# CONSIDERATIONS ON URBAN AREAS AND FLOATING DEBRIS IN DAM -BREAK FLOOD MODELLING.

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## 1. SUMMARY

Every model is a story, describing real-life and more or less significant simplifications are a must in all flow modelling work. The art in modelling is to use these simplifications and gain results, accurate enough to serve the tasks of the analysis. In the case of uncertainty in approach and available methods sensitivity analysis and add-on empirical approaches are useful tools to define upper and lower limits of the results. Even in cases of highly sophisticated modelling commonly the flow in urban areas are strongly simplified and the model only deals with "clean water". Also winter and ice problems are not considered, even in cases of long-lasting winter conditions (4-6 months annually).

Urban areas and floating debris are subjects for new model development The flow in urban areas as well as improvement of accuracy of modelling approaches are important for several reasons. Safety evaluations of the population at risk and structural safety of buildings located within the dam-break flood path are necessary for emergency/rescue action planning. Following the concept of the potential damage definition by a damage parameter formed by a product of water depth (D) and flow velocity (v); DAMGPM = D*v (m2/s) the accurate simulation of the flow through urban areas gains of high importance. Different modelling approaches can be applied to improve the accuracy of flow modelling of urban areas.. The processes of de-rooting trees and other vegetation on riverbanks and over-bank flow areas as well as sediment transport and deposition at critical areas should be topics for important research, but unfortunately little new modelling development is available today. The modelling approaches to evaluate the effect the floating debris and sediment have on the flood wave propagation can be studied in principle. The information available consists mainly of after-flood observations of the remains of debris jams. More event observations are available on ice break-up. Ice-run and on the formation of ice jams.

Based on this information a simplified modelling method of the cloggage mechanism of bridges and gate openings of secondary dams located within the flood path can be developed and the concept of this approach will be discussed in this article. The effects an ice-cover might have on the dam-break flood wave propagation will be discussed in principle and a simplified modelling solution will be introduced.

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## 2. MODELING CONSIDERATIONS RELATED TO URBAN AREAS

### 2.1 General

There are two major tasks, why the flood wave propagation through urban areas and the flood wave arrival at certain locations in urban areas are of special interest. The type of task can have effect on the application of different modelling technologies.

Task 1 Define the flow in urban areas and evaluate the damaging parameter (most commonly flow-velocity x water depth). Flow velocities and water depths are significant at areas concerning task 1. Such areas are near dam areas with a relatively steep gradient of the terrain.

Task 2 Define the flood propagation directions and speed in urban areas. This is of importance especially in large cities, where flooding can effect a large number of people and especially the flooding of underground facilities may be of concern. Flow velocities and water depths are commonly moderate at areas concerning task 2.

### 2.2 Modelling methods serving Task 1

The modelling methods applied shall have the capabilities to simulate high flow velocities in the study area. Different approaches may be used to describe the effect of buildings on the flow.

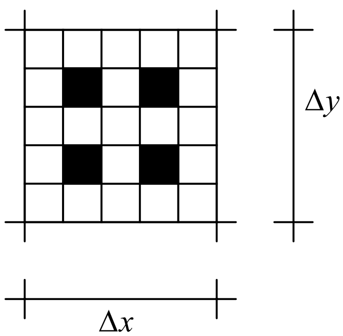
1. The most common approach has been to evaluate the effect of structures on the flow by adjusting roughness. In this approach the volume of the building in not considered and in tightly constructed urban areas the mean flow velocities remain significantly lower than expected for the flow propagating between the buildings. This approach is functional only when the number of buildings is small or the magnitude of the dam-break wave is submerging the area with a depth several times the height of the buildings. This is nevertheless a rare situation, applicable only to very high dams (approx. 100 m and above)

2. The approach is to describe the urban areas with geometry. Depending on the type and size of the buildings and urban infrastructure the layout of such types of models is complex and large. Practically it needs the use of terrain modelling and city model applications (tested at RESCDAM-pilot project. In the case of using a 1D-network model a complex flow-network along roads and between houses has to be developed. In the case of 2D modelling the minimum sizes of houses dictate the minimum size of the elements or the grid. In the RESCDAM pilot project urban area grids of 5 and 10 m squares were developed and the 10-m grid was used in the flow model, due to computational modelling limitations.

