Äspö Hard Rock Laboratory

TRUE Block Scale project

Difference flow measurement in borehole KI0025F03 at the Äspö HRL

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December 1999

International Progress Report

IPR-01-55

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Report no.	No.
IPR-01-55	F56K
Author	Date
Rouhiainen, Heikkinen	99-12-01
Checked by	Date
Approved	Date
Christer Svemar	02-08-23

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Keywords: Groundwater, flow, log, measurements, bedrock, borehole, Äspö

Abstract

The Difference Flowmeter (DIFF) was used in Äspö Hard Rock Laboratory in the TRUE Block Scale borehole KI0025F03 located at -450 m level in the tunnel. In this borehole DIFF was used in detailed logging mode. Flow and single point resistance were logged with high depth resolution.

Sammanfattning

Differensflödesmätaren (DIFF) användes i borrhål KI0025F03 i TRUE Block Scale-området, lokaliserat på –450 m-nivån i Äspö HRL. I detta borrhål användes DIFF med högfrekvent loggning. Flöde och SP (Single Point resistance) loggades med hög upplösning i djupled.

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1 Introduction

Flow logging is one step in the borehole characterisation process at the Äspö Hard Rock Laboratory. It constitutes the basis in the TRUE Block Scale Project for identification of conductive fractures and zones.

The measurements were carried out in borehole KI0025F03, cf. Figure 1-1. The diameter of the hole is 76 mm. Detailed flow logging using the DIFF was performed in this borehole. The borehole was fully open during the measurements. The expected results of the performed DIFF flow measurements are the locations and flow rates of leaky fractures in the borehole.

The field work has been conducted by PRG-Tec Oy in September 1999. The DIFF flowmeter has been used previously in Posiva's site characterisation in Finland as well as in other boreholes of the True Block Scale Project (Rouhiainen and Heikkinen, 1998, 1999) and the SELECT-2 project (Rouhiainen and Pöllänen, in press).

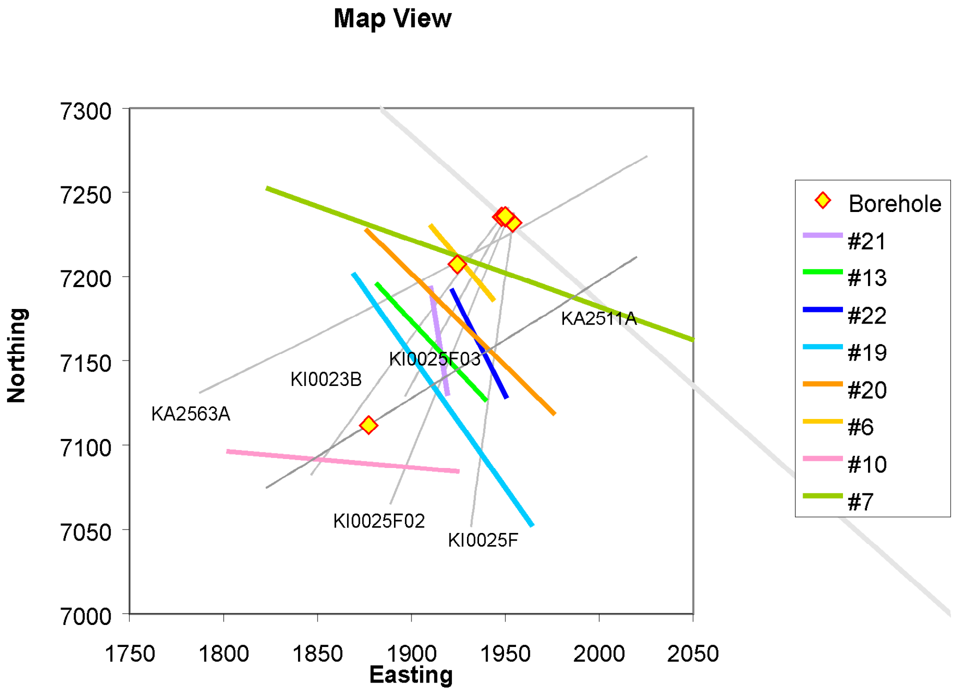

Figure 1-1 *Plan view showing the location of borehole KI0025F03, and the other TRUE Block Scale boreholes superpositioned on the reconciled March'99 structural model (Doe, 1999)*

2 Principles of measurement and operation

The method is a development of the conventional measurement of flow along a borehole. However, it is not the flow along the hole, but the changes of flow with depth that are useful. Measurement of flow along a hole is problematic, especially when the flow is strong because small changes in the flow may be concealed. This problem can be avoided if the changes of flow are measured directly.

