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IDENTIFYING SEEPAGE IN DITCHES AND CANALS IN POLDERS IN THE NETHERLANDS BY DISTRIBUTED TEMPERATURE SENSING

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ABSTRACT: Seepage in ditches and canals, a common feature in polders in The Netherlands, is investigated making use of temperature sensing by fiber optic cable. By its high spatial and temporal resolution capabilities the technique reveals the complex ensemble of all effects that define the water temperature on the bottom of the watercourses in three polders where a 1300 m long cable was located. From the temperature signature the location of suspected seepage zones in the water courses can be determined more precisely. The study shows that the sensing of seepage through temperature is time dependent as the signature can temporarily fade and can be extremely localized. This shows the potential for the applied technique.

Keywords: DTS, seepage, temperature, polders, fiber optic cable

INTRODUCTION

Temperature as a tracer to determine seepage from groundwater into surface water has been widely used in the past (Anderson 2005, Conant 2004, Stonestrom 2003). However, little experience on distributed temperature sensing by means of a glass fiber optic technique in water courses in polders exist. For the temperature sensing technique by fiber optics a pulsing laser light is transmitted into a glass fiber optic cable. The reflected signal received is then analyzed for deformations of frequency and amplitude (the so-called Raman backscatters) that relatively simple can be related to temperature (Lopez-Higuera J.M., 2002). Through the technique a high spatial and temporal resolution of temperature observations is obtained along the fiber optic cable. With this, detailed monitoring patterns in temperature behavior can be captured but also incidental changes in temperature. The technique has found several applications in industrial process control. In Germany and Sweden the technique is applied for leakage detection in embankments and reservoir dams, where a fiber optic cable is embedded in the structures (Johansson et al. 1999, 2000). Some applications for research purposes are known in hydrology and water management (Selker et al. 2006a, Selker et al. 2006b, Westhoff et al. 2007, Lowry et al. 2007). These publications describe results from temperature observations by fiber optics in small rivers, lakes and on glaciers.

In this paper the technique is applied to measurements of temperature on the bottom of ditches and canals in three polders in the Netherlands, with the primary goal to investigate applicability of the technique to locate seepage locations. At each site continuous measurements took place for a number of days (3 to 4 days) during the summer of 2007.

It is expected that temperature anomalies in surface water will be observed at locations where seepage from groundwater or seepage through dikes or levies enters a canal or ditch. This is of interest for several reasons. Finding a seepage location is a first step in assessing its consequences in terms of stability of soils or construction works in polders.

Monitoring temperature and the extent of the effect on surface water can provide further insight into its consequences on both water management quantitative aspects and water qualitative or ecological aspects.

MATERIALS AND METHOD

For the observations technology of Sensornet (Sentinel DTS-LR, London, England, see http://www.sensornet.co.uk) has been applied. After connecting the fiber optic cable the Sensornet Sentinel DTS-LR system delivers almost immediately temperature results in an ASCII data file over 1 m intervals. The 1 m is defined by the time the laser light travels during a pulse. From the travel time of the laser

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light and its reflection it can be derived from which position along the cable a certain reflection originates. This defines the average temperature over 1 m of cable at that position. According to specifications of the system accuracy of 0.01°C in the averaged temperature can be obtained when measuring and averaging results over 30 minutes. Measurements at all locations in this research were averaged over a 10 minute time interval. This results in 3 times less observations per averaged result and hence a theoretical reduction in accuracy by √3. However, the maximum difference in temperature that was to be expected in the watercourses as a result of seepage water would be at least in the order of several degrees, hence accuracy of the measurement system is not an issue here.

Two different brands of fiber optic cable were applied. At the first two locations a four fiber optic glass PE cable multimode 50/125 µm was applied. At the last location temperature was observed with a 6 mm diameter, steel armed and PE covered cable, manufactured by Kaiphone Technology, Taiwan. This cable conveys two optic glass fibers (multimode 50/125 µm) protected by a stainless steel inner tube, embedded in gel to avoid direct stress on the fiber optics as stress can affect the reflected laser signal.

Tests have demonstrated (Selker et al. 2006a) that in similar cables the time to adapt to temperature changes is very acceptable; within 15 seconds 95% of a temperature change is observed by the cable.

