Conclusions

The present study aims at improving knowledge, understanding and modelling of morphological evolution of rivers, especially in unsteady flow conditions with changes in regime (transcritical flows). To achieve this objective, a one-dimensional two-layer shallow-water model, originally developed by Capart (2000) and completed by Capart and Young (2002) and Spinewine (2005), appeared as a promising tool, compared to the common Saint-Venant – Exner approach. Such a two-layer model was thus analysed in depth, extended and assessed by comparison with experimental results, some existing, some carried out in frame of the present research.

The main principles and equations of the two-layer model have been developed by the above-cited authors. In the present study (chapter 2), an extensive demonstration is proposed in order to clarify as much as possible the capabilities and limitations of the model. In particular, use of specific control volume, encompassing and following the inter-layer interfaces, resulted in an accurate definition of the relation between erosion / deposition rate and shear stresses, leading to a unique expression for both erosion and deposition cases. An eigenstructure analysis applied as well to Saint-Venant – Exner as to the new model, allowed to compare how information propagates in each model. Concerning the Saint-Venant – Exner equations, new approximated analytical formulations of the eigenvalues were proposed. For the two-layer model, a new non-dimensional number Z_{sw} was defined, substituting for the Froude number, and thus allowing to characterise the flow regime in an original way.

The numerical method (chapter 3) relies on finite volume, with LHLL flux computation at the cell interfaces. Although Spinewine (2005) had defined two distinct shear stresses τ_{ws} and τ_{sw} on each side of the interface between the water and the transport layers, these two shear stresses were considered as equal for the source term estimation in the case of deposition. This assumption was discussed and released in the present approach.

In previous researches, the two-layer model was applied to dam-break simulation, where no specific treatment of the boundary conditions was required. In more general cases of unsteady flows the boundary conditions are of great influence. One of the major aims of the present work was to develop a treatment of boundary conditions adapted to a two-layer model (chapter 4). This method, based on use of the specific two-layer Froude number, allows that a great range of boundary conditions can be imposed properly. The main advantage of the two-layer model is the fact that it is possible to impose the solid discharge directly as a boundary condition, which is not so simple for the Saint-Venant – Exner model.

No real calibration process was proposed by the former authors for the friction coefficients of the two-layer model. A special attention was paid to develop such a procedure from uniform flow conditions (chapter 6). A method is proposed to determine these parameters, either by comparison to common uniform-flow and transport formulae, or from experimental results. For a wide range of flow conditions, the two-layer model revealed to be in surprisingly good agreement with some of the well-known solid transport formulae, while the description of the transport mechanism is completely distinct. However, such an agreement is observable only if the velocities are allowed to be distinct in both water and transport layers. Although the solid discharge is well fitted, the likelihood of the computed values of specific parameters (typically the thickness h_s and velocity u_s of the sediment layer) by comparison is not yet clear and has to be checked in further experiments.

The two-layer model was applied to some unsteady flow examples, and compared as well to Saint-Venant – Exner results as to experimental measurements (chapters 7 and 8). Four cases were studied: (1) a control section over a transition between mild and steep slopes (Bellal et al., 2004); (2) a hydraulic jump over a mobile bed (Bellal et al., 2003); (3) a subcritical flow over a transition between a fixed and a mobile bed; and (4) a scour hole development at the toe of a sill. The two first experiments were realised by

Mourad Bellal, the third one was carried out specifically in the framework of the present thesis and the last one with the assistance of undergraduate students. The following conclusions were deduced from the comparison between experimental and numerical results.

