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Description of hydrogeological data in SKB´s database Geotab

Bengt Gentzschein
Swedish Geological Company,

Uppsala, December 1986

SVENSK KÄRNBRÄNSLEHANTERING AB

SWEDISH NUCLEAR FUEL AND WASTE MANAGEMENT CO

BOX 5864 S-102 48 STOCKHOLM
TEL 08-665 28 00 TELEX 13108-SKB

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CONTENTS

1. INTRODUCTION

Since 1977 Swedish Nuclear Fuel and Waste management Co., SKB has been performing a research and development programme for final disposal of spent nuclear fuel. The purpose of the programme is to aquire knowledge and data of radioactive waste. Measurement for the characterisation of geological, geophysical, hydrogeological and hydrochemical conditions are performed in specific site investigations as well as for geoscientific projects.

Large data volumes have been produced since the start of the programme, both raw data and results. During the years these data were stored in various formats by the different institutions and companies that performed the investigations. It was therefore decided that all data from the research and development programme should be gathered in a database. The database, called GEOTAB, is a relational database. It is based on a concept from Mimer Information System, and have been further developed by Ergo-data. The hardware is a VAX 750 computer located at KRAB (Kraftverksbolagens Redovisningsavdelning AB) in Stockholm.

The database comprises four main groups of data volumes. These are:

- Geological data
- Geophysical data
- Hydrogeological data
- Hydrochemical data

In the database background information about the investigations and results are stored on line in the VAX 750, while raw data files are stored on magnetic tapes at KRAB.

This report deals with hydrogeological data and describes the data flow from the measurements at the sites to the result tables in the database. Almost all the hydrogeological investigations were carried out by the Swedish Geological Survey, SGU, before 820701 and by Swedish Geological Co, SGAB, after that date. Thus hydrogeological data have been stored both at SGU and SGAB.

The hydrogeological investigations have been divided into five methods and each method is presented separately in the database. In addition there are three more methods in GEOTAB. They comprise data that have been evaluated or calculated on the basis of the results from the other five methods, i.e. they constitute hydraulic conductivity values at depths for different hydraulic units of the bedrock. Thus there are eight hydrogeological methods in GEOTAB. They are:

- SHTINJ: Single Hole Transient Injection Tests.
- SHSINJ: Single Hole Steady State Tests.
- GRWB : Ground Water Level Registrations in Boreholes.
- INTR : Interference Tests.
- PIEZO : Piezometric Measurements at Depths in Boreholes.
- HUFZ : Hydraulic Unit Fracture Zones
- HURM : Hydraulic Unit Rock Mass
- ROCKRM: Hydraulic Unit Rock Types in the Rock Mass

At SGU/SGAB the hydrogeological data were stored on line on PRIME 750 computers, on magnetic tapes or in filed paper protocols. During 1985 and 1986 the data files were transferred from SGU and SGAB to data files on the VAX computor or to magnetic tapes at KRAB. The data from the protocols were punched to data files either on PRIME (before the transfer) or on VAX. Then the flyleafs (tables containing background data) and the result tables in the database were loaded with data from the transferred files. Some tables were loaded directly by means of punching of the protocol data.

In the following chapters the data flow of each method is described separately.

2. SINGLE HOLE TRANSIENT INJECTION TESTS

The purpose of the single-hole transient injection tests is to determine the hydraulic conductivity and other hydraulic parameters of the bedrock such as skinfactor and piezometric pressure, Ahlbom et al 1983, Andersson and Persson 1985. During the tests water is injected through steel pipes or an umbilical hose down to test sections in up to 1000 m long boreholes. These sections are delimited by inflatable rubber packers. The packer spacing is in general 20 m or 25 m but also other section lengths exist. A test cycle starts with inflation of the packers (30 min). Then follows the two hour long injection phase when water is injected under constant pressure (c. 200 kPa). In the third and last phase (also two hours) the water flow to the test section is stopped and the pressure falls off. The injection starts and ends by opening and closing respectively of a test valve, located just above the test section. During the whole test cycle packer pressure, ground-water pressure in the test section, water flow and water temperature are registered and stored on tapes or on protocols. After data processing the single hole transient injection tests result in a number of plots which make it possible to determine the hydraulic parameters of the test section.

Two types of equipment, steel pipe equipment and umbilical hose equipment, have been used in the water injection tests. The equipment and the testing procedures are described in detail by Almén et al (1983). Collection and storage of data from the two outfits differs. In the following the data flow for the two equipments are described each separately.

2.1 Steel Pipe Equipment System, Version 2

Single hole transient injection tests with the steel pipe system version 2 were performed during the period 1981-1983 at five sites.

2.1.1 Routines for Collecting, Processing and Evaluation of Data

Data flow is presented in the block diagram in Figure 2.1.

The parameters measured during a test were pressure, temperature and injection flow rate. Two pressure transducers measured packer pressure and section pressure respectively. The section pressure value was supressed just before the injection phase, Almén et al 1983. Air temperature in the measurement housing and temperature of the injected water were monitored by two temperature transducers. Pressures and temperatures were registered and stored automatically by the datalogger, while the injection flow values were manually registered. The datalogger also stored background data and reference pressures that were set on a thumb wheel device.

A single hole injection test with this equipment comprised eight stages, Table 2.1. During the whole measurement sequence datalogger values were recorded by a cassette recorder. The pressure values were also registered on a chart recorder and displayed on a multimeter. During the injection phase a constant injection pressure (c. 200 kPa) was maintained by regulating the water flow through the flow meter. The flow rate was noted in a protocol.

A test in one test section resulted in one flow protocol, one comment protocol and one chart from the chart-recorder. The cassette tape usually contained data from two tests, one on each side of the tape.

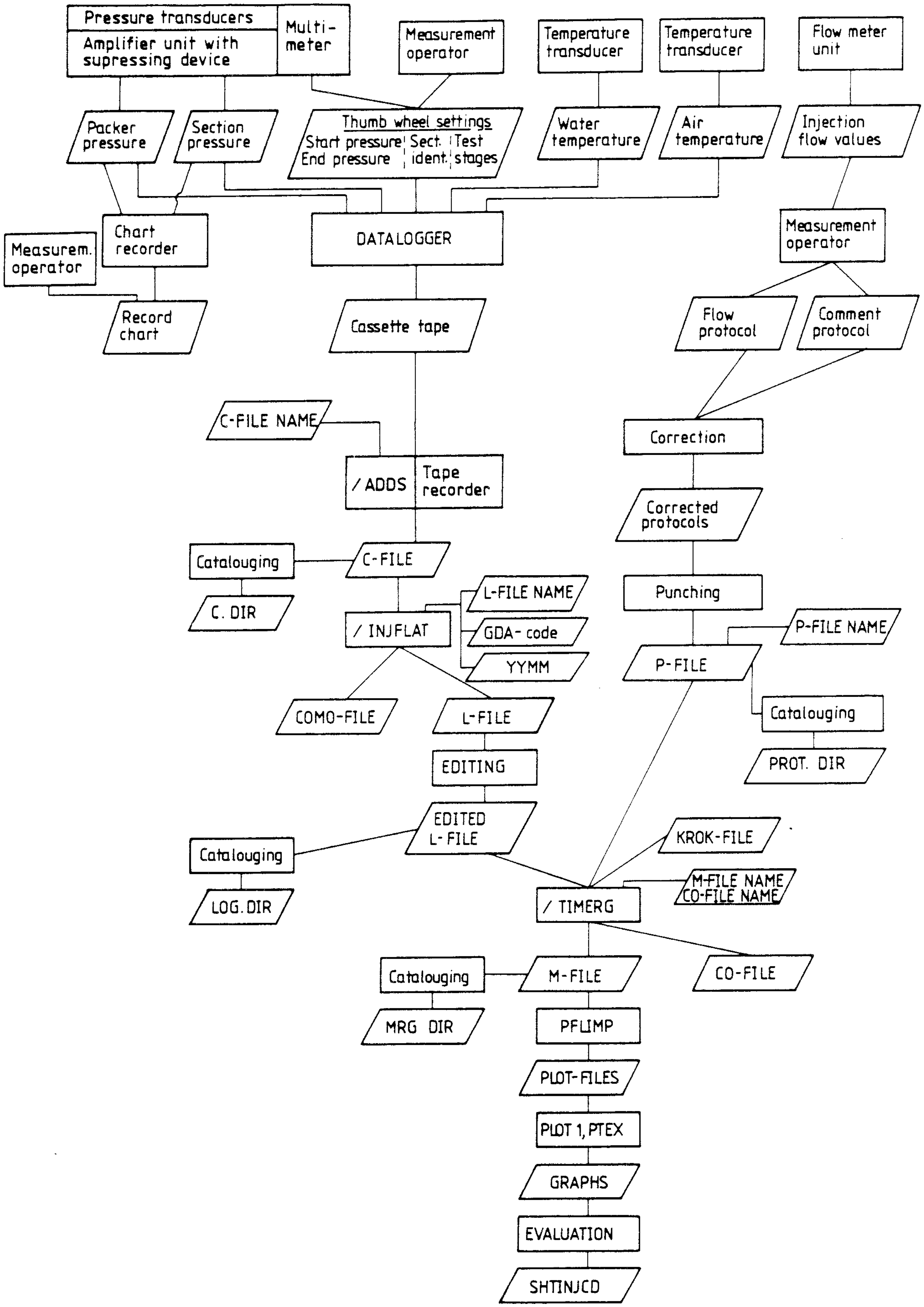


Figure 2.1 Data flow for data from single hole transient tests with the steel pipe equipment system, version 2.

Table 2.1 Different stages of a single hole water injection test, steel pipe equipment, version 2.

Stage	0:	Section identifications are set on the thumb wheel	
"		The section pressure stabilizes	
"	1:	The stable absolute pressure is set on the thumb wheel	
		Supression of absolute section pressure	t = 0
"	2:	Packer inflation starts	
"	3:	The test valve is closed	t = 25
"	4:	The test valve is opened, injection starts	t = 30
"	5:	The test valve is closed, injection is stopped and the fall-off phase starts	t = 150
"	6:	The fall-off phase ends and the packers are deflated	t = 270
"	7:	Stable absolute pressure after the test is fed into the data logger via the thumb wheel	

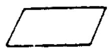
t = minutes from test start

When a number of tests had been performed the measurement operators sent the resulting data for data processing and storing. A deliverence ususally comprised 5-10 cassette tapes and the protocols and charts from the corresponding test sections.

The data on the cassette tape were read to a C-file on the PRIME 750-computer (at SGU before 830401, at SGAB after that date). The flow protocols were, after correction, punched to P-files. The C-file was then converted to a L-file, which besides the identification and the date contains the same data as the C-file. But in the L-file pressures and temperatures are in Pa and centigrades respectively and data from each scanning are on one line. The L-file was edited by the hydrogeologist. The P-file, the corresponding L-files and a file containing the inclination of the actual borehole were merged to M-files and CO-files.

On the basis of the data in the M-file 11 graphs from each test section were plotted. The plots were sent to the hydrogeologist at SGU/SGAB who evaluated them and determined the hydraulic conductivity, skin factors and other parameters of the test sections. The results were noted in a result protocol and then punched to the result table SHTINJ in the GEOLIS database. GEOLIS was a database in SGU´s PRIME 750. After 820701 GEOLIS was transferred to SGAB´s PRIME 750 in Luleå.

During 1986 the result table SHTINJ was transferred to the VAX 750 computer at KRAB in Stockholm and the GEOTAB database, where the results of the transient injection tests can be found in the table SHTINJCD.

2.1.2 Description of Data Volumes () in the Block Diagram Figure 2.1

Section pressure and packer pressure

The output signals from the pressure transducers were received at ground level by an amplifier, amplifying the signal from 0.05 mV/kPa, to 0.1 mV/kPa and 1.0 mV/kPa, respectively for different purposes. The section pressure was registered by the data logger and the chart recorder in two channels respectively, see appendix 3, one registrating the absolute pressure the second registrating the supressed absolute pressure, which was equal to the injection pressure. Also the packer pressure was registered by the data logger and the chart recorder.

Thumb wheel settings

A thumb wheel facility was connected to the data logger. The thumb wheel settings were registered by the data logger and stored on the tape at each scanning. The settings varied depending on the current stage of the injection test, appendix 2. Input data from the thumb wheel was test stage (see Table 2.1), stable absolute pressure in five digit resolution before and after the test in millibars and section identity. The section identity consists of borehole number, distance to the upper limit of the section and a section code, see appendix 2.

Air temperature and water temperature

Air temperature of the measurement housing and the temperature of the injection water were monitored during the whole injection test. The outsignal from the temperature sensors was 10 mV/^{o}C.

Injection flow values

The flow meter unit consisted of five flow meters connected in parallell. The measurement operator read the flow values on the flow scales and the flow meter in question and noted them in the flow protocol. The flow values were read with increasing intervals during the injection, appendix 1.

Cassette tape

All the data registered by the channels of the data logger as well as the channel numbers, the thumb wheel settings and the time were stored on the cassette tape. The parameters stored were

Absolute section pressure	from channel 0	(mV)
Supressed -"-	" " 1	"
Packer pressure	" " 8	"
Air temperature	" " 9	"
Water temperature	" " 7	"
Date, time	" datalogger	DD, hhmmss
Test stage	" thumb wheel	one digit (0-7)
Borehole number	" " "	two digits
Distance to section	" " "	three digits
Section length code	" " "	one digit (1-4)
Stable pressure before test	" " "	(mbar) five dig.
Stable pressure after test	" " "	" "

The resolution of the pressure values recorded on the casette was 3 1/2 digit. For injection pressures less than 2 bars which was the normal, the resolution was 1 m bar recorded as supressed section pressure. The supressed section pressure was set to zero at the moment the stable pressure before test was set on the thumb wheel device with five digit resolution.

As a rule the cassette tape contained data from two injection tests, one on each side.

On the cassette the operator wrote the borehole name (site code + borehole number), upper and lower limit of the test section, the date of the test and his own signature.

When data from a cassette tape was processed and evaluated the content of the tape was aborted.

Record chart

On the chart from the chart recorder absolute section pressure, supressed section pressure (= injection pressure) and packer pressure was registered during the entire test cycle. The resolution of the input signals, channels and pen-colour are shown in appendix 3. The paper feed varied according to a scheme, shown in appendix 1. On the chart the measurement operator noted section identification, change in paper feed, pressure values and time during the test, shift in test stages and other comments useful for the hydrogeologist. The pressure values, used for calibrating the drawings on the chart, were taken from the multimeter.

The chart was used when editing the C-file and in some few cases for evaluation when the logger registration failed. The charts are filed in the archive at SGAB, Uppsala.

Flow protocol

The flow protocol entails a table and a protocol head. The table consits of 4 columns. The first column gives time from injection start (min/sec), the second gives the flow meter number, the third shows the scale division on that flow meter and finally the fourth column shows the water flow (m^3/s) at the time given. The protocol head consists of borehole name, test section limits (m), date, signature of the measurement operator, distance (m) between section and pressure transducer (L_K), distance (m) to ground-water level from top of borehole casing, injection pressure in bars and the result of the flow test. If there was any flow during the flow test (injection when the test valve was closed) the operator noted corresponding flow meter number, scale division and the flow value in the protocol head.

The intervals between flow registrations are given in appendix 1.

Comment protocol

Two types of comments were written on the comment protocol: comments concerning registration and processing of data and comments concerning the evaluation of data. A protocol head comprises borehole name, section limits, signature, date, L_K-value and ground-water level, see flow protocol.

C-file and C-file name

The C-files were named according to the following convention:

CBHNR.k.n.ev (example: CGI12.1.3)

C = type of file; C = cassette file
BH = site code, two letters; GI for Gideå, KM for Kamlunge ...
NR = borehole number within the site; 1-99
k = number of deliverence, group of cassettes from one borehole
n = file number within the deliverence
ev was seldom used and was assigned modified C-files

One C-files contains all data registered by the datalogger during one or more tests and stored on one cassette tape. Each scanning comprises three lines in the file. Stable pressures before and after the test are in millibars. The rest of the pressure values as well as the temperature values are in mV.

Positions and formats of the C-file are presented in appendix 4.

The C-files are now (1986) stored on magnetic tapes at SGAB, Luleå.

C.DIR

C.DIR has five columns

		ofset	length
column 1:	File name	1	11
" 2:	Borehole name	12	9
" 3:	Upper limit of test section (m)	23	3
" 4:	Lower " " " " (m)	27	3
" 5:	Comments	29	79

In some cases columns 3 and 4 are longer.

The borehole names in column 2 were assigned according to a convention used in SGU´s and SGAB´s database GEOLIS. The borehole names comprise a GDA-code and a borehole number as follows

AKSSNRnnn (example: AKGI12000)

where AKSS = See GDA-code below
NR = Borehole number. Two digits 1-99
nnn = Sample number, always = 000 for hydrogeological measurements

The C.DIR file is now (1986) stored in PRIME 750 (SGAB, Luleå).

L-FILE name, GDA-code and YYMM

Input data to the programme /INJFLAT are, with the exception of the C-file, L-file name, GDA-code and YYMM (year and month).

The L-file name is the same as the C-file name except that the first letter is a L (= loggerfile) instead of a C, e.g. LGI12.1.1

The GDA-code is a code describing boreholes, used in the GEOLIS-database at SGU/SGAB. The code has four letters:

AKSS (example: AKGI)

A = Engineering geology
K = Borehole type (K = cored drillhole, H = percussion drillhole)
SS = Site code, FJ for Fjällveden, GI for Gideå etc.

YYMM is year and month of the test in question.

L-FILE

The L-FILE is a converted C-file and contains the same data as the latter i.e. data from the datalogger. In the L-file data from each scanning are on the same line. The absolute section pressures before and after the test are expressed in Pascal. The other pressure values are expressed in Pa and the temperatures are expressed in centigrades. Format and positions of the L-file are described in appendix 4.

COMO-FILE

During the run of the program /INJFLAT a COMO-FILE is opened and closed. A COMO-FILE is a terminal file in the operating system of PRIME 750. It contains all the text displayed on the terminal during a session. An example of a COMO-FILE is shown in appendix 5. When the data processing was finished the COMO-FILE was deleted.

EDITED L-FILE

The original L-file was edited by the hydrogeologist. The result is an edited L-file, which contains the same data as the original L-file, appart from the adjustment made by the hydrogeologist. These are in general few and do not concern the data derived from the pressure- and temperature sensors.

The edited L-files are now (1986) stored on magnetic tapes at SGAB, Luleå.

LOG.DIR

LOG.DIR has five columns

			ofset	length
column	1:	File name	1	10
"	2:	Borehole name	12	9
"	3:	Upper limit of test section (m)	22	3
"	4:	Lower " " " " (m)	26	3
"	5:	Comments	30	79

The borehole names in column 2 were assigned according to a convention used in SGU´s and SGAB´s database GEOLIS, see C.DIR.

The comments of column 5 also includes notes about the corrections of the original L-file, made by the hydrogeologist.

LOG.DIR is now (1986) stored on magnetic tapes at SGAB, Luleå.

Corrected protocols

Corrected protocols were the same as the flow- and comment protocols from the site. But the protocols were checked by the hydrogeologist and missing data were if necessary, completed. Of special importance were dates and identities of the boreholes and test sections, since these data had to be equal to the identifications of the corresponding L-file(s).
The corrected flow- and comment protocols are now (1986) in the archive at SGAB, Uppsala.

P-FILE and P-FILE NAME

The P-file contains flow rate values and comments written on the protocols by the measurement operator and if necessary completed by the hydrogeologist. The P-file comprises three record types. The first record type contains data from the flow protocol head, the second record type shows water flow rate and finally the third record type contains comments from the comment protocols. The format of the P-files is presented in appendix 4.

The P-files are now (1986) stored on magnetic tapes at SGAB, Luleå.

The P-files were named according to the following convention:

PSSNR.k (example: PGI12.1)

P = File type, P = Protocol file
SS = Site code; GI = Gideå, KM = Kamlunge etc
NR = Borehole number within the site; 1-99
k = Number of deliverence, group of cassettes from one borehole

PROT.DIR

PROT.DIR has six columns

			ofset	length
column	1:	File name	1	10
"	2:	Borehole name	16	9
"	3:	Upper limit of test section (m)	26	3
"	4:	Lower " " " " (m)	30	3
"	5:	Date of test (YYMMDD)	34	6
"	6:	Comment	40	79

The borehole names were assigned according to a convention used by SGU/SGAB, see C.DIR.

PROT.DIR is now (1986) stored on magnetic tapes at SGAB, Luleå.

