Multiparameter Measurements for Network Monitoring and Leak Localising

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Abstract
Leakage monitoring in large zones of water distribution networks is a huge challenge. One possibility for network monitoring in large zones is measuring at selected points. This can be done with systems which only use flow measurements or with combined measurements of the flow, pressure and noise parameters (multiparameter measurements).

This paper describes the principles of multiparameter measurements for the purpose of network monitoring and leak localising in water distribution systems and gives an example for possible data interpretation of such measurements. In the second part of the paper the results from a field study in the city of Röthis in Austria are described, where a network monitoring system is installed on the basis of mulitparameter measurements.

Principles of multiparameter measurements
Multiparameter measurements used for physical water loss management are combined measurements of more than one of the following parameters at selected points in water distribution networks:

- flow (bidirectional)
- pressure
- noise
- temperature

It is possible to combine two of these parameters, e.g. flow and pressure or flow and noise, but combinations of all three parameters are of advantage. There are sensors available containing all these parameters, but it is also possible to use single instruments for measuring the parameters separately.

Water lost at leaks causes an increase in system input, but also the hydraulic conditions (flow, pressure) within the distribution network may change. Practical experience has shown that variations in flow and pressure due to leakage or other abstractions can be tracked over large ranges of the distribution network, especially during times of low consumption (note: the size of this “detection” range depends on the leak rate and the hydraulic sensitivity of the distribution network). Therefore, flow measurements within the distribution network provide an indication for the area of the leak position. It is possible to create “virtual” measuring zones within the distribution network (Figure 1). Virtual measuring zones are parts of the distribution network which are not physically separated from the rest of the distribution network or from the rest of a district metered area (DMA). In these virtual measuring zones variations of the hydraulic conditions or other parameters (noise) can be detected by surrounding measuring points.

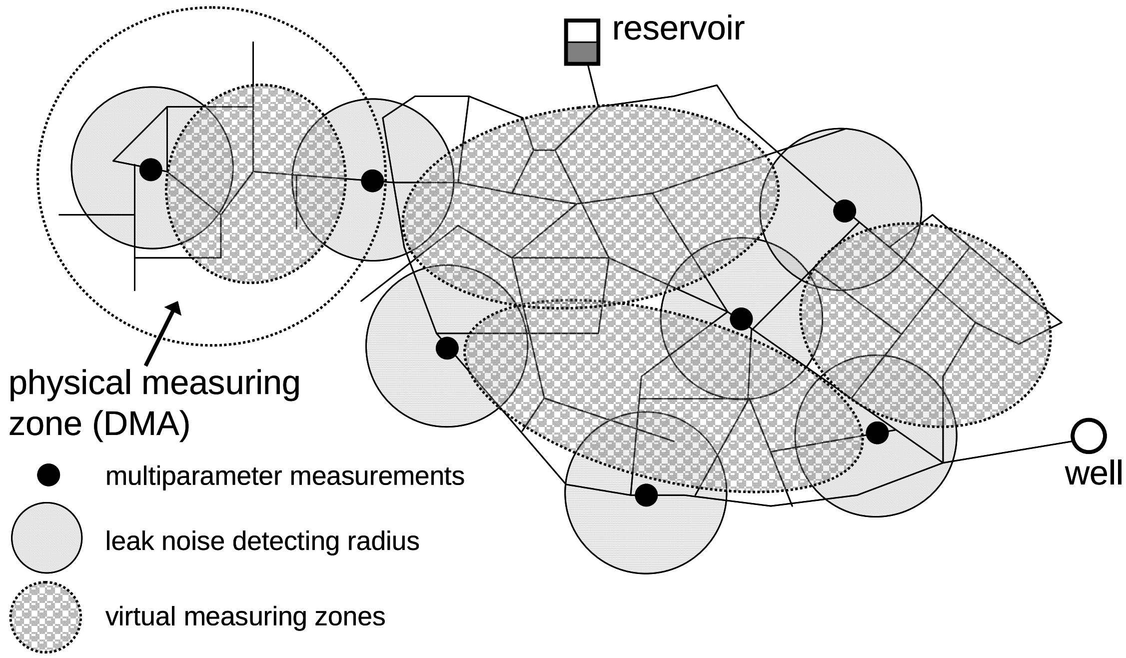

Figure 1: Schematic diagram of virtual and physical measuring zones (Koelbl 2009)

Due to additional measurements of (leak) noise, further information about the location of the leak can be obtained. In general, radii of single noise measurements overlap each other do not overlap each other, depending on the spatial density of multiparameter measurement points. However, if one or more noise recorders detect a leak noise signal, a direct indication of the leak location is provided. If none of the measuring points detects a leak noise signal, the area of leak location can be narrowed down indirectly since the existence of a leak can be ruled out in a determined area around each measuring point (depending on the boundary conditions: pipe material, pipe diameter, soil etc.).

