Determination of the Overflow of a Stormwater Regulator Using Numerical Modeling

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1 Introduction

1.1 The Stormwater Regulator

A stormwater regulator is a structure generally found on a combined sewerage network, i.e., one draining both stormwater and wastewater. It is considered mainly as a "relief valve" and its main role is to protect the installations located downstream from it on the network, such as weirs, tanks, drop shafts, and treatment plants. This "relief valve" role is coupled with a contradictory obligation: only overflowing when strictly necessary, in order to avoid discharging harmful wastewater into the natural environment. This protection is provided by limiting the volume conveyed, the excess flow being either discharged into the natural environment or stored in specific basins for subsequent treatment [1].

A stormwater regulator is also a source of savings during network construction, since the pipes can be sized for smaller average flow rates and peak flows can be diverted.

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P. Gourbesville et al. (eds.), *Advances in Hydroinformatics*, Springer Water,
https://doi.org/10.1007/978-981-10-7218-5_56

Several types of stormwater regulator exist, the most widespread probably being those that divert overflows over a frontal or side crested weir, combined with a downstream converging section that limits the flow passing through it. This article discusses this type of structure.

1.2 Operation of a Stormwater Regulator

The operating principle of an overflow-type stormwater regulator is simple: a flow enters the structure chamber via one or more feeder sewers, and is primarily drained out of the chamber via a sewer leading to the downstream network. The water in the regulator chamber rises to a level that depends on the capacity of this downstream sewer. The greater the flow, the greater the increase in water level. When the water level reaches the weir crest, it begins to overflow, thus limiting the rise in level in the structure. The water that flows over the weir is released into the natural environment or a storage tank via an outlet pipe. Structures connected to the natural environment usually have a check valve fitted to their outlet, to prevent water flowing from the natural environment into the network during flooding. Figure 1 illustrates this operation.

1.3 Legislation in France

In France, application of the 1992 Water Act [2], reinforced by the ministerial circular of 6 November 2000 [3] and the decree of 21 July 2015 [4], requires monitoring systems to be fitted to urban wastewater networks. In particular, the

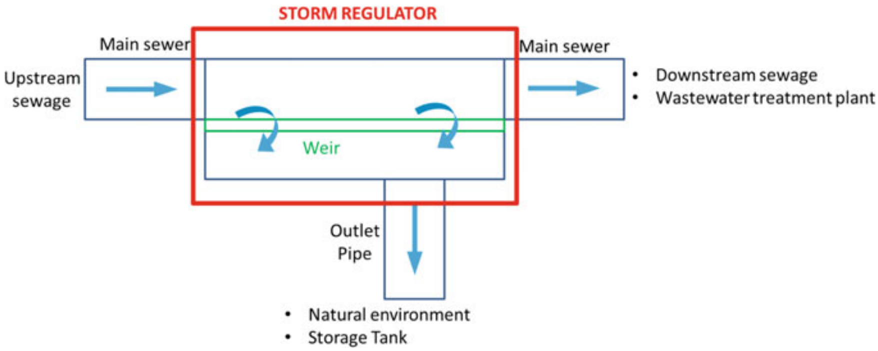

Fig. 1 Operating diagram of a stormwater regulator—Overflow operation

owner must know the characteristics of flows discharged into the natural environment by stormwater regulators. The regulators must hence be fitted with instruments in order to estimate the volumes released.

1.4 The Problem Encountered

Although most stormwater regulators operate under the same principle, the architecture of each one depends closely on its location on the network, particularly in respect to the upstream and downstream sewers, its proximity to the natural environment, its elevation, etc. Since many such structures were built long before the legislation requiring discharge volumes to be estimated came into force, the way in which they operate is known at a general level but often misunderstood.

Moreover, the instrumentation on the structure is based on noninvasive measurements, with sensors sheltered from the flows and from debris carried along in the sewers to prevent them being exposed to premature wear. Consequently, one of the very few measurements that can be taken on the structure is of water depth at a particular point, by means of an ultrasound sensor fixed to the structure roof.

The volume estimation is hence based on an empirical law derived from the discharge capacity of the structure, depending on water depth at certain measurement points. When the structure is complex (hydraulic jump, confluence of several sewers, reduced sections, etc.), it is often essential to use a CFD-type 3D model to optimize placement of the measuring equipment and extract a discharge capacity law that is reliable and acceptable (cf. the practical guidelines for setting up self-monitoring on sewerage networks drawn up by the Rhine/Meuse water authority [5]).

