

## Water pressure in the rock and flow measurements

### A7.1 Water pressure measurements in the rock mass

#### A7.1.1 Introduction

The hydraulic properties of the rock, geometry of tunnels and depositions holes, water pressure far away from the tunnels and the hydro-mechanical properties of the backfill and buffer govern the saturation of the buffer and backfill. It is important to measure the water pressure in the rock for the interpretation of the measurements in the buffer and backfill and to sample data useful for the modelling of the saturation process.

This appendix presents the still on-going (2014) measurements in Section I. Section II has been dismantled and pressure measurements are no longer performed there. Any earlier measurements are presented in Goudarzi (2014).

#### A7.1.2 Measurements in the boreholes

A large number of boreholes are instrumented with one or several packers. In all packed-off sections, the water pressure is measured. Each borehole section is connected to a tube of polyamide that via lead-through holes ends in the G-tunnel. All pressure transducers are placed in the G-tunnel to facilitate easy calibration and exchange of transducers that are out of order. The transducers are connected to the HMS system at Äspö Laboratory and it is a flexible system for changing the logging frequency. The maximum scan frequency is 1/second. During periods with no hydraulic tests, preliminary the logging (storing a value in the data base) frequency is 2/hour with an automatic increase of the sampling frequency if the pressure change since last registration is larger than 2 kPa. During hydraulic tests, the sampling frequency is up to 1 logging every 3rd second (maximum logging rate possible).

All data now shown in plots are quality verified data from the SICADA database, which is a change from earlier reports when data was collected from the HMS system itself.

#### A7.1.3 Instrumentation with bentonite packers in Section I

Section I will be in operation for a long time, possibly up to 20 years, and there will be no access to the instruments in the boreholes for a long period. It was decided to develop a new type of packer that was not dependent of an external pressure to seal-off the borehole sections. These packers are made of compacted bentonite with rubber coverage. For chemical reasons the bentonite is not allowed to be in contact with the surrounding water in the rock mass and therefore the packers have a cover made of polyurethane (PUR-rubber). This rubber also protected the packers against unwanted wetting during transport and installation. After installing all packers in a borehole, the compacted bentonite was wetted to make it swell and expanded against the borehole wall. This packer system is used in 14 boreholes with a length between 12 and 50 meters in the tunnel floor and the walls, see Rhén et al. (2001).

Due to the expected high temperature near the deposition holes two boreholes (KA3574A and KA3576A) were equipped with stainless steel pipes instead of polyamide tubes.

In some sections used for circulation or hydrochemistry sampling purposes in Section I, a dummy is installed to reduce the water-filled volume of the section. Depending on the purpose the dummies were made either by high-density polyethylene (circulation sections) or PEEK (hydrochemistry sections) material. The dummy consists of two parts, positioned around the centre rod.

The packers were inserted into the borehole with Ø 20 mm massive stainless steel rods. A special designed manual-hoisting rig was used to insert the equipment into the boreholes. When the packers were at their correct position the equipment was attached to a locking device mounted on the tunnel wall at the borehole collar. Before insertion, the equipment was cleaned with a cleaner delivering hot steam (100°C) at high pressure.

The instrument configuration for the boreholes provided with bentonite packers is summarised in Table A7-1 and illustrated in Figures A7-1 and A7-2.

