Continuous Modelling of Inflow/Infiltration in Sewers with MouseNAM

- 10 years of experience

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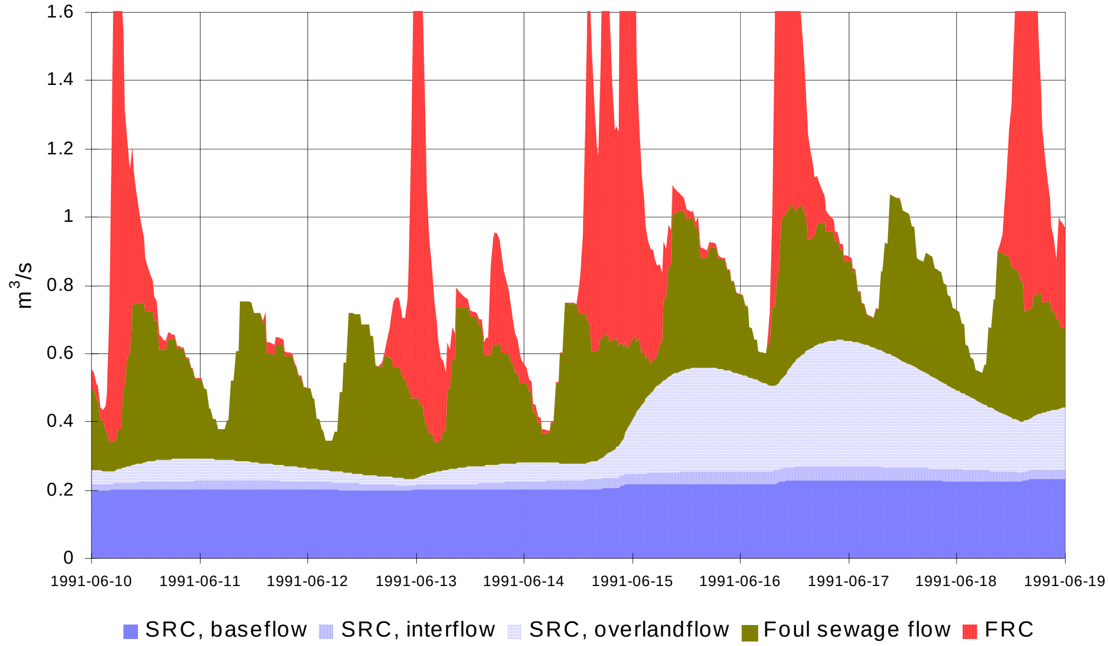


