Groundwater Study and Emergency Implementation Plan

Tapa Municipality Water Supply

Final Draft Report

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HEDESELSKABET

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0 SUMMARY

With support from the Danish Enviromental Protection Agency (DEPA), an emergency groundwater study has been accomplished in order to assess the risk of oil contamination from the former Russian airbase in Tapa and to identify and prioritize alternative groundwater sources.

Tapa Town is located approximately 90 km to the east of Tallinn in Estonia and has a population of around 8,000 people. Until 1993 the town was host to a large Russian airbase that has caused heavy contamination of the aquifer by jetfuel.

Two alternative well fields have been proposed, one at Moe (Moe I) located 3-5 km from Tapa Town and one located 2 km from Tapa Town (Moe II). The scope of this study has been to estimate the water yield and the water quality at the two well fields and to assess the risk of contamination. Finally a costed emergency implementation plan for the preferred well field has been prepared.

Field work including test pumping and collection of water samples from the the well fields and the deep water supply wells in Tapa has been performed in March 1997.

From the groundwater study it is concluded:

- That no oil product, BTEX or chlorinated solvents are found in the deep wells at Tapa.

- That the water quality at the preferred well field, Moe II, located 2 km east of Tapa Town, meets Estonian standards.

- That the Ordovician groundwater complex (I) below Tapa Town in the long term must be excluded as a source for drinking water, that there is a long-term risk of contamination of the Cambrian-Ordovician groundwater complex (II), and that The Cambrian-Vendian groundwater complex (III) is well-protected.

- That the risk of contamination of the preferred well field, Moe II, based on a preliminary assessment, is insignificant.

It is recommended to initiate an emergency water supply plan regarding the Moe II well field. Prior to this, a well field investigation including a riskassessment has to be worked out. In addition it is recommended to rehabilitate well PK-113 C-V (III) and to examine the well installations of the remaining water supply wells. Finally it is recommended to continue and improve the current monitoring and remediation programmes.

Implementation of an emergency water supply based on the well field at Moe II will require investment of EEK 10,5 m (preliminary estimate).

