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Wireless low power real-time solutions for tailings dams — a case study

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Abstract

Failures of tailings dams are amongst the most hazardous incidents that can occur at a mine. Historically, 20 tailings dam failures occur per decade. Failures can originate from overloads, anomalous behaviour of the material used to build the dam (normally tailings), or from problems with the drainage mechanisms, which result in an increase of pore water pressure and, therefore, a loss of resistance. Prevention and protection are hence crucial, and real-time monitoring and improvement of dam construction are key tools for the safety management of the embankments.

Monitoring with geotechnical sensors in tailings dams brings valuable information about the safety factor of the stability of the dam. The automation of such sensors permits obtaining data at high frequency and in real-time remotely, so when predefined alarm or alert thresholds are exceeded, an alarm signal is activated.

LS-G6 is a wireless low power monitoring solution, consisting of a data acquisition system which collects data from the sensors and sends it wirelessly to the gateway (central station). This system has been installed in the tailings dam of the Aguas Teñidas mine (Spain) to automatically acquire data from 8 piezometers. An analysis of the quality of the radio transmission between the data loggers and the gateway, separated between 1.6 and 1.9 km, is presented in this paper. Results on the performance of the radio indicated high quality data transfer where 90 to 100% of the radio packages have been sent and received successfully. Also, data from sensors that were collected with hourly to daily frequencies are presented.

Due to the automation, changes in sensor measurements were recorded that were not detected with manual readings during previous years at the Aguas Teñidas mine. The monitoring system presented in this paper provides control in real-time of the mine's tailings dam. In addition, many other sensors may have been integrated during further phases to control mine hydrology equipment, and stability measurements of the open pit area and access roads.

1 Introduction

Tailings dam failures are amongst the most hazardous events that can cause extensive loss to life, property and health. The mining industry has experienced several significant tailings dam failures over past decades: Merriespruit, South Africa, 1994 (Strydom & Williams 1999), (Figure 1), Omai, Guyana, 1994 (Haile 1997); Aznalcollar, Spain, 1998 (Alonso & Gens 2006a; 2006b), Sullivan, Canada, 1991 (Davies et al. 1998); Aitik, Sweden, 2000 (Göransson et al. 2001); Bento Rodrigues, Brazil, 2015 (Hinman 2015). Historical records of disastrous events in tailings dams show that about 20 incidents occur per decade, with a tendency to shift from developed countries to developing countries.

Figure 1 Aerial view of the Merriespruit dam after it had collapsed. Image from Tailings.info n.d., Merriespruit Tailings Dam Failure, Virginia, South Africa

To maintain the impoundment integrity is one of the most challenging tasks in mine waste management. Failures can originate from overloads, anomalous behaviour of the material used to build the dam (normally tailings), or from problems with the drainage mechanisms, which cause a raise in pore water pressure and a loss of resistance (Vanden-Berghe et al. 2011). Prevention and protection are therefore crucial, and real-time monitoring and improvement of dam construction are key tools for the safe management of the embankments.

For decades, tailings dam checks consisted of periodical visits to boreholes to perform manual measurements with a variety of instruments, such as water level meters, piezometers in open wells, or inclinometers. Manual data acquisition systems provide scarce data and takes a long time, which is a disadvantage since a dam could lose resistance rapidly and the measurements may not avert a crisis. An automatic sensor network makes it possible to get data very fast. The measured parameters are directly related to soil shear strength, and by measuring automatically and continuously, information regarding the safety of the dam and expected deformations is available in real-time.

Most tailings dams have water level meters and inclinometers installed in boreholes to enable periodic measurements. Piezometers provide pore water pressures, whereas inclinometers measure the lateral displacements at depth. Other sensors that may be of interest are waste management gauges to measure the water level in dams, or settlement cells to monitor settlement processes of the walls and surroundings. Meteorological stations to measure rainfall may be a critical consideration in new climatic scenarios.

The development of a consistent monitoring strategy is crucial. Wireless monitoring solutions consist of data acquisition systems which collect the data from the sensors and send it wirelessly to the gateway (central station). Automatically, the gateway uploads the data to the internet or an intranet. The system presented in this paper has a long range radio communication capability between the data loggers (placed next to the sensors) and the gateway, which make this system a powerful solution for monitoring many sensors in multiple areas simultaneously.

