Use of real time control modelling on the urban sewage system of Nancy

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Abstract Since 1991, European Legislation on the urban treatment of wastewater requires local authorities to take into account the treatment of polluted water transported by the sewerage system and this during dry and wet weather conditions. In the seventies, the urban Community of Grand Nancy constructed storage tanks in its sewerage system in order to prevent flooding and wish today to use them to reduce and control the pollution discharges into the receiving water. This action is a part of a European LIFE project 1996–2000. The main aim of this project was to assess the effectiveness of reducing pollution of one particular retention basin, the 12,000 m^3 Gentilly tank. This one has two operating modes: protection against floods during heavy rain and reduction of pollutant overflows during lighter rain. To assess its effect on the pollutant discharge, the HYDROWORKS DM™ software and its Real Time Control Module have been used, calibrated and validated. As this study is still in progress, this paper describes the studied site and the modelling results under different weather conditions and shows that the mathematical model can be used to simulate the operation of the catchment area and its associated sewerage system realistically.

Keywords HYDROWORKS DM; modelling; quality; real time control; sewage system

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Introduction

The Urban Community of Grand-Nancy (North Eastern France) constructed storage tanks in its sewerage system during the 1970s in order to prevent flooding. The community's project to reduce stormwater pollution in the natural environment by making the sewerage system more efficient was implemented as part of a European LIFE programme in 1996 (Schmitt *et al.*, 1999). Those involved included the Urban Community of Grand-Nancy (CUGN), the International Water Centre (NANCIE), the Laboratoire Central des Ponts et Chaussées (LCPC), Anjou Recherche (AR) and the Rhine-Meuse Water Agency (AERM). As part of this programme, extensive measurements of rainfall, flow and pollution were made in a section of the Nancy sewerage system, the Boudonville catchment area. The main aim of this project was to assess the effectiveness of reducing pollution in the Gentilly storage tank. Moreover, the data collected were also intended to improve the knowledge of how to control urban rainwater pollution and to assess the overall operation of the catchment area by modelling.

As this study is still in progress, this paper describes the results of one of the study topics, the mathematical modelling of the network taking into account the impact of the storage tank. The latter, using the position of the drain valve, has two operating modes: protection against floods during heavy rain and reduction of pollutant overflows during lighter rain.

The Boudonville catchment

The Boudonville catchment area covers the north west part of Nancy on the left bank of the Meurthe river. The catchment has an area of 620 ha with a population of about 40,000. About 40% of the area is impermeable and the average slope of the catchment area is 0.034 m/m. The catchment is drained by a mixed system, partly separate and partly

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combined. In order to prevent flooding, the Nancy Urban District has built a number of retention tanks, including the 12,000 m^3 Gentilly basin which is fed by a system draining an area of 150 hectares. The other retention tanks, constructed primarily to prevent flooding, in the catchment area (see Figure 1) are Vologne (1,700 m^3), Boudonville (4,000 m^3) and Haut-du-Lièvre (2,500 m^3). Several measurement points were set up on the site (see Figures 1 and 4): three rain gauges in the catchment area, twenty water height gauges at strategic points in the system and six water sampling units.

The storage tank of Gentilly and its control

The 12,000 m^3 basin of Gentilly is a rectangular sturcture (80 × 40 m^2 of surface for approximately 4 m height of average water) and is managed by a sluice on the outflow. The level in the basin is managed either to regulate the water flow downstream of the basin to prevent flood risks or to use the basin as a storage-decantation tank to reduce pollution overflows into the Meurthe river.

The "flood prevention mode"

The "flood prevention mode" has been used since 1991 and is adopted for the "strong" rains. The sluice position is adjusted according to a water level measurement in the main collector downstream (Libération point, see Figures 2 and 4) of the tank. When the level reaches 0.70 m, the valve is closed gradually to be completely closed when the level reaches 1.30 m. If the level at the Libération point goes down again to a value lower than 0.70 m, the valve opens gradually. The algorithm controlling the valve is proposed in Figure 3.

The "depollution mode"

An "experimental depollution mode" for the "small" rains was tested in 1996. The sluice was closed since the beginning of the rainfall and opened after 24 hours in order to optimize the decantation of the effluents. However, a TSS peak has been observed when the sluice is opened and as the basin become empty. An increase in pollution (especially for ammonia an TKN) has been observed after 15 hours storage. Consequently, the basin needs to be modified to obtain acceptable levels of pollution in the water released.