MEASUREMENT RESULTS

The measurement locations in the Wieringermeerpolder, Bovenkerkerpolder en Groot Mijdrecht Noord were selected for known or suspected occurrences of seepage. Near to where the polders boder on high level canals or reservoirs seepage is most likely.

In combination with a need for a save location for the monitoring equipment and the need for an undisturbed power supply all measurements start from a pumping station.

Wieringermeerpolder

From the pumping station “Lely” the DTS cable (four fiber multimode) extends 1300 m into the canal known as “Lage Kwelvaart” (see Fig. 1), which is approximately 25 m wide. At the location of the pumping station the Wieringermeerpolder boders on the IJsselmeer. Because of the large difference in the polder water level (-6.60m AMSL) and the IJsselmeer level (-0.40m AMSL), seepage near the pumping station was expected. This was indeed confirmed by relatively cold water in the “Lage Kwelvaart” that persists at a distance of 150 m from the pumping station over the period of observation (see Fig. 2). Clearly observable is the diurnal temperature rhythm. Around the position of 350 m the rhythm runs ahead in time compared to its surroundings. This faster heating and cooling is explained by the fact that the cable was accidentally positioned closer to the sides of the canal and hence was in less deep water. More cold zones can be identified (temporarily at 450 m, 700 m) but its causes could not be established by only the DTS measurements.

It was confirmed that during the period of observations no discharge by pumping from the “Lage Kwelvaart” occurred.

Bovenkerkerpolder

Observations in the main drainage canal and a side canal of the Bovenkerkerpolder, near Amstelveen, were carried out over two periods, i.e. from 2-5 July and 26-30 July. However, the DTS cable (four fiber multimode) remained unchanged in position over the full period. From the pumping station the cable runs for 750 m

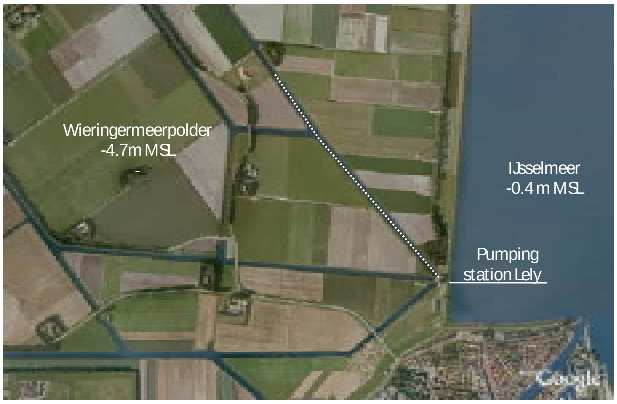

Fig.1 DTS set-up in the Wieringermeerpolder

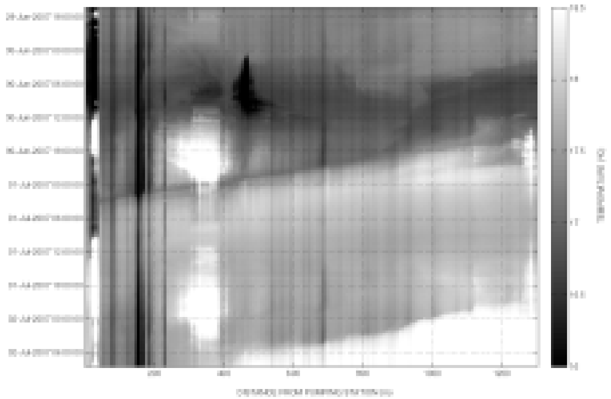

Fig. 2 Temperature observations Wieringermeerpolder

through the 15 m wide and 1.2 m deep main canal and afterwards takes a bend in a much smaller side canal of 4 m wide and 0.7 m deep (see Fig 3).

Most remarkable are the five seepage zones between distances 200-400 m from the pumping station (see Fig. 4) that were observed. These zones were not observed when discharge occurred in the canal, as was the case between 4 and 5 July as a result of pumping due to abundant rain that started in the evening on 3rd of July. The locations of seepage could be confirmed by observations with a digital thermometer, although the extent of most zones was limited (2-3 m in diameter) and the temperature difference was easily disturbed by wading.