**Table A7-1. Instrumentation configuration in Section I. “Lead-through”: pipes between the packers.**

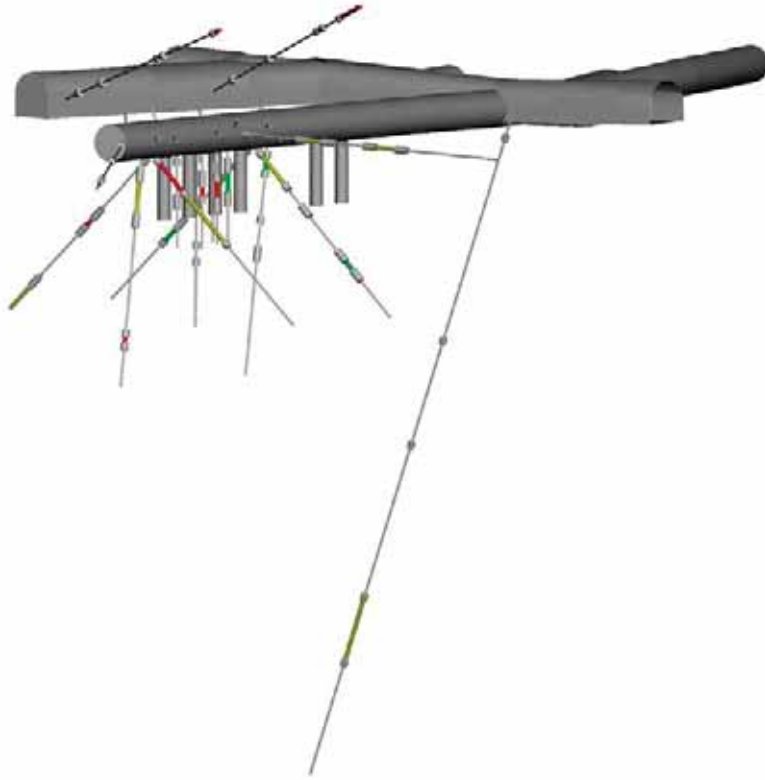
| Borehole:sec | Sec. length (m) | Type of section | Type of dummy | Packer length | Lead-through (no:diameter:type) |
|--------------|-----------------|-----------------|---------------|---------------|---------------------------------|
| KA3563G:1    | 15–30.01        | P               |               | 2 m           | 1:6/4:PA                        |
| KA3563G:2    | 10–13           | P               |               | 2 m           | 2:6/4:PA                        |
| KA3563G:3    | 4–8             | P               |               | 1 m           | 3:6/4:PA                        |
| KA3563G:4    | 1.5–3           | P, C            | HD            | 1 m           | 6:6/4:PA                        |
| KA3566G01:1  | 23.5–30.01      | P               |               | 2 m           | 1:6/4:PA                        |
| KA3566G01:2  | 20–21.5         | P, C            | HD            | 2 m           | 4:6/4:PA                        |
| KA3566G01:3  | 12–18           | P               |               | 2 m           | 5:6/4:PA                        |
| KA3566G01:4  | 7.3–10          | P               |               | 1 m           | 6:6/4:PA                        |
| KA3566G01:5  | 1.5–6.3         | P, F            |               | 1 m           | 8:6/4:PA                        |
| KA3566G02:1  | 19–30.1         | P               |               | 1 m           | 1:6/4:PA                        |
| KA3566G02:2  | 16–18           | P, C            | HD            | 2 m           | 4:6/4:PA                        |
| KA3566G02:3  | 12–14           | P               |               | 1 m           | 5:6/4:PA                        |
| KA3566G02:4  | 8–11            | P               |               | 2 m           | 6:6/4:PA                        |
| KA3566G02:5  | 1.3–6           | P, F            |               | 1 m           | 8:6/4:PA                        |
| KA3572G01:1  | 7.3–12.03       | P               |               | 2 m           | 1:6/4:PA                        |
| KA3572G01:2  | 2.7–5.3         | P, C            | HD            | 2 m           | 4:6/4:PA                        |
| KA3573A:1    | 26–40.07        | P               |               | 2 m           | 1:6/4:PA                        |
| KA3573A:2    | 21–24           | P, F            |               | 2 m           | 3:6/4:PA                        |
| KA3573A:3    | 14.5–19         | P               |               | 2 m           | 4:6/4:PA                        |
| KA3573A:4    | 10.5–12.5       | P, F            |               | 2 m           | 6:6/4:PA                        |
| KA3573A:5    | 1.3–8.5         | P               |               | 1 m           | 7:6/4:PA                        |
| KA3574G01:1  | 8–12.03         | P               |               | 1 m           | 1:6/4:ST                        |
| KA3574G01:2  | 5.1–7           | P               |               | 1 m           | 2:6/4:ST                        |
| KA3574G01:3  | 1.8–4.1         | P, C            | HD            | 1 m           | 5:6/4:ST                        |
| KA3576G01:1  | 8–12.01         | P               |               | 2 m           | 1:6/4:ST                        |
| KA3576G01:2  | 4–6             | P, HC           | PE            | 1 m           | 2:6/4:ST, 1:1/8"/2:PE           |
| KA3576G01:3  | 1.3–3           | P               |               | 1 m           | 3:6/4:ST, 1:1/8"/2:PE           |
| KA3578G01:1  | 6.5–12.58       | P               |               | 1 m           | 1:6/4:PA                        |
| KA3578G01:2  | 4.3–5.5         | P, HC           | PE            | 2 m           | 2:6/4:PA, 1:1/8"/2:PE           |
| KA3579G:1    | 14.7–22.65      | P               |               | 1 m           | 1:6/4:PA                        |
| KA3579G:2    | 12.5–13.7       | P               |               | 1 m           | 2:6/4:PA                        |
| KA3579G:3    | 2.3–11.5        | P               |               | 2 m           | 3:6/4:PA                        |
| KA3584G01:1  | 7–12            | P               |               | 2 m           | 1:6/4:PA                        |
| KA3584G01:2  | 1.3–5           | P               |               | 1 m           | 2:6/4:PA                        |
| KA3590G01:1  | 16–30           | P               |               | 1 m           | 1:6/4:PA                        |
| KA3590G01:2  | 7–15            | P, F, F         |               | 1 m           | 4:6/4:PA                        |
| KA3590G01:3  | 1.3–6           | P, HC           |               | 1 m           | 5:6/4:PA, 1:1/8"/2:PE           |
| KA3590G02:1  | 25.5–30.01      | P, F            |               | 2 m           | 2:6/4:PA                        |
| KA3590G02:2  | 15.2–23.5       | P               |               | 2 m           | 3:6/4:PA                        |
| KA3590G02:3  | 11.9–13.2       | P, HC           | PE            | 2 m           | 4:6/4:PA, 1:1/8"/2:PE           |
| KA3590G02:4  | 1.3–9.9         | P               |               | 1 m           | 5:6/4:PA, 1:1/8"/2:PE           |
| KA3593G:1    | 25.2–30.02      | P               |               | 1 m           | 1:6/4:PA                        |
| KA3593G:2    | 23.5–24.2       | P, HC           | PE            | 1 m           | 2:6/4:PA, 1:1/8"/2:PE           |
| KA3593G:3    | 9–22.5          | P               |               | 2 m           | 3:6/4:PA, 1:1/8"/2:PE           |
| KA3593G:4    | 3–7             | P, F            |               | 2 m           | 5:6/4:PA, 1:1/8"/2:PE           |
| KA3600F:1    | 43–50.1         | P               |               | 1 m           | 1:6/4:PA                        |
| KA3600F:2    | 40.5–42         | P, HC           | PE            | 1 m           | 2:6/4:PA, 1:1/8"/2:PE           |
| KA3600F:3    | 20–39.5         | P               |               | 2 m           | 3:6/4:PA, 1:1/8"/2:PE           |
| KA3600F:4    | 1.3–18          | P               |               | 1 m           | 4:6/4:PA, 1:1/8"/2:PE           |
| KA3510A:1    | 125–150         | P               |               | 1 m           | 1:6/4:PA                        |
| KA3510A:2    | 110–124         | P, F            |               | 1 m           | 3:6/4:PA                        |
| KA3510A:3    | 75–109          | P               |               | 1 m           | 4:6/4:PA                        |
| KA3510A:4    | 51–74           | P               |               | 1 m           | 5:6/4:PA                        |
| KA3510A:5    | 4.5–50          | P               |               | 1 m           | 6:6/4:PA                        |
| KG0021A01:1  | 42.5–48.82      | P, HC           |               | 1 m           | 1:6/4:ST, 1:1/8"/2:PE           |
| KG0021A01:2  | 37–41.5         | P               |               | 1 m           | 2:6/4:PA, 1:1/8"/2:PE           |
| KG0021A01:3  | 35–36           | P, C            | HD            | 1 m           | 5:6/4:PA, 1:1/8"/2:PE           |
| KG0021A01:4  | 19–34           | P               |               | 1 m           | 6:6/4:PA, 1:1/8"/2:PE           |
| KG0021A01:5  | 5–18            | P               |               | 1 m           | 7:6/4:PA, 1:1/8"/2:PE           |
| KG0048A01:1  | 49–54.69        | P, HC           |               | 1 m           | 1:6/4:ST, 1:1/8"/2:PE           |
| KG0048A01:2  | 34.8–48         | P               |               | 1 m           | 2:6/4:PA, 1:1/8"/2:PE           |
| KG0048A01:3  | 32.8–33.8       | P, C            | HD            | 1 m           | 5:6/4:PA, 1:1/8"/2:PE           |
| KG0048A01:4  | 13–31.8         | P               |               | 1 m           | 6:6/4:PA, 1:1/8"/2:PE           |
| KG0048A01:5  | 5–12            | P               |               | 1 m           | 7:6/4:PA, 1:1/8"/2:PE           |

