Technical Note

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Subject	Seismic Monitoring Network Technical Specifications - RevB		

1 Introduction

This note aims to provide the technical performance specifications for the seismic monitoring network that shall be deployed at the salt caverns in Heiligerlee (HL) and Zuidwending (ZW). This seismic monitoring network shall be able to record relevant seismic activity at the salt caverns in order to assess any potential hazard due to operations. We propose a preliminary design for the monitoring network using already available locations.

2 Network Specifications

The monitoring network shall achieve the following performance requirements:

- The monitoring system shall be able to detect and locate all events down to at least a magnitude of -1.0 within an area extending 500m away from the salt caverns;
- The location accuracy (95% confidence intervals) shall be better than 50m horizontally and 150m vertically, in order to be to distinguish which salt cavern the event has occurred in or next to;
- The maximum azimuthal gap in coverage should not exceed 90º, assuming a source at the centre of the network; and
- The monitoring instruments shall record a frequency content wide enough, from 1Hz to 250Hz, in order to record micro tremors as well as possible rock collapse in brine.

The network should incorporate sufficient redundancy so that data quality and analysis capability is not compromised in the event of a reasonable percentage of equipment failure.

3 Instrumentation and Measurements

Measurements and data interpretation shall need to provide reliable determination of microseismic source parameters, such as origin time, magnitude and 3D location (latitude, longitude and depth).

The sensors in the monitoring network should have sufficient sensitivity to reliably resolve ground motion for the smallest magnitude events of interest. The recorded data should have a minimum signal-to-noise ratio of three for an event of the minimum magnitude (-1.0) near the zone of interest, in order to provide reliable identification of seismic phases and corresponding location accuracy. We expect that a noise level and a sensitivity below 0.1 μm/s (or equivalent for hydrophone) shall be required.

The sensors and the digital recording equipment shall have a high dynamic range.

The seismic sensors can be a combination of hydrophones and 3D geophones or accelerometers, in order to optimize the costs of the network, while providing enough information on the failure mechanism and wave propagation attributes, as well as providing data for required location accuracy.

In order to determine the actual ground motion at the sensor locations, the calibration information or instrument response of the sensors and recording equipment shall be provided.

The Contractor shall provide the technical specifications of the instruments that they intend to use in the microseismic monitoring network.

4 System Operation

Real-time data shall be required for the network, which should be fully integrated within the existing KNMI seismic monitoring network. The Contractor shall examine the best option to achieve real-time data coverage, between cable and 4G, which shall involve checking the reliability of the local 4G coverage.

A full and complete metadata shall be created and maintained. This shall include the location of each station and the serial numbers of all instrumentation present as well as the instrument response data, along with a history of any changes to that instrumentation due, for example, to failure.

Continuous data from all stations in the system shall be archived. The archived data shall contain not only the raw data but also the instrument response information. The recorded time series and metadata, both for individual events and the continuous recordings from each site shall be in an internationally recognised format for data exchange.

5 Data Interpretation

The data interpretation methodology should be sufficient to provide a three dimensional view of the events. Each event data point shall include, as a minimum, longitude, latitude, depth, magnitude, time at origin and type of movement.

6 Monitoring Strategy

6.1 Existing Instruments and Possible Locations

Several locations are available to install monitoring instruments either inside salt caverns or at the surface. Figure 1 shows the available surface locations (dark green areas) and available salt caverns.

