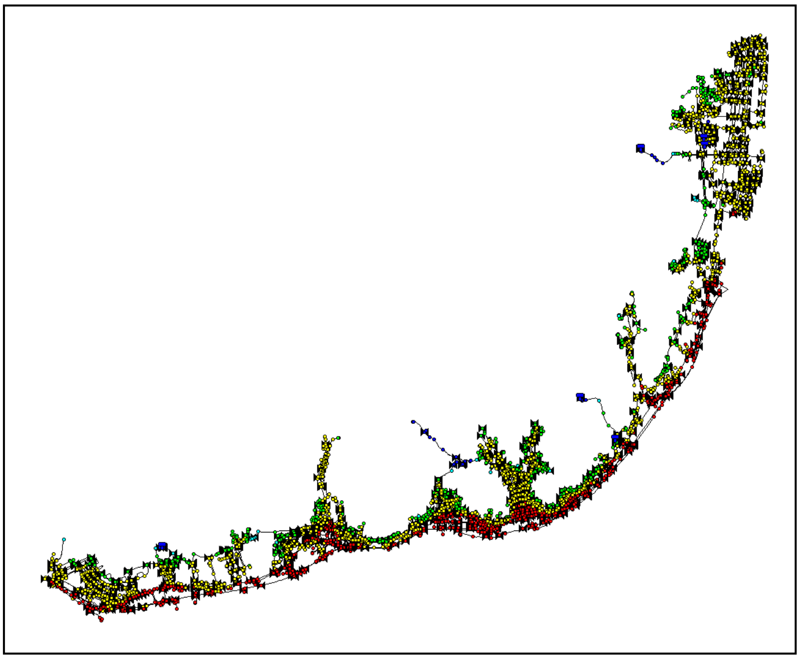
Demonstration of early warning and distributed disinfection control for water distribution network in Lisbon

Demonstration Report



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Demonstration of early warning and distributed disinfection control for water distribution network in Lisbon

Demonstration Report

SEVENTH FRAMEWORK PROGRAMME

COLOPHON

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Demonstration of early warning and distributed disinfection control for water distribution network in Lisbon - Demonstration Report

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Contents

1 INTRODUCTION

Like most utilities worldwide, the Lisbon drinking water distribution system (DWDS) utilizes chlorine residual as the last barrier against microbial hazards. Raises in temperature – mean and episodic (e.g. heat waves), as well in the waters organic matter (NOM) contents, are expected climate change consequences. Hence, climate change effects bring added difficulties to the already complex task of managing chlorine residual concentration in the Lisbon DWDS. Throughout the system, chlorine residual concentration must be kept as low as possible in order to minimize the formation of toxic disinfection by-products, but should not be below the level required for efficient disinfection. Accordingly, the Portuguese legislation recommends chlorine residual concentrations to be kept between 0.2 mg/L and 0.6 mg/L. Given the extension and complexity of the Lisbon distribution network, such conditions are not easy to manage, particularly in what concerns chlorine dosages and siting of booster stations since chlorine concentration decays as the water travels along the system.

The modelling of chlorine is an essential tool for the management of disinfectant residual in DWDS. However, the simulation of chlorine behaviour in DWDS is still complex, as it relies on the accuracy of hydraulic models to describe flows and travel times, as well as on the certainty of the used chlorine decay rate coefficients. In this context, in addition to the determination of sound decay rate coefficients, real time monitoring of hydraulic and quality parameters is of keen importance for model implementation, calibration and use (Monteiro et al.).

With respect to decay rate coefficients estimation, it was intended to apply the results produced in PREPARED Task 5.2.3 on the Influence of drinking water temperature and NOM increases on chlorine residual decay (D5.2.6). Outputs form PREPARED WPs 4.1, 4.2, 4.4, 4.5 were expected to be applied to improve hydraulic and quality monitoring and modelling.

Accordingly, in pursuing the Lisbon DWDS demonstration (Task 1.2.7) objectives, the following integrations were envisaged:

- Real-time monitoring / modelling of chlorine (WP4.4/WP4.5);
- Optimization of sensor needs and location (WP3.5);
- Data Assimilation software (WP3.6);
- Feasibility and necessity of booster chlorination stations (WP4.2/WP4.4);
- Upgrading of hydraulic/chlorine modelling by integrating end-user demands (WP4.4);
- Adjustment of chlorine decay rate coefficients to water NOM and temperature (WP5.2);
- Modelling and Control Platform and supporting software (WP4.1/WP4.2); with the overall objective of designing, implementing and demonstrating a system for real-time control of chlorine residual concentration in Lisbon DWDS.