These modifications consist in the separation of the initial tank into two parts (see Figure 15). Each compartment will be equipped downstream with three valves at different levels: one to discharge the higher water part, one to discharge the intermediate water part and the

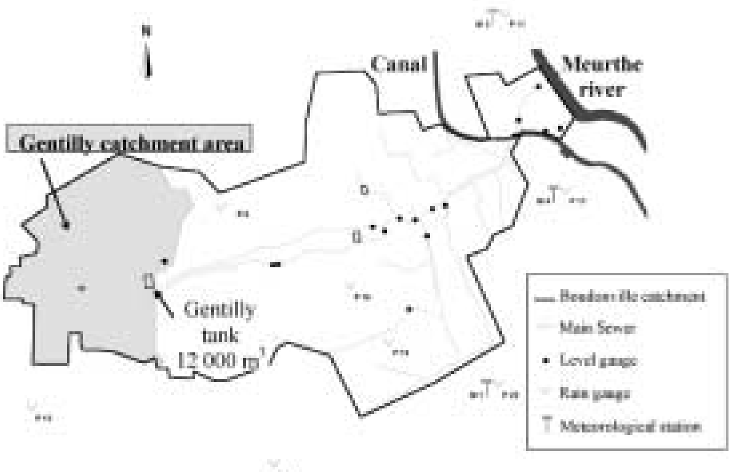

Figure 1 General description of the site and the measurement points

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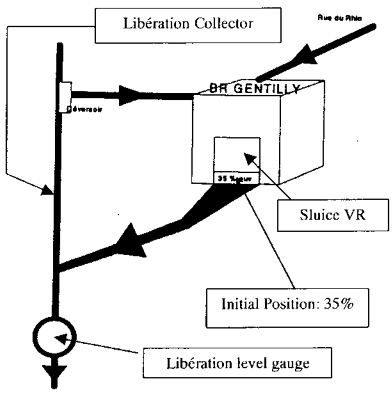

Figure 2 Simplified view of the Gentilly basin

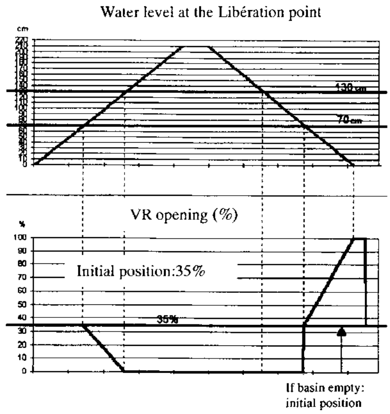

Figure 3 "Flood prevention mode" presentation

last one to discharge the lower part. Each compartment will be equipped with a water level gauge and a turbidimeter. These modifications are under way and have, therefore, not yet been taken into account in the model.

Mathematical modelling

Aim of the modelling and methodology

The aim of the modelling is to propose rules of management to obtain an optimal operation of the Gentilly tank in terms of quantity and quality, by observing the impact of this management on the network. The mathematical model was created using the software HYDROWORKS DM™ (1998) (hydraulic and quality) and the Real Time Control (RTC) module.

The use of modelling has been made in four stages:

- *First stage*: a hydraulic and pollution calibration and validation in dry weather conditions,
- *Second stage*: a hydraulic and pollution calibration and validation for several rain events with low precipitation, with the drain valve of the basin closed during the event (corresponding to the "experimental depollution mode"),
- *Third stage*: a hydraulic validation for heavy rain events, using the Real Time Control Module of the software to simulate the modelling of the sluice management,
- *Last stage*: the impact of the management on the sewer system will be studied with the same model. Tank modifications to improve the quality of the effluents by increasing the decantation will be taken into account in the simulations. It will be possible, using the results of a specific measurements campaign, to generate theoretical drainage pollutant flows that will be used as input data in the model.

Networks model

The catchment area was divided into 177 subcatchment areas, the areas obtained varying from 0.2 to 25.6 ha. There were 218 nodes. The model was set up as connections between these nodes, giving 213 connections with a total length of 28 km. There were various shapes of sewers: circular, oval or special (rectangular, semi-circular, etc). Figure 4 shows the diagram of the system modelled using HYDROWORKS DM™ (Magne *et al.*, 1996).