With the new flow guide, flow along the hole outside the test section is directed so that it does not come into contact with the flow sensor. The flow into or out from the borehole in the test section is the only flow that passes through the flow sensor. Instead of inflatable packers, rubber disks are used at both ends of the flow guide. These isolate the borehole section to be measured, see Figure 2.1.

The DIFF flowmeter can be used in several ways. The main modes are the difference flow measurement and the detailed flow logging.

When difference flow measurements are carried out in the surface boreholes, the flow rates are measured two times, without pumping the borehole and when the borehole is pumped. This corresponds measurements in closed and open borehole conditions when the work is done in a tunnel. The hydraulic head along the borehole is then constant, since the hydraulic conductivity of the borehole is very high compared with the conductivity of bedrock. Consequently the difference in head over the rubber disks used in the flow guide is very small. The rubber disks are designed in such a way that they are always pressed against the borehole wall. Difference flow measurements differ from the conventional double packer tests in that there is no extra hydraulic pressure difference in the borehole section being measured relative to the remaining part of the hole.

Constant hydraulic head in the borehole implies that the water density in the hole is constant and that there are no losses due to friction. If this is not the case, the hydraulic head at the measuring depth needs to be ascertained.

A single difference flow measurement at one depth interval normally takes 12 minutes. This time includes waiting time for temperature stabilisation, a flow measurement by the thermal pulse method, a flow measurement by the thermal dilution method and lifting of the cable to the next depth interval. The thermal dilution method is used to expand the range of measurement to include higher flow rates. The flow range measured is normally 0.1 – 5000 ml/min. The results are used for determination of hydraulic head and conductivity of fractures.

The other logging mode, the detailed flow logging was used in this study. It is normally used only when the borehole is pumped or when the borehole is open in the tunnel measurements. The flow rate is measured in small depth increments, typically 0.1 m. Only thermal dilution method is used for flow determination. This is done to speed up the measurement. The flow range measured is normally 2 – 5000 ml/min. The results are used for exact location of the conductive fractures and classifying them on the basis of flow rates.

