Published in Water Science & Technology, Vol45, No 2, pp. 19–26, IWA Publishing 2002.

MANAGEMENT OF A DETENTION - SETTLING BASIN USING RADAR DATA AND RISK NOTION

Dominique Faure*, Pierre Auchet**, Olivier Payrastre***.

** NANCIE, 149 rue Gabriel Péri, BP 290, 54515 Vandoeuvre Les Nancy, France, faured@nancie.asso.fr*
*** Communauté Urbaine du Grand Nancy, 22 - 24 Viaduc Kennedy, CO 36, 54035 Nancy, France*
**** CETE de l'Est, 71 rue de la Grande Haie, BP 8, 54510 Tomblaine, France*

ABSTRACT

This paper presents a practical application of sewage network management strategy using radar data to control a detention-settling basin. This practical application, used in operational mode since January 2000, is based on three main notions. Firstly, the use of radar data without rainfall estimation. Secondly, the definition of some gradual risk levels for the sewage network by a detailed modelling of the sewage system functioning. Thirdly the definition of relations between risk levels for the sewage network and types of rain events defined from radar data. The operational application produces gradual alarms for decision-making assistance: *no risk*, *potential risk* and *confirmed risk.*

KEYWORDS

decision-making assistance, forecasting, radar, real time control, risk management, sewage system, urban, hydrology

INTRODUCTION

Radar data was gradually integrated in projects of urban sewage network management, either for a better spatial estimation of rainfall, or for rainfall forecasting. Originally, radar rainfall forecasting was used to anticipate on decision making in case of storm event, in relation with protection against floods. Recently, rainfall forecasting has been considered for the management of all common rain events, in order to reduce rain water pollution overflows into the natural environment. In Europe, many studies have been realised in relation to the needs of great urban centres: without being exhaustive, it is possible to cite among recent research works in the United Kingdom *Armstrong et al., 1996* (London) *Cluckie et al., 1996* and *Griffith et al., 1997* (Manchester), *Yuan et al., 1999* (Bolton) , in Germany *Johann et al., 1999* and *Pfister et al., 1999* (Gelsenkirchen-Buer), in Spain *Martí Marquès et al., 1999* (Barcelona), in Italy *Bazzuro et al., 1999* (Genoa). In France, several sewage network management strategies have been developed integrating radar data, and some sewage system managers currently use radar forecasting in operational mode: the Hauts-de-Seine and the Seine-Saint-Denis counties, and the urban agglomerations of Bordeaux, Marseille and Nancy. Facing operational constraints, these examples of operational utilisation evolved from dynamic management to scenario based management of sewage facilities (*Browne et al., 1998, Schmitt et al., 1999*).

This paper presents the practical application realised in Nancy (Northeast France) for the control of a 12 000 m^3 detention-settling basin. This basin is used with a double objective requiring two opposed types of management: protection against floods and reduction of pollutant overflows. This application, used in operational mode since January 2000, is based on the risk notion and on gradual alarms generated according to information on rain areas extracted from radar images.

DESCRIPTION OF THE CONTEXT

Since the seventies, Nancy Urban Authorities have built a great number of detention basins, initially designed for protection against flooding. The current objective is to use these storage capacities to limit waste water discharges into the Meurthe river during all common rain events. But this new objective should preserve the initial function of the basins for heavy rainfall. The major difficulty is related to the important rainfall variability in space and time in case of storm events. For this type of rain event, a recent study carried out on actual urban catchment areas in Nancy indicates that quantitative rainfall forecasting should not exceed a few minutes for small catchment areas limited to few square kilometres. On account of the fast reactions of the Nancy sewage network, this delay is insufficient to make the sewage system safe in case of wrong initial option of management (*Faure et al., 1999a*). In consequence, a management strategy has been developed using new radar data processing, to estimate a long time in advance a risk level for the sewage network. The result is of probability type, but is sufficient to produce a real decision-making assistance in operational conditions.

A first detention-settling basin was selected to experiment this concept within the framework of a European Life96 project (*Schmitt et al, 1999*). This basin called "Gentilly" is located upstream the main Boudonville combined sewage network (figure 1). The Gentilly basin (12 000 m^3) is used to protect the area downstream, close to the city centre. Under these conditions, risks of flooding should be reduced to the minimum. The Gentilly basin is used with two different modes of management:

- A mode of management called "protection against flooding" (PAF mode) used for very significant rains: storage of effluents is minimum in order to preserve a maximum reserve of storage necessary to limit peaks of flow into the sewage network.
- A mode of management called "protection against pollution" (PAP mode), used for all common rains: the filling of the basin starts at the beginning of the rain, the objective being to store the maximum of effluents. A free volume of storage is preserved in the basin, in order to limit a possible reduced peak of flow.