Some drawbacks of the Saint-Venant – Exner model were clearly identified. In that model, the solid discharge is calculated with a closure relation assuming that the actual sediment transport is equal to the equilibrium one. This restriction makes this model not adapted to calculate fast transient flows like dam-break flows, when the bed evolution rate becomes comparable to hydrodynamic changes. Another implication, due to the fact that the solid discharge is calculated with a closure relation, is that it cannot be imposed properly as a boundary condition. Moreover, the Saint-Venant – Exner model is sensitive to discontinuities, a small difference in the flow variables (depth and velocity) may induce a significant difference in solid discharge, which may lead to instabilities, even if some solutions are proposed. Finally, that model does not allow to know the transport layer depth or velocity. Nevertheless, for river flows, when the transport layer is very thin compared with the water depth, and when the changes in flow regime are not too fast, the Saint-Venant – Exner model remains a good option. The results in modelling the knickpoint migration and the hydraulic jump over a mobile bed were quite satisfactory. As predicted, the comparison with experiment in the case of the scour hole was less adequate, at least without use of bed-load loading law.

Compared with the experimental results, the most complete formulation (two-velocity / two-concentration) of the two-layer model, with an appropriate boundary-condition treatment, gave good results, rather better than those obtained with the Saint-Venant – Exner model. Contrarily to the Saint-Venant – Exner model, the solid discharge can be calculated even in non-equilibrium conditions and imposed as a proper boundary condition. Nevertheless, a perplexing point is the fact that the internal eigenvalues may become conjugate complex, which could correspond to physical instabilities (like bed-forms), but this interpretation is still a matter for conjecture.

Nevertheless, even in this case, the model remained numerically stable, and the results liable, among others in terms of mass conservation.

The comparison between the various versions of the model indicated that the assumption on the velocity in the transport layer is of great importance. From the uniform-flow analysis, it was found that the fundamental assumption considering identical velocity in the water and the transport layer was not adapted. Then, the one-velocity two-layer model is not able to reproduce unsteady flows. On the other hand, assuming a constant ratio between the velocity in the water and the transport layer gave results quite close to those obtained with the complete model. Nevertheless, in the examples treated in the present work, the velocity ratio calculated by the complete two-layer model was not varying much, which may explain why the results revealed similar. The eigenvalues of this simplified model remain always real, not depending on the flow conditions.

The assumption on the sediment concentration in the transport layer appeared to be less important for the treated examples, except that use of an appropriate concentration in the transport layer gave more realistic transport layer depth and velocity. Moreover, it allows to take into account the mass and momentum exchanges between the water and the transport layer. Nevertheless, in some of the treated examples (e.g. the erosion hole), when the sediment concentration in the transport layer was imposed lower than a threshold value, instabilities appeared.

Of course, such a research does not cover all the problems of the field of investigation, and many questions are still open to further researches. At least some of them can be pointed out.

Additional research work should be done on the significance of appearance of conjugate complex eigenvalue. Is the problem well posed? Is there a link with physics? Is there really a loss of one degree of freedom? Is only the real part of these eigenvalues significant? Is it still appropriate to use a hyperbolic solver? Some paths to answer are proposed in this work, but deeper studies should confirm those intuitions.

Another point to be deepened is the respective role of transport layer depth and velocity in the formation of solid discharge. Is the model really able to reproduce these parameters of the flow? Specific measurement of those two parameters could help to better understanding the model behaviour.

In order to be able to deal with problems with more complex vertical velocity field, occurring for example in the case of the erosion hole, an additional turbulent layer could be added between the water and the transport layer. New laws should be defined at the interfaces between the layers. Perng (2006) dealt with such problems, in the case of a submerged water jet inducing erosion of the bed, and his works could serve as a starting point to such developments.

The presented models, based on an explicit finite-volume numerical scheme, are not designed to reproduce large time scale morphological evolutions. Another numerical method, allowing larger time steps and then requiring less computational time, should be developed

Finally, these models can be easily extended to take into consideration a geometrical change in the channel (El Kadi Abderrezzak and Paquier, 2004 for Saint-Venant – Exner equations and Castro et al., 2005 for the two-layer model) or to a two-dimensional approach (two-dimension formulation already proposed in Capart and Young, 2002). For example, a bank erosion treatment as proposed by le Grelle and Zech (2003) could be introduced. Nevertheless, the extension of the boundary conditions to such models may reveal to be rather complex.