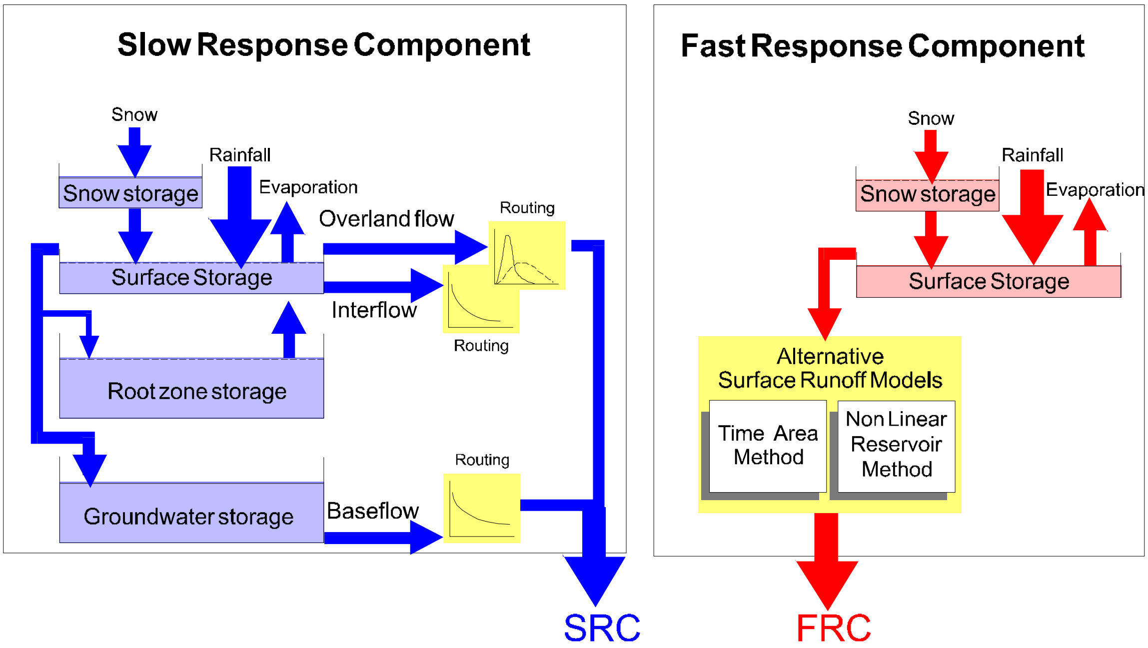
Introduction

Computer models used in traditional modelling of runoff in sewer networks are normally sufficient when analysing peak flow situations in storm water drainage systems with high degree of connected impervious area. However, the effects from rainfall induced infiltration and groundwater infiltration have in most sewer networks a considerable significance in many problems, especially when studying volumes, i.e. modelling of wastewater treatment plant (WWTP) inflows and combined sewer overflows (CSO's). While these slower runoff processes not only are affected by the actual rainstorm but also to a large extent by the hydrological conditions, it is difficult to model these phenomena with traditional surface runoff modelling techniques.

In traditional analysis of urban drainage problems, artificial rainstorms with relatively short duration based on rainfall statistics, are often applied. It was a standard methodology during the 80's, and the method applied in most corners of the world during the 90's. This is a reasonable approach when the return period for the rain is about the same as the return period for the effects in the collection system. However, this assumption is not valid if the slow runoff processes, like infiltration and drainage into the sewer network, are significant as they often are when studying CSO's or inflows to WWTP's. In these cases continuous modelling with long-term rain series is required from which statistics from the effects can be produced, rather from the precipitation input.

The NAM concept

The MouseNAM model takes into account both the fast runoff component from impervious areas and the slow runoff component caused by infiltration into the sewer system from the surrounding soil, the latter strongly affected by the hydrological history, i.e. preceding events. Normally, this flow component, according to model calibrations within close to 100 catchments, is responsible for about 50% (extremes up to 90% exist) of the total annual WWTP inflow volume and thereby causing the main seasonal flow variation pattern. This has shown to be extremely important within areas affected by snowmelt induced runoff, for example in the middle and northern parts of Sweden, but also in areas with large seasonal variations of rainfall.



The hydrological processes can be described with the MouseNAM concept, a general hydrological model for urban catchments. MouseNAM takes into account both the fast response component (FRC) from impervious areas and the slow response (SRC) caused by infiltration into the sewer system from the surrounding soil. The individual hydrological processes are lumped together to a conceptual approach, imitating the land phase of the hydrological cycle. The water is stored in four different types of storage: snow, surface, root zone, and groundwater. Processes such as infiltration and evaporative consumption as well as snowmelt and precipitation continuously update the amount of water in the storage zones.

Application areas and demand for data

Some of the input parameters are related to the corresponding physical data, but the final model verification has to be based on a comparison with historical observed discharges, daily averages extending over several years and a few months with higher resolution in time, i.e. minutes or hours. When applying MouseNAM to urban areas, the following parameters related to the FRC are the most important:

- The contributing catchment area
- The response function, i.e. time of concentration and time area curve when using the time area method, or storage coefficient when using the non-linear reservoir method

and to the SRC:

- The contributing catchment area
- The storage capacity for surface storage
- Overland flow coefficient describing the infiltration capacity
- The time constants for the overland flow and baseflow components

The precipitation data needed for long term SRC-calibrations consist typically of daily values. The precipitation observation values can be corrected to account for estimated measurement errors due to evaporation, wetting and aerodynamics. The correction for liquid precipitation is normally +10-20% (above 0^{o}C) and for solid precipitation (below 0^{o}C) +15-33%, depending on the estimated wind exposure on each measurement site. For snowmelt modelling air temperature data is used: either 24-hour mean values or for example two (or more) times a day. Potential evaporation site-specific data is normally only needed on a monthly basis, monthly normal values for each location.