Flow measurements

The following types of flow meters are preferably used for continuous flow measurements at measuring points within the distribution network:

- magnetic inductive flow meters of full-bore type
- magnetic inductive flow meters of insert type
- ultrasonic flow meters

The disadvantage of magnetic inductive flow meters of the full-bore type and, in general, also of ultrasonic flow meters, is that these types can only be installed in common shafts or measuring chambers, whereas magnetic inductive flow meters of the insert type can also be installed in cost-saving special shafts (Figure 2).

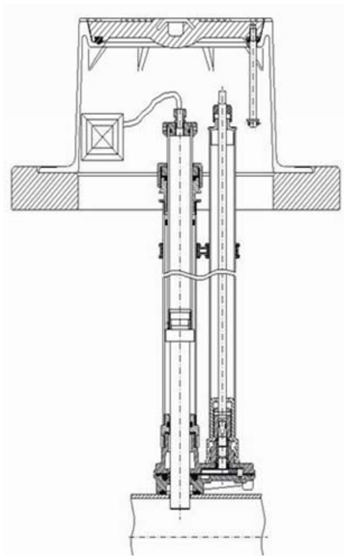

Figure 2: Cost saving special shaft (example)

Noise measurements

Noise recorders can be situated on the outside of pipes, on fittings or directly in the water medium. Noise measurements in the water medium can increase the "detection" radius since the sound propagation within the water might be better than in the pipe wall, especially in plastic pipes.

Continuous noise loggings over the whole day have the advantage that leaks may be detected more easily than with noise measurements only during the night hours. This is due to the typical noise development of leaks. Usually the most intensive noise appears when the leak occurs and at the “breakthrough” of the leak. After a certain time the hollow space within the ground around the leak is filled with water and then the leak noise decreases. Therefore, the likelihood of detecting a leak noise is much higher using a continuous noise recording (Figure 3).

Positioning of multiparameter measurements

An adequate spatial density of measurement points is necessary for significant multiparameter measurements. The positioning of the multiparameter measurements is carried out on basis of hydraulically aspects. As mentioned above, these measurements can be used in non-divided networks or large measurement zones, as well as in DMAs.

The single measurement points should be equipped with data loggers and should be connected to a SCADA (Supervisory Control and Data Acquisition) system.

Interpretation of multiparameter measurements

Multiparameter measurements provide information about hydraulic and/or acoustic variations in water distribution systems due to leakage and changed positions of closing valves or abstractions of hydrants (Sax & Schreitmüller 2007).

In general, the interpretation of multiparameter measurement data should be carried out by comparing actual data with previous data from comparable hydraulic conditions. Figure 3 gives an example of how to interpret such measurements.