3. The approach is to use larger element or grid sizes and develop a concept of permeability of each element. This permeability is also named "urban porosity" or "transmissivity of a built-up area" with clear similarities to flow in a porous fractured medium. The permeability is computed in both x and y directions as well as based on shapes of the buildings and covering

percentage of the total flow area of the element by the structures. This concept was already used in 1994 by Molinaro, Di Filippo and Ferrari, "Modelling of flood wave propagation over flat, dry areas of complex topography in presence of different infrastructure", International Conference on Modelling of Flood Propagation over Initially Dry Areas, ENEL-CRIS, Milano, Italy, p.128.

A summary introduction is also given in ICOLD Bulletin 111, Dam-break Flood Analysis, 1998, p 223. A simplified sketch of buildings in a computational cell is shown in Figure 1.




$A_e=n_l\Delta x\Delta y+ n_l\Delta y(1- nl_1)\ \Delta x$

Where:

$n_1$ = ratio between the "free length" and the total length ($\Delta x$ *or* $\Delta y$) of each cell side;
$\Delta x$, $\Delta y$ = length of the cell side.

Figure 1 Concept of Urban Permeability

The effect of the different methods on the results is a task of the RESCDAM project and will be reported in the final report of this project.

## 2.3 Modelling Methods serving Task 2

The area of application are large city areas with relatively flat bottom geometry and a clearly defined channel network of regulated rivers and canals. The city area is protected by dykes against river flows of a certain design flood, which commonly differs depending on the importance of the protected city area.

Two different models are combined! The channel network is modelled with a dynamic 1D-flow model, while the City areas (polders) are modelled with (simplified) 2D models. Connection boundaries between the two modelling systems are operational sites, like sluices and pumping stations as well as potential dyke (dam)-break locations where dyke-breaks could occur under certain flood stages in the river channel network.

Special interest is paid to the problem that in large cities a lot of underground space is in extensive use (shopping malls, cinemas, parking garages etc.). A flood invasion of the underground facilities could endanger large numbers of people. A model simulation of the flooding of city areas, including the endangering of underground facilities has to be done and emergency actions planning has to consider the large amount of people on move.