2 Methodology

The methodology drawn up by Artelia for using 3D modeling to define the discharge capacity law of a stormwater regulator is generally based on two models

- A one-dimensional model of the network in its entirety, in order to establish the ranges of flows that can occur at the structure. This model is both a conventional urban hydrological model, adjusted using the results of a measurement campaign, and a propagation model that solves the Saint Venant equation in the networks;
- A three-dimensional model of the structure, covering all the components that influence flows within it. This model is built using the OpenFOAM software. It is based on three-dimensional surveys performed at the structure during a visit prior to starting the modeling.

2.1 Example of a Network Study Using the CANOE Software

(Figures 2, 3 and 4)

2.2 Example of a Three-Dimensional Survey of a Structure

A team of two people from Artelia visits the structure, records its key characteristics, takes photos of it (Fig. 5), measures its dimensions and schematizes its operation (Fig. 6).

Following processing of the data, a three-dimensional geometry that accurately represents the actual structure is obtained (Fig. 7).

Fig. 2 Extract from a map of design drainage areas in a 1D model, showing the pipe route and the injection points on the network (urban hydrological modeling)

Fig. 3 Extract from a map in a 1D model, showing propagation in the network. In this case, a stormwater regulator

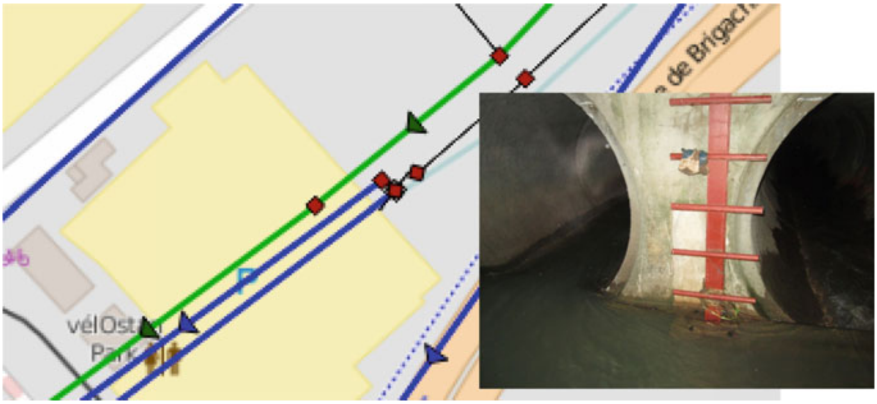

Fig. 4 Extract from a map in a 1D model, showing propagation in the network. In this case, a diverging structure on an urban network is being modeled

Fig. 5 Pictures of a visit to a stormwater regulator—Haguenau (France)

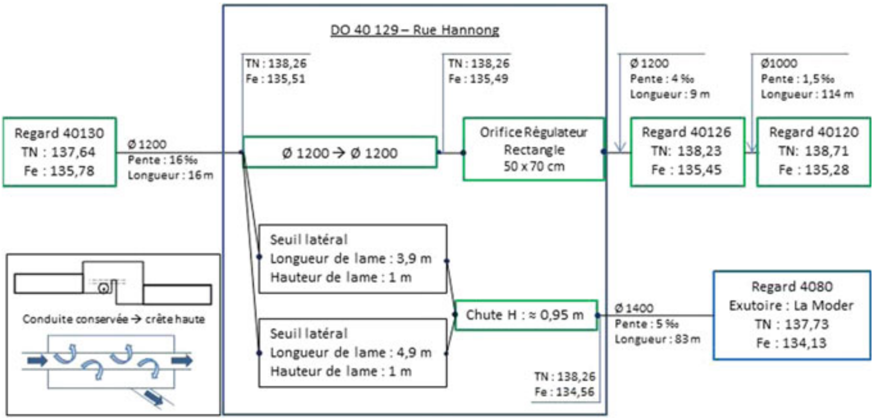

Fig. 6 Hydraulic block diagram drawn up following the visit—Haguenau(France)