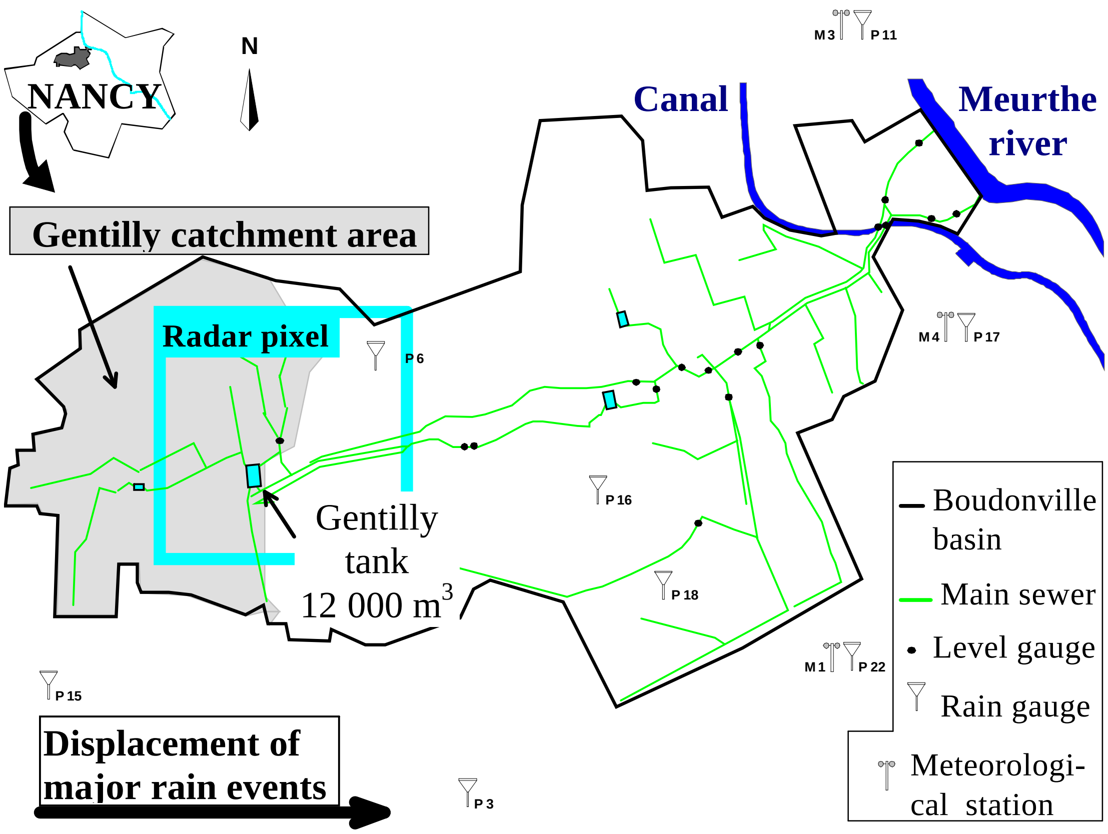

Figure 1: Boudonville basin (6.6 km², 37000 inhabitants), and catchment area of Gentilly (1.5 km²). A radar pixel is located and indicates the scale (blue square of 1km²).

DEFINITION OF THE MANAGEMENT STRATEGY

The management strategy, based on the identification of different types of rain events, has been defined in three steps:

- The analysis of hydraulic risks for the sewage network using detailed modelling of the behaviour of the network and historical hydrological data. Results allowed to define four different risk levels and to characterise seventeen historical rain events in relation to these risk levels.
- The definition of criteria to discriminate these different types of rain events by radar images analysis compatible with operational conditions of use. These criteria were defined using historical radar images for the seventeen selected rain events.
- The definition of an automatic procedure that produces gradual alarms in relation with the Gentilly basin management.

Hydraulic risk analysis

The *Department* of *Centralised Technical Management* of Nancy Urban Community has registered rain gauge data and water levels in the sewage network since 1985. In addition, radar data has been available since 1995. Seventeen rain events were selected over a 3 years period of measurements from 1995 to 1998. This selection comprises events having given the most significant flows during this period (including a decennial event), and other events less significant but representative of common rain events.