KROK-FILE

The KROK-files are the result of the borehole geophysical measurements, and they describe the inclination and the declination of the boreholes every tenth meter (Eriksson 1986). The KROK-file has three columns:

Column 1: Depth along the borehole (m)
" 2: Angle against horizontal plane (degrees)
" 3: Angle against vertical north-south plane (degrees)

The KROK-file was named according to: KROK*SSNR, where SS = site code and NR = borehole number. The KROK-files are stored on magnetic tapes at SGAB, but the contents of them have been read into the table DEVANGLE in SKB´s database GEOTAB.

M-FILE and M-FILE NAME

The M-FILE is a merged file. Its origin is one P-file, a number of L-files and data from the KROK-file. The P-file and the L-files comprise flow rate data and logger data, respectively, from the same test sections. Thus the M-file contains data from one deliverence from the measurement operators relevant for data evaluation.

The M-file name is the same as the P-file name with the exception that the first letter is a M (= merged file) instead of a P (example: MGI12.1).

In the M-file the absolute section pressure values were corrected for the distance between the test section and the pressure transducer (= the L_K-value). Apart from this the data of the M-file are the same as found in the L-files, P-file and KROK-file respectively, appendix 4.

The M-files are stored on magnetic tapes at SGAB and SGU. During 1986 copies of the M-files were transferred to magnetic tapes at KRAB in Stockholm.

CO-FILES

The CO-files have the same name as the corresponding M-files with the difference that the CO-file names begins with CO (= comment file) instead of M. The contents of the CO-files concern the same test sections as the corresponding M-files. The CO-files comprise data from the head of the flow protocol and comments written on the comment protocols. Unfortunately the comments are missing in many CO-files, since they were deleted during the data process. The CO-files also contain average inclination of the test sections calculated by the program /TIMERG. The average inclination was used for the correction of the absolute section pressure in the M-file. The format of the CO-files is shown in appendix 4.

The CO-files are stored on magnetic tapes at SGAB, Luleå. During 1986 copies of the CO-files were transferred to magnetic tapes at KRAB in Stockholm.

MRG.DIR

MRG.DIR has six columns:

			ofset	length
column	1:	File name	1	9
"	2:	Borehole name	15	9
"	3:	Upper limit of test section (m)	25	3
"	4:	Lower " " " " (m)	29	3
"	5:	Date of test (YYMMDD)	33	6
"	6:	Comments	40	40

The borehole names in column 2 were assigned according to a convention used in SGU´s and SGAB´s database GEOLIS, see C.DIR.

MRG.DIR is now (1986) stored on magnetic tapes at SGAB, Luleå. During 1986 a copy of MRG.DIR was transferred to magnetic tapes at KRAB in Stockholm.

PLOT-FILES

The programme PFLIMP generate 11 plot files for each injection test. The plotfiles are named as follows:

Plot_nsec_BHid   (example: A1_0240_AKGI12000)

where

Plot = Name of graph; UT,A1-A4, B1-B4, C1 and C2
sec = Upper limit of test section (m)
n   = serial number for sections with the same "sec" during one plot session.
BHid = Borehole name according to the GEOLIS´ convention (see C.DIR)

When the plotting was finished the plotfiles were deleted.

GRAPHS

Eleven graphs were generated from each test. They were called UT,A1-A4, B1-B4, C1 and C2:

UT is a flyleaf presenting key values of flow and pressure and a preliminary value of hydrualic conductivity.

A1-A4 shows pressure-, flow- and temperature variations during the whole test cycle of an injection test in linear scale.

B1-B4 show pressure- and flow variations during the injection phase in logarithmic or semi-logarithmic scale.

C1, C2 show pressure variations during the fall-off phase in logarithmic or semi-logarithmic scale.

The graphs are filed in the archive at SGAB, Uppsala.

SHTINJCD

The results of the transient single hole injection tests are stored in a table in SKB´s database GEOTAB. The table is called SHTINJCD and it has 21 columns.

column 1:	IDCODE;	5 characters: TSSNN; T = borehole type (K = cored borehole, H = percussion borehole), SS = Site code, NN = borehole number.
" 2:	SECLEN;	Section length (m)
" 3:	SECUP;	Borehole length to test section, upper limit (m)
" 4:	TYPE;	Test equipment: MV = Umbilical hose equipment, RG = Steel pipe system
" 5:	BC;	Hydraulic boundary: PB = positive boundary, NB = negative boundary
" 6:	TP;	Duration of injection phase (s)
" 7:	TPH;	Duration of fall-off phase (s)
" 8:	KSS;	Steady-state hydraulic conductivity
" 9:	KI;	Hydraulic conductivity determined from injection phase (m/s)
" 10:	KT;	Hydraulic conductivity determined from fall-off phase (m/s)
" 11:	K;	Best representative hydraulic conductivity (m/s)
" 12:	T;	Transmissivity (m^2/s). T = K x SECLEN
" 13:	ZI;	Skinfactor calculated from injection phase
" 14:	ZT;	" " " fall-off "
" 15:	PI;	Stable absolute pressure before test (kPa)
" 16:	DPFPI;	Natural piezometric pressure of the test section from fall-off phase (kPa)
" 17:	DPOPI;	Pressure difference before injection and before test (kPa)
" 18:	FLOWREG;	Flow regime, R = radial, SP = spherical, L = linear, SS = steady state
" 19:	GOODNESS;	Judgement of data quality: G = good, N = normal, B = bad
" 20:	COM50;	Comment
" 21:	INDAT;	Input date to database (YYMMDD)

2.1.3 Description of Processes (☐) in the Block Diagram, Figure 2.1

Pressure transducers, Amplifier unit with supression device and Multimeter

The pressure transducer (Kistler 4043 A 100) that measured the section pressure was connected via coupling adapters and cannular tubes to the test section, Almén et al 1983. It was placed at a distance L_K from the test section. The difference between the pressure of the test section and the measured pressure was later corrected in the data processing.

The packer pressure monitoring transducer (Kistler 4043 A 50) was placed at ground surface in the measurement housing but connected to the packer pressurizing system (Almén et al 1983).

In the amplifier unit the signal from the pressure transducers were amplified from 0.05 mV/KPa to 0.1 mV/KPa and 1 mV/KPa respectively for different purposes. Due to the limited resolution of the datalogger, 3 1/2 digit, a supression device was included in the amplifier unit. This facility was used to supress the section pressure to zero before test start. The injection pressure was then recorded with the resolution of 1 mbar.

A digital multimeter was connected to the amplifier. With the help of a switch on the amplifier the measurement operators could read the absolute section pressure, the supressed section pressure (= injection pressure) or the packer pressure on the multimeter display during the whole test cycle. The pressures were displayed with 5 1/2 digit which means the resolution of 1 mbar for pressures less than 200 bar. The stable pressures before and after the test were taken from the multimeter the moment they were set on the thumb wheel, Table 2.1. Readings from the multimeter were also used for the calibration of the chart recorder.

Measurement operators

There were two measurement operators at every borehole performing the tests. The operators lowered the measurement probe to the test section and commenced the test by starting up the monitoring and the data collecting instruments. They started and ended the water injection phase by opening and closing of the test valve. Another valve, also regulated by the operators, started and ended the packer inflation, Almén et al 1983. By aid of a thumb wheel device on the logger important data for the evaluation of the test were set, appendix 2. During the test cycle the operators changed the speed of the chart recorder and the scanning intervals of the logger, appendix 1. Before a borehole was tested the flow meter units were calibrated by the measurement operators. During the injecton phase they regulated the injection pressure by increasing or decresing the flow through the flowmeter unit. The values of the flow meter scales were noted in the flow protocol. The operators also completed the flow protocol with other data and noted comments on the comment protocol.

When a number of tests were finished the operators sent data to the site hydrogeologist. A deliverence comprised record charts, cassette tapes and protocols from corresponding sections. Before the sending date and section identity were noted on the cassettes and on the charts.

The whole test as well as the work of the measurement operators were supervised by the site hydrogeologist.

Temperature transducers

The water temperature sensor was connected to the outflow of the flow meter unit, while the air temperature sensor was placed in the measurement housing, Almén et al 1983.

Flow meter unit

The flow meter unit, consists of five flow meters of type Brooks rotameter, connected in parallell, Almén et al 1983. The flow meters are graded. The water flow is achieved by reading the graded scale and then transforming the scale values to water flow rate in accordance with a calibration made before the tests of each borehole. By increasing or decreasing the flow through the flow meter unit a constant pressure during the injection phase, read on the multimeter, was achieved. The flow values were read and recorded (in the flow protocol) manually at stepwise increasing intervals, appendix 1.

Chart recorder

Parallell with the datalogger the measurement values were also registered (from the amplifier) on a chart recorder, Almén et al 1983. This was done primarly in order for the measurement operators to be in control of the progress of the test. The registration was also used for evaluation in case of datalogger breakdown and when editing the C-file. The chart recorder registered packer pressure, absolute- and supressed section pressure, appendix 3. The paper feed varied during the test, appendix 1.

Datalogger

The control unit of the data collection system was a datalogger, type Minilogger ML 10-A, Almén et al, 1983. The datalogger had 10 input channels for recording of analog signals and a parallel digital channel to which a thumb wheel device was connected. Moreover the logger included an internal clock and a tape recorder. Pressure and temperature values were assembled in the datalogger scanning being affected at stepwise increasing time intervals, appendix 1.

By aid of the supression facility, earlier described, the injection pressure in the test section was registered. The thumb wheel device made it possible to register "external" data, such as stable pressure before test, section identity, the different stages of the injection test etc, appendix 2.

Day of the month and time in hours, minutes and seconds were given by a clock in the data logger. These day/time values were registered on the tape at every scanning.

/ADDS, Tape recorder

/ADDS is an abbreviation of the programme SEG BBPRAV>CASSETTE> £ADDS on PRIME. The programme transferred data from the cassette tape to a C-file on the PRIME computer. Input data were data on the tape and the name of the C-file. Output of /ADDS was the C-file. The transfer was done by the data department at SGU before 830401 and then by SGAB.

The tape recorder used when reading data from the cassette tape to the PRIME computer was from A.D. Data Systems, Rochester N.Y. USA. The model was 817 and the serial number was 6322.

Catalouging

The C-files, the L-files, the P-files and the M-files were catalouged in the catalouge files C.DIR, PROT.DIR, LOG.DIR and MRG.DIR respectively. The catalouging was made by a data operator at SGU before 830401 and then by a data operator at SGAB. In LOG.DIR the hydrogeologist noted the corrections of the L-file he had done.

/INJFLAT

/INJFLAT is an abbreviation of the programme SEG BBPRAV>GEOLIS> £INJFLAT on PRIME. The programme convert a C-file to a L-file, which is a flat file and easy to read and edit. The programme also convert pressure and temperature values from mV in the C-file to Pa and ^{o}C respectively in the L-file. Input to the programme are C-file, C-file name, L-file name, GDA-code and year and month of the test. During the run of /INJFLAT key lines of the L-file, including section identity and date, and number of lines read and written are displayed on the terminal. Errors of the C-file are also displayed. Before starting of /INJFLAT a COMO-FILE, which stores text displayed on the terminal, is opened. The COMO-file was used during the editing of the L-file. /INJFLAT was run by a data operator at SGU before 830401 and then by a hydrogeologist at SGAB.

EDITING

The origin of the L-file is pressure- and temperature values from the transducers and the thumb wheel settings. In many cases the measurement operator made mistakes when he fed the datalogger via the thumb wheel. These errors were corrected by a hydrogeologist by editing the L-file. The most common errors were the wrong date, the wrong section limits, or incorrect stage number, Table 2.1. In some cases the datalogger failed and pressure values or time were taken from the record chart.

During the editing the hydrogeologist was helped by the flow- and comment protocols, the record chart, the COMO-file and his own knowledge of the stages of a water injection test.

The corrections of the L-file were catalouged in LOG.DIR.

Correction (of protocols)

When the site hydrogeologist had received the protocols from the measurement operators he checked that the protocols were correctly filled up and that they were ready for punching. If necessary he also completed the protocols with the water flow rate.

Punching

The corrected flow and comment protocols were punched to P-files by Pääjärvi stansbyrå, Uppsala before 830401. After that date the data division of SGAB (Luleå) did the punching.

/TIMERG

/TIMERG is an abbreviation of the programme BBPRAV>GEOLIS>£-TIMERG on PRIME. The programme merges P-files, L-files and KROK-files to M-files and CO-files. During the run of the programme key data of the P-file and the L-file are displayed on the terminal. Key data are borehole name, section limits and data of the test section that the files contain. It is important that the key data of the L-files are the same as in the P-file. The merging procedure was handled by the data operator at SGU before 830401 and then by the hydrogeologist at SGAB.

The programme also correct the absolute section pressure of the L-file. The correction is necessary since the pressure transducer is placed a distance L_K from the test section. The correction is made with the aid of the L_K-value (from the P-file) and the inclination of the borehole (from the KROK-file).

PFLIMP

PFLIMP is an abbreviation of the programme SEG IGDUHY>PLOT>£IN-J.MP on PRIME. The programe generates plot-files. Input is a M-file. Output are 11 plot-files. The plotting procedure was handled by the data department at SGU before 830401 and then by the data division at SGAB.

PLOT1, PTEX

Two plot programmes on PRIME were commonly used. They were PLOT1 (abbrev. for IGDUHY>PLOT>£PLOT_IGDUHY.1) and PTEX (abbrev. for IGDUHY>PLOT>£TEKPLT.A1_A4). 11 graphs were plotted, one for every plot file. The diagrammes UT, A1-A4 were plotted on a Tectronix-plotter, while the diagrammes B1-B4, C1 and C2 were plotted on a Calcomp-plotter.

EVALUATION

By the aid of the graphs the test sections were evaluated and parameters such as hydraulic conductivity, skinfactors and natural section pressure were determined. Theory and evaluation methods are described in a number of reports, Ahlbom et al 1983, Andersson and Persson 1985. In some cases, when the data-logger failed, the record chart and the flow protocols were used for the evaluation.

2.2 Steel Pipe Equipment System, Version 3

During 1985 and 1986 the steel pipe equipment has been modified to a large extent. The data collection and the data processing will be computer controlled in the same way as in the umbilical hose system, Almén et al, 1986.

Since the modified system is not yet completed the data flow for the 3rd version of the steel pipe equipment is not described in this report.

2.3 Umbilical Hose Equipment System Version 1

Single hole transient injection tests with the umbilical hose equipment version 1 were performed during the period 1981 - 1986 at seven sites.

2.3.1 Routines for Collecting, Processing and Evaluation of Data

The data flow is presented in the block diagram in Figure 2.2.

The pressures measured during a test were section pressure, packer pressure, barometer pressure and ground-water pressure just below the ground-water level. Three temperatures were mea-

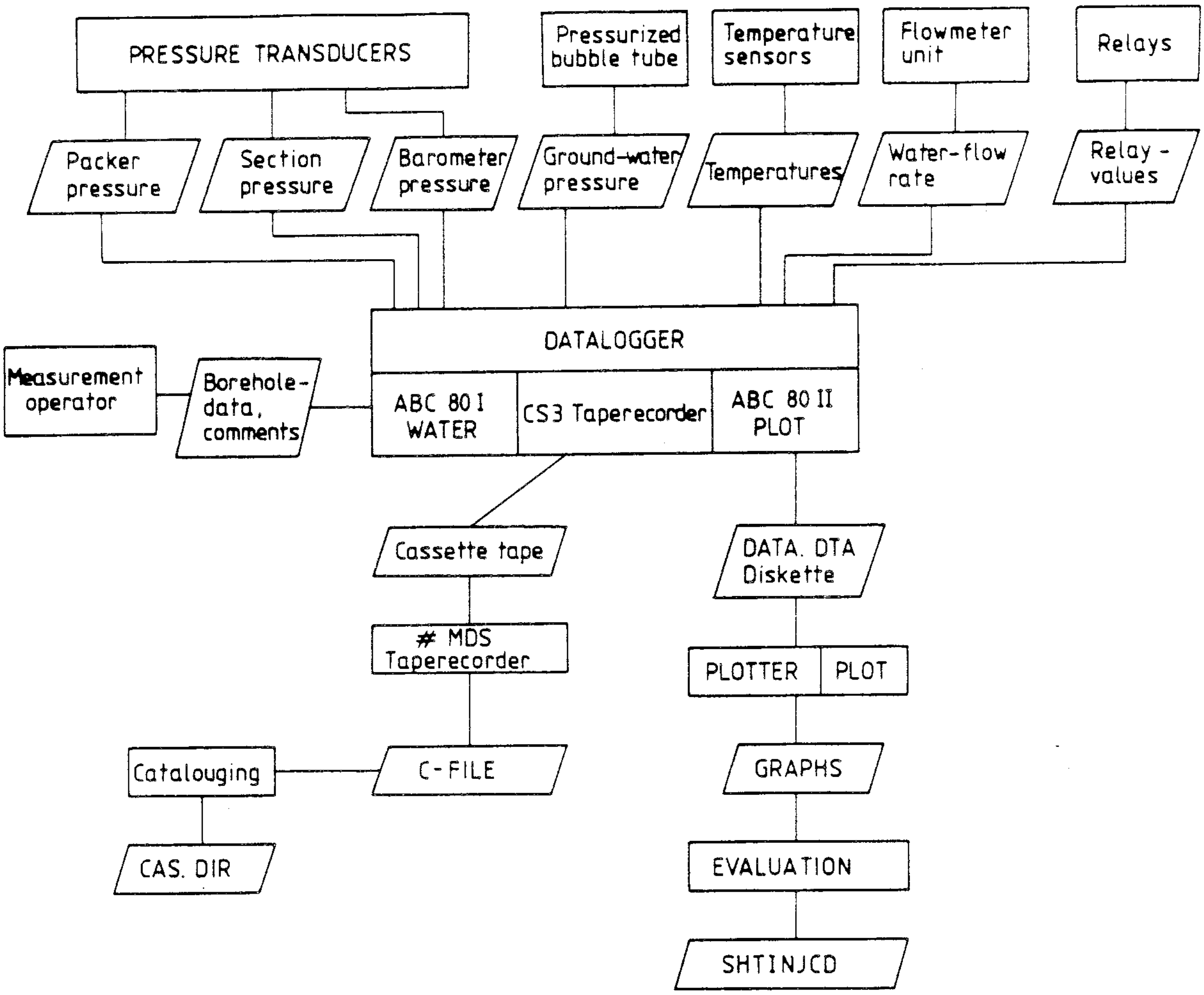


Figure 2.2 Data flow for data from single hole transient tests with the umbilical hose system, version 1

sured: temperature of the injection water, temperature in the test section and outer air temperature. Finally the injection flow rate was monitored.

The test began with starting up the monitoring and data collecting units. The measurement probe, containing the packers and the sensors, was then lowered to the test section. Via the ABC 80 computer borehole data such as borehole name, the inclination of the borehole, length to test section and section length were fed into the datalogger. The data logger and the ABC 80 registered and monitored all the data necessary for evaluation during the entire test cycle. Data was stored on a cassette tape. The system also automatically regulated valves, packer pressure, injection pressure and injection flow during the measurement sequence in accordance with the demands of a constant head transient injection test. Comments could be entered on the data tape when the measurement cycle was completed. During the test measurement quantities could be graphically displayed on the screen of the ABC 80.

When the injection test was finished the data on the cassette tape was transferred to a diskette on a second ABC 80 unit. The same ABC 80 was used when 11 graphs from each test section were plotted on a plotter.

When a number of tests (generally 10-20) were completed the resulting data were sent to the site hydrogeologist for evaluation and storing. A deliverance comprised cassette tapes (two tests on each tape), diskettes (one for every test) and graphs (eleven graphs for every test).

Before April 1, 1983 the hydrogeologist sent the cassette tapes to the data department at SGU for reading to C-files on the host computer (PRIME). After 830401 the reading procedure was performed by the data division at SGAB to SGAB´s PRIME 750.

Using the graphs the hydrogeologist determined the hydraulic parameters of the test sections. The results were noted in a result protocol and then punched to the result table SHTINJ in the GEOLIS database, see chapter 2.1.1. GEOLIS is a database

in SGU´s PRIME 750. After August 1, 1982 GEOLIS was transferred to SGAB´s PRIME 750 in Luleå.

During 1986 the result table SHTINJ was transferred to the VAX 750 computer at KRAB in Stockholm and the GEOTAB database, where the results of the transient injection tests can be found in the table SHTINJCD.