For calibration of FRC (and fast reacting SRC-components) periods with high-resolution precipitation and flow data are needed.

European examples – overview

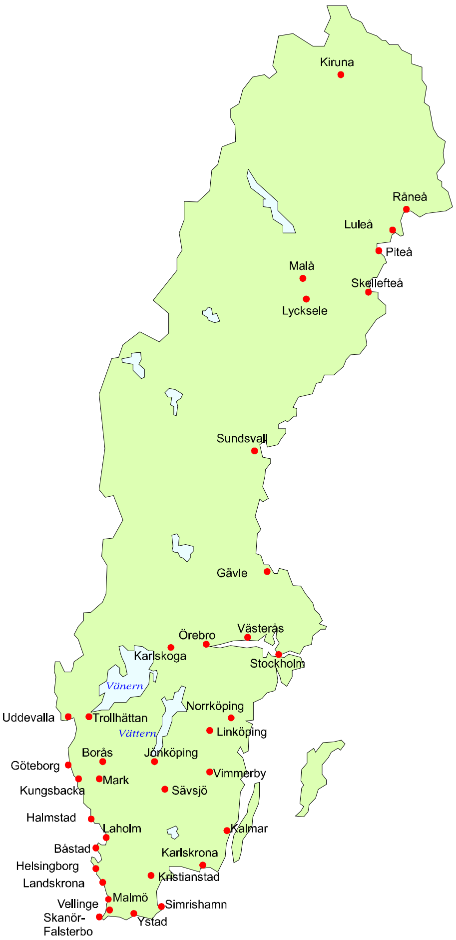
A large number of applications have been carried out, especially in Sweden, to describe and model hydrologically affected infiltration flows into sewer systems with the help of the general hydrological model description within the MouseNAM model.

In total about 100 catchment have been modelled, ranging in size from about 100 ha up to more than 200 km^2. The map shows the location of some of the Swedish sewer catchments, where MoseNAM models have been applied.

The model has been used as a tool in the analyses of the function of sewer systems in order to achieve a realistic description of varying baseflow conditions.

The application areas have mainly been interpretation of long term measurements at treatment plants and pumping stations, to outline the effect of alternative design programs for the sewer system (combined sewer overflows, risk of flooding) and the treatment plant inflows.

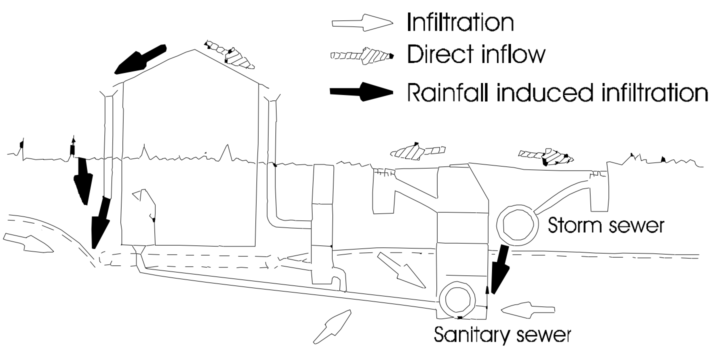
There are also applications reported from larger cities of other European countries like Prauge, Zagreb, Ljubljana and worldwide like Sydney and Auckland.



