WATER QUALITY MODEL SET-UP AND CALIBRATION – A CASE STUDY

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ABSTRACT

The availability of water quality modelling tools in the field of urban drainage opens up possibilities for an enhanced design and management of urban drainage systems, involving measures that are based on quality aspects and no longer merely based on hydrodynamic understandings. This paper presents the results of a case study on the transport of dissolved pollutants in urban drainage systems. During a flow survey campaign flows and pollutants were measured in the Wezembeek Oppem subcatchment (east of Brussels, Belgium) and in the Burslem Tunstall subcatchment (Stoke-on-Trent, United Kingdom). An attempt was made to reproduce the measured values of flow and ammonium concentration (a typical dissolved pollutant) using the INFOWORKS CS (Wallingford Software, UK) modelling tool.

INTRODUCTION

The European Union's Council Directive 91/271/EEC Annex I on Requirements for Urban Waste Water states that

"Collecting systems shall take into account waste water treatment requirements. The design, construction and maintenance of collecting systems shall be undertaken in accordance with the best technical knowledge not entailing excessive costs, notably regarding

- *volume and characteristics of urban waste water,*
- *prevention of leaks*
- *limitation of pollution of receiving waters due to storm water overflows."*

Water quality modelling tools can provide the means to meet the requirements as stated in the Council Directive. The presented case study looks at the INFOWORKS CS (Wallingford Software, UK) modelling tool regarding its capacity to accurately model the transport of dissolved pollutants in a sewer system. The case study is restricted to one dissolved pollutant, namely NH_4.

CATCHMENT DESCRIPTION

The Wezembeek Oppem subcatchment (see figure 1) is located in the south-eastern part of the Woluwe catchment. The urban drainage system of Woluwe serves approximately 300 000 inhabitants of the eastern part of the Brussels Capital Region and the neighbouring Flanders Region. Up until now this wastewater is discharged without any treatment directly into the river Zenne. Full treatment for the whole of the Brussels Region is planned to be operational in 2006. The Wezembeek Oppem subcatchment serves about 12 000 people and is characterised by a large interaction between the sewer system itself and the receiving waters with small brooks and rivers flowing into the sewerage system (and vice versa). The latter results – together with the fact that the sewers are used for draining purposes – in a strongly combined drainage system with an important baseflow. In the Wezembeek Oppem catchment there is no significant industrial activity. The land use of the catchment is mainly residential with quite a few green areas. The model itself is very simplified only retaining the larger conduits.

The city of Stoke-on-Trent and the town of Newcastle-under-Lyme are located to the north of the Midlands region in the northern part of Staffordshire county. The urban conurbation has a population of approximately 322 500. The original sewerage system was designed around the 'Six Towns', namely Tunstall, Burslem, Longton, Stoke, Hanley and Fenton, where each town had its own sewage treatment works. As the city expanded other outlying areas contributed their own sewage works to the network. Following the formation of the Severn Trent Water Authority in 1974 the number of sewage treatment works was rationalised until, with the abandonment of the Burslem Sewage Treatment Works in 1993, all the flow discharged to the Strongford Sewage Treatment Works at the southern part of the City. The Stoke-on-Trent catchment has a strong industrial history, although in recent years there has been a decline in the mining, steel and pottery industries on which the city was founded. Out of the whole of the Stoke-on-Trent area the subcatchment of Burslem and Tunstall has been selected for this case study (see figure 1). As opposed to the Wezembeek Oppem model, the Burslem Tunstall model is very detailed.

DISSOLVED POLLUTANT MODELLING

The transport of dissolved pollutants is classically modelled throughout the sewer network using the advection-dispersion equation. INFOWORKS CS adapts this approach but does not take any dispersion into account assuming that dispersion of dissolved pollutants is negligible (along the conduit). Together with the assumption that the flow is one-dimensional, it is assumed that the dissolved pollutants are well mixed across the section of the conduit and that dissolved pollutants are transported at local mean flow velocity. The advection equation is implemented in INFOWORKS CS as follows:

$$\frac{\partial \boldsymbol{c}}{\partial \boldsymbol{t}} + \boldsymbol{u} \cdot \frac{\partial \boldsymbol{c}}{\partial \boldsymbol{x}} = 0 \qquad (1)$$

In INFOWORKS CS dissolved pollutants are considered to be conservative substances. No in sewer transformation processes are taken into account.

Ammonia nitrogen was chosen as a typical dissolved pollutant Ammonia nitrogen exists in solution in two forms (see equation 2), namely as the ammonium ion (NH_4^+) and as ammonia gas (NH_3) depending on the pH and temperature of the wastewater [Butler and Davies, 2000].

$$NH_3 + H^+ = NH_4^+ \qquad (2)$$

POLLUTANT SOURCES

In dry weather the main dissolved pollutant source is the domestic (and industrial) wastewater. In wet weather an additional source of dissolved pollutants is the washed off flow of (polluted) rain water that flushes the gully pots and entrains the during the antecedent dry weather period built up pollutants into the sewerage system. In INFOWORKS CS rainwater is considered to be clean and wash off of dissolved pollutants is not modelled as such. The only additional inflow of dissolved pollutants into the drainage systems is caused by flushing of the gully pots.

