Modelling of River Network
with Widespread Floodplain Valleys

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Abstract

One-dimensional models of unsteady flow provide a good representation of flow transformation as long as the conditions of flow are close to the assumptions of 1D motion, i.e., there is one predominant flow direction which coincides with river longitudinal gradient. However, this assumption is too simplistic when a lengthy river section with widespread floodplain valleys is being modelled. When developing a numerical model of river hydrodynamics, correct representation of flow transformation through these water-course elements is the most important, but also the most challenging part. Motion of liquids in floodplains may not be regarded as one-dimensional (particularly in the initial phase of filling the valley with water and in the closing phase, when water returns to the main channel). Representation of these would require 2D models. One of the methods used to represent spatial motion of water on floodplains in 1D unsteady flow models is to split the river cross-section into its active and inactive zones. The fundamental difficulty is to determine the range of active cross-section. Pasche’s method is one of possible techniques applicable for this purpose.

1. Introduction

Since the possibility arose of applying numerical methods to differential equations describing the motion of free surface liquids, numerous specialist works have dealt with modelling of unsteady flows in open channel networks. This refers in particular to the well known numerical models based on de Saint-Venant equations (Abbott 1991, Cunge 1989). These models provide a good representation of flow transformation provided that there is no great discrepancy between flow conditions and the assumptions of one-dimensional motion, i.e., there is one predominant flow direction
which coincides with river longitudinal slope (Maidment 1992), and the transversal and vertical components are negligible. This criterion, together with correct data describing channel geometry, drag, flow balance and its time-dependant distribution, allows the researcher to obtain reliable results useful in design, water management and flood protection (Wosiewicz 1996).

However, the assumption required in one-dimensional models, i.e., that of one prevailing flow direction, is too simplistic when modelling a lengthy river section with widespread floodplain valleys. Natural, vegetated and widespread floodplains are decisive for the transformation of flow through a watercourse for flood waves. Motion of liquids in floodplains may not be regarded as a one-dimensional phenomenon (particularly in the initial phase of filling the valley with water and in the closing phase, when water returns to the main channel) and a comprehensive representation of these would require two-dimensional models. Despite considerable progress, practical applicability of such models for long river sections is still unrealistic, which is chiefly due to the cost of reliable measurement data required for the model.

One-dimensional models of unsteady flow are therefore only a tool for analysis and forecasting of flood wave transformations for long river sections and river networks. Nevertheless, they must take into account the spatial character of motion, which is achieved by extra parameters ensuring better representation of real flow conditions in widespread floodplain valleys.

2. Equations describing one-dimensional unsteady motion of liquids in open channels

One of the methods to represent the spatial character of motion in floodplains in one-dimensional unsteady flow models is to split the river cross-section into the active cross-section \( A_c \) (flow-related) and the inactive (dead) zones \( A_o \), with the overall river cross-section being the sum of these two: \( A = A_c + A_o \).

![Fig. 1. Computational division of river cross-section into its active \( A_c \) and dead \( A_o \) component.](image)

The mass conservation equation, in which all of the cross-section is considered, looks as follows (Maidment 1992):
\[
\frac{\partial Q}{\partial t} + \frac{\partial (A_c + A_o)}{\partial x} = q.
\]

The momentum equation (2) takes into account only the active part, hence the total cross-section area is substituted with the active cross-section area:

\[
\frac{\partial Q}{\partial t} + \frac{\partial (\beta Q^2/A_c)}{\partial x} + g A_c \left( \frac{\partial h}{\partial x} + S_f + S_i + W \right) = 0,
\]

where \( Q \) – flow rate \([\text{m}^3/\text{s}]\), \( h \) – water table ordinate \([\text{m}]\), \( x \) – cross-section position coordinate \([\text{m}]\), \( t \) – time \([\text{s}]\), \( g \) – acceleration due to gravity \([\text{m/s}^2]\), \( q \) – unitary lateral inflow on the length of the watercourse \([\text{m}^3/\text{s}/\text{m}]\), \( \beta \) – momentum coefficient \([-]\), \( S_f \) – hydraulic gradient \([-]\), \( S_i \) – term representing the loss due to the cross-section getting narrower or wider \([-]\), \( W = qQ/A_c \) – term representing the unitary lateral inflow in the equation of motion \([\text{m}^3/\text{s}^2]\).

### 3. Determining the range of active cross-section

The key difficulty is to determine the range of the active cross-section zone. One of the methods to do it is that of Pasche (1984), used in the unsteady flow modelling system SPRUNER (Wosiewicz 1996). It is assumed that the active part of cross-section consists of the area which determines inbank capacity and of the \( b_{II} \) zone (Fig. 2.) of interaction between the main channel and floodplains, calculated according to the formula (Laks 2005):

\[
b_{II} = \frac{R_{II}^4}{8 \ g \ n_z^2 (0.068 \ e^{0.056})} \]

where \( R_{II} \) – hydraulic radius of floodplain \([\text{m}]\), \( n_z \) – floodplain roughness coefficient, \( C_T \) – slip-velocity in Pasche’s method \([-]\).

Further details on the method to determine the range of the \( b_{II} \) zone can be found in (Laks and Kałuża 2005, Laks and Wosiewicz 1997).