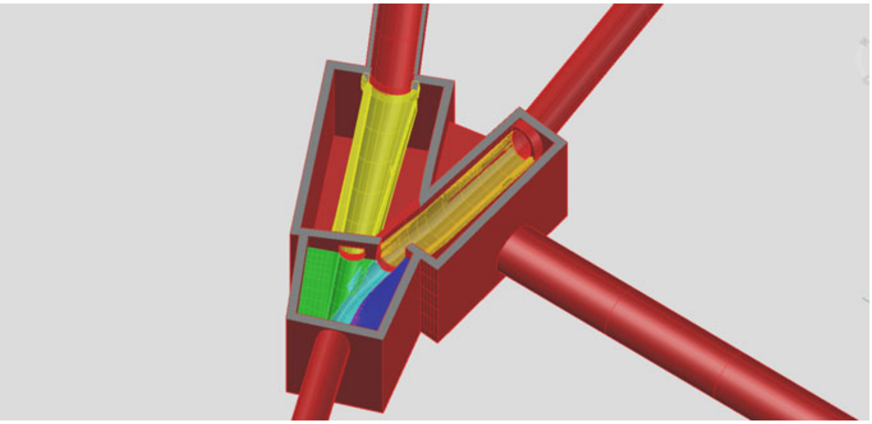

Fig. 7 Geometry of a stormwater regulator—Haguenau (France)

2.3 3D Modeling Methodology

Three-dimensional modeling of the structures comprises several stages:

- Integration of the three-dimensional geometry of the structure and spatial discretization (meshing) using the OpenFOAM software;
- Simulation of a set of operating points obtained from the one-dimensional model of the network. Our methodology draws on operating points with fixed inflow rates, enabling the outflow rate to be calculated accurately for a specific flow combination. On account of the time lag between a flow entering via a sewer and steady flow conditions being established in the structure, it is difficult to conceive how an overflow law could be defined with variable inflows;
- Analysis of flow behavior in the structure at the various operating points.
- Extrapolation of a discharge capacity law based on the calculated operating points and water depth measurements at potential sensor positions.

3 3D Modeling of a Stormwater Regulator

The two examples presented below illustrate the complexity of the problems inherent to estimating stormwater regulator overflow volumes.

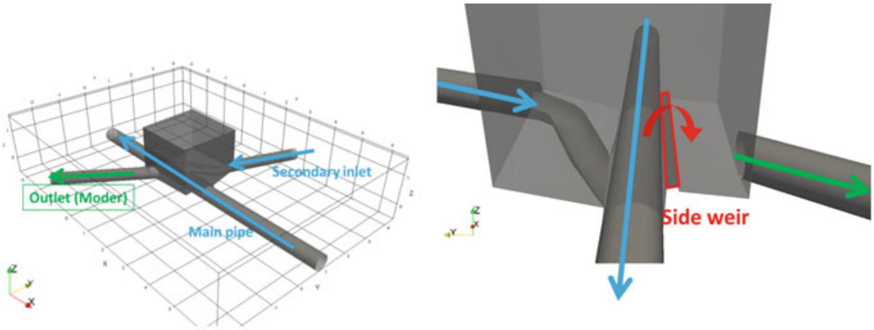

Fig. 8 Geometry of stormwater regulator—Schweighouse

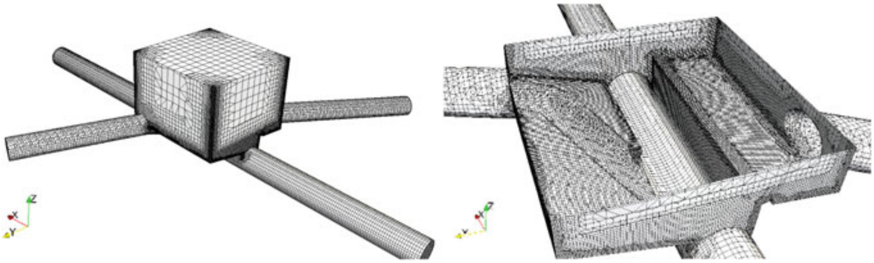

Fig. 9 Mesh of stormwater regulator—Schweighouse

3.1 Example of the Schweighouse Regulator

This regulator is located in the town of Schweighouse (E. France). It comprises two incoming sewers, an outgoing sewer, and a sewer discharging into the natural environment (the river Moder). It operates on the principle of a side weir running along the bottom of the main sewer (DN500). The second feeder sewer (DN400) arrives at the weir at an angle, at an elevation higher than that of the main sewer. Figure 8 presents the geometry of this structure.