FLOW SURVEY DESCRIPTION

The model of the Wezembeek Oppem catchment is provided by Aquafin and is the result of a Hydronaut study of the Woluwe catchment. The model is assumed to be well calibrated for storm modelling purposes. During a five month period (January till May, 1999) flows were measured in the Wezembeek Oppem catchment (see figure 1). In this flow survey campaign water quality samples were taken and analysed at four time periods. Two of which were aimed to be dry weather measurements and two of which were aimed to be wet weather measurements. In dry weather samples were taken every three hours. In wet weather samples were taken every hour. Although the aim was to survey two wet weather periods, the water samples of period (18/05/99) were taken in dry weather conditions. The flow survey data show a significant difference in baseflow (see also table 1). Remarkable is that although the dry weather flow differs in a non-negligible way, the ammonium measurements show no difference for the surveyed dry weather periods. One could expect that, due to the raised baseflow, more dilution would occur. Yet the latter is not true. This implies that the baseflow is far from clean itself and that – if one assumes that the domestic inflow pattern does not change – the baseflow shows the same diurnal concentration pattern as the domestic wastewater does.

The model of the Burslem Tunstall catchment is provided by Haswell Consulting Engineers who – on behalf of Severn Trent Water – performed a UPM study on the Stoke-on-Trent catchment. Out of the survey period (October 1999 till February 2000) three survey events are retained, two of which represent a dry weather situation and one a wet weather situation. In dry weather quality samples were taken every hour. In wet weather the first 10 samples were taken every 15 minutes. The remaining samples were taken every 30 minutes. The sampling location is not the same as the flow monitoring point. At the end of dry weather period (16-12-99) a rain event occurs. However, no rainfall data is available. The measured ammonium concentration for both the dry weather periods varies in a non-negligible way.

SIMULATION SET-UP AND RESULTS

For the Wezembeek Oppem catchment a six-day dry weather period is used to determine a diurnal flow input pattern. A distinction is made between wastewater and baseflow and the model was calibrated assuming a daily per capita water use of 130 litre. The flow pattern was verified for the remaining survey periods. Using the same flow pattern made it incumbent to vary the baseflow. The baseflow values used for the different measurement periods are listed in table 1. The data provided by the dry weather survey of 03-11-99 are used to establish a calibrated flow profile (see figure 2). The pattern was validated for the remaining survey periods. As a reference the flow input profile established by Butler [Butler *et al.*, 1995] is also plotted in figure 2. It can be seen that, besides the flow peak around noon, the Wezembeek Oppem input profile is similar to the Butler profile.

In a first stage an input concentration profile for NH_4 was used as it was established by Butler *et al*. [Butler *et al.*, 1995] (see figure 3). The profile is based on an analysis of UK data on the different household appliances and their contribution to the pollutant load. It should be stressed that the profile was established as a result of an input analysis and not by reverse modelling. The profile was modified until the accordance between the predicted and the observed ammonium concentration was acceptable. For the Wezembeek Oppem catchment the calibrated NH_4 input concentration profile diverts only slightly from the one suggested by Butler (see figure 3).

Note that although the baseflow differs, the measured NH_4 profiles for the three dry weather periods are almost equal in the Wezembeek Oppem catchment. As we consider the baseflow to be clean, the mean input concentration of ammonium should vary. So three different input concentrations were found for the corresponding survey period. By comparing the observed ammonium concentration with the corresponding baseflows (see table 1) one can see that there is a quasi-linear relationship between both. This relationship is used to estimate the NH_4 input concentration for survey period (07-05-99).

This methodology gives satisfying results although that the assumption of a clean baseflow is not valid. Yet nothing can be said on the degree and extent of pollution of the baseflow and the impact on the sewer system without further information on the quality aspects of the baseflow that enters the sewer system.

Figures 4 through 7 show good results for the Wezembeek Oppem catchment. In dry weather the modelled flow and ammonium concentration fit the measured values reasonably well. In wet weather the incoming rain water causes dilution which is modelled accurately.

Flow Survey Period	Baseflow [m^3/s]	NH_4 Concentration [mg N/l]
(17-03-99)	0.0583	55
(28-04-99)	0.1683	135
(07-05-99)	0.1760	140
(18-05-99)	0.2370	180

Table 1 Baseflow and mean NH_4 input concentration for the different survey periods for the Wezembeek Oppem catchment

The flow input profile for the Burslem Tunstall catchment on the other hand does not show any distinct peaks during the day. The pattern rather shows a day-night variation than a diurnal variation.

Applying the Butler input concentration profile results in a quasi constant predicted ammonium concentration at the sampling point. A very peaked input profile will be needed in order to be able to model any variation in the concentration at the sampling point. The calibrated ammonium input concentration profile for the Burslem Tunstall catchment – for the dry weather period (03/11/99) – shows two extremely pronounced peaks. These peaks can not be found in the Butler profile and are physically unrealistic. However these peaks are needed for the calibration of the model. Nevertheless, the measured morning peak in ammonium concentration could not be modelled at all. The validation of the calibrated profile is also poor (see figure 9). Therefore one is advised not to use the unrealistic input concentration profile but a constant input concentration. One can use the Butler ammonium input concentration profile if the flow input profile is similar to the Butler profile. The latter is not the case for the Burslem Tunstall catchment, so a constant input profile should be used. Unknown processes or low flow velocities could be a possible reason why the variation of the ammonium concentration can not be modelled accurately. In dry weather the maximum velocity is about 0.5 m/s whereas the maximum velocity for the Wezembeek Oppem