Combined and separate sewer systems

It is possible to simulate the inflow and infiltration flow variations to any type of sewer system by means of MouseNAM. The concept has been applied on *storm sewers*, *combined sewers* and also, actually the most common application, on systems to varying extent characterised as *separated sanitary sewers*. In fact the latter type always shows some hydrological flow component, often depending on drainage systems connected or infiltration. Regardless of type of system the methodology can be the same, although in a storm sewer usually the baseflow variations are of less importance. The difference is the relative amounts of inflow from foul sewage, fast runoff component and the slow response component, respectively. These conditions, naturally, have to be clarified from case to case.

Possible sources of infiltration/inflow

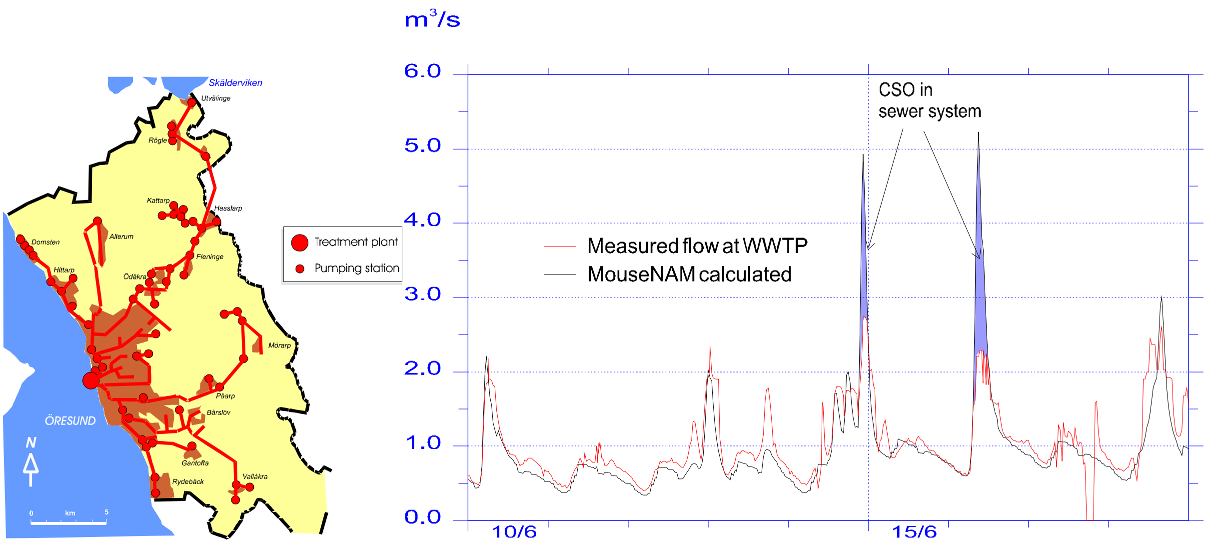


Model verification results

While MouseNAM basically is a lumped hydrological model, it is not suited to simulate more specific hydraulic phenomena like CSO´s. Therefore verification of peak flow situations has to be carried out for less intense rainstorms (without CSO events) or for periods where CSO's do not appear or, preferably, combined with a hydrodynamic pipe flow model like MouseHD. With a well verified model, on the other hand, the difference between the observed and the simulated discharge can be interpreted as a rough estimate of the overflow volume from the sewer system in the simulated catchment.

