
34.51	35.92	-1273.77	4022117.73	35.78	35.64	35.49	35.35
34.48	35.92	-1301.85	4020815.88	35.78	35.63	35.48	35.34
34.44	35.92	-1329.93	4019485.95	35.77	35.62	35.47	35.32
34.41	35.92	-1358.01	4018127.94	35.77	35.61	35.46	35.31
34.38	35.92	-1386.05	4016741.90	35.76	35.61	35.45	35.29
34.36	35.92	-1399.32	4015342.58	35.76	35.60	35.45	35.29