Type of section:

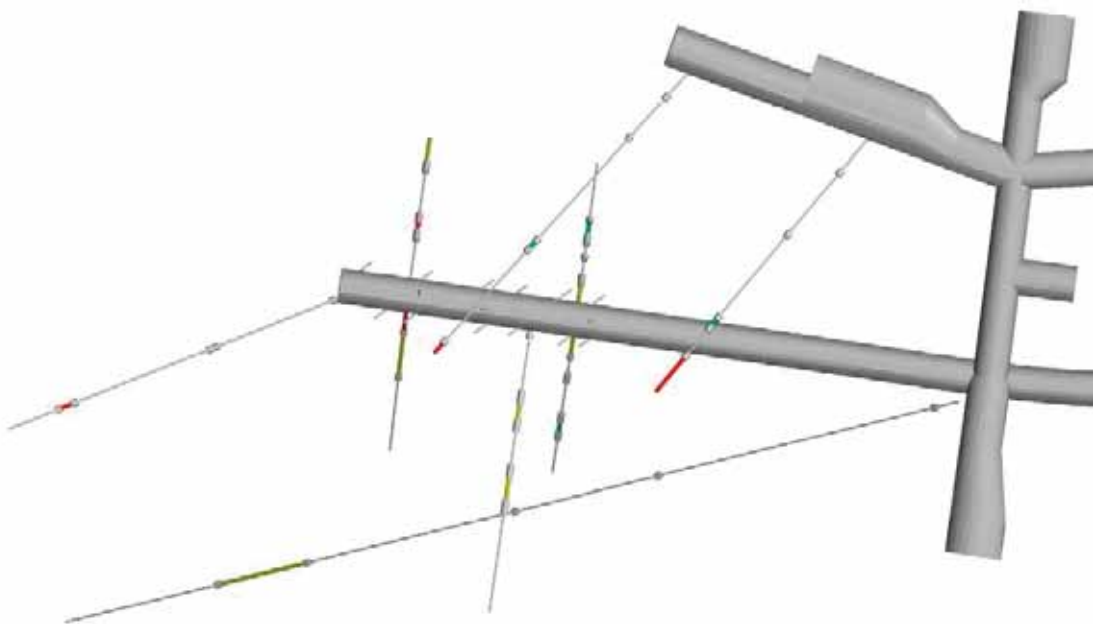
P Pressure measurement  
 C Circulation possible  
 HC Hydrochemistry sampling  
 F Flow

Materials:

PA Polyamide  
 ST Steel  
 PE PEEK  
 HD HD1000 (High Density Polyethylene)



**Figure A7-1.** View of the drilled core holes in the Prototype Repository Section I. The length from the I-tunnel to the end of the TBM-tunnel is 90 m. The diameter of the TBM tunnel is 5 m and the diameter of the deposition holes is 1.75 m. The depth of the deposition holes is 8.37 m in the centre and 8.15 m along the deposition hole wall. The diameter of the core holes is 76 mm except for the short core holes in the roof of the TBM tunnel that have a diameter of 56 mm. The monitoring boreholes used in the presentation in this report are located in the inner part of the tunnel surrounding the area with the four innermost canister holes. Also included are two holes drilled from the G-tunnel and the long hole KA3510A drilled from the main tunnel.



**Figure A7-2.** Overview of Section I in Prototype Repository.

#### A7.1.4 Instrumentation with mechanical packers

In Section 1 sixteen short boreholes (2 m) in the tunnel roof and walls are equipped with mechanical packers, see Table A7-2. After insertion into the hole, the pulling of a nut on the centre pipe expanded the packer. Since these holes are directed upwards, the de-aeration required an extra lead-through connected to a tube ending in the innermost part of the borehole. The de-aeration was made during the backfilling and in boreholes with very little flow the de-aeration was made by filling water through the outer tube.

**Table A7-2. Boreholes instrumented with mechanical packers (“Inclination”: inclination of the borehole).**

| Borehole  | Borehole length (m) | Inclination (°) |
|-----------|---------------------|-----------------|
| KA3563A01 | 2.06                | -7.7            |
| KA3563D01 | approx. 2           | 2.8             |
| KA3563I01 | 2.15                | 73              |
| KA3566C01 | 2.1                 | 3.5             |
| KA3568D01 | 2.3                 | -2.3            |
| KA3573C01 | 2.05                | 34.9            |
| KA3574D01 | 2.05                | 12.6            |
| KA3578C01 | 2.09                | -5.4            |
| KA3578H01 | 1.9                 | 59.1            |
| KA3579D01 | 2                   | -1              |
| KA3588C01 | 2.04                | -4              |
| KA3588D01 | 1.9                 | -1.8            |
| KA3588I01 | 1.96                | 65.6            |
| KA3592C01 | 2.1                 | 4.4             |
| KA3597D01 | 2.22                | 3.1             |
| KA3597H01 | 2.06                | 55.1            |

#### A7.1.5 Calibration intervals

Recalibration of pressure transducers are made a couple of times every year.

#### A7.1.6 Pressure measurements

In this section pressure measurement of all monitored holes in the Prototype repository is shown in plots below. The pressure values plotted are daily mean values. The definition of day 0 is the day the heating of canister 1 started, i.e. 2001-09-17. In Table A7-3 the dates of the starting of the heaters in Section 1 are presented.

**Table A7-3. Heaters in canisters.**

| Canister in deposition hole | Started    | Stopped    |
|-----------------------------|------------|------------|
| 1 (DA3587G)                 | 2001-09-17 |            |
| 2 (DA3581G)                 | 2001-09-24 | 2004-12-01 |
| 3 (DA3575G)                 | 2001-11-10 |            |
| 4 (DA3569G)                 | 2001-11-24 |            |

The position of pressure measurement is indicated for all observation sections.