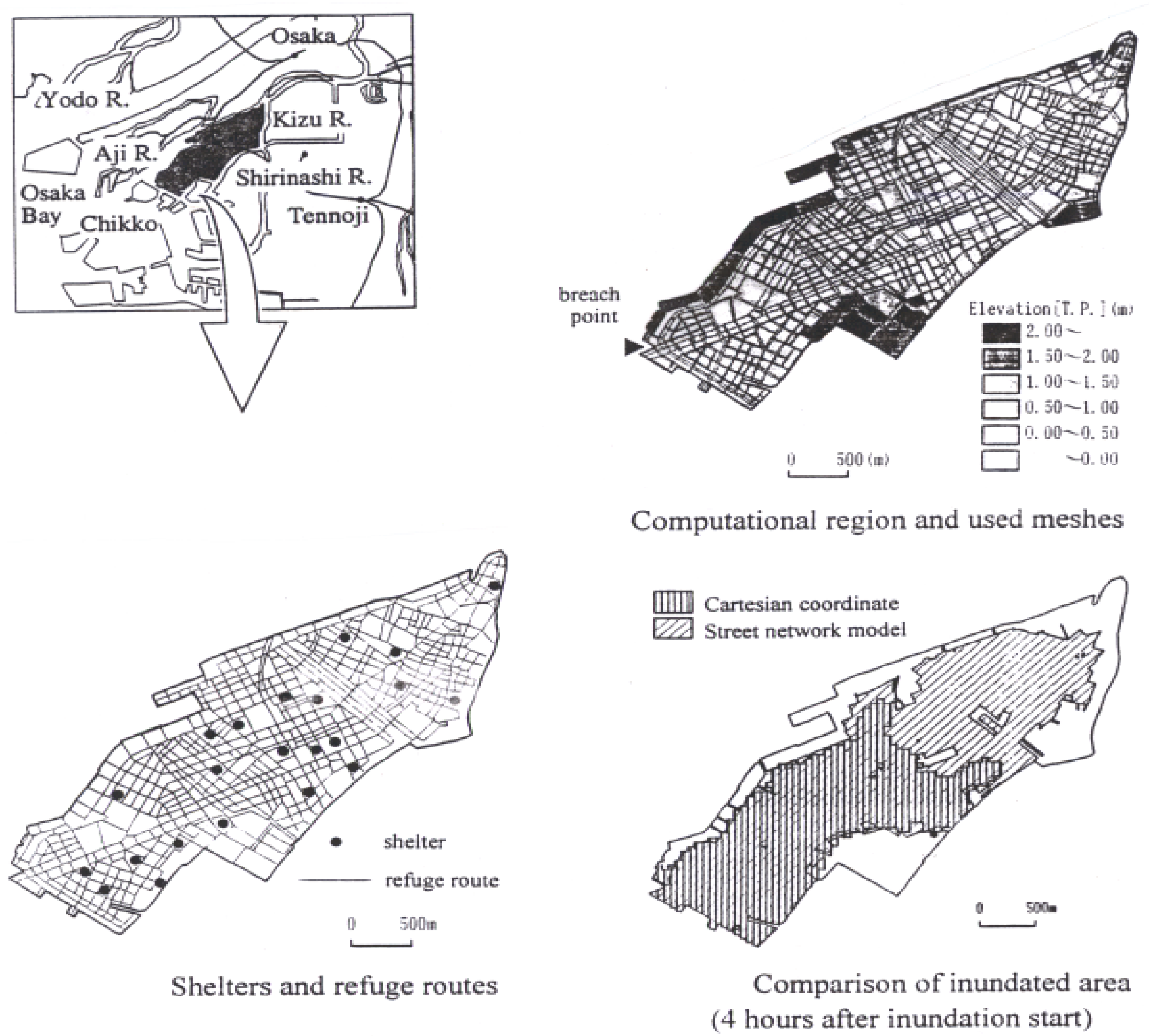



Figure 2 K.Inoue, Japan,"Mathematical models for overland flood flows and their application to urban areas"

Models of this type have been recently developed in China and Japan and reported at the '99 International Symposium on Flood Control, November 10-13, 1999 Beijing China. K.Inoue, Japan,"Mathematical models for overland flood flows and their application to urban area"; K.Inoue, K.Kawaike, K.Toda, Japan "Refuge analysis under storm surge based on the street network model". K.Toda, K.Inoue, S.Murase, Japan "Numerical simulation of inundation flow due to heavy rainfall in urban area". Ruitian QIU, China "Present situation on urban flood control and its solutions for flood mitigation in China"; J.Guan, X.Cheng, L.Wang, China, Flood simulation for Shanghai urban area"; X.Cheng, J.Qiu, "Development and application of numerical model for flood simulation in urban area". A reprint of the modelling concept is presented in Figure 2.