2.3.2 Description of Data Volumes (▱) in the Block Diagram Figure 2.2

Section Pressure

Section pressure was measured by two pressure sensors called P1 and P2, placed beneath the upper packer in the test section. Only data from one of the two sensors were stored on the casette tape. In the beginning of the measurement sequence the stable absolute pressure of the test section, called P8, was stored. P8 was the reference pressure when the differential pressure (dP) of the test section was determined. During the injection phase dP was equal to the injection pressure in the measurement section.

Packer Pressure

The packer pressure was monitored by two pressure transducers, named P4 and P14. Pressure values from one of them (P4) were stored in the data file. They were placed at ground surface and were connected to the packer pressure system.

Barometer Pressure

The barometer pressure was measured by a pressure sensor BO at ground surface.

Ground-water Pressure

The air drive pressure, that made the air pass through the bubble tube, corresponded to the ground-water pressure in the bubble tube. The air drive pressure was measured by the pressure sensor P7.

Temperatures

Three temperatures were measured during the entire measurement sequence: Temperature of the water in the test section, temperature of the injection water and outer air temperature.

Water Flow Rate

The injection water flow rate was measured by three flow meters, covering the measuring range 0.005 - 117 ml/second. Before the injection phase, a reference measurement was made by opening a cannular tube in the system, Almén et al 1983.

Relay Values

The different valves of the pressurizing system of the umbilical hose equipment were regulated by means of relays, Almén et al 1983. The number of the relay and whether the relays funcioned or were released (negative number) was registered and stored by the datalogger.

Borehole Data and Comments

Before the start of the injection test the measurement operators typed borehole data on the keyboard of the ABC 80 computer. The borehole data were registered by the datalogger and were as follows:

SSNN: Borehole name, SS=site code, NN=borehole number
Date: Date of test; Year,Month,Day
IW: Inclination of the borehole (degrees)
L: Length of test section (m)
LO: Length to upper limit of test section along the borehole (m)
LB: Length of the bubble tube (m)
DW: Diameter of the borehole (mm)

When the test sequence was completed the operators could feed comments via the ABC 80 unit.

Cassette Tape

The values regarding pressure, temperature, flow and relays as well as the borehole data registered by the datalogger were stored on the cassett tape, see C-file.

As a rule the cassette tape contained data from two injection tests, one on each side.

On the cassette the operator wrote the borehole name (site code + borehole number) upper and lower limit of the test section, the date of the test and his own signature.

When the processing and the evaluation of data from the tapes was finished the tape content was aborted.

C-FILE and C-File Name

The C-Files were named according to the following convention:

CBHNR.NL (example: CKM12.1A)

C:	Type of file; C = cassette file
BH:	Site code,two letters; GI for Gideå, KM for Kamlunge...
NR:	Borehole number within the site; 1-99
N:	Number of cassette from each borehole
L:	Side of the cassette tape, A=A-side, B=B-side

One C-file contains the data registered by the datalogger and stored on the cassette tape during one test, including the borehole data fed in by the measurement operators, appendix 6 and 7. Pressure, temperature and flow rate are indicated in kPa, ^{o}C and ml/s respectively. The ground-water head is indicated in vertical distance between the top of the casing and the ground-water level. This value is calculated by the programme "WATER" from the bubble tube pressure, the length of the bubble tube and the inclination of the borehole. In the C-file the numbers of the relays used during a test sequence are stored, appendix 6 and 7.
The C-files were stored on magnetic tapes at SGAB and SGU. During 1986 the C-files were transferred to magnetic tapes at KRAB.

CAS.DIR

CAS.DIR has five columns:

Column 1: File name
Column 2: Borehole name
Column 3: Upper limit of section
Column 4: Lower limit of section
Column 5: Comments

The borehole names in column 2 were assigned according to a convention used in SGU´s and SGAB´s database GEOLIS, see chapter 2.1.2.

CAS.DIR is now (1986) stored on magnetic tapes at SGAB. During 1986 a copy of CAS.DIR was transferred to magnetic tapes at KRAB.

DAT.DTA, Diskette

The data stored on the cassette tape were transferred to a file named DATA.DTA on a diskette via the second ABC 80 computer. This was done when a test was finished or during the test by the program PLOT.

Thus, the diskette contains data from one test, the same data that can be found in the corresponding C-file, appendix 6 and 7. Section identity and date of test were written on the diskette.

The diskettes are currently (1986) in the archive at SGAB, Uppsala.

GRAPHS

Eleven graphs were generated from each test. With a few exceptions they look like the graphs obtained from transient injection tests with steel pipe equipment, chapter 2.1.2, and they were called A0, A1-A4, B1-B4, C1 and C2.

A0 is a flyleaf presenting key values of flow and pressure and a preliminary value of hydraulic conductivity. A1-A4 show pressure, flow temperature and ground-water level variations during the whole measurement sequence in a linear scale.

B1-B4 show pressure and flow variations during the injection phase in a logarithmic or a semi-logarithmic scale. C1, C2 show pressure variations during the fall-off phase in a logarithmic or a semi-logarithmic scale.

The graphs are filed in the archive at SGAB, Uppsala.

SHTINJCD

The results of the water injection tests were stored in the table SHTINJCD in SKB´s database GEOTAB, see chapter 2.1.2.

2.3.3 Description of Processes (▭) in the Block Diagram, Figure 2.2

PRESSURE TRANSDUCERS

The different pressures were monitored by pressure transducers, type Kistler 4043A100. The section pressure meters, P1 and P2, were located in the test section just below the upper packer. The packer pressure sensors, P4 and P14, were connected to the packer pressurizing system at ground surface. Also the barometic pressure sensor B0 was placed at ground surface.

Pressurized Bubble Tube

The ground-water head was determind by means of a steel pipe of length known (=LB) and air was made to pass through the pipe by means of a back pressure valve. The air drive pressure measured by the pressure sensor P7, corresponded to the water column height in the pipe.

From the drive pressure, LB and the inclination of the borehole the ground-water level in the borehole was determined. This was done by the programme "WATER".

Temperature sensors

The temperatures were measured by temperature sensors, type PT100, range 0-100 centigrades. They were placed in the test section (water temperature in the test section T2), in the measurement trailer (temperature of the injection water T3) and outside the measurement trailer (outer air temperature T4).

Flow Meter Unit

Three flow meters (Fisher and Porter, Minimag and OBF) measured the water flow rate. They represent three strictly delimited measurement ranges.

Q1= 117-1.17 ml/s
Q2= 1.7-0.08 ml/s
Q3= 0.1-0.005 ml/s

Q1 was always connected. The other two flow meters were automatically switched on when the flow rate decreased. The flow meters measured a change in voltage applied across a measurement hole, Almén et al 1983.

From 1985 a new flow meter unit was utilized. This was a Micromotion D 65-SJ within a maximum flow of 1455 l/min and a zero stability of $\pm$ 0.09 ml/min.

Measurement Operators

The measurement operators started the measurement sequence by executing the programme "WATER" on the ABC 80 computor. During the test they controlled the data flow on the display of the computer and intervened when necessary with corrections of measurement values or calculation routines. Via the ABC 80 they also fed borehole data to the datalogger. When a test was finished the operator plotted the graphs by means of a second ABC 80 and the program "PLOT" on the plotter. They also noted section identities and date of test on the cassettes and on the diskettes.

DATALOGGER

The datalogger used was a Monitor Lab. It registrered the measurement values and sent them to the ABC 80 computer for processing. The datalogger was connected to a SIO card. The card holds two channels of which the datalogger uses one referred to as channel A, Almén et al 1983.

ABC 80, CS3 Tape Recorder, WATER and PLOT

The heart of the system was an ABC 80 (I) computer comprising the programme "WATER". It controlled the measurement process and received measurement values from the datalogger. After processing the measurement values were stored by the data tape recorder.

A second computer, ABC 80 (II), was used for transferring measurement data from the cassette tape to a diskette and for plotting the graphs immediately after completion of the test.

When the registered data were processed by the ABC 80 (I) unit they were stored by the tape recorder. The tape recorder was a CS3 recorder, connected to the B-channel of the SIO card, Almén et al 1983.

The software of the system is divided into two main programmes: "WATER" and "PLOT". "WATER" is used when collecting data whereas "PLOT" is used for transferring data from the cassette tapes to the diskettes and for plotting the graphs. Independent drive routines are used for the plotter, for the CS3 tape recorder and for handling of data received from the datalogger. These drive programmes are written in Assembler (machine language) and cannot be revised without special equipment. Other drive routines are enclosed in the main programmes in the form of sub-routines and consequently written in BASIC. The Assembler routines are loaded by means of special BASIC programmes named "MON" and "PLOTDRIVE", resp. The programmes of the system are presented in Table 2.2.

Table 2.2 Programmes used for the umbilical hose equipment

Program	Purpose of Program
BOFA.BAC	Initiates the drive routine for the datalogger
MON.ASM	Drive routine for the datalogger, Assembler programme
MON.BAC	Basic programme, which loads the drive routine MON
CS3.ASM	Drive routine for the CS3-tape recorder
IECLINK.ASM	Automatic start routine. Loads from the CS3-tape recorder
WATER.BAC	Main programme for data collecting
PLOT.BAC	Initiates the drive routine of the plotter
PLOTDRIVE.BAC	Basic programme, which loads the drive routine of the plotter
PLOTUT.BAC	Main programme for plotting, manual
PLOTTA.BAC	Main programme for plotting, automatic

The "WATER" programme simultaneously performs three different main tasks:

- Controls the measurement process
- Shows the operator what is going on
- Saves measurement data for subsequent evaluation

The control function has been included in the form of a sequence table where a complete measurement cycle is automatically run through once it has been initiated. A measurement cycle consists of a packer sealing phase, an injection phase, and a fall-off phase immediately afterwards. Below is a description of the activities stored in the sequence table . "T" signifies minutes after start of measurement.

T = 0 Certain input data, such as date, name of drillhole, length of measurement section, are stored in the tape recorder

T = 1 The relief valve opens. Measurement data begin to be stored on the tape

T = 2 Inflation of the packers. Adaption of the feed water tank pressure to the ground-water level. Initiating of rapid measurement value storage (every other second). The biggest flow meter is switched in to pressurize the hose.

T = 3 Stopping of rapid measurement value storing.

T = 22 Checking that flow = 0 (no leaks). The cannular test valve is opened. Automatic exchange of flow meters initiated.

T = 25 Saving of cannular flow for subsequent check. Closing of cannular test valve. Closing of the relief valve (after 821000).

T = 29 Repeat check that flow = 0. Closing of relief valve (before 821000). Switching in of the biggest flow meter.

T = 30	The now pressurized packers are cut off from their pressure tank. Supervision of packer pressure initiated. Rapid measurement value collection started. Test valve opened. This is the starting point of the injection phase.
T = 31	Rapid measurement value collection stopped. Automatic exchange of flow meters initiate. Regulation of overpressure in measurement section to 200 kPa is initiated.
T = 150	Regulation of the pressure in the measurement section discontinued. Rapid measurement value started. Test valve closes. This is the end of the injection phase and the initiation of the fall-off phase.
T = 151	Rapid measurement value collection stopped. Checking that flow = 0.
T = 170	Cannular test valve is opened.
T = 174	Checking that cannular flow = previous cannular flow. Flow meters disconnected. Test of change in pressure in measurement section initiated. Should the pressure decrease slowly enough the test can be discontinued, i e the computer jumps to T = 270.
T = 270	Packer pressure released. This is the end of the fall-off phase.
T = 300	One measurement cycle completed. The data storing is discontinued. comments may be entered on the data tape.

During the injection phase (from T = 30 to T = 150) the programme aimed to maintain an injection pressure of 200 kPa. The time, however, that was required to reach a constant pressure was too long in many test sections, up to 10 minutes. Therefore the programme was modified. The "new" programme succeeded in reaching a constant injection head much faster, often before 60 seconds of injection. The "old" programme was used from 1981 to 1983 and the "new" programme from 1984 to 1986.

There were two plotting programmes: one automatic and one manual,Table 2.2. The automatic is ordinarily to be used for productional diagrams as soon as possible on preprinted forms. The manual programme makes it possible to plot random measurement values in order, e g to check transducer or a regulation device.

Of great importance in the automatic plotting programme was the criteria for the start of the injection phase and fall-off phase ($t = 0$ and $t' = 0$ respectively). The criteria were as follows:

$t = 0$ the scanning that preceeded the scanning when $Q_{tot} > 500$ ml or $dp > 10$ kPa

$t' = 0$ The scanning that preceeded the scanning when $dP2 > 2$ kPa

where

$t =$ Time from injection start in the B-graphs (s)
$t' =$ Time from fall-off start in the C-graphs (s)
$Q_{tot} =$ Injection volume during injection phase (ml)
$dp =$ Injection pressure during injection phase (kPa)
$dP2 =$ Pressure drop during fall-off phase (kPa)

MDS Tape Recorder

The data tape was read into the host computer by means of a MDS tape recorder and a programme named # MDS. The host computer was SGU´s PRIME before April 1, 1983 and then SGAB´s PRIME 750.

Cataloguing

The C-files were catalogued by data operators at SGU before April 1, 1986 and then by a hydrogeologist at SGAB.

PLOTTER

The plotter used was for A4 and manufactured by Houston Instruments (model EDMP-2M). I was connected directly to the V:24 gate in the keyboard of the ABC 80.

EVALUATION

The graphs of the test sections were evaluated and parameters such as hydraulic conductivity, skinfactors and natural section pressure were determined. Theory and evaluation methods are described in a number of reports, Ahlbom et al 1983, Andersson and Persson 1985.

2.4 Umbilical Hose Equipment System, Version 2

As for the steel pipe system the umbilical hose system has been modified during 1985 and 1986. The new equipments will have improved data collecting and data processing units, Almén et al 1986. Since the system is not completed yet the umbilical hose equipment, version 2, is not described in this report.

3. SINGLE HOLE STEADY-STATE INJECTION TESTS

The purpose of the steady-state injection tests is to determine the hydraulic conductivity of the bedrock in boreholes. This is done in many test sections during a relatively short period of time. The lengths of the test sections are in general 2m or 3m. The steady-state tests start in the same way as the transient tests, chapter 2, with a packer sealing phase. Then follows the injection phase when water is pumped through the steel pipes or the umbilical hose down to the delimited test section under constant pressure.

There is no fall-off phase. When the injection is finished the test sequence is completed. The duration of the two phases differs depending on the equipment used.

3.1 Steel Pipe Equipment System, Version 1

During 1977-1980 the single hole steady-state tests were performed by the aid of the steel pipe equipment, version 1. This equipment did not have any recording instrument. The measurement data were noted manually in protocols and only flow and pressure values at the end of the injection phase were taken in account when determining the hydraulic conductivity. The packers used were sealed against the borehole wall in a hydromechanical way, and their length were 0.3 m. The packer sealing phase varied between 10 and 30 minutes, while the injection phase varied from approx 3 minutes to approximately 30 minutes.

3.1.1 Routines for Collecting, Processing and Evaluation of Data

Data flow is presented in the block diagram in Figure 3.1.

During a test section pressure, injection pressure and injection flow rate were measured. The section pressure was monitored by a pressure transducer connected to the test section and located just above the upper packer. The injection flow was

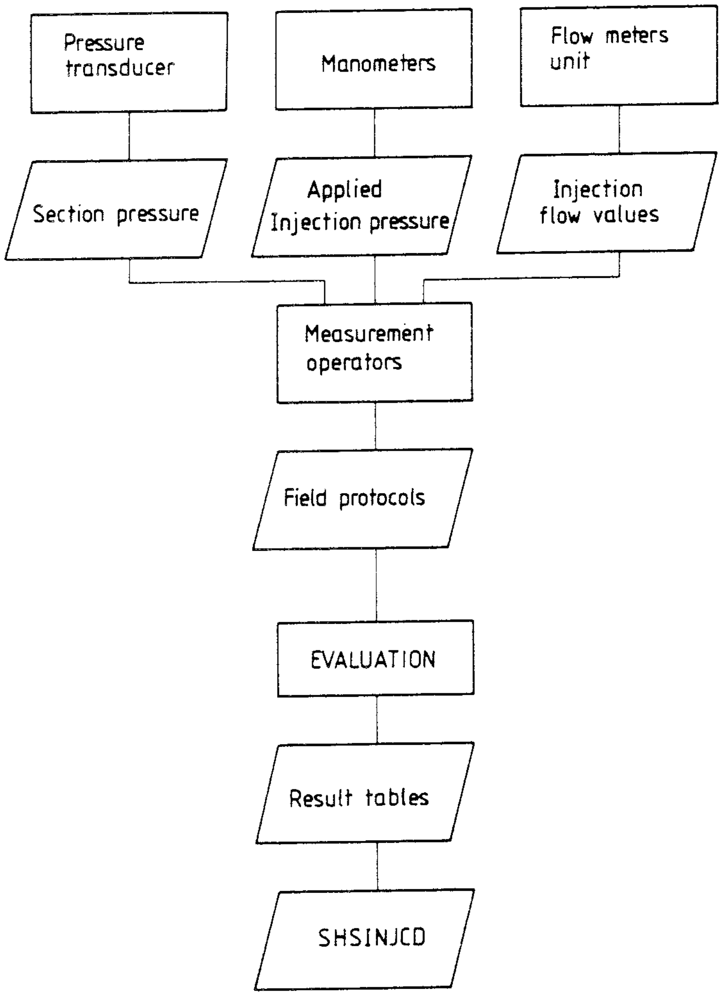


Figure 3.1 Data flow for data from single hole steady-state tests with the steel pipe equipment, version 1

measured by a flow meter unit in the measurement housing. Two manometers were connected to the outflow pipe of the flow meter unit. They measured the applied injection pressure during the injection phase.

The output signal from the pressure transducer was received at ground level by an amplifier unit. Before the injection phase the absolute pressure of the test section was supressed and a reference pressure was stored by the aid of a supression facility. The supressed pressure value was equal to the injection pressure during the injection phase. On a digital display on the amplifier unit the pressure values could be read. The injection pressure at injection stop was noted in a measurement protocol. Unfortunately, the pressure transducers were out of order in many cases. Then the injection pressure was taken from the manometers instead.

During the injection phase a constant injection pressure was maintained by regulating the water flow passing through the flow meter unit. The regulation was done by the measurement operators. The flow value at injection stop was noted in the measurement protocol.

The test sections were tested several times consequtively with different pressures. The injection pressures used were 200 kPa, 400 kPa and sometimes 600 kPa or 800 kPa.

When a number of tests were completed the measurement protocols were sent to a hydrogeologist at SGU. The hydrogeologist calculated the hydraulic conductivity of the test sections.

The results of the steady-state tests with this equipment have been stored in the table SHSINJCD in SKB´s database.

3.1.2 Description of Data Volumes (▱) in the Block Diagram, Figure 3.1

Section Pressure

The section pressure was measured by a transducer placed above the upper packer of the test section. In the tests performed during 1977 (in eight boreholes) the transducer was connected to the test section through a plastic pipe. To eliminate deformations of this connection during the packer sealing phase the equipment was modified and from 1978 the transducer was connected to the test section through a telescope pipe made of stainless steel.

The output signal from the pressure transducer was received at ground level by an amplifier unit, amplifying the signal and presenting the section pressure on a display on the amplifier unit. By the aid of a supression facility the absolute section pressure was supressed before the injection phase. At the same time the absolute section pressure was stored as a reference. The supressed pressure was equal to the injection pressure in the test section during the injection phase. A switch on the amplifier unit made it possible to read the absolute pressure, the supressed pressure and the reference pressure on the display. The pressure values on the display were presented in bars with two decimals. When the pressure transducer malfunctioned the injection pressure was determined by subtracting the pressure losses in the pipe string from the manometer pressure.

Applied Injection Pressure

The two manometers measured the excess pressure caused by the injected water. Thus this pressure was equal to the applied injection pressure during the injection phase.

Injection Flow Value

The flow meter unit consisted of six flow meters connected in parallel. The measurement operator read the scale divisions on the flow scales and the flow meter in question. But only one flow value at the end of the injection phase was noted in the measurement protocol.

Measurement Protocol

The measurement protocol contained a protocol head and a table for measurement data. The protocol head comprised borehole name, date of test, identity of transducer, manometers and flow meter unit and occasionally the vertical distance between the top of the casing and the ground-water level.

The data table comprised section limits along the borehole, absolute pressure before packer sealing, constant injection pressure from transducer and/or the manometers, flow meter number and scale division corresponding to the water flow at the end of the injection phase and the signature of the measurement operators. Furthermore, there was a comment column, where the operators noted pressures during the test, duration of the packer sealing phase, water temperature and other data relevant for the evaluation of the test. The table contained data from 2-4 tests. The pressure values were expressed in bars with two decimals.