In general sections close to the prototype rock wall indicate lower pressure head than further away from the prototype.

In the longer holes the section closest to the wall has a lower head than sections deeper into the rock mass.

A pressure drop 2002-05-07 for most of the observation sections are shown in the plots. The most major pressure change happens in the lowest section of KA3566G02 (approx. 70 m) but are also clearly visible for Section 2-4 of the same borehole. The pressure recovered during the evening of 2002-12-02. The cause for the pressure change is unknown.

Several sections have had a slight decreasing trend since the summer of 2002. This trend was in most cases discontinued after 2004-11-01 when the draining of Section I was closed down.

During the period 2003-05-08 until 2003-05-15 a total of 19 hydraulic tests (TC 1) were done in several of the boreholes in Section I and II. The tests caused groundwater pressure interference in the whole of the prototype repository area. Since the tests were mostly short-time tests it is only shown in some of the borehole section plots.

During the summer 2003 (2003-07-13 to 2003-08-05) no pressure data was recorded. In some of the long boreholes inclined to the south of the prototype show a pressure drop in mid-August.

Hydraulic single hole tests were done in nine boreholes during 2003-10-21–10-23 (TC 2). The tests caused groundwater pressure interference in the whole of the prototype repository area. Since the tests were mostly short-time tests it is only shown in some of the borehole section plots.

Hydraulic single hole tests were done in eight boreholes during 2004-02-02–02-04 (TC 3). The tests caused groundwater pressure interference in the whole of the prototype repository area. Since the tests were mostly short-time tests it is only shown in some of the borehole section plots.

A pressure drop of around 700 kPa in KA3566G01:4 is observed 2004-02-25. It remained so for some weeks before recovering, but dropped again in May and remains that way at the end of the month. This pattern was observed in this section during the spring 2003. The following investigation showed a faulty data-scan coupling (corrosion) which was replaced 2004-08-10.

Hydraulic single hole tests were done in eight boreholes during 2004-08-11–08-18 (TC 4). The tests caused groundwater pressure interference in the whole of the prototype repository area. Since the tests were mostly short-time tests it is only shown in some of the borehole section plots.

During the period 2005-01-19 until 2005-01-28 a total of 26 hydraulic tests (TC 5) were done in several of the boreholes in Section I and II. The tests caused groundwater pressure interference in the whole of the prototype repository area. Since the tests were mostly short-time tests it is only shown in some of the borehole section plots.

During week 36, starting 2005-09-05, several boreholes have a rather sudden drop in pressure which does not recover immediately. The reason is not known yet.

Hydraulic single hole tests were done in eight boreholes during 2005-11-28–12-02 (TC 6). A total of 17 tests were done. The tests caused groundwater pressure interference in the whole of the prototype repository area. Since the tests were mostly short-time tests it is only shown in some of the borehole section plots.

In KA3573A the pressure in Section 3 suddenly decreases around 200 kPa 2006-02-12/13. This is the initial phase as it turned out later, see below, of the total pressure loss of that section.

In KA3566G01 Sections 2 and 3, and 4 and 5 respectively are short-cut from 2006-03-03. The reason is not known.

A pressure drop in several borehole sections on the south side of the prototype repository is observed from approximately 2006-04-18. At the same time the drainage from Section 1 increases from 1.5 to 9 L/min. Section KA3573A:3 which lost most of its pressure head is believed to lead groundwater, together with sections KA3573A:2 & 4, into the Section 1 backfill. In earlier investigations this borehole had flow rates over 50 L/min (Rhen and Forsmark 2001). The following borehole/sections are affected by this pressure drop event: KA3510A:3-5, KA3566G01:1, KA3573A:2-4, KA3590G01:1-2, KG0021A01:1-4 and KG0048A01:1-4. The pressure decrease is probably a result of a leaking tube or a tube coupling from KA3573A:3. The pressure in KA3573A:3 is now at the same level as the pressure in the backfill (around 500 kPa).

Hydraulic single hole tests were done in eight boreholes during 2006-09-25–09-29 (TC 7). A total of 17 tests were done. The tests caused groundwater pressure interference in the whole of the prototype repository area. Since the tests were mostly short-time tests it is only shown in some of the borehole section plots.

In November/December 2006, dilution measurements were made KA3563G:4, KA3566G01:2, KA3566G02:2, KA3572G01:2, KA3574G01:3, KG0021A01:3 and KG0048A01:3.

The work with excavating a new tunnel niche from I-niche, for sealing experiments, commenced in March 2007. The project is called “Sealing of Tunnel at Great Depth”. Since it is situated rather close to the Prototype Repository it is expected to influence the pressure levels around the prototype.

During the period March–December 2007, the drilling and testing of three boreholes in niche I, KI0010B01, KI0014B01 and KI0016B01 causes major pressure head fluctuations in most of the observation sections in the prototype repository. The overall groundwater head level decreases during this period but late in the period seems to recover. The new boreholes are drilled within the project “Sealing of Tunnel at Great Depth”.

The pressure transducers in KA3510A were taken out of operation 2007-08-20. The reason is the on-going tunnel construction works in the I-niche. They were taken in operation again in August 2008.

KA3566G02 transducers do not seem to work properly since the start of the “Sealing of Tunnel at Great Depth” project in the summer of 2007.

Hydraulic single hole tests were done in eight boreholes during 2007-10-15–10-19 (TC 8). A total of 17 tests were done. The tests caused some groundwater pressure interference in the prototype repository area.

The pressure in KA3574G01:2 suddenly start rising from 2008-08-30.

Hydraulic single hole tests were done in eight boreholes during 2008-10-20–10-24 (TC 9). A total of 17 tests were done.

Fan grouting was done in the project “Sealing of Tunnel at Great Depth” during several periods during the spring 2009.

There is a sudden pressure decrease in KA3510A:1 and KA3510A:2 2009-04-16 which last until 2009-05-07.

No pressure recordings are made in HMS between 2009-05-23 and 2009-06-11.

During the period 2009-11-09 until 2009-11-19 six interference-tests (TC 10) were done in boreholes KA3539G:2, KA3542G02:5, KA3554G01:2, KA3590G02:1, KG0021A01:3 and KG0048A01:3. Flowing periods were 6 hours for each of the boreholes.

The general pressure trend is decreasing pressures since January 2008.