catchment is about 2 m/s. Further research is needed in order to be able to determine the reason why the variation of ammonium concentration could not be modelled accurately.
Figures 8 through 10 show the simulation results for the Burslem Tunstall catchment. The ammonium concentration is predicted reasonably well for the dry weather period of 03/11/99. The morning peak however could not be modelled mainly because of the very low flow velocities occuring at night. It should be noted that the dry weather period of 03/11/99 was the calibration period and that the validation of the model settings for dry weather do not apply very well for the validation period of 16-12-99. In wet weather the dilution rate is modelled accurately although the moment at which the dilution occurs is not modelled satifactory. The latter is due to the poor hydraulic calibration of the model.

CONCLUSION

The results of the case study show that the ammonium concentration in the Wezembeek Oppem catchment can be predicted in a satisfactory way using the INFOWORKS CS quality modelling tool. The study catchment of Wezembeek Oppem is characterised by a significant and variable baseflow. Analysis of the quality data showed that this baseflow is far from clean itself. However, the results of the quality simulations are acceptable assuming a clean baseflow and raising the mean input concentration of ammonium. The case study of the Wezembeek Oppem catchment has proven that, in a first stage, the ammonium input profile established by Butler *et al.* [Butler *et al.*, 1995] can be properly used for calibration purposes.

The study catchment of Burslem Tunstall is characterised by low flow velocities (especially in dry weather) and the dissolved pollutant modelling suffers from that. Further research is needed in order to be able to understand the reason why the ammonium concentration could not be modelled accurately in de Burslem Tunstall catchment.

ACKNOWLEDGEMENT

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Directive 91/271/EEC on Urban Waste Water Treatment (1991).

Wallingford Software, INFOWORKS CS Online Help.

FIGURES

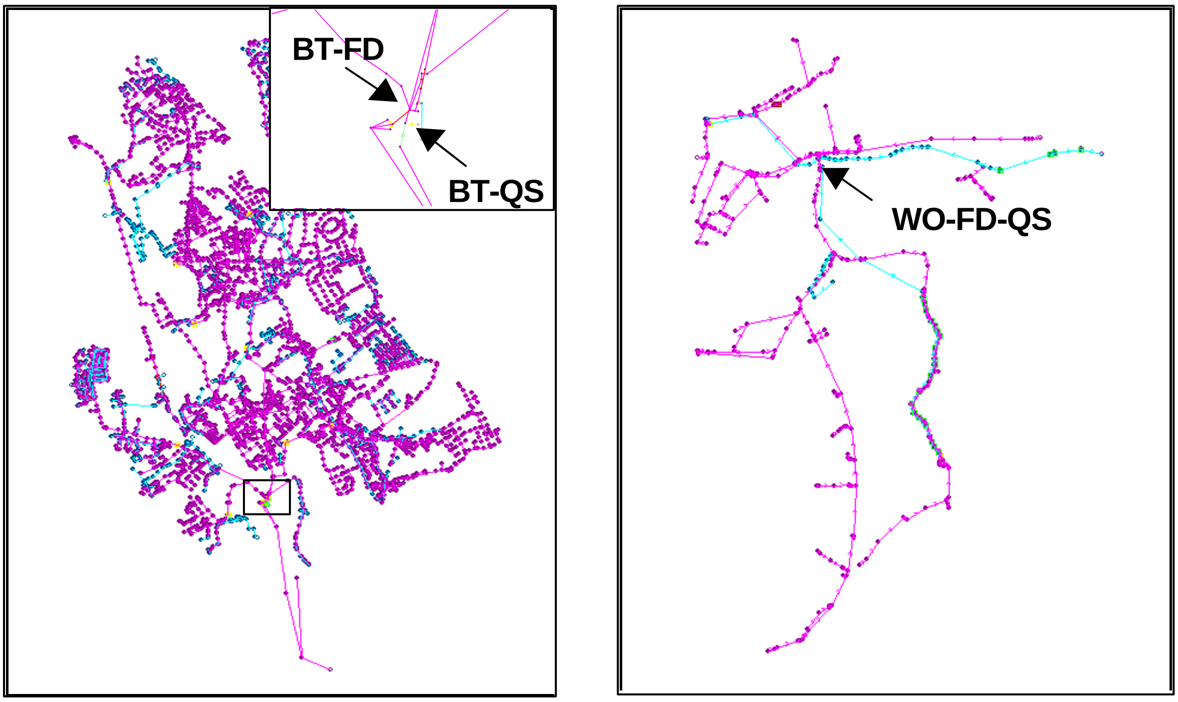

Figure 1 The Burslem Tunstall catchment (left) and the Wezembeek Oppem (right) including monitoring sites of flow data (FD) and quality sampling (QS)