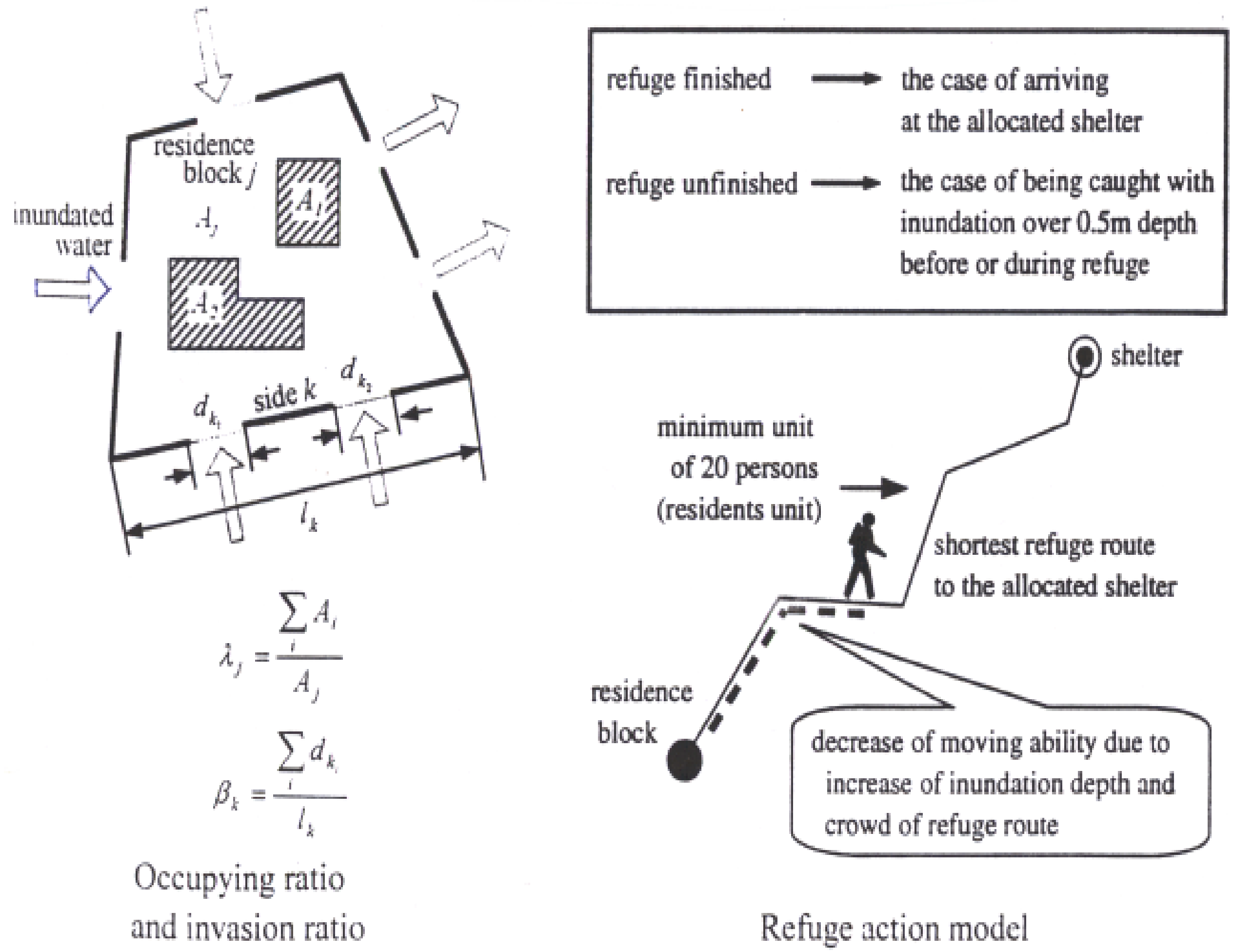



Figure 3 Usage of the urban flow model for evacuation/refuge action planning
K.Toda, K.Inoue, S.Murase, Japan "Numerical simulation of inundation flow due to heavy rainfall in urban area".

## 3. MODELING CONSIDERATIONS RELATED TO FLOATING DEBRIS

Many observations of damages caused by flash floods or dam-break floods indicate that floating debris and debris jams are a substantial additional risk during flooding. The information available is commonly only a description of the final situation after the flooding and photographs of the remaining damages and debris jams. Floating debris is consisting of:

1) Material deposited on the land surface and easily to be carried off by the flood wave. These “debris deposits” are mainly timber, stored for construction purposes on off-channel areas reached by the flood wave.

2) Brushes and trees located at areas where high velocities might occur during the flood wave propagation. This process is a coupled one with surface erosion causing the de-rooting of the vegetation.
3) In areas with high velocities and significant water depths trees might be bend and broken. Lifting forces of submerged trees might support the de-rooting process.
4) Wooden built houses and storage buildings may be removed from their foundations and carried off by the flood.

A research should be conducted consisting of physical modelling of the surface erosion process in areas with different type of vegetation. This physical hydraulic laboratory research should be supplemented with field measurements. Existing reports of flood damages should be revised with possible identification of areas from where the floating debris was originated. A comparison should show how much was the volume of floating debris in total and how much of this volume was deposited in areas along the main flood course and in jams within it.

An analysis on floating debris has to be started with a mapping of potential debris sites. A map of flow velocities or tractive forces should be prepared with the results of the "Clean Water Dam-break flood analysis". A superposition of the velocity areas over a "Vegetation map" allow an evaluation of the "Vegetation at Risk" and a volumetric amount of floating debris. It is obvious that well grown trees can withstand significant flooding, as reported in flood observations. In addition to high velocities and high water depths the time of flooding and the pre-conditions (natural flood before dam-break) have effect on the amount of floating debris.