Fig. 3 DTS set-up in the Bovenkerkerpolder

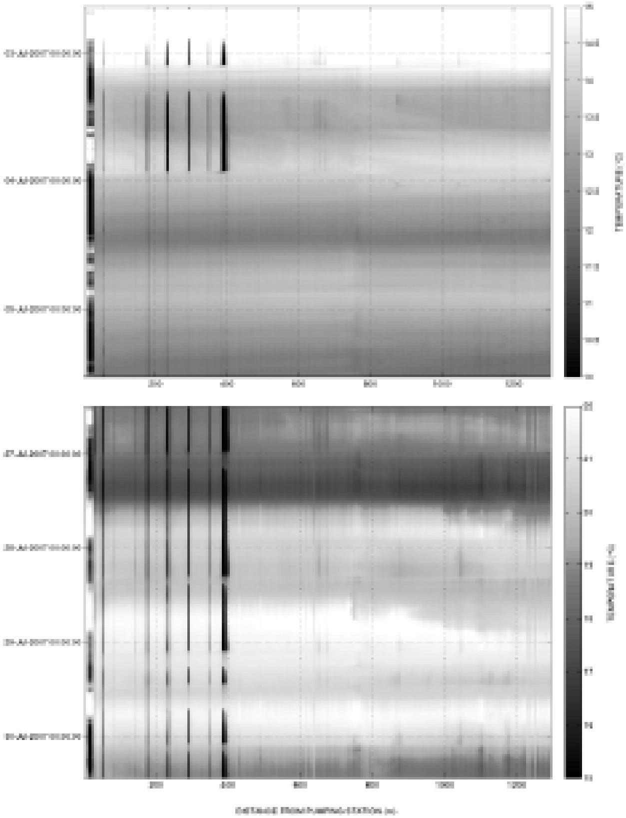

Fig. 4 Temperature observations in Bovenkerkerpolder (2-5 July 2007) and (26-30 July 2007)

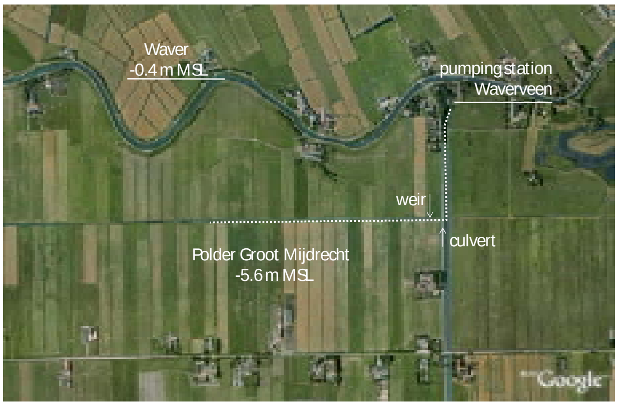

Fig. 5 DTS set-up in polder Groot Mijdrecht

Groot Mijdrecht Noord

The polder “Groot Mijdrecht Noord” is a deep polder (-6.00m NAP) and therefore, together with its high permeability of its base layers well known for large seepage amounts. The DTS observations (with a Kaiphone cable) took place in the 30 m wide main drainage canal to the “Waverveen” pumping station over a distance of 450 m and for the remaining 850 m in a side canal that drains by an overflowing weir into the main canal. Several smaller ditches again end up in the side canal (see Fig. 5).

To discharge the large seepage amounts the “Waverveen” pumping station is frequently operated even when no rain occurs. This occurred 8 times during the period of observation from 30 July – 2nd August. When no pumping takes place the seepage zones (0-50 m, 270-310 m, 380-410 m) clearly show up by the cooler water that appears (see Fig. 6).

The pumping has no affect on the side canal as it discharges over the weir. When superimposing the scaled time-distance-temperature diagram onto the map, it can be concluded that most cold spots in the side canal are caused by cold water from the even smaller side ditches (see Fig. 7).