The developed work and obtained results were presented and discussed in the PREPARED WP4.4/WP1.2 Workshop on Drinking Water Network Quality Modelling that was held in EPAL premises in Lisbon on the 4th and 5th of November 2013. The workshop was attended by Brabant Water, the Eindhoven-Demo utility (PREPARED Task 1.2.9), also related to water quality modelling and prediction, in this case in a DWDS that does not use disinfectant residual.

2 FINDINGS

2.1 The Lisbon drinking water distribution system

The Lisbon DWDS supplies a population of about 520 000. While most water is of surface origin (ca. 92%), the system also distributes a smaller fraction of underground water.

The DWDS, with an average daily demand of 170 000 m^3, comprises 1 450 km of main pipes, 11 service reservoirs with a total storage capacity of 430 000 m^3, 9 pumping stations, 4 rechlorination points and 73 000 service connections. Chlorine residual concentration is controlled within 0.2 mg/L and 0.6 mg/L. Operationally, the system is divided into 153 District Metered Areas (DMAs).

Network operation and maintenance are supported by a complete set of information systems, which include a Maintenance IS (Maximo), GIS (G-InterAqua), a SCADA system, Customer and Billing Management Systems (AquaMatrix), an EPANET-based hydraulic model with dedicated routines for processing demand and flow data, with systematic exports from the GIS records.

Free residual chlorine, pH, turbidity, water temperature and conductivity are monitored on-line by sensors mostly installed at the network entry points, in service reservoirs and pumping facilities.

2.2 Description of work

EPAL's SCADA system data and spot samples analysis, multi-parameter (temperature, pH, ORP, conductivity, turbidity, free & total chlorine) sondes (Intellitec Intellisonde 14000) were used for in-line monitoring, model development and calibration. The sensors have a daily telemetry link and are equipped with alarm functions.

EPANET 2.0 was used for hydraulic modelling and was calibrated based on 15-minute pressure and flow measurements taken at peak and average consumption days. Conductivity was used as a water-origin tracer for validation of the hydraulic model, whilst analysis of free chlorine concentrations in spot samples and assays to determine bulk decay coefficients were undertaken by EPAL's Central Laboratory. EPANET Multi-Species eXtension was used for quality parameters modelling. In addition Excel programming with INP and MSX files data input was performed for hydraulic and water quality simulations.

Preliminary work was developed using a pilot zone covering six DMAs, four of which are bi-directional transport DMAs with through flow. The total length of mains in this pilot study zone is 32.4 km, with pipe diameters ranging between 50 and 400 mm and ages from around six years (HDPE, ca. 70%) to around 35 years (cast iron, ca. 3%). Three multi-parameter sondes were used for water quality in-line monitoring.

Model development, implementation, calibration and validation followed the methodology previously implemented in the TECHNEAU project (Dias et al. 2010). Accordingly, the following steps were undertaken for developing chlorine residual decay models:

- Validation and recalibration of hydraulic model – updated versions of the study zones were developed, redistributing consumption and recalibrating the hydraulics based on the existing all-pipe hydraulic model. The resulting model flows were compared with telemetry data for the main entrance points, as well as with simulated and real pressures at one intermediate point;
- Analysis of water source mixing – conductivity data originating from the sondes was used to estimate the water origin characterisation, allowing the simulation and validation of water mixing from two sources;

- The first step of free chlorine model – bulk decay coefficients (K_b) were determined in EPAL Central laboratory;
- Chlorine model calibration and validation - determined K_b values in combination with simulations of water sources mixing and field measurements of chlorine were used to estimate wall decay coefficients (K_w), calibrate and validate models. These procedures were undertaken with water from a single origin and under source mixing conditions.

After the success of this pilot zone model, it was decided to develop a water quality model for a complete altimetric supply zone. The selected sub-system has 25 DMAs with a total length of 296 km, with pipe diameters between 25 and 1200 mm and ages ranging from around eight years (HDPE, ca. 44%) to around 63 years (cast iron, ca. 11%).

This sub-system has an average daily demand of 32 000 m^3, three service reservoirs with a total storage capacity of 83 000 m^3 (two of those ensure pressure stability in the network), two pumping stations (Olivais and Barbadinhos) and 14 400 service connections, including 200 large consumers.