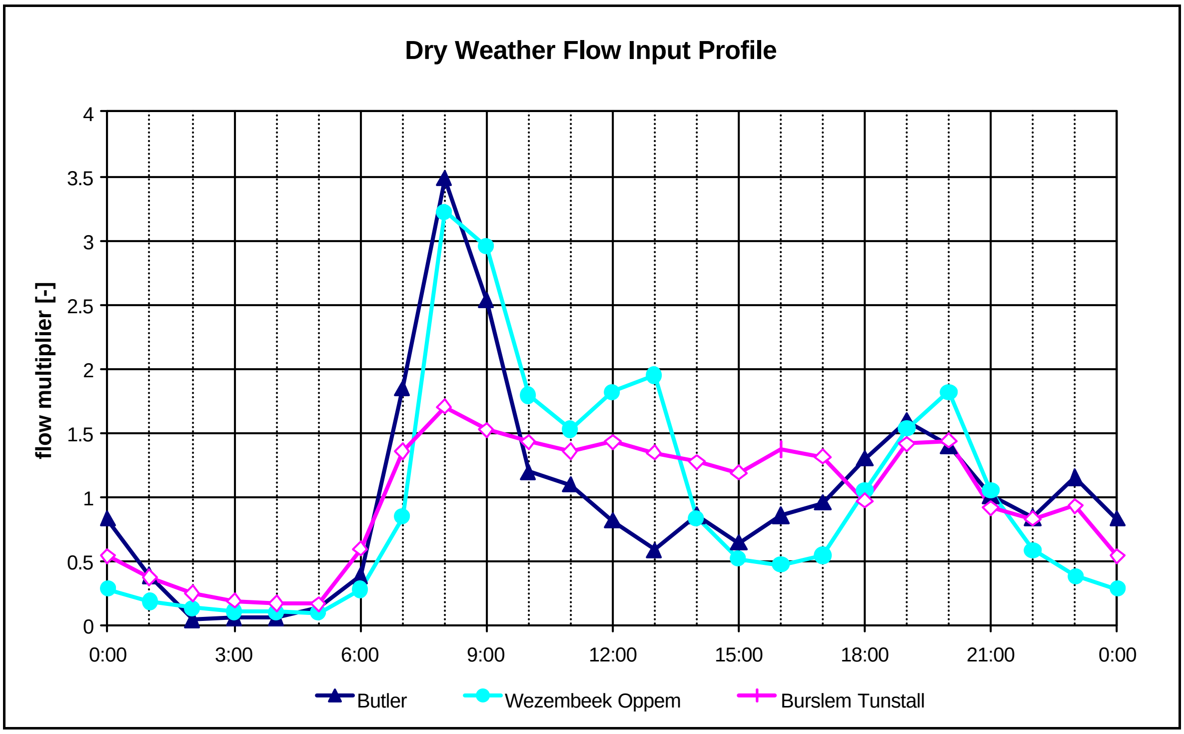

Figure 2 Domestic wastewater input profile

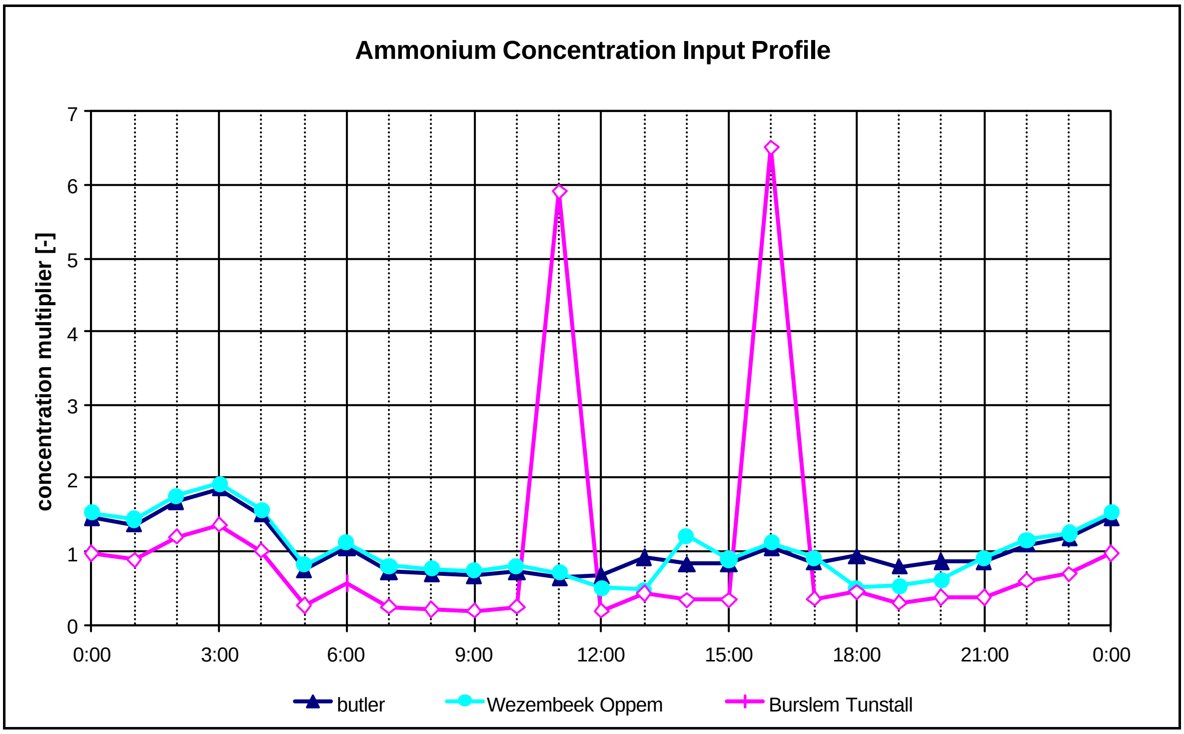

Figure 3 **Ammonium concentration input profile**