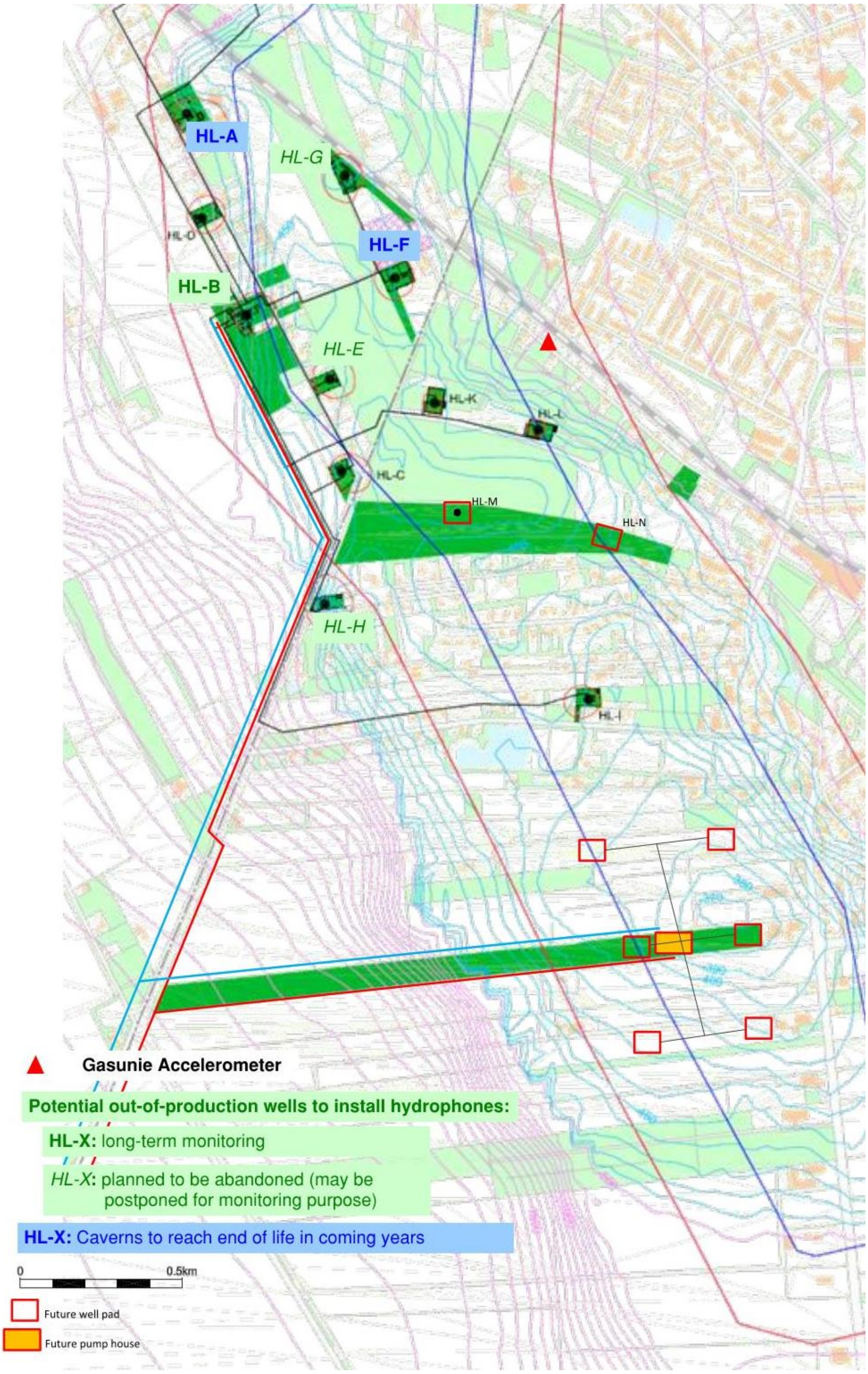

Figure 1: Locations of Gasunie accelerometer, of caverns that could potentially host a recording instrument, presently or in the future. The dark green areas are AzkoNobel property and could potentially be used for installation of surface monitoring equipment.

Gasunie already has an accelerometer in place in the vicinity of the salt caverns and its location is shown in Figure 1 (red triangle). From the recordings at this accelerometer, the noise level is about:

- 2×10^{-5}g in the X direction;
- 5×10^{-5}g in the Y direction; and
- 3×10^{-5}g in the Z direction.