This model has three key features:

• A bi-directional flow between the two pumping stations Olivais and Barbadinhos, depending of network operations, a feature similar to the pilot zone case study but with a larger dimension;

• A uni-directional flow after Barbadinhos pumping station, which can receive water form one of the sources or a mixture of those two;

• Two storage tanks to ensure pressure stability in the network (Contador-Mor and Vale Escuro).

As in the preliminary work, eight multi-parametric sondes were installed for in-line water quality monitoring. TEVA-SPOT software, from the U.S. EPA, was used to select and optimize the sonde installation locations. For this purpose, contacts were made and EPAL expressed suitability and interest in testing PREPARED “Multi-objective sensor location tool” (D3.5.2). However, the tool was not made available to EPAL during the course of the Lisbon Demo development, whilst the same applies to data assimilation software (D4.2.3).

2.3 PREPARED WP4.4/WP1.2 Workshop

In the one day and half workshop, which was attended by 25 participants from EPAL (15), LNEC (4), Brabant Water (2) and four Portuguese utilities not involved in PREPARED (4), apart from the introduction of the PREPARED framework and objectives, presentations were focused on DWDS water quality processes (chlorine behaviour, discolouration, microbial regrowth) state of the art description and modelling. The latter was the subject of Brabant Water and EPAL presentations describing their DWDS water quality modelling exercises, mainly concerning microbial regrowth (Eindhoven) and chlorine residual (Lisbon).

Following the presentations, in-depth and comprehensive discussions took place in the sessions “Theory vs. practice: issues and constraints” (1.5 h) and “Lessons from Lisbon & Eindhoven demonstration sites: discussion and wrapping up” (>>1.5 h).

2.4 Preliminary monitoring and modelling studies

Decay coefficients for the main water source were relatively low ($K_b \approx -1.01\ 10^{-2}\ h^{-1}$), which are consonant with the waters low NOM levels (DOC ≈ 1 mg L^{-1}). The approach used for calibration and validation of the hydraulic model included the use of conductivity as tracer (Figure 1).

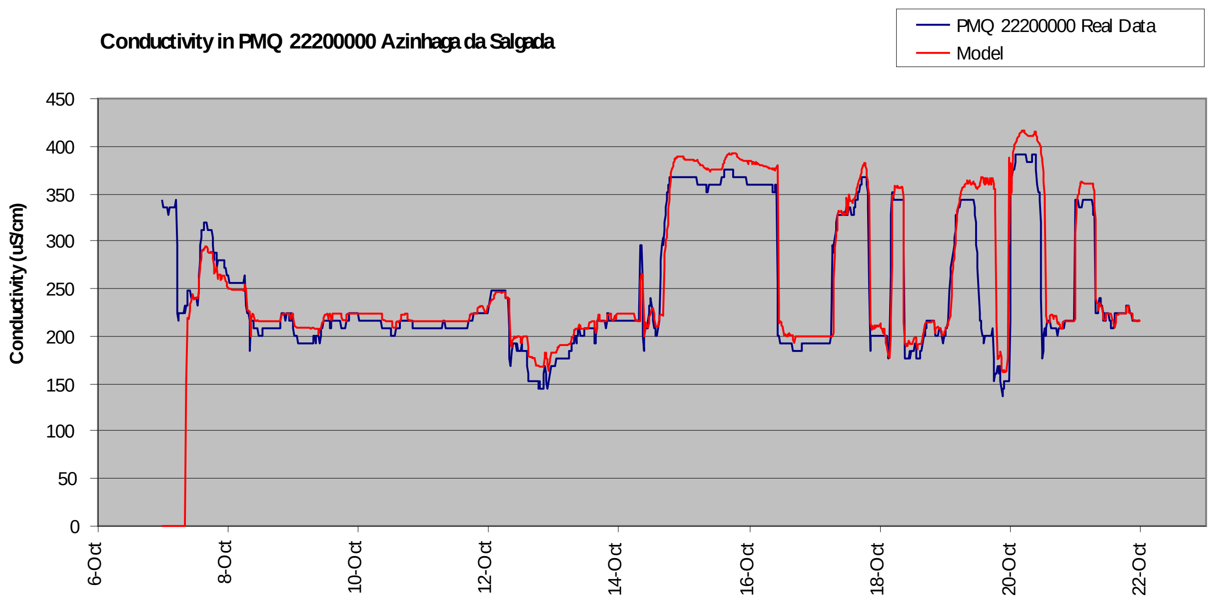

Figure 1 - Validation of the hydraulic model based on conductivity values at the intermediate water quality sonde.