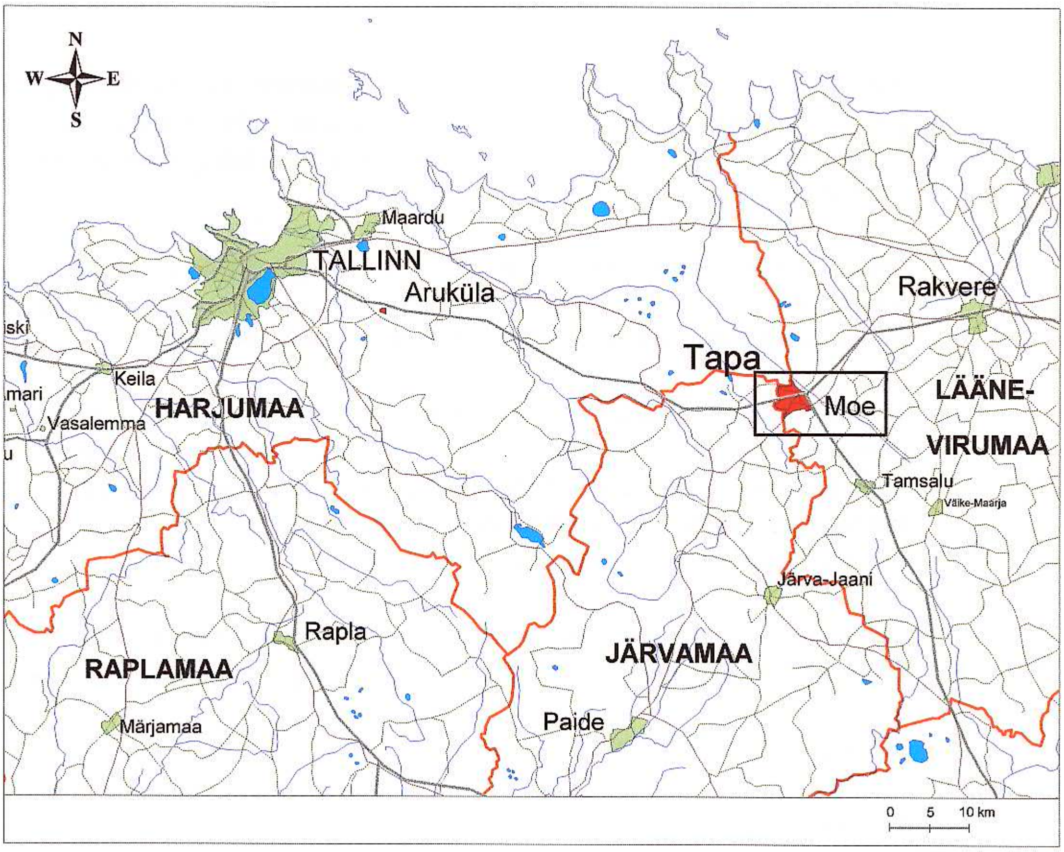

N
W
E
S
Maardu
TALLINN
Aruküla
Rakvere
Keila
HARJUMAA
Vasalemma
Tapa
Moe
LÄÄNE-
VIRUMAA
Tamsalu
Väike-Maarja
Järva-Jaani
Rapla
RAPLAMAA
JÄRVAMAA
Märjamaa
Paide
0 5 10 km

Figure 1.1

1 INTRODUCTION

The project titled "Groundwater Study and Emergency Implementation Plan, Tapa Municipality Water Supply" is part of the Danish Enviromental Protection Agency's (DEPA) grant-aided environmental programmes including assistance to the small urban municipalities in Estonia.

A programme of environmental co-operation between the Estonian Ministry of Environment (EME) and DEPA was agreed upon in July 1996, involving increased support to cover several small towns including Tapa and Aruküla.

This present report comprises the results of the groundwater study and predesign plan for Tapa Municipality Water Supply.

1.1 Background

Tapa Town is located approximately 90 km to the east of Tallinn in Estonia and has a population of around 8,000 people. Until 1993 the town was host to a large Russian airbase which has caused heavy contamination of the surface aquifer by jetfuel. The location of Tapa Town and the former Russian airbase is shown in Figure 1.1.

With support from DEPA and EME, remedial action was initiated in 1994 to remove free jetfuel from the groundwater and till 1996 a total amount of 95 m^3 of jetfuel has been abstracted. In spite of the remediation effort, a risk exsist, that the jetfuel contamination will spread to the deeper aquifers and contaminate Tapa Town's water supply wells.

On this basis, DEPA has supported an Emergency Groundwater Study to estimate the risk of the oil contamination and to identify and prioritize alternative well fields. DEPA has asked Hedeselskabet, Environmental and Energy Division (HEED) to manage this project. The present report which comprises the results of this project is prepared by HEED with assistance from the Estonian company MAVES A/S. All analyses have been worked out by the Estonian Environmental Research Center (EERC) with the exception of analyses for chlorinated solvents, which have been analyzed by Hedeselskabet's Laboratory (HL).

1.2 Purpose of the project

The purpose of the project is to:

<u>Assess the risk of contamination to the deep wells in Tapa</u>

An assessment of the potential risk of contamination to the deep wells is to be prepared on the basis of the results from the "Tapa - Airbase, Estonia: Groundwater Contamination Project"/1,2/.

Identify and prioritize alternative well fields

Based on the requirements for the future water supply as defined by the municipality and the results of the risk assessment, the potential new well fields in Tapa is to be identified and prioritized by examining the yield, the groundwater quality and the physical condition of the wells.