The model was discretized into approx. 300,000 cells measuring between 2 and 20 cm. Figure 9 illustrates the mesh of the structure.

The one-dimensional simulation determined the ranges of potential flows through the two incoming sewers: between 50 and 100 l/s for the main sewer, and 50 and 400 l/s for the secondary sewer.

Since the regulator is fitted with a knife gate valve on its outlet to the natural environment, no downstream influence on the natural environment was considered. A free flow of fluid was imposed on the sewer network outlet: the flow passing through this outlet was hence only limited by the pipe capacity at the converging section.

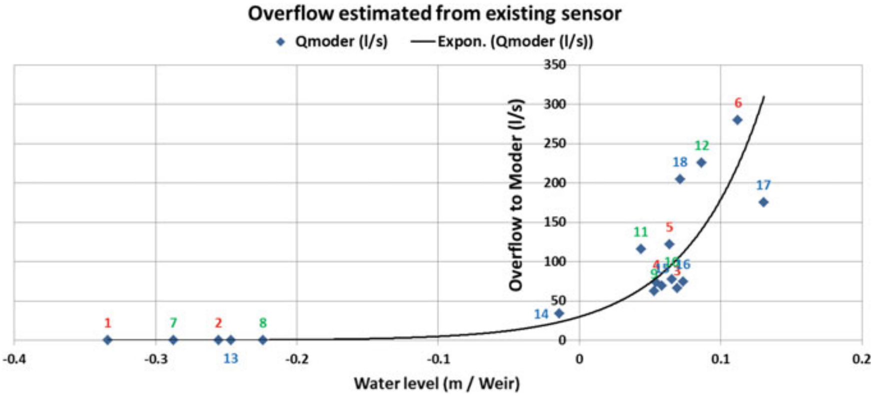

Fig. 10 Estimation of overflow from existing sensor—Schweighouse

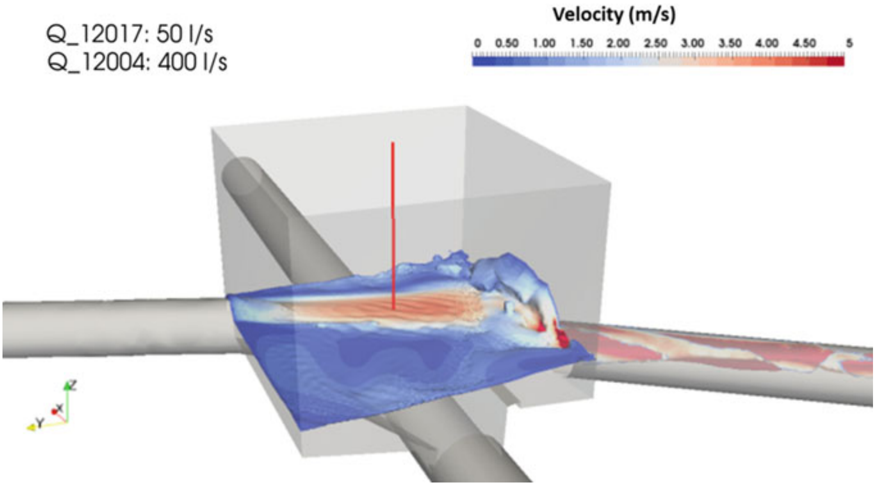

Fig. 11 Location of existing sensor—Schweighouse

A set of 18 operating points on the structure was simulated, combining the inflows through the two feeder sewers. Since a sensor had already been fitted to the structure, a discharge capacity law as a function of the water depth at this sensor was estimated. An exponential law was found, with an acceptable correlation. However, a bias is seen for the highest flows, as shown on the curve in Fig. 10.

An analysis of the flow through the chamber found that the existing sensor had been fitted in a particular area of the flow: it is directly impacted by the current stream from the secondary sewer, when the flow from this sewer exceeds the capacity of its dedicated gutter (Fig. 11).