The measurement protocols are currently (1986) stored in the archive at SGAB, Uppsala.

Result Tables

The result from the steady-state injection tests were noted in tables. These tables vary. In general, they comprise 6 columns containing section limits, flow meter number, scale divison, flow rate at the end of the injection phase, constant injection pressure in the test section and hydraulic conductivity (m/s) of the test section. The injection pressure value (expressed in meter water column) was taken either from the transducer or the manometer. In the latter case, pressure losses in the steel pipes were subtracted from the read value.

SHSINJCD

The results of the single hole steady-state tests were stored in a table in SKB´s database GEOTAB. The table is called SHSINJCD and it has 10 columns.

Column 1:	IDCODE:	5 characters: TSSNN, T=borehole type (K=cored borehole, H=percussion borehole) SS=site code, NN=borehole number
Column 2:	SECLEN:	Section length (m)
Column 3:	SECUP:	Borehole length to test section, upper limit (m)

Column 4: TP: Duration of injection phase (s)

Column 5: K: Steady-state hydraulic conductivity (m/s)

Column 6: T: Transmissivity, T=K x SECLEN (m^2/s)

Column 7: DP: Injection pressure in section during injection phase (kPa)

Column 8: QP: Water flow rate at injection stop (m^3/s)

Column 9: COM50: Comments

Column 10: DATE: Input date of data to data base

3.1.3 Description of Processes (☐) in the Block Diagram, Figure 3.1

Pressure Transducer and Amplifier Unit

The pressure transducers were located above the upper packer in the borehole, see chapter 3.1.2. During 1977 two transducers from Entran Devices Inc, EPN 350 1000 AW and EPN 350 2000 AW, were used. They were coupled in parallel and had different measurement ranges, 0-1000 psi and 0-2000 psi respectively. From 1979 transducers from CJ Enterprises (CJ DC 60-23) were used. They had a measurement range between 0 and 99.99 bar.

Each pressure transducer was connected to a specific amplifier unit at ground level. The unit had a supression facility and a digital display, which presented the measured pressure value in bars. A switch on the amplifier box enabled reading of the absolute pressure, the supressed pressure and the stored reference pressure on the display. The amplifier unit was designed and produced by Studsvik Energiteknik AB, which also calibrated the unit together with the corresponding pressure transducer.

Manometers

The two manometers were connected to the outflow of the flow-meter unit. The measurement ranges were 0-0.6 MPa and 0-1.6 MPa respectively.

Flow Meter Unit

The flow meter unit consisted of 4-6 flow meters connected in parallel, type Brook´s rotameters with mutually overlapping measurement sectors, Almén et al 1983. The measurement values read on the flow meters were later converted to flow rate values in accordance to calibration diagrams from the manufacturer. The lowest measurable flow rate varied between 1.42×10^{-8} m^3/s and 1.33×10^{-7} m^3/s depending on the flow meters used. Maximum measurable flow rate was 1.08×10^{-3} m^3/s.

Measurement Operators

There were two measurement operators at every borehole. They brought down the measurement probe to the test section and started the measurement sequence by expanding the rubber packers against the borehole wall. During the injection phase the operators maintained a constant injection pressure by regulating the water flow throught the water flow meters. They wrote down the pressure and flow values as well as other data in the measurement protocol.

EVALUATION

On the basis of the measurement protocols a hydrogeologist at SGU evaluated the single hole steady-state tests. The water flow values of the protocols were converted into water flow rate (m^3/s) by means of calibration diagrams from the manufacturer of the flow meters. If the pressure transducer were out of order the injection pressure in the test section was taken from the manometers. Then the pressure losses in the infiltration pipe string were subtracted from the read value on the manometer. The pressure losses were determined earlier for different flow rates and different pipe string lengths in a calibration test performed on an airfield. When the pressure and flow values were determined the hydraulic conductivity of the test sections were determined according to the equation.

$$K = \frac{Qp}{L \times H} \times \frac{1 + \ln (L/dw)}{2 \pi} \qquad (3.1)$$

where

K = Hydraulic conductivity (m/s)
Qp= Water flow rate at injection stop (m^3/s)
L = Length of the test section (m)
H = Constant injection head in the section (m water col)
dw= Diameter of the borehole (m)

3.2 Steel Pipe Equipment System, Version 2

Single hole steady-state injection test with steel pipe equipment version 2 were performed at four sites during the years 1982 and 1983.

3.2.1 Routines for Collecting, Processing and Evaluation of Data

Data flow is presented in the block diagram Figure 3.2.

The data collecting routines and instruments were almost the same for steady-state test with this equipement as for the transient test with the same equipment, chapter 2.1. The difference between the two methods was that during the steady-state tests the measurement sequence was interrupted 15 minutes from the water injection start and as a consequence stage 4 (Table 2.1) became shorter and stage 5 was omitted.

The data of the cassette tapes were read into the host computer and filed in the catalogue file C.DIR. However, no L-files nor

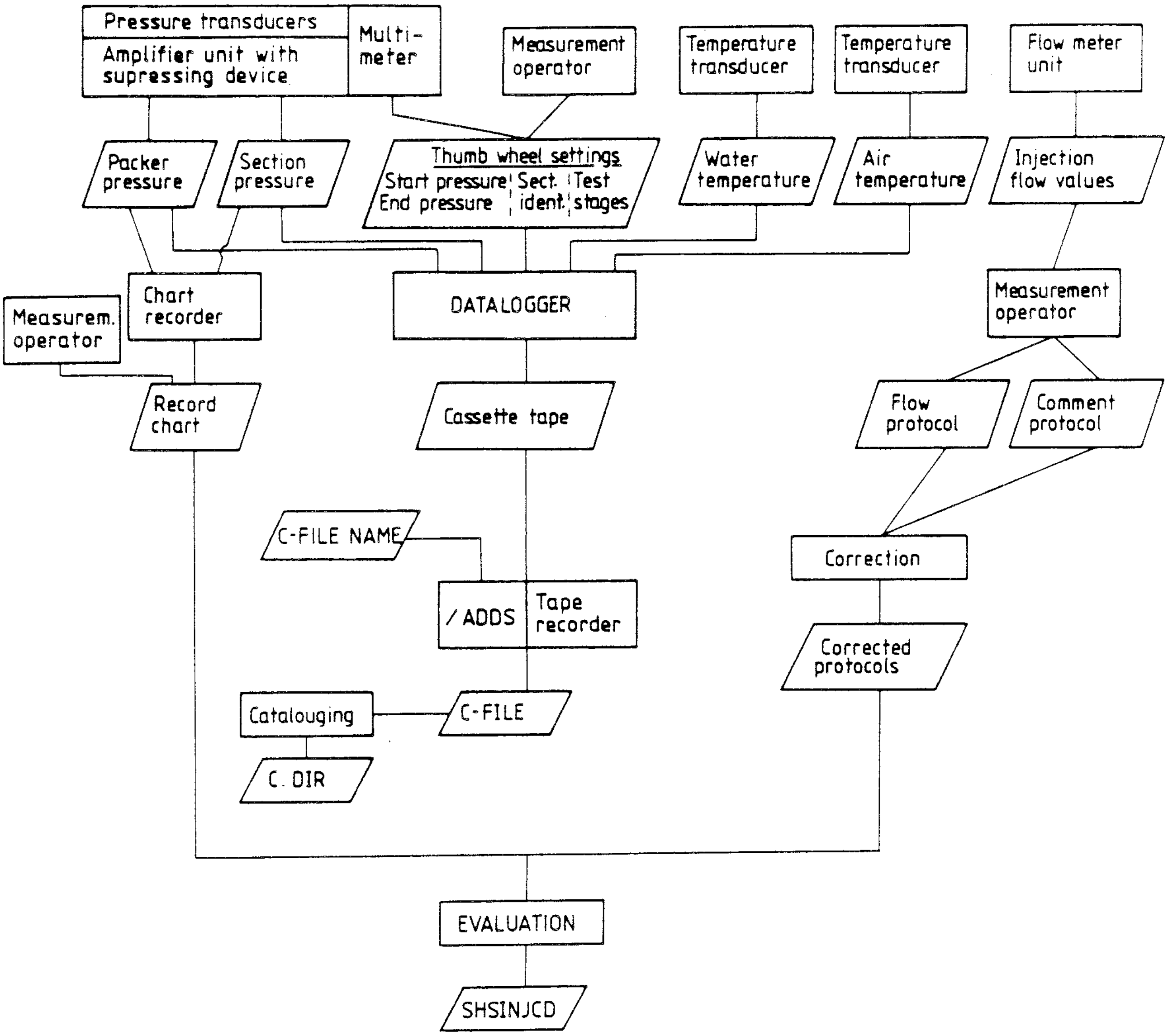


Figure 3.2 Data flow for data from single hole steady-state tests with steel pipe equipment, version 2.

M-files were created. The protocols were checked and completed but they were not punched into P-files.

On the basis of the data from the record charts and the protocols the hydrogelogist at SGAB determined the hydraulic conductivity of the test sections. The results were during 1986 stored in the table SHSINJCD of the database GEOTAB.

3.2.2 Description of Data Volumes (▱) in the Block Diagram in Figure 3.2.

All the data volumes of Figure 3.2 except one can also be found in Figure 2.1 and they are described in section 2.1.2. The one that is not described in that section is

SHSINJCD

The results of the single hole steady-state test with the steel pipe equipment versioin 2 have been stored in the table SHSINJCD in SKB´s database. SHSINJCD is described in section 3.1.2.

3.2.3 Description of Processes (□) in the Block Diagram in Figure 3.2.

Also the processes of Figure 3.2 are described in chapter 2.1.2 with one exception, which is

EVALUATION

A hydrogeologist at SGAB determined the constant injection pressures in the test sections from the record charts. The flow rates at injection stop was taken from the corrected protocols. The hydraulic conductivity was then calculated according to equation 3.1, chapter 3.1.3.

3.3 Umbilical Hose Equipment System, Version 1

Single hole steady-state tests with the umbilical hose equipment version 1 have been performed at two sites (Kamlunge 1983 and Finnsjön 1986).

3.3.1 Routines for Collecting, Processing and Evaluation of Data

Data flow is presented in the block diagram in Figure 3.3.

The routines for collecting and processing of data as well as the instruments were almost the same for steady-state tests with this equipment as for the transient tests with the same equipment, chapter 2.2. Also the programmes and the hardware were the same. The difference in performance between the two methods was that during the steady-state tests the water injection phase was interrupted 15 minutes from the injection start. Thus the control functions were manually stepped forward from T=45 to T=270 in the sequence table, described in chapter 2.2.3. Another difference was that the steady-state test resulted in fewer graphs.

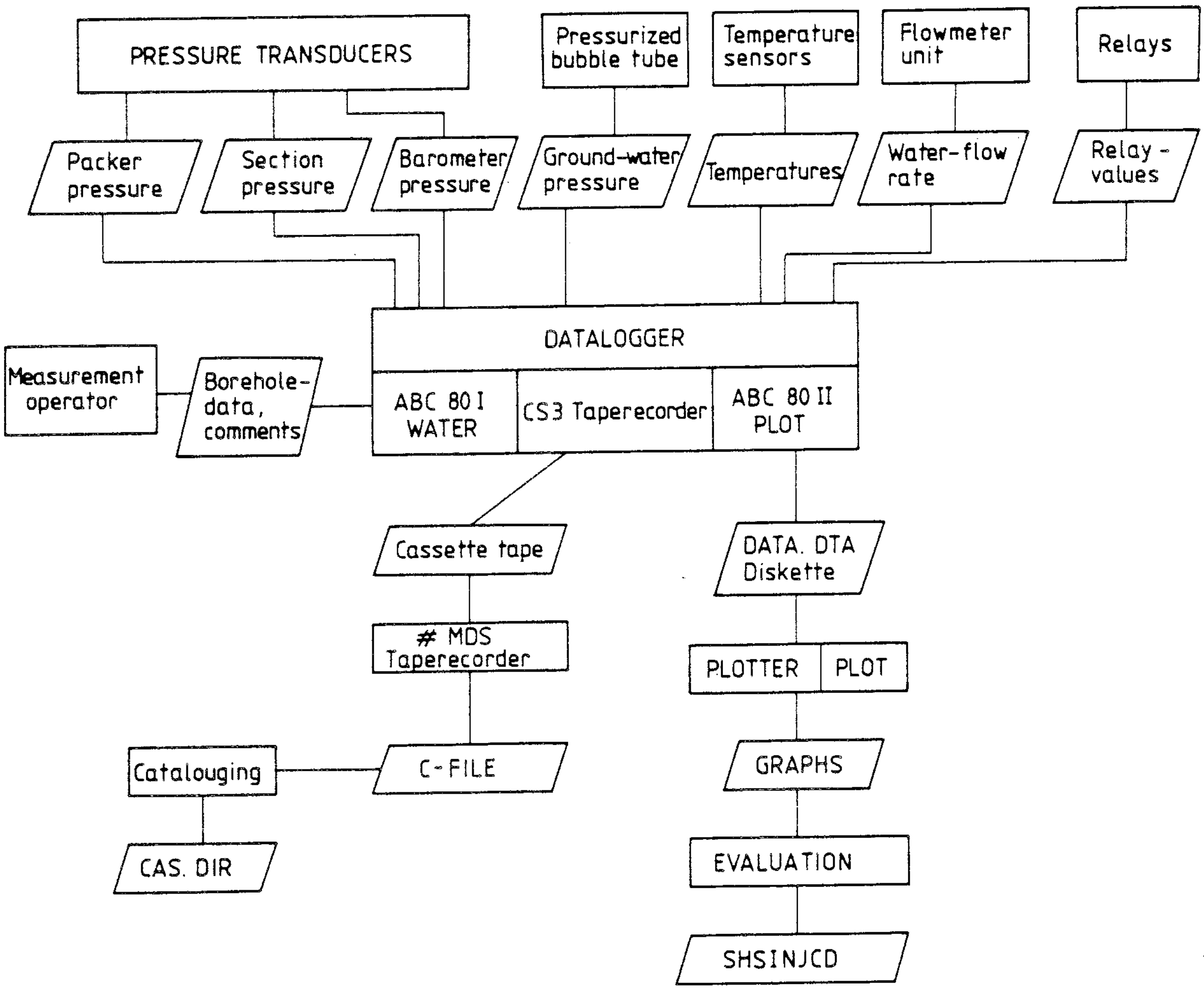


Figure 3.3 Data flow for data from single hole steady-state tests with the umbilical hose system, version 1.

3.3.2 Description of Data Volumes (▱) in the Block Diagram in Figure 3.2.

Almost all the data volumes and processes of Figure 3.3 are the same as in Figure 2.2 and described in chapter 2.2.2. The ones that differ or are not described earlier are described below.

GRAPHS

When a steady-state injection test with the umbilical hose equipment was completed only the five A-plots were plotted, i e the graphs A0, A1-A4, see chapter 2.2.2.

SHSINJCD

The results of the steady-state injection tests with the umbilical hose system have been stored in the table SHSINJCD in SKB´s database. SHSINJCD is described in chapter 3.1.2.

3.3.3 Description of Processes (▭) in the Block diagram in Figure 3.2.

Also the processes of Figure 3.3 are described in chapter 2.2.3 with one exception, which is

EVALUATION

On the basis of the graphs from the steady-state tests the site hydrogeologist determined the hydraulic conductivity of the test sections according to the equation 3.1, chapter 3.1.3.

4. GROUND-WATER LEVEL MEASUREMENTS IN BOREHOLES

One of the most important factors that influence the ground-water flow within an area is the level of the ground-water table. The position of the ground-water table have been determined by measurements of the ground-water levels in boreholes. The measurements have been carried out partly by manual level registrations with the help of sounding equipment, partly by continous monitoring equipments. The latter were water-level gauges before 1984 and the GRUND-system from 1985. Some boreholes have been delimited by inflatable rubber packers and the ground-water table has been registered above and/or below the packers.

4.1 Manual Ground-water Level Registrations

In up to c. 50 boreholes in each investigated area the position of the ground-water level was manually registered. This was carried out by soundings (before 1985). The registration frequency was in general 2-5 times/mounth. In between 5 to 15 boreholes in each site the boreholes were delimited into two sections by inflatable rubber packers. The ground-water head was then measured in both sections.

4.1.1 Routines for Data Collection and Data Flow

Data flow is presented in the block diagram in Figure 4.1.

Ground-water level registrations

The measurement operator measured the distance from the top of the borehole casing to the ground-water head along the borehole. In case of delimiting packers the lower section was connected to the ground surface by a plastic tube through the packers. The distance to the ground-water level was then measured from the top of the tube to the water level in the tube.

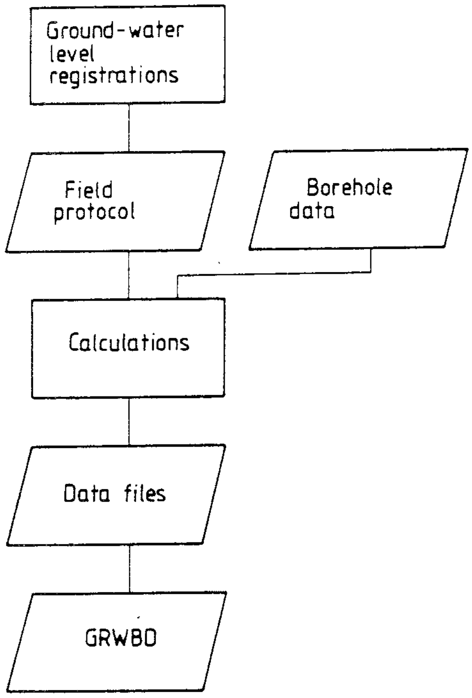


Figure 4.1 Data flow for data from manual ground-water registrations

Field protocol

The ground-water level values (in metres) were noted in a field protocol - one value for each borehole/section and measurement occasion. When all the boreholes in an area (during one day) were sounded the field protocol were sent to the responsible hydrogeologist. The field protocols are now in the archive at SGAB, Uppsala.

Calculations and Borehole data

The responsible hydrogeologist calculated the level above the sea of the ground-water head for every registration occasion. The data used for this calculation were apart from the measured value the inclination of the boreholes and the altitudes of the top of the borehole casings.

Data files

The result of the hydrogeologists calculations were noted in a protocol and then punched into data files in the PRIME-computor at SGAB. In general it was one data file for each site. The data files comprise five columns containing borehole name, date of measurement, registered value (m), vertical lenght between the top of the casing and the ground surface (m) and the ground-water level in metres above the sea level. The data files are now (1986) stored on magnetic tapes at SGAB, Luleå. The protocols are in the archive at SGAB, Uppsala.

GRWBD

The data files containing the results of the manual ground-water level registrations were transferred to the VAX-computor at KRAB and the results were stored in a table in SKB´s database GEOTAB. The table is called GRWBD and is has 6 columns.

column 1: IDCODE; 5 characters: TSSNN; T = Borehole type (K = cored borehole, H = percussion borehole), SS = site code, NN = borehole number.

column 2: BHPART; Part of borehole: U = upper part above the packer, L = lower part below the packer, N = the whole borehole - no packer.

column 3: DATE; Date of measurement (YYMMDD)

column 4: GRWHEAD; Ground-water level (m.a.s.l.)

column 5: COM; Comments

column 6: INDAT; Input date of data to data base.

4.2 Continous Ground-water Level Registrations by Recording Gauges

In three of the vertical boreholes of the investigated sites during the period 1982-1983 the ground-water level was monitored by recording gauges.

4.2.1 Routines for Data Collection and Data Flow

Data flow is presented in the block diagram in Figure 4.2.

Recording gauges

The recording gauges used were SMHI-gauges type R 16.

Record charts

The ground-water level variations were registered by the pen carriage on the record chart, which was applied on a cylinder

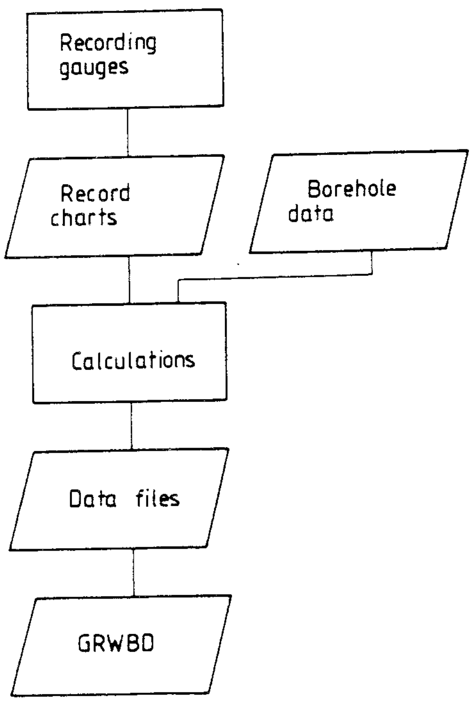


Figure 4.2 Data flow for data from ground-water level registrations by gauges

driven at a constant speed. The record chart was changed monthly. Once a week or every fortnight the gauge was calibrated by sounding of the ground-water level. At these occasions the distance from the reference level to the ground-water level and the date and time of the calibration were noted on the record sheet.