By integrating K_b into the hydraulic model and calibrating K_w from the chlorine levels provided by the sondes and field measurements, a calibrated model was developed with the capability of simulating chlorine behaviour quite satisfactorily (Figure 2).

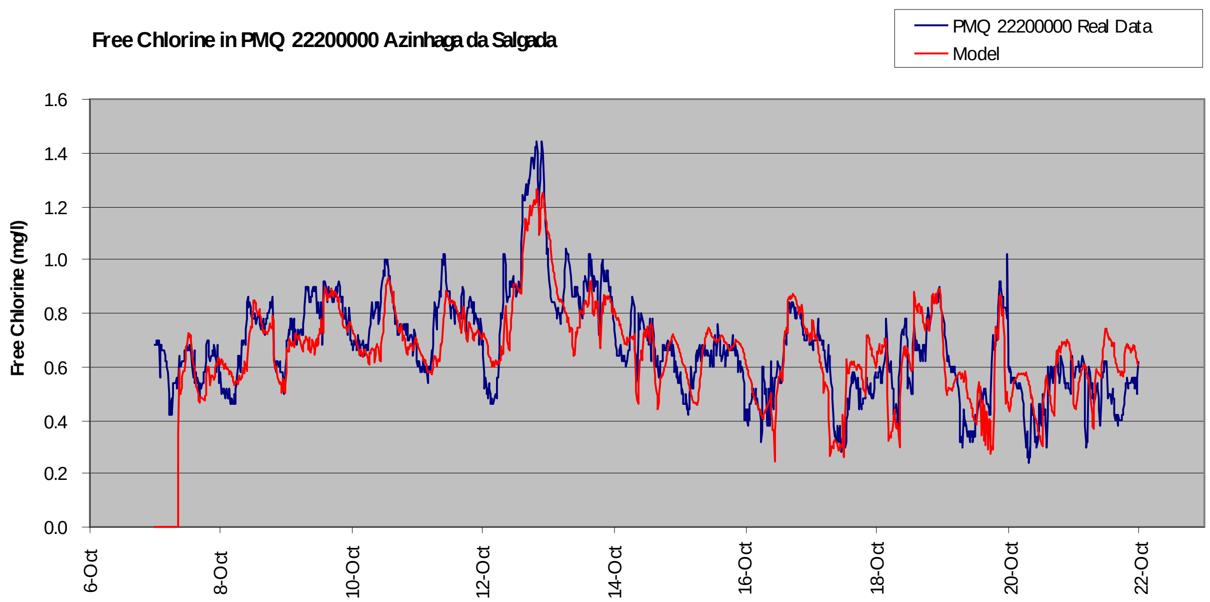

Figure 2 - Simulated and measured chlorine concentrations at the intermediate water quality sonde.

2.5 Demonstration studies

Despite being an extension of the successful preliminary studies and results being highly advantageous in terms of experience and understanding gained, the undertaking of the complete altimetric supply zone water quality model was rendered too complex, so much so that the desired objectives could not be fully materialized.
Nevertheless, the modelling exercise was useful in identifying some difficulties in both hydraulic and water quality modelling, namely those arising from:

- Even after a complete calibration with more than 900 pressure and flow patterns, there are limitations of EPANET 2 to model DWDS hydraulics in large and complex networks – particularly in network extremes;
- Highly demanding expertise and labour required, along with difficulties in calibrating and maintaining the eight water quality sondes installed, whilst working correctly during the time required to calibrate and validate the water quality model;
- Challenges in estimating actual chlorine decay coefficients as an input for EPANET Multi-Species eXtension MSX files for water with varying proportions of different origins, as driven by mixing in DWDS.

Results for the PREPARED Task 5.2.3 regarding the influence of water temperature and NOM increases on chlorine residual decay (D5.2.6) were not delivered in time to be integrated in the Lisbon Demo. However, these clearly suggest that the difficulties described above in the chlorine residual modelling will be inflated under the ongoing and forecasted climate changes, namely those related to mean and episodically increases in DWDS water temperature and NOM (Grobe et al. 2013).

