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# Water Distribution Network Model Calibration and Continuous Maintenance: Terrassa, A Real Application

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**Abstract:** The WDN model calibration has been and it still is a research area of interest [1]. This process has been well studied and the different steps required were already established. The availability of more and more data encourages the idea of applying these methodologies since the more the state of the system is known the better the estimations will be. Nevertheless, the application of all the academic proposals and experiences in real networks involve some major handicaps. First of all, the data validation and reconstruction before using them for the model calibration and for the model use afterwards. There are some automatic tools for calibration but they focus on the last step of the process when the parameters have to be tuned. Some previous steps that require an ad hoc solution. These issues represent a gap between academia and real practice. This paper presents a successful experience carried out with the collaboration of the municipal water company of Terrassa (TAIGUA) with a research group located in the same city with a long experience in water research. The objective of the project is to improve the existing models, establish their potentials and propose strategies for their final adjustment. The results are different depending on the availability of data. The district metered areas (DMA) presented have different characteristics and are representative of interesting situations for other practitioners. The models that result will allow a better management of the network including energy optimization, leak detection and localization and quality supervision.

**Key words:** WDN, calibration, simulation

## 1. Introduction

The understanding of industrial plants requires the use of models by engineers and operators. When the system is as complex as a water distribution network (WDN) these models become huge, in terms of number of variables and parameters, and complex. Since the second part of the last century WDN have been modelled using simplified equations [2]. Each equation can be parametrized by lab experiments but such a practice is unrealistic regarding thousands of them. Furthermore, the information is automatically translated from GIS to modelling software and such a process can introduce errors. The reliability of any information generated by these models will depend on how well adjusted it is to the real behaviour of the network.

It may seem a contradiction that WDN model calibration is still a research area of interest though this process has been well studied and the different steps required were already established [3]. The availability of more and more data encourages the application of these methodologies [4] in order to get better estimations of the state of the network. These data are seldom used straightforwardly or they shouldn't be. They require validation, reconstruction. Furthermore, the academic proposals and experiences in real networks require ad-hoc adjustments. There are some automatic tools for calibration but they focus on the last step of the process when the parameters have to be tuned. Some previous steps that require an ad hoc solution. These issues represent a gap between academia and real practice.

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This paper presents a successful experience carried out with the collaboration of the municipal water company of Terrassa (TAIGUA) with a research group located in the same city with a long experience in water research [5]. The objective of the project is to improve the existing models, establish their potentials and propose strategies for their final adjustment. The results are different depending on the availability of data. The district metered areas (DMA) presented have different characteristics and are representative of interesting situations for other practitioners. The models that result will allow a better management of the network including energy optimization, leak detection and localization and quality supervision. In the next section the problem statement is presented including the objectives of the work. In section 3 the methodology applied to the network is described and analyzed step by step. A pressure floor is selected in order to illustrate the methodology; it is described in section 4. The results obtained for this example are presented in section 5. Finally, the conclusions and future work are discussed.

## 2. Problem Statement

According to Ormsbee and Lingireddy [3], the process of calibrating a water network model can be divided into seven steps: identify intended use of the model, determine initial estimates of the model parameters, collect calibration data, evaluate the model results, perform the macro level calibration, perform the sensitivity analysis and perform the microlevel calibration. Existing models were analyzed in the light of this work.

Regarding the intended use of the models, three model use types were identified in TAIGUA. In all of them the modelled physical behaviour is required to be valid. The differences arise in the precision of the demand model. A type one model is one that suffices for planning purposes within a ten year horizon. A type two model is more precise in the demand model and can be used to make predictions in peak days that may arise in the short term. A type three model is the most precise regarding the demands of the nodes. Its precision requirements need telemeter measurements to be fed constantly. This model would allow leakage detection. According to this characterization, existing models were focused on a model of type one or two.

The initial estimates of the model parameters of the network model were generated using GIS (Geographic Information System) data and the base demands in the demand model was based on billing data.

The data collected for calibration were obtained from both the tank flow meters and the ones that establish hydraulic boundaries within a sector of the distribution network. Also tank water level and pressure gauge measurements were collected. Typically flow and tank level measurements were being collected as part of normal operations. Less typical is the availability of pressure measurements. If needed they are obtained from calibration campaigns.

A simulation was performed followed by an evaluation of the model results which was performed quantitatively comparing the model predicted and field collected measurements.