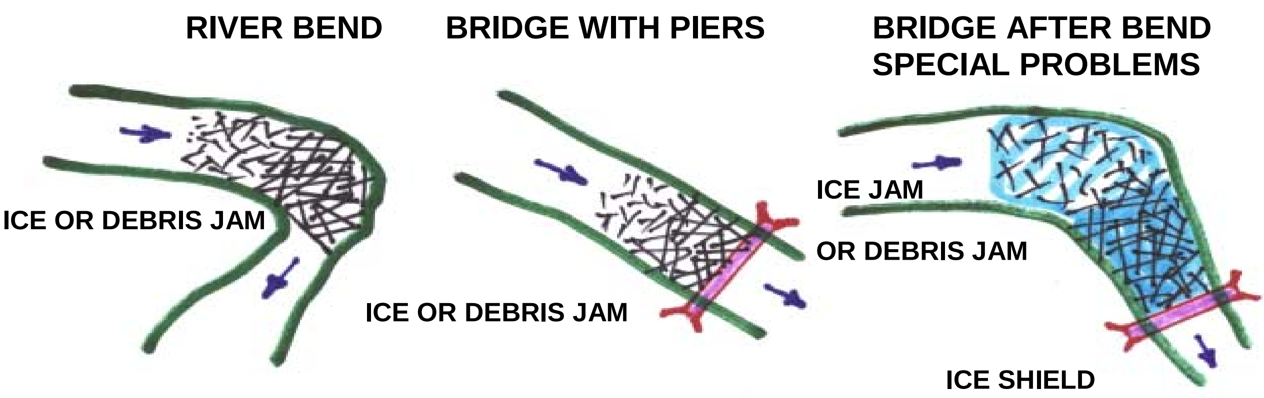



Figure 3. Potential Ice- or Debris-jam sites

The process of a debris jam to form is similar to Ice jams in Cold Regions. The difference lies in the fact that floating debris is commonly far more non-homogenous than ice and is containing long and stiff material which is difficult to pass through common bridge openings or gates of secondary dams. A conceptual description of the debris jamming process is shown in figures 3 and 4.