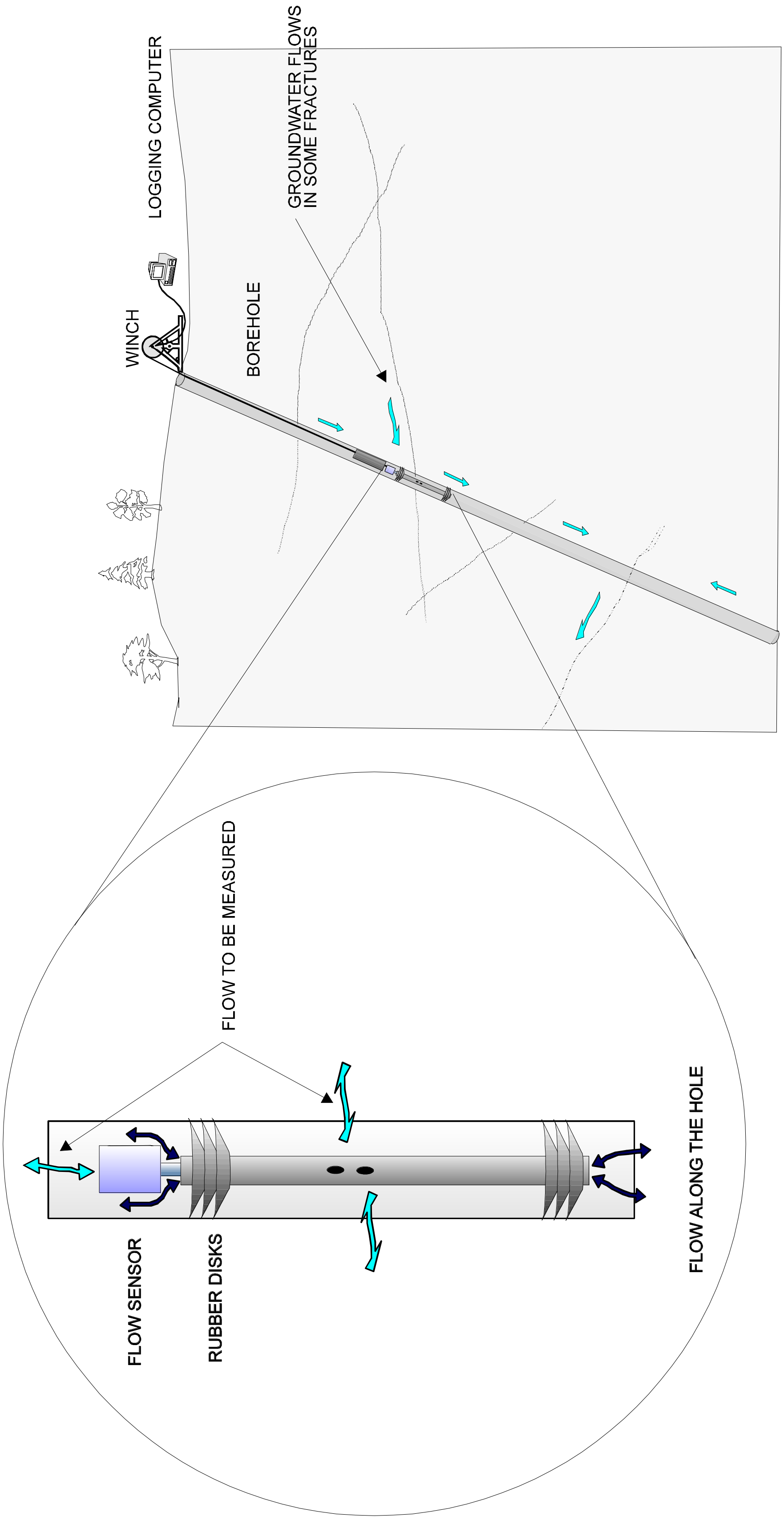

***Figure 2-1** Schematic of the downhole equipment used in the DIFF flowmeter.*

3 Equipment specifications

The DIFF flowmeter measures the flow of groundwater into or out from a borehole within a given section. A flow guide is used to separate the section to be measured. The flow guide maintains the section at the same hydraulic head as the rest of the hole. Groundwater flowing through the section is guided past the flow sensor. Flow is measured using the thermal pulse and thermal dilution methods. Measured values are transmitted in digital form to the PC computer. (Rouhiainen and Pöllänen 1998).

Type of instrument:	Difference Flow Meter (DIFF).
Borehole diameters:	56 mm, 66 mm and 76 mm.
Geometry of measurement:	A variable length of test section is used, 1 m long section was used in this study .
Method of flow measurement:	Thermal pulse and thermal dilution methods.
Speed of measurement:	Depends the rate of flows to be measured.
Range of flow measurement:	0.1 - 5000 ml/min, both directions when both the thermal pulse and thermal dilution methods are used. 2 – 5000 ml/min when only the thermal dilution method is used as in this study.
Accuracy of flow measurement:	+/- 10 % of the current result.
Additional measurements:	
Temperature:	0 – 40 C, accuracy +/- 0.1 C
Single point resistance:	1 – 100000 Ohm
Conductivity of water:	0.2 – 100 S/m, accuracy +/- 5 % of the current reading
Winch:	Mount Sopris Wna 10, 0.55 kW, 220V/50Hz.
Logging computer:	PC, Windows 95
Flow sensor calibrated	August 1999

4 Results

The detailed flow logging was performed with 1.0 m section length and with 0.1 m depth increments in borehole KI0025F03, see Appendices 1 - 7. The method provides the depth and thickness of the conductive zones with a depth resolution of 0.1 m. To make measurements more quickly, only the thermal dilution method was used for flow determination.

The section length determines the width of a flow anomaly of a single fracture. If the distance between leaky fractures is less than one metre the anomalies will be overlapped resulting in a stepwise flow anomaly. The electrode of the single point resistance tool is located within the upper rubber disks. Thus the depth of the resistance anomalies of the leaky fractures fit with the lower limit of the flow anomalies.

The depths of the plotted flow data are measured from the tunnel wall to the upper end of the test section. The depths of leaky fractures are marked in the appendices of the detailed flow logs.

The total flow out from the open borehole KI0025F03 was about 24 l/min. The measured flow range in this borehole was 2 – 5000 ml/min. The plotted flow values below 2 ml/min and above 5000 ml/min should be taken as qualitative results only.

5 Discussion and conclusions

Most of the measurement was performed unmanned during the night between September 21 and 22. No disturbing factors which could negatively affect the flow measurements, such as gas inflow or bad borehole conditions, were found in the borehole, or in the collected data.

There are more single point resistance anomalies than flow anomalies. A resistance anomaly without a flow anomaly indicates an open, but hydraulically non-conductive fracture, under the assumption that no electrically conductive minerals are present. As a rule there is a single point resistance anomaly at a flow anomaly. The smallest inflows may enter from a small fracture aperture, which may be difficult to detect using single point resistance techniques, especially if the structures are along the borehole.

