Constructing uncertainty budget for a two-dimensional hydraulic model

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Abstract. In this study the combined uncertainty of a two-dimensional (2D) hydraulic model expanded at 95% confidence level is estimated and the uncertainty budget for the model outputs is attempted to be constructed. It has been shown that many uncertainty sources in the inputs as well as the procedure applied have a significant impact on the accuracy of two-dimensional hydraulic modelling: the uncertainties in the model inputs due to variations in Manning’s ‘n’ Coefficient assigned, the bridge modelling methods, the equation sets; Diffusion Wave and Full Momentum Equations employed and the geometric data sets for the same river system in the Black Sea Region of Turkey are assessed. To estimate an appropriate M’n’C and other model inputs of model for a river system with a wide 2D flow area is a daunting task. Therefore, any attempt to quantify uncertainties in the assigned values must be based on the samples large enough to obtain statistically significant results. To achieve this task, Monte Carlo Method is utilized to estimate the contribution of the likely variations of model inputs onto ‘the combined expended uncertainty at 95% confidence level in two-dimensional hydraulic modelling’.

1. Introduction

River systems are interconnected waterways that often change to reach a state of dynamic equilibrium which is a fragile balance between flow conditions, sediment transport, and environmental habitat in a river system. To study river systems in detail, complex hydraulic models have been developed. These models calculate flow depths and energy losses through a river system and are defined as 1, 2, or 3 dimensional models. All model packages focus on the calibration of the roughness parameter, which, together with the geometry, is considered to have the most important impact on predicting inundation extent and flow characteristics. In addition to the roughness coefficient, downstream boundary condition and assigned coefficients for bridge and weirs along with the limitations and the simplifications in non-linear equations made by the models will have significant impact on the accuracy of the model results.

The floods have destructive impacts on economic development and human health. The researches have indicated that such extreme events are expected to increase in the frequency, duration and intensity due to the global warming and posing larger risks to economic and human life. According to ‘EM-Dat’ statistics, between 1900 and 2006 in the total of 2,857 flood events, 803 thousand people have lost their lives, 2.76 billion people have been affected adversely. The estimated economic losses from these natural disasters exceeds 311 billion dollars [1]. Similarly, in Turkey, between 1989 and 2002 in the total of 124 flood events, 324 people have died and 307.5 thousand hectares of the lands were inundated [2]. Therefore, it is paramount importance in taking necessary measures to mitigate the impact of such
disasters on human life. For this reason, the tools such as flood modelling software and estimating the uncertainty in calculated parameters which, in turn, assists on predicting magnitude of feature floods with the confidence levels in these parameters are crucial in eliminating the adverse impact of natural disasters on human life. In recent years, modellers and hydrologists in the hydrological and hydraulic community have been encouraged to conduct uncertainty analysis as standard practice in water resource research [3, 4, 5] and projects are to be a risk-based approach to flood hazard assessment and management to support designs, in which decision makers are provided with model predictions together with their associated uncertainties. Therefore, uncertainty analysis, conducted to quantify the uncertainty in model outputs induced by the uncertainty in the inputs, and presenting model results together with their associated uncertainties increase confidence in hydraulic model predictions.

In this study, the sources of uncertainties of a 1D and 2D flood inundation model are attempted to be quantified by focusing on the uncertainties in the input data, model parameters and model structure. The uncertainty sources in the model are identified as: uncertainties in assigned Manning’s Roughness Coefficients, the downstream boundary conditions-normal depth-, in the weir coefficients of bridge deck and bridge model, in the weir coefficients of lateral weirs connecting 1D areas to 2D areas, due to cell sizes of 2D flow areas, in geometric data and reach length chosen, due to the equation sets, DW or FM and uncertainty due to iteration estimated by HEC-RAS. Firstly, the Hydraulic Model Simulation is run with the inputs that are assumed to be the values close to ‘true’ values. While the most appropriate ‘Unsteady Computation Options and Tolerances’ recommended by the User Manual are applied for the model, the uncertainties due to the upstream boundary condition, the flow data, are not evaluated in this study. Then, MCM is utilized to estimate the contribution of the likely variations of inputs in ‘the combined expanded uncertainty at 95% confidence level in 2D hydraulic modelling. Finally, the methodology outlined in “Guide to the Expressing Measurement Uncertainty”, GUM, [6] and “Evaluation of measurement data: Supplement 1 to the “Guide to the expression of uncertainty in measurement” Propagation of distributions using a Monte Carlo method” [7] is adopted for the calculating combined expanded uncertainty at 95% confidence level.

