Hydrological Run-off in MIKE 11- Draft

- User requirements and proposed solution/implementation

Contents

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1 Purpose

This document outlines the user requirements for inclusion of supplementary hydrological runoff methods e.g. routing routines in MIKE11. The basic requirements to the applied methods and their intended use are outlined. Alternative solutions to meet the user requirements are discussed and accompanied by cost estimates / time schedules. The document serves to reach a decision on the most feasible solution.

Further detail on the user requirements will be carried out prior to implementation.

2 Background

MIKE11 is among the most recognised models in river hydraulics. The model was originally developed for river hydrodynamics and through continued development it today offers various wave models and a large number of sophisticated features for hydraulic analysis, flooding, hydraulic structures etc.

MIKE SHE is a hydrological modelling system, which is mainly used for water resources assessments including both surface and sub-surface flow. Channel water levels and run-off are key simulation variables in integrated water resources modelling.

MIKE11 and MIKE SHE were coupled to improve MIKE SHEs channel flow capabilities, to increase the potential uses of the combined models and to avoid parallel development/maintenance of two river codes.

Although the coupling has made other types of more advanced hydraulic applications possible (e.g. wetlands/floodplains) a severe problem still exists for the common use of MIKE11 in long term water resources analysis.

The problems faced by a number of users include:

- numerical instabilities - mainly when river segments runs dry
- water balance errors - enhancements to the stability sometimes occur on the expense of conservation of mass
- extremely small time steps (in hydrological sense) are required to prevent the above problems

Other less critical problems arise from inconsistencies in the specification of river cross sections (i.e. steep gradients caused by wrong datum) or possible mismatch between cross section levels and topography. These problems are basically caused by inconsistent input to the model, but warnings should be issued during start up of the models to save the user for a time consuming manual check of his set-up.
The low flow problems are as far as the experience shows not related to the coupling of the two modelling systems, but the general handling of dry river reaches in MIKE11. MIKE11 has introduced an artificial slot to prevent discontinuities and numerical instabilities. The MIKE11 development group investigated if the slot solution could be improved to avoid instabilities and allow larger time steps. The conclusion on the work was that the solution of

the Saint Venant equations (momentum and continuity) for the existing wave approximations was not possible when e.g. a rise in water levels from within the slot to the general cross section takes place quickly e.g. in a single time step. To overcome this problem the time step in the simulation typically has to be reduced to less than 5 minutes.

This may be feasible in hydrodynamic - 'event'-based simulations, but it is not satisfactory when running long term water resources simulations.

At the current stage it is thus necessary to offer a different approach, which either should be based on a simplified version of the present wave models or a lumped, empirical method which eliminates the above mentioned problems.

3 User Requirements for a Hydrological Runoff/Routing Method

The basic requirements are:
- An unconditionally stable numerical scheme to simulate flows and corresponding water levels
- A mass-conserving method i.e. no water balance errors
- Time steps in the order of hours
- Calculation of flows and water levels in parts of the river network (e.g. individual branches or reaches), i.e. combine complex HD branches with simple routing branches in the same setup
- Full integration with the existing MIKE 11/MIKE SHE coupling approach, implying that river aquifer exchange and flood-mapping must be applicable also for simple flow routing branches
- Setup of simple and advanced branches must be identical in the MIKE 11 user interface partly to use the existing coupling routine and partly to allow switching between advanced and simple.

A routing/runoff element represents e.g. a river branch. By serial coupling of empirical routing expressions from calculation node to calculation node (Q-points) the flow along a branch is described. The corresponding water levels are derived by use of rating curves, which may be user specified or preferably determined by the model considering bed slope, Manning numbers and cross section characteristics. The variations in water level along the branch are essential with respect to the MIKE SHE - MIKE 11 coupling routines.

