RISK ANALYSES FOR SEWER SYSTEMS BASED ON NUMERICAL MODELLING AND GIS

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ABSTRACT

Within the urban area - the sewer system represents a significant investment which has been made during the last century. An inadequate design of a sewer system may cause severe economical and environmental damage. Reasons could be inadequate flow capacity of the sewers resulting in flooding of residential areas; combined sewer overflows causing pollution incidents and maybe killing of fish in the receiving waters. Alternatively an accident may happen in urban areas where different pollutants may enter the sewer system, either accidentally, or intentionally flushed down into the system to remove it from the surface area.

The flow and transport of pollutants in sewer systems can be described by use of numerical models which can be setup and calibrated to reproduce the flow and transport pattern in the sewers. These models can be used to simulate existing conditions and for the development of suggestions for optimization of a sewer system. Such an optimization could include introduction of real time control or new construction works within the system.

This paper describes the MOUSE system for modelling of flow and pollution transport in urban sewers and possible applications of the modelling system. These applications feature

analyses of an urban flooding problem and a study of the transport of dissolved pollutants in sewer systems. The applications show that such a modelling system is suitable for design of optimum alleviation schemes, for emergency planning and for off line training in emergency procedures.

THE MOUSE SYSTEM

MOUSE is an analysis software package for urban sewer systems. It has been developed especially for applications on personal computers, Ref. /1/,/2/. The package contains a number of modules of varying sophistication for the simulation of rainfall run-off from catchments and flows in sewer networks. The hydrodynamic (HD) module of the MOUSE package, used for simulation of the pipe flow, was first developed by the Danish Hydraulic Institute in 1986. The HD module is based on the full St. Venant equations and it is able to simulate looped systems with various structures such as: pumps, weirs and basins and it includes a fully featured reactive real time control optimization. Currently there are more than 800 MOUSE installations throughout the world.

MODELLING OF URBAN FLOODING

The problems of urban flooding range from water coming into basements of houses to large parts of cities being inundated for several days. Most modern cities in Europe and North America often have small scale local problems due to insufficient draining capacity of the sewer system, while other cities, eg in Asia, may have more severe problems due to insufficient drainage and much heavier local rainfall.

APPLICATION EXAMPLE FROM DHAKA, BANGLADESH

In Bangladesh, the Dhaka Metropolitan area has experienced water logging for the last years. Even a little rain causes a serious problem for certain city areas, so that parts of Dhaka are inundated for several days. The water depth in some of the inundated areas may be as much as 30-50 cm which creates large infrastructural problems for the city. The city of Dhaka is protected from river flooding by an encircling embankment. Most of the time during the monsoon season the water level in the river remains higher than the water level inside the city area, consequently the city drainage depends very much on the water levels of the peripheral river systems. Hence, standard drainage by gravity may not always provide sufficient alleviation to the flooding problems. In order to facilitate drainage it has now been planned to install pumps at some of the outlets to the rivers. Additional major reconstruction work has also been proposed.

In order to show the applicability of MOUSE to studies of urban flooding, the hydrodynamic model of MOUSE has been setup for a sub-catchment of Dhaka city. The

MOUSE model computes both water levels and flow for the drainage pipes and for the streets. In order to evaluate the results for the various alleviation schemes, a Digital Elevation Model (DEM) has been established for the catchment area. The results, in terms of water depths in the streets, are then used for generation of flood inundation maps based on the DEM and the ArcView based MOUSE GIS system. The flooded areas for a rain storm with a 2 year return period can be seen in ***Figure 1***. The application of the MOUSE model, in conjunction with ArcView, provides the capability of showing the simulated flooding scenarios of the past together with the current observed inundated areas. This means that the model can easily be verified. Further, various alleviation schemes can be evaluated and optimized before the final implementation of the construction works. At present the MOUSE model has been verified against the inundated areas, the more detailed results from this application will become available during the spring 1997.

All together, this way of using numerical models provides a methodology for developing sustainable alleviation schemes by means of integrated management based on GIS and numerical simulation technology. Such tools should be very cost efficient for planning and management of the drainage system of Dhaka City in the future.