Fig. 2. Determining the range of active cross-section.
4. **Computer implementation**

The above assumptions on the range of active flow zone have been implemented in the unsteady flow modelling system SPRUNER (Wosiewicz 1996), developed at the Faculty of Land Reclamation and Environmental Engineering at the University of Life Sciences in Poznań.

The system determines the active flow zone according to the following scheme:
- for water levels below the inbank capacity, the active zone and the overall cross-section coincide,
- for water levels exceeding the inbank capacity, for each tabulated water level ordinate the range of active zone is calculated according to formula (3) for both the left and the right banks,
- given the range of active zone, the surface area $A_c(h)$ is calculated, together with all other parameters required for numerical solving of de Saint-Venant equations.

Each cross-section corresponds to two sets of data, separately for the active part and for the entire flow area. The system also stores the values of $C_T$ calculated from Eq. (3) for each cross-section, separately for the left and the right floodplain. This parameter is considered a model-specific constant, the value of which can be determined in the process of calibration the model to the real situation.

5. **Analysis of the size of active flow zone for selected cross-sections of the Warta river**

The size of the active part of the cross-section (as a function of water depth) has been analysed for three characteristic river cross-sections of the Warta river (Figs. 3 and 4). It has been assumed that $C_T$ is 5.0.

The cross-section 350+100 (Fig. 3), located in the region of Koninsko-Pyzderska valley, is characterized by widespread floodplains which are decisive for the transformation of flood waves. The width of floodplain valley is 3150 m, the width of the main channel is 70 m. For this cross-section, the active zone area does not exceed 14% of the overall cross-section area.

![Fig. 3. Computational cross-section of the Warta river at km 350+100. Surface area of the active cross-section and the entire cross-section](image-url)
For some cross-sections and a specific water level, the total surface area of the cross-section may be equal to that of the active zone, which is shown in the example given in Fig. 4. This means that the valley is filled to such a depth for which also in the floodplains there is one predominant direction of flow coinciding with that of the longitudinal gradient of the watercourse.

Fig. 4. Computational cross-section of the Warta river at km 348+000. Surface area of the active cross-section and of the entire cross-section.

For the same cross-section (km 348+000), the change in the percentage of active area in the entire cross-section area is presented as a function of water table level (Fig. 5). This plot describes the two principal work-phases of floodplains. In phase one, the valley is being filled up, hence the share of the active zone falls. In the floodplains the momentum is not transferred in the direction of the longitudinal axis of the watercourse (transversal and local gradients prevail). Phase two refers to the moment when the filling is sufficient for the active zone share to start rising again. Local or transversal gradients are no longer decisive for the direction of flow in the floodplains. The floodplain valley increasingly transfers momentum in the direction consistent with the dominant flow direction, until in all the cross-section, the water flows through the entire cross-section in the direction parallel to the longitudinal axis. This description is clearly very simplistic, but it shows how the spatial character of motion in the floodplains can be included into one-dimensional models.

Fig. 5. Computational cross-section of the Warta river at km 348+000. Percentage of active cross-section in the entire cross-section as a function of water level.
The presented examples of computational cross-sections of the Warta river show that the range of the active flow zone may be calibrated with considerable impact on computational results. For widespread floodplain valleys the key calibration parameter is not the roughness coefficient but $C_T$ from formula (3). It is this parameter that will be decisive for the size of active zone. Consequently, it will define the influence of floodplains on flow transformation.

6. Calculation of flow transformation for the 1997 flood wave on the Warta river section from the Jeziorsko reservoir to Oborniki

In order to verify the methodology described above, a one-dimensional model was developed of a 180 km section of the Warta river between cross-sections km 384+150 (lower dam post at the Jeziorsko reservoir) and km 206+300 (IMGW gauging station in Oborniki).

The model comprised 244 computational sections, 221 cross-sections, 27 bridges, 4 by-pass channels (in Kolo, Konin, Šrem and Poznań), 2 embankment weirs, and one riverside reservoir (the Golina polder). Two tributaries – Prosna and Ner – were taken into account. Calculations were carried out for two variants: with and without the active zone. The model was also calibrated. Results are shown in Fig. 6.

![Fig. 6. Comparison of calculated and measured hydrographs at the gauging station in Poznań.](image)

For the variant with no separated active flow there is no sufficient agreement between measured and calculated results. This refers to the wave shape, time of maximum discharge and the discrepancies between levels at individual points of the hydrograph. In the variant in which a separate active flow zone is considered, the input wave is considerably transformed and its shape is in good agreement with measurements. Calculated time of maximum levels and discharges coincides with the time determined based on measurements. Discrepancies between measured and calculated results occur in the values of water table ordinates. However, it should be stressed that the procedure of calibration was very simplistic and consisted of merely three „predictor-corrector” steps. More sophisticated model identification methods, e.g., optimisation methods using gradient solution search algorithms, might lead to better agreement of calculated and measured results.
7. Conclusions

The schemes described in this paper, developed for the representation of widespread floodplain valleys, introduce new parameters into one-dimensional unsteady flow models based on de Saint-Venant equations. These parameters require calibrating in the process of calibrating the model to the real situation. In practice, for each simulation in which a flood wave is analysed a parameter must be chosen (in the above scheme $C_T$) which determines the range of active zone and its water level-dependant behaviour. In this way, no out of range roughness coefficient values are introduced into the model, which, in fact, indicates that either the physical background of the model is inadequate or the data describing the watercourse geometrics is uncertain, although geometry is generally considered reliable.

References


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