In order to consider various initial states of the Gentilly basin, the hydraulic risk analysis was realised using modelling with *Hydroworks*^{DM} software (*Payrastre, 1999*). The detailed hydraulic model of the sewage network was provided by the *Engineering and Design Department* of the Urban Community (figure 2). The main hydraulic constraint is located at the node called "Libération", and the leak flow of the Gentilly basin is controlled in real time to limit the flow at this node below 3 m^3/s in PAF mode.

For the two modes of management (PAP and PAF modes), two initial conditions were considered :

1. the rain event was supposed isolated, and the Gentilly basin was empty at the beginning of the event;
2. the rain event followed another event, and the basin was supposed to be filled by the first rain, except a variable free volume of storage.

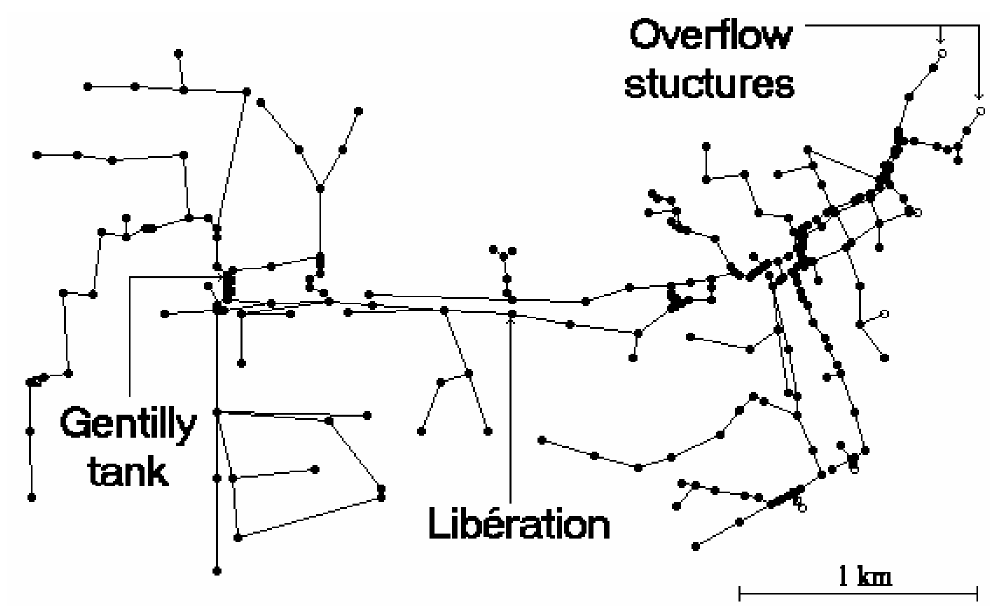

Figure 2: Hydraulic model of the Boudonville combined sewage network
(lines =collectors, dots = nodes).

The modelling results were interpreted in function of the total volume of effluents flowing through the Gentilly basin, the maximum flow observed at the Libération node for the PAF mode, and the minimum value of the free volume to be preserved in the basin for the PAP mode. The objective was to define a few types of rain events, the number of these types being limited in order to facilitate real time recognition of the type in operational use. Four types were defined for the seventeen historical rain events, in relation to the Gentilly basin management (table 1).

Types of risk	rain events observed	Description
NR1	6/17	Events which never cause important flow into the combined sewer network.
NR2	5/17	More significant events but which do not correspond to a real risk for the sewage network, even if the basin is filled before the beginning of the rain (free volume equal 0 m^3).
R1	4/17	Important events being able to produce a flood risk in case of bad management of the basin. These events require a free volume of storage to be preserved, before and during the rain event, in order to limit peaks of flow into the sewage network. This free volume varies between 3000 m^3 and 4000 m^3.
R2	2/17	Exceptional events. These events absolutely require the basin to be empty before the beginning of the rain, and the management to be in PAF mode.

Table 1: Classification of the seventeen historical rain events.