RESULTS DISCUSSION

Observations at the different locations have demonstrated significant spatial and temporal variations

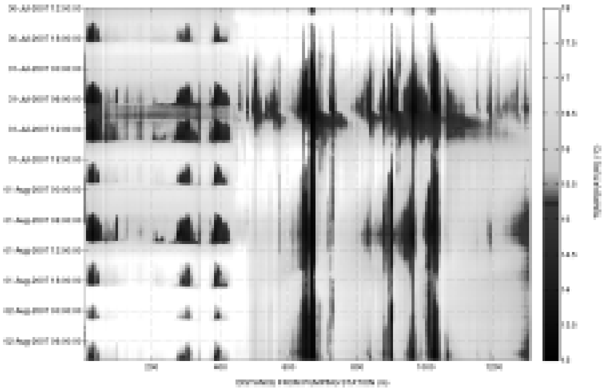

Fig. 6 Temperature observations in polder Groot Mijdrecht Noord

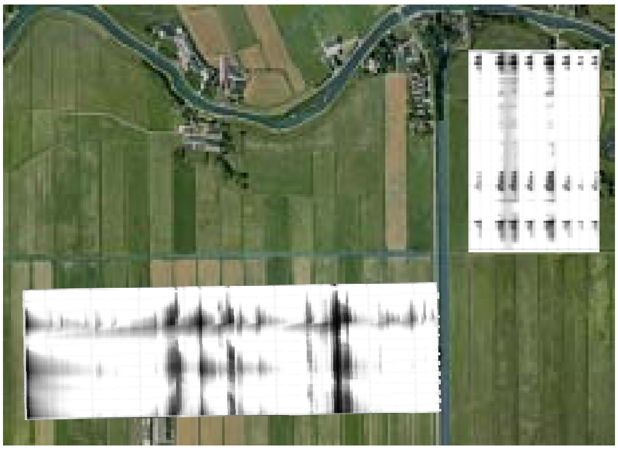

Fig. 7 Location and temperature observations in polder Groot Mijdrecht Noord (Google Earth)

of temperature in canals and ditches. Causing factors of these variations are various and can be categorized into energy exchange between water and atmosphere, energy exchange between masses of water, either diffusive or convective and exchange of energy between the water and the surrounding land.

The effect of all the factors together will result into temperature changes of the canals and ditches in time and space.

Hence measurements of temperature in canals and ditches shall provide results that are potentially highly non stationary and spatially non homogeneous. In this context it should be realized that the observations of temperature as provided in the previous chapters are one dimensional observations in a three dimensional space. The observations provide information along the canals and ditches but neither in cross sectional direction nor in the vertical.

Despite the complex ensemble of processes (Boyd and Kasper, 2003) that determines the temperature at a certain spot in the water, some general explanations from the observations can be formulated.

Diurnal Temperature and Temperature Waves

A diurnal temperature rhythm is often observed, but not everywhere and at all times. When a rhythm is observed the maximum water temperature falls much later than noon and even after midnight is not an exception. Hence also the coldest moments not necessarily occur at night and have been even observed around noon. There is obviously a delay in heating (and cooling) of water bodies through temperature differences of the atmosphere and radiation. A delay will be even more pronounced for temperature sensing on the bottom of a canal. Temperature measurements at locations that are shallower in a canal can therefore show a forward shift in time of the day and night rhythm compared to results of deeper locations. The observations of the Wieringermeerpolder hint to this explanation. Firstly, at the distance 300m to 400m the cable was closer to the sides of the canal and therefore less deep in the water, which caused a shift in the diurnal pattern. Secondly, due to a gradual change of depth along the canal - 2.2 m deep near the pumping station to 1.2 m deep at 1300 m - the delay in heating or cooling resulted in a temperature wave. No discharge in the canal in the Wieringermeerpolder occurred during the period of observation. Occasionally translating temperature waves were also observed in the Bovenkerkerpolder, of which the exact cause(s) could not be established. The temperature wave that occurred in the shallow and narrow side ditch (700m-1300m) to the main draining canal in the Bovenkerkerpolder is remarkable. Three days in a row a warm water wave moving to the end (into the direction of 1300m) could be observed. If this is caused by a depth difference in the ditch this would mean the ditch becomes deeper to the end. During the cooling process in the diurnal rhythm no longer a wave is observed. On 29/07 when 10.5mm of rain was measured no wave at all occurred.

Identification Seepage Zones

A diurnal rhythm in temperature is disturbed at places where sufficient water with a different temperature reaches the cable. Seepage from groundwater with an approximate constant temperature shows as a band in the time-distance- temperature diagrams. At the Wieringermeerpolder and Groot Mijdrecht Noord which were selected for known zones of seepage, the seepage could be indeed confirmed by DTS observations. The several seepage zones in the Bovenkerkerpolder between distances 150m and 200m came as a complete surprise. Manual temperature measurements did confirm the existence of very localized seepage in the stagnant water.