The long range communication between the gateway and data loggers could range up to 15 km in an optimal situation (line-of-sight). In the context of a mine, this means that the gateway could be placed at the mine's central office and still reach almost any point at the mine where a sensor is placed. In addition, data loggers use embedded batteries that make the system autonomous up to 10 years, which enhances maintenance cycles of the monitoring system.

The data collected are compared to pre-established thresholds in order to achieve an indicator of the stability of the dam. Hence, the network is also used as a low power warning system for the embankment stability. The monitoring system has been installed successfully on several mine sites over the world to provide a real-time monitoring of the main tailings dam. Furthermore, many other sensors have been integrated during additional phases to monitor mine hydrology and the stability of the open pit process area and access roads (Figure 2).

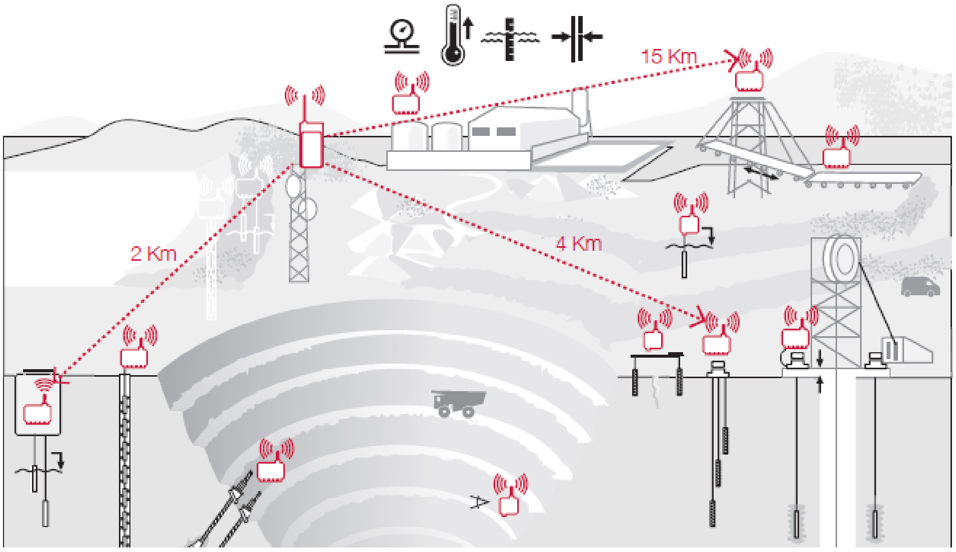


Figure 2 Schematic drawing showing the capacity of the wireless monitoring system presented in this paper to monitor several assets in an open pit mine

The objective of this work is to describe the technical features of a long range wireless low power monitoring system and its implementation at the tailings dam of the Aguas Teñidas mine in Spain (Figure 3).

Figure 3 Aerial view of the Aguas Teñidas mine, South of Spain

2 Aguas Teñidas mine: settings

The Aguas Teñidas mine (Figure 3) is located in the South of Spain, in the Iberian Pyrite Belt (Figure 4). The Iberian Pyrite Belt is one of the zones that divides the South Portuguese Zone, the most meridional terrain in the European Variscan Belt. The massive sulphide deposits at the north of the Iberian Pyrite Belt, where the Aguas Teñidas mine is located, are placed in felsic volcanic rock with a low percentage of shales (Tornos Arroyo 2008).

