# Advances in practical applicability of DTS in sewer systems

Rémy Schilperoort[1], Cornelis de Haan[1], Erik Liefting[1], Henk Nijhof[2], Arjo Hof[3], Christophe Meijer[4] and Jeroen Langeveld[1,5]

[1] Partners4UrbanWater, Javastraat 104A, 6524 MJ, Nijmegen, the Netherlands (Email: *remy.schilperoort@urbanwater.nl; cornelis.de.haan@urbanwater.nl; erik.liefting@urbanwater.nl*)
[2] Regional Water Authority Zuiderzeeland, P.O. Box 229, 8200 AE, Lelystad, the Netherlands (Email: *h.nijhof@zuiderzeeland.nl*)
[3] Municipality of Almere, P.O. Box 200, 1300 AE, Almere, the Netherlands (Email: *ahof@almere.nl*)
[4] Municipality of Urk, P.O. Box 77, 8320 AB, Urk, the Netherlands (Email: *c.meijer@urk.nl*)
[5] Department of Sanitary Engineering, Delft University of Technology, PO Box 5048, 2600 GA, Delft, the Netherlands (Email: *j.g.langeveld@tudelft.nl*)

**Abstract**

Fibre-optic Distributed Temperature Sensing is used to locate sources of infiltration and inflow in sewer systems. Several recent developments enhance the practical applicability of the method such as (1) the use of shorter cables in combination with high-quality manual connectors for easier installation and (2) automatic data analysis for early clogging detection. With these advances the DTS method can be applied with less effort as well as at lower costs.

**Keywords**

Distributed Temperature Sensing (DTS); infiltration and inflow; monitoring

## INTRODUCTION

Distributed Temperature Sensing (DTS) is a monitoring technique that allows pinpointing sources of infiltration and inflow in sewer systems. It uses fibre-optic cables that serve as temperature sensors inside the sewer pipes under investigation. A DTS monitoring unit at one end of the cables collects and processes the data. Typically, DTS generates temperature data sets that are long-term (weeks or even months on end) and highly detailed in space (readings up to every 25 cm along the sewer pipe) and time (one measurement up to every 15 seconds).

The idea behind the application of DTS in sewers is that illegal inflows can often be recognized by the temperature anomalies they cause in the sewer system. For instance, wastewater from an illicit connection causes unexpected high temperatures in a storm sewer. Vice versa, storm water discharged into a foul sewer often causes sudden temperature drops. The long-term and detailed DTS data allows pinpointing the problem both in time and space.

Since 2008, DTS has been applied in a few dozen projects, in a number of different types of sewer systems, and addressing a wide variety of sewer-related problems (e.g. Hoes *et al.*, 2009; Siska *et al.*, 2014; Østertoft *et al.*, 2015). Many of these projects have had a piloting character to test the DTS technology under varying circumstances. Based on the experience from these projects, several ‘challenges’ have been identified that need attention to ease the use of DTS. This abstract describes two of these ‘challenges’ as well as developments to tackle these.

## CHALLENGES AND DEVELOPMENTS

### Cable installation

The installation of fibre-optic cables into a sewer system has in several projects proven a demanding task. Typically, in these projects one or multiple cables of 1.000 to 2.000 m each are used. The use of such long cables comes with disadvantages:

- the handling of long cables is demanding. Long cables get easily tangled during installation (see Figure 1, left) or may break due to improper handling. To prevent this, large teams of five to six labourers are required as well as adequate equipment such as a sewer cleaning truck, or draw wires. Such teams are able to install roughly 2 km of cable per day. As a result of these large teams and limited daily production the costs of installation can be significant: sometimes up to one third of total project costs;
- long cables are not easily relocated. During a project the initial DTS monitoring results may suggest that it would be interesting to study an adjacent sewer section that is currently not under investigation (for instance because temperature anomalies are observed at the end of a cable). Relocation of (a section of) the cable during the project would then become opportune, but this is not easily executed with long cables.

