Trials of Screen-Printed Chloride Sensors for Environmental Sensing: Fluvarium Tests

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Introduction

This paper describes a trial of 21 low-cost, and robust chloride sensors, networked and tested in a fluvarium. Results are reported from both surface flows and sub-surface flows and it is shown that such sensors give a valuable insight into such transports, and offer the potential for a new paradigm in hydrologic monitoring.

The sensors used are reported in [1]. In summary, they are potentiometric chloride sensors utilising a layer of silver chloride (AgCl) on top of a silver electrode. The resulting structure generates a potential that follows the Nernst equation, which predicts a sensitivity of approximately -59.2 mV per decade change in chloride concentration (pCl) at a temperature of 298 K, as given by:

$$E = E_o - 0.0592 \log C_{Cl^-}$$

Here, E = Electrode potential (V)
E_o = Offset potential (V)
C_{Cl^-} = Chloride ion concentration (M)

Sensor Fabrication

The sensors were made using a standard microelectronics screen printing process with commercial pastes, as shown in Figure 1. The silver electrode and the insulating glass layers are processed first, before the active Ag/AgCl layer is grown electrochemically. Screened cables are soldered to the terminal end and sealed with silicone rubber before use.

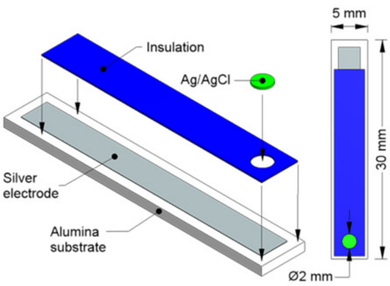

Figure 1: Schematic of screen printed sensor.

Sensor System

The system consists of an analog processing board, a digital board, and a waterproof housing. The analog processing board allows up to 8 individual sensors to be connected and measured against a single reference. Each sensor is measured individually and then amplified by a gain factor which can be varied to allow for different expected ranges of chloride, thus allowing the full range of the following analog to digital converter to be used. For multiple data loggers, clock synchronisation is achieved by setting the clock via a temporary GPS module. Data is stored on SD card or transmitted by radio.

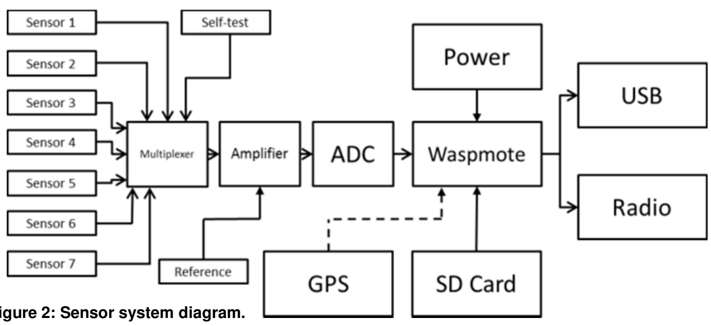

Figure 2: Sensor system diagram.

Fluvarium

The fluvarium consisted of a 20m long channel which had been filled with an example river bed. This was used as a representative environment. The slope of the fluvarium was adjustable and the flow rate could be controlled and measured at the outflow. Figure 3 shows a photograph along the length of the fluvarium. Sensors can be seen placed in situ.

Figure 3: Sensors located in fluvarium

[1] A. Cranny, NR. Harris, M. Nie, JA. Wharton, RJK. Wood and KR. Stokes, *Screen-printed potentiometric Ag/AgCl chloride sensors: Lifetime performance and their use in soil salt measurements*, Sensors & Actuators A, 169 (2011) 288-294.

Experiment

14 sensors were distributed along the length of the fluvarium at 30cm intervals, inserted into the "river bed" to a depth of about 20mm. A further 7 sensors were placed in the surface flow, co-located with the 7 buried sensors furthest from the inlet. At the inlet, 100ml of 100mM NaCl solution was added with no flow into the water soaked fluvarium and this formed a pool. Sensor 2 in Figure 4 was placed near the downstream end of this pool as a reference. The other sensors shown in Figure 4 are those buried in the river bed, moving downstream. Figure 5 shows the surface flow sensors at the end of the fluvarium. Table 1 lists times of subsequent events, as marked in the figures.

Event	Time (mins)	Description
1	54	Fluvarium tilted
2	107	200 ml water added
3	114	200 ml water added
4	129	200 ml water added
5	139	400 ml water added
6	164	600 ml water added
7	185	1,000 ml water added
8	204	Flume turned on

Table 1. Chronology of fluvarium events.

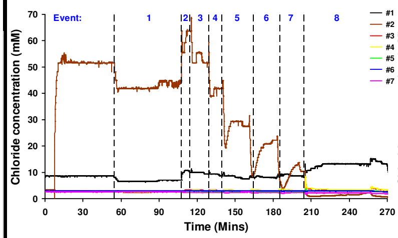

Figure 4: Results from embedded upstream sensors. Sensor 2 is in the inlet pool.

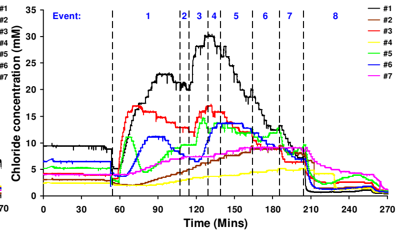

Figure 5: Results for downstream surface flow sensors.

Discussion

Figure 4 shows that the sensor in the inlet pool responds very quickly. Sensor 1 (embedded, but nearest the inlet) also shows a small response. There is a response as the fluvarium is tilted and sensors 1 and 2 show an increase in concentration. This is due to the relatively poorly mixed inlet solution starting to move towards the outlet and move downstream. This effect is emphasised as the first volume of water is added at 107 minutes. The addition of the water pushes the higher concentration further down the fluvarium as is shown by sensor 2. Other additions are then seen to indicate a reduced concentration as the salt slug is replaced by a more dilute solution. When the flume is turned on at about 200 minutes a steady flow of water establishes itself after a few minutes and sensor 2 then shows a similar reading to the other sensors, indicating that the salt pool has been flushed. Sensor 1 continues to rise as salt is pushed through the river bed, but starts to fall as the experiment finishes.

Figure 5 shows the surface flow sensors located further down the fluvarium. The picture is less clear here. Visual inspection of the sensors showed that a preferred meandering flow path was being established in the fluvarium and that sensors 1, 3 and 5 were positioned in that flow. Other sensors were not in the preferred flow path and so were seeing different driving functions. A third set of co-located but buried sensors were also measured but the results showed no significant variation from baseline and so are not reported.

Conclusions

- These screen-printed chloride sensors are able to produce results in both fluid and wet soil environments.
- This work illustrates the pitfalls in interpreting spot measurements in a distributed environment: sensors positioned just a few cm away from a preferred flow path will give results that are significantly different from those located in the preferred flow.
- A distributed network of these low-cost robust chloride sensors offers the opportunity to measure chloride events with high spatial and temporal resolution in a range of environments.

Acknowledgements

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