2. Model description

In this study, HEC-RAS 5.06 has been used to perform two dimensional (2D) unsteady flow simulations. HEC-RAS is designed to perform one-dimensional (1D), 2D or combined 1D and 2D hydraulic calculations for the full network of natural or constructed channels. The Navier–Stokes equations are nonlinear partial differential equations describing the motion of fluids. St. Venant equations used in Hydraulic Model Packages are derived from Navier-Stokes Equations for shallow water flow conditions. HEC-RAS has options of ‘2D Diffusion Wave equations’ and the 2D Saint Venant [Full Momentum, (FM)] equations. FM based equation includes to the local and convective acceleration terms and is recommended to be used for the conditions where highly dynamic flood waves, tidally influenced conditions, abrupt contraction and expansions, model wave propagation due to rapidly opening and closing gate structures are experienced.

\[
\frac{d\nu}{dt} + u \frac{d\nu}{dx} + v \frac{d\nu}{dy} + g \frac{dH}{dy} - \nu \left( \frac{d^2\nu}{dx^2} + \frac{d^2\nu}{dy^2} \right) + c_i \nu + f_u = 0
\]  

(1)

Where \( u \) and \( v \) are the velocities in the Cartesian directions, \( g \) is the gravitational acceleration, \( \nu \) is the horizontal eddy viscosity coefficient, \( c_i \) is the bottom friction coefficient and \( f_u \) is Coriolis parameter. In this equation, the first three derivatives represent ‘Local and Convective Acceleration’, the forth, the fifth and the last two represents ‘Pressure Force’, ‘Eddy Losses’ and ‘Friction force and Coriolis term’ respectively.

On the other hand, in shallow flows, the barotropic pressure gradient (gravity) term and the bottom friction terms are the dominant terms and unsteady, advection, and viscous terms in the momentum equations can be disregarded. The momentum equation then becomes the two dimensional form of the Diffusion Wave Approximation. Combining this equation with mass conservation yields a one equation
model, known as the Diffusive Wave Approximation of the Shallow Water equations [8, 9, 10]. Implicit Finite Volume Method of HEC-RAS 5.06 uses finite volume approximation for both the temporal and spatial derivatives in terms of the dependent variable on the unknown timeline [10, 11]. Unlike the Explicit Finite Differences Method, Implicit Finite Volume Method provides a solution through the time-lines simultaneously for all points since the advance solution of St Venant equations are required for the time-step size for the numerical stability and the accuracy [11, 12].

3. Method of uncertainty estimation
A 2D hydraulic modelling has some uncertainties either in inputs or model parameters, which affects accuracy of the model outputs. Therefore, all inputs of the reference model were worked on rigorously and chosen carefully according to the guides articulated in HEC-RAS Manuals to achieve higher accuracy in the outputs. Then the normal distributions are constructed with the mean sets to the expected model input values of roughness coefficients, downstream boundary conditions, bridge deck, lateral weir and drag coefficients, geometric data-sets, and reach lengths between consecutive cross-sections (X-Ss) and the standard distributions were defined for these mean sets. Finally, Monte Carlo Method (MCM) is utilized to estimate the contributions from likely variations in these inputs into the outputs. The models were run for each realization to estimate the cumulative uncertainty in the outputs, namely the Maximum Water Surface Elevation (MWSE) for the flow hydrographs of a 50 year return period.