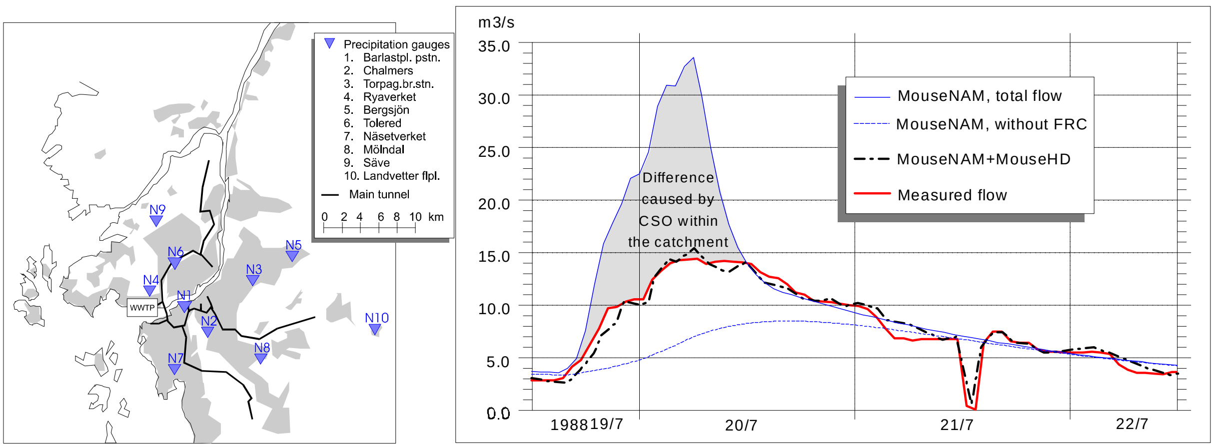
Two examples are given below, where the total inflow to the sewer system as calculated by a calibrated MouseNAM model is compared to the measured flow at the treatment plant.

Helsingborg Oresundsverket WWTP catchment:



The MouseNAM simulation here is based on precipitation data from only one rain gauge in the centre of the city, where most impervious area is situated.

Goteborg Rya WWTP Catchment:

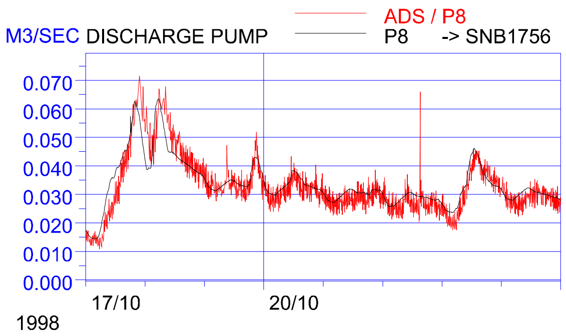


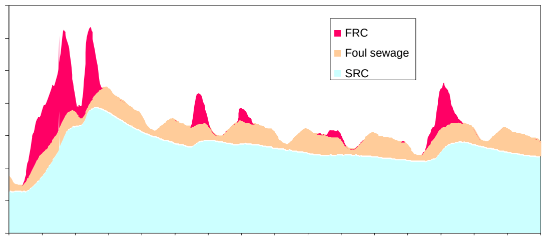
The MouseNAM simulation is based on precipitation data from 10 rain gauges within the catchment. In the figure the total flow calculated by MouseNAM is compared to the measured flow at the treatment plant. There is also shown the simulation result when the transport processes within the tunnel system is taken into account, by a hydrodynamical MouseHD model.

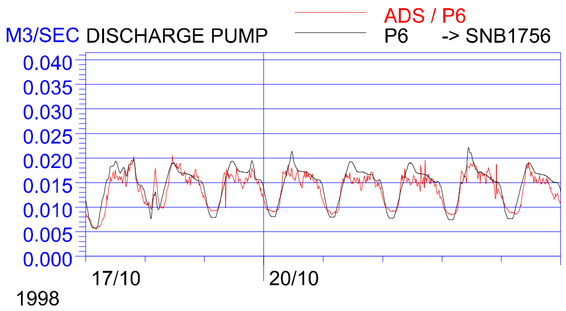
The figures below show that it is possible by means of MouseNAM to describe most varying inflow conditions as expressed by the relative magnitude of foul sewage flow, slow and fast response component, respectively. Some key numbers are expressed in the table.

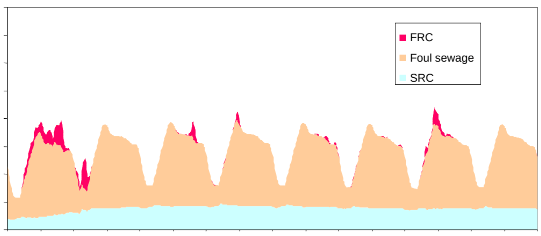
	No persons	SRC(ha)	FRC(ha)
Upper figure	2200	72	2.5
Lower figure	4500	11	0.3

The figures to the left show MouseNAM simulated flows compared to measured flow values, the figures to the right the composition and relative magnitude of flow components in the modelled flow.