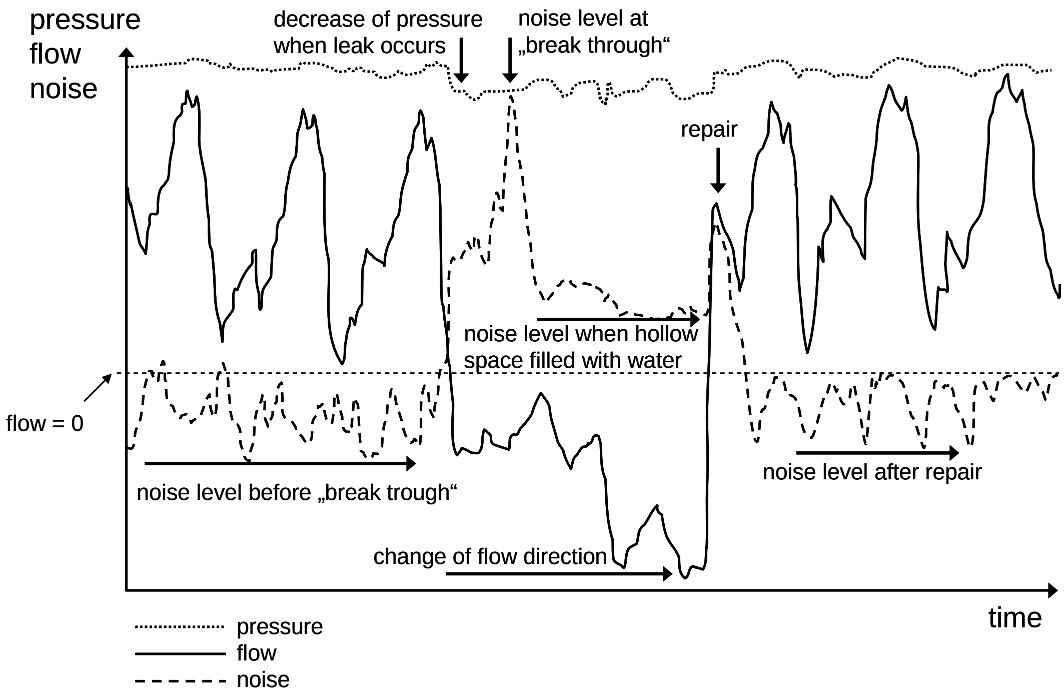

Figure 3: Example of multiparameter measurements (schematic diagram), (Koelbl 2009)

Field Study in Röthis

The Röthis water supply system is about 20 km long and is entirely composed of metallic pipes (steel or ductile iron). Two natural springs (Bachtobel spring and Tuggstein spring) are used as sources and there are three storage tanks (HB Bild, HB Sulz and HB Vorderland / Röthis) within the system.

In the Röthis water distribution system a multiparameter system of the WLM-SYSTEM type (MWM – Martinek Water Management GmbH) is installed. Each of the WLM sensors measures parallel flow (inductive flow measurement within the medium water), pressure and noise (piezoelectric-polymer sensor). The four WLM sensors are situated in the central part of the network near the HB Vorderland / Röthis reservoir (see Figure 4):

MS 1	Könighofweg	MS 3	Räterweg
MS 2	Torkel	MS 4	Römerweg

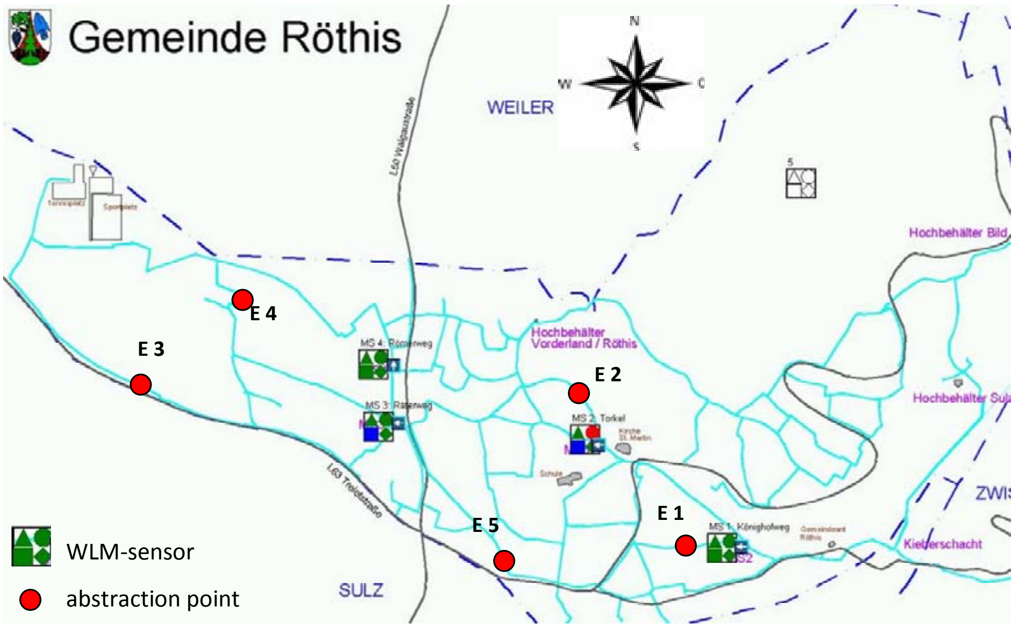

Figure 4: Overview of Röthis water distribution system

The principle of the WLM-SYSTEM is a comparison of reference values for flow, pressure and noise, which are defined when the system is installed, with current measurements. Deviations from the reference values can indicate leakage. After successful leak detection and repair, the new reference values are automatically adjusted by the system. The AQUALYS software automatically selects those sensors where the tolerance levels are exceeded.