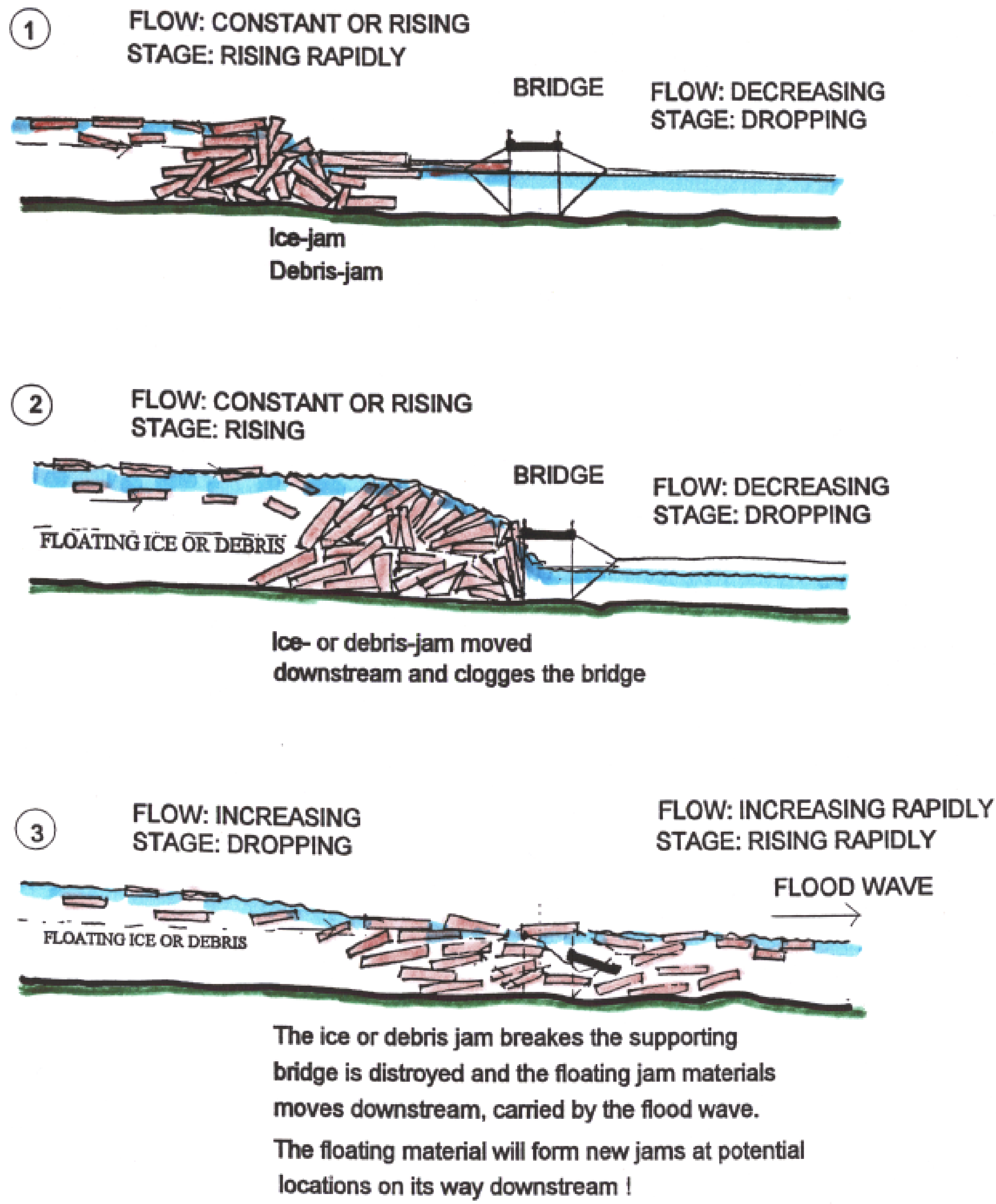



Figure 4. Conceptual introduction of the formation and breaching of ice- or debris-jams.

## 4. MODELING CONSIDERATIONS RELATED TO SEDIMENT TRANSPORT

**Erosion, transport and deposition of sediments and suspended load.**

One approach to account for “mud flow” is to use a higher density for the water-soil mixture. This method has been applied to the dam-break flood analysis of tailing dams where the stored media was water with a high content of solids or mud. Some modelling packages provide the option to route liquids of different densities than “clean water”. Any analysis has to consider erosion, transport and deposition of sediments. Although these processes are all valid through time and at all location of the flow paths one of the three processes is dominating, depending on time and location.

During natural floods the erosion of the river bed mainly occur as bottom erosion, while the major part of the suspended load (fine material) might be wash load, transported into the river from areas sensitive to surface erosion. Some erosion of the riverbanks may occur and surface erosion of areas beside the river might occur if the flow enters side areas and changes the flow line of the riverbed. Deposition of the transported erosion material occurs in areas with significant changes in flow velocity at ponds or lakes along the river course and in flood plains. Many of the changes are caused by the fact that natural floods might take from weeks to months.

Dam break floods differ from natural floods in the aspect that they are far more dynamic with higher flow velocities and water depths in areas never flooded. The surface erosion of such areas might be significant and large amounts of erosion material can be “washed” into the main river course. This material might get in balance with the erosion/transport/deposition in certain river reaches, where then mainly bank erosion can be the channel-forming factor. The dam break event is commonly rather short in time (ranging between hours and some days) and the erosion might act only locally. Sediment and suspended load transport will occur in reaches with high flow velocities and deposition of the carried sediments will occur at locations with minor flow velocities, possibly behind debris-jams.. Especially culverts and bridges are sensitive to cloggage by sediments, possibly in combination with floating debris.

There are several possibilities to take sediment problems into consideration when preparing a dam-break flood analysis. A conceptual approach to add consideration to “clean water flood routing is the following:

1) Evaluate the amount of fine material from the dam eroded during breach formation and assume this to move as wash-load along with the flow to downstream reaches. Derive the concentration of this material in the flow (suspended load).
2) Evaluate the amount of course material from the dam eroded during breach formation and assume this material to move along the bottom of the flow channel. Derive the concentration of this material in the flow (bed load).
3) Evaluate the sensitivity for scouring (surface erosion) of the areas below the dam, considering armoured riverbeds, surface protection (vegetation, road surface etc.) and provide a map of erosion sensitivity of channels and off channel areas flooded by the event.