The record sheets are (now) 1986 filed in the archive at SGAB, Uppsala.

Calculations and Borehole data

The record sheets were sent to the site hydrogeologist who from the ground-water level curve and borehole data calculated the average altitude of the ground-water level for every day during the actual month. This was done only for the two sites Fjällveden and Gideå. The borehole data used were the altitude of the top of the borehole casing and the vertical distance between the reference level and the top of the borehole casing.

Datafiles

The results of the calculations described above were punched into data files on the PRIME-computor, see chapter 4.1.1.

GRWBD

The data files were transferred to the VAX-computor at KRAB and their content were stored in the table GRWBD in SKB´s database, see chapter 4.1.1.

4.3 Ground-water Registrations by the Monitoring System GRUND

Since 1985 the ground-water level in boreholes have been measured by the specially designed ground-water table monitoring system GRUND, Almén et al 1986. The system consists of the following parts:

- monitoring probe
- packer
- wire, hoses and cable to the surface
- portable computer

The monitoring probe is a microprocessor-controlled unit designed to measure and store the ground-water level in a borehole. In deep boreholes a packer is installed in order to isolate the upper part of the borehole. The probe and the packer are placed 5-10 m and c. 10 m respectively below the ground-water table. The GRUND system can be left for several months without maintainance. The portable computer is used only for initiating the registration and for collecting of data.

4.3.1 Routines of Collecting and Processing Data

Before the registration start a simple slug test is performed in the actual borehole to ensure that the surrounding rock is permeable enough to respond to the ground-water level variations of the bedrock. The slug tests are carried out with inflated packers.

The measurements are initiated by the "start" programme of the portable computer (Epson HX-20). The measurement interval and the storage criteria can now be fed into the GRUND microprocessor unit. The communication with the GRUND unit is done with the help of hexadecimal codes.

Depending on the storage conditions the GRUND-system can be left without maintainance for several months or even years. In general, though, data is dumped after 2-3 months of registration.

The registered data in the memory of the GRUND unit are transferred to the Epson Hx-20 with the help of the programme "Fetch". Another programme saves data on the microcassette. It is also possible to list the registered values and to produce a simple plot. This is done on the built-in plotter of the HX-20

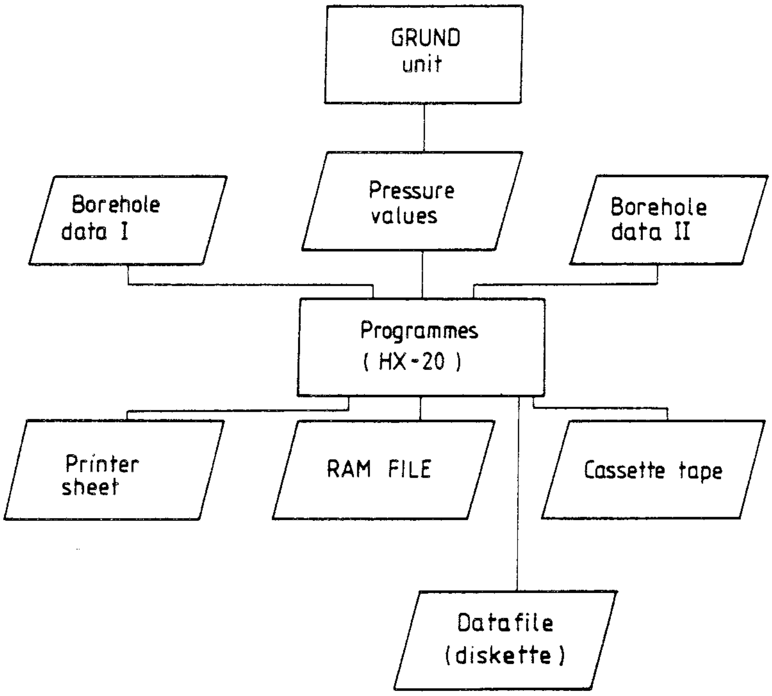
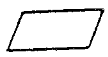


Figure 4.3 Data flow for data from ground-water pressure registrations by the GRUND system

computer.

When the registrations from the boreholes of an area have been stored in the memory of the Epson HX-20 or on the microcassette tapes data are transferred to discettes of a PC. A plotting programme enables the ground-water data to be presented as ground-water pressures, ground-water heads or levels related to any chosen reference level.

4.3.2 Description of Data Volumes () in the Block Diagram in Figure 4.3

Pressure values

The pressurē transducer measures the ground-water pressure at the level of the measuring probe in mV. The output signal in mV represent different amounts of pressure for the individual pressure transducers. The pressure is measured and stored depending on preset conditions. Standard conditions are measurement every sixth minutes and storage of data every six hours or if the pressure change is greater than c. 20 mm of water colmmn compared to the preceeding stored value. These preset values can be changed via the GRUND microprocessor unit. Until fetching of data the pressure values are stored in the memory of the GRUND unit. The pressure values are stored in hexadecimal characters. The 2096 most recently collected values can be stored.

Borehole data I

When a measurement sequence is initiated the "start"-programme asks for a "Text". A message of maximum 15 characters comprising borehole name and depth to the pressure transducer can then be entered.

Borehole data II

In the beginning of the programme "HX-20 DATA" there is a table. Certain basic data are entered to this table. These data are unit number, scale constant (SC), ofset constant (OF), and inclination of the borehole in degrees (IW).

RAM FILE

By the help of the programme "Fetch" the stored data in the memory of the GRUND-unit is transferred to the RAM FILE of the HX-20 computer. The pressure values of the RAM FILE is still in mV and are expressed in hexadecimal characters.

Printer sheet

Via the built-in printer of the Epson HX-20 data from the RAM FILE are listed and simply plotted on a printer sheet. On the printer sheet basic data such as GRUND-unit number, borehole name, depth of the packer and date of print out are shown. A standard set-up in hexadecimal characters of the status of the GRUND unit is also presented. The listed pressure values are expressed in LSB (Least significant bits). One LSB represent different pressures for each GRUND-unit. A common value is 4 mm water column per LSB.

Cassette tape

By the help of the programme "Tape out" data stored in the RAM FILE is saved on a cassette tape. Data are not changed or converted during the saving procedure.

DATA FILE

The date files in the EPSON HX-20 is transferred to an ABC 80 diskette. In the future the ABC 80-computer will be replaced by a Digital Equipment PC 350. The transfer is done by the help of the programmes "Export data" and "HX-20 DATA". The data file is named as follows:

KSSNNddM.ymm   example: HKL1210M.609

where
K = Borehole type (K = cored borehole H = percussion borehole)
SS = Site code, KL = Klipperås etc
NN = Borehole number (1-99)
dd = Distance to pressure transducer along borehole, integer (m)
M = Metres
y = Last digit in the year of dumping
mm = Month of dumping

The ten first lines of the data file contain borehole data and technical data. Then follows measurement date/time and pressure values. The pressure values in the data file are expressed in m water column above the transducer, see appendix 8. The data files are not yet (1986) stored in the database.

4.3.3 Description of Processes (☐) in the Block Diagram Figure 4.3

GRUND unit

The GRUND unit is encapsulated in a water proof probe with accumulators and a pressure transducer. It is based on a CMOS processor and an integrating A/D converter. A 4 kByte RAM provides data storage and an EPROM circuits holds the program. The unit also contains a crystal controlled oscillator, a counter that can be fine tuned to a proper frequency and a DC/DC converter, Almén et al 1986.

The probe is vented via a hose to the surface, which means that the registered pressure values represent the ground-water head. For a pressure range of 10 m water column the resolution of the readings is 4 mm. The temperature range of the probe is 0 - 30 ^{o}C.

Programmes, EPSON HX-20

The stored data in the GRUND unit may be transferred to a portable computer Epson HX-20, which includes a built-in printer and a microcassette recorder.

The computer is also used for starting measurements and checking certain functions such as clocks and accumulator voltage. The communication with the GRUND unit is done with the help of hexadecimal characters. The software consists of seven self-instructing programs:

"Fetch"

Fetches the status message and all the data stored in the GRUND unit. The information is stored in the memory of the HX-20 together with the time of fetch operation. The RAM FILE of the computer will contain all the data.

"SIO"

The HX-20 acts as a terminal. The operator can use the GRUND commands. The characters are transmitted from the keyboard and the answers are displayed on the LCD display.

"Tape out"

Data stored in the RAM FILE is saved on a microcassette.

"Printer"

Data from the RAM FILE is listed and simply plotted by means of the built-in printer.

"Read tape"

Data stored on a tape cassette is read to the RAM FILE.

"Start"

Enter the measurement interval, the interval between compulsory storages, and the limit value for conditional storage.

"Export data"

Data files can be exported to another computer.

"HX20 DATA"

Transfers data from the RAM FILE to the PC. "HX20 DATA" and "Export data" are run simultaneously. In the beginning of "HX20 DATA" there is a table, in which each line comprise unit number, scale constant (SC), ofset constnat (OF) and borehole inclination (IW). Based on these facts the programme convert the pressure values from mV to m water column.

5. PIEZOMETRIC MEASUREMENTS WITH THE PIEZOMAC I SYSTEM

The purpose of the piezometric measurements is to determine the long-term natural piezometric pressure variations of the bedrock at different depths. This is done by delimiting deep boreholes into measurement sections by the aid of inflatable rubber packers and then monitor the ground-water head of the individual sections. The piezometric measurements are carried out using the Piezomac system. This system comprises a data collection and control unit (Piezomac), multipressure probe, analog probe, packers, pressure tubings and a data transfer and communication unit, Almén et al 1983. The equipment enables continous and simultaneous registrations of the hydraulic head in the measurements sections for periods of 3-6 weeks or longer.

During 1985 and 1986 the PIEZOMAC System has been modified. The new equipment, called PIEZOMAC II, has an improved measurement probe, new hardwares and new plotprogrammes, Almén et al 1986. Since the new equipment is not yet completed, the data flow of the PIEZOMAC II system is not described in this report.

5.1 Routines for Collecting, Processing and Evaluation of Data

Data flow is presented in the block diagram in Figure 5.1.

The multipressure probe measures the ground-water head of the measurement sections and the analog probe measures alternative parameters, mostly the air pressure. The Piezomac-unit controls the measurement and stores the registered data. Scanning frequency, constants and date/time of measurement start are fed into the Piezomac-unit. Data are stored in the Piezomac-unit as a P-file which is transferred to the host computer at Malå either via radio and the telephone network or via a tape recorder. In case of radio transfer the P-file is sent to a main computer at Malå and then to the PRIME 750 computer at Luleå. The cassette tape is sent to Luleå and the content is read into a

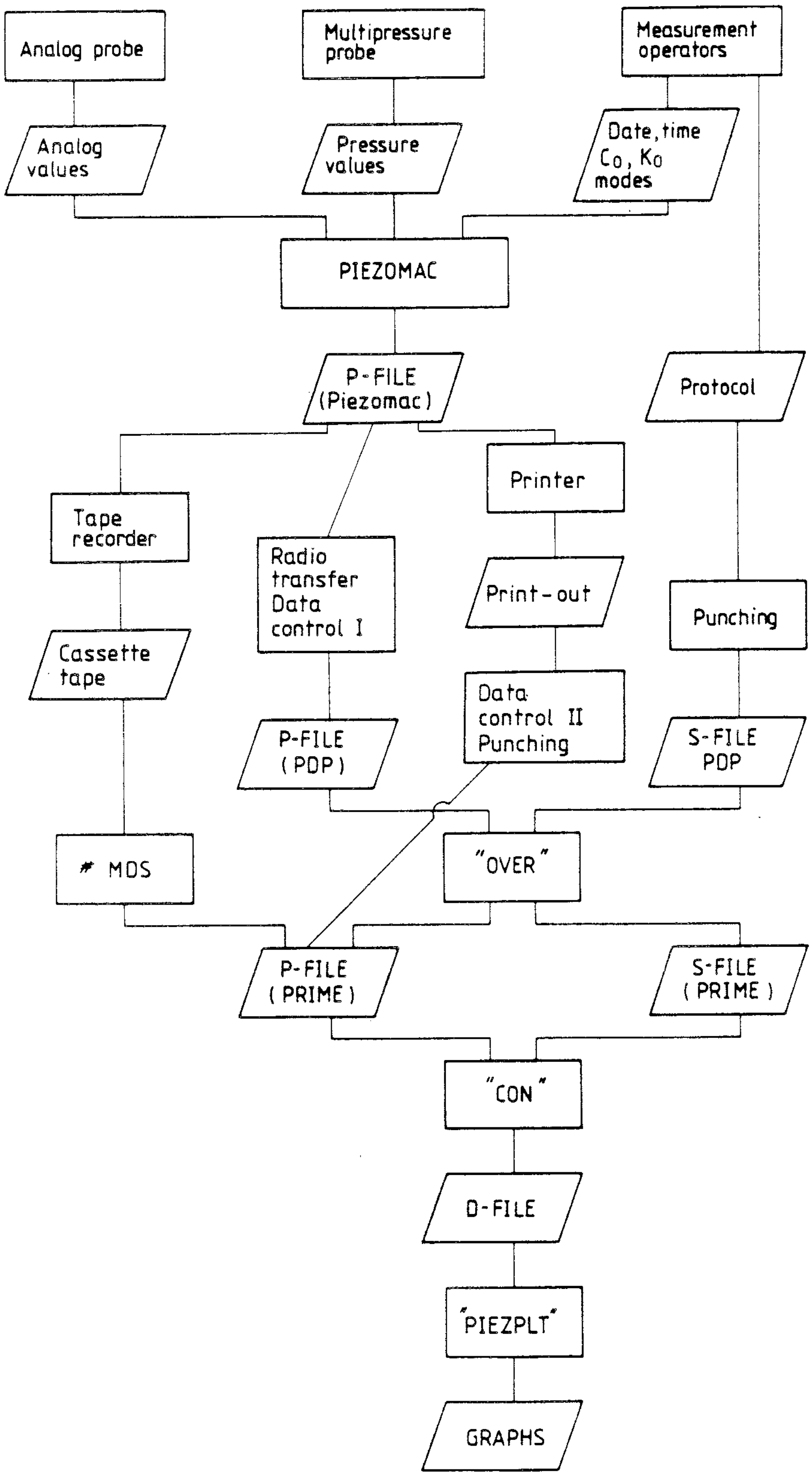


Figure 5.1 Data flow for data from piezometric measurements with the PIEZOMAC I system.

P-file on PRIME 750. There is a third way of transfering data used in the piezometric measurement at the Fjällveden and Svartboberget sites. There the P-files were printed by a field printer and the print-out was sent to Luleå where it was punched to a P-file on PRIME 750. The measurement operator writes down basic data such as instrumental constants, packer configuration etc on a protocol. The protocol is punched to a S-file on the main computer at Malå and then sent to PRIME 750 via the telephone net. Via the radio/tele communication the measurement sequence can be supervised and the field instruments can be reprogrammed during the continuance of the measurement process.

The P-file and the S-file are merged to a D-file, which contain all registered measurement data and the relevant background data.

The D-files is input data for plotting programmes, which produce graphs that present the data from each individual section either as raw data or calculated ground-water pressures or ground-water heads.

5.2 Description of Data Volumes (▱) in the Block Diagram Figure 5.1

Pressure values

The pressure is measured by the pressure transducer in the pressure measurement probe. The measured pressure represent the sum of the barometer pressure and the section pressure subtracted with the pressure difference between the level of the transducer and the level of the upper limit of the measurement section. The ground-water pressure of the measurement sections can thus be expressed as follows:

$$P_s = P_m - B + g \times (SECUP - LT) \times \sin(IW) \qquad (5.1)$$

where P_s = Ground-water pressure in the measurement section at the level of the upper packer (kPa)

P_m = Measured pressure (kPa)

B = Barometer pressure (kPa)
g = gravity constant (m^2/s)

SECUP = Length to upper limit of the section along the borehole from the top of the casing (m)
LT = Length to pressure transducer from the top of the casing along the borehole (m)
IW = Inclination of the borehole (degrees)

The measurement frequency differs depending on the mode that has been fed into the Piezomac-unit.

Analog values

The analog values are values measured by the analog probe. The analog probe can collect analog signals from any transmitter or transducer, but the analog values mostly represent barometer pressure when piezometric measurement is performed. The values from the analog probe are collected and processed in a similar way as for pressure values.

Date, time, modes, C_o and K_o

Before the measurement start the measurement operator feed certain data into the Piezomac unit via the keyboard. These are data and time (DDhhmm) of measurement start and ofset constants for the multipressure probe (C_o) and the analog probe (K_o) respectively. Furthermore the scanning mode is set. The different modes are as follows:

P = Pump mode, rapid scanning, c. 1 measurement per minute, only values from one borehole are accurate. This mode is usually not used in the piezometric measurements.
C = Continous measurement, some minutes between every scanning
N = Normal measurement, the scanning interval is stored in PIEZOMAC
T = First scanning after packer inflation
Ö = First scanning after packer deflation

The modes T and Ö are not set by the measurement operator but by the conversion programme "CON" later in the data processing. The modes P, C, and N can be changed from the office via the radio/tele communication.

P-FILE (Piezomac)

The measurement values are stored in the memory of the Piezomac as a P-file (appendix 9). The values are expressed in mV. The file has 3 record types according to the following:

Record type 1: YYYY MM:DD hh:mm; Date/time of measurement period start

Record type 2: DD:MM hh:mm S; Date/time of measurement, S= scanning mode

Record type 3: $(n_b + n_a)$ x 5 x (sss vvvvvv); measurement values compensated for the ofset constant(C_o) sss = seconds after time in record type 2. vvvvvvvv = stored value, one for each measurement section. The section values are in the same order as the corresponding section limits in the S-file. If there are less than five sections the data of the upper section is repeated. Record type 3 is repeated depending on the number of boreholes (n_b) and the number of analog probes (n_a). The order of the boreholes/probes is the same as in the S-file. Only the last scanning is valid for the values of the analog probe(s). vvvvvvvv = -32767 means bad value.

Cassette tape

The P-file of the Piezomac-unit can be recorded on a cassette tape by the aid of a tape recorder. The content of the cassette is the same as the corresponding P-file and has the same format.

If the radiotransfer do not function the cassette tape is read to a P-file on PRIME 750.

Print-out

The measurement data of the Piezomac-unit can be printed by the aid of a field printer. The print-out has the same format as the P-file.

If the data transfer via radio/telephone or the cassette recorder fails the print-out is punched to a P-file on PRIME 750.

Protocol

On a protocol the measurement operator writes down necessary background data. These are borehole name, date/time of packer inflation and packer deflation, length, diameter, inclination and azimut of the borehole, x- y- and z-coordinates (local) of the borehole casing, measurement section limits, calibration constants(s) for the probe(s) and length from top of casing to the pressure transducer along the borehole.

S-FILE (PDP)

The protocol is punched into a S-file on the PDP 11-73 computer at SGAB, Malå. The S-file contains the background-data necessary for evaluation of the piezometric measurement and has the following format:

Record 1: 3 x (YYMMDDhhmm)
Record 2-6: Ident, C_1, LB, DW, IW, AW, X, Y, Z, LT,
n_s x (SECUP, SECLOW), n_s x r, K_0

where

3* (YYMMDDhhmm) = Date/time for measurement start, packer inflation and packer deflation respectively
Ident: Identification of borehole(s) or analog probe.
The boreholes are named according to the GEO-

LIS-convention, see chapter 2.1.2.

C_1 :	Calibration constants for the probes	
LB :	Length of the borehole	(m)
DW :	Diameter of the borehole	(mm)
IW :	Inclination of the borehole	(degrees)
AW :	Azimut of the borehole	(degrees)
X,Y,Z	Local x- y- and z-coordinates for the top of the casing. z in m.a.s.l	(m)
LT :	Length from top of the casing to the pressure transducer along the borehole	(m)
n_s :	Number of measurement sections	
SECUP:	Length to upper limit of section from top of casing	(m)
SECLOW:	Length to lower limit of section from top of casing	(m)
r :	Length from section to pumphole (only used in interference tests , chapter 6)	(m)
K_o :	Ofset constant of the analog probe	

P-FILE (PDP)

Via radio and the telephone net the P-file of the Piezomac-unit is transferred to a P-file on the PDP-computer at SGAB, Malå. Incorrect data are deleted, but apart from this the two P-files has the same content and format.