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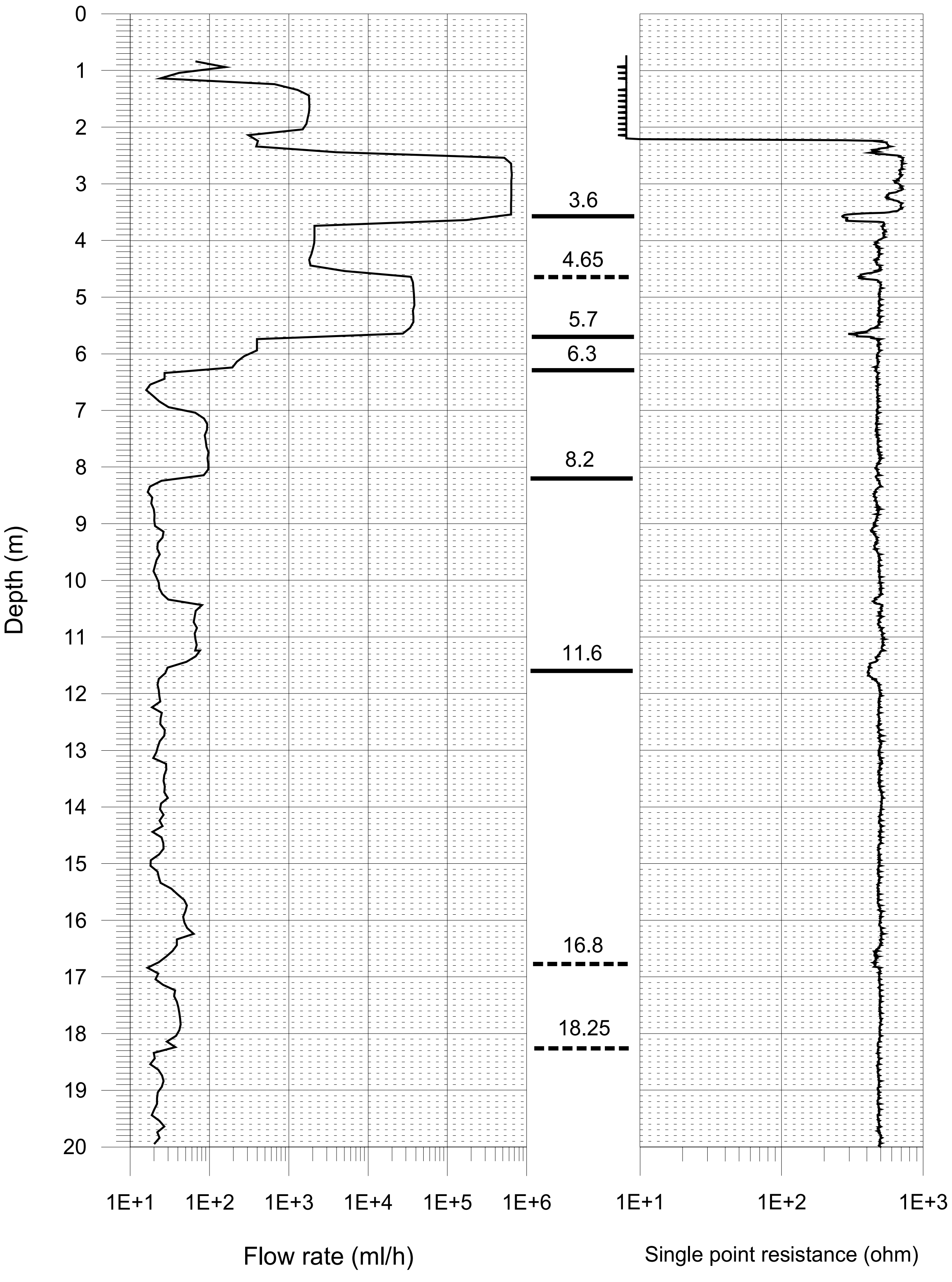
Appendices