4) Evaluate a concept of layers (1999 Yang & Greimann, Active layers and Parent layers) and provide information on layer thickness and soil properties to the map stated in section 3
5) Especially the soil of fields and soil of gardens has to be assumed as highly erosion sensitive. The thickness of these active layers can be assumed to be 0.3-0.5 meters.
6) The erosion an deposition process can be modelled in a coupled approach, meaning that flow model and sediment model are coupled and the changes in geometry resulting from the former time step in the computation is used in the flow calculation. A more simple approach is to run the models stepwise, non-coupled and update the flow model's geometry, when necessary. In the reach were erosion and deposition are in balance only transportation of the incoming total load (wash-load + suspended load + bottom sediment load) is taking place.
7) The transport of the material into different areas is either simulated by the model or evaluated empirically.
8) Deposition of material in the downstream area of the model can be of special interest when considering the cloggage of bridge openings. Depositions will most probably also effect downstream boundary conditions of the model.

A simplified sediment routing model (BEED) has been introduced by (1996 Singh) and the development of a more complex procedure has been reported by (1999 Yang & Greimann).

Basically there are three different approaches to calculate erosion, sediment transport and deposition equations:

I) <u>A critical flow velocity concept.</u> Erosion of different soil materials, possibly protected by vegetation, start at a certain critical flow velocity. At lower flow velocities transport of eroded soil material or wash-load is taking place and at certain second boundary, low flow velocities sedimentation take place. The critical flow velocity concept is simple but it does not account for different velocity distribution, at different depth of the flow.

| Soil Material of the Bottom | $V_{crit}$(m/s) Critical Flow Velocity | | Slope |
|---|---|---|---|
| | Erosion resistant | Non Ero. resitant | % |
| Fine Sand (noncolloidal) | | 0.40 | 0.01-0.3 |
| Sandy Loam (noncolloidal) | | 0.50 | 0.01-0.3 |
| Alluvial Silts (noncolloidal) | | 0.60 | 0.01-0.3 |
| Grassed Channel (Grass Mixture) | 1.50 | 1.20 | 0.3-5 |
| Grassed Channel (Grass Mixture) | 1.20 | 0.90 | 5-10 |
| Bermuda Grass | 2.40 | 1.80 | 0.3-5 |
| Bermuda Grass | 2.10 | 1.50 | 5-10 |
| Annual Crops | 1.10 | 0.75 | 0.3-5 |

Table 1. Critical flow velocities at which erosion starts

II. A critical shear stress concept takes into account that the weight component of a water collume and the friction force at the bottom are causing a force named Tractive Force, Drag Force or Shear Stress. For the force at unit bottom surface it is:

$\boldsymbol{\tau_o = \gamma DS}$ where $\gamma$= Specific weight of water, D=Water depth and S=Slope of the Energy line

Similar to the critical flow velocities, critical values on shear stress $\boldsymbol{\tau_{cr}}$ are defined by formulas, tabels and graphs in hydraulic handbooks.