In the coupled model sink/sources along the river reach controls the lateral inflow/outflow in terms of drainage, base flow and overland contributions. The exchange must be computed along the river branch (depending on spatial resolution of the MIKE SHE grid) and flows and water levels must be computed/distributed in a number of nodes along the branch. It is proposed that the general layout of computational nodes for ordinary MIKE 11 branches is used to control the ' resolution' of river flow computations.

Calculation of discharge/water level in a single node may be sufficient to describe lateral inflow/outflow and to account for the along a reach more Q/H nodes must be included. A series of routing elements may be specified to provide the degree of detail needed for e.g. the water level variations along a branch. A sub-division into separate routing elements requires in principle, specification of several sets of routing parameters and an option should be included in the user interface to use one set of parameters for all routing elements in the branch. The transformation of flow hydrographs between the routing elements must include the contributions from lateral sinks/sources.

The routing/runoff elements must easily be incorporated in a Mike11 river network. The river network should consist partly or entirely of routing elements. Routing branches must be connected directly to branches solved by the existing wave approximations. Routing is specified branch wise and default routing method and parameters/coefficients are applied.

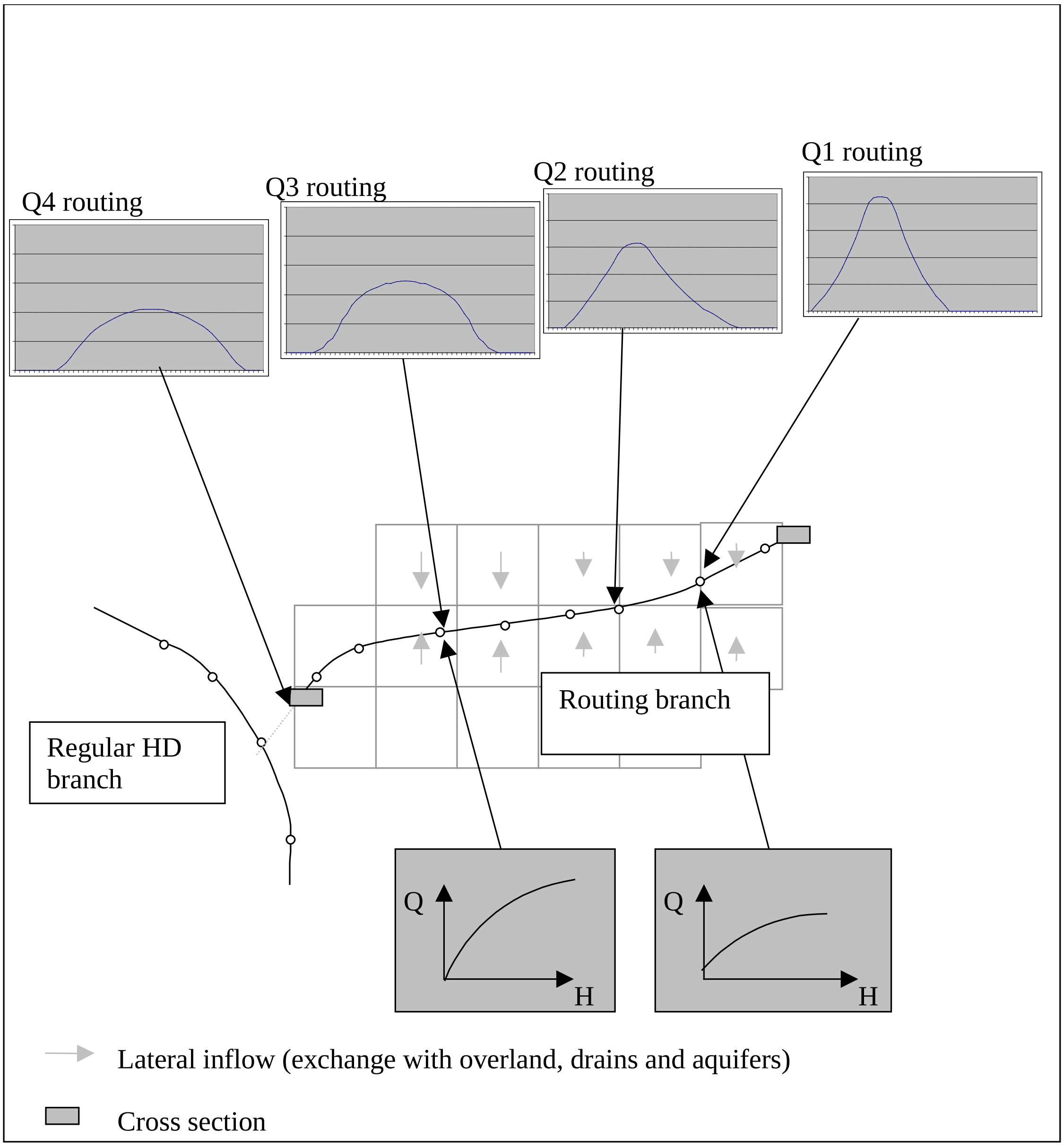

Figure 1 Routing branch (inflow/outflow) coupled to underlying MIKE SHE grid system

4 User Interface

The incorporation of routing elements in the MIKE 11 user interface requires:
- routing types should be added to the present selection of branch types
- a dialogue to specify parameters and coefficients used in the routing algorithm (added to existing routing page)
- dialogue and tool to generate/define rating curves

All other inputs for the routing elements must be identical to the regular branch definitions in order to allow switching between simple and advanced methods.

In order to make river-aquifer exchange calculations a water level and basic cross-sections geometry is needed. The following is suggested:

- The user specifies cross-sections as for a normal MIKE 11 model.
- The user specifies/generates a Q/h relation where cross sections are specified i.e. as a minimum upstream and downstream. MIKE 11 would calculate flows and water levels along the branch for the specified number of Q and H points or MIKE SHE would interpolate water levels between MIKE 11 h-points to fit with MIKE SHE's river-link reference system.