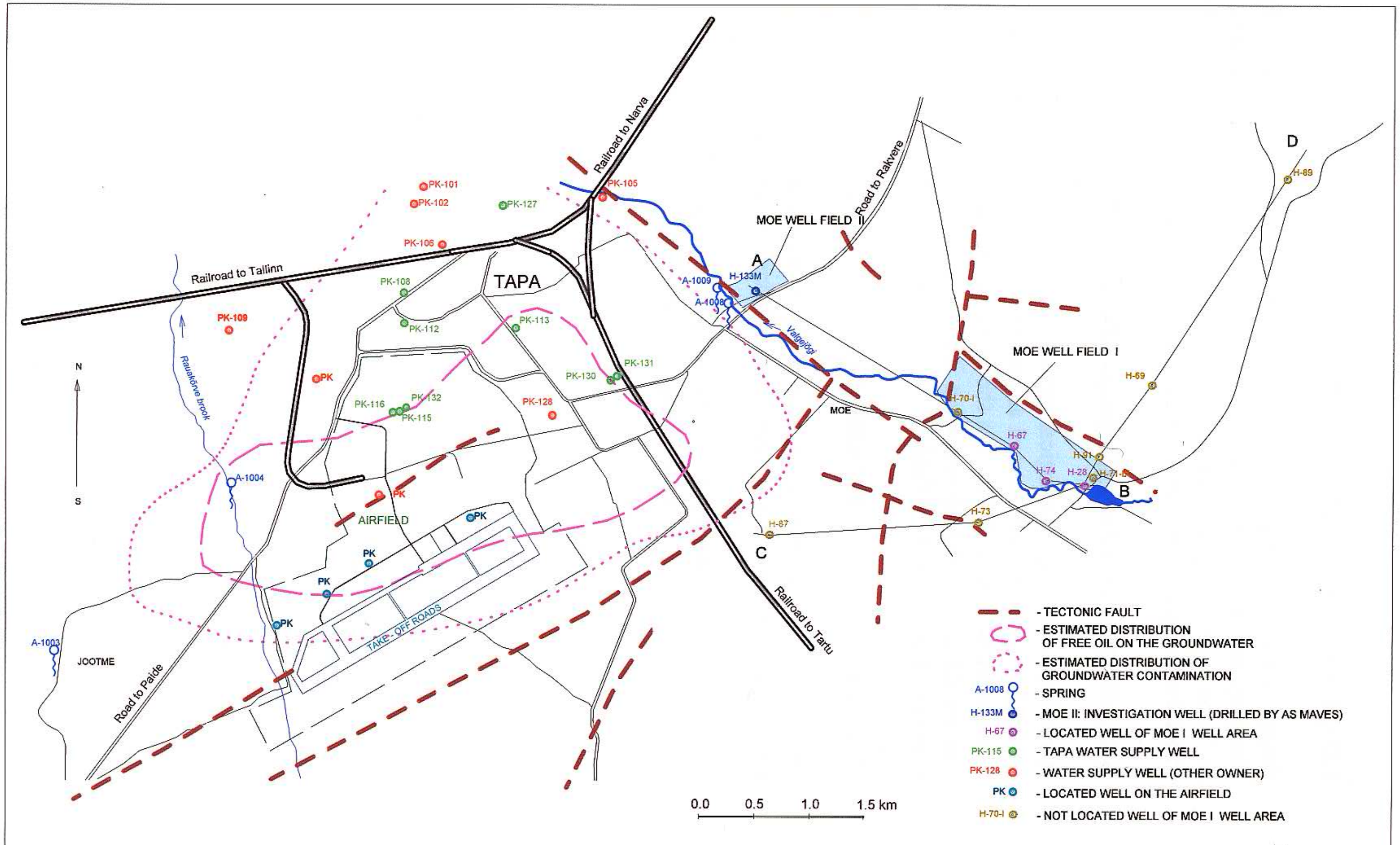
Assess the need for a new remediation strategy

A mathematical hydrogeological model of the area between Tapa and Valgejõgi River has been calibrated as part of the "Tapa Airbase Groundwater Contamination Project"/2,5/. On the existing model further run of simulations for different pumping scenarios is to be prepared to assess the risk for contamination of the Moe fields.

Prepare an emergency implementation plan of the proposed well field

An emergency implementation plan is to be prepared to meet the requirements of water demand and water quality defined by the municipality.

The predesign and emergency implementation plan form the basis for starting final design and preparation of plans and specifications of the new well field.



Railroad to Narva
Railroad to Tallinn
Railroad to Tartu
Road to Rakvere
Road to Paide
TAPA
MOE WELL FIELD II
MOE WELL FIELD I
MOE
AIRFIELD
TAKE - OFF ROADS
JOOTME
Raudoja brook
A
B
C
D
N
S
PK-101
PK-102
PK-127
PK-105
PK-106
PK-108
PK-109
PK-112
PK-113
PK-116
PK-132
PK-115
PK-128
PK-130
PK-131
PK
A-1009
A-1008
A-1004
A-1003
H-133M
H-70-I
H-67
H-74
H-28
H-69
H-89
H-73
H-87
- TECTONIC FAULT
- ESTIMATED DISTRIBUTION OF FREE OIL ON THE GROUNDWATER
- ESTIMATED DISTRIBUTION OF GROUNDWATER CONTAMINATION
A-1008 - SPRING
H-133M - MOE II: INVESTIGATION WELL (DRILLED BY AS MAVES)
H-67 - LOCATED WELL OF MOE I WELL AREA
PK-115 - TAPA WATER SUPPLY WELL
PK-128 - WATER SUPPLY WELL (OTHER OWNER)
PK - LOCATED WELL ON THE AIRFIELD
H-70-I - NOT LOCATED WELL OF MOE I WELL AREA
0.0 0.5 1.0 1.5 km