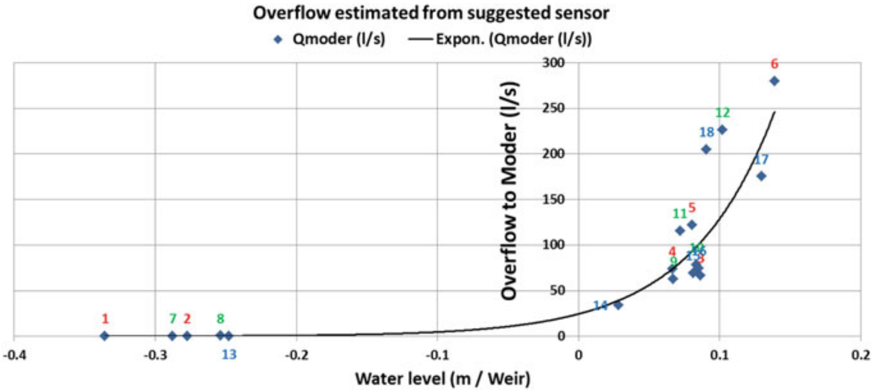

Fig. 12 Estimation of overflow from suggested sensor position—Schweighouse

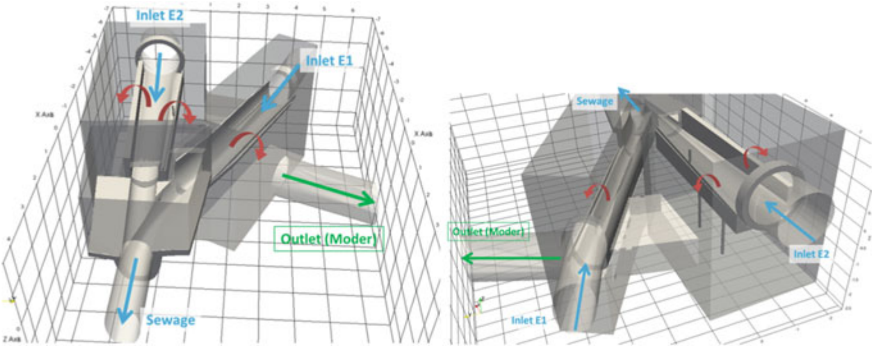

Fig. 13 Geometry of stormwater regulator—Haguenau

A different sensor position was hence proposed, further downstream from the chamber and outside the influence of the current stream. Moving this sensor to a new position enabled a law correlated more closely with the results from the operating points to be established (Fig. 12).

3.2 Example of the Haguenau Regulator

This regulator is located in the town of Haguenau (also in E. France). It comprises two incoming sewers, an outgoing sewer, and a sewer discharging into the natural environment (the river Moder). Its operation is highly complex, via three separate chambers, three side weirs and a downstream confluence at two different elevations. The first sewer (E1), a 1300 × 800 ovoid pipe, includes a side weir on its left bank

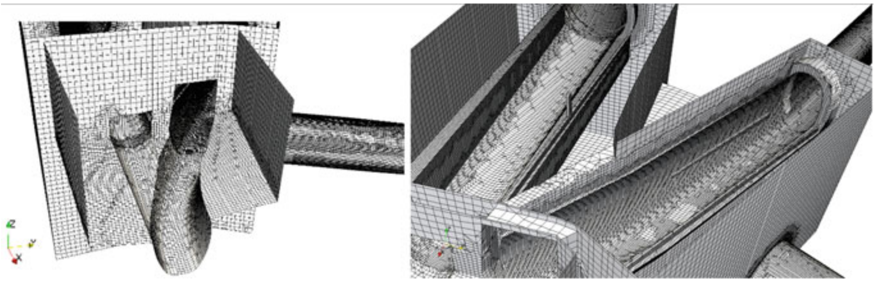

Fig. 14 Mesh of stormwater regulator—Haguenau

before the confluence with the second sewer (E2). Sewer E2, of DN1300, includes a weir on its left bank and a weir on its right bank, at two different heights. Its channel hence crosses the structure forming a bridge, before the confluence with sewer E1. Its elevation is 15 cm above that of E1. Figure 13 presents the geometry of this structure.

The model was discretized into approx. 1,000,000 cells, measuring 2–20 cm. The mesh is illustrated in Fig. 14.

The one-dimensional simulation determined that inlet E1 was subject to flows of up to 1.5 m^3/s, and inlet E2 to flows of up to 4.8 m^3/s. A 10-year rainfall scenario was analyzed in order to determine a set of 38 operating points representing the flow in the regulator.

The regulator outlet in the river Moder is set very low in the river bed. There is hence a possibility of the structure being subject to influence from downstream. However, any influence from the river on regulator weir operation can be ruled out given the large head between the channels conveying the water and the chamber invert.