- Inclusion of hydraulic structure can only be included as a Q/h relation
- .

I strongly recommend forgetting all about alternative 1 and choosing alternative 2. Alternative 2 would offer something new, which would complement what we already have very well. Alternative 1 is more or less the same as we got and it is not going to

5 Routing Methods

A few simple and efficient routing methods should be included. At the time being it is the intention to include a Muskingum scheme and screening of additional methods should be done to identify other methods, which are generally applicable. Other options may include combined linear reservoirs presently used in NAM, routing elements tailored for reservoirs etc. The effects of storage changes, attenuation and the methods ability to describe both rising leg and the recession of the hydrograph must be considered. The implementation of various methods is considered a minor part of the development compared to a flexible combination of branch types and water level computations. Consequently, an open interface should be provided, which facilitates implementation of additional methods. It should be investigated if a general formulation can be found to include all of the selected methods.

Some commonly used methods can be found in *E.M. Wilson, Chapter 8: Flood Routing, Applied Hydrology, V.T. Chow et al., Chapter 8: Flow Routing* and *CTI-MIKE 11 Reference Manual - Chapter 3: Routing.*

As an alternative to routing methods a quasi-stationary solver (QS) has been suggested. The QS solver must be used for the entire network and can not be used on individual branch level. The QS solver allows much larger timesteps and since MIKE 11 does not use varying timesteps in different parts of the network all of branches must be solved by either HD or QS.

6 Existing MIKE 11 Elements

The quasi-stationary solver is available in MIKE 11. It meets one of the requirements in terms of longer simulation time steps. It is not necessarily unconditionally stable and mass conserving, but is likely to represent a substantial improvement compared to the wave models presently available in the user interface.

The quasi-stationary solver has been developed for morphological studies and water quality simulations i.e. long term sediment transport or eutrophication simulations. It does not at present include the source/sink terms of the other MIKE 11 solvers, which are used for the MIKE SHE - MIKE 11 coupling.