Radar images analysis

Since 1995, the *Urban Hydraulic Department* of the Nancy Urban Community has used a system of real time weather radar data processing (*Faure et al., 1999b*). The objective of this analysis was to determine a set of criteria in order to discriminate between rain events corresponding to a risk for the sewage network (R1 and R2) and other rain events (NR1 and NR2). In order to identify risk conditions a long time before the beginning of rainfall over the agglomeration, identification of typical rainfall structures prevailed rather than estimating (or forecasting) rainfall at ground level. Two types of criteria were considered :

- Criteria providing a general description of the rainy activity over all the region: the result is a characterisation of the rainy activity realised by an automatic analysis of the histogram describing the pixel value distribution for each radar image.
- Criteria describing all the intense rain cells identified over a large region around the agglomeration (size, density, direction and speed of displacement). These cells are extracted from radar images using a segmentation by thresholding based on a method of relaxation. The interest of the method is the statistical and local adjustment of the threshold.

For the seventeen rain events, this analysis was carried out with historical images provided by a C band radar located 30 km in the East of Nancy, and integrated in the National French Radar Network named ARAMIS (table 2). Radar data was used directly from digitised values of reflectivity, without rainfall estimation. Ground echoes were filtered, but other sources of errors of the radar measurement were not treated. Criteria identified by this analysis were considered not very sensitive to these errors.

Antenna diameter	3.05 m
Antenna protection	5.70 m radome
Wavelength	5 cm
Acquisition mode	PPI
Duration of a turn of antenna	≅ 70 seconds
Elevation of the radar beam	0,7°
Aperture of the radar beam	1,25°
Maximal range	512 km
Data digitalisation	54 levels, in dBz
Image frequency	5 minutes
Pixel size	1 km^2

Table 2: Nancy radar characteristics.

The results of this analysis were used to define an automatic procedure usable in real time to identify rain events with risk for the Boudonville sewage network. It is possible to note that one (or more) intense rain cell was observed over the agglomeration for all the R1 and R2 events. For all NR1 and NR2 events, flow into the sewer network was not linked to intense rain cells. Another observation was that the size of these cells could not be a direct criterion to determine if the situation is critical or not.

Operational application

The objective was to define a warning system allowing to detect a potential risk for the Boudonville sewage network a long time before the beginning of rainfall over the agglomeration. This operational application was developed in a security context: for all rain events which produce significant flows the Gentilly basin should be managed in PAF mode, and a management in PAF mode is acceptable for other events under two conditions. The number of not relevant alarms should be limited, and these alarms should not disturb the normal working of the technical department in charge of the sewage system management. In addition, for protection against pollution, the Gentilly basin should be managed in PAP mode for the greatest number of common rain events.

The existing radar data processing system used in Nancy has been upgraded to integrate new treatments, specifically defined for these requirements. The system determines in real time two risk levels for the sewage network: a level of *potential risk* based on the detection of intense rain cells in a "potential risk" area, and a level of *confirmed risk* based on the detection of intense rain cells in a "confirmed risk" area. Figure 3 presents an example of graphic display for the storm event of June 07, 1998. This example is exceptional on account of the number of intense rain cells detected. The potential risk area is a large circle around the agglomeration (radius equal to 80 km) in order to take into account unpredictable new generations of intense rain cells. The confirmed risk area is more restricted and is automatically modified in function of speed and direction of the rain cells displacements. As a result, alarms of potential risk (PR alarm) or confirmed risk (CR alarm) could be generated according to an automatic procedure taking into account :

- the risk level estimated for each area,
- the speed of displacement of the rain cells,
- the type of rainy activity estimated over all the region,
- the volume of effluents stored in the Gentilly basin.

In addition, an official procedure has been edited and is currently observed by the technical staff. Default management of the Gentilly basin is the PAP mode. In case of PR alarm, a human supervisor has the possibility of setting the mode of management in PAF mode according to his assessment of the situation. When a CR alarm is generated, the supervisor must imperatively set the management in PAF mode in order to guarantee security. If the radar is not working properly, the mode of management is set in PAF mode.

VALIDATION RESULTS

Before operational implementation, this procedure was validated in two steps using the complete operational software and numerous historical radar data.

First validation was realised for the seventeen rain events used to define the four types of rain events. Expected CR alarms were defined as alarms linked to R1 and R2 events, and were compared to alarms generated by the system. Results presented in table 3 and table 4 indicates a 100% generation rate of CR alarms for events really linked to a risk for the Boudonville sewage network, and a reduced rate of unnecessary CR alarms limited to the NR2 type of events. Although the number of events is reduced, table 4 indicates criteria values characterising the procedure efficiency, such as the Critical Success Index (CSI) or the Rousseau Index (RI). Concerning R1 and R2 events, it is interesting to note that the CR alarms were generated between one and two hours before the beginning of rainfall over the agglomeration. These results could be considered acceptable according to the objectives defined for the operational application.