Pressure increases occurs KA3588C01:1 and KA3588D01 during the months of January and February 2010. It decreases after a while. The reason is unknown.

Preparations for demolition of the outer plug, Section II, started at the end of November 2010. During 2010-11-23 and 2010-11-24 groundwater sampling is made from several boreholes within the prototype Section I and II. A pressure decrease is clearly seen in the plots for several of the observation sections in both sections.

Demolition work of the outer plug of Section II started during December 2010 and was finalized during February 2011. The work was done by drilling several boreholes into the concrete plug continued by mechanical impact with a hydraulic hammer and a hydraulic breaker. All demolition work in the tunnel section II was finalized by 2011-12-15.

The boreholes in Section I closest to the plug between Section I and II show an obvious pressure drop during 2011 due to the demolition of Section II. The pressure recovers during 2012.

The pressure recovery has continued during 2013.

A pressure drop occurs in the period close to 2013-11-01 in almost all of the remaining borehole-sections of the Prototype Section I. The reason for this remains unknown so far.

In Table A7-4 the pressure sensor status 2014-01-01 is estimated based on pressure head data.

**Table A7-4. Apparent pressure sensor status.**

| Borehole:sec | Secup (m) | Seclow (m) | Pressure status<br>2014-01-01 | Comment  |
|--------------|-----------|------------|-------------------------------|--|
| KA3510A:1    | 125.00    | 150.00     | OK                            |  |
| KA3510A:2    | 110.00    | 124.00     | OK                            |  |
| KA3510A:3    | 75.00     | 109.00     | OK                            |  |
| KA3510A:4    | 51.00     | 74.00      | Not OK                        | Pressure very low since June 2010              |
| KA3510A:5    | 4.50      | 50.00      | OK                            |  |
| KA3563A01:1  | 0.65      | 2.06       | OK                            |  |
| KA3563D01:1  | 0.65      | 2.01       | OK                            |  |
| KA3563G:1    | 15.00     | 30.01      | OK                            |  |
| KA3563G:2    | 10.00     | 13.00      | OK                            |  |
| KA3563G:3    | 4.00      | 8.00       | OK                            |  |
| KA3563G:4    | 1.50      | 3.00       | OK                            |  |
| KA3563I01:1  | 0.65      | 2.15       | OK                            |  |
| KA3566C01:1  | 0.65      | 2.1        | OK                            |  |
| KA3566G01:1  | 23.50     | 30.01      | OK                            |  |
| KA3566G01:2  | 20.00     | 21.50      | OK                            |  |
| KA3566G01:3  | 12.00     | 18.00      | OK                            |  |
| KA3566G01:4  | 7.30      | 10.00      | Not OK                        | Shortcut between sections 4 and 5              |
| KA3566G01:5  | 1.50      | 6.30       | Not OK                        | Shortcut between sections 4 and 5              |
| KA3566G02:1  | 19.00     | 30.10      | Not OK                        | Pressure drop May 2007. All sections shortcut! |
| KA3566G02:2  | 16.00     | 18.00      | Not OK                        | Pressure drop May 2007. All sections shortcut! |
| KA3566G02:3  | 12.00     | 14.00      | Not OK                        | Pressure drop May 2007. All sections shortcut! |
| KA3566G02:4  | 8.00      | 11.00      | Not OK                        | Pressure drop May 2007. All sections shortcut! |
| KA3566G02:5  | 1.30      | 6.00       | Not OK                        | Pressure drop May 2007. All sections shortcut! |
| KA3568D01:1  | 0.65      | 2.30       | OK                            |  |
| KA3572G01:1  | 7.30      | 12.03      | OK                            |  |
| KA3572G01:2  | 2.70      | 5.30       | OK                            |  |
| KA3573A:1    | 26.00     | 40.07      | Not OK                        | Probable tube failure in section 3             |
| KA3573A:2    | 21.00     | 24.00      | Not OK                        | Probable tube failure in section 3             |
| KA3573A:3    | 14.50     | 19.00      | Not OK                        | Probable tube or tube coupling failure         |
| KA3573A:4    | 10.50     | 12.50      | Not OK                        | Probable tube failure in section 3             |
| KA3573A:5    | 1.30      | 8.50       | Not OK                        | Probable tube failure in section 3             |
| KA3573C01:1  | 0.65      | 2.05       | OK                            |  |
| KA3574D01:1  | 0.65      | 2.05       | OK                            |  |
| KA3574G01:1  | 8.00      | 12.03      | OK                            |  |
| KA3574G01:2  | 5.10      | 7.00       | Not OK?                       | Sudden pressure increase 2008-08-30            |
| KA3574G01:3  | 1.80      | 4.10       | OK                            |  |
| KA3576G01:1  | 8.00      | 12.01      | OK                            |  |
| KA3576G01:2  | 4.00      | 6.00       | Not OK?                       | Pressure decrease starting Jan. 2009           |
| KA3576G01:3  | 1.30      | 3.00       | OK                            |  |
| KA3578C01:1  | 0.65      | 2.09       | OK                            |  |
| KA3578G01:1  | 6.50      | 12.58      | OK?                           | Shortcut between sections                      |
| KA3578G01:2  | 4.30      | 5.50       | OK?                           | Shortcut between sections                      |
| KA3578H01:1  | 0.65      | 1.90       | OK                            |  |
| KA3579D01:1  | 0.65      | 2.00       | Not OK                        | Air in borehole section?                       |
| KA3579G:1    | 14.70     | 22.65      | OK?                           | Shortcut between sections                      |
| KA3579G:2    | 12.50     | 13.70      | OK?                           | Shortcut between sections                      |
| KA3579G:3    | 2.30      | 11.50      | Not OK                        | Air in borehole section?                       |
| KA3584G01:1  | 7.00      | 12.00      | OK                            |  |