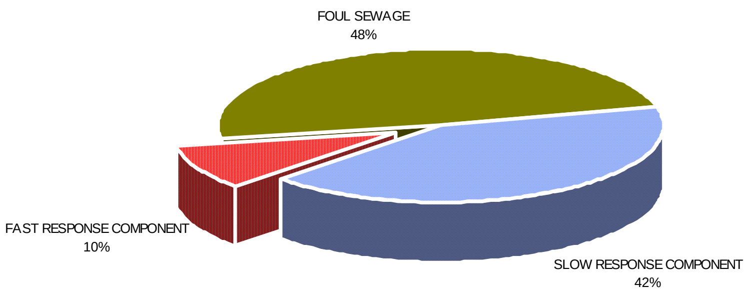






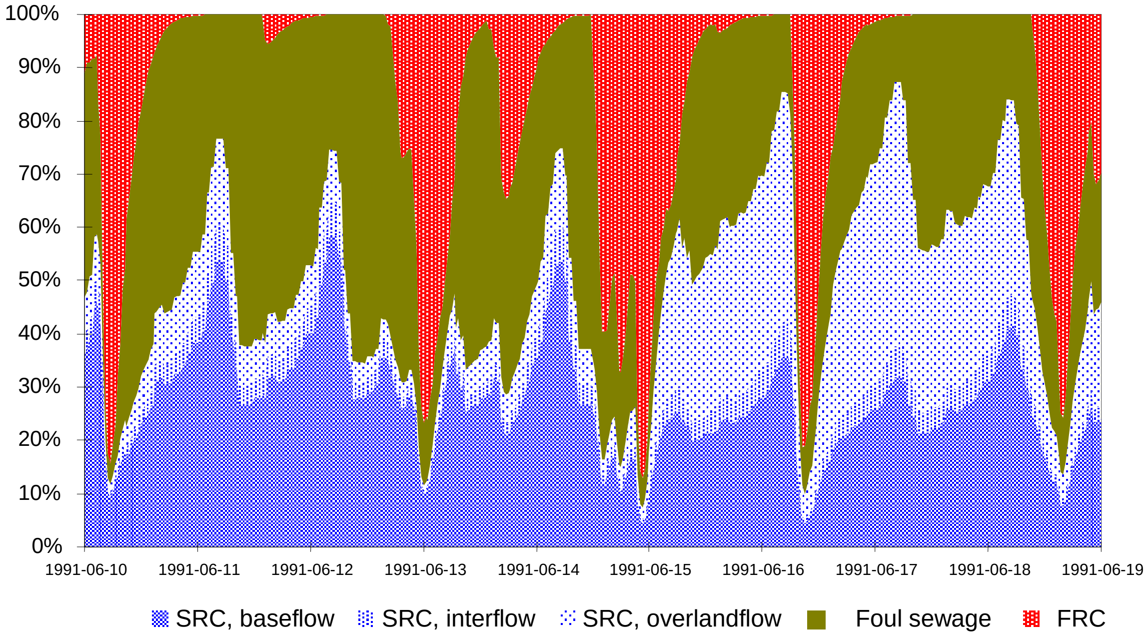


Catchment water balance and time variations

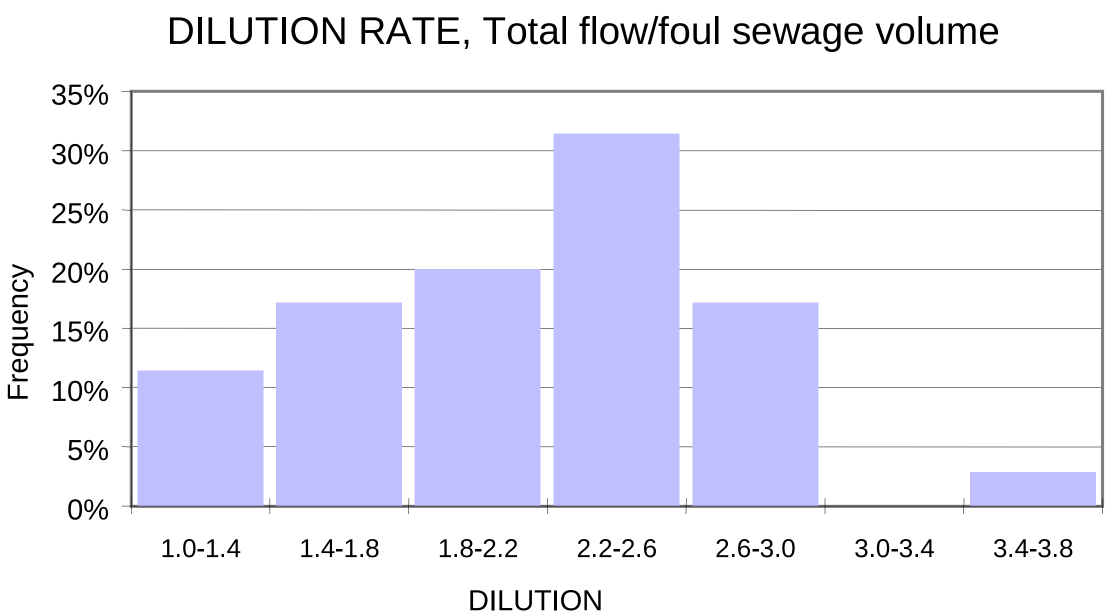


When the load and distribution of infiltration and inflow is known the water balance for a sewer catchment can be established. Both mean values