As it is stated in the OIML G 1-101 [7, 6], the 2D Hydraulic Model involving the solution of a finite-element model requires large computing times. Therefore, it is not possible to use a sufficiently large value of M for MCM to obtain adequate distributional knowledge of the output quantity. GUM stated that ‘in such a case an approximate approach would be to regard gy(ƞ) (probability density function with variable ƞ for the output quantity Y) as Gaussian (as in the GUM) and proceed as follows. A relatively small value of M, 50 or 100, for example, would be used. The average and standard deviation of the resulting M model values of Y would be taken as y and u(y), respectively. Although this use of a small value of M is inevitably less reliable than that of a large value in that it does not provide an approximation to the PDF for Y, it does take account of model non-linearity’ [7]. Hence, 870 simulations for M’n’C and 693 simulations for the other four inputs; the downstream boundary conditions, the bridge deck, the lateral weir and drag coefficients were conducted to achieve statistical convergence and a realistic representation of the probability distribution. The Box–Muller transform, a pseudo-random number sampling method, is deployed to generate normally distributed random numbers within the given upper and lower limits of the model inputs when the uncertainties due to errors in the model inputs are estimated with the use of MCM’s. MCM cannot be used for the uncertainty sources such as, the cell sizes of the meshes, 2D Equation sets (Diffusion Wave and Full Momentum), Manning’s Roughness Coefficient of 2D Flow Areas and Bridge Modelling approach since only two or limited numbers of model options are possible to estimate these uncertainties. In these cases, the upper and lower limits of error are determined from the model simulations. When the upper and lower limits of an error are ±α without a confidence level and there is a reason to expect that extreme values are equally likely within this range, then the rectangular distribution is considered to be the most appropriate also known as a Uniform Distribution that has constant probability. Hence, as a divisor, ki – reducing factor – \( \sqrt{3}\approx 1.732 \) is used to determine the standard deviation for rectangular distribution [13, 6].

4. Geometric and hydrologic data
Camdere and Koprucu Creeks start in the mountains of the eastern Black Sea Region; the rivers generally flow north-west across the Plateau and through the Kemalpasa Valley before reaching the Black Sea. Digital Elevation Model is generated from the data collected by an instrument whose accuracy is Real-Time Kinematic (RTK) positioning ‘H 1cm+1ppm, V 2cm+1ppm’ and PP ‘H ‘0.25cm+1ppm, V 0.5cm+1ppm’ with a confidence level of 99.9%. The digital elevation models (DEM) generated from a ground-based differential GPS (DGPS) survey, contained more than 41,263 points within the 2.33 km² [14]. The X-S data at 2 meter intervals within the study area were was generated by HAC-RAS 5.06 Rasmapper.
5. Manning’s roughness coefficients for reference model

It is known that it is great difficult to the determination of the roughness coefficient; and, the channels do not have a single value of M’n'C for all occasions. The well-known and used Cowan Method along with the relationships established between Manning’s formula and Universal Log Law, the relationship between sheer velocity and other hydraulic parameters, are used to determine the appropriate ‘n’ values. Utilizing those algorithms, the average value of M’n'C for the reaches is determined by re-calculating the ‘n’ values from the parameters produced by the hydraulic simulation yielding the smallest errors in calculations.

Firstly, an estimation process for M’n'C developed by Cowan [15] was used to determine the roughness coefficients. The bed load samples throughout the reaches were taken. The particle size analyses by means of sieves (sieve analysis) were undertaken. Although the method deployed did not eliminate subjectivity in the assigning of ‘n’ values to the reaches, by deploying this method all flow resisting factors were taken into consideration. Then M’n'C for the reaches are re-estimated using the Hydraulic Simulation results; namely mean velocities, friction slopes, shear velocities, Nikuradse’s roughness height from Universal Log Law and the empirical formula explaining the relationship between M’n'C and other Hydraulic Parameters as outlined in Ozbey [16]. Iterative calculations are undertaken and M’n'C for the reaches yielding the smallest errors in Flow Calculation by HEC-RAS are accepted for the average value. The assigned M’n'C for the reaches are also checked against M’n'C calculated from the hydraulic model results as outlined above. It is found that there is strong agreement between the assigned and calculated values. On the other hand, assigning appropriate roughness coefficient for a floodplain is an arduous task, and it greatly vary with the variation of relative depth, surface roughness and discharge. It should be noted that the Manning’s roughness coefficient was developed for one-dimensional flow motion only. The use of sections to divide the text of the paper is optional and left as a decision for the author. Where the author wishes to divide the paper into sections the formatting shown in table 2 should be used.

6. Error sources

As is known, a 2D Hydraulic model numerically predict water depth and flow velocity along reaches for the given flood hydrograph as the upstream boundary condition. Although the model’s predictions are based on a deterministic approach, a Hydraulic Model can lead to the considerable cumulative uncertainties in the results due to uncertainties in input variables. Moreover, uncertainty in a hydraulic model may be due to some simplification made within a model as well as a modeller’s knowledge in defining the required ‘true’ - input quantities for a model. Therefore, knowledge of the source and magnitude of the uncertainty are of paramount importance to understanding and interpreting a model’s outputs for risk assessment and safe design of hydraulic structures, such as bridges and levees. In this study, the Error Sources in Hydraulic Modelling are as defined below:

Manning’s Roughness Coefficient: Although all measures in assigning ‘n values’ for the reaches are taken when assigning the M'n'C value for each reach and segment of the system, the process is one of the main sources of uncertainty in any hydraulic modelling; and, the magnitude error in assigning the M’n’C along the reach cannot be eliminated completely. The studies [16, 17] undertaken have shown that even the best approximation in the coefficient can be in error as high as ±25%. Hence, the upper and lower limits of probable range around the assigned value were determined.