An analysis of the flow in the structure revealed a highly complex operation, the water level in sewer E1 being directly influenced by the incoming flow from sewer E2. The water level in sewer E1 is always affected, irrespective of the operating mode, and the weir on the left bank of this sewer is the first to start overflowing, as shown on Fig. 15.

Overflows at all three weirs of the structure only occur during exceptional events, when flows from both inlets are high. The confluence chamber is partially submerged, and the overflow rate is high. The chamber bottom is partially filled (Fig. 16).

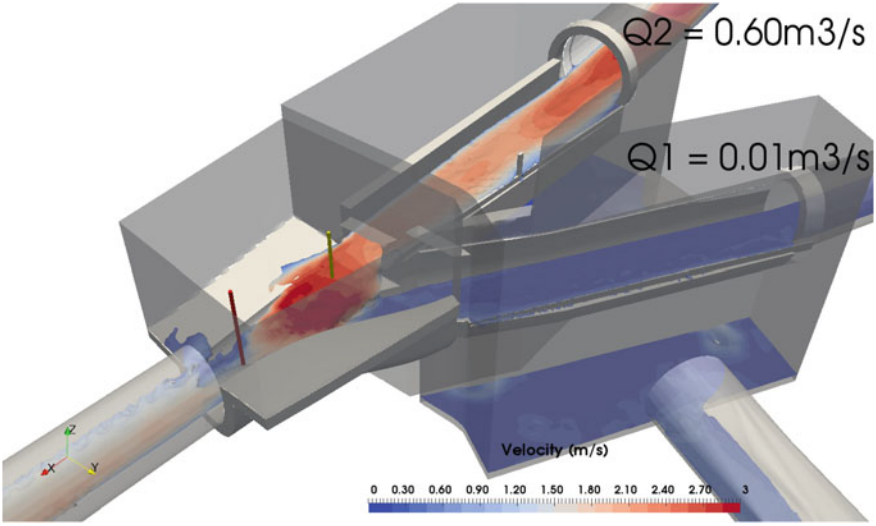

Fig. 15 Overflow at weir E1—Haguenau

The complexity and interdependence of the two sewers make it difficult to establish a discharge capacity law for the structure. Indeed, it is not possible to treat the two inlets separately and to add up the overflows at each one. The decision was hence taken to place a sensor at the confluence of the two outfalls. The position of this sensor can be seen on Fig. 16 above (the red line at the confluence). A fourth-order polynomial relation was defined in order to estimate overflows as a function of water level at this sensor. It is shown in black on the curve in Fig. 17.

The relation is well suited and accurate for the flow points with a water depth of less than 80 cm. Above this value, the flow rate can as much as double for a given water depth at the sensor. To offset this discrepancy above a 80 cm water depth, the fitting of a second sensor, also in the confluence chamber, was considered. A sixth-order polynomial relation based on water depth at this sensor enabled the previous relation to be corrected.

Figure 18 shows the location of the two sensors proposed for the Haguenau regulator (red for the main sensor, yellow for the correcting sensor). It also shows the correction made to the polynomial relation based on a single sensor. The green triangles that can be seen on the graph are the points found with the corrected relation. This correction can cause a slight bias on low flow rates, but it provides a better approximation of high flow rates. It was hence proposed that it should only be activated when the main sensor detects a water depth greater than 80 cm.