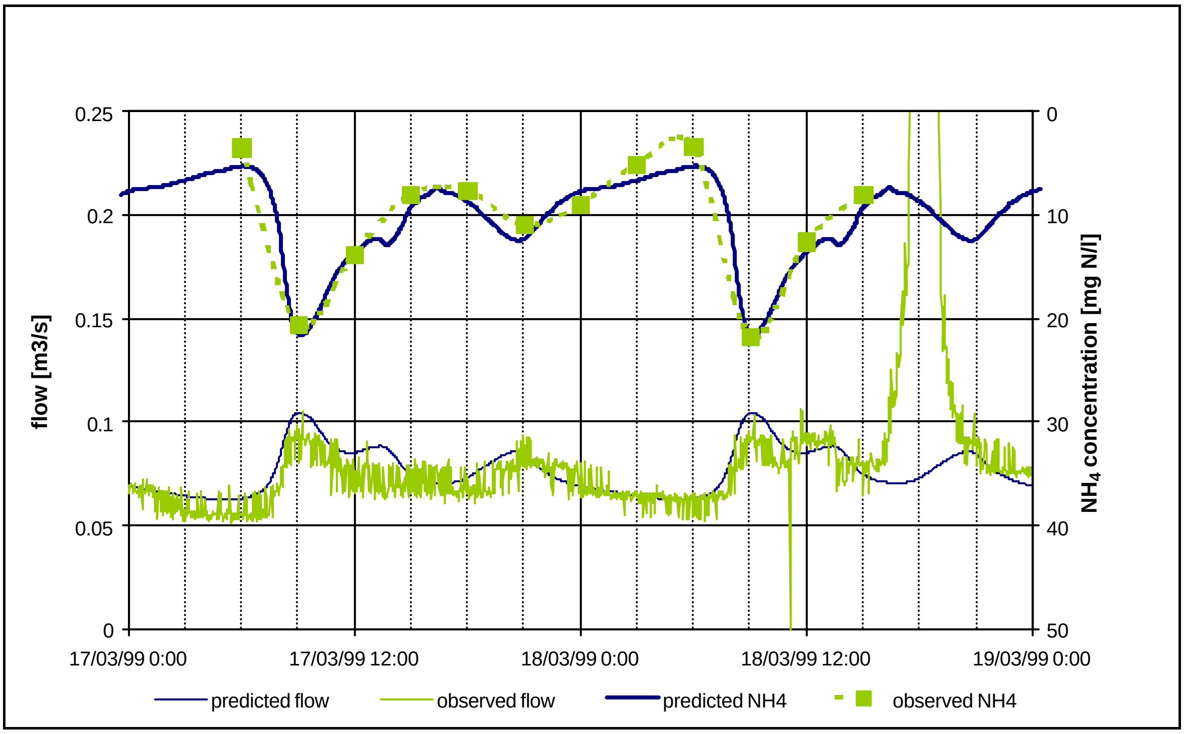

Figure 4 **Wezembeek Oppem – Dry Weather Flow 17-03-99 – Predicted and observed flow and NH_4 concentration**