**Table A7-4. Continued.**

| Borehole:sec | Secup (m) | Seclow (m) | Pressure status<br>2014-01-01 | Comment                      |
|--------------|-----------|------------|-------------------------------|------------------------------|
| KA3584G01:2  | 1.30      | 5.00       | OK                            |                              |
| KA3588C01:1  | 0.65      | 2.04       | OK                            |                              |
| KA3588D01:1  | 0.65      | 1.90       | Not OK                        | Not in operation any longer? |
| KA3588I01:1  | 0.65      | 1.96       | OK                            |                              |
| KA3590G01:1  | 16.00     | 30.00      | Not OK?                       | Shortcut between sections.   |
| KA3590G01:2  | 7.00      | 15.00      | Not OK?                       | Shortcut between sections.   |
| KA3590G01:3  | 1.30      | 6.00       | OK                            |                              |
| KA3590G02:1  | 25.50     | 30.01      | OK                            |                              |
| KA3590G02:2  | 15.20     | 23.50      | OK                            |                              |
| KA3590G02:3  | 11.90     | 13.20      | OK                            |                              |
| KA3590G02:4  | 1.30      | 9.90       | OK                            |                              |
| KA3592C01:1  | 0.65      | 2.01       | Not OK?                       | Air in borehole section?     |
| KA3593G:1    | 25.20     | 30.02      | Not OK                        | Very low pressure in section |
| KA3593G:2    | 23.50     | 24.20      | OK                            |                              |
| KA3593G:3    | 9.00      | 22.50      | OK                            |                              |
| KA3593G:4    | 3.00      | 7.00       | OK                            |                              |
| KA3597D01:1  | 0.65      | 2.22       | Not OK?                       | Air in borehole section?     |
| KA3597H01:1  | 0.65      | 2.06       | OK                            |                              |
| KA3600F:1    | 43.00     | 50.10      | OK                            |                              |
| KA3600F:2    | 40.50     | 42.00      | OK                            |                              |
| KA3600F:3    | 20.00     | 39.50      | OK                            |                              |
| KA3600F:4    | 1.30      | 18.00      | OK                            |                              |
| KG0021A01:1  | 42.50     | 48.82      | OK                            |                              |
| KG0021A01:2  | 37.00     | 41.50      | OK                            |                              |
| KG0021A01:3  | 35.00     | 36.00      | OK                            |                              |
| KG0021A01:4  | 19.00     | 34.00      | OK                            |                              |
| KG0021A01:5  | 5.00      | 18.00      | OK                            |                              |
| KG0048A01:1  | 49.00     | 54.69      | OK                            |                              |
| KG0048A01:2  | 34.8      | 48         | OK                            |                              |
| KG0048A01:3  | 32.80     | 33.80      | OK                            |                              |
| KG0048A01:4  | 13.00     | 31.80      | OK                            |                              |
| KG0048A01:5  | 5.00      | 12.00      | OK                            |                              |

### A7.1.7 Drainage of Section I

The drainage system in Section I was shut down 2004-11-01. It resulted in a major pressure increase in most borehole sections close to the prototype tunnel. The pressure increased until 2004-12-06.

The drained water amount was approximately 2.5 L/min. The flow rate of weir MG0004G decreased accordingly with the same order of magnitude after November 1.

The drainage system was re-opened 2004-12-06 due to electrical problems with the canister heaters. It is still open (2009-06-01). The pressure in most borehole sections within Section I decreased rapidly again after the re-opening.

In mid-April 2006 the flow rate from Section I rather suddenly increase to 9 L/min, while pressure decreases in several boreholes on the south side of the prototype. This is a result of tube failure in borehole section KA3573A:3.

The flow rate from Section I was still around 9 L/min at the end of 2010.



### **A7.1.8 Flow measurements**

Earlier estimations and measurements of in-leaking ground water amounts to the tunnel system are presented in Forsmark et al. (2001) and Rhén and Forsmark (2001).

Data from eleven flow weirs are presented in this data report, out of which six is currently (2014) in operation.

A weir at the tunnel G opening measures the inleaking amounts from this tunnel. The weir was taken in operation in January 2002-01-21 and is named MG0004G. The water from MG0004G is led to PG5. The pumped water amounts from Section I mentioned above was prior to November 1, 2004, when the drainage of Section I was closed down, included in the rates from this weir station which is clearly shown in the diagram below. The packer or tube failure of KA3573A:3 2006-04-18 resulted in an increase of water being drained from Section 1 due to the fact that groundwater in the rock got contact with the backfill in section 1 via the borehole. Until the beginning of 2006 the trend was decreasing.

The weir MF0061G halfway down tunnel F measures today the in-leaking amounts from the first half of tunnel F, see plot of this weir. Earlier, until autumn 2001, in-leaking water from tunnel G was led to tunnel F and weir MF0061G thereby to some extent explaining the high flow rate during that period. The in-leaking water in tunnel J+ is included in the flow rate of MF0061G.

The weir MA3426G measures the flow rates from the south part of tunnel J and tunnel at chainage 3,426–3,514 m. Until December 2003 the in-leaking amounts from tunnel section 3,515–3,600 was included in the presented flow rate. The in-leaking water in tunnel I is included in this weir's flow rate.