The model then underwent a micro calibration phase which yielded poor results. These poor results could be due to the lack of a complete macro level calibration step.

In this work, this macro level calibration process will be described and illustrated.

## 3. Methodology

After the data collection phase is finished, data is tested for time completeness to establish the existence of a sufficiently large time range for calibration. Interruptions in the data flow due to temporal malfunctioning of telemetry equipment or other causes are not rare.

The availability of data from all the flowmeter sensors that establish DMA (District Metered Area) boundaries is especially important since a mass balance calculation allows to know the demand of the set of nodes within the boundary. This demand can be imposed on the model by reassigning the demand curve on each node respecting the weight given by its base demand parameter. In case of lack of data from any such boundary flowmeters, DMA boundaries in the model should be rearranged.

The qualitative evaluation of the previously computed demand within a subsector can reveal sensor malfunctioning, for example, if this demand yields a negative value.

Additionally, the availability of data from all the sensors that constitute a boundary condition of the model, such as tank level sensors is important. Given all the boundary conditions and the real demand imposed on the model, a simulation can be performed and its results compared to measured values.

The first qualitative assessment of the results of the simulation can be comparing the imposed mass balance in each DMA with the one obtained in the simulation. Since the result has to be exactly the same, any difference may be revealing the existence of valves that are not closed in the model but are closed in the real network or an incorrect network geometry or a badly established boundary.

A quantitative evaluation of the differences can then be performed. In the case of pressures, differences above 30% are considered to be excessive and can be caused, for example, by inaccurate tank telemetry or incorrect pressure zone boundaries. Differences above 30% in flows can be explained by causes similar to the ones mentioned when comparing mass balances.

Correcting all of the previous causes would complete the macro level calibration phase. One could then perform a second simulation and give the calibration results in a more normalized way to conclude the phase with a quantitative evaluation of the differences to decide if a micro level calibration is necessary. In industry, the validation criteria are often taken from commercial packages that have become standards to compare with other members in the community. The companies taking into account not only the academic results but also the experience of the end-users have developed these criteria. In this work the criteria proposed by Bentley [6] have been used. They are clearly formulated in Table 1 and Table 2. Regarding flow, one has to distinguish between primary pipes, which have flow over 10% of the total demand, and secondary pipes, which have flow less or equal than 10% of the total demand. For primary pipes an acceptable calibration level is ±5% difference between simulated and measured flow. For secondary pipes, this difference is allowed to be ±10%. Regarding pressure, 85% of the measurements have to lie within the less stringent among the following criteria: ±5 m or ±5% of the maximum head loss throughout the system; 95% of them within ±0.75 m or ±7.5% and 100% within ±2 m or ±15%.

## 4. Case Study

Terrassa's WDN is divided into eight pressure floors, which eases its management. The pressure variations within these floors are reasonable and they can be supplied mainly by gravity from the tanks. The hydraulic models are built following this structure. Thus, the company generated eight hydraulic models. This allows the analysis of each pressure floor. Furthermore, depending on the size and instrumentation, each pressure floor is divided in DMA. Such sectorisation eases the monitoring of the supplied and consumed water in order to evaluate the performance of the system.

**Table 1 Flow criteria for the model.**

| ***Flow criteria*** | | |
|---|---|---|
| *Main pipes* | Flow > 10% total demand | error < ±5% |
| *Secondary pipes* | Flow ≤ 10% total demand | error < ±10% |

**Table 2 Pressure criteria.**

| ***Pressure criteria*** | |
|---|---|
| *85% of the measurements* | error < ±0.5 m or error < ±5% maximum head loss |
| *95% of the measurements* | error < ±0.75m or error < ±7.5% maximum head loss |
| *100% of the measurements* | error < ±2.0m or error < ±15% maximum head loss |

We have chosen a pressure floor for illustrating the methodology. It is called Sulleva (S0200). It has four DMA (S021, S022, S023 and S024). The flows between two DMA are monitored. Water comes from a tank whose level is also monitored. There is a pressure sensor installed in Sulleva. Finally, a calibration campaign was carried out in 2019 recording the pressure with four data loggers installed in one hydrant for each DMA during a day. This day was the one chosen for the calibration of the model as the pressure could be validated.

Fig. 1 presents the hydraulic model of Sulleva pressure floor. The water source is the reservoir signalled with a square. The boundaries of the four DMA's are signalled by the flowmeters and valves signalled by triangles. Finally, the pressure sensors are signalled by a circle.