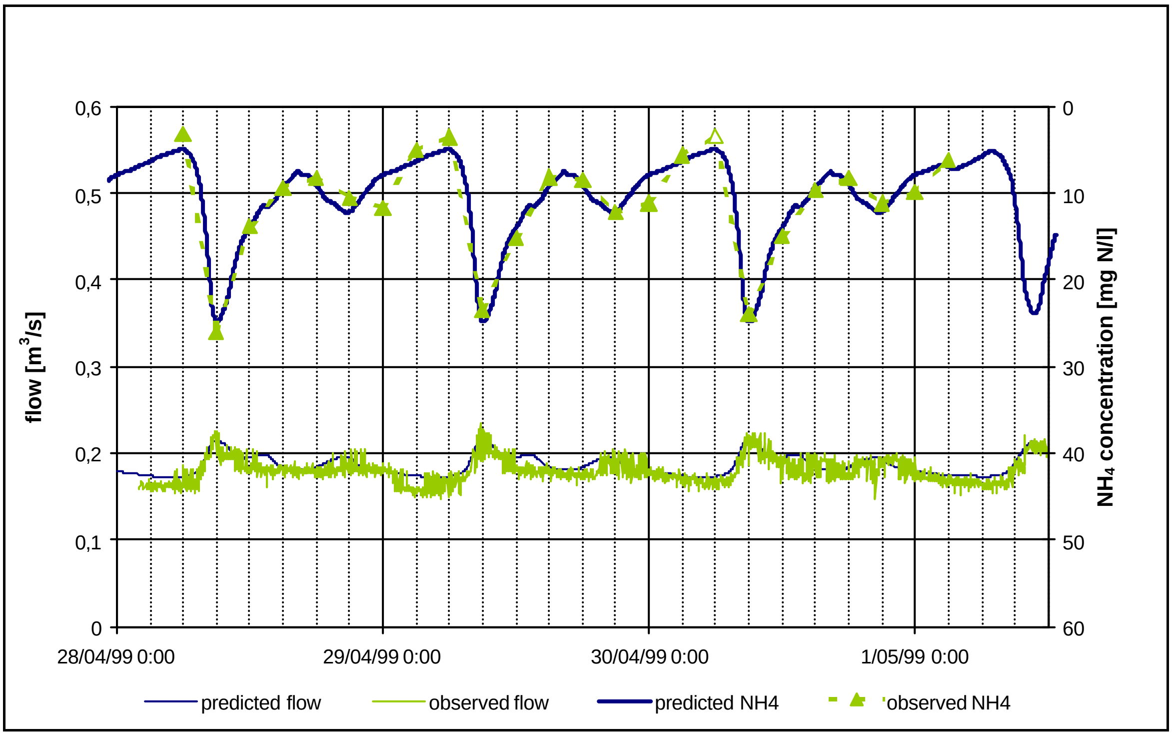

Figure 5 **Wezembeek Oppem – Dry Weather Flow 28/04/99 – Predicted and observed flow and NH_4 concentration**

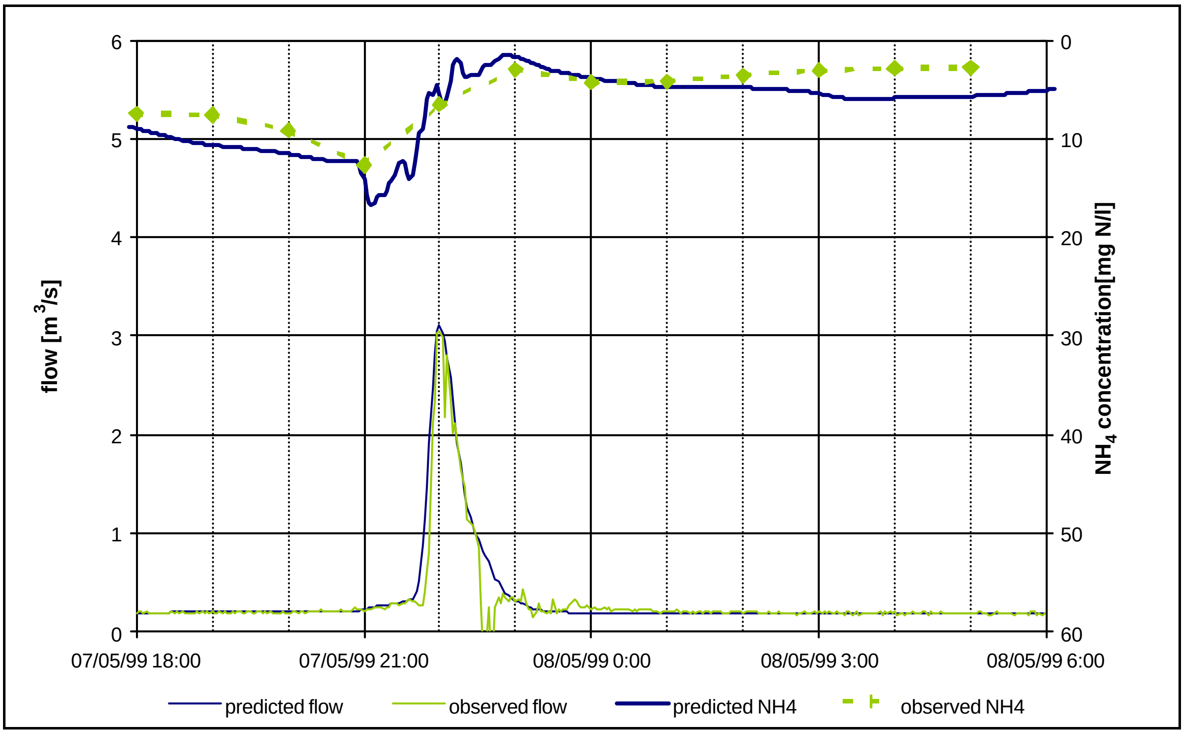

Figure 6 **Wezembeek Oppem – Storm of 07/05/99 – Predicted and observed flow and NH_4 concentration**