Usually the WLM sensors are active during the night hours when the water consumption is low. The different parameters are measured over duration of 30 min. and analysed afterwards with the integrated software. The data are transferred via GSM to a computer. It is also possible to access the sensor directly for the generation of important hydraulic data.

Measurement setup

In addition to the WLM sensors installed at the MS 1 Könighofweg measurement point, a mobile ultrasonic flow meter and sensors for noise measurement were installed (Figure 5). The noise measurements were logged on a computer.

Different volumes were abstracted from following abstraction points during the five tests (see Figure 4):

E 1	*Salzacker (about 120 m from MS 1)*
E 2	Torkelweg (about 150 m from MS 2 and 600 m from MS 1)
E 3	Treiestraße (about 650 m from MS 3)
E 4	Alte Landstraße (about 700 m from MS 3 and MS 4)
E 5	*Rautenastraße (about 600 m from MS 1 and 600 m from MS3)*

In the following, the tests with abstractions at E 1 (Salzacker) and at E 5 (Rautenastraße) are described in detail because the results of these two tests are also representative for the other tests.

Figure 5: Ultrasonic flow measurement, WLM-sensor and noise sensors in MS 1

Figure 6: Abstraction E 1 at Salzacker

Test 1, Abstraction at Salzacker (E 1)

The abstraction point at Salzacker is only about 120 m away from the MS 1 measurement point at Könighofweg. Therefore measureable noise signals from the WLM sensor and the additional noise loggers on the outside pipe wall in MS 1 were expected. The abstraction was carried out using a hydrant and the abstracted volume of water was controlled by means of a flow meter (Figure 6).

Figure 7 shows the parameters detected by the WLM sensor in MS 1 during the abstraction (red = pressure, blue = flow, green = noise). It can be seen that the leak noise increases or decreases in relation to the abstraction volume. After some variations in the abstraction volume at the beginning, an almost constant abstraction of 0.7 l/s was implemented. The leak noise produced was clearly detected by the WLM sensor and also by the alternative measurements. The lower noise level at an abstraction of 0.2 l/s and the peak in the noise curve when closing the hydrant are also readily identifiable in the graph. The reaction of the flow measurement in MS 1 at different abstraction volumes is significantly noticeable in the left section (at the beginning of the measurements).

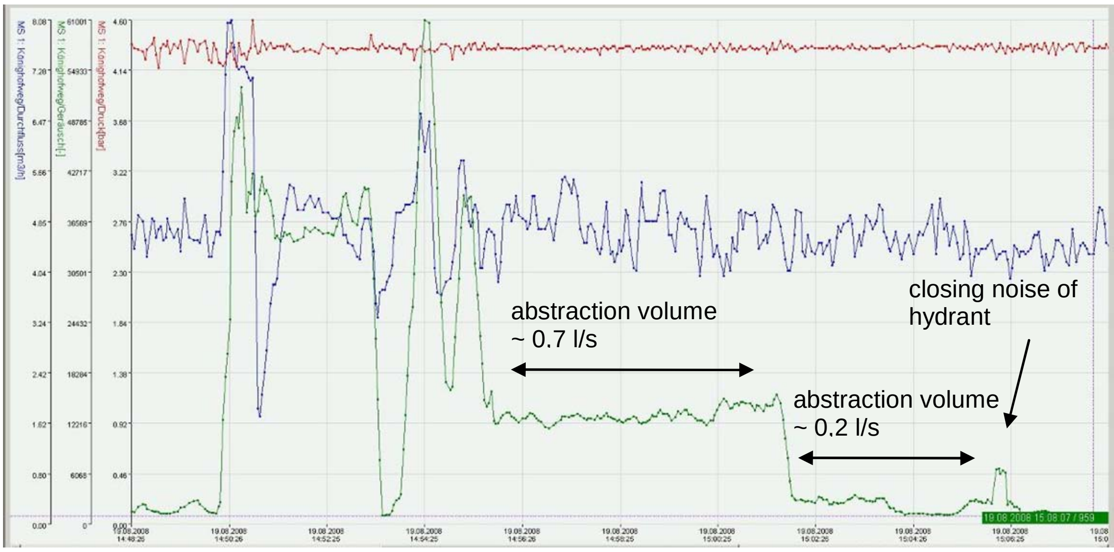

Figure 7: Parameters of MS 1 Königshofweg for test 1 at Salzacker (E 1)

A triaxial (S1) and two uniaxial (S2 and S3) acceleration sensors of different sensitivities were used for the noise measurements on the outside pipe wall (Figure 8). Due to redundant information from sensors S2 and S3, the measurement results of the three coordinate directions of sensor S1 (triaxial acceleration sensor) are presented below.