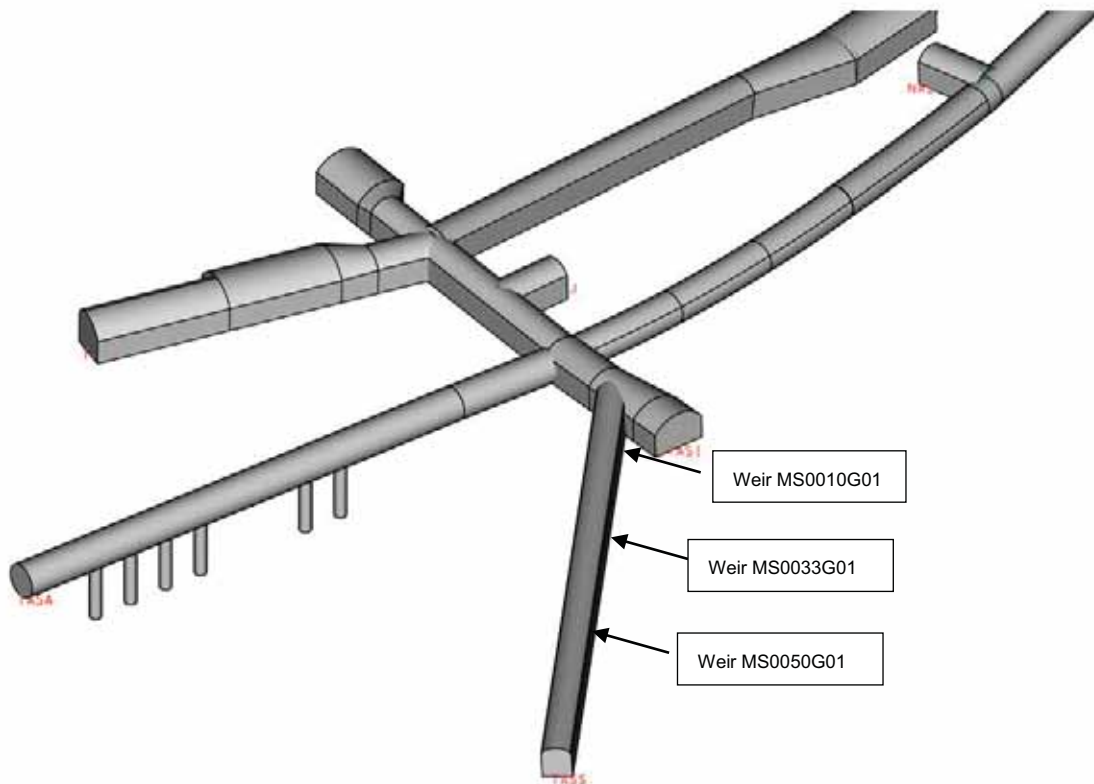
In December 2003 three new flow measurement weirs were constructed in the A-tunnel outside Section II plug. They are called MA3515G, MA3525G and MA3535G (in operation 2003-12-10). The water from these three weirs is led to MA3426G. Continuous measurement is done since the spring of 2004. Manual measurements done in December 2003 show a flow rate for MA3515G of 0.175–0.19 L/min, for MA3525G of 1.15–1.25 L/min and for MA3535G of 0.38–0.45 L/min. The increase of flow during October 2004 was caused by yet unknown causes, but it is believed that the final grouting that was done around Plug 2 October 8, 2004 is the cause to it. The flow rates have now decreased once again.

Two weirs have, during the winter 2004/2005, been constructed inside niches I and J+. They are called MI0008G (in operation 2005-01-20) and MJ0033G (in operation 2005-01-20) respectively. The water from MI0008G is led to MA3426G. The water from MJ0033G is led to MF0061G. MI0008G is included in the continuously measurement program (HMS) while MJ0033G is measured manually approximately every fortnight. The readings from MI0008G have however not been correct since August 2005 and therefor no readings are presented since then. Manual readings will be made in the future. A manual reading 2006-06-26 shows a flow of 2.85 L/min which is within the same order of magnitude as the flow readings of the pre-August 2005 period.

MI0008G was plugged 2007-08-02 during the preparations of the construction of Tunnel S which will start inside niche I and the water is led to MA3426G.

The automatic registration of flow in MA3515G, MA3525G and MA3535G were cancelled during autumn 2007 due to the on-going tunnel construction work in the I-niche. The registration was resumed in April 2008 and continued until November 2010 when preparation started for the demolishing work of Prototype Section II.

No measurement of the flow into the A-tunnel from the intersection with tunnel I-J and the inner prototype plug is made today (2014). An attempt to construct a measurement weir 4–7 meters from the plug was made a couple of years ago (2012?) but the flow was very low and was not possible to quantify with the methodology available.



**Figure A7-3.** The tunnel-system including the TASS-tunnel with indication of the weir locations in TASS.

The flow rate in MA3426G has been extremely high during the period June until November 2007. This is due to that in-leaking water from the new boreholes KI0010B01 and KI0016B01 together with the water previously measured in MI0008G is led to MA3426G. A single rate measurement 2007-10-18 gives a flow rate from KI0010B01 of 44 L/min and from KI0016B01 of 7 L/min.

The pre-investigations for TASS resulted in major in-leaking amounts through the three long core holes drilled in the planned direction of TASS. During this period the in-leaking accumulated initial flow rates from the three boreholes was approximately 230 L/min, but the overall flow rate during the period until they were grouted was approximately 65 L/min which is the increase of flow in weir MA3426G where the water was directed.

Three weirs are located within the TASS-tunnel and their locations are shown in Figure A7-3 above, measuring the flow into sections 10–33 m, 33–50 m and 50–80.7 m respectively.

#### **A7.1.9 Water sampling**

Water sampling for chemical analysis have been done at several occasions, see Table A7-5. Each one of them may have a short-lived effect on the hydrostatic pressure in the rock mass. In some cases the flowing of a section continued for several days and the following pressure response is clearly shown in the subsequent plot.

**Table A7-5. Water sampling dates in boreholes close to the Prototype Repository. Start and stop of times are for the flowing of the section.**