FIGURE 2.1

2 GENERAL GEOLOGY AND HYDROGEOLGY

2.1 Topography and Surface Geology

The surface topography in the Tapa-Moe area is quite flat with surface elevations between 87 and 122 meters above sea level. It is a karst landscape with good hydraulic contact between the surface soils consisting of shallow Quaternary deposits and the underlying fractured Ordovician limestone.

The studied well fields north and south of Moe are located on the eastern river bank of the Valgejôgi River Valley with shallow Quaternary deposits and good contact between the river and the limestone aquifer. This is confirmed by multiple springs entering the river in this reach. The location of the Moe well fields are shown in figure 2.1.

Just upstream the well site south of Moe, the river valley is quite narrow. Here thick quaternary deposits cover the fractured limestone and the river is dammed to form a small reservoir. Further upstream the valley bottom becomes more wide and flat at elevations around 98 meters above sea level.

2.2 Geological setting

The regional geology is described in detail in previous investigation reports /1,2/. A general geological profile is shown in Figure.2.2.

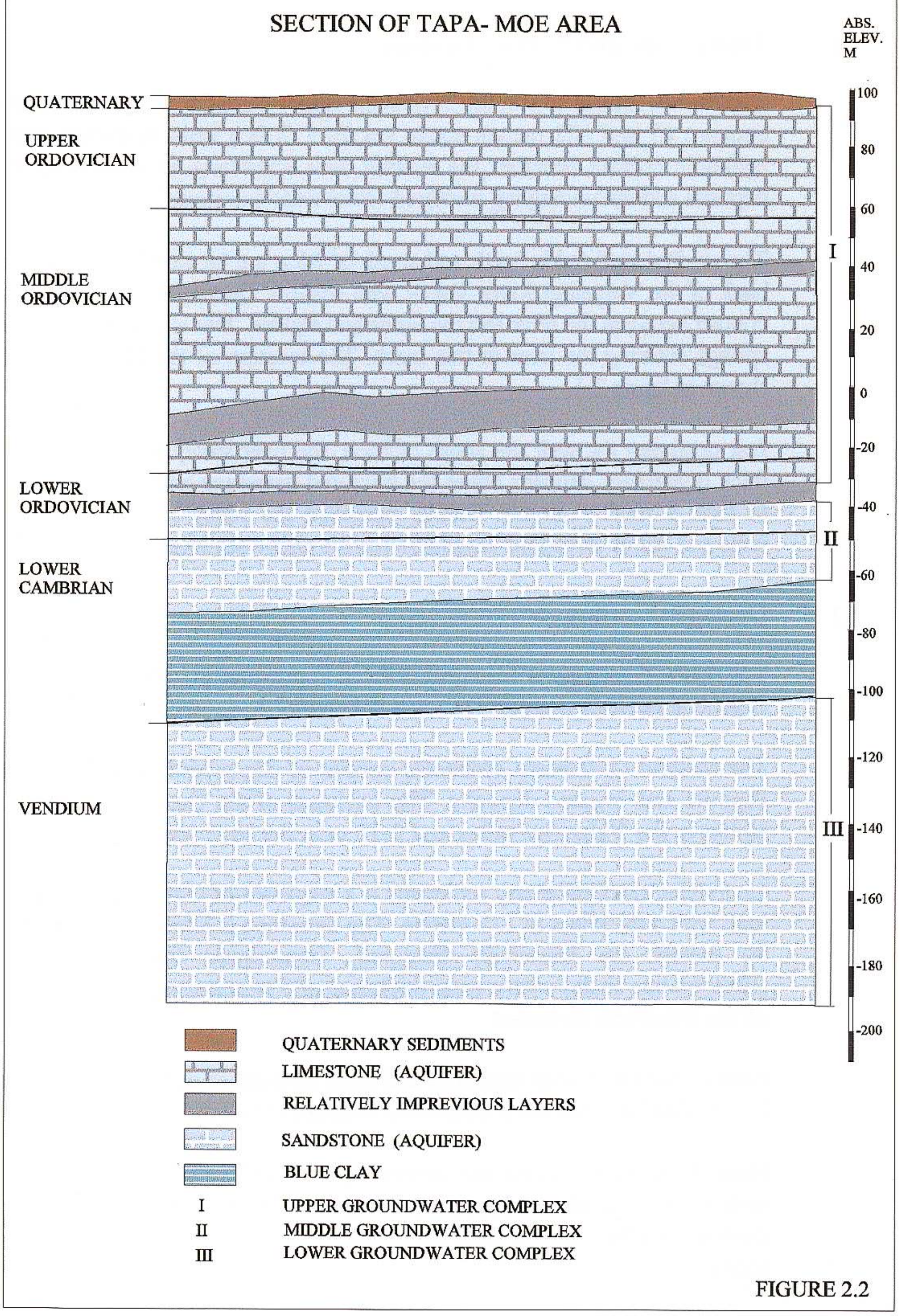
The shallow Quaternary sediments consits of clayey and sandy till, meltwater deposits and organic deposits. The thickness of the Quaternary layer is 0.5-4 meters in the Valgejõgi valley and 2-10 m in the Moe well areas.