Appendices 1 - 7 DIFF results in detailed logging mode, borehole KI0025F03

FLOW RATE AND SINGLE POINT RESISTANCE LOGS
DEPTHS OF LEAKY FRACTURES
ÄSPÖ, KI0025F03



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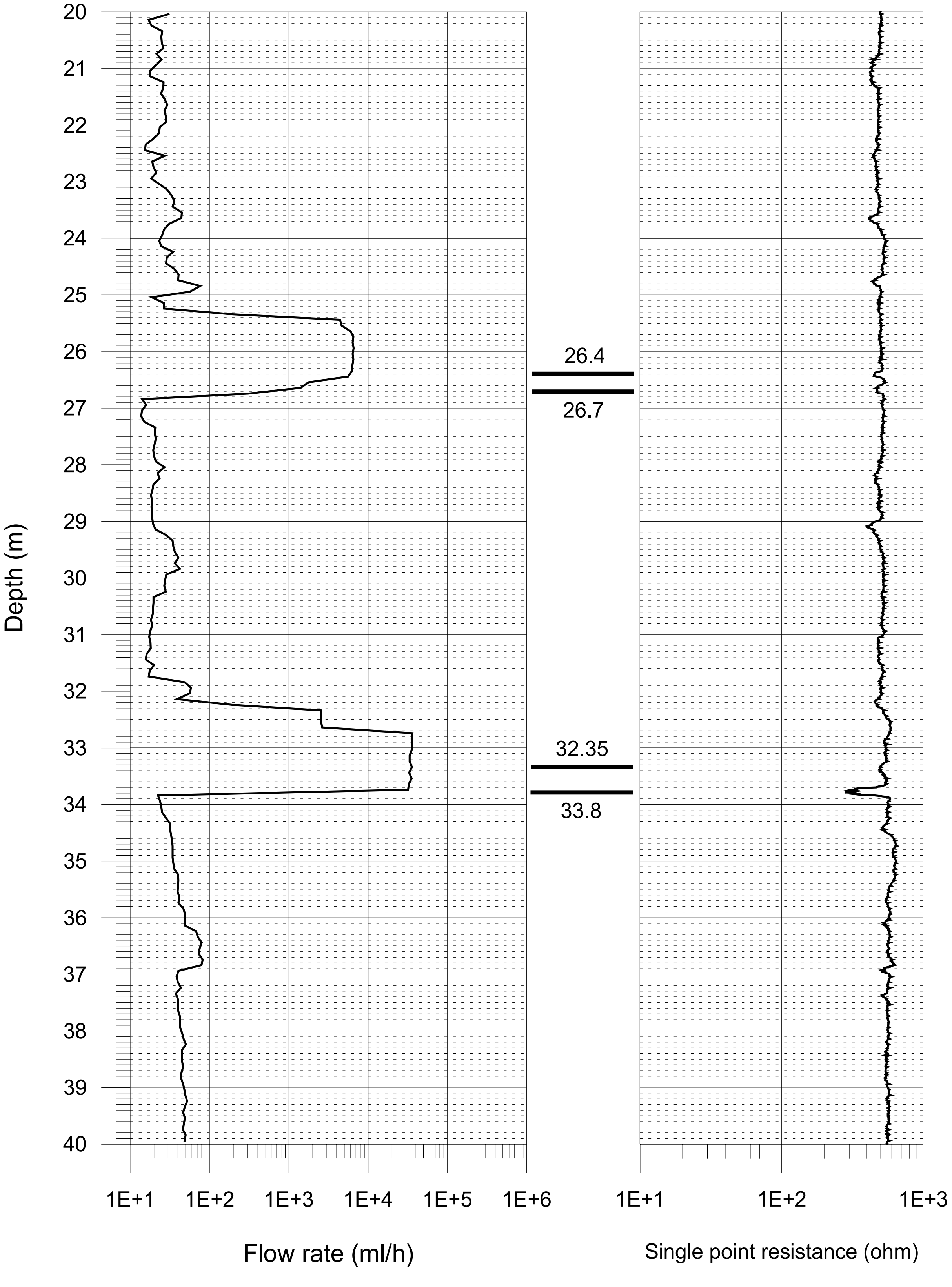