**Figure 1. Improper fibre-optic cable handling (left) and newly tested IP68 LC fiber-optic cable connector (right)**

The above disadvantages have prompted the use of much shorter cables (~300 m) that can be used to build up a cable network for DTS measurements. The installation of such short cables requires smaller teams, less equipment and is faster than working with longer cables. The problem with short cables, however, is the need for connections between all cable sections. Welding of cables can be performed in the field (i.e. next to a sewer manhole, leaving the welding box inside the manhole), but this is time-consuming, requires a specialist and generally yields connections with inferior quality compared to factory welding. But even with pre-installed (factory) connectors severe signal loss can occur. Tyler *et al*. (2009) demonstrate the result of having multiple sequential standard E2000 connectors in a cable: “half of the original signal is lost after passing through only three connectors, and the noise introduced through multiple connectors overwhelms the temperature signal after seven or eight connectors”, see Figure 2. Building a cable network for DTS monitoring out of many short fibre-optic cables would hence require connectors with much smaller losses than the tested E2000 connectors. Moreover, the connector should be easy to use to facilitate quick application in the field.

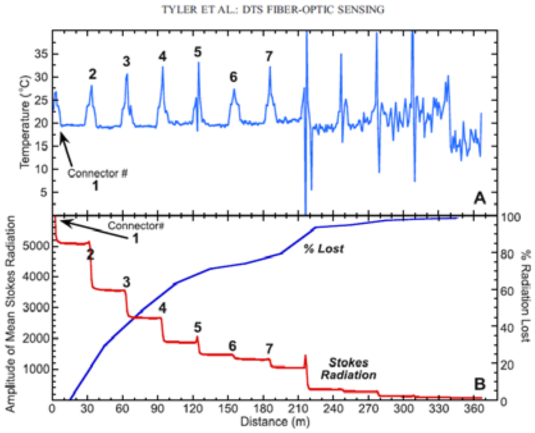

**Figure 2. Test results taken from Tyler *et al.* (2009) showing large signal losses with an increasing number of connectors (B) resulting in inaccurate temperature readings (A)**

A promising connector for building fibre-optic cable networks for DTS monitoring is an IP68 LC cable connector, see Figure 1 (right). It uses twisting male-female-type connectors attached to the end of the cables to be connected. The actual connection can be made within seconds and is hence easy applicable. To assess the signal loss using this type of connector, a laboratory experiment was conducted using a 500 m fibre-optic cable with 9 sequential connectors (a connector every 50 m) positioned to monitor surrounding air temperatures, in combination with a Silixa XT-DTS unit. Figure 3 shows the results. Over the entire 500 m cable length a total signal loss of roughly 30% occurs, only part of which is due to connector losses. The largest connector loss occurs at connector 7 with an instant 5% signal loss. Connector 9 proved damaged which explains the temperature anomaly around x = 450m. In total, signal loss due to the connectors is limited, especially compared to the Tyler *et al.* results, and is acceptable in terms of the usability of the DTS data in the search for infiltration and inflow.

Prototypes of the connectors are further tested in August/September 2016 in a field test with the municipalities of Almere and Urk in cooperation with the Zuiderzeeland Regional Water Authority. The aim of the project is to search for illicit connections (wastewater inflows) in a 3 km storm sewer. The cable network will be built up out of multiple 300 m cable sections applying a dozen IP68 LC cable connectors, in combination with a Yokogawa DTSX3000 unit.