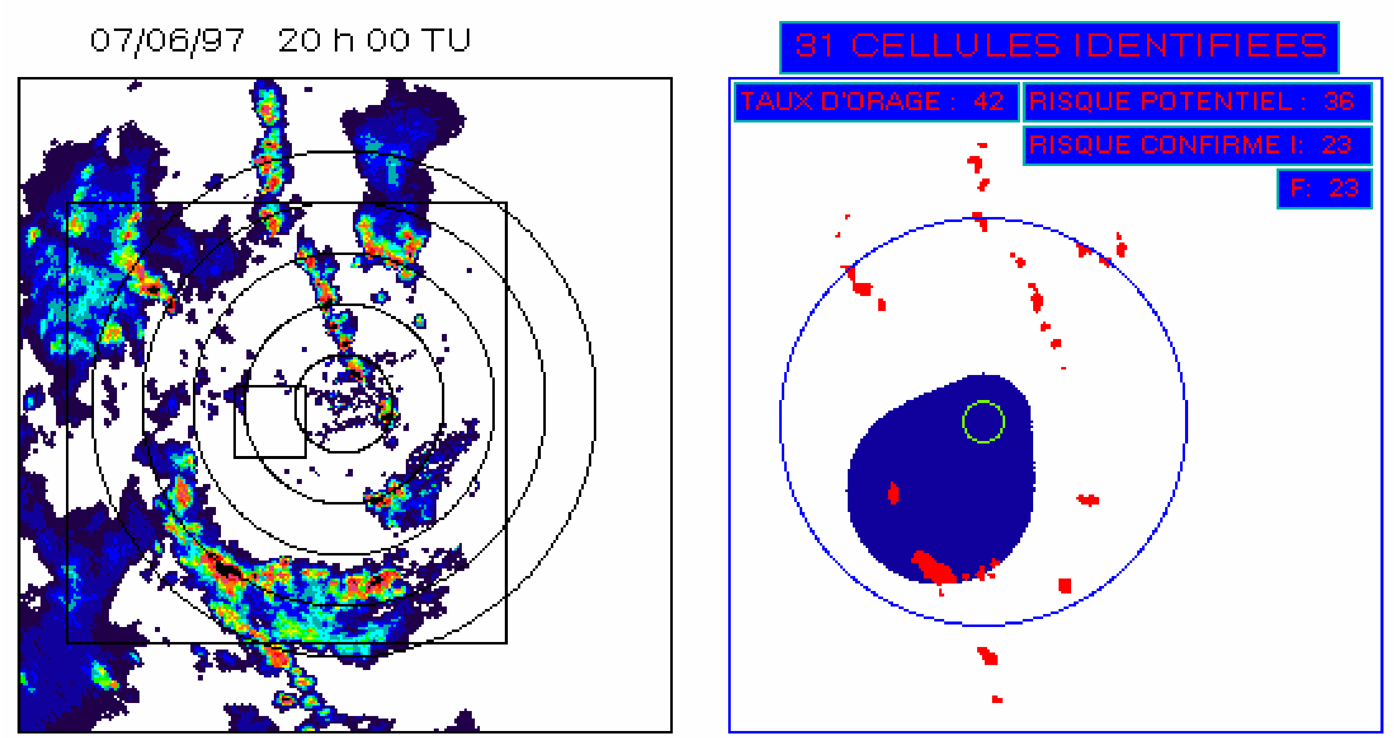

Figure 3: Example of processing results. Left, radar image in dBz levels (size = 256*256 km, space between circle = 20 km). Right, plot of the 31 rain cells identified, and risk areas defined for this image (blue circle = potential risk area, blue filled area = confirmed risk area)

hydraulic risk	generation of CR alarm	no CR alarm
R2	2/2	0/2
R1	4/4	0/4
NR2	2/5	3/5
NR1	0/6	6/6

Table 3: Rate of generation or no generation of CR alarms for 17 rain events.

		observed CR alarms Y	observed CR alarms N
expected CR alarms	Y	a = 6	b = 0
	N	c = 2	d = 9

$CSI = a/(a+b+c) = 0.75$

$RI = [4ad - (b+c)^2]/[(2a+b+c)(2d+b+c)] = 0.757$

Table 4: Comparison between expected and observed CR alarms.