over a long period of time as well as short-term variations can be illustrated. The figure above comprises mean values of 7 years for Helsingborg Oresundverket WWTP catchment.

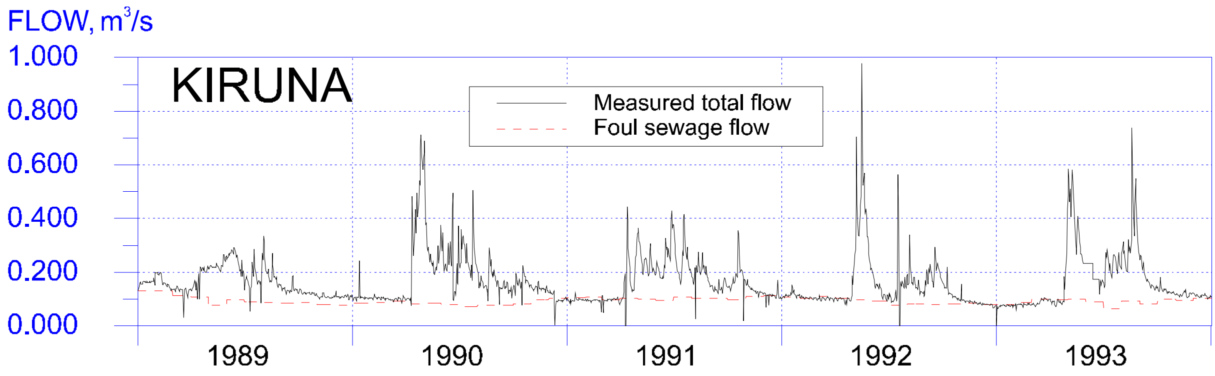
Below the water balance for a shorter period with 0.5 h resolution is illustrated for the same catchment.