Underlying the Quaternary sediments is a sequence of Ordovician limestone and marl with a thickness of 135 meters. The limestone is lithified and the upper 15-30 meters are intensively fractured. Glauconitic limestone and shale (Dictyonema shale) with a total thickness of 5 m are present in the lower part of the limestone sequence.

Beneath the Ordovician limestone and marl, sandstones of Lower Ordovician and Lower Cambrian age are found with a thickness of 40 meters.

Beneath the Lower Cambrian sandstone, Lower Cambrian "blue clay" is found with a thickness of 40 meters, which again is followed by a 90-meter thick sequence of Cambrian-Vendian sandstone situated on the crystalline basement rocks.

The area is penetrated by several tectonic fracture systems running mainly in northwest-southeastern or northeast-southwestern directions. The fracture systems result in a block-like geologic structure in the Moe well areas. The mi-



SECTION OF TAPA- MOE AREA
ABS. ELEV. M
QUATERNARY
UPPER ORDOVICIAN
MIDDLE ORDOVICIAN
LOWER ORDOVICIAN
LOWER CAMBRIAN
VENDIUM
I
II
III
100
80
60
40
20
0
-20
-40
-60
-80
-100
-120
-140
-160
-180
-200
QUATERNARY SEDIMENTS
LIMESTONE (AQUIFER)
RELATIVELY IMPREVIOUS LAYERS
SANDSTONE (AQUIFER)
BLUE CLAY
I UPPER GROUNDWATER COMPLEX
II MIDDLE GROUNDWATER COMPLEX
III LOWER GROUNDWATER COMPLEX

FIGURE 2.2

nor fracture systems are found down to a depth of 15-30 m, whereas the major zones penetrate the whole limestone sequence. A cross-section of the Tapa-Moe area is shown in figure 2.3.

2.3 General Hydrogeology

The regional hydrogeology is described in detail in previous investigation reports /1,2/.

There are three major groundwater complexes in the region: the Ordovician (I), the Cambrian-Ordovician (II) and the Cambrian-Vendian (III). The three groundwater complexes are shown in Figure 2.2.

The upper groundwater complex (I) belongs to the Ordovician limestone sequence and consists of several aquifers separated by relatively impermeable layers. These "aquitards" between the upper aquifers do not appear as a lithologically distinct layer, but are controlled by the difference in the secondary fracture porosity.