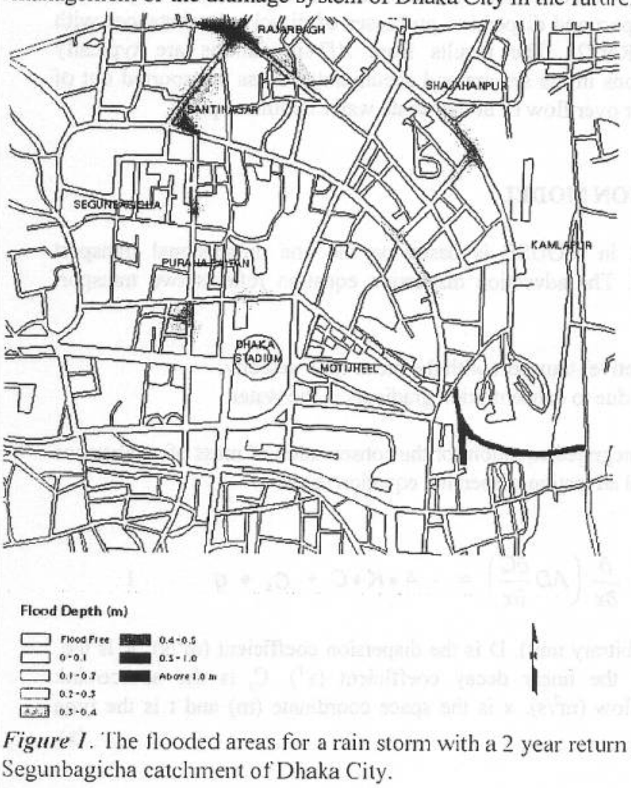


Figure 1. The flooded areas for a rain storm with a 2 year return period for the Segunbagicha catchment of Dhaka City.

MODELLING OF POLLUTION TRANSPORT

At present, the transport of pollutants in sewer systems is basically a concern in the part of the world where the environmental issues are seen as being very important. Typically, in these areas flooding problems are small and local and most of the concern is focused to reduce the damages from pollutant discharges from the sewer systems. A special case of such analysis is the study of accidental spills of dangerous substances into sewer systems.

In order to reduce the damage of a dangerous pollutant discharge, it is important to be able to describe the transport and dispersion processes in the actual system and hence it is necessary to have a good description of the flow conditions in the sewers. When such description is available, it is for example possible to calculate the time before the hazardous discharge reaches a critical point (waste water treatment plant or receiving waters) and thereby predict the time available to evaluate what measures are the most efficient to minimize the damage. In the present study the transport of pollutants was described by the use of MOUSE TRAP (*TRA*nsport of *P*ollutants) an add-on module to the hydrodynamic MOUSE model, see Ref./1/. The MOUSE TRAP module includes an A*dvection*-D*ispersion*, (*AD*), which combines the transport and dispersion processes of dissolved substances with the hydraulic processes, see Ref./2/. The results from *AD*-simulations are typically concentrations at selected locations in the sewers and accumulated mass transported out of the system, eg at combined sewer over flow or at the waste water treatment plant.

THE ADVECTION-DISPERSION MODEL

The advection-dispersion model in MOUSE is based on the one dimensional transport equations for dissolved material. The advection dispersion equation reflects two transport mechanisms:

- The advective (or convective) transport with the mean flow velocity,
- The dispersive transport due to concentration gradients in the water.

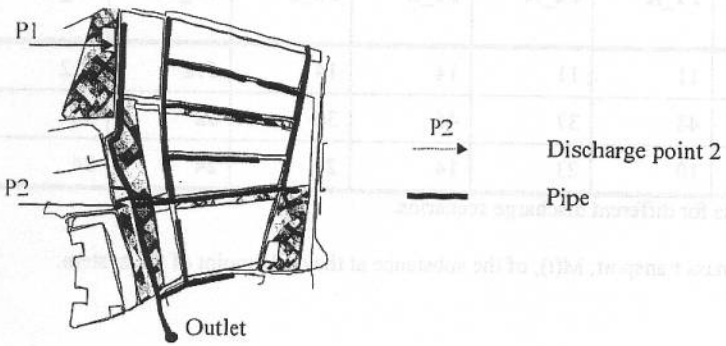
The one-dimensional vertically integrated equation for the conservation of mass of a substance in solution, ie the one dimensional advection-dispersion equation reads:

$$\frac{\partial(AC)}{\partial t} + \frac{\partial(QC)}{\partial x} - \frac{\partial}{\partial x}\left(AD\frac{\partial C}{\partial x}\right) = - A \bullet K \bullet C + C_s \bullet q \qquad 1$$

where: C is the concentration (arbitrary unit), D is the dispersion coefficient (m^2/s), A is the cross-sectional area (m^2), K is the linear decay coefficient (s^{-1}), C_s is the source/sink concentration, q is the lateral inflow (m^2/s), x is the space coordinate (m) and t is the time coordinate (s).

APPLICATION OF THE ADVECTION-DISPERSION MODEL TO THE CITY OF KARLSTAD, SWEDEN

The Swedish Rescue Services Agency was interested in studying the transport of hazardous substances within the sewer systems, see Ref./3/. The main reason for this was to increase the knowledge and understanding about transport processes in sewer systems within the operational staff. They often have to handle such accidental discharges caused by flushing down the discharge into the pipe system. The study also included a creation of an educational example, based on an application that could be used in the education program for fire-engineers. The study area is an industrial area in the city of Karlstad with approximately 40 ha of catchments connected to the storm drainage system. The storm drainage system discharges into the River Klarälven. An existing hydraulic MOUSE-model of the system was used to calculate the surface runoff and resulting discharge in the pipes. The hydraulic model had been verified against flooding records for measured rain events in a earlier project. In ***Figure 2*** the pipe system and the catchment for the example from Karlstad is shown.