P-file (PRIME)

The P-file on the PRIME-computer originates either from the corresponding P-file on the PDP-computor or from the cassette tape or from the print-out from the Piezomac. In all three cases the format is the same as in the P-file of the Piezomac.

The P-files from PRIME 750 are now (1986) stored on magnetic tapes at SGAB, Luleå.

The P-files are named according to the following convention:

PBHNR.YYMMDD (example: PKM03.830324)

P = "Piezomac file"
BHNR = Borehole name
YYMMDD = Start date of measurement

S-file (PRIME)

The S-file from the PDP-computer is transferred to an identical S-file on the PRIME 750-computer at SGAB, Luleå. The S-file name is the same as the corresponding P-file except that the first letter is a S instead of a P (example: SKM03.830324).

D-FILE

The P-file and the S-file are merged to an D-file which contain all the data necessary for the evaluation of the piezometric measurement (appendix 9). A measurement with n probes (n or n-1 boreholes) have the following format:

Record 1-n : Ident., C, LB, DW, IW, AW, x, y, z, LT,
n_s x (SEUP, SECLOW), n_s x r, K_o;
explanations see the S-file
Record n+1: empty
Record n+2-...: YYMMDDhhmm,S, n x 5 x (sssvvvvvvvv)
where

YYMMDDhhmm = Date/time of measurement
S = Scanning mod P, N, S, T or Ö
n = Number of boreholes or probes
sss = Seconds after YYMMDDhhmm
vvvvvvvv = Measured pressure in the sections respectively (metres of water column)

The pressure values are in the same order as the corresponding section limits in records 1-n.

The D-file names are the same as the P-file names except that the first letter is a D instead of a P, e.g. DKM03.830324.

The D-files were stored on magnetic tapes at SGAB, Luleå. During 1986 copies of the D-files were transferred to magnetic tapes at KRAB in Stockholm.

GRAPHS

By the aid of the plot routine PIEZPLT various graphs can be generated. Input data is the D-file. The graphs present the data from each individual section either as raw data or calculated ground-water pressures or ground-water heads.

5.3 Description of Processes (□) in the Block Diagram in Figure 5.1

Multipressure probe

The multipressure probe is placed c. 20 m below the ground-water level. I consists of a number of solenoid valves, a pressure transducer (Kistler 4043 500 kPa), a pressure amplifier and a A/D-converter. The measurement values are obtained at a resolution of 0.03 kPa. Pressure tubes connect all measurement sections with the multipressure probe. At the solenoid valves the pressure transducer is connected to the pressure tubes from the individual measurement sections, one at a time, Almén et al 1983.

Analog probe

During piezometric measurements it may sometimes be of interest to monitor other parameters. For this purpose an analog probe is used for measuring analog parameters in a similar way as for the multipressure probe. The most common parameter measured by the analog probe is the barometer pressure.

Measurement operators

The measurement operators lower the equipment in the borehole and connect all the cables and tubes. When starting up the measurement the operators feed the Piezomac-unit with certain background data. More background data is written down on a protocol. When necessary the measurement operators dump data either on a cassette tape or via a printer.

PIEZOMAC

The Piezomac data collection and control unit is a computer controlled unit for simultaneous operation of 1-5 measurement probes, Almén et al 1983. It also receives and stores data from the probes together with time data and transfers the data to other units. Piezomac consists of

- Microcomputer
- Semi- conductor storage (up to 74 kByte)
- Keyboard
- Display
- Serial inputs/outputs (9 pcs. 300 baude)

The Piezomac has low power-consumption during a measurement sequence and can measure for a couple of months on two batteries. The batteries can be recharged of a solar cell module.

Tape recorder

Data stored in the memory of the PIEZOMAC can be recorded by a tape recorder.

Printer

A printer type Epson MX-100 have been used for print-out of data from the Piezomac.

Radio transfer, Data control I

Data from the Piezomac may be transferred via radio, modems and the telephone network to the PDP-computer at SGAB, Malå. During the transfer data is checked and identified in order to be subsequently processed, and successively plotted on a monitor or on paper. In this way the measurement can be continously supervised from the office. From the PDP-computer the field instrument can also be reprogrammed during the measuring process i.e. the scanning mode can be changed.

Data control II, Punching

If the data transfer via radio/telephone or via the tape recorder failed the corrected print-out from the field printer was punched to a P-file on PRIME 750. This was done by the data department at SGAB, Luleå.

Before the punching the print-out from the field printer was checked and incorrect data were excluded before punching. This was done by the responsible hydrogeologist.

The field protocol written by the measurement operators was punched to a S-file on the PDP-computer at SGAB, Malå.

"OVER"

"OVER" is a routine that transfer data (the P-file) from the PDP-computer in Malå to PRIME 750 in Luleå. The transfer is performed automatically every night. The routines calls for the programmes OVERS.SEG and CON.SEG. Principally OVERS is a transfer via SAFT-protocol but it can overlay a file or add data.

MDS

#MDS is a programme that reads data from the cassette tape to a P-file on PRIME 750.

"CON"

CON is the programme that creates the D-file. Input files are the P-file and the S-file. It also convert the mV-values to pressures with the help of the calibration constants in the S-file. In addition CON changes the scanning mode at the first scanning after packer inflation and packer deflation to T and Ö respectively. The format for reading up the P-file and printing of the D-file is given by the files DSC.P01 and D.DSG (on PRI-ME) respectively.

"PIEZPLT"

PIEZPLT is a routine on PRIME 750 for generating plots either on a terminal screen or on paper. The plotting routine is handled by the data department at SGAB. Input data is the D-file.

6. INTERFERENCE TESTS

By means of interference tests hydraulic properties such as hydraulic conductivity, storage coefficient and skin factor can be determined. The difference compared with the single hole injection tests (chapters 2 and 3) is that the parameters obtained from interference tests represent a larger rock volume. The purpose of the interference test is often to decide the hydraulic properties of a fracture zone.

An interference test starts with a "pump phase", when water is pumped at constant flow capacity from or to a borehole. After a period, varying between some hours to some weeks, the pumping is stopped and a "recovery phase" starts, when the disturbed ground-water head recovers to its natural level. The pump well and adjacent observation boreholes can be delimited by inflatable rubber packers. During the whole test period the variations of the ground-water level or the ground-water pressure is registered in all the influenced boreholes and measurement sections. The registration frequency is high in the beginning of the two phases but it decreases with increasing time.

The interference test have been carried out either with automatic registration of the ground-water pressure by the Piezomac system (chapter 5) or with manual registration of the ground-water head by means of soundings. In the following the data flow for the two methods of registration is described each separately.

6.1 Interference Tests with Manual Registration of the Ground-water Level

6.1.1 Routines for collecting processing and evaluation of data

Data flow is presented in the block diagram in Figure 6.1.

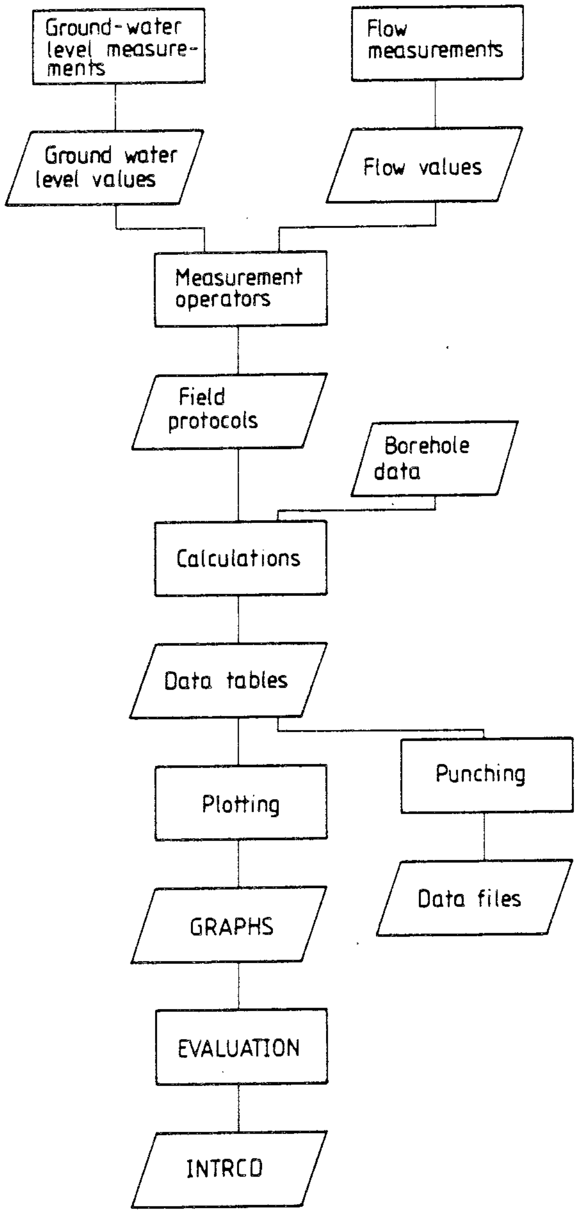


Figure 6.1 Data flow for data from interference tests with manual ground-water registrations

The parameters measured during an interference test is ground-water levels of the measurement sections/boreholes and the flow rate of the pump. The ground-water levels are measured by means of soundings. The flow rate is measured either by a flow meter or by measuring flow volumes during a delimited time.

For the test pumping a submersible pump is most often used. But the ground-water head of the pump hole has also been lowered by means of gas-lift pumping.

When the equipment have been installed in the boreholes the field personnel measure the ground-water levels in the measurements sections before the packer inflation and just before the pump start. In the beginning of the pumping- and recovery periods respectively the measuring frequency is high but it decreases with increasing time. The flow is regulated to a constant rate by the flow meter. During the pump test the flow is checked and sometimes corrected.

The measurement data are noted in field protocols. With the help of these the responsible hydrogeologist calculate the draw-down or recovery of the ground-water level at every measurement occasion. The results are noted in a data tables. The data tables are punched to datafiles, which now are stored on magnetic tapes at KRAB, Stockholm.

The data of the data table is plotted on a number of diagrams. The diagrams show the ground-water level draw-down or recovery versus the time in a logarithmic or semi-logarithmic scale.

By the aid of the diagrams the interference test is evaluated and parameters such as hydraulic conductivity, skinfactor and storage coefficient are evaluated.

The results of the interference tests are stored in the table INTRCD in SKB´s database GEOTAB.

6.1.2 Description of Data Volumes (▱) in the Block Diagram in Figure 6.1

Ground-water level values

The measured values are the distance (in metres) between the top of the borehole casing and the ground-water level along the borehole. The measurement frequency differ for different interference tests but as a rule the measurement frequency in the pump well and in the observation holes close to the pump well is 2-3 measurements/minute during the first 5 minutes of the pumping phase and the recovery phase. Succesively the time intervals between the registrations increase and after five days the frequency is 1-2 measurement per day. Observation holes at a greater distance from the pump hole are measured at a lower frequency.

Flow values

When a submersible pump is used the flow is generally measured by a flow meter (type Brooks rotameter) and the flow values are read on the scale of the flow meter.

During interferene test carried out by means of air lift pumping the flow is usually determined by measuring flow volumes during a delimited time.

Field protocols

The measurement data are written down in the field protocols (one for each borehole) by the measurement operators. The columns of the protocols comprise date and time of measurement, ground-water level value or flow scale value (alternatively flow volume per unit of time).

The field protocols are now (1986) filed in the archive at SGAB, Uppsala.

Borehole data

The responsible hydrogeologist needs certain borehole data to convert the field protocols to data tables. These data are inclination of the boreholes and altitude of the tops of the borehole casings.

Data tables

The results of the calculations of field data are written down in data tables. The respective columns of the tables contain the following data: borehole name, date/time of measurement, minutes from the pump start or recovery start, vertical drawdown or recovery after the pump start or recovery start respectively for the measurement sections. The data tables are now filed in the archive at SGAB, Uppsala.

Data files

The data of the data tables is punched to data files. The 100 first lines of the data files contain a description of the actual data file. The rest of the lines have the following format.

column 1: Borehole idcode; TSSNN : T= borehole type, (K= cored borehole,H= percussion borehole), SS= site code, NN= borehole number
column 2: Date/time of measurement (YYMMDDhhmmss)
column 3: Time from pumpstart or time from recovery start (min)
column 4: Vertical distance from the top of the casing to the ground-water level for the upper measurement section (m)
column 5: Vertical distance from the top of the casing to the ground-water level for the second measurement section from the ground surface (m)
column 6: Vertical distance from the top of the casing to the ground-water level for the third measurement section from the ground surface (m)

Section limits of the the measurement sections are noted in the beginning of the data file. The data files are stored on magnetic tapes at KRAB.

GRAPHS

The data in the data files are plotted in a number of graphs. In the graphs the following parameters are plotted.

s against $\log t$ (or $\log t'$)
$\log s$ against $\log t$ (or $\log t'$)
s against $\log(t/r^2)$ (or $\log(t'/r^2)$)
s_p against $\log r$
s_p against $\log(t'/(t_p+t'))$
Q_p against $\log t$

where s = Draw-down during the pump phase or recovery during the recovery phase for each section respectively (m)

t = Time from pumpstart during pump phase (s)

t' = Time from pump stop (s)

t_p = Duration of the pump phase (s)

s_p = Draw-down at pump stop

r = Distance beetween the measurement sections of the observation holes and the pump well (m)

Q = Water flow rate (m^3/s)

The graphs are now in the archive at SGAB, Uppsala.

INTRCD

The results of the interference tests with manual registration of the ground-water level are stored in the table INTRCD in the database. The table has 16 columns.

column 1:	IDCODE;	5 characters: TSSNN; T= borehole type (K= cored borehole,H= percussion borehole), SS= Site code, NN= borehole number
column 2:	BHTYPE;	Borehole type (P= pump hole,O= observation borehole)
column 3:	START;	Start date of measurement period (YYMMDD)
column 4:	SECUP;	Borehole length to test section, upper limit (m)
column 5:	SECLEN;	Length of measurement section (m)
column 6:	END;	End date of measurement period (YYMMDD)
column 7:	K;	Hydraulic conductivity of the measurement section (m/s)
column 8:	T;	Transmissivity of the measurement sections (m^2/s)
column 9:	S;	Storage coefficent
column 10:	S_s;	Specific storage coefficient (m^{-1})
column 11:	SKINFAC;	Skinfactor
column 12:	LEAKFAC;	Leakage factor
column 13:	RWF;	Effective borehole radius (m)
column 14:	HUNIT;	The hydraulic unit that the measurement section intersect

column 15:COMMENT; Comments
column 16: INDAT; Input date of data to the database (YYMMDD)

6.1.3 Description of Processes (▭) in the Block Diagram in Figure 6.1

Ground-water level measurements

The ground-water heads of the boreholes and the measurement sections are measured by means of soundings. The sections below the packers are measured via tubes leading from the ground surface through the packers to the actual section.

Flow measurements

When the interference test is performed with a submersible pump the water flow is in general regulated and monitored by the same flow meter used in the water injection tests with the steel pipe equipment (sections 2.1.3 and 3.1.3).

In the case of air lift pumping the water flow is usually determined by measuring flow volumes from the pump well during delimited time periods.

Measurement operators

The measurement operators install the equipment in the boreholes and on the ground surface. They start the test and registrate ground-water levels and the water flow and note the measurement data in protocols. They also keep the pump flow at a constant level.

Calculations

The responsible hydrogeologist calculate the draw-down during the pump period and the recovery during the recovery period for each measurement. He also transform the time of measurement to minutes after pump start and pump stop respectively. The results are written down in data tables.

Plotting

The graphs are plotted either manually or by the help of standard programmes on a PC.

Punching

The data tables are punched to data files either directly to the host computor (PRIME 750 at SGAB or VAX 750 at KRAB) or via an ABC 800 PC.

EVALUATION

The tests have been evaluated according to the theories for interference tests in single-porous media or double-porous media (Andersson and Hansson 1986, Carlsson and Gustavsson 1984).

6.2 Interference Tests with Automatic Registration of the Ground-water Pressure by the PIEZOMAC I System

6.2.1. Routines for Collecting, Processing and Evaluation of Data

Data flow is presented in the block diagram in Figure 6.2.

The data collecting routines and instruments are almost the same for interference tests with the PIEZOMAC I system as for piezometric measurements performed with the same equipment (chapter 5). In the interference tests, though , two or more multipressure probes are connected to the Piezomac-unit, which is not always the case during the piezometric measurements.

Furthermore pump or injection flow from or to the pump well is measured and regulated in the interference tests. The water

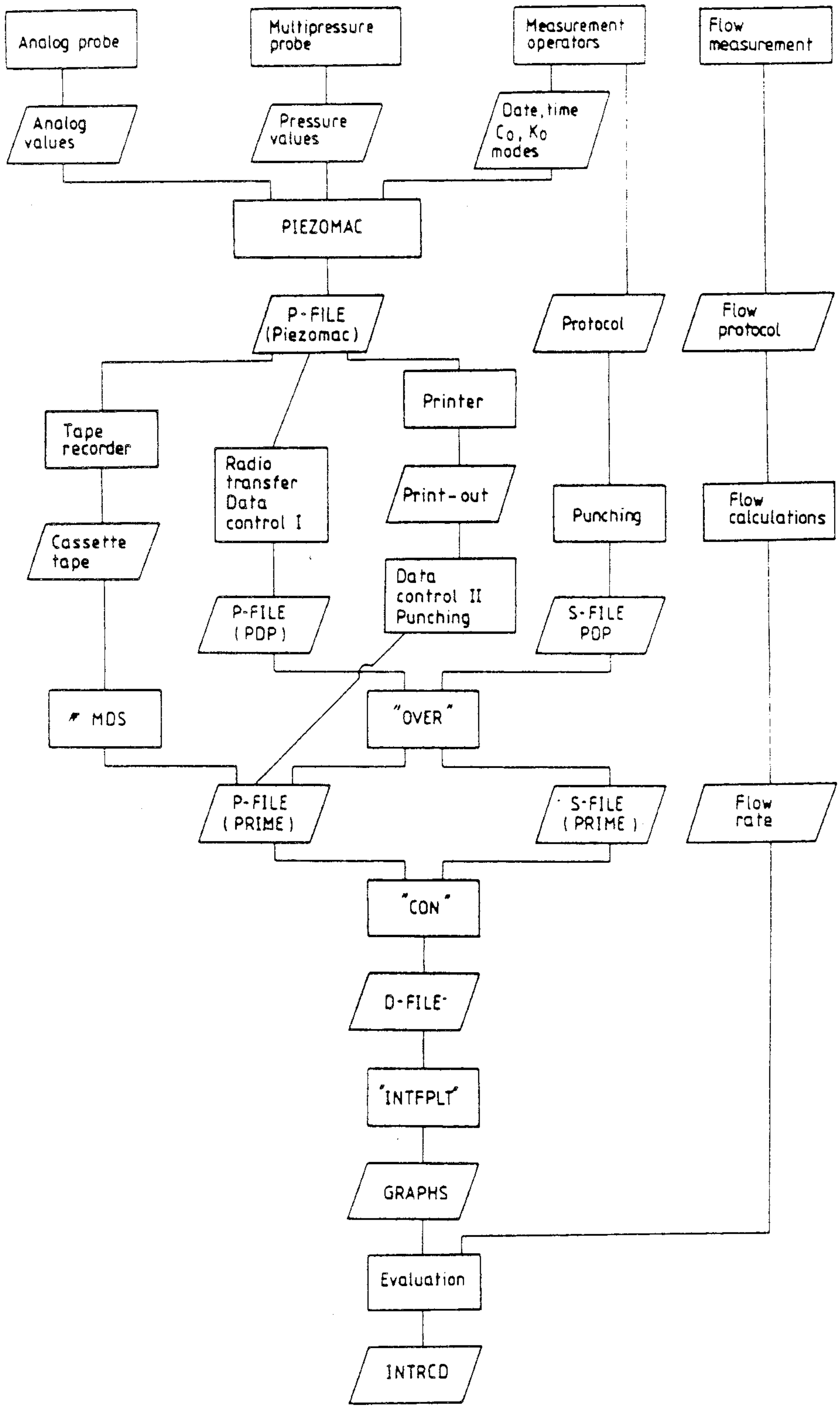


Figure 6.2 Data flow for data from interference tests with the PIEZOMAC I system.

flow is measured by same type of flow meter that is described in Section 6.1.