Dry weather and "small" events simulation results

The water height was measured at 11 points and the pollution was measured at 3 points (upstream of the Gentilly basin, Jacquinot and Crosnes) for TSS, COD, BOD, NH_4 and

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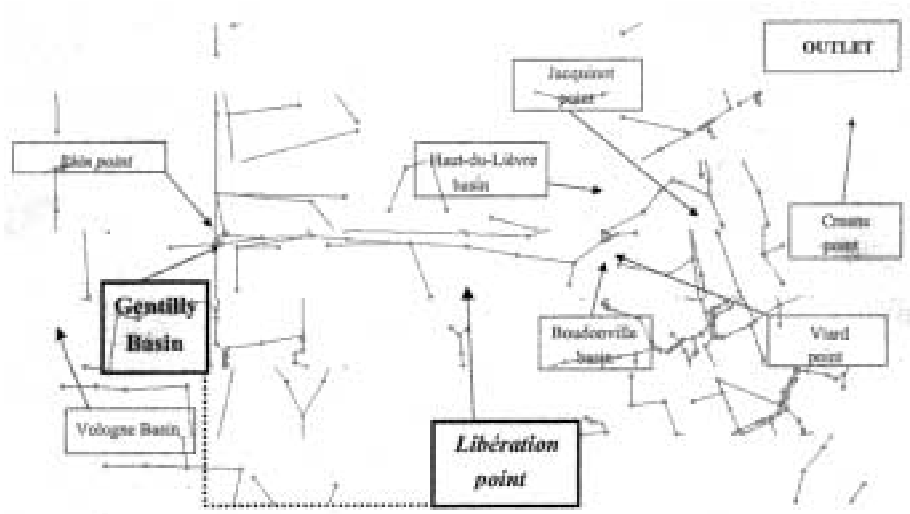

Figure 4 Diagram of the system modelled using HYDROWORKS DM

TKN. These measurements have been used for the operations of calibration and validation in hydraulic (with a mean runoff coefficient of 33%) and pollution during dry weather and “small” rainfall events (water height less than 12 mm in 9 hours) for which the drain valve of the basin was closed.

Detailed hydraulic and pollution results can be found in Zug *et al*. 1999. Figures 5 and 6 show an example of the water level in the Gentilly basin and TSS concentrations results downstream of the basin. Hydraulic results are presented in Table 1.

The satisfying correlation of the results obtained while calibrating and validating the water and pollution parameters meant that the mathematical model could be used to assess the volume of water and pollution entering the Gentilly basin during “small” rainfall events.

“Flood prevention mode” simulation results

Two rainfall events which have activated the “flood prevention mode” (e.g. a water level up to 70 cm at the Libération point, see Figure 3) have been selected to validate the mathematical model and its Real Time Control Module during “strong” rain events. This validation has been carried out using a mean runoff coefficient of 38% (33% was used for the small events) and with the translation of the regulation algorithms of the Gentilly and Boudonville tanks (Figure 3).

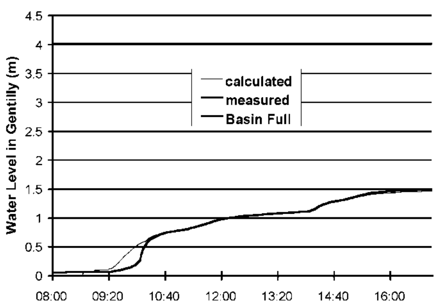

Figure 5 Hydraulic calibration during wet weather (29/10/96 rainfall): Gentilly basin

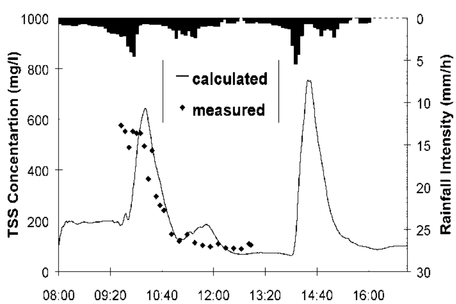

Figure 6 Pollution calibration during wet weather (29/10/96 rainfall): Jacquinot point

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The 26/08/97 (see Figure 7) rainfall has been chosen because the water level at Liberation was just up to 70 cm and activated the “flood prevention mode”, which managed especially the drainage of the Gentilly basin with a maximal opening of 68% (see Figure 11). The water level and volume in the basin was of 2 m and 3,600m^3.

The 22/07/95 rain series consists of three rainfall events. If the two first ones didn’t activate the flood prevention mode, the last one (between 16 and 19 h, see Figure 8) caused the complete filling of the basin of Gentilly (12,000m^3) in only 40 minutes. During this event, the position of the drainage sluice varied between 10 and 84%.