## 5. Results

The data are checked and it is confirmed that there is a complete set of data for the day in which the pressure data logger registered the pressure in this pressure floor. Thus, the curves for the demands in each DMA and the boundary conditions (head of the reservoir) can be generated and introduced in the model as patterns (Fig. 2 and Fig. 3).

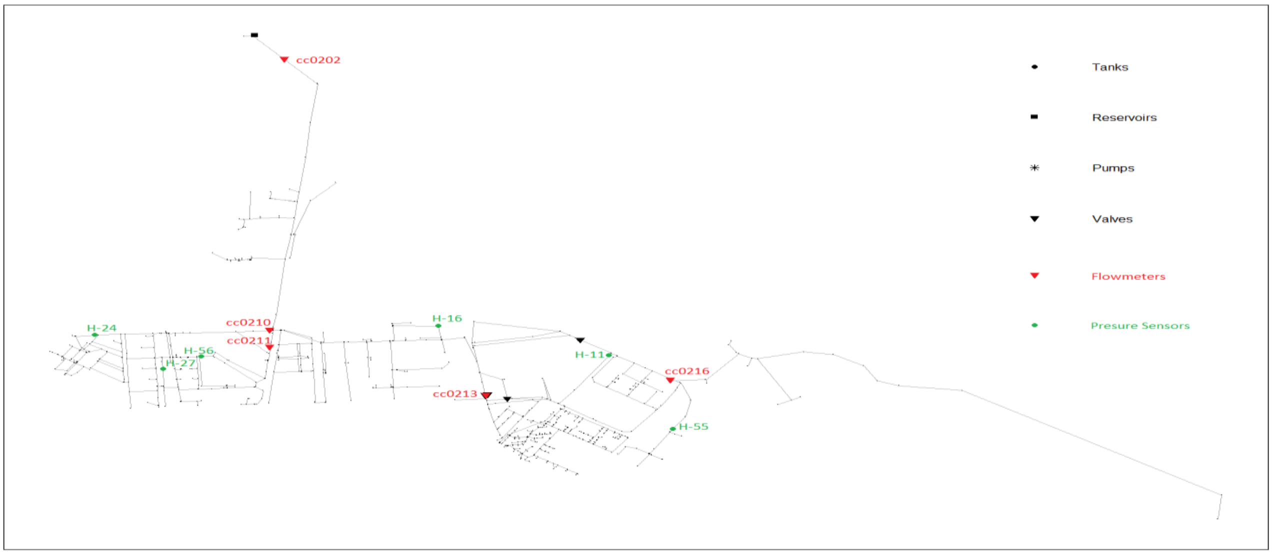


**Fig. 1 Hydraulic model of Sulleva pressure floor.**

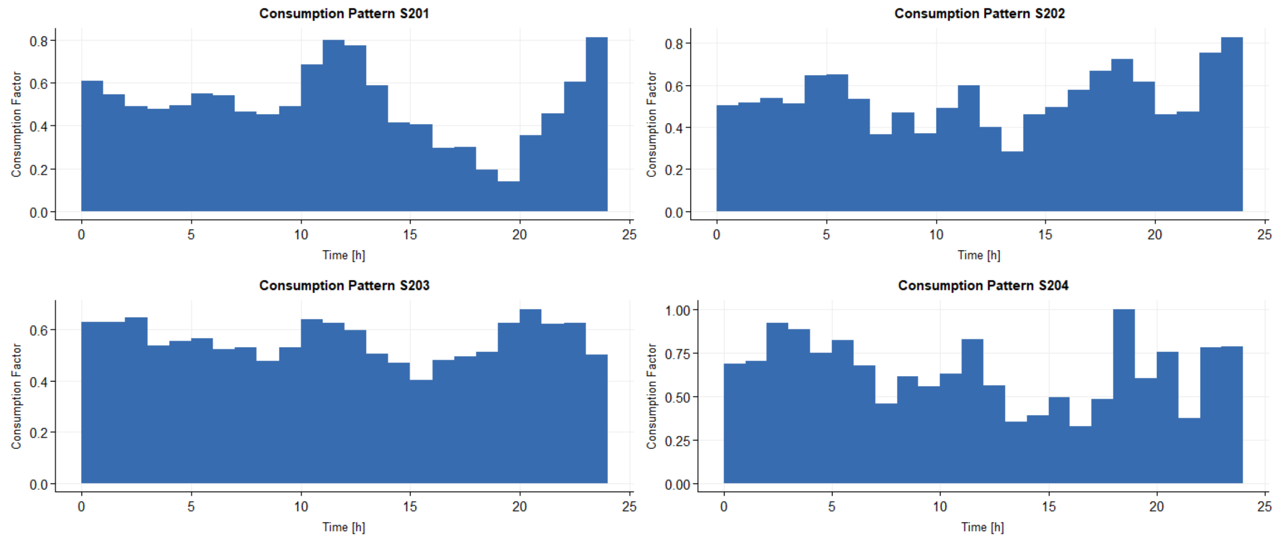


**Fig. 2 Demand curves for the four DMA.**

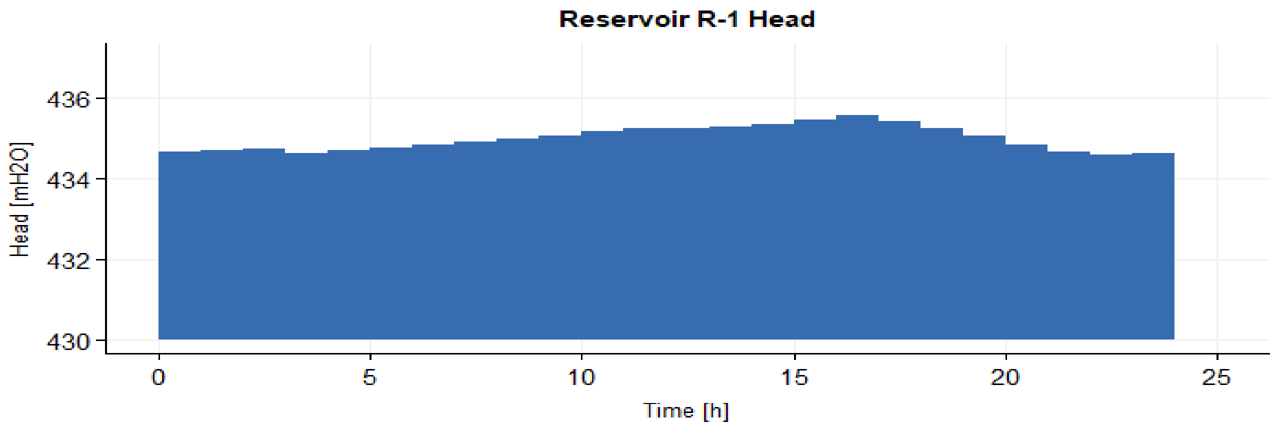


**Fig. 3 Head curve for the reservoir.**

The flows predicted by the model allowed, first of all, to validate that DMA were well defined through the mass balance analysis presented in Fig. 4. The comparison of flows and pressures are presented in Fig. 5 and Fig. 6.

With the results obtained the validation criteria presented in section 3 are evaluated. They are all fulfilled or, in two cases, slightly violated. This evaluation is presented in Table 3 and Table 4.

## 6. Conclusion

The methodology proposed in this paper deals with the sources of major disajudments between prediction and measurements in the network. This phase provides models type 1 and type 2 and it is mandatory to carry out further calibration in order to obtain models type 3. It has been applied to three of the eighth pressure floors of the WDN in Terrassa. The use of available measurements as tank levels and inflows allowed a better adjustment of the predictions while highlighting some inconsistencies in the available data. Thus, one outcome is the detection of faulty sensors. Another improvement in the models has been the detection and updating of valve status.