The routines for data processing of the measurement values of the probes are identical(all the way from the probes to the D-file) to the piezometric measurements described in Chapter 5. The flow values from the manual flow meter is noted in a protocol and the average flow rate of the pumping period is calculated.

On the basis of the D-file 14 graphs can be plotted. The graphs are evaluated and hydraulic parameters such as hydraulic conductivity, skinfactor and storage coefficent are determined. The results of the interference tests are stored in the table INTRCD in the GEOTAB database.

During 1985 and 1986 the PIEZOMAC system has been modified. The new equipment, called PIEZOMAC II, has an improved measurement probe, new hardwares and new plotprogrammes, Almén et al 1986. Since the new equipment is not yet completed the data flow of the PIEZOMAC II system is not described in this report.

6.2.2 Description of Data Volumes (▱) in the Block Diagram in Figure 6.2

Most of the data volumes in Figure 6.2 are identical or almost identical to the data volumes of Figure 5.1 and they are described in Section 5.2. The data volumes that differ or are not described earlier are completed below.

P-FILES AND D-FILES

The P-files and the D-files have the same format as described in section 5.2, but there are small differences in the content that are worth noticing.

In the record type 3 the five first stored pressure values always come from the pump well in the interference tests. If there are less than 5 sections in the well the data are repeated. If the scanning mode is P (in record type 2) only measurement data from the pump well are valid. Apart from this the P-files and the D-files have the same format as described in Chapter 5.

S-FILE

The format of the S-file is the same as described in section 5, but the second record always correspond to the pump well.

Flow protocol

The flow values read on the scale of the flow meter are noted in a flow protocol.

Flow rate

The responsible hydrogeologist calculate the average flow rate during the pumping period in (m^3/s). This value is later used in the evaluation of the interference test.

GRAPHS

By the aid of the plot routine INTFPLT one flyleaf, called A0, and 14 different graphs can be plotted. The flyleaf show relevant borehole data such as borehole-length, inclination of the boreholes , limits of the measurement sections, distances between the pump hole and the measurement sections, length to the pressure transducer from the top of the casing and pressure values (kPa) at the beginning and the end of the pumping phase. The graphs are called A1, B1 - B7, C1 - C5 and D1. They show pressure and flow variations before pump start(A1), during the pump phase(B1 - B7),during the recovery phase(C1 -C5) or after the recovery according to the following:

A1: P	vs	t_{abs}	
B1: dP_1	vs	$\log t$	
B2: $\log dP_1$	vs	$\log t$	
B3: $\log dP_1$	vs	$\log(t/r^2)$	
B4: Q	vs	$\log t$	
B5: dP_1	vs	$(t)^{1/4}$	
B6: dP_1	vs	$\log r$	(at pump stop)
B7: $\log dP_1$	vs	$\log r^2$	(at pump stop)
C1: dP_3	vs	$\log(t'/(t_p+t'))$	
C2: $\log dP_2$	vs	$\log t'$	
C3: dP_2	vs	$(t')^{1/4}$	
C4: dP_2	vs	$\log r$	(when $t+t'=2t_p$)
C5: $\log dP_2$	vs	$\log r^2$	(" " ")
D1: P	vs	t_{abs}	

where

P= absolute pressure

t_{abs} = absolute time

t= time from pump start

dP_1 = pressure draw-down

r= distance from measurement section to pump well

Q= Water flow rate

dP_2= pressure recovery

dP_3= residual pressure recovery

t'= time from pump stop

t_p = duration of pump phase

INTRCD

The results of the interference tests are stored in the table INTRCD in the GEOTAB database. INTRCD is described in chapter 6.1.2.

6.2.3 Description of Processes (□) in the Block Diagram in Figure 6.2

Most of the data processes in Figure 6.2 are identical to those in Figure 5.1 and are consequently described in section 5.3. The ones not defined earlier are described below.

Flow measurements

The water flow from or to the pump well is measured by the same type of flow meter used in the interference tests with manual registrations, section 6.1.3. The flow is in some cases maintained at preset constant capacity by means of an automatic regulation unit, Almén et al 1983. The regulation unit keeps the flow constant within 1%. The flow values read on the scale of the flow meter are registered at intervals that vary depending on if they differ from the preset value.

Flow calculation

Data from the flow protocol are converted to flow rates and the average flow rate (in m^3/s) of the pumping sequence is calculated by the responsible hydrogeologist.

"INTFPLT"

INTFPLT is a plot routine on PRIME 750 for generating plots either on a terminal screen or on paper. The plotting routine is handled by the data department at SGAB.

Evaluation

The tests have been evaluated according to the theories for interference tests in single-porous or double-porous media (Andersson and Hansson 1986, Carlsson and Gustavsson 1984).

7. HYDRAULIC UNITS

The bedrock in some of the investigated study sites have been subdivided into hydraulic units according to their hydraulic properties, i.e. their hydraulic conductivity at depths. This division is basic to the construction of a descriptive model of the sites respectively. The following three main units have been identified:

- rock mass
- local fracture zones
- regional fracture zones

This classification is based on the results from the geological and tectonic investigations which indicate the location and extension of existing regional and local fracture zones. The fracture zones located on the ground surface are correlated to intervals in the boreholes by means of core mapping and geophysical measurements. The hydraulic conductivity values of the borehole intervals that intersect the fracture zones are determined from the results of the transient injection tests, chapter 2. In the database local fracture zones and regional fracture zones are brougth together to one method called fracture zones. The hydraulic conductivity values of the measurement sections that do not intersect the fracture zones represent the hydraulic unit rock mass. In some study sites differences in hydraulic conductivity between different rock types in the rock mass have been confirmed. In these cases the rock mass has been divided into sub units. Accordingly there are three methods in the data base, which correspond to a hydraulic unit respectively. The methods are:

- Hydraulic unit fracture zones
- Hydraulic unit rock mass
- hydraulic unit rock types in the rock mass

The data flow of the methods are described separately in the following sections.

7.1 Data Flow of the Method Hydraulic Unit Fracture Zones

Data flow is presented in Figure 7.1

SHTINJCD

The table SHTINJCD in the GEOTAB database contains the results of the single hole transient injection tests, see chapter 2.

Selection

The widths of the fracture zones in the boreholes are determined from the geologic and tectonic investigations of the core and from borehole geophysical measurements. The measurement sections that cover the fracture zones in the boreholes are initially selected. The section lengths are depending on the performance of the tests and the width of the zone.

Hydraulic conductivity values

After the selection the result is a number of hydraulic conductivity values from sections that entirely or partially are penetrated by the fracture zones.

Borehole data

The borehole data needed for the calculations are the initial inclinations (IW) of the boreholes.

Calculations

If the measurement section is entirely covered by the fracture zone the hydraulic conductivity (K) of the zone is equal to the measured value. The depth of the K-value is then calculated according to equation 7.1.

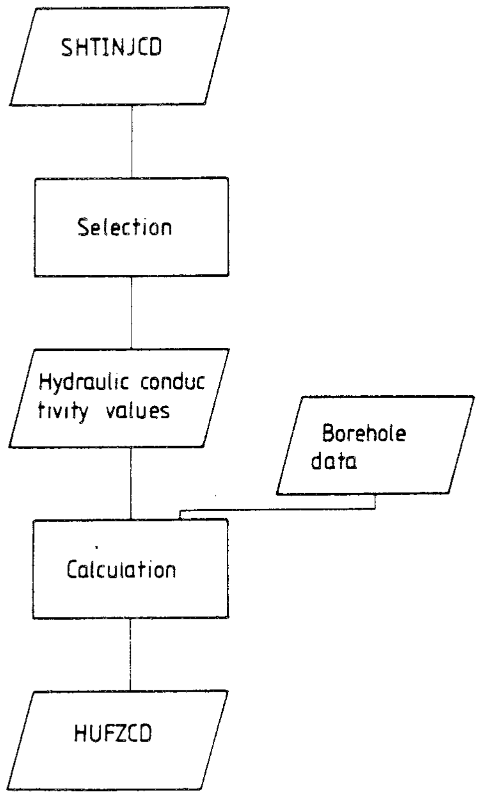


Figure 7.1 Data flow of the method "hydraulic unit fracture zones".

$$d_z = (L_0 + L/2) \times \sin(IW) \qquad (7.1)$$

where

d_z = Vertical depth of the fracture zone (m)
L_0 = Length to upper limit of the measurement section (m)
L = Length of the measurement section (m)
IW= Inclination of the borehole (degrees)

If the section is only partially penetrated by the zone the K-value is calculated according to equation 7.2

$$K_z = (K \times L)/L_z \qquad (7.2)$$

where

K_z = Hydraulic conductivity of the fracture zone(m/s)

K = Measured K-value (m/s)

L_z = Width of the zone in the borehole (m)

The vertical depth is in the case of a partially penetrated section calculated as follows:

$$d_z = (L_{z0} + L_z/2) \times \sin(IW) \qquad (7.3)$$

where

L_{z0} = Borehole length to upper limit of the fracture zone (m)

If the fracture zone covers a section limit the zone is divided into two parts each one represented by a K-value.

HUFZCD

The results of the calculations described above are stored in a table called HUFZCD in the GEOTAB database. HUFZCD has 12 columns.

IDCZON	: Idcode for the fracture zone; ZZSSNN; ZZ= zonecode (VZ for vertical or subvertical zone, HV for horizontal or subhorizontal zone), SS= site code, NN= borehole number	
IDCODE	: Idcode for borehole; TSSNN, T= borehole code (K= cored borehole, H= percussion borehole), SS= site code, NN= Borehole number	
ZONUP	: Borehole length to zone, upper limit	(m)
ZONLOW	: Borehole length to zone, lower limit	(m)
VERTDEP	: Vertical depth to the middle of the zone	(m)
TW	: True width of the zone	(m)
DIP	: Dip of the zone	(degrees)
CL	: Length of crushed rock in the zone	(m)
KU	: Hydraulic conductivity of the zone	(m/s)
COM30	: Comments	
INDAT	: Input date of data to database	

7.2 Data Flow of the Method Hydraulic Unit Rock Mass

Data flow is presented in Figure 7.2.

SHTINJCD

The table SHTINJCD in the GEOTAB database contains the results of the single hole transient injection tests, see chapter 2.

Selection

The 25 m or 20 m measurement sections that do not intersect the fracture zones are selected. In addition single packer tested sections of deviating lengths can be selected.

Hydraulic conductivity values

The result of the selection is a large number of hydraulic conductivity values representing the hydraulic unit rock mass.

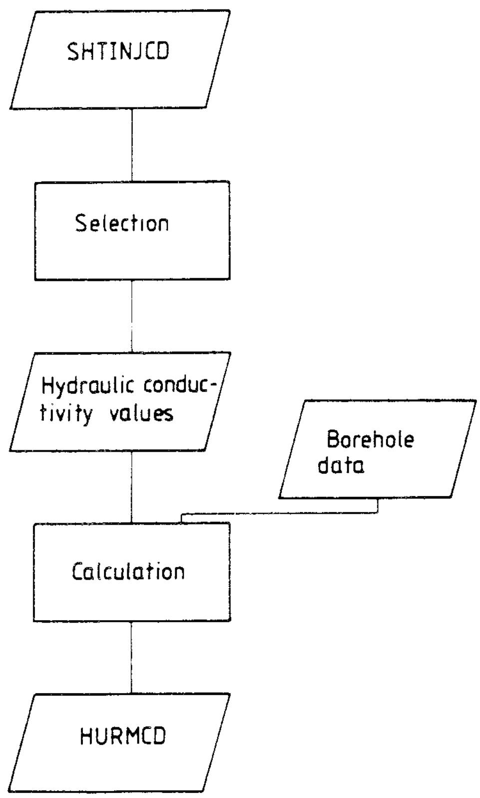


Figure 7.2 Data flow of the method "hydraulic unit rock mass".

Borehole data

The borehole data needed for the calculations are the initial inclinations (IW) of the boreholes.

Calculations

The vertical depth of the selected K-values are calculated according to equation 7.1. Many measurement section from single packer tests have approximately twice the length of the rest of the sections. These sections are represented by two K-values, equal to the measured value, but with separate depths.

HURMCD

The results of the calculations described above are stored in a table called HURMCD in the GEOTAB database. HURMCD has 8 co- lumns.

IDCODE	:	Idcode for borehole; TSSNN, T= boreholecode(K= cored borehole,H= percussion borehole), SS= site code, NN= Borehole number
SECUP	:	Borehole length to measurement section, upper limit(m)
SECLEN	:	Section length (m)
VERTDEP	:	Vertical depth to the middle of the section (m)
K	:	Best representative hydraulic conductivity of the section from transient injection test. (m/s)
ROCKT	:	Rock type; H if the section intersect the main rock type, S if the section intersect the subordinate rock type
COM30	:	Comments
INDAT	:	Input date of data to database

7.3 Data Flow for Data from the Method Rock Types in the Rock Mass

Data flow is presented in Figure 7.3.

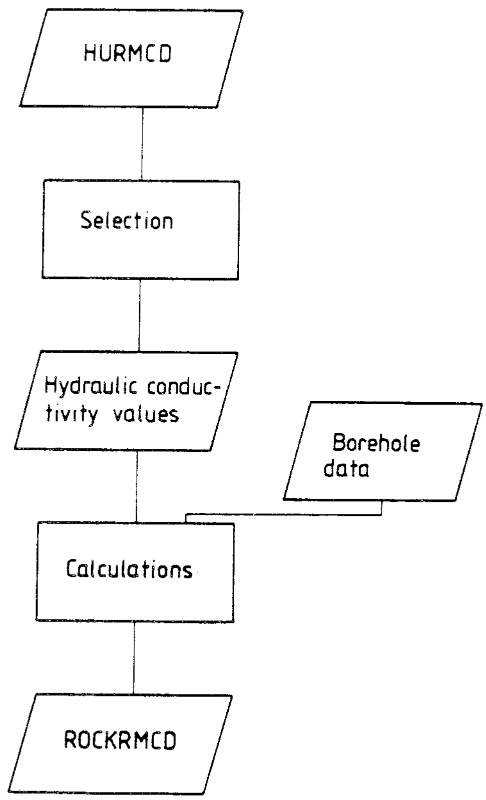


Figure 7.3 Data flow of the method "hydraulic unit rock types in the rock mass".

HURMCD

The content of HURMCD is described in the preceeding section 7.2.

Selection

In some investigated study sites layers of subordinate rock types have higher K- values than the host rock. In these cases the measurement sections, which represent the rock mass and are intersected by the subordinate rock type, are selected to a sub unit of the rock mass.

Hydraulic conductivity values

The selection results in hydraulic conductivity values from sections of the rock mass that contain the subordinate rock type.

Calculations

If the measurement section is entirely covered by the subordinate rock type the hydraulic conductivity of the subordinate rock type is equal to the measured value. The depth of the K-value is then calculated according to equation 7.4.

$$d_s = (L_0 + L/2) \times \sin(IW) \qquad (7.4)$$

where

- d_s = Vertical depth of the subordinate rock type (m)
- L_0 = Length to upper limit of the measurement section (m)
- L = Length of the measurement section (m)
- IW = Inclination of the borehole (degrees)

If the section is only partially penetrated by the subordinate rock type the K-value is calculated according to equation 7.5

$$K_s = \frac{K \times L - K_r \times L_r}{L_s} \qquad (7.5)$$

where

- K_s = Hydraulic conductivity of the subordinate rock type (m/s)
- K = Hydraulic conductivity of the section concerned (m/s)
- K_r = Hydraulic conductivity of the main rock type, at the actual depth obtained from regression analysis (m/s)
- L_s = Length of the subordinate rock type in the section (m)
- L = Length of the section concerned (m)

- L_r = Length of the main rock type in the section (m)

The regression analysis mentioned above is a Power curve analysis of the form $K(z) = a z^b$ (a,b = constants, z = depth) with the K- values from the rock mass as input data.

The corresponding depths for the K- values from eq. 7.5 are calculated according to the following:

$$d_s = (L_{s0} + L_s/2) \times \sin(IW) \qquad (7.6)$$

where

L_{s0} = Borehole length to upper limit of the subordinate rock type (m)

ROCKRMCD

The results of the calculations described above are stored in a table called ROCKRMCD in the GEOTAB database. ROCKRMCD has 10 columns.

IDCODE : Idcode for borehole; TSSNN, T= borehole code(K= cored borehole,H= percussion borehole), SS= site code, NN= Borehole number

SUBUP : Borehole length to upper limit of subordinate rock type (m)

SUBLOW : Borehole length to lower limit of subordinate rock type (m)

SECUP : Borehole length to measurement section, upper limit(m)

SECLEN : Borehole length to measurement section, lower limit(m)

VERTDEP: Vertical depth to the middle of the subordinate rock type (m)

KSUB : Hydraulic conductivity of the subordinate rock type (m/s)

KREG : Hydraulic conductivity of the main rock type, from regression analysis (m/s)

COM30 : Comments

INDAT : Input date of data to database

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APPENDIX 1

MANUAL OF THE DATACOLLECTING UNITS DURING A TRANSIENT INJECTION TEST WITH STEEL PIPE EQUIPMENT VERS. 2 , A COMPILATION

Item	Chart recorder Paper feed	Datalogger Scanning interval	Thumb wheel settings	Flowmeter Reading interval	Remarks
1	-	-	10NNPQQQ	-	
2	-	1 min	"	-	
3	-	"	110RRSSS	-	When pressure is stable
4	-	5 min	"	-	1 minute after item 3
5	20 cm/h	"	"	-	When recorder is adjusted
6	"	"	120RRSSS	-	Packer inflation
7	"	1 min	130RRSSS	-	The test valve is closed at least 30 min after item 6
8	10 cm/min	10 sec	"	-	Immediatly before item 9
9	"	"	140RRSSS	-	The test valve is opened (Injection phase starts)
10	"	"	"	20 sek	0- 2 min injection time
11	1 cm/min	30 sec	"	30 sek	2- 5 min "
12	"	1 min	"	60 sek	5- 30 min "
13	20 cm/h	5 min	"	5 min	30-119 min "
14	10 cm/min	10 sec	"	5 min	119-120 min "
15	"	"	150RRSSS	-	The test valve is closed (Injection phase ends, Fall-off phase starts)
16	"	"	"	-	0- 2 min Fall-off phase tim
17	1 cm/min	30 sec	"	-	2- 5 min "
18	"	1 min	"	-	5-30 min "
19	20 cm/h	5 min	"	-	30- min "
20	"	1 min			1 min before item 21
21	"	"	160RRSSS	-	Packer deflation
22	"	"	170TTUUU	-	When pressure is stable
23	"	"	"	-	Wait at least 1 min before the logger is switched-off!
24	0	0		-	Note the zero-points of the chart recorder !

APPENDIX 2

THUMB WHEEL SETTINGS DURING A TRANSIENT INJECTON TEST WITH STEEL PIPE EQUIPMENT, VERS. 2

Thumb wheel settings	Remarks
0XXX XXXX	Invalid data
1XXX XXXX	Valid data
10NN PQQQ	Section identity NN: Borehole number (01-99) P: Section length code (1 = 1 m, 2 = 5 m, 3 = 25 m, 4 = 10 m) QQQ: Borehole length to upper limit of test section (m)
110R RSSS	Absolute section pressure before test (from multimeter) RR: Absolute pressure, bars (integers) SSS: " " " (decimals)
120R RSSS	Packer inflation, test valve open
130R RSSS	Test-valve is closed
140R RSSS	Injection starts, test valve is opened
150R RSSS	Injection ends, Fall-off phase starts, the test valve is closed
160R RSSS	Fall-off phase is stopped, packer deflation
170T TUUU	Absolute section pressure after test (from multimeter) TT: Absolute pressure bars (integers) UUU: " " " (decimals)

The second digit of the thumb wheel settings is the code for the different stages of a transient injection test, Table 2.1.