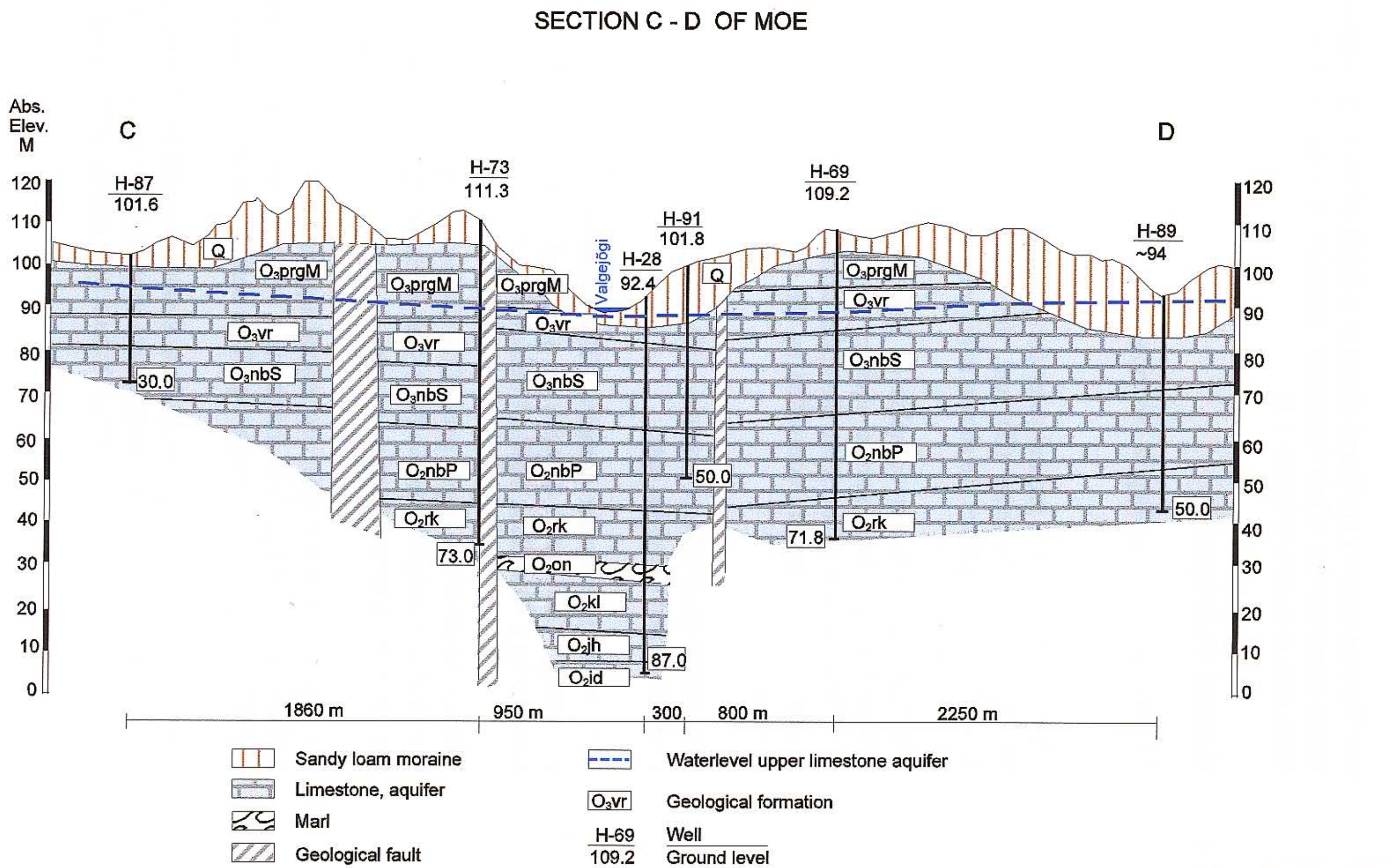
The middle groundwater complex (II) belongs to the sandstone sequences of Ordovician and Cambrian age.

The lower groundwater complex (III) is connected to the Cambrian-Vendian sandstone. This water complex is separated from the Ordovician-Cambrian complex by a 40 m thick aquitard described as the Cambrian "blue clay".

The limestone of the upper part of the Ordovician groundwater complex has a very high transmissivity in the Moe well fields, from 4300-6200 m^2/day, due to the presence of several fracture systems.

The water table in the upper unconfined aquifer lies 1-2 m above the piezometric surface in the lower aquifer, indicating a vertically downwards leakage/gradient. In the Moe well areas the upper aquifer is confined to semi-confined.

The water table of the upper aquifer is situated from 91 to 98 meters a.s.l. with a groundwater flow from the Airbase area towards the northeast, the north and the northwest. The ground level at the Airbase base is around 100 meters a.s.l.