| Borehole  | Start date/time     | Stop date/time      | Secup  | Seclow | Section number         |
|-----------|---------------------|---------------------|--------|--------|------------------------|
| KA3600F   | 2001-10-15 10:30:00 | 2001-10-15 10:45:00 | 40.50  | 42.00  | 2                      |
| KA3600F   | 2001-10-15 10:45:00 | 2001-10-15 11:15:00 | 43.00  | 50.10  | 1                      |
| KA3573A   | 2002-09-24 10:30:00 | 2002-09-24 11:00:00 | 26.00  | 40.07  | 1                      |
| KA3573A   | 2002-09-24 11:40:00 | 2002-09-24 13:40:00 | 21.00  | 24.00  | 2                      |
| KA3600F   | 2002-09-25 11:00:00 | 2002-09-25 13:40:00 | 40.50  | 42.00  | 2                      |
| KA3600F   | 2002-09-25 11:25:00 | 2002-09-25 11:44:00 | 43.00  | 50.01  | 1                      |
| KA3510A   | 2002-12-12 08:30:00 | 2002-12-12 08:50:00 | 4.50   | 50.00  | 5                      |
| KA3510A   | 2002-12-12 08:30:00 | 2002-12-12 08:52:00 | 110.00 | 124.00 | 2                      |
| KA3510A   | 2002-12-12 10:30:00 | 2002-12-12 11:04:00 | 75.00  | 109.00 | 3                      |
| KG0048A01 | 2003-06-03 10:06:00 | 2003-06-03 10:12:00 | 32.80  | 33.80  | 3                      |
| KA3566G02 | 2003-06-04 12:30:00 | 2003-06-04 17:30:00 | 16.00  | 18.00  | 2                      |
| KG0021A01 | 2003-06-30 11:03:00 | 2003-06-30 11:09:00 | 35.00  | 36.00  | 3                      |
| KA3600F   | 2003-07-03 13:51:00 | 2003-07-03 13:53:00 | 40.50  | 42.00  | 2                      |
| KA3572G01 | 2003-08-11 15:28:00 | 2003-08-28 15:00:00 | 2.70   | 5.30   | 2                      |
| KG0021A01 | 2003-09-18 09:40:00 | 2003-09-18 09:55:00 | 35.00  | 36.00  | 3                      |
| KG0048A01 | 2003-09-18 09:45:00 | 2003-09-18 09:55:00 | 32.80  | 33.80  | 3                      |
| KA3573A   | 2003-09-25 09:00:00 | 2003-09-25 10:00:00 | 26.00  | 40.07  | 1                      |
| KA3600F   | 2003-09-25 09:00:00 | 2003-09-25 09:45:00 | 43.00  | 50.10  | 1                      |
| KA3600F   | 2003-09-25 09:30:00 | 2003-09-25 10:00:00 | 40.50  | 42.00  | 2                      |
| KA3573A   | 2003-09-29 10:20:00 | 2003-09-29 10:40:00 | 21.00  | 24.00  | 2                      |
| KA3566G02 | 2003-09-29 11:00:00 | 2003-09-29 13:50:00 | 16.00  | 18.00  | 2                      |
| KA3590G01 | 2003-09-30 09:00:00 | 2003-09-30 12:45:00 | 16.00  | 30.00  | 2                      |
| KA3600F   | 2004-02-17 09:55:00 | 2004-02-17 10:11:00 | 40.50  | 42.00  | 2                      |
| KG0021A01 | 2004-02-17 10:27:00 | 2004-02-17 10:43:00 | 35.00  | 36.00  | 3                      |
| KG0048A01 | 2004-03-02 09:24:00 | 2004-03-02 09:40:00 | 32.80  | 33.80  | 3                      |
| KA3590G01 | 2004-03-03 21:36:00 | 2004-03-03 21:36:00 | 7.00   | 15.00  | 2                      |
| KA3572G01 | 2004-04-02 10:35:00 | 2004-04-07 10:15:00 | 2.70   | 5.30   | 2                      |
| KA3573A   | 2004-09-21 09:23:00 | 2004-09-22 09:54:00 | 26.00  | 40.07  | 1                      |
| KA3600F   | 2004-09-21 09:23:00 | 2004-09-22 10:03:00 | 43.00  | 50.10  | 1                      |
| KA3573A   | 2004-09-22 09:2200  | 2004-09-22 10:03:00 | 21.00  | 24.00  | 2                      |
| KA3600F   | 2004-09-22 09:18:00 | 2004-09-22 09:44:00 | 40.50  | 42.00  | 2                      |
| KA3590G01 | 2004-11-15 11:16:00 | 2005-01-20 09:40:00 | 7.00   | 15.00  | 2                      |
| KA3566G02 | 2004-11-19 08:30:00 | 2004-11-22 09:53:00 | 16.00  | 18.00  | 2                      |
| KA3566G02 | 2005-02-03 10:20    | 2005-03-10 14:00    | 16.00  | 18.00  | 2                      |
| KA3573A   | 2005-09-26 10:58:00 | 2005-09-26 10:58:00 | 21.00  | 24.00  | 2                      |
| KA3600F   | 2005-09-26 10:42:00 | 2005-09-26 10:42:00 | 40.50  | 42.00  | 2                      |
| KA3510A   | 2005-10-03 09:24:00 | 2005-10-03 09:29:00 | 110.00 | 124.00 | 2                      |
| KA3573A   | 2005-10-05 10:30:00 | 2005-10-05 11:05:00 | 26.00  | 40.07  | 1                      |
| KA3600F   | 2005-10-07 09:20:00 | 2005-10-07 10:03:00 | 43.00  | 50.10  | 1                      |
| KA3510A   | 2005-10-07 12:15:00 | 2005-10-07 12:38:00 | 110.00 | 124.00 | 2                      |
| KA3600F   | 2006-07-12 09:37:00 | 2006-07-12 10:04:00 | 40.50  | 42.00  | 2                      |
| KA3572G01 | 2006-07-12 10:00:00 | 2006-07-18 15:35:00 | 2.70   | 5.30   | 2                      |
| KG0021A01 | 2006-07-12 13:40:00 | 2006-07-12 14:29:00 | 35.00  | 36.00  | 3                      |
| KG0048A01 | 2006-07-12 14:42:00 | 2006-07-12 15:36:00 | 32.80  | 33.80  | 3                      |
| KA3590G01 | 2006-07-13 09:55:00 | 2006-07-13 16:00:00 | 7.00   | 15.00  | 2                      |
| KA3566G02 | 2006-07-13 10:10:00 | 2006-07-13 19:25:00 | 16.00  | 18.00  | 2                      |
| KA3510A   | 2006-09-20 08:30:00 | 2006-09-20 08:35:00 |        |        | No section data avail. |
| KA3573A   | 2006-10-02 10:15:00 | 2006-10-02 10:37:00 | 21.00  | 24.00  | 2                      |
| KA3600F   | 2006-10-02 09:50:00 | 2006-10-02 10:10:00 | 40.50  | 42.00  | 2                      |
| KA3573A   | 2006-10-03 09:50:00 | 2006-10-03 10:17:00 | 26.00  | 40.07  | 1                      |
| KA3600F   | 2006-10-03 09:50:00 | 2006-10-03 10:13:00 | 43.00  | 51.10  | 1                      |
| KA3600F   | 2007-01-09 14:32:00 | 2007-01-09 14:58:00 |        |        | No section data avail. |
| KA3572G01 | 2007-01-10 09:30:00 | 2007-01-16 10:33:00 |        |        | No section data avail. |
| KA3566G02 | 2007-01-11 08:57:00 | 2007-01-11 16:35:00 |        |        | No section data avail. |
| KA3590G01 | 2007-01-15 09:07:00 | 2007-01-15 14:37:00 |        |        | No section data avail. |
| KG0021A01 | 2007-01-10 09:50:00 | 2007-01-10 10:21:00 | 35.00  | 36.00  | 3                      |
| KG0048A01 | 2007-01-10 13:59:00 | 2007-01-10 14:26:00 | 32.80  | 33.80  | 3                      |