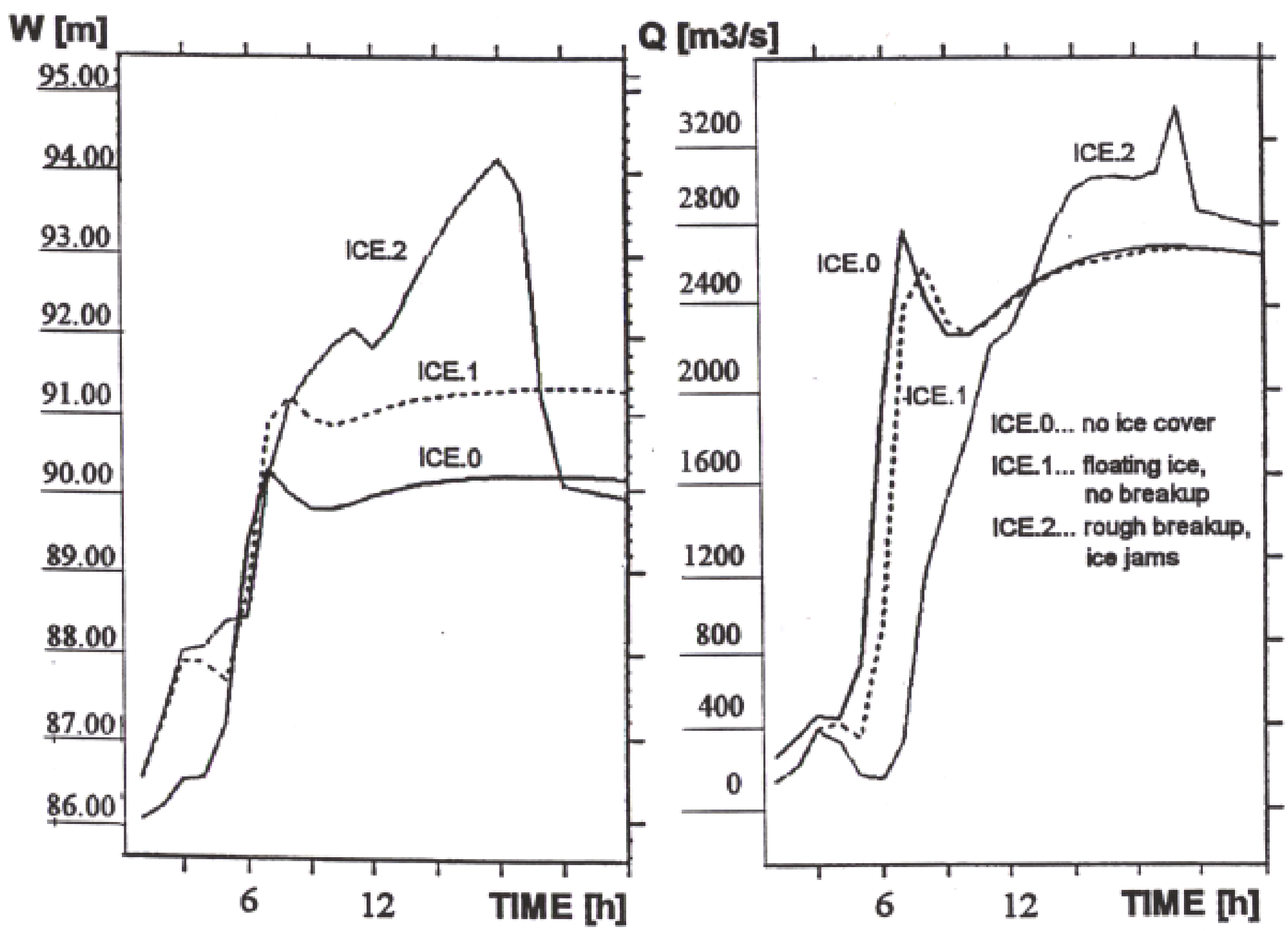
III. A lift force concept consider that lift forces may arise for at least two reasons. First when a particle rests on the bottom of a channel this is in the area where velocity gradients are steepest resulting in the building up of pressure differences which are causing the up-lift of the particle. Secondly the same particle might experience up-lift because of up-wards directed velocity components due to turbulence. If the magnitude of the lift becomes equal to the weight the smallest drag force would initiate motion. Allthough lift forces obviously contribute to the incipient-motion problem "critical lift" criterions are not common. Beside lift forces altimes also drag forces exist. Observation based data used for the critical shearstress definition also include the lift forces causing partially the start of the erosion.

## 5. MODELING CONSIDERATIONS RELATED TO WINTER PROBLEMS AND ICE COVER

The modelling of the effect winter conditions might have on a dam-break flood, needs to mainly consider the most critical period during the winter. The conceptional approach is as follows:

1) A dam-break flood analysis is prepared for the open water surface condition, using a dam-break discharge hydrograph, valid for the winter period. stable ice-cover of an observed or statistically determined thickness has formed on the river reach below the dam. This ice-cover lies on a water level adjusted to the assumed flow situation in the river. It is assumed that the flood wave created by the dam-break would break the ice-cover, which would become floating and creating additional roughness.
2) The Ice-cover is assumed to be moving with the flood wave and to create ice-jams at potential sites. Depending of the magnitude of water surface rise a part of the Ice volume of the river channel may be assumed to be transported to the floodplains and deposited there. The remaining part of the ice volume will be forming the ice-jam.
3) An empirical breaching criteria will be used to simulate the domino effect ice jamming might have on the flooding of the downstream valley.
4) The procedure 3) to 4) is repeated for the river reaches formed by potential ice-jam sites.

It is obvious that this method only can provide a rough estimate how ice problems might boost dam-break flooding in the winter period. It pays to evaluate even the effect of intentional or accidental operation of controlled spillways for flood release capacity and evaluate the effect during a winter period (Figure 5).




**DAM BREACH HAZARD ANALYSIS BREACHICE.86**
**STAGE AND DISCHARGE HYDROGRAPH AT CROSS-SECT.45 km 74.55**

Figure 5 Stepwise evaluation procedure to account for ice problems at DBFA.