Validation was completed by simulation of the procedure for a very important set of historical radar images. An exact simulation of the operational application was realised for 324 rainy days from 1995 to 1998, representing more than 90 000 radar images. This set comprises the greatest part of radar images including rain areas recorded during three years of continuous measurement in Nancy. Results indicate that CR alarms were generated for only 12% of the rainy days, corresponding to 16% of the cumulated rainfall on the catchment area of the Gentilly basin (figures 4 and 5). These 39 rainy days include all the rain events having induced a maximum water level at the Libération node above the warning threshold defined by the technical departments of the Urban Community (70 cm). These results were in accordance with the initial objective of the Life96 project: to safely store more than 80% of the annual volume of effluents flowing through the basin.

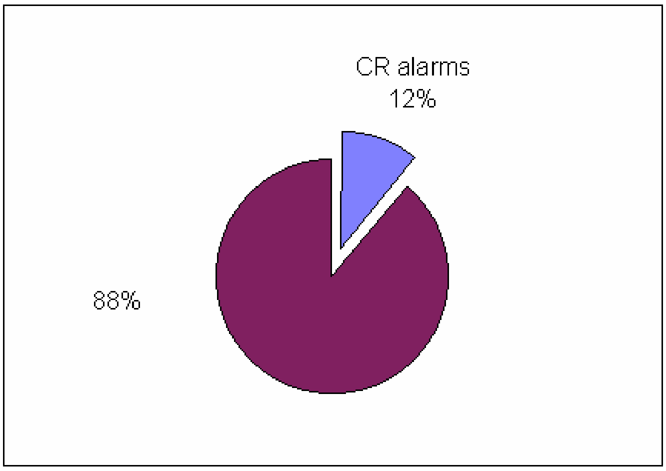

Figure 4: Percentages of rainy days generating a CR alarm from March 1995 to February 1998

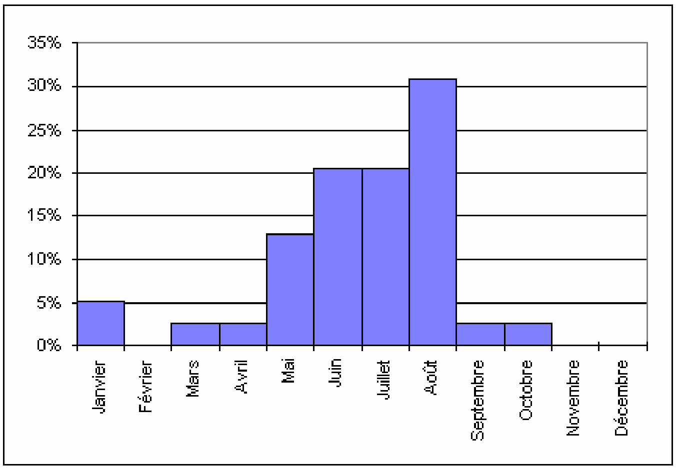

Figure 5: Annual distribution of these rainy days (from March 1995 to February 1998)

CONCLUSION

The operational application has been used by the Technical Department in charge of the sewage system management in Nancy to control the Gentilly basin since January 2000. This management strategy is based on three major points summarised below: firstly, the definition of some gradual risk levels for the sewage network by a detailed modelling of the sewage system behaviour. Secondly, the utilisation of radar images to characterise a type of rain event without rainfall estimation. Thirdly the definition of relations between risk levels for the sewage network and information extracted from radar data, in order to produce gradual alarms: *no risk*, *potential risk* and *confirmed risk.*

The major advantage of this procedure based on the risk notion is to describe a general situation several hours before the beginning of rainfall over the Agglomeration. Equally, the procedure's sensitivity to the usual errors in rainfall measurement by radar should be reduced in comparison with methods using rainfall estimation (or forecasting) at ground level. A difficulty is that such alarms only correspond to a probability of heavy rainfall over the agglomeration. Nevertheless, simulations completed for three nearly complete years of radar data showed that confirmed risk alarms would be generated for only 12% of the rainy days during this period.

The practical application of this procedure for the management of a strategic detention-settling basin in Nancy shows that this approach can be complementary to the quantitative forecast of rainfall. Results are dependent on the sewage network and on local climatology, and cannot be directly extrapolated to all the contexts in all the agglomerations. But the principle of the study can be extended to other cases requiring an alarm procedure using radar data.