2.6 PREPARED WP4.4/WP1.2 Workshop

In addition to corroborating the modelling difficulties described above, the workshop emphasised the usefulness and need for hydraulic models to support sizing, design and operation of drinking water networks, particularly in respect to the objective of shortening water travel distances and times. The use of hydraulic models incorporating water demand patterns at network extreme zones was recognized as fundamental in order to support simulation of water quality parameters. Likewise, it was acknowledged that the algorithms required for determining and describing many DWDS water quality processes are often impracticable owing to the excessively large number of variables involved. As was demonstrated by the KWR presentation on the modelling of microbial regrowth as a function of the water temperature, more suitable and confident results are achievable through simple and expedite formulations.

3 CONCLUSIONS AND RECOMMENDATIONS

3.1 Conclusions

The Lisbon DEMO work, which was entirely developed by EPAL technical staff, matched the company's own objectives, namely to:

- Update and improve modelling of DWDS hydraulics and water quality;
- Improve water quality monitoring in the distribution network;
- Deepen understanding of water quality dynamics in the DWDS;
- Support planning of chlorine booster stations needs and siting.

Despite the limitations in developing and implementing the PREPARED Task 1.2.7 "Demonstration of early warning and control distributed disinfection distribution network in Lisbon", EPAL has unquestionably become better prepared to manage Lisbon DWDS water quality, particularly under the impacts of ongoing and forecasted climate changes.
In this respect, the DEMO exercise, difficulties encountered and the workshop allowed for conclusions to be drawn that are of great benefit to the utility, particularly with regard to modelling and water quality management in its DWDS.

Given the importance of the lessons they provide, the following conclusions should be highlighted:

- The calibration of supporting hydraulic model is crucial for successful DWDS quality modelling;
- When different water sources are supplied into DWDS, the analysis of water quality parameters, such as conductivity, may provide useful tracers to measure water make-up and travel times for hydraulic model validation;
- Likewise, water quality monitoring (e.g. chlorine) should provide useful data for water quality model calibration and validation, as well as for virtual sensor design and integration, and further application of the developed model to the management of DWDS water quality;
- However, the implementation, operation and maintenance of a system for real-time multi-parameter monitoring, such as the one tested in this Demo, is a highly complex task mainly owing to:
    a) Limited number of DWDS sites suitable for sonde installation, due to restrictions on physical access and conditions and theft/accidental damage protection;
    b) Expertise and labour availability time requirements are far beyond modelling teams day to day work, particularly for maintenance, calibration and verification of measurements delivered/transmitted by the sondes over long time periods;
    c) In addition to those required for monitoring, a number of spare sondes and sensors in good functioning conditions are needed for replacements – such as the batteries for multi-parametric sondes whilst telemetry data transmission is also a complex system, susceptible to a number of fault types.

3.2 Recomendations

In addition to appropriate protection and management of water sources, adequate treatment, proper DWDS operation and maintenance, reduction of water travel and residence times and preventing low flow situations are crucial to counteract degradation of water in DWDS.

For these aims, smart network design and operation supported by rigorous modelling of DWDS hydraulics and water quality are fundamental. In this respect, the workshop identified some constraints which deserve particular consideration, hence, taking into account the lessons learned from developing the Lisbon Demo and the need to tackle climate change impacts, the following main recommendations should be developed:

- Conventional models for DWDS hydraulic simulation do not, generally, allow the modelling of water flows in many peripheral networks zones, where most often low flow situations occur. For this purpose, hydraulic models that incorporate consumer demand patterns (Blokker et al. 2006) should be integrated in the modelling;
- Systems for real-time monitoring of DWDS hydraulic and quality parameters are useful tools to feed hydraulic and water quality models and support the network operation, as well as contributing to early-warning systems. However, mostly owing to their complexity and vulnerability, it should be taken into account that in practice their implementation, maintenance and operation are exceedingly demanding in terms of equipment, expertise and labour;
- Over-sizing is a common cause of extended water travel and residence times and low flow in DWDS. Whilst such situations are not manageable in most constructed systems, smart DWDS design and scaling should be implemented in new systems, as well as in those undergoing rehabilitation. Countries such as Portugal, where this goal is restrained by "outdated" legal obligations to meet firefighting demands, should consider the revision of the pertinent legislation;
- Owing to the influence of DWDS water temperature (Monteiro et al. 2012) and NOM (Grobe et al. 2013) effects on the decay of disinfectant residuals, in order to improve modelling certainty chlorine decay coefficients need to be estimated for the range of temperatures occurring and each time changes in water quality may occur, due to changes or limitations in the treatment processes, changes in water source quality after extreme rain events or algal blooming in catchments, for example.

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