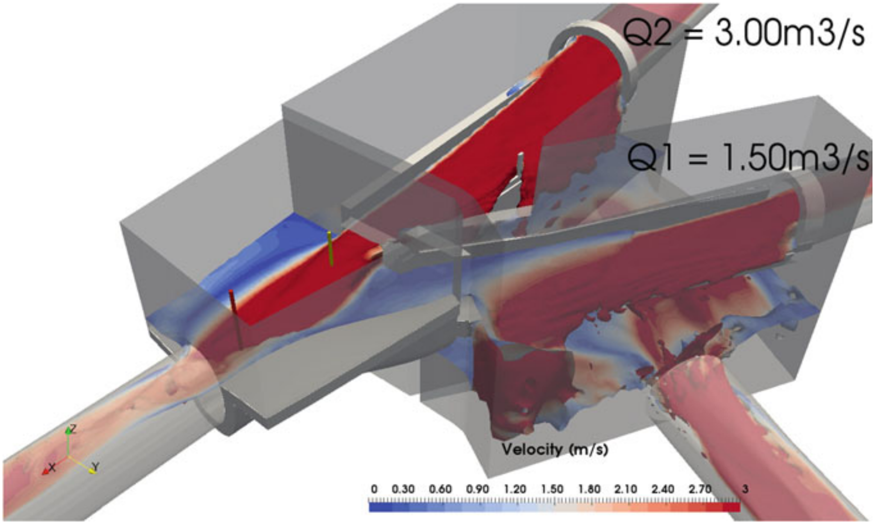

Fig. 16 Overflows at the 3 weirs—Haguenau

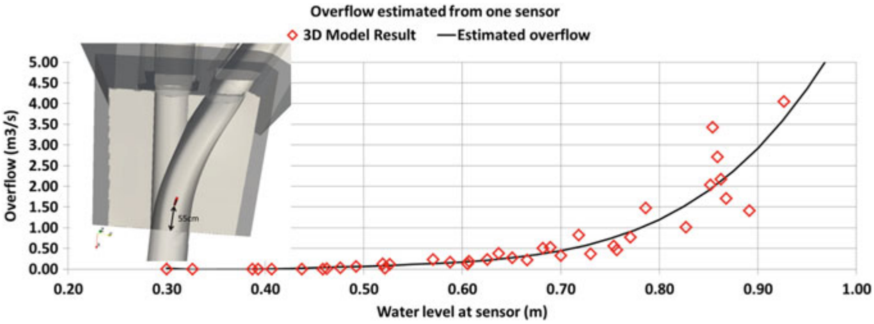

Fig. 17 Estimation of overflow from suggested sensor position—Haguenau

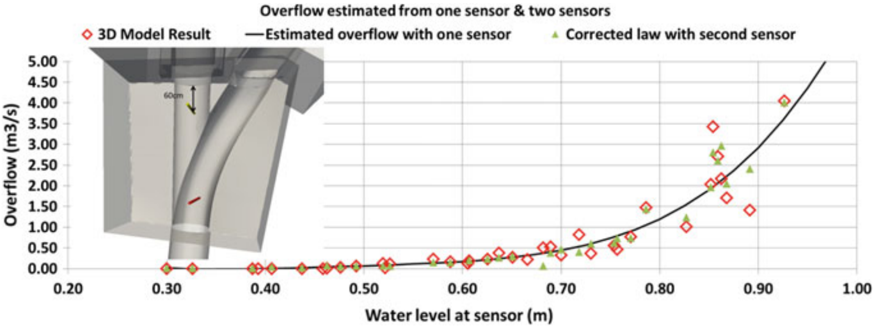

Fig. 18 Location of the two sensors and corrected estimation of overflow from two sensors—Haguenau

4 Conclusion

In France, application of the 1992 Water Act, reinforced by the ministerial circular of 6 November 2000 and the decree of 21 July 2015, requires wastewater and stormwater network operators to estimate the volumes of effluent released into the natural environment by their structures, stormwater regulators in particular. This estimate must be based on a robust discharge capacity law giving an accurate approximation of the volumes.

The two examples presented illustrate the complex nature of the problem of estimating overflow volumes at stormwater regulators. The use of a 3D model is often essential given the unique nature of each structure, combined with the fact that none of these structures was designed to be fitted with instruments. Furthermore, a given model cannot be applied to several regulators on account of the highly diverse range of architectures used.

Three-dimensional modeling, combined with an expert appraisal of surveys taken in the field and closely managed one-dimensional modeling of the network, provides a reliable, efficient solution to the need to define discharge capacity laws for these structures.

The reliability of the study methodology developed by Artelia has been confirmed through the completion of several assessments on structures with different sizes, characteristics, and layouts.

References

1. Vazquez, J., Zug, M., Phan, L., Zobrist, C. Guide technique sur le fonctionnement des déversoirs d'orag, 2006.
2. Loi n°92-3 du 3 janvier 1992 sur l'eau.
3. Circulaire DE/SDPGE/BLP du 6 novembre 2000.
4. Arrêté du 21 juillet 2015.
5. Guide pratique Mise en place de l'autosurveillance des réseaux d'assainissement, Agence de l'Eau Rhin Meuse, février 2016.