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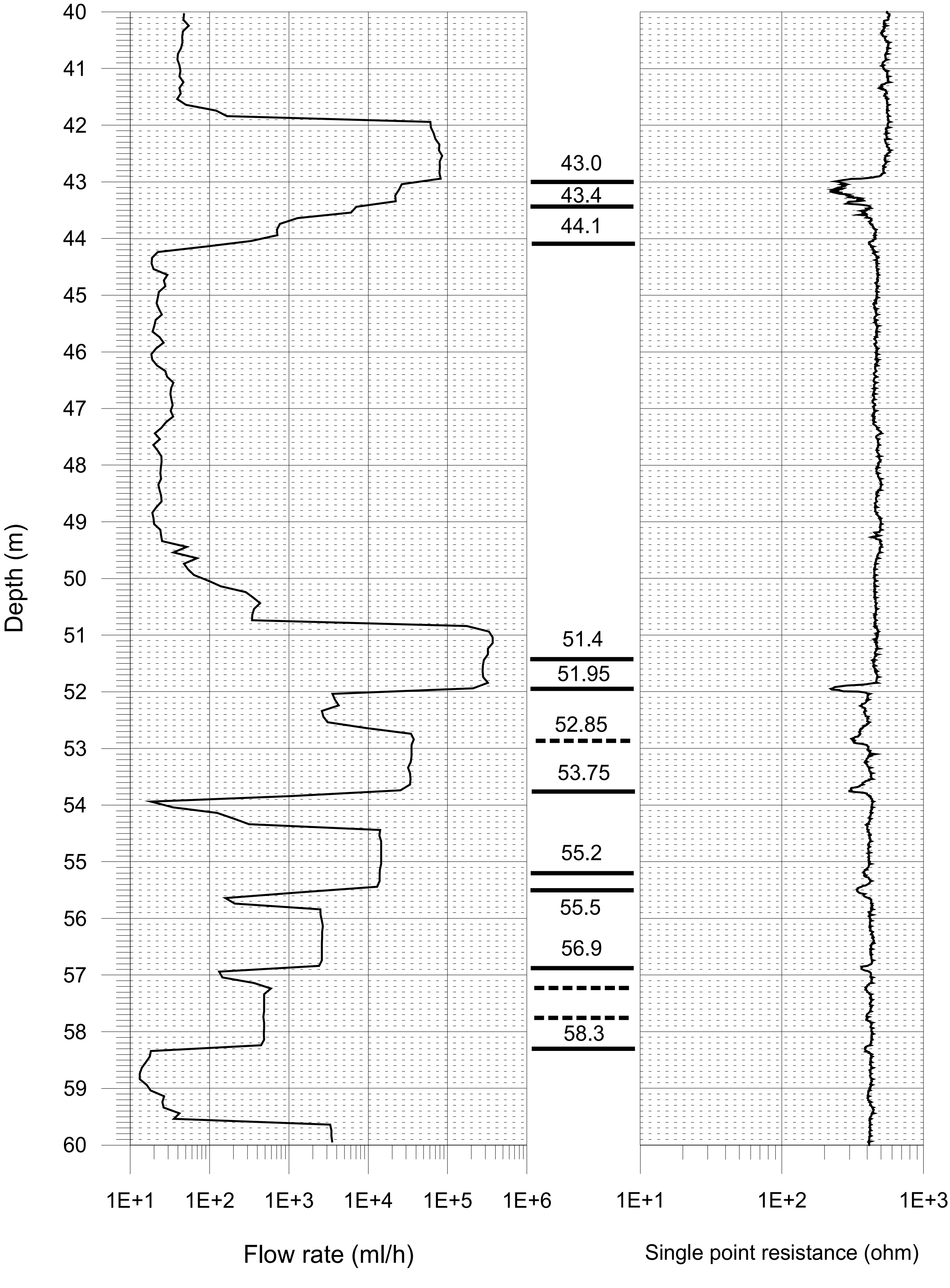

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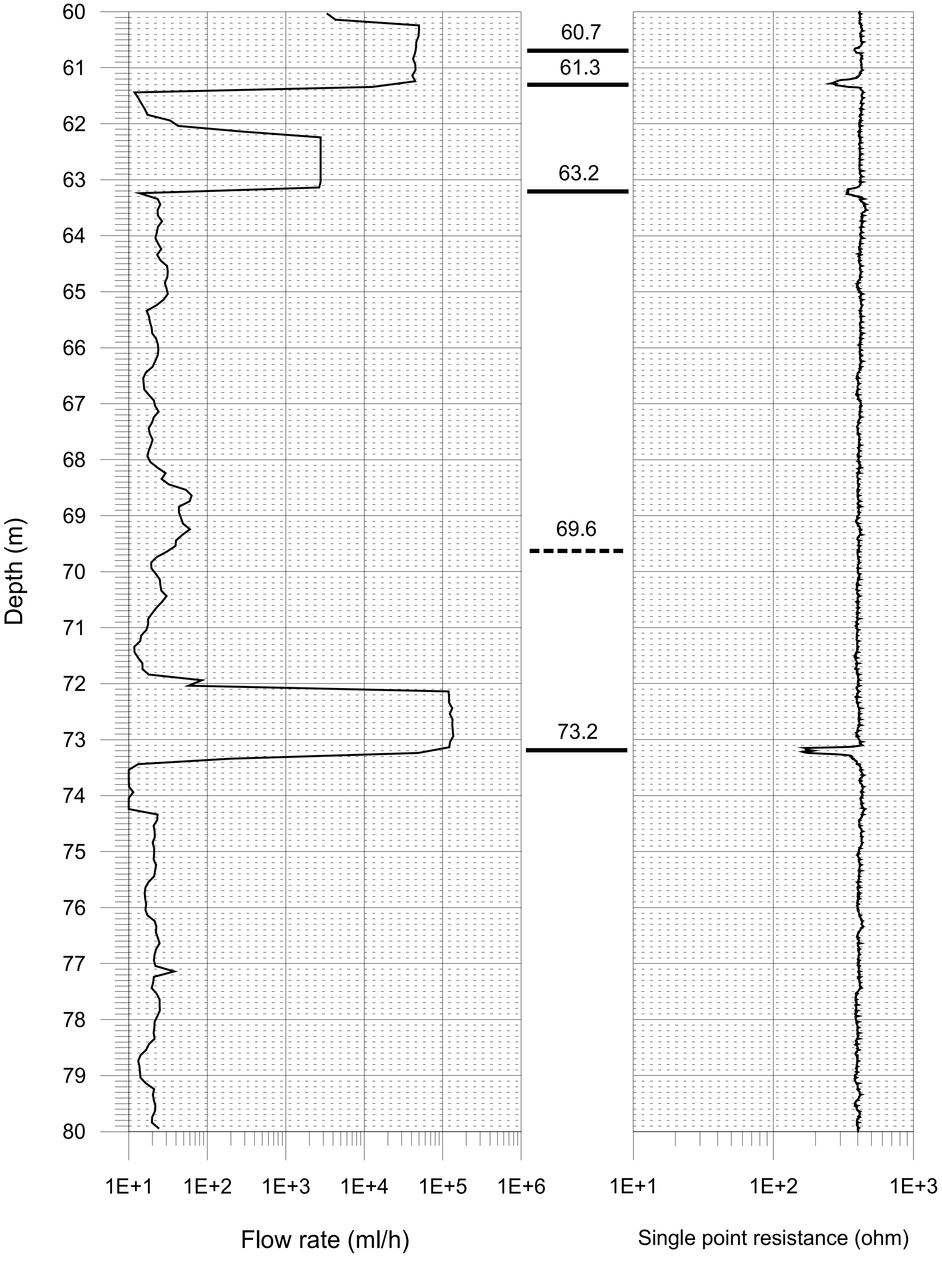