Performance of this accelerometer shall be specified and this accelerometer shall be included in the network design.

For the salt caverns:

- Four caverns are currently available to install monitoring equipment: HL-B, HL-E, HL-G and HL-H (in green in Figure 1);
- Three of these four caverns are planned to be abandoned: HL-E, HL-G and HL-H. However, the plan to abandon these caverns may be postponed for monitoring purposes; and
- Two salt caverns will reach end-of-life in the coming years: HL-A and HL-F (in blue in Figure 1). These caverns could therefore host monitoring instruments in the future, possibly from the caverns that will be abandoned.

6.2 Feasibility Study

The typical approach in designing a seismic network consists in first performing a feasibility study. The feasibility study shall provide different options for seismic network designs, with an estimate of the technical performances for each design. The feasibility study shall provide the following information:

- Number of stations necessary to achieve the required performance specifications;
- Location of the different stations (surface location and depth in the salt caverns); and
- Associated capex plan.

Typically, the feasibility study shall determine whether the performance specifications are achievable by using only the surface locations and caverns available. If it is achievable, the feasibility study shall provide:

- The minimum number of instruments required to achieve the required performance and the corresponding optimum configuration of the recording instruments; and
- The performance (magnitude sensitivity and location accuracy) achievable with a smaller network (with one and two fewer instruments) and the corresponding optimum configuration.

If the required performance is not achievable with the available locations for monitoring equipment, the feasibility study shall provide:

- The performance achieved by networks of four to twelve recording instruments, optimally distributed at the available locations;
- The requirements in terms of monitoring instruments outside of the available locations in order to achieve the required performance.

This information shall support the decision-making process in order to select a network design as fit for purpose as possible, which respecting budget and time constraints.

6.3 Network Design Strategy

Given the sense of urgency to deploy a seismic monitoring network, time needs to be optimised while reaching a compromise between the time taken to install the network, the cost of the network and the technical performance of the network.

When installing a seismic-monitoring network, a progressive approach is the preferred way to reduce the cost. Initially a limited network should be installed, which provides preliminary data on existing noise levels and refine estimates of achievable technical performance. This initial set of data shall then be used to expand the network, if necessary, to a final network. This shall be optimised in terms of technical performance and cost. Even if the initial network needs to be extended, the data from this initial network shall already be useful. This is a way to install a seismic network as quickly as possible. This shall depend on the conclusions of the feasibility study.

KNMI already has some stations in place, as shown in Figure 2, but most of these stations are too far from the salt caverns to provide the expected sensitivity and accuracy. Only G57 may be close enough to be integrated into the local seismic monitoring network.