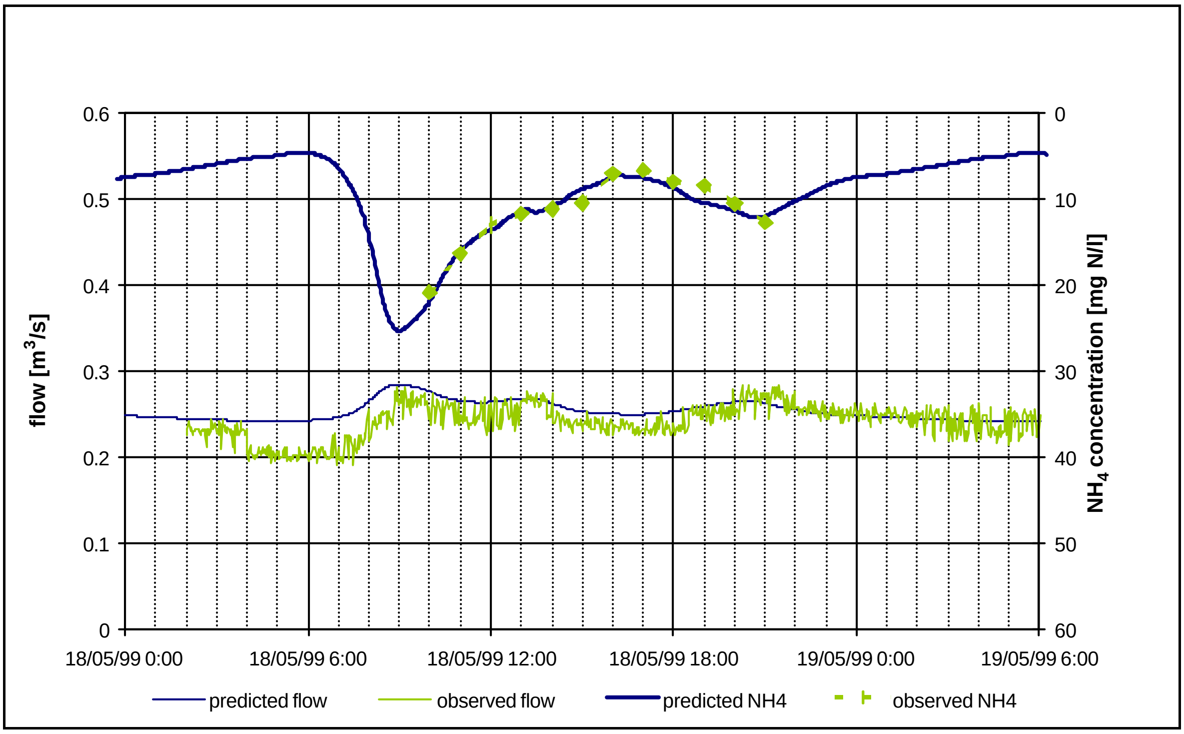

Figure 7 **Wezembeek Oppem – Storm of 18/05/99 – Predicted and observed flow and NH_4 concentration**

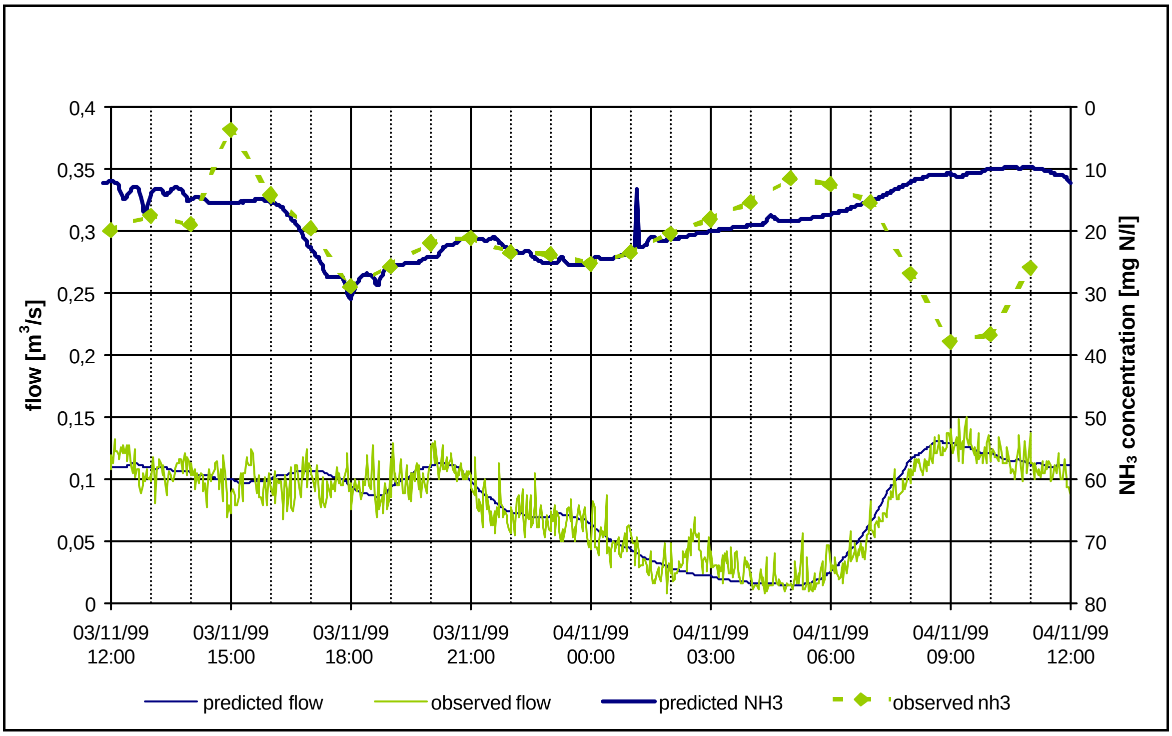

Figure 8 **Burslem Tunstall – Dry Weather Flow 03/11/99 – Predicted and observed flow and NH_4 concentration**