The distribution of dilution rates (total flow / foul sewage flow volume) for 40 larger Swedish wastewater treatment plant catchments, 4-year mean values:

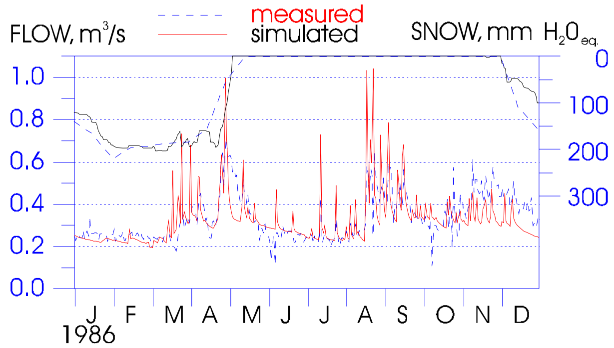


Snowmelt processes



In the northern parts of Sweden, together with other parts with a "cold climate" the snowmelt period means a high flow load during a relatively long period of time on sewer systems and treatment processes in wastewater treatment plants connected to the sewer systems. For several weeks the wastewater is cold and diluted, which can be detrimental, especially for biological treatment processes.

The description of the snowmelt process in MouseNAM is based on the temperature index approach, i. e. the calculated runoff volume from the snowpack is proportional to the number of positive degree days (^{o}C . day). For the accumulation of precipitation and runoff from the snowpack, temperature data for the calculation period is used. Precipitation and a simultaneous negative temperature add the precipitated volume to the snow storage. At a positive temperature the snowmelt starts.



With a reliable model description it is then possible to perform long term simulations in order to simulate the effect of different sewer design strategies. It is also possible to use a verified model to make flow forecasts calculations in different time scales, provided the future development of climatic factors are known through weather forecasts.

The present MouseNAM snowmelt model has shown to work reasonably well if data is used on a daily basis and the objective is to roughly predict snowmelt induced runoff volumes. When a correct timing of the flow is important, the water holding capacity of the snow should be included in the model. This advanced degree day method has recently been included into MouseNAM.

CONCLUSIONS - Constant baseflow vs hydrological modelling

Traditional modelling technique of runoff in sewer networks, where constant baseflow conditions are assumed, is normally sufficient when analysing peak flow situations in storm water drainage systems with high degree of connected impervious area. However, there are situations when that approach will not give correct results.

In the Swedish city of Västervik simulations of the combined sewer systems for evaluating Combined Sewer Overflows (CSO) were performed using synthetic design storms in 1991. A few years later the simulations were performed using the same hydrodynamic set up but the input data were based on long term historical rain series and a more general hydrological description by using the MouseNAM concept. The results of the two simulations using different types of modelling technique, i.e. single event modelling vs continuous modelling were so different that it was proposed to make the same kind of simulations for a few other model areas. In Västervik the total average yearly simulated CSO volume was 60 000 m^3 when using single event modelling and 160 000 m^3 when simulated using continuous modelling.

In the table below are results shown from long-term simulation tests, where alternative approaches were applied on a variety of sewer catchments. Different CSO's were in this study characterised as "upstream" (i.e. throttled to a low degree), "downstream" (i.e. highly throttled), and "at basin" (i.e. large volumes available).

Catchment location	Type of CSO	Annual CSO volumes in relation to MouseNAM modelling technique		
		Design storms	Rain series, constant infiltration	Rain series, simulated infiltration (MouseNAM)
Malmo	Downstream	61%	61%	100%
Jonkoping	Upstream	167%	100%	100%
Stockholm	At basin	26%	106%	100%

The table shows that a single event modelling approach with design storms generally produced relatively larger CSO volumes at upstream CSO´s and relatively lower volumes at downstream CSO´s compared to continuous hydrological simulations. For CSO´s located at highly throttled retention basins, the former method produced much smaller CSO volumes than latter method. A method with a constant baseflow but historical rain data for the FRC component gave results that were similar to the case with hydrological modelling, except at some of the downstream CSO´s, typically highly throttled, i.e. where the system capacity at times was low compared to the simulated infiltration.

The conclusions were that accurate simulations of CSO:s, especially those highly throttled and containing large retention basins, can only be accomplished by performing hydraulic simulations with input data based on long term continuous high resolution rain series and simulated time variation of groundwater infiltration and rainfall induced infiltration. MouseNAM – the standard modelling technique for the next millennium?