ACKNOWLEDGEMENT

This work forms part of a major programme carried out in partnership with the International Water Centre, the Metropolitan Authority of Nancy, the Laboratoire Central des Ponts et Chaussées, Anjou-Recherche, and the Rhine-Meuse Water Agency. The operational project was supported by the European Life96 programme.

REFERENCES

Armstrong R.J., Noble I.A. (1996) *The use of real time control and radar rainfall in the modelling of a large complex sewer system*, 7th ICUSD, Hannover/Germany, 1996, Proceedings Vol. 2, pp. 947-952, IAHR/IAWQ, ISBN 3-00-000860-8.

Bazzurro N., Gallea A., Lasagna A. (1999) *Integrated planning and management of urban drainage waste water treatment and receiving water system: the experience of AMGA*, 8th ICUSD, Sydney/Australia, 1999, Proceedings Vol. 1, pp. 340-348, IEA-IAHR/IAWQ, ISBN 0 85825 718 1.

Browne O., Auriaux G., Idier F., Delattre J.M. (1998) *A decision aid system for real-time operation of Seine Saint-Denis sewer network*, 3ème conférence Internationale sur les nouvelles technologies en assainissement pluvial, Novatech98, Lyon, 4-6 mai 1998, Proceedings vol. 2, pp. 147-154, GRAIE, ISBN 2-9509337-2-6.

Cluckie I.D., Han D., Tilford K.A., Lin K., Tyson J. (1996) *Real-time control of urban drainage systems using a Multiple Attribute Radar System (MARS)*, 7th ICUSD, Hannover/Germany, 1996, Proceedings Vol. 2, pp. 953-958, IAHR/IAWQ, ISBN 3-00-000860-8.

Faure D., Schmitt J.P., Auchet P. (1999a), *Limits of radar rainfall forecasting for sewage system management: results and application in Nancy*, 8th ICUSD, Sydney/Australia, 30 August 1999, proceeding Vol. 1, pp. 441-449, , IEA-IAHR/IAWQ, ISBN 0 85825 718 1.

Faure D., Auchet P. (1999b) *Real time weather radar data processing for urban hydrology in Nancy*, Phys. Chem. Earth (B), Vol. 24, No 8, pp. 909-914, 1999 Elsevier Science Ltd.

Griffith R.J., Cluckie I.D., Shepherd G.W. (1997) *The utilisation of weather radar for strategic urban drainage modelling*, XXII General Assembly of the EGS, 21 - 25 April, 1997, Vienna/Austria.

Johann G., Redder A., Verworn HR., *Aspects of high resolution radar processing for urban applications in real time*, Phys. Chem. Earth (B), Vol. 24, No 8, pp. 895-901, 1999 Elsevier Science Ltd.

Martí Marquès J., Verdejo Rabassó J.M., Alsina Viñolas M., Malgrat Bregolat P. (1999) *Use of meteorological radar in the real time operation of the sewers of Barcelona*, 8th ICUSD, Sydney/Australia, 1999, Proceedings Vol. 4, pp. 1855-1862, IEA-IAHR/IAWQ, ISBN 0 85825 718 1.

Payrastre O. (1999) *Utilisation du radar météorologique pour l'aide à la gestion en temps réel d'un bassin de retenue: exemple du bassin de Gentilly à Nancy*, DEA/1999-01, Ecole Nationale du Génie de l'Eau et de l'Environnement de Strasbourg, FR.

Pfister A., Cassar A. (1999) *Use and benefit of radar rainfall data in an urban real time control project*, Phys. Chem. Earth (B), Vol. 24, No 8, pp. 903-908, 1999 Elsevier Science Ltd.

Schmitt J.P., Faure D., Badot R. (1999) *Sewage system management strategy to reduce rain water pollution overflows: the case of an underground storm basin in Nancy*, 8th ICUSD, Sydney/Australia, 1999, Proceedings Vol. 1, pp. 395-402, IEA-IAHR/IAWQ, ISBN 0 85825 718 1.

Yuan J.M., Tilford K.A., Jiang H.Y., Cluckie I.D. (1999) *Real time urban drainage system modelling using weather radar rainfall data*, Phys. Chem. Earth (B), Vol. 24, No 8, pp. 915-919, 1999 Elsevier Science Ltd.