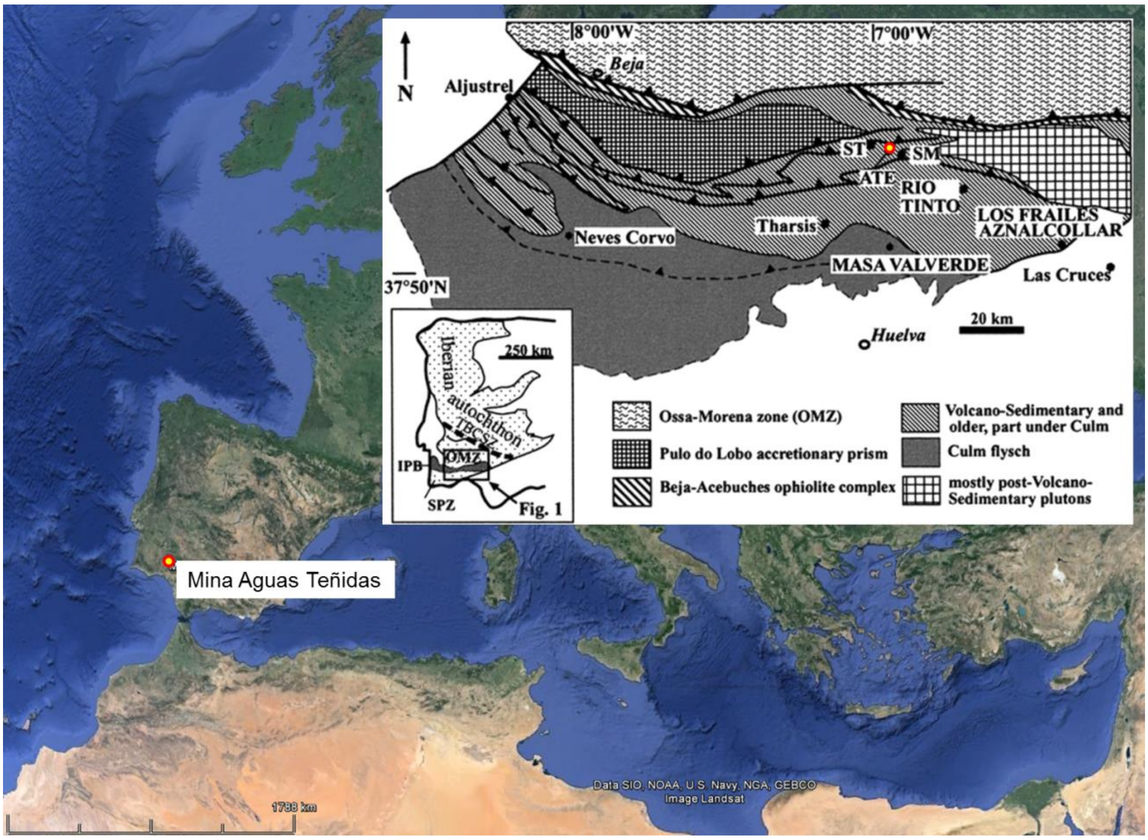


Figure 4 Location of the Aguas Teñidas mine, in the South of Spain (source: Google Earth). In the right upper corner, the location of the mine (dot) in a detailed geological map of the Iberian Pyrite Belt (source: geology.gsapubs.org)

The area is rich in mineral ore, which includes gold, silver, copper, tin, lead and iron, making it interesting for mining exploitation since the Roman era. Aguas Teñidas is an underground exploration mine orebody in a mining district exceeding 250 km where copper and zinc are mined.

The tailings dam is designed to have a maximum height of 36 m (Figure 5) and has been designed as a dual lift. It has been constructed using paste tailings and rock fill, and the slopes are 2Horizontal:1Vertical upstream and 2.5Horizontal:1Vertical downstream, with a crest of 6 m in width. The external layer of paste tailings is approximately 3 m thick. Currently the dam is constructing Phase I, with a maximum height of 20 m.