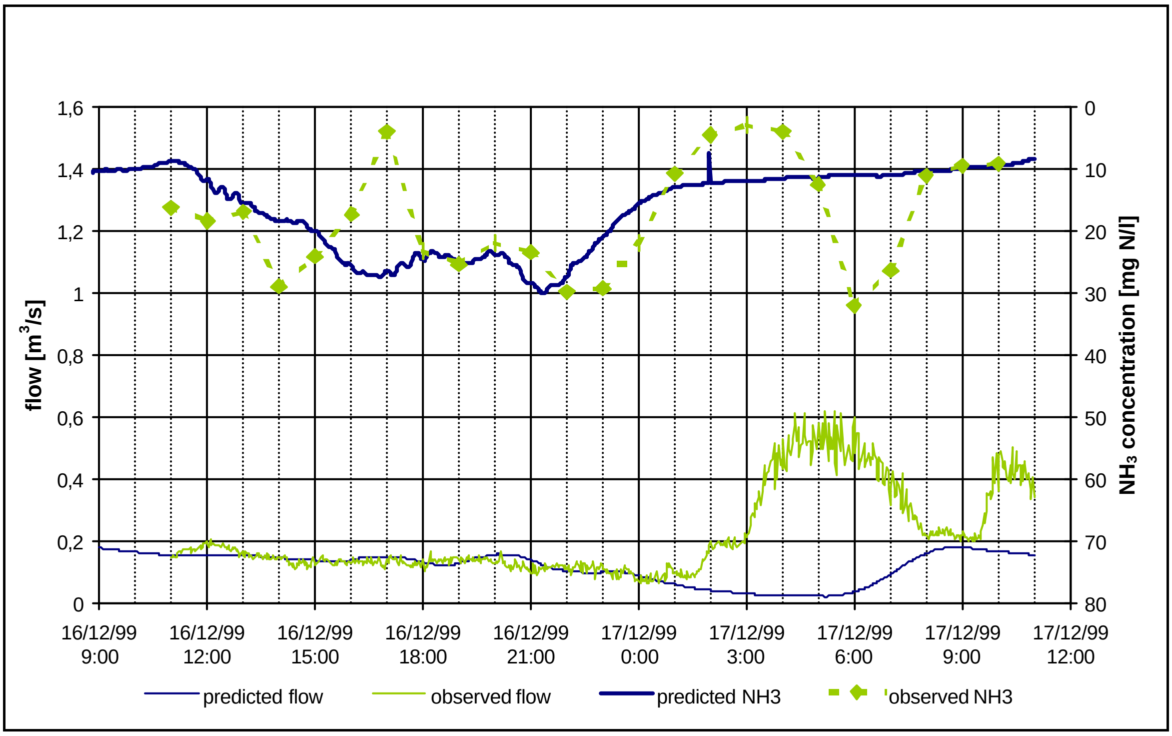

Figure 9 **Burslem Tunstall – Dry Weather Flow 16/12/99 – Predicted and observed flow and NH_4 concentration**

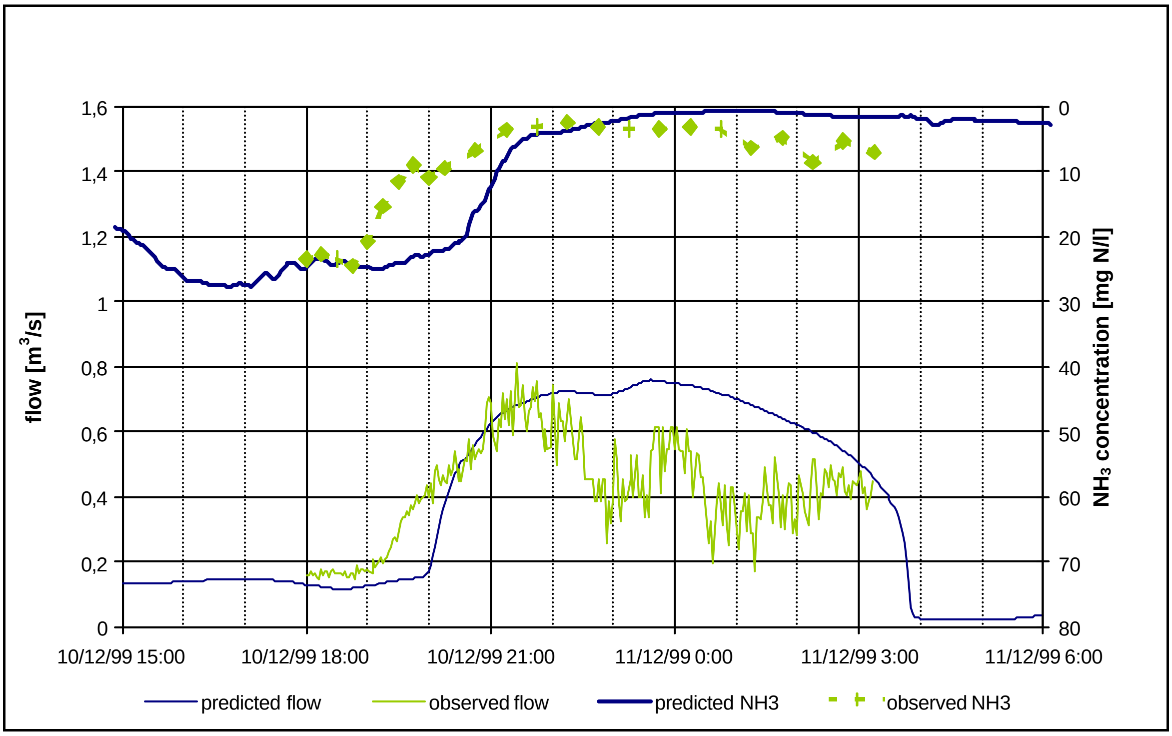

Figure 10 **Burslem Tunstall – Storm of 10/12/99 – Predicted and observed flow and NH_4 concentration**