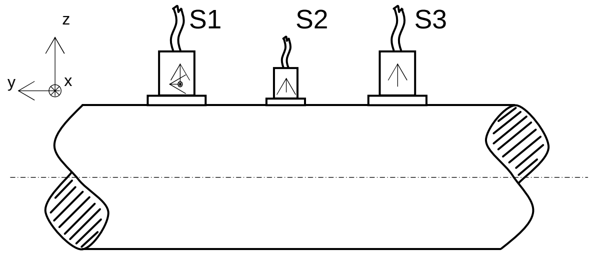

Figure 8: Sketch of pipe with triaxial (S1) and uniaxial (S2, S3) acceleration sensors

Figure 9 toFigure 11 show sections of a spectral analysis of the three signals from the triaxial acceleration sensor. Figure 9 represents the short time spectrum in x-direction, Figure 10 the short time spectrum in y-direction and Figure 11 the short time spectrum in z-direction. In all three figures the axis of abscissa represents the time axis (unit minutes) and the axis of ordinates represents the frequency (unit Hz). Preliminary investigations have shown that no significant frequencies higher than 4 kHz occur. Therefore, the diagram shows the range from 0 to 4 kHz. The amplitude of the Fourier-spectrum is coded by colour (unit dB).

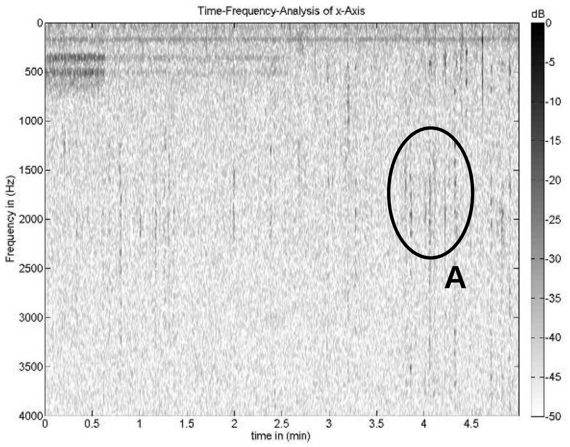

Figure 9: Spectrogram of the 3 coordinate directions of S1 x-axis

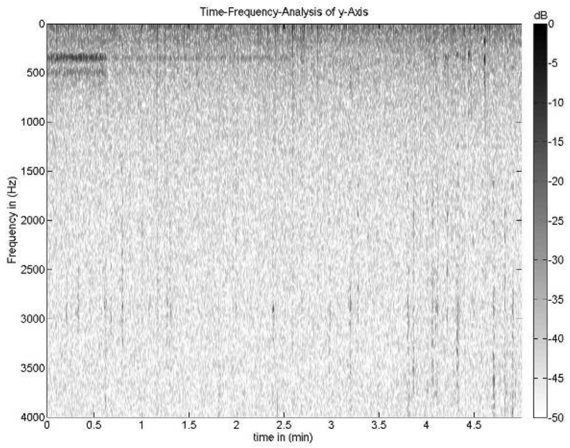

Figure 10: Spectrogram of the 3 coordinate directions of S1 y-axis

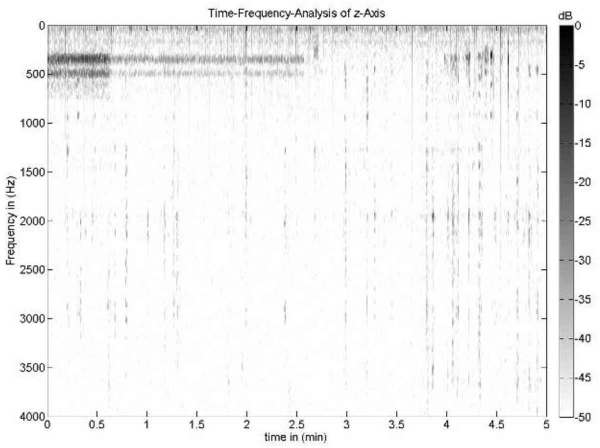

Figure 11: Spectrogram of the 3 coordinate directions of S1 z-axis

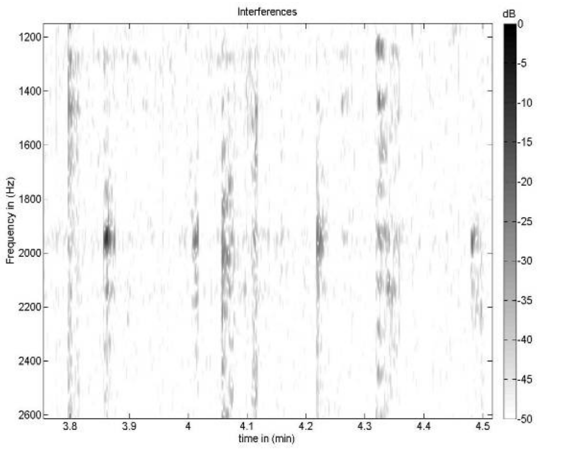

Figure 12: Detail A of Figure 9; interferences, which launch from outside into the system

The figures show that all three oscillation directions cover similar frequencies, with the main components at ~160Hz, ~340Hz and ~490Hz. This supports the assumption that the propagation of structure-borne sound in the pipe does not just occur in one direction, but takes a coupled form. However, the z-component (normal to the surface and flow direction) represents the main energy part.