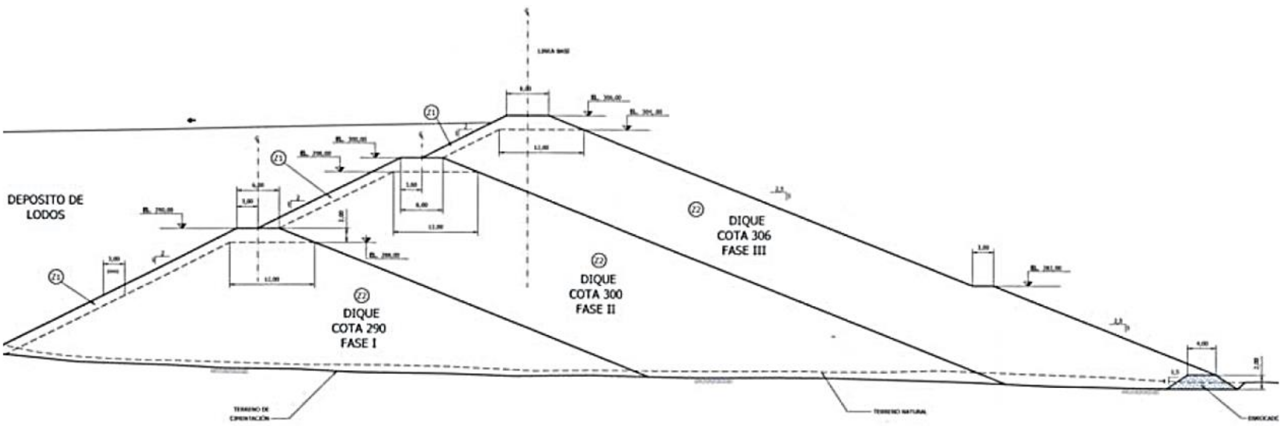


Figure 5 Transverse section of the Aguas Teñidas tailings dam (source: Martínez-Santamaría et al. 2008)

3 Monitoring system

3.1 Sensors

There are several sensors installed around the tailings dam of the Aguas Teñidas mine. A total number of 9 piezometers have been installed between the crest and the base of the dam (Figure 6). The piezometers installed are vibrating wire piezometers, manufactured by Geokon (4500S), with a range of 0.35, 0.7 and 1.0 MPa. The piezometers have been connected to automated monitoring systems and provide the frequency of the vibrating wire which relates to the pore water pressure, and temperature data using a thermistor.

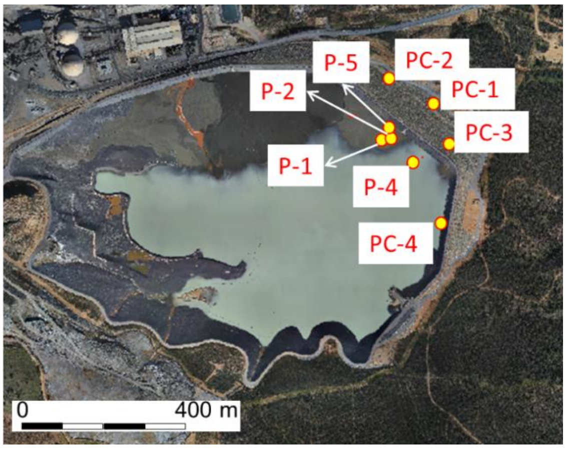


Figure 6 Location of 8 of the 9 piezometers located at the tailings dam of the Aguas Teñidas mine (here only the 8 piezometers that are being monitored with the wireless system are located)

The piezometers are installed at different depths between 1 and 35 m around the dam coronation.

Besides the installed piezometers, there are other existing sensors in the surrounding area of the dam, which may be included in the automated monitoring network in the future.

3.2 Wireless long range and low power monitoring system

Loadsensing LS-G6 is a system of dataloggers and gateways equipped with long range wireless communications. The dataloggers are designed to obtain data from a variety of sensors (voltage, digital, vibrating wire etc.). Data is transmitted wirelessly through radio communications to the gateway, which makes the data available to the clients through the internet.

In this project, the eight piezometers were connected to four wireless dataloggers, allowing remote connectivity to the piezometers through a gateway for internet access. The system architecture is shown in Figure 7.