Downstream Boundary Condition, Normal Depth: The normal depth for the downstream boundary condition is another source of uncertainty in hydraulic modelling. The studies undertaken have shown that even the best approximation in the energy slope can be in error as high as ±15%. A similar process, outlined above for M’n'C value, was applied to estimate the uncertainty due to probable error in Downstream Boundary Condition.

Weir Coefficient for the Bridge Deck: Under free flow conditions where discharge is independent of tail water, the coefficient of discharge C in the weir formula varies between 1.38 - 1.71 for broad-crested weirs depending primarily on the head over the crest and value of “C” increases with head [18, 16]. Increased resistance to flow caused by obstructions, such as trash on bridge railings, curbs, and other
barriers, would decrease the value of C. With the very little data on bridge decks, it is recommended that a weir coefficient of 1.44 for bridge decks would be reasonable [19]. In this study it is assumed that the error in the assign weir coefficient may be as high as a 30 percent.

Lateral Weir Coefficient – the boundary between 1 and 2 D areas: Weir coefficient for the Lateral Weirs connecting 1D areas to 2D areas is considered an uncertainty source. It is obvious that the coefficient would change with the lateral weir angle in degrees to the flow direction hence, the error assigning ‘Lateral Weir Coefficient’ emanates not only from the angle of oblique flow but also from the banks conditions where water flooding onto flood plains. Therefore, the error in estimating the coefficient for the lateral weir could not be as high as ±25%.

Reach Length and Number of Section: The lengths of reaches between the X-Ss along the study area for the bench mark model are limited to no longer than 4 meters. Then, by taking the control points of the stream into account, the lengths of reaches between the X-Ss are extended from 2 meters to 36 meters. As a result, the hydraulic models with 18 geometric data-sets with different reach lengths are re-simulated to estimate the uncertainty due to variation in geometric data-sets along the channels. However, X-Ss that are located at the vicinity of the structures and other control points where there are abrupt changes in channel or floodplain geometry, slope, and discharge are placed in according to recommendations by HEC-RAS Manual to capture the more rapidly changing flow characteristics. The process does not only take into account the impact of reach length between the X-S’s on the combined expanded uncertainty in estimated MWSE but also the uncertainties emanating from the random errors in DEM.

Differences in cell sizes of 2D Flow Areas: Digital Elevation Model (DEM) is used to create the three dimensional surfaces of the Camdere and Koprucu Creeks watershed. A DEM containing a grid cell size of 10 meters was used to describe 2D Flow areas at the left and right banks. As is known, ‘the computational mesh will control the movement of water through the 2D flow area. Specifically, one water surface elevation is calculated for each grid cell center at each time step’ [8]. Advanced time step control is used to optimize maximum Courant number allowed at any 2D cell or 1D X-S. If the maximum Courant Number is exceeded, then the time step is cut in half for the next time interval. Despite the fact that advanced time steps control adjusting time step to keep the Courant Number below 1 threshold and HEC-RAS uses an implicit solution scheme so that Courant numbers can be greater than one and still maintains a stable and accurate solution, the cell size increases to 12.5 X 12.5 meters to estimate the differences between two different scenarios. The model was re-simulated with DEM containing a grid size of 12.5 meters.

2D Equation Set: Diffusion Wave and Full Momentum: As mentioned earlier HEC-RAS two options for equation sets, therefore, the equation set is considered another uncertainty sources. The hydraulic model was simulated by utilizing both methods to be able to see the differences in estimated water levels.

Bridge Modelling Approach and the coefficient for piers [19]: HEC-RAS gives two options for the bridge modelling approach: Standard Energy Method and Momentum Equation. The weight component in the one-dimensional form of the conservation of momentum equation is “off” by default in HEC-RAS and the weight force is disregarded during the momentum calculations if a bridge momentum weight force is very large i.e., upstream energy is computed lower than downstream energy. Hence the differences in MWSE due to the bridge models are considered an uncertainty source.