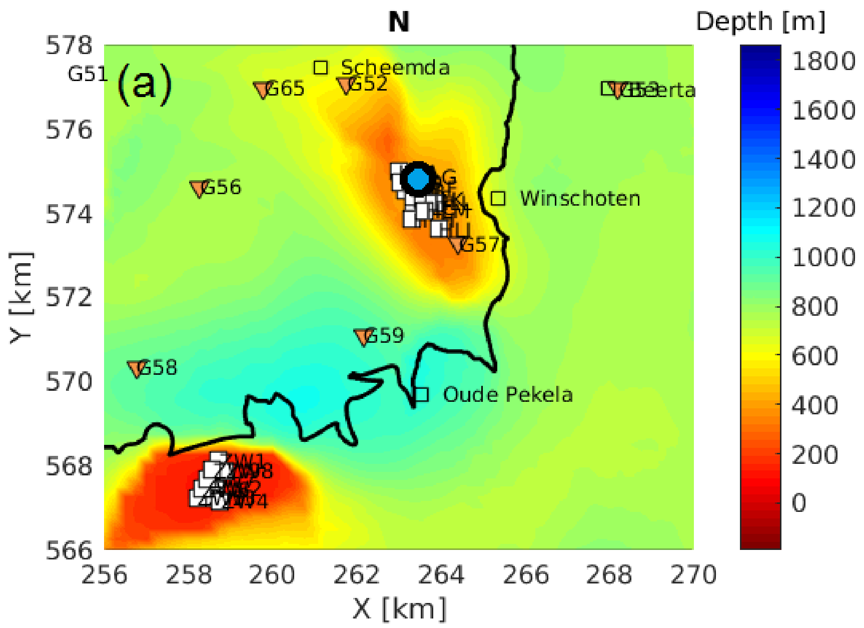

Figure 2: Location of the KNMI seismic stations (orange triangles) with respect to the salt caverns of Heiligerlee (HL) and Zuidwending (ZW). The map's background represents the depth of the North Sea group sediments so that the salt domes appear in red. The border of the Groningen gas field is indicated by the black line.

7 Preliminary Seismic Network Design

To facilitate the development of the network, a preliminary seismic network has been developed to monitor seismic activity within the HL salt dome. The Contractor shall provide a quote on the cost to build such a network and a realistic system commissioning date (date at which the system will be able to start acquiring and providing data). Note that the system shall be in place as soon as possible and not later than 30 September 2018. The Contractor should suggest modifications to this layout, in order to maximise performance. These should be discussed and agreed during an inception meeting.

The preliminary design consists of six three-component (3C) geophones and four hydrophones. Three of the hydrophones are located within the wells of three salt caverns and one is positioned inside the fourth salt cavern, in order to be below the casing shoe in that cavern. The six 3C geophones are located within shallow 20m-deep boreholes (Figure 3). The ten instruments are therefore divided into:

- Four hydrophones, located below the casing shoe of the available caverns:
    - One hydrophone at a depth of 700m inside HL-B;
    - One hydrophone at a depth of 900m inside HL-E;
    - One hydrophone at a depth of 650m inside HL-G; and
    - One hydrophone at a depth of 700m inside HL-H.
- Six 3C 1Hz geophones divided as follows:
    - Four 3C 1Hz geophone located in shallow 20m-deep boreholes next to the boreholes of the salt caverns HL-B, HL-E, HL-G and HL-H; and
    - Two 3C 1Hz geophones located within shallow boreholes, at a depth of 20m, at locations indicated in Figure 3.

The use of the two additional shallow boreholes will provide a better azimuthal coverage of the network.

The depth of the shallow boreholes has been selected at 20m in order to minimize the amount of surface noise and attenuation from Holocene sediments. An analysis of the thickness of Holocene deposits from DINOloket (GeoTop v1.3 geological model) reveals that the thickness of Holocene deposits is less than 3.5m within 2km of the centre of the site (Figure 4) and that the depth of the bottom of the Boxtel (BX) layer is always less than 15m. The depth of 20m therefore ensures that the instruments are located within the Peelo (PE) formation (Figure 4).

The use of 1Hz geophones will enable the monitoring network to capture low frequency signals, while the hydrophones will capture higher frequency content.

Figure 5 provides a cross section of the different caverns and the locations of the hydrophones and geophones in the wells of the selected caverns.

For future development, if the plan to abandon caverns HL-G, HL-E and/or HL-H is adopted, the option to embed 3C geophones in the seal of these caverns shall be considered. The hydrophones may be displaced to caverns HL-A and HL-F when operations in these caverns cease.