Figuer 2. Våxnäs catchment and hydraulic model with discharge points in Karlstadt.

DEFINED DISCHARGES SCENARIOS

To visualize the effects of a pollutant discharge a number of scenarios were defined. Possible variables for the accident were the point of discharge, the amount of discharge and weather conditions during the accident. Two discharge points were chosen, P1 and P2 see, ***Figure 2***. The amount of discharge was described as 20 m^3 during 30 minutes with possibility of 5 m^3 being added, corresponding to water/foam for flushing the surface.
The following scenarios were described:

Scenario	*Description*
P1_A	Discharge point P1, total discharge 20 m^3 during 30 minutes, dry weather.
P2_A	Discharge point P2, total discharge 20 m^3 during 30 minutes, dry weather.
P1_B	Discharge point P1, total discharge 25 m^3 during 30 minutes, dry weather.

P2_B	Discharge point P2, total discharge 25 m^3 during 30 minutes, dry weather.
P1_C	Discharge point P1, total discharge 20 m^3 during 30 minutes, rainfall.
P2_C	Discharge point P2, total discharge 20 m^3 during 30 minutes, rainfall.

RESULTS

The following key figures were presented for each scenario to facilitate the comparison;

Q_{max} = Maximum discharge in outlet point
T_{max} = Time from discharge begins until maximum discharge is reached in outlet.
M_{max} = Total out transported mass of substance at time T_{max}

The results for each scenario is given in the table below.

Scenario Parameter	**P1_A**	**P2_A**	**P1_B**	**P2_B**	**P1_C**	**P2_C**
Q_{max}, l/s	11	11	14	14	512	512
T_{max}, minutes	48	37	46	36	32	32
M_{max}, %	10	23	14	29	24	84

Table 1. Results for different discharge scenarios.

Figure 3 shows the mass transport, M(t), of the substance at the outlet point of the system.

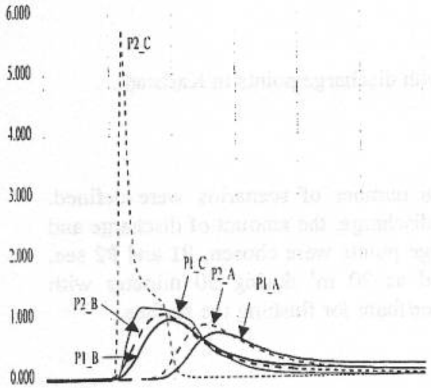


Figure 3. Mass transport out of the system.

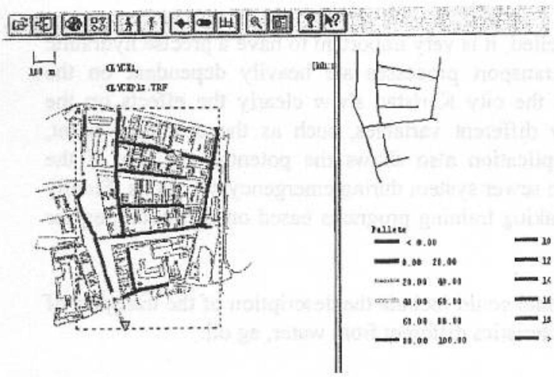


Figure 4. Plan plot in MikeView

The results were also analyzed according to the plan-plot in *Figure 4.* With the presentation program MikeView, see Ref./4/, it is possible to a create colored animation of the pollution transport in the system (eg flows, concentrations, mass transport). This gives a good overview of the effects in the whole system instead of only studying results in single points. Mike View was the basis for creating the application example which will be used in the education program for fire-engineers.

The results shows that the distribution of areas connected to the sewer system are important for the transport of pollutants during rainfall. The difference between scenario P1_C and P2_C is explained by the fact that most of the areas are connected downstream of the discharge point P1. This means that most of the discharge during rainfall is generated below the point P1 giving a much faster mass transport out of the system than if the discharge enters point P2. The transport time to the outlet is shorter for all the scenarios for point P2 than point P1, due to the shorter distance to the outlet.

CONCLUSIONS

The presented examples show the possibility of simulating the flow, water depths and the transport and dispersion of dissolved pollutants in sewer systems.

The application of MOUSE to simulate the flooding of the city of Dhaka shows the capability of the model to reproduce the inundated areas in a sub-catchment of the city. The application of the model will continue with an optimization of the alleviation schemes in order to reduce the flooding of the city area. The modelling results are shown together with geographical data providing a good visualization of the effect of the alleviation schemes.

When the transport of pollutants is modelled, it is very important to have a precise hydraulic description of the system since the transport processes are heavily dependent on the hydraulic conditions. The results from the city Karlstad show clearly the effects on the pollution load at the outlet caused by different variables, such as the discharge point, weather and flow conditions. This application also shows the potential for use of the numerical model for the operation of the sewer system during emergency situations. Finally it also demonstrates the potential for making training programs based on the model, eg for fire-engineers.

Future developments of the MOUSE model could include the description of the transport of different substances with material characteristics different from water, eg oil.

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