Maximum error estimated by HEC-RAS: Finally, the maximum error calculated by HEC-RAS for the Hydraulic Model provided in ‘Runtime Message Report’ is also added into uncertainty calculation estimated for water surface levels for each section

7. Constructing uncertainty budget [20]
To construct the uncertainty budget, all sources of error and associated data were entered in a table, see table 1. In this table, $U_i$, $k_i$, $c_i$, and $v_i$, expanded uncertainty, coverage factor, sensitivity coefficient and degrees of freedom of an input $i$, respectively are evaluated and tabulated. Then the process recommended in ISO GUM is implemented to estimate the combined expanded uncertainty at 95% confidence level in the output which is the MWSE for a 1 in 50 years flood hydrograph in this study.
Table 1. Table for uncertainty budget for the river station at 352 m (at u/s bridge).

| Uncertainty Components | Estimated Values – Type A& B estimates | | | | | |
|------------------------|----------------------------------------|---|---|---|---|---|
|                        | $U_i$ (m) | $k_i$ | $U(h_i)$ (m) | $c_i$ | $|c_i.u(h_i)|^2$ | $v_i$ | $|c_i.u(h_i)|^4/v_i$ |
| M’n°C for 1D Areas ±25% | 0.148 | 2 | 0.0756 | 1 | 0.0756 | 0.0057 | 100 | 3.26E-07 |
| M’n°C for 2D Areas ±50% | 0.012 | 1.73 | 0.0071 | 1 | 0.0071 | 0.0001 | 27 | 9.41E-11 |
| Normal Depth ±15%     | 0.002 | 2 | 0.0011 | 1 | 0.0011 | 0.0000 | 100 | 1.48E-14 |
| Different Geometric Data Sets | 0.154 | 2 | 0.0788 | 1 | 0.0788 | 0.0062 | 100 | 3.85E-07 |
| Bridge Weir Coefficient ±25% | 0.004 | 2 | 0.0018 | 1 | 0.0018 | 0.0000 | 27 | 4.13E-13 |
| Lateral Weir Coefficient ±25% | 0.004 | 2 | 0.0019 | 1 | 0.0019 | 0.0000 | 27 | 4.34E-13 |
| Drag Weir Coefficient ±25% | 0.001 | 2 | 0.0003 | 1 | 0.0003 | 0.0000 | 100 | 9.01E-17 |
| Mesh Cell Size 10 m ±25% | - | 1.73 | -0.0586 | -1 | -0.0586 | 0.0034 | 100 | 1.18E-07 |
| Bridge Model Approaches | - | 1.73 | -0.1040 | -1 | -0.1040 | 0.0108 | 27 | 4.33E-06 |
| Equation Sets DW or FM | - | 1.73 | -0.0206 | -1 | -0.0206 | 0.0004 | 27 | 6.73E-09 |
| HEC-RAS Error Calculation | 0.003 | 1.73 | 0.0015 | 1 | 0.0015 | 0.0000 | 27 | 1.88E-06 |

Because the value of degrees of freedom beyond ‘100’ will have a negligible effect on the final outcome, in assigning the value the more practical approach is taken for the other Type B contributions and the value of 27 is chosen, which represents a “good” estimate of uncertainty. Then, the effective degree of freedom for the overall uncertainty in the measurement is given by the Welch-Satterthwaite formula. The error sources in Hydraulic modelling relate directly to the measurand, hence the sensitivity coefficients for all error sources in model simulation are taken as 1.

8. Result and discussion

The analysis indicated that while the combined uncertainties expanded to 95% confidence level in the MWSEs estimated for the X-Ss along the reaches within the 1D areas have varied between 0.12 cm and 0.65 cm. They have varied between 0.13 and 0.67 cm for the cells within the 2D areas. It should be emphasized that the largest uncertainties in MWS were estimated for the Cells located just upstream of the bridges. Average magnitude of uncertainty in MWSE for the X-Ss is between 25 and 35 cm. By the same token, the largest uncertainties in MWS were estimated for the Cells located just upstream of the junction and those at the vicinity of locations where the abrupt changes in the flow conditions are observed. The models have not showed a high number of failed runs since every effort has been made to ensure that the appropriate values for the inputs of the model and the most realistic likely error ranges for these parameters are assigned. The analysis has also shown that, 693 to 870 simulations for all four parameters and M’n°C value respectively are adequate because within the given error range, a variation at 4 decimal points in any inputs does not alter the estimated MWS for the sections along the reaches and the cells throughout the 2D flow areas.