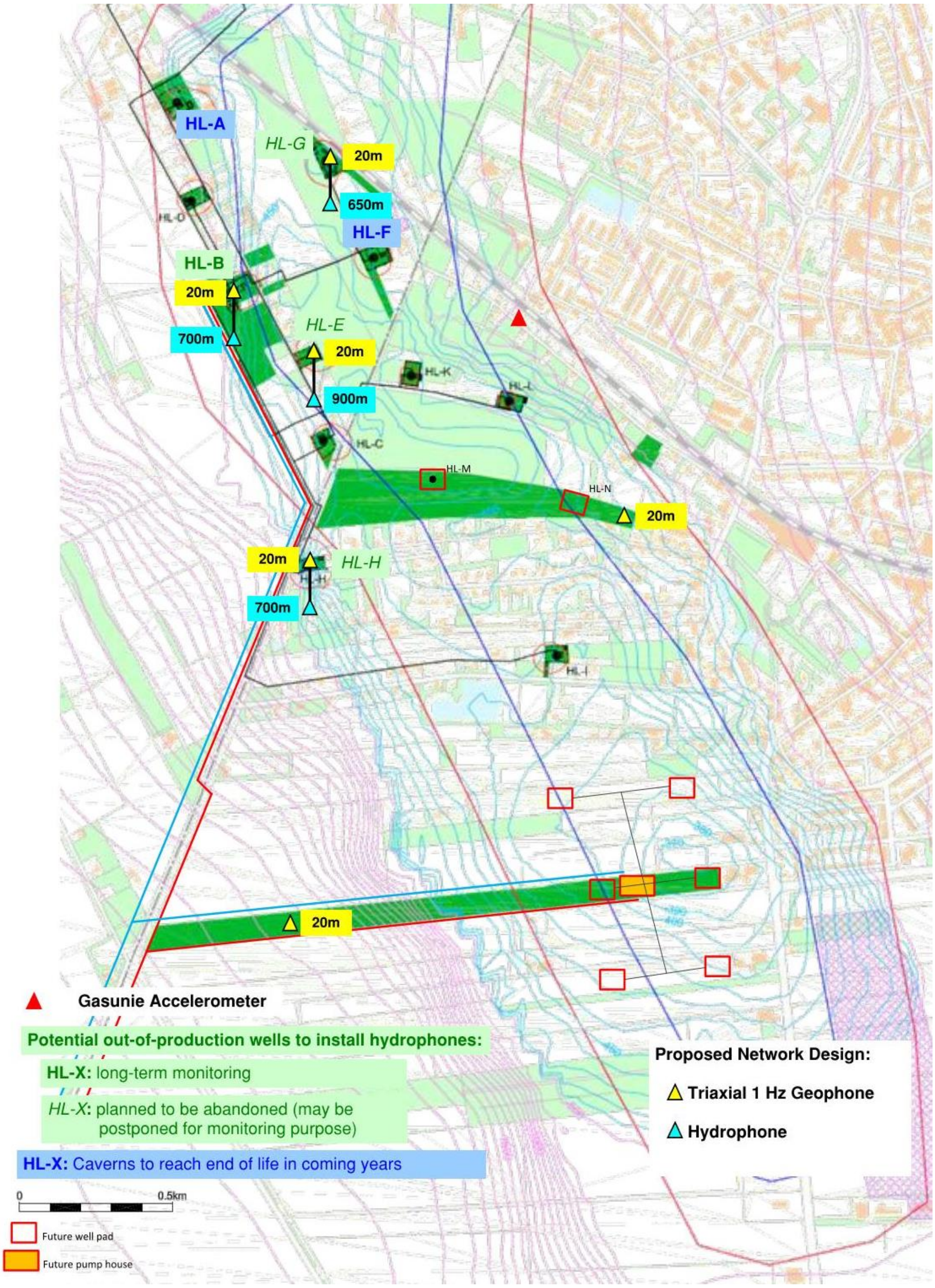

Figure 3: Map showing the location of the 10 instruments proposed in the design of the microseismic monitoring network in the HL salt dome. The depths of the different instruments are indicated in the Figure.