The regular spatial pattern of the seepage locations hints at artificial perforation of the lower clay zones of the canal floor. Most likely are construction works that have been in place and when removed left a perforation in the impermeable clay layer underneath the peat top layer.

Although a difference can be observed in the spatial extent (bandwidth) of the seepage zones, this is not necessarily an indication of the total seepage at the location of these zones in the canal. Verification showed that the seepage is not over the full width (15m) of the canal bottom, meaning that the cable even could have missed the seepage zone.

The diagrams of Bovenkerkerpolder and Groot Mijdrecht demonstrate that seepage is not necessarily permanently traceable for different reasons. Discharging excess drainage water through pumping stations will establish a current in the canals and ditches, which can result in a complete (temporal) fading of the seepage effect on the temperature pattern in these water courses. This is clearly noticeable in the Bovenkerkerpolder where pumping started late on 3 July and continued some days thereafter. The same applies to the suspected seepage zones over the first 440 m in Groot Mijdrecht.

Detailed observations on the diagram of the seepage zones indicate that the temperature difference with surrounding water can fade temporarily, for other reasons as well.

In the Bovenkerkerpolder there was no discharge recorded at the pumping station over the period 26/07 – 30/07. Nevertheless, the extent of each of the six seepage zones in the direction of the fiber glass cable between 150 and 400 m is not constant. It was confirmed by manual temperature observations that the seepage when occurring shows as very local in extent (a few meters in diameter) on the bottom of the canal. A possible explanation of the fading of the seepage zones is that the temperature pattern is temporarily disturbed (at least at the location of the cable) by e.g. heating of the water, wind or rain or even density currents from temperature gradients in the water.

Cold or warm water disturbances that show as a band in the time-distance-temperature diagram, are not always caused by seepage. Drainage of water direct form the land surface or through drainage pipes can result in disturbances, as well as drainage of shallow ditches into deeper water. The cold water bands that show in Groot Mijdrecht between 440m and 1300m coincide at several spots with the location of side ditches (see Fig. 7). It could well be that the difference in temperature is caused by seepage that occurs in the side ditches.

CONCLUSIONS AND RECOMMENDATIONS

The scanning by the DTS technique of ditches and canals in The Netherlands revealed a wealth of information. The primary aim was to test the applicability of the technique to monitor and discover seepage in ditches and canals. It showed that DTS can discover seepage in ditches and canals at places that were not known before. Suspected spots of seepage could be confirmed and assessed on its exact location and extent.

The advantage of the DTS technique, compared to incidental measurements is that, due to its high spatial and temporal resolution spots can be identified where the effects of seepage can fade temporarily for various reasons. In this respect noticeable is the fading effect of currents in a water course on the temperature signal of a seepage spot when excess water is discharged through pumping stations. Atmospheric heating and cooling can disturb the signal by initiating turbulent processes or just by causing minimum temperature differences. Yet, less obvious are the effects of rain and wind on the fading signature.

Other spatially distributed temperature measurements, such as infrared thermal observations from aerial surveys result in surface temperature images, whilst seepage in canals and ditches is most pronounced at the water course’s floor, where the cable is located.

On the other hand the results have demonstrated that with the DTS technique the total ensemble of temperature effects on canals and ditches is recorded, and hence further analysis and common sense is required to confirm seepage. In most cases this can be solved by visual inspections of suspected seepage zones in search of other plausible explanations. Apart from real seepage, drainage pipes, side ditches and conducts are the most common features that give seepage like signatures.

However, to be able to explain all observed temperature effects much more observations would be required. Obviously measurements of air temperature, radiation (including local shade), wind and precipitation would be required in addition to what was mentioned above. Longitudinal depth profiles of ditches and canals and depth of the cable proved to be of vital importance, as well as assessing water covering vegetation and turbidity of the water.

Installation of the 1300 m fiber optic cables manually cases with the help of a boat turned out to be easy. The cables could be re-used every time, without damaging the fragile glass fiber inside. Hence, bending and stress on the cable during the installation and removal had no negative impact on the fibers. However, pre-caution should be considered against mechanical impacts such as mowing and excavation activities.

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