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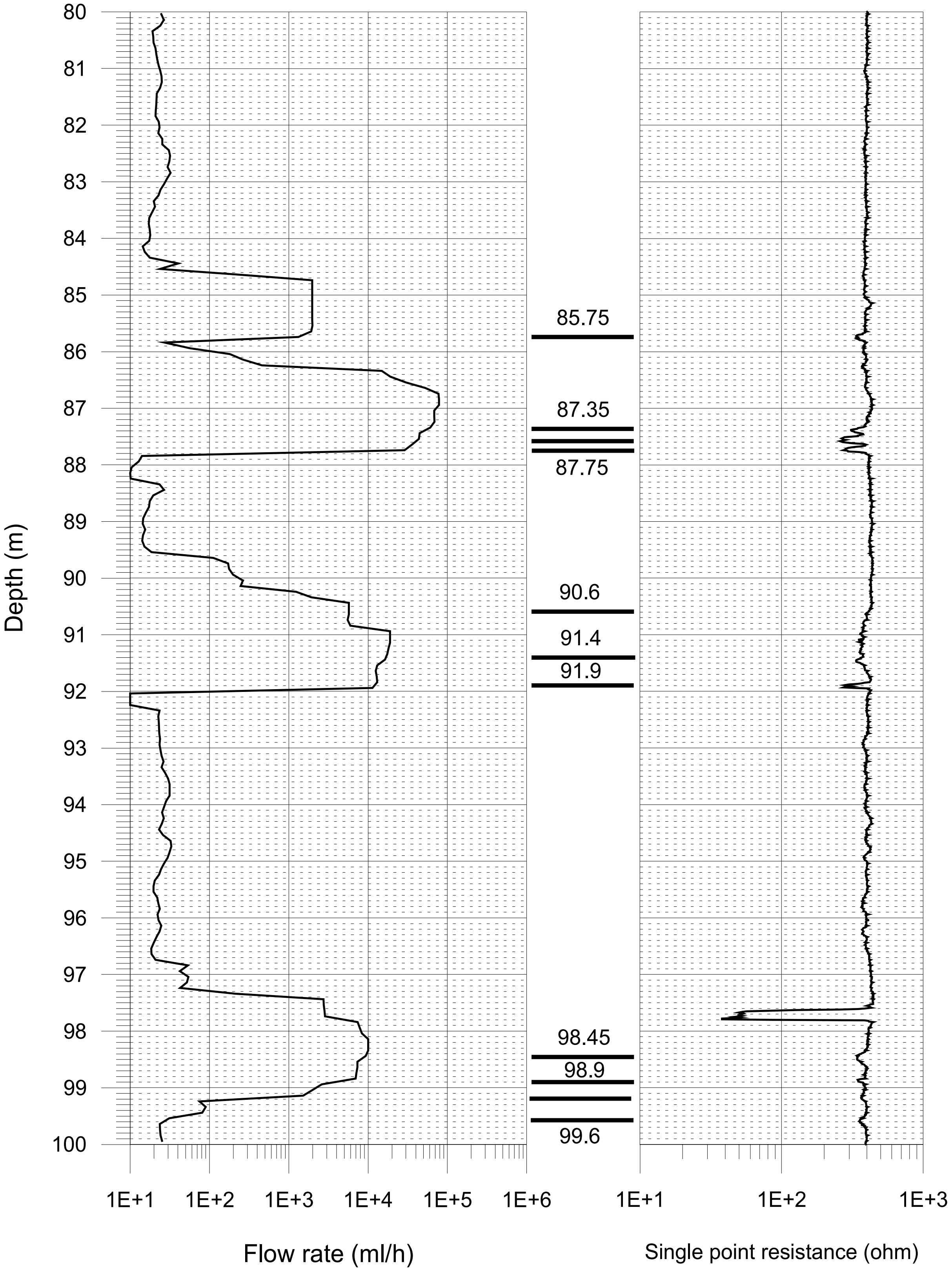