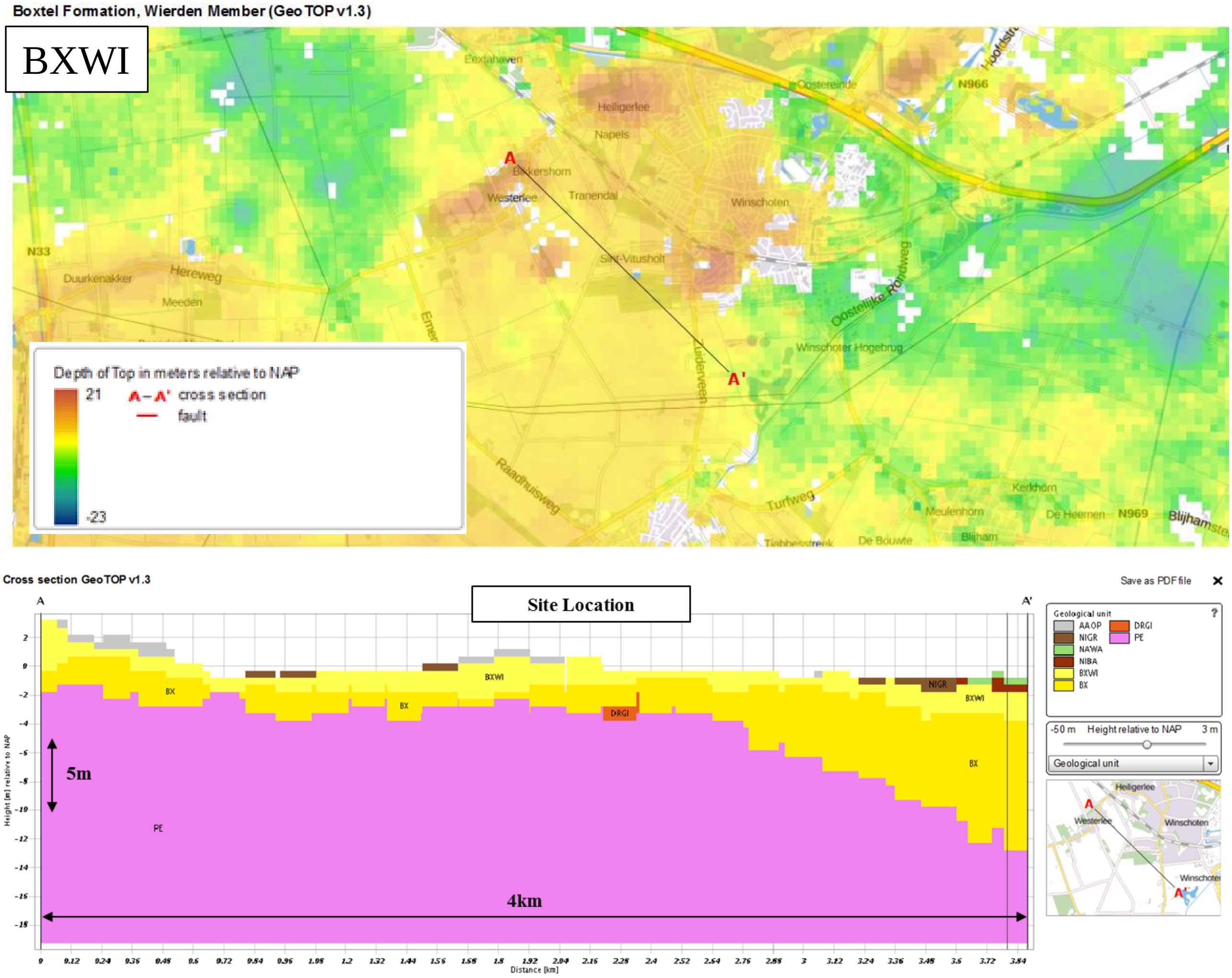

Figure 4: Depth of the top of the Pleistocene sediments (top) and cross-section along the AA' profile (bottom). Note that both BX and PE layers on the cross section are Pleistocene sediments.