SECTION C - D OF MOE
Abs. Elev. M
C
D
H-87
101.6
H-73
111.3
H-91
101.8
H-28
92.4
H-69
109.2
H-89
~94
Valgejõgi
Q
O3prgM
O3vr
O3nbS
O2nbP
O2rk
O2on
O2kl
O2jh
O2id
30.0
73.0
87.0
50.0
71.8
50.0
1860 m
950 m
300
800 m
2250 m
Sandy loam moraine
Limestone, aquifer
Marl
Geological fault
Waterlevel upper limestone aquifer
Geological formation
Well
Ground level

FIGURE 2.3

3 WATER SUPPLY CONDITIONS

3.1 Existing Water Supply

Tapa Town's water supply system, managed by Tapa Vesi, supplies piped water for approx. 65% of the population at around 8,000 people /4/. There are seven deep-wells currently connected to the town's water supply system.

One well abstract water from the Ordovician (O) aquifer complex (I). Four wells abstract water from the Cambrian-Ordovician (C-O) aquifer complex (II) and two wells from the Cambrian-Vendian (C-V) aquifer complex (III). Two wells owned by the Tapa Railway are also connected to the water main, although these only supply water to the railway dwellings and depots. The remaining 35% of the population is supplied with water from private owned deep wells, from cisterns or public taps.

The location of Tapa Vesi water supply wells are shown in Figure 2.1. An overview of the water supply wells in Tapa is given in Table 3.1.

Tabel 3.1 Deep water supply wells

Owner	Well No.	Aquifer	Average yield 1996
Tapa Vesi	108	O (I)	19
Estonian Consumers Cooperation	109	O (I)	70[2]
Tapa Vesi	112 127 130 131	C-O (II)	292 264 213 470
Estonian Railways	105 106	C-O (II)	430[3] 340[3]
Bakery	102	C-O (II)	25[3]
Vasar	101	C-O (II)	200[3]
Transport Company	128	C-O (II)	220[3]
Tapa Vesi	113	C-V (III)	not in operation
Tapa Vesi[1]	115 116	C-V (III)	504 not in operation

1 former military wells

2 estimated by Maves A/S

3 /3/

The total water quantity pumped out from Tapa Vesi's supply wells in 1996 were 643,672 m^3, corresponding to an average of 1,763 m^3/day. The average quantity per day was from 1,650-2,100 m^3 based on the monthly record from Tapa Vesi. The total consumption of water in Tapa including industrial water was approx. 4,000-4,500 m^3/day during the last years.

The main part of the water supply for the population, approx. 80%, is abstracted from the Cambrian-Ordovician (C-O) aquifer complex (II), 17% from the Cambrian-Vendian (C-V) aquifer complex (III) and approx. 3% from the Ordovician (O) aquifer complex (I).

At present the yield from existing deep wells does only just satisfy the current need for water. Since 1989 there has been a decrease in the yield of well no.105 and 106 (C-O) (at approx. 600 m^3/day) and well no. 113 (C-V) has mainly been out of operation since 1991 (yield 500-800 m^3/day). This water deficit has been partly compensated by operating other wells at full capacity. Still, there is a water deficit of 500-600 m^3/day compared to previous years.

3.2 Water Quality, General Assessment

The water quality in wells around Tapa Town, abstracting water from the Ordovician aquifer complex (I), is generally satisfactory with respect to inorganic chemical components. However, low-quality groundwater is found in wells situated around large cattle farms. In these wells the water contains elevated concentrations of nitrogen compounds probably due to over-application of organic and inorganic fertilizers. This kind of contamination is found in the upper 5-10 m of the upper aquifer. At depths below 10-15 m the water quality is satifactory. At some locations the water contains high concentrations of fluor (F), iron (Fe^{2+}) and a total hardness over the Highest Permissible Content (HPC). Around the military airbase the water quality in the upper 5-10 m of the aquifer is unacceptable due to the jetfuel contamination from the airbase and due to infiltration from the sewer system.

In the deeper groundwater complexes (II and III) the water quality is generally reported to be satisfactory although the concentrations of iron tend to be high at some locations.

The water quality is measured frequently in accordance with the established monitoring programme. Standard analyses for groundwater quality and chemical analyses for contaminants are accomplished once a year. Within this study additional sampling and analyses for water quality and contaminants have been accomplished. The results of analyses are shown in Enclosure 1. A description and evaluation of the water analyses are given in Section 4.2.

3.3 Water Supply, Extension Plans

The predicted water consumption in the nearest future will be at the same level as the last years, around 4,000 m^3/day. However, due to the poor technical condition of several water supply wells and the risk of affecting the water quality from the airfield contamination and other sources it is uncertain, whether it will be possible to ensure an abstraction of 4,000 m^3/day in the future. So the need for identifying alternative well fields is obvious.