While the uncertainties due to M’n°C and geometric data-sets with different reach lengths have uniform impact on combined expanded uncertainties in MWSE estimated for all X-Ss throughout the entire study area, the uncertainty due to Normal Depth has a relatively higher impact on the uncertainties estimated for the sections closer to the end of the river than those at upstream of the bridge located 72 m upstream of downstream boundary, as expected. The uncertainty in MWSE due to Lateral Weir Coefficient may be as significant as 0.02 m where the over bank flow is excessive at the same time the river is meandering; therefore, the angle of oblique flow to the lateral weir is not parallel.
Figure 1. Camdere river system flood inundation map for Q₅₀ flow hydrograph from reference model and 95% probability inundation map (light blue).

The uncertainty due to bridge model approach, as well as the weir and drag coefficients have an impact on the overall uncertainty in water surface elevation at the sections closer to the bridges. The uncertainties in MWSE due to variation in M'n'C value in flood plain (0.06 to 0.090) are significant especially for the cells within the flood plains but not so significant for 1D flow areas as it is expected. The maximum errors estimated by HEC-RAS are also greater for the cells compared to those estimated for the sections within 1D areas.

Table 2. Estimated maximum water surfaces and combined expanded uncertainties at 95% confidence level at the selected cells located through 2D flow areas – (the cells with a water depth above 1.5 m chosen if available).

| Cells at 2D Flow Areas | Maximum Water Surface & Uncertainty at 95% Conf. Level | Cells at 2D Flow Areas | Maximum Water Surface & Uncertainty at 95% Conf. Level |
|------------------------|------------------------------------------------------|------------------------|------------------------------------------------------|
| Perimeter 1            |                                                      | Perimeter 3            |                                                      |
| C00                    | 23.5049 ± 0.6554                                     | C1207                  | 7.8728 ± 0.2989                                      |
| C38                    | 23.5049 ± 0.6458                                     | C2241                  | 26.1066 ± 0.1999                                     |
| C59                    | 23.5049 ± 0.6623                                     | C650                   | 10.4920 ± 0.3514                                     |
| Perimeter 2            |                                                      | Perimeter 3            |                                                      |
| C322                   | 8.8334 ± 0.1722                                      | C1154                  | 8.8446 ± 0.1232                                      |
| C1179                  | 20.5691 ± 0.1310                                     | C1363                  | 5.1466 ± 0.3408                                      |

Table 3. Estimated maximum water surfaces and combined expanded uncertainties at 95% confidence level at the selected x-sections located along the reaches.

| River Station          | Maximum Water Surface & Uncertainty at 95% Conf. Level | River Station          | Maximum Water Surface & Uncertainty at 95% Conf. Level |
|------------------------|--------------------------------------------------------|------------------------|--------------------------------------------------------|
| R1 Reach-1             |                                                        | R1 Reach-Lower         |                                                        |
| 2077 m.                | 28.9200 ± 0.3824                                       | 480 m.                 | 9.1500 ± 0.1787                                       |
| 1773 m.                | 25.4831 ± 0.2690                                       | 72 m.                  | 4.5800 ± 0.6189                                       |
| 1693 m.                | 24.7320 ± 0.2662                                       | 4 m.                   | 3.0800 ± 0.3845                                       |
| 1425 m.                | 21.9291 ± 0.2233                                       | R2 Reach 1             |                                                        |
| R1 Reach-Lower         |                                                        | 760 m.                 | 39.0132 ± 0.3116                                      |
| 1392 m.                | 21.4704 ± 0.3910                                       | 500 m.                 | 34.9782 ± 0.6521                                      |
| 720                    | 11.9061 ± 0.4342                                       | 300 m.                 | 28.0264 ± 0.2353                                      |
| 352 m.                 | 8.8500 ± 0.2899                                       | 40 m.                  | 22.0200 ± 0.2621                                      |

It should also be noted that, the Hydraulic Models use the Saint Venant Equations to predict the movement of the flood wave along a river, which are based on the principal of conservation of mass, energy and momentum. In many case, the solution of this problem in a real life situation is difficult and/hence, all numerical models are required to make approximations such as; channel flow is assumed...
to be one-dimensional and unsteady; vertical velocities are negligible, vertical pressure gradients are hydrostatic, which imposes additional limitation in estimating the forces acting on each fluid component, such as viscous shear stresses and bed friction.

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