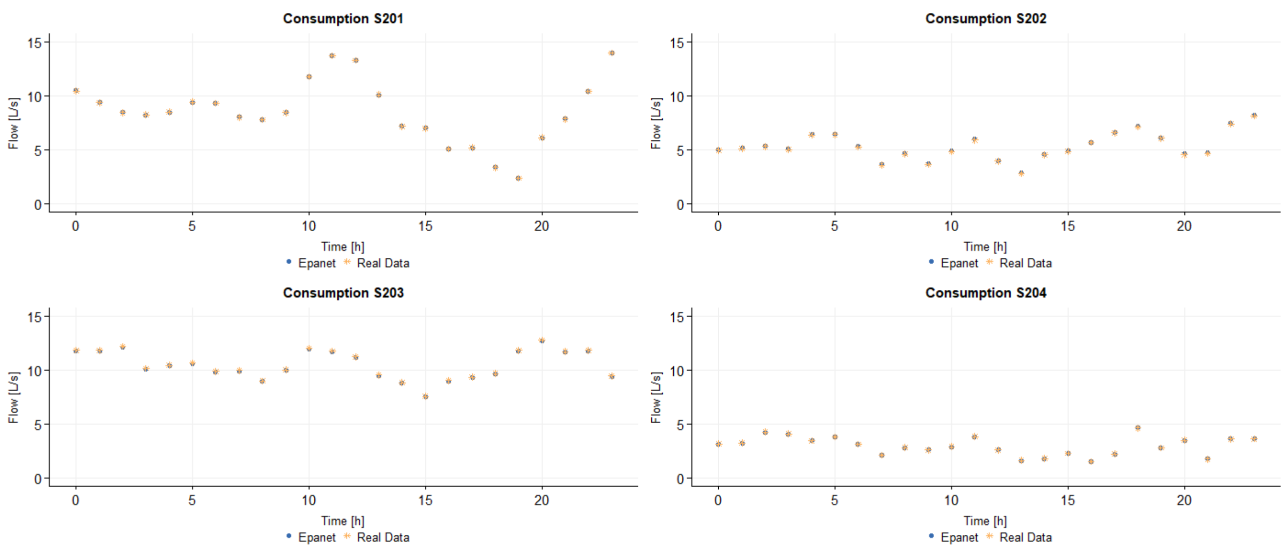


**Fig. 4 Measured mass balance of the DMA's compared with the predicted mass balance.**

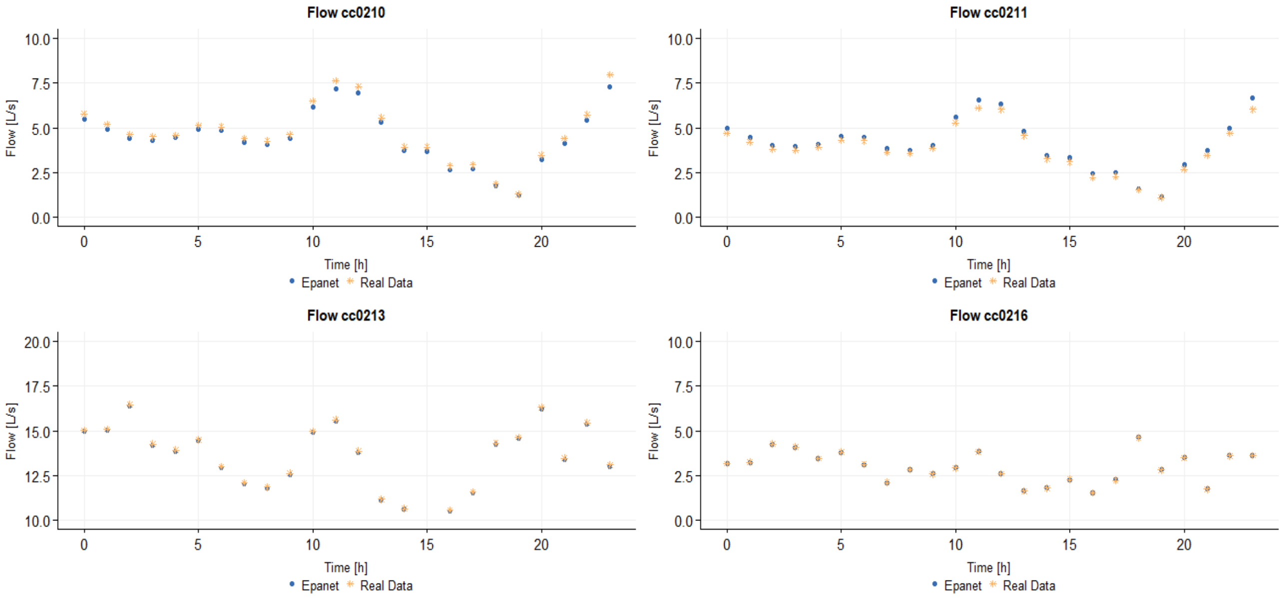


**Fig. 5** Measured flows compared with the predicted flows.

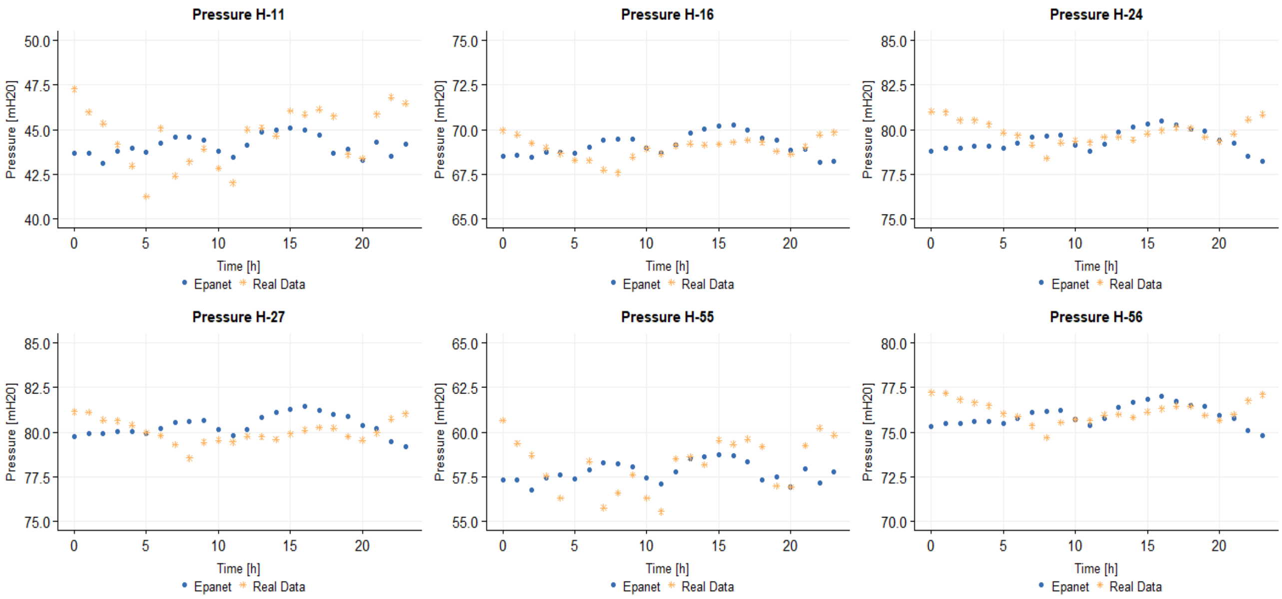


**Fig. 6** Measured pressures compared with the predicted pressures.

**Table 3** Evaluation of the flow criteria.

| Flowmeter | Daily total Volume [$m^3$] | % of Total Demand | Type | Criterium error < 5% |
|---|---|---|---|---|
| cc0202 | 2366.2 | 100 | Main The first | 0.03% |
| cc0210 | 408.5 | 17.3 | main | 5.1% |
| cc0211 | 331.9 | 14.03 | main | 6.4% |
| cc0213 | 1167.4 | 49.3 | main | 0.49% |
| cc0214 | 256.6 | 10.8 | main | 0.0% |

**Table 4 Evaluation of the pressure criteria.**

| Pressure sensor | 85% | | 95% | | 100% | |
|---|---|---|---|---|---|---|
| | Error < 2 m | Error < 0.5 m | Error < 3.1 m | Error < 0.75 m | Error < 6.2 m | Error < 2 m |
| H11 | 100 | 100 | 100 | 100 | 100 | 100 |
| H16 | 100 | 100 | 100 | 100 | 100 | 100 |
| H24 | 100 | 100 | 100 | 100 | 100 | 100 |
| H27 | 100 | 100 | 100 | 100 | 100 | 100 |
| H55 | 100 | 100 | 100 | 100 | 100 | 100 |
| H57 | 100 | 100 | 100 | 100 | 100 | 100 |
| Sardana | 100 | 0 | 100 | 0 | 100 | 100 |
| Global | 100 | 86 | 100 | 86 | 100 | 100 |

The results presented in this paper for Sulleva illustrate how reliable a model can be when data are available. Once the model is validated with the field data of the calibration campaign a model of type 1 and type 2 is provided using historical data. In order to obtain a type 3 model microcalibration process will be carried out in future. This microcalibration process requires new pressure or flow measuremtns within the DMA as the objective is to include different patterns in the same DMA. In this pressure floor this process does not seem as necessary as in some DMA's of the other pressure floors.

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