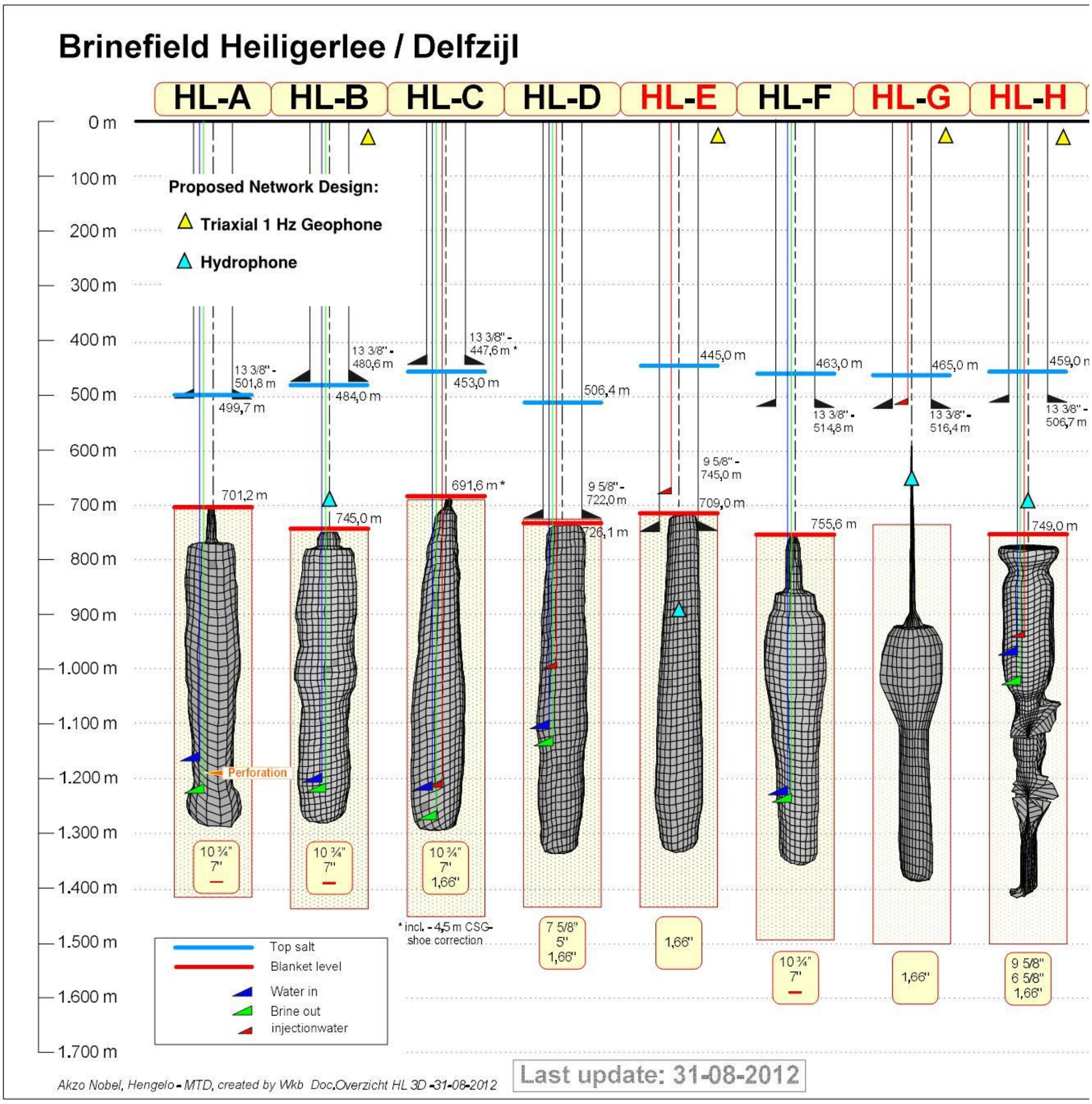

Figure 5: Cross section showing the depth of the instruments installed in or near the wells of the salt caverns.

DOCUMENT CHECKING (not mandatory for File Note)

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