The examination of measurements of the various rain-gauges implemented in the catchment show the heterogeneity of this event since the recorded maximum values vary between 252 and 72 mm/h. A series of simulations carried out with measurements of the various recording rain-gauges did not make it possible to reproduce measurements and mainly volumes transited. The observation of the radar pictures this day shows the stormy character of this episode which does not allow the direct use of measurements available for modelling. Nevertheless, the characteristics of this rainy series and particularly its importance (near to a decennial frequency of the two first hours), make it an event extremely interesting for the study. Thus, and in front of the difficulty of taking into account a simultaneous phenomenon of spatialization and displacement of the rain, the choice was made to retain continuous and proportional rainfall losses. We used measurements levels and volume in the basin of Gentilly over the period of 09h00 to 15h00 to calculate the relationship between the forwarded volume of water and that of the rain recorded by the rain-gauge located at the Haut du Lièvre. This calculation indicates a proportional and continuous rain loss equivalent to 30%. This value was retained to transform the rain of 22/07/95 and to carry out simulations.

Figures 9 to 14 give the various results obtained for water level in the Gentilly basin, Libération and the Boudonville Nord point (near the outlet of the system). They appear to be of excellent quality in spite of the various assumptions exposed here before.

Five rainy events of very different characteristics regarding the level of the precipitated heights, the maximum intensities, the configurations, allowed us to obtain results of good

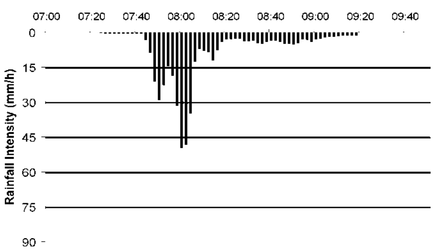

Figure 7 26/08/96 Rainfall: Hyetograph

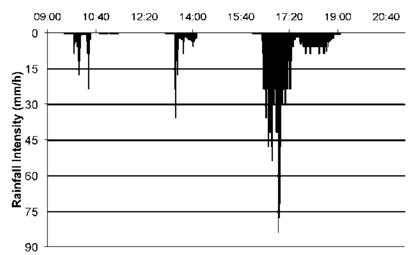

Figure 8 22/07/95 Rainfall: Hyetograph

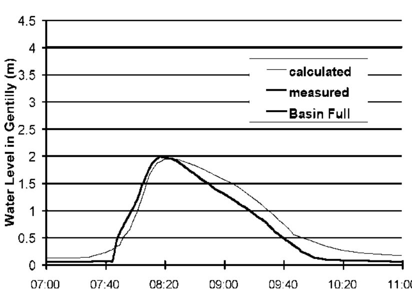

Figure 9 26/08/96 Rainfall. Level in Gentilly

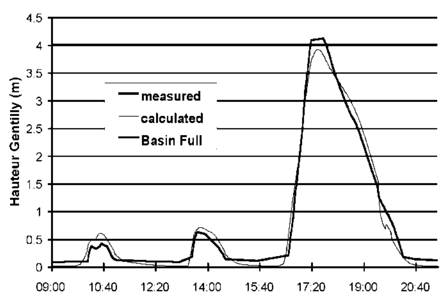

Figure 10 22/07/95 Rainfall. Level in Gentilly

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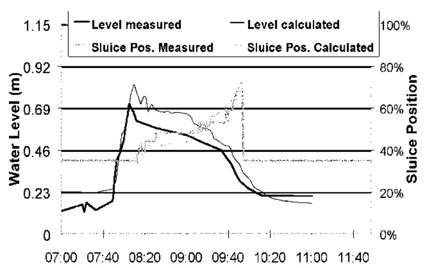

Figure 11 26/08/96 Rainfall. Level in Libération

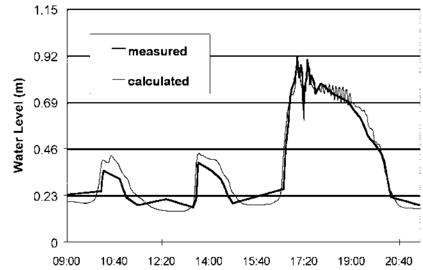

Figure 12 22/07/95 Rainfall. Level in Libération

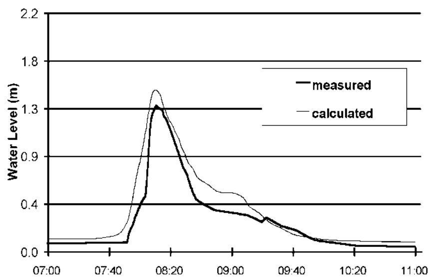

Figure 13 26/08/96 Rainfall. Level in Boud. Nord

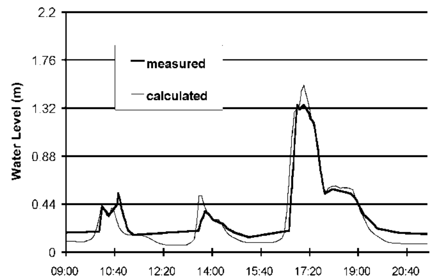

Figure 14 22/07/95 Rainfall. Level in Boud. Nord

general quality for the water level evaluation. Indeed, HYDROWORKS DM™ and its RTC module make it possible to reproduce, the forms, temporal positions as well as the extreme values and this with a precision of about 10% on the maximum heights and volumes of the tank of Gentilly. Table 1 presents some hydraulic results.