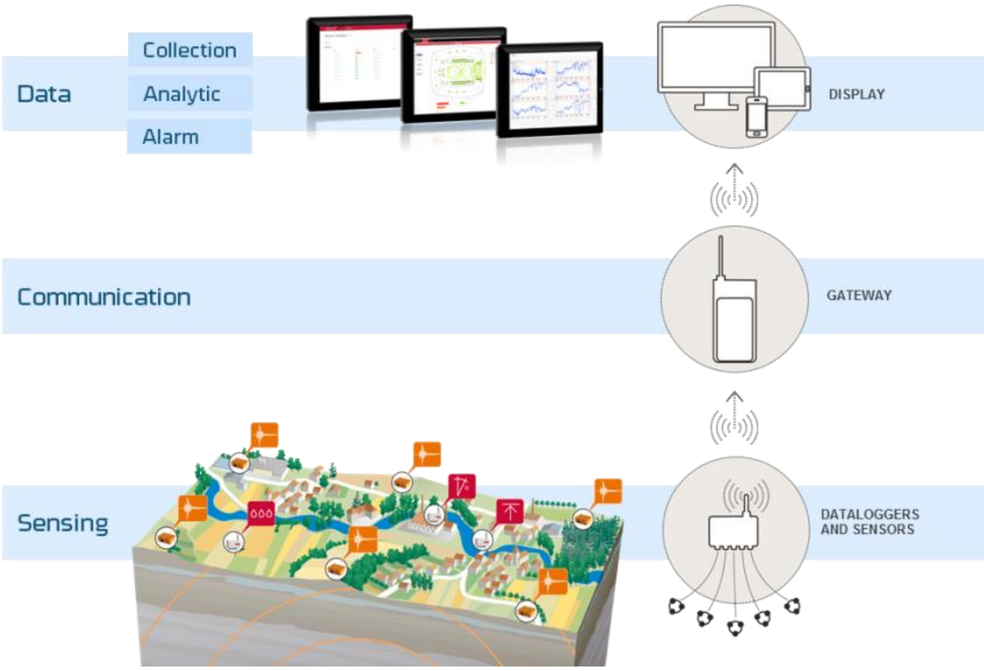
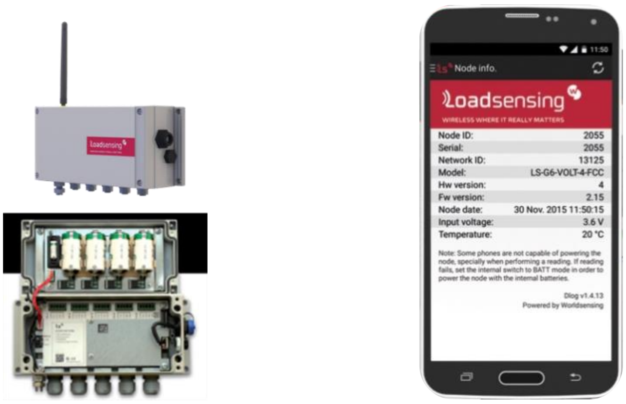


Figure 7 Overview system architecture

The Loadsensing LS-G6 series is designed for data acquisition from sensors with several types of outputs such as vibrating wire, analogue and digital outputs. The vibrating wire datalogger reads the data from the piezometer using spectral analysis (Chirp z-transform). The datalogger is powered by four 3.6 Volt batteries (standard C type). The batteries power the datalogger to execute the measurements and store them, but also power the sensor. The resolution of the datalogger readings is 0.12 Hz, and the accuracy is 0.018% of the full scale. The datalogger performs the readings of the vibration frequency of the vibrating wire and thermistor.

The dataloggers are weatherproof (IP68), re-casing is not required (Figure 8(a)).



(a) (b)

Figure 8 (a) External and internal view of one of the Loadsensing LS-G6 datalogger; (b) view of the Android application DLOG

The configuration of both the piezometers and the dataloggers was done with an Android software (Figure 8(b)). This application permits simple and fast connection to the LS-G6, and the configuration of the sensors and datalogger parameters, such as the sampling frequency.

The data logger networks are structured with a star topology, centred in the gateway (Figure 9). In contrast to other wireless solutions with mesh topology, this product does not require repeaters between the sensors and gateway, since the gateway connects and communicates directly to each datalogger. This is possible due to the long range communications capability that characterises the WS Sub 1GHz radio system.