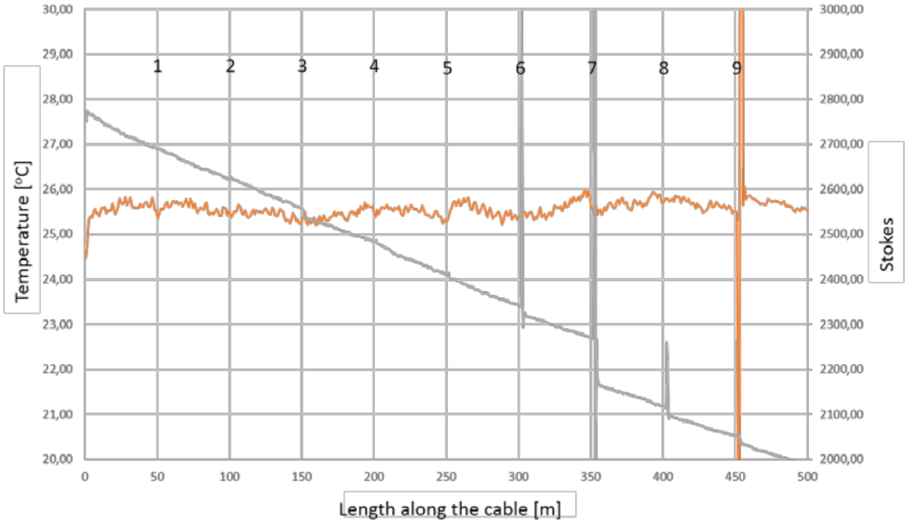

**Figure 3. Test results for a 500 m fiber-optic cable using 9 sequential IP68 LC-connectors**

## Clogging of pipes

The installation of fibre-optic cables (or any other object) into a foul sewer enlarges the risk of the build-up of pollutants around the cables. Especially in small diameter pipes (<= Ø160mm) this may ultimately lead to clogging. A straightforward solution is the proactive regular cleaning of all (small diameter) pipes under investigation, but this is expensive and time-consuming.

An alternative has proven the use of DTS data: a full blockage can easily be visually recognized in the data. In the example in Figure 4 a blockage (at x = 805m) causes all upstream (warm) wastewater spills to remain around the spill locations whereas the spills downstream the blockage move downstream the system.

In terms of data processing a blockage can be detected by systematic analysis of the DTS data for each location along the cable. Each location can be characterized in terms of daily temperature variations (minimum, maximum values, number of variations, variance of the signal, etc.) that depend on the location in the sewer system. A change in behaviour may indicate a gradual built-up of pollutants on the cable and ultimately clogging of the cable. The blockage in Figure 4 can be detected checking for minimum temperatures: all locations upstream x = 805m show unexpected high minimum daily temperatures.

An automated data analysis procedure can continuously monitor possible blockages and send reactive maintenance teams into the field.

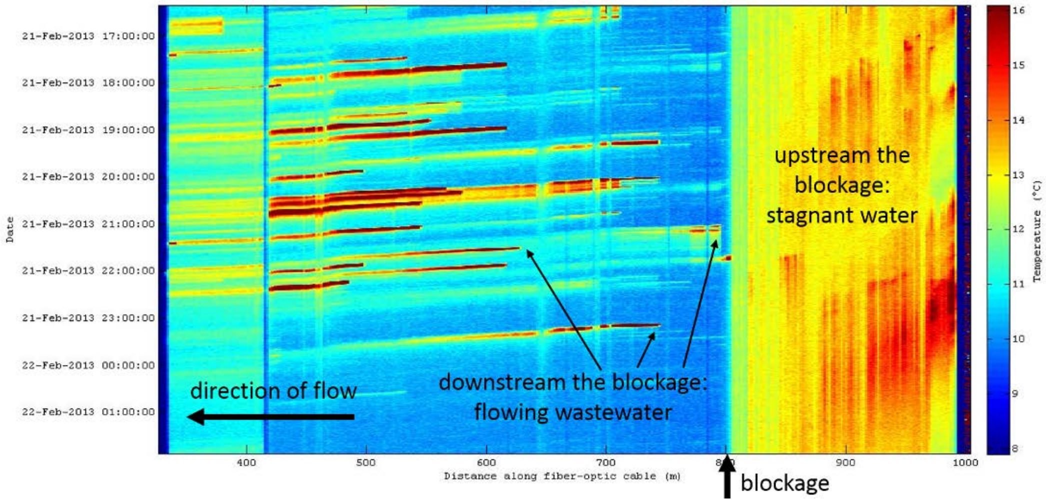

Figure 4. DTS monitoring results showing a blockage in the pipe at x = 805

## CONCLUSIONS

The advances in the practical application of DTS in sewer systems reduce the costs and risks involved with the DTS monitoring technology. This eases the use of the technique to resolve the wide-spread problems of infiltration and inflow in sewers.

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