The mathematical model of the Boudonville catchment and the RTC module translating the rules of management of the valve of Gentilly are thus validated in hydraulics and allow us to forecast a good representation of the future instructions which will be implemented.

Impact of the management on the sewer

The impact of the management of Gentilly basin on the sewer system will be studied taking into account its modifications: two compartments (B1 and B2) and six sluices (see Figure 15). If the hydraulic model can be used without any other validation, the pollution transfer into the basin (and this for each compartment) and at the different drainage sluice must be calibrated and validated using measurements. A series of measurements envisaged at the beginning of the year 2000 should allow this stage of calibration and validation of the model. Using the RTC Module to control the management of the seven sluices, the

Table 1 Hydraulic results for the Gentilly basin

	"Small" rainfall			"Important" rainfall	
Stage	Calibration	Validation	Validation	Validation	Validation
Rainfall	29/10/96	02/05/96	20/06/96	26/08/97	22/07/95*
Vol calulated (m^3)	1855.9	1027.1	935.4	3503.4	14561
Vol measured (m^3)	1938.3	1055.1	825.4	3625	16047**
Error (%)	**–4.3**	**–11.1**	**13.3**	**–3.4**	/
H max calculated (m)	1.45	1.12	1.07	1.95	3.9
H max measured (m)	1.48	1.17	1.02	1.98	4.11
Error (%)	**2**	**–4.9**	**5.2**	**–1.7**	/

* comparison made on the third part of the rainfall series
** volume calculated using a level measured of 4.11 m into the basin

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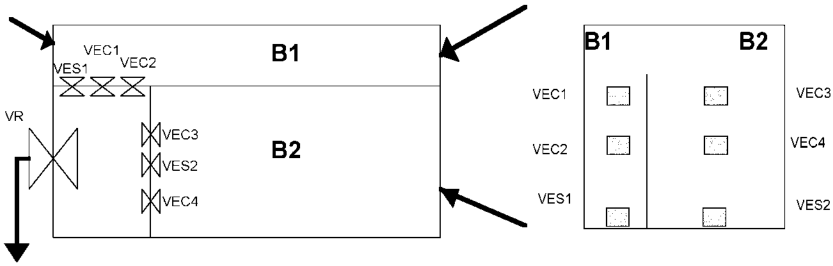

Figure 15 General description of the modified basin

behaviour of the network in terms of hydraulics and pollution will be studied from three different aspects:

- Using isolated rain events, to test the effectiveness on only one rain,
- Using composite rain events, for example to test the influence of a second rain occurring during the draining of the basin,
- Using a long series of rain events (for example one year) to test the efficiency of the long-term system.

Conclusions

The purpose of this study of modelling the sewer network of the Boudonville urban catchment is not limited to a simple comparison between simulations and measurements, but is to validate a mathematical tool the use of which will make it possible to better understand, characterize and finally anticipate the behaviour of the network from the point of view of hydraulics and pollution.

The hydraulic mathematical model is validated and the good quality of the results obtained for different rainfall events, with and without management of the valve of regulation of the basin of Gentilly shows that it could be used without significant modifications in the later phase: the study of the impact of quantity and quality on the sewer system and the receiving water. Nevertheless, the study of the 22/07/95 rainfall events indicates that for the future exploitation of the model, it will be advisable to take account of the heterogeneity of the rain (which represents the principal input of the model) and also the level of spatialization (taken into account in the various recording rain-gauges), but also the level of the displacement of the rain. In these two cases, it seems that the coupling of radar information and pluviographic ones should provide significant elements for the strategies of management of the whole of the network.

Concerning pollution, the first results obtained are satisfactory and make it possible to validate the mathematical model for weak rains but with the valve of closed regulation, i.e. without influence of pollution forwarded by the basin of Gentilly. The rest of the study cannot be completed until modification of the Gentilly basin has been completed: it will then be possible to assess how pollution behaves in the modified basin. This work should enable finer management and better pollution reduction by decantation.

The success of such a project requires accurate measurements and modelling. Moreover, close collaboration between those carrying out the study and those running the system is an added advantage in achieving the objectives and setting up and testing the management rules.

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