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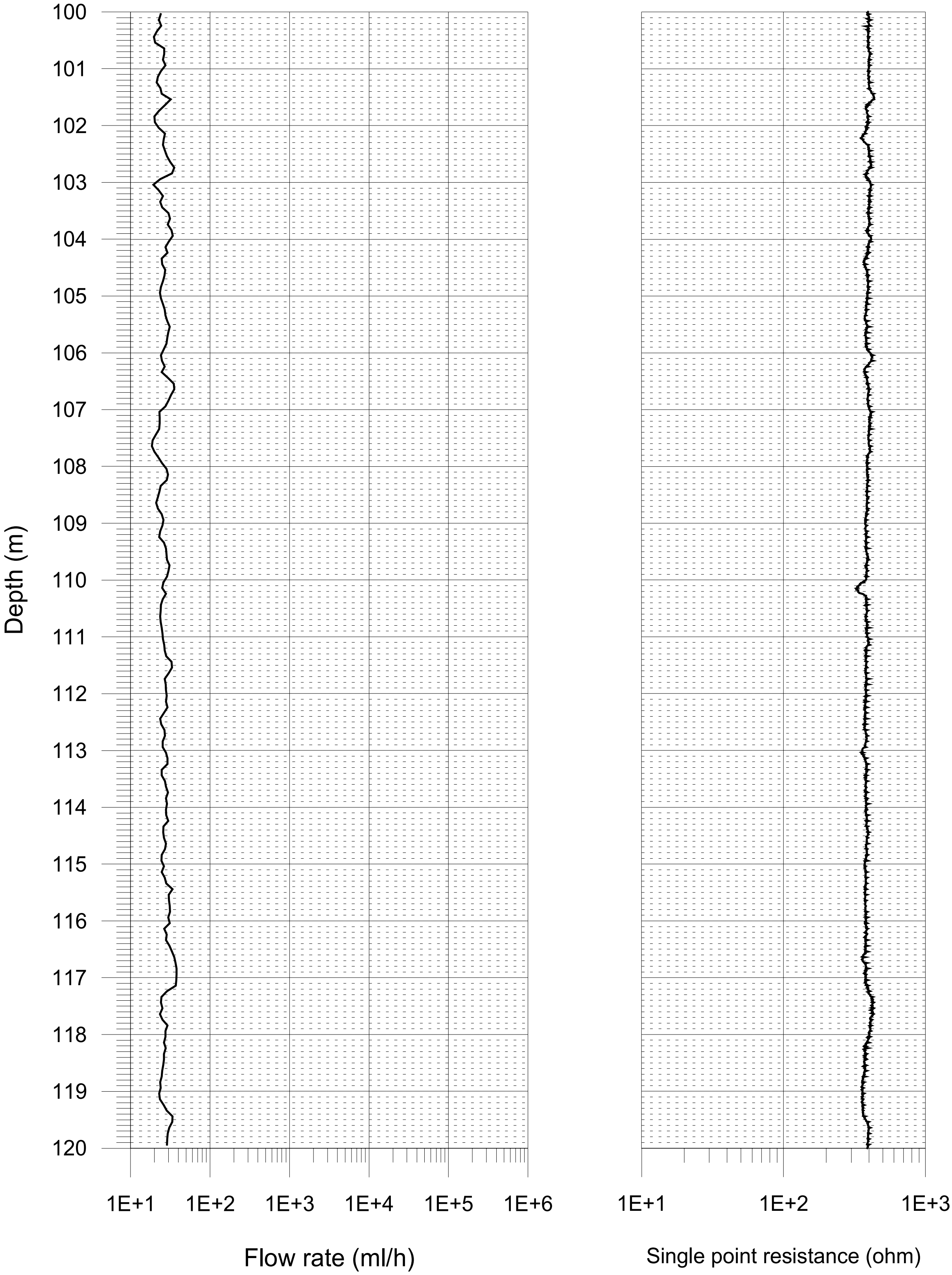

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