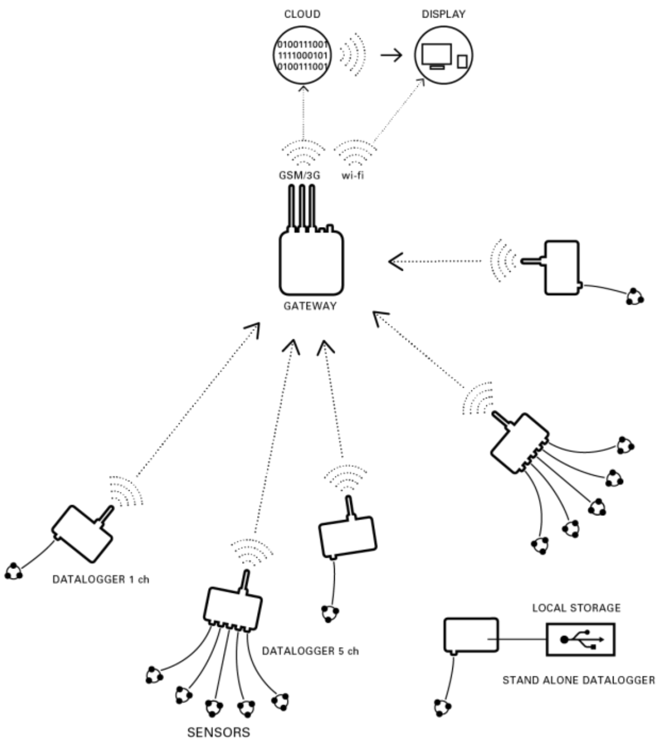


Figure 9 Star topology of Loadsensing networks

Thanks to the long range technology, the relative positions of the gateway and data logger is not a determining factor in the installation. The location of the gateway at the Aguas Teñidas mine offices was sufficient to cover all the communication nodes at the waste dam.

4 Results: monitoring in the tailings dam

4.1 Wireless communication performance

The wireless sensor network in the Aguas Teñidas mine (Figure 10) was deployed gradually, starting on September 2015 and continued over the following months until eight data loggers were deployed by 5 November 2015. The gradual increase of the monitoring network did not require any change of the central station (gateway). As the data loggers were being configured for inclusion in the network (using the specific secure settings of the radio system), they were automatically appearing in the network management software.

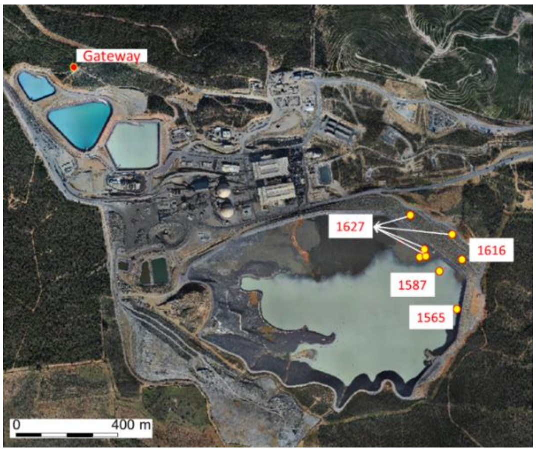


Figure 10 Location of the LS-G6 wireless dataloggers (serial number indicated) and the gateway (at the mine office)

The sampling rates for piezometers PC-1, PC-2, P-1, P-2, P4 were established at 24 hours, while piezometers PC-3 and PC-4 were sampled every hour. Data received from the day of installation of each data logger have been analysed to compare the number of packages received by the gateway against the number of packages transmitted.

Table 1 Details on the installation, sampling rates and parameters of the performance of the radio according the number of packages expected and received

Sensor	Datalogger SN	Distance to gateway (km)	Installation date	Sampling rate	No. of readings (until 04/02/2016)	No. of readings received (until 04/02/2016)	% of readings received
PC-1	1627	1.62	05/11/2015	24 h	92	92	100
PC-2	1627	1.62	05/11/2015	24 h	92	92	100
PC-3	1616	1.83	30/09/2015	1 h	3408	3090	90.67
PC-4	1565	1.92	16/09/2015	1 h	3329	3256	97.81
P-1	1627	1.62	05/11/2015	24 h	92	92	100
P-2	1627	1.62	28/09/2015	24 h	92	92	100
P-4	1587	1.78	05/11/2015	24 h	92	86	93.48
P-5	1627	1.62	05/11/2015	24 h	92	92	100

The radio received between 90 and 100% of the transmitted packages. The data logger that showed the lowest performance is connected to PC-3, which is not the furthest data logger from the gateway. However, this data logger was placed inside a manhole (Figure 11). The manhole cover screened the signal and many transmitted packages were lost. Even with this limitation, 90% of the radio packages were received by the gateway.

Figure 11 Location of datalogger 1616, connected to PC-3

4.2 First results

The sensors were installed at Aguas Teñidas mine between 2008 and 2010. Prior to automated monitoring, the data was manually collected every week or month. The alarm capabilities of a system that is read only once a week or month is limited since tailings dam instability can occur in hours or days. In Figure 12 it can be observed that manual monitoring of the piezometer levels, the data apparently did not exceed the hypothetical alert threshold for several years.