It is also noticeable that the amplitude of the Fourier-spectrum is significant higher within the first 42 seconds than in the following 2 minutes. This correlates with the higher noise level induced by the higher extraction volume of 0.7 l/s, which was also detected by the WLM sensor (see Figure 7). The next 2 minutes show the results during the extraction of 0.2 l/s. While the dominant frequencies remain almost the same, the corresponding amplitudes decrease, as expected. Finally, after closing the hydrant, the two frequency components (340Hz and 490Hz) disappear because of the lack of excitation.

Beside the detection of the supposed main components also all vibrations, which couple into from outside (e.g. vehicles directly above or near the measurement point) are detected. An example of such interference is presented in Figure 12.

Because the extraction point is served from two sides with water, and because there was also consumption in the network during the testing time, which is superimposed in the measurement data, the reaction of the flow measurement in MS 1 at Könighofweg was not that significant for lower extraction volumes.

Test 5, Abstraction at Rautenastraße (E 5)

The extraction point E 5 at Rautenastraße is located between the measurement points MS 1, MS 2 and MS 3 (see Figure 4).

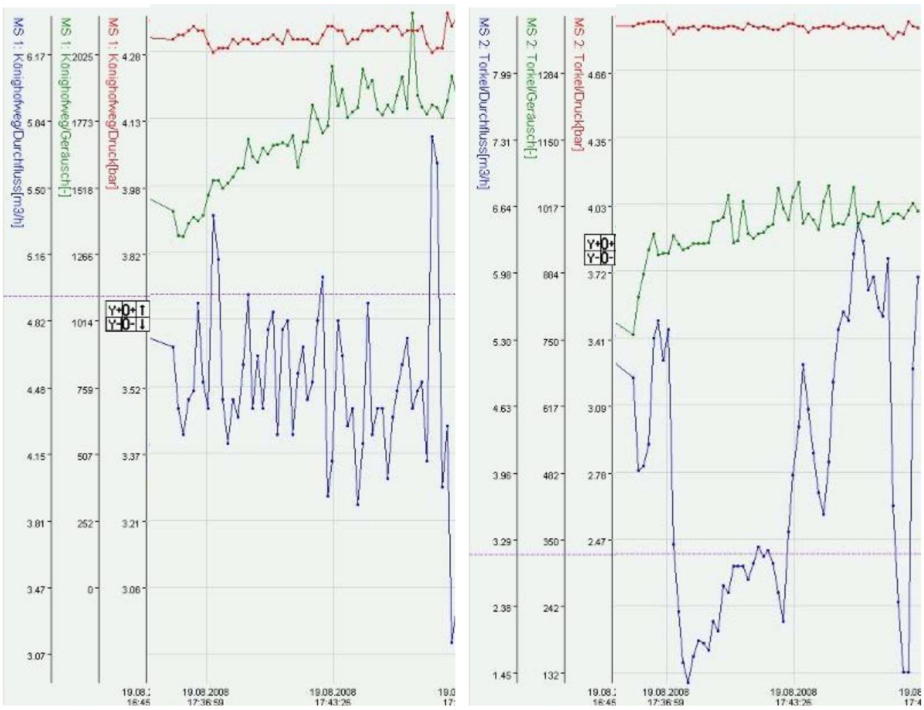

Figure 13: Pressure, noise and flow at MS 1 (Könighofweg) and MS 2 (Torkel) for test 5