In ongoing development work DHI is developing routing routines in co-operation with CTI, Japan. The routing expressions have been tailored to Japanese conditions and may not be used directly in this context, but the possibilities of reusing and perhaps generalising the existing work should be further explored.

In the CTI development the hydraulic computation may be replaced by a routing element in selected river branches i.e. only Q is calculated as opposed to Q and H in an ordinary branch. The routing element has by definition only one calculation node, but by adding routing elements in chainages along a branch several Q nodes may be introduced.

The available methods cover both traditional routing and reservoir/flood routing. They all require an inflow hydrograph and some parameters used for producing an outflow hydrograph.

The CTI routing elements can be combined with ordinary HD branches. It is, however, not possible to specify a HD branch upstream of a routing branch.

At present the CTI routing does not require any cross section information.

Due to a copyright agreement between CTI and DHI it is not possible to simply extent the CTI development. Instead a new set of dialogues and calculation routines must be introduced. It is, however, possible to reuse some of the code without violating the agreement.

The CTI routines do not consider water levels and cross section information. This must be added to allow the MIKE SHE -MIKE 11 coupling.

7 Proposed Solutions

Two alternative solutions may be outlined:

Alt. 1: Further development of the quasi-stationary solver
The advantage of choosing this option relies on the solver already being available.
The disadvantages include the extra work required to include source/sinks, the inability to combine dynamic and QS approach in different parts of the network. Some adjustments will be needed to resolve a known problem in relation to hydraulic structures and it must be checked if this option effectively solve the dry river problem.
Question:
How does the handling of dried reaches in the QS solver differ from the slot solution used in existing wave approximations?
Is the QS solver capable of describing storage changes in e.g. reservoirs?

Alt. 2: Incorporation of simplified routing expressions
The advantage of this approach is the possibility to include commonly used routing methods, which would be useful in a wider water resources context. The routing branches have already been introduced in the MIKE11 code and user interface exists *– but in a form not directly compatible with the current needs and additional coding is therefore required*. A series of methods may be implemented depending on user requirements.

Disadvantages include the accuracy of simulated water levels and the fact that some knowledge on routing parameters/coefficients is needed (in principle derived from hydrograph analysis).

8 Cost Estimates

Alt 1: QS solver

Task	Estimated man time	Estimated cost *)
Implement source/sinks	1 weeks	
Structure adjustments	2 weeks	
Dry river handling	1 weeks	
Testing	2 weeks	
Total	6 weeks	App. 155.000 Dkk

*)

Alt 2: Routing/runoff branches

Task	Estimated man time	Estimated cost *)
Extend dialogues (UI)	2 weeks	
Rating curve tool	2 weeks	
Rating curve dialogue (UI)	2 weeks	
Implement routing expressions	2 weeks	
Testing	1 weeks	
Total	9 weeks	App. 232.000 Dkk

9 Resources and Timing

Time schedule relative to start of development. To be initiated as quickly as possible - preferably in 2000. With the current workload of all MIKE 11 developers it will, however, be very difficult to initiate the development in 2000. Both engine and GUI-developers are heavily booked, so the developments will have to be postponed till beginning of 2001.

10 Recommendations

Looking at the two alternative solutions, their ability to meet the user requirements and the resources required to implement them it appears that the routing branch solution is more feasible than the QS solver.

Some of the main arguments are:

- The routing method is not using the 'slot' technique to avoid dried river, which implies that problems related instability and mass balance errors is eliminated
- The routing method allows combined use of simple routing branches and full hydrodynamic branches

- The implementation of routing branches and the user interface could be partially be taken from the existing CTI development.
- It is uncertain if the QS solver effectively will eliminate the current problems e.g. dried rivers.

Some of the main arguments against the routing option are:

- It requires more resources to implement the routing option

11 References

1) Engineering Hydrology, E.M. Wilson, Chapter 8: Flood Routing
2) Applied Hydrology, V.T. Chow et al., Chapter 8: Flow Routing
CTI-MIKE 11 Reference Manual - Chapter 3: Routing