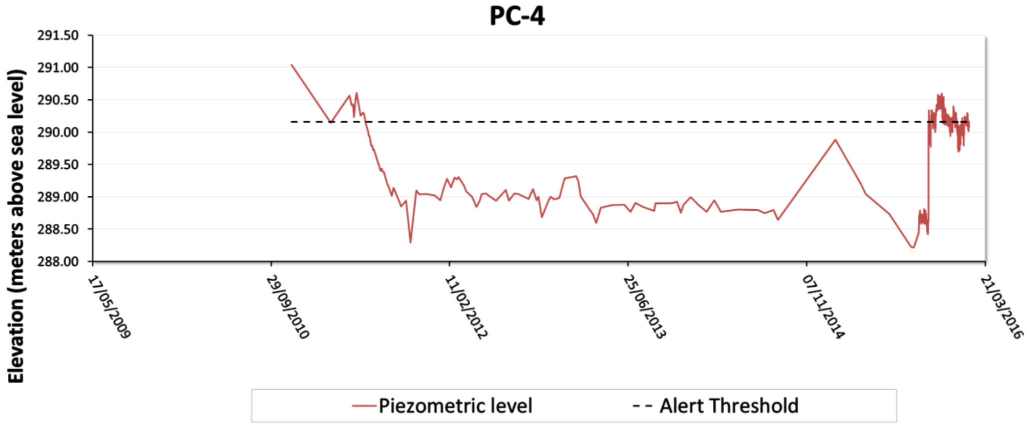


Figure 12 Data from the piezometer PC4 collected since its installation until the 4 February 2016. One hour sampling rate

However, once the data started to be automatically acquired (1 hour sampling rate), hypothetical alert messages were issued. Mine personnel responsible for the monitoring system received notification of the anomalous behaviour, and were able to investigate the causes.

The data of the piezometer P1 (Figure 13) is collected automatically at a 24 hours sampling rate, allowing the mine services to have information to compare against the established alarm threshold. Since the system was installed in November 2015, the readings never exceeded the fixed threshold.

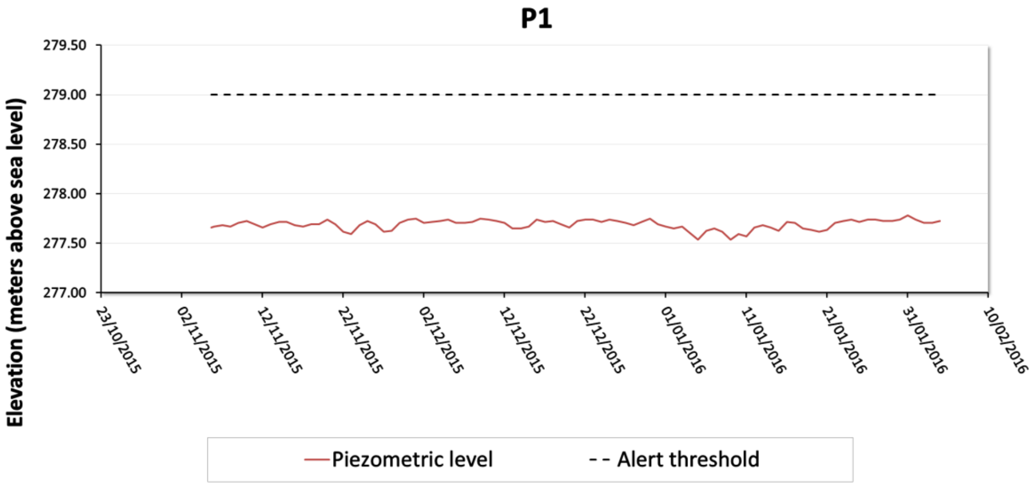


Figure 13 Example of data from piezometer collecting data at 24 hours sampling rate

5 Conclusion

In this paper, the results acquired at the Aguas Teñidas mine situated in the Iberian Pyrite Belt are presented. The wireless sensor network installed between September and November 2015 has shown that the radio performed with a 90 to 100% reliability in terms of the packages received until 4 February 2016. Moreover, a comparison between the monitored data before the installation of the data loggers and the data acquired from November onwards has provided results for alarm capabilities of the system. This provides the opportunity to have detailed data of any potential occurrence of instability at the crest of the mine or the surrounding area.

The case study presented in this work provides information on the capability of the wireless, low power system, which has demonstrated that it is a reliable and robust solution. The advantages of the long range wireless system are efficiency, safety, robustness and flexibility. The network is also easy to upscale and use, and cost effective compared to cable or manual data collection.

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