Figure 13 and Figure 14 show that the WLM sensors in MS 2, MS 3 and MS 4 react with decreased and negative flows, whereas the flow in MS 1 is clearly positive at high extractions at E 5. On the basis of these data, the leak location can be assumed to be in the area east of MS 3 and MS 4, south of MS 2 and west of MS 1. Furthermore, the missing leak noise at all the WLM sensors is an indication that the simulated leak is not located near one of the sensors (note: the increased noise level at the sensors is again due to the increased flow noise). With this combined information it is possible to narrow down the possible leak location to an area of about 500 m radius around the real extraction point. Together with some step tests (closure of some closing valves) the existing WLM system would support a quick and simple narrowing down of the leak location to a single pipe section.

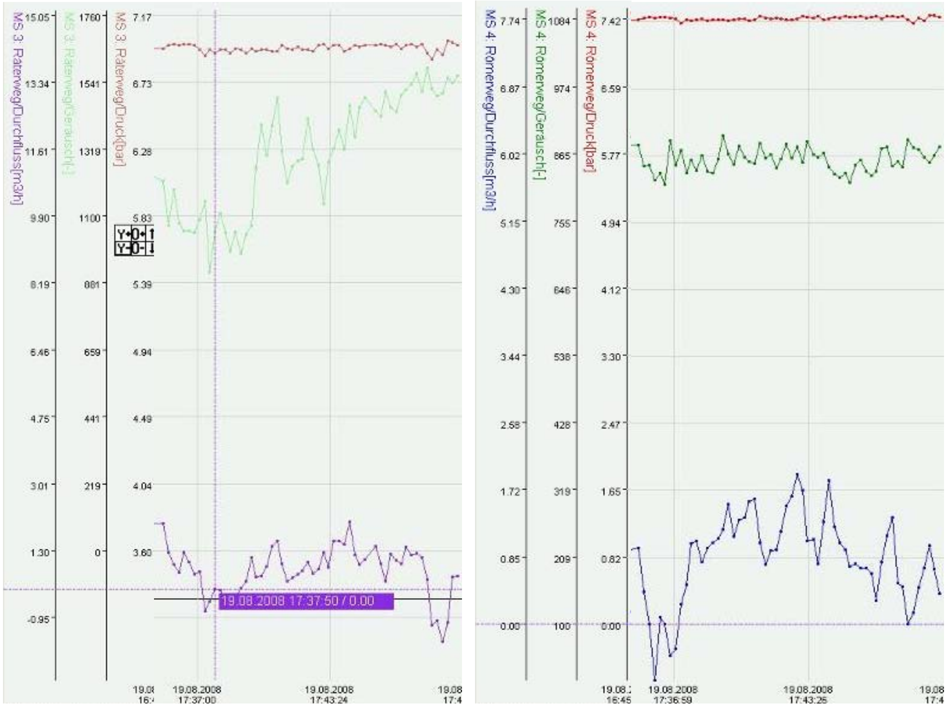

Figure 14: Pressure, noise and flow at MS 3 (Räterweg) and MS 4 (Römerweg) for test 5

Conclusion and Outlook

Multiparameter measurements provide an opportunity for leakage monitoring in large measuring zones and networks without measuring zones, but also within DMAs. Another benefit of such measurements is the support in the localising of leaks.

Combined measurements of the parameters of flow, pressure and noise have an advantage in data interpretation in comparison with a system which only uses flow measurements. Due to the additional information of noise and pressure data the possible location of a leak can be narrowed down much more easily. This fact became evident in the field study in Röthis.

For water supply system in good condition like those in central Europe, the methodology of DMAs is seen quite critical due to disadvantages in supply safety and maintenance; e.g. fire fighting or increased need for flushing pipes. the methodology of multiparameter measurements has proven to be a real alternative to DMAs for such systems, especially in large zones of (often historical) city centres. Up to now multiparameter systems for the purpose of network monitoring have already been installed in several cities in Europe but also on other continents.

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