Two possible alternative well fields were considered during this groundwater study, the Moe I well field situated 3-5 km southeast of Tapa and Moe II well field 2 km east of Tapa. The Moe I well field was extensively studied by the Russians during the early 1980's and has been testet during this study. The Moe II well field was suggested during a project preparation visit to Tapa and was taken into consideration due to the close location to Tapa. The Moe II well field was only been briefly studied within this project. The location of the two alternative well fields are shown on Figure 2.1.

Another possible alternative for future extension of the water supply is to consider a more intensive exploitation of the deep Cambrian-Vendian aquifer Complex (III).

4 TECHNICAL ANALYSES

4.1 Aquifer Test

During the period 4-7 March, 1997 a series of tests was performed on the wells H-28, H-67 and H74 at Moe I well field, and well H-133 at Moe II well field. Well H-133 was drilled in February 1997 as a part of this study to assess the water quality at the proposed well field. The location of the wells are shown in Figure 2.1. Description of the wells and the results of the tests are included in Enclosure 2. The well construction and well logging are shown in Enclosure 3. The tests were performed to assess the water quality in the well fields and to confirm the water yield of the wells, found at the previous investigation /6/.

The previous water yield of the wells could not be fully confirmed from the test, due to the physical conditions of the well installations and the pump equipment. However, it is assumed that the previous test data /6/ still can be regarded as representative of the wells in Moe I well field. At the Moe II well field the yield from the well H-133 is estimated to be 20 - 30 m^3/h. However, longterm tets from fully equipped pumping wells are needed to estimate the hydraulic parameters of the auifer at the Moe II well field.

4.2 Chemical Analyses

Water samples from selected wells of Tapa water supply and Moe I and Moe II well fields are analyzed for contant of oil components and chlorinated solvents by means of gas chromatographic analyses. The results of the analyses are shown in Table 4.2 and Enclosure 1.

Table 4.2 Water samples from Tapa and Moe well fields

Well	Aquifer	BTEX[1]	Jetfuel	Chlorinated solvents
Moe I Well Field	µg/l			
H-28	O (I)	<0,1	<10	n.a.
H-67	O (I)	<0,1	<10	0,04[2]
H-74	O (I)	<0,1	<10	n.a.
Moe II Well Field				
H-133	O (I)	<0,1	<10	0,04[2]
Tapa Water Supply				
PK-112	C-O (II)	<0,1	<10	n.a.
PK-131	C-O (II)	<0,1	<10	n.a.
PK-132	C-O (II)	<0,1	<10	n.a.
PK-115	C-V (III)	<0,1	<10	0,1[3]

n.a. not analyzed

1 Benzene, Toluene, Ethyl-benzene and Xylene

2 Chloroform

3 0,07 µg/l chloroform, 0,03 µg/l tetrachlormethan, <0,01 µg/l PCB

It appears from Table 4.2 that samples from Tapa water supply and Moe well fields do not contain oil components and jet fuel. Three samples are analyzed for chlorinated solvents and in all three samples chloroform is detected in very low concentrations. In one sample, taken from well PK-115, tetrachlormethan is found in very low concentration. The presence of chlorinated solvents in the water samples is caused by contamination from chlorinated drinking water used in the laboratory in Tallinn during handling of samples.

4.3 Groundwater Chemistry

The wells in the Moe well fields and the Tapa water supply can be clearly separated by different groundwater chemistry. The anion and cation composition of the wells are shown in Figure 4.2 and 4.3.

The wells H-28, H-67, H-74 and H-133 are all located in the upper aquifer of the Ordovician groundwater complex. This is reflected in the cation composition in which calcium is the predominant species. Magnesium is the second most abundant cation. With respect to the anions bicarbonate is the most predominant species. The upper Ordovician aquifer is near to the surface and has a high redox potential shown by the amount of nitrate. The wells H-28, H-67 and H-74 seem to be affected by fertilizers as opposed to the well H-133 where nitrate content is low compared to the other wells. In general, the upper aquifer is vulnerable to the land use. This is shown in the sample from H-28 in which both high organic matter content and bacterial counts show the impact of the land use. The quality of the water of the wells from the Ordovician groundwater complex (I) is listed in Table 4.3