APPENDIX 3

INPUT SIGNALS TO THE DATA LOGGER AND THE CHART RECORDER DURING A INJECTION TEST WITH STEEL PIPE EQUIPMENT, VERS. 2

Datalogger

Channel	Input signal	
0	Absolute section pressure	100 mV/bar
1	Supressed section pressure	100 mV/bar
2-6	Not used	
7	Temperature of the measurement housing	
8	Absolute packer pressure	100 mV/bar
9	Temperature of the injection water	

Chart recorder

Channel	Input signal	Range of measurement	Pen colour	Pressure/10 scale division
1	Absolute section pressure 10 mV/bar	100 mV	black	1 bar
2	Supressed section pressure 100 mV/bar	50 mV	red	0.05 bar
3	Not used			
4	Packer pressure 10 mV/bar	50 mV	blue	0.5 bar

APPENDIX 4

DESCRIPTION OF DATA FILES FROM SINGLE HOLE TRANSIENT INJECTION TESTS, STEEL PIPE EQUIPMENT VERS. 2

I C-FILE (cassette file)

Three lines/scanning

Line no 1: Position 1-2: Date (DD)
" 3-8: TIME (hhmmss)

Line no 2: Position 1: 0 = invalid data, 1 = test data
" 2: Stage of the injection test
0 = Section identifications are set on the thumb wheel.
1 = Supression of section pressure. Stable absolute section pressure is set on the thumb wheel.
2 = Packer inflation starts
3 = The test valve is closed
4 = The test valve is opened, injection starts.
5 = The test valve is closed, the injection is stopped and the fall-off phase is started
6 = The fall-off phase is ended, packer deflation
7 = Stable absolute section pressure is set on the thumb wheel

Position 3-8: If stage (position 2) = 0:
pos. 3-4: Borehole number (01 - 99)
pos. 5 : Section length code (1=5 m, 2=10 m, 3=25 m, 4 =10 m)
pos. 6-8: Length to upper limit of test section (m
If stage (position 2) = 1-6
pos. 3-8: Stable absolute section pressure before test (mb).
If stage (position 2) = 7
pos. 3-8: Stable absolute section pressure after test (mb).

Line no 3:	Position 1:	Channel number (= 0)
	Position 2-7:	Absolute section pressure value (mV)
	Position 9:	Channel number (= 1)
	Position 10-15:	Supressed section pressure value (mV)
	Position 17:	Channel number (= 7)
	Position 18-23:	Temperature value of the measurement housing
	Position 25:	Channel number (= 8)
	Position 26-31:	Packer pressure (mV)
	Position 33:	Channel number (= 9)
	Position 34-39:	Injection water temperature value

II P-FILE (protocol file)

The file has three Record types

<u>Record type 1; Protocol head, H in position 5</u>

Position 1-3:	Number of protocol (section) in the file
Position 5:	H
Position 7-15:	Borehole code; GDA-code and borehole number
Position 17-19:	Borehole length to upper limit of test section (m)
Position 21-23:	Borehole length to lower limit of test section (m)
Position 25-30:	Date (YY MM DD)
Position 33-37:	Signatures of the measurement operator(s)
Position 39-43:	Applied injection pressure (bars)
Position 45-54:	Result of flow test, 2-3 digits. The first digit is always flow meter number, the second and thirc are scale values on that flow meter.
Position 56-61:	L_K = distance between test section and pressure transducer (m)
Position 63-68:	Borehole length between ground-water level and top of casing (m)

Record type 2; Water flow data, D in position 5

Position 1-3: Number of protocol (section) in the file

Position 5: D

Position 7-11: Time from injection start (mmmss)

Position 13-22: Injection water flow rate (m^3/s)

Position

Record type 3; Comments, C in position 5

Position 1-3: Number of protocol (section) in the file

Position 5: C

Position 13-72: Comments on the test

III L-FILE (logger file)

Position 1-9: Borehole code, GDA-code and borehole number

Position 11-13: Borehole length to upper limit of test section (m)

Position 15-17: Borehole length to lower limit of test section (m)

Position 19-24: Date (YY MM DD)

Position 26-31: Time (hh mm ss)

Position 33: Stage of the injection test, see C-FILE

Position 35-42: Stable absolute section pressure before and after the test (Pa).
The pressure value is not corrected for the effect of L_K

Position 46-53: Supressed section pressure = Injection pressure (Pa)

Position 57-64: Absolute section pressure (Pa)
The pressure value is not corrected for the effect of L_K

Position 68-75: Packer pressure (Pa)

Position 79-86: Temperature of the injected water (^oC)

Position 90-97: Air temperature of the measurement housing (^oC)

IV M-FILE (merge file)

Position 1-33: See L-FILE

Position 35-42: Stable absolute section pressure before and after test (Pa).
The pressure value is corrected for the effect of L_K

Position 46-53: See L-FILE

Position 57-64: Absolute section pressure (Pa).
The pressure value is corrected for the effect of L_K.

Position 68-97: See L-FILE

Position 102-110: Injecton flow rate (m^3/s)

Position 113-121: Distance between test section and pressure transducer = L_K (m)

Position 123-132: The inclination of the borehole (degrees)

V CO-FILE (comment file)

Position 1-24: See L-FILE

Position 26-30: Signatures of the measurement operators

Position 32-36: Applied injection pressure (bars)

Position 38-41: Result of flow test, 2-3 digits. The first digi· is always the flow meter number, the second and third are the scale values on that flow meter.

Position 42-46: Distance to ground-water level from top of casing (m)

Position 48-52: L_K = distance between test section and pressure transducer (m)

Position 55-122: Comment

Position 123-129: The inclination of the borehole at the depth of the section (degrees)

Position 131-162: Comment

APPENDIX 5

EXAMPLE OF A COMO-FILE FROM TRANSIENT INJECTION TEST WITH STEEL PIPE EQUIPMENT, VERSION 2.

```
OK, /INJFLAT
INPUT FILE: CGI5.1.4
OUTPUT FILE: LGI5.1.4
GIVE BOREHOLE GDA-CODE (4 LETTERS):AKGI
GIVE YEAR AND MONTH OF TEST (YYMM): 8209

AKGI05000 145 - 170 820926
ILLEGAL SEQUENCE OF THUMBWHEEL SETTINGS
OUTPUT RECORD  28

AKGI05000 170 - 195 820926
ILLEGAL SEQUENCE OF THUMBWHEEL SETTINGS
OUTPUT RECORD  72
FINNISHED!
  673 RECORDS READ
  224 RECORDS WRITTEN
OK, /INJFLAT
INPUT FILE: CGI5.1.1H5
OUTPUT FILE: LGI5.1.5
GIVE BOREHOLE GDA-CODE (4 LETTERS):AKGI
GIVE YEAR AND MONTH OF TEST (YYMM): 8209

AKGI05000 195 - 220 820927

AKGI05000 220 - 245 820927
FINNISHED!
 1214 RECORDS READ
  404 RECORDS WRITTEN
OK, /INJFLAT
INPUT FILE: CGI5.1.6
OUTPUT FILE: LGI5.1.6
GIVE BOREHOLE GDA-CODE (4 LETTERS):AKGI
GIVE YEAR AND MONTH OF TEST (YYMM): 8209

AKGI05000 245 - 270 820928

AKGI05000 270 - 295 820929
ILLEGAL SEQUENCE OF THUMBWHEEL SETTINGS
OUTPUT RECORD 181
FINNISHED!
 1035 RECORDS READ
  345 RECORDS WRITTEN
OK, STAT UN


USR=141719  LFFS

FILE   FILE       OPEN     FILE
UNIT   POSITION   MODE     TYPE   RWLOCK  TREENAME
 127   000001400     W      DAM   NR-1W   <KBS4A3>IGDUHY>DATA>C_GI5.1


OK, COMO -END
```

APPENDIX 6

EXAMPLE OF AN DATAFILE FROM TRANSEINT INJECTION TEST WITH UMBILICAL HOSE EQUIPMENT, VERSION 1.

```
TRANSIENT INJEKTIONSTEST; KONSTANT TRYCK
FJ8
DATUM 820715
IW, 60,grader
L , 25,m
LB, 6,m
DW, 56,mm
000:20:12:17     0
RÄ, 2,nr
T , 1,min
000:20:12:48     1
LO, 70,m
T4, 22.22,´C
P1, 53.2,kPa
P8, 600,kPa
dP, 0,kPa
P2, 600,kPa
Q , 0,ml/s
PO, 287.2,kPa
GO,-3.05441,m
P4, 76,kPa
BO, 101.08,kPa
T2, 7.22,´C
T3, 28.9,´C
000:20:13:17     1
LO, 70,m
P1, 53,kPa
P8, 600,kPa
dP, 0,kPa
P2, 600,kPa
Q , 0,ml/s
PO, 287,kPa
GO,-3.05543,m
T2, 7.21,´C
T3, 28.9,´C
RÄ, 12,nr
RÄ, 11,nr
RÄ, 5,nr
RÄ, 6,nr
T , 2,min
000:20:13:30     2
dP, 0,kPa
P2, 600,kPa
Q , 0,ml/s
000:20:13:32     2
dP, 0,kPa
P2, 600,kPa
Q , 0,ml/s
000:20:13:38     2
dP, .2,kPa
P2, 600.2,kPa
Q , 0,ml/s
000:20:13:39     2
dP, 0,kPa
P2, 600,kPa
Q , 0,ml/s
      .
      .
      .
      .
      .
      .
001:00:04:36   299
P1, 53.2,kPa
dP, .2,kPa
P2, 600.2,kPa
Q , 0,ml/s
PO, 262.2,kPa
GO,-3.10945,m
T2, 7.21,´C
T3, 24.84,´C
001:00:05:08   299
P1, 53.2,kPa
dP, 0,kPa
P2, 600,kPa
Q , 0,ml/s
PO, 262,kPa
GO,-3.11047,m
T2, 7.21,´C
T3, 24.83,´C
DATA SLUT
$
```

APPENDIX 7

DESCRIPTION OF DATA FILE (C-FILE) FROM SINGLE HOLE TRANSIENT INJECTION TEST, UMBILICAL HOSE EQUIPMENT VERSION 1

Line 1: Headline; Transient injection test; constant pressure

Line 2: Borehole name; SSNN (SS = Site code, NN = borehole number)

Line 3: Date of test (YYMMDD)

The following lines are either technical data/measurement values or scanning time. The scanning time has the following format:

ddd : hh : mm : ss MMM

where ddd = Day number after start date of test
hh : mm : ss = time of day (HH MM SS)
MMM = Commenced minutes from test start

The technical data and measurement values have the following format:

Technical data or measurement parameter, value, dimension

The technical data or measurement parameters are

IW :	Inclination of the borehole	(degrees)
L :	Length of test section	(m)
LB :	Length of bubble tube	(m)
DW :	Diameter of the borehole	(mm)
T :	Commenced minutes from test start	(min)
LO :	Length to upper limit of test section	(m)
Q :	Water flow rate	(ml/s)
GO :	Vertical distance from ground-water level from top of casing, negative	(m)
BO :	Barometer pressure	(kPa)
PO :	Injection drive pressure	(kPa)

P1 : Absolute section pressure from pressure transducer P1 (kPa)

P2 : Absolute section pressure from pressure transducer P2 (kPa)

P8 : Absolute pressure in test section before packer inflation (kPa)

dP : Differential section pressure, P1-P8 or P2-P8 (kPa)

P4 : Packer pressure (kPa)

T2 : Temperature in the test section (centigrades)

T3 : Temperature in the measurement trailer (centigrades)

T4 : Outer air temperature (centigrades)

RÄ : Relay numbers - positive if the relays functioned, negative if the relays were released, see table A.1.

Table A.1 Relay values used in the umbilical hose system, version 1

Relay values on	off	Type, function
0	-16	Cannula test
1	-1	Test valve
2	-2	Relief valve
3	-3	Flow meter 3
4	-4	Flow meter 2
5	-5	Flow meter 1
6	-6	Pressure regulation
7	-7	Upper measurement range flow meter 1
8	-8	Reserve
9	-9	Reserve
10	-10	Reserve
11	-11	Packer deflation
12	-12	Packer inflation
13	-13	Reserve
14	-14	Reserve
15	-15	Rapid scanning
16	-16	See relay number 1

The measurement time for the measurement values is the time showed on the preceeding "scanning line" respectively.

APPENDIX 8

EXAMPLE AND DESCRIPTION OF DATA FILE FROM GROUND-WATER REGISTRATION BY THE GRUND SYSTEM.

FILE: HKL0810M.609

LINE NUMBER	LINE TEXT
1	GRUND 2.0 nr 022
2	HKL08 10M
3	09/08/86 13:25:32
4	001001F0FB35C7176281
5	00080600033B005A
6	CN, 22, nr
7	SC, 16.943, bar/volt
8	OF, -132, LSB
9	IW, 50, grader
10	IN, 360, S
11	19860104011332
12	GO, -1.16493, m
13	19860104131332
14	GO, -1.16826, m
.	
.	
.	
2017	19860907080132
2018	GO, -1.78324, m
2019	$

Description of the content of the data file

LINE 1: Version number of the GRUND system and serial number of the unit.

LINE 2: Borehole name and Length from top of casing to pressure transducer (m),, M = metres

LINE 3: Date and time of dumping of data MMDDYY HHMMSS

LINE 4-5: 36 hexadecimal characters with the following meaning:

0010 Four characters which give the hexadecimal starting address of the parameter area. Here the address is 10H.

01FDFB	The number of measurements performed since the previous reset of the cells. The number is incremented by one for each measurement.
35	The number of measurement values not stored since the last stored measurement. Refers to conditionally stored measurements.
C7	Always equal to C7.
1762	The memory address of the next data word to be stored. The data storage takes up the hexadecimal addresses 0800 to 17FF. Data will be stored starting at 0800 with two byte per data word. When the area is full, data will be stored from the starting address again. The memory will thus contain the 2048 latest stored data words.
81	Always equal to 81.
00	Not used by the GRUND unit. Can for instance contain the offset voltage of the pressure gauge or the serial number.
08	The limit value for conditional data storage. A measurement value will be stored if it differs from the latest stored value by the given number of LSB (least significant bits). A zero will cause all values to be stored.
06	The number of conditional data values to be measured before the next compulsory data storage.
0003	The number of four seconds periods to the next measurement. The clock of the GRUND unit is incremented once every four seconds. This is the shortest time interval measured.
3B	The total number of conditional data storages between two consecutive compulsory data storages.
005A	The interval between measurements expressed as a number of four seconds periods. 5AH means one measurement every 6 minutes.

LINE 6: Circuit card number nr = number

LINE 7: Scale Constant

LINE 8: Ofset constant, LSB = Least significant bits

LINE 9: Inclination of the borehole in degrees (= grader).
IW = 90 for vertical boreholes

LINE 10: Measurement interval in seconds (s)

LINES 11, 13, 15 .... (uneven line numbers): Date and time of stored measurement (YYYY MM DD HH MM SS)

LINES 12, 14, 16 .... (even line numbers): Stored measurement value expressed in m water column below top of casing.

LINE 2019: $ = END OF FILE

APPENDIX 9(1)

EXAMPLE OF A P-FILE FROM AN INTERFERENCE TEST WITH THE PIEZOMAC I SYSTEM

```
Month Hour
  Day  Minute Mode
12:09 12:34 N
027 +06583 060 +06583 094 +06582 127 +06582 160 +06582
029 +13590 062 +13598 095 +13577 129 +13588 162 +13586
030 +08404 064 +08407 097 +08437 130 +08425 164 +08395
032 +11610 065 +11608 099 +11618 132 +11609 165 +11612
034 +08167 067 +08167 100 +08184 134 +08187 167 +08199
12:09 13:18 P        Number of seconds after absolute time
005 +06563 017 +06563 027 +06556 038 +06554 049 +06552
007 +1358[illegible] 018 +135[illegible]9 029 +13[illegible]93 040 +1[illegible]594 050 +[illegible]3594
008 +08407 019 +0840[illegible] 030 +08438 041 +08425 052 +08397
010 +11579 021 +11576 032 +11586 042 +11577 053 +11578
011 +08146 022 +08143 033 +08151 044 +08143 054 +08135
12:09 13:19 P        Measurement values at the time given
006 +06550 016 +06548 027 +06547 038 +06546 049 +06544
007 +13592 018 +13598 029 +13578 039 +13590 050 +13590
008 +08408 019 +08404 030 +08437 041 +08428 051 +08396
010 +11575 020 +11573 031 +11581 042 +11571 053 +11572
011 +08124 022 +08123 033 +08130 043 +08127 054 +08122
12:09 13:20 P
005 +06543 016 +06542 027 +06541 038 +06539 048 +06538   Probe 1
007 +13588 017 +13594 028 +13573 039 +13586 050 +13585     ..  2
008 +08407 019 +08406 030 +08402 040 +08431 051 +08396     ..  3
009 +11569 020 +11566 031 +11575 042 +11564 053 +11566     ..  4
011 +08103 022 +08106 032 +08118 043 +08114 054 +08108     ..  5
12:09 13:21 P
005 +06537 016 +06536 027 +06536 037 +06535 048 +06534
006 +13583 017 +13590 028 +13570 039 +13582 050 +13581
008 +08407 019 +08403 029 +08402 040 +08433 051 +08405
009 +11562 020 +11560 031 +11570 042 +11557 052 +11560
011 +08096 021 +08095 032 +08107 043 +08100 054 +08097
12:09 13:22 P
005 +06532 016 +06531 026 +06530 037 +06530 048 +06529
006 +13580 017 +13587 028 +13567 039 +13579 049 +13578
008 +08405 018 +08401 029 +08405 040 +08428 051 +08401
009 +11556 020 +11554 031 +11562 041 +11552 052 +11554
010 +08084 021 +08083 032 +08099 043 +08094 053 +08090
12:09 13:22 P
006 +06528 016 +06527 027 +06527 038 +06525 049 +06525
007 +13578 018 +13584 028 +13565 039 +13576 050 +13576
008 +08406 019 +08405 030 +08403 041 +08430 051 +08400
010 +11551 020 +11548 031 +11558 042 +11546 053 +11549
011 +08078 022 +08077 033 +08091 043 +08086 054 +08083
12:09 13:23 C
023 +06523 052 +06521 081 +06520 110 +06518 139 +06517
024 +13571 053 +13577 083 +13558 112 +13571 141 +13571
026 +08405 055 +08401 084 +08402 113 +08434 142 +08404
028 +11544 057 +11540 086 +11548 115 +11535 144 +11536
029 +08068 058 +08066 087 +08077 116 +08073 145 +08067
12:09 13:26 C
023 +06515 052 +06515 081 +06513 110 +06511 139 +06510
024 +13570 053 +13578 083 +13559 112 +13571 141 +13571
026 +08405 055 +08400 084 +08403 113 +08433 142 +08404
028 +11531 057 +11528 086 +11536 115 +11523 144 +11524
029 +08051 058 +08051 087 +08066 116 +08059 145 +08054
12:09 13:28 C
023 +06509 052 +06509 081 +06507 110 +06506 139 +06504
024 +13571 053 +13578 083 +13558 112 +13572 141 +13571
026 +08406 055 +08405 084 +08400 113 +08433 142 +08405
028 +11519 057 +11516 086 +11524 115 +11512 144 +11513
029 +08037 058 +08036 087 +08053 116 +08043 145 +08041
033 +08242 067 +08242 100 +08255 133 +08263 166 +08265
```

APPENDIX 9(2)

EXAMPLE OF A D-FILE FROM AN INTERFERENCE TEST WITH THE PIEZOMAC I SYSTEM

```
Ident  C1  LB DW IW AW  X       Y      Z      LT      SECUP  SECLOW                                  3 x r
AHGI2400062176E-3  40150 90      902.0   1224.0 106.31  30.95
AHGI2000030635E-3 100110 90  0   740.0   1238.0 107.58  40.98  0.00 42.70 43.70 53.70 54.70100.00        125.0125.01
25.0
AHGI2300035787E-3  90150 90  0   870.0   1266.0 116.92  29.15  0.00 30.00 31.00 90.00                     45.0 45.0
AHGI05000332S6E-3 115110 55210   886.0   1268.0 115.09  43.72  0.00 44.00 45.00 57.00 58.00115.00         32.0 12.0
24.0
AHGI0100030635E-3 153115 55210   902.0   1224.0 106.35  16.98  0.00 18.00 19.00 26.00 27.00 53.00          10.0 10.0
60.0
Day/Time Mode                            Seconds/Measurement values
8212091234T        27409304.6 60409304.6 94409242.4127409242.4160409242.4 29416329.6 62416574.7 95415931.3129416268.3162416207.1 3
030075
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8212091321P         5406444.4 16406382.3 27406382.3 37406320.1 48406257.9  6416115.1 17416329.6 28415716.9 39416084.5 50416053.9
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8212091322P         5406133.6 16406071.4 26406009.2 37406009.2 48405947.1  6416023.3 17416237.7 28415625.0 39415992.6 49415962.0
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D Kirk Nordstrom
US Geological Survey, Menlo Park, USA
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Royal Institute of Technology, Stockholm, Sweden
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Trygve Eriksen
Royal Institute of Technology, Stockholm, Sweden
Hilbert Christensen
Studsvik Energiteknik AB, Nyköping, Sweden
Erling Bjergbakke
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Geophysical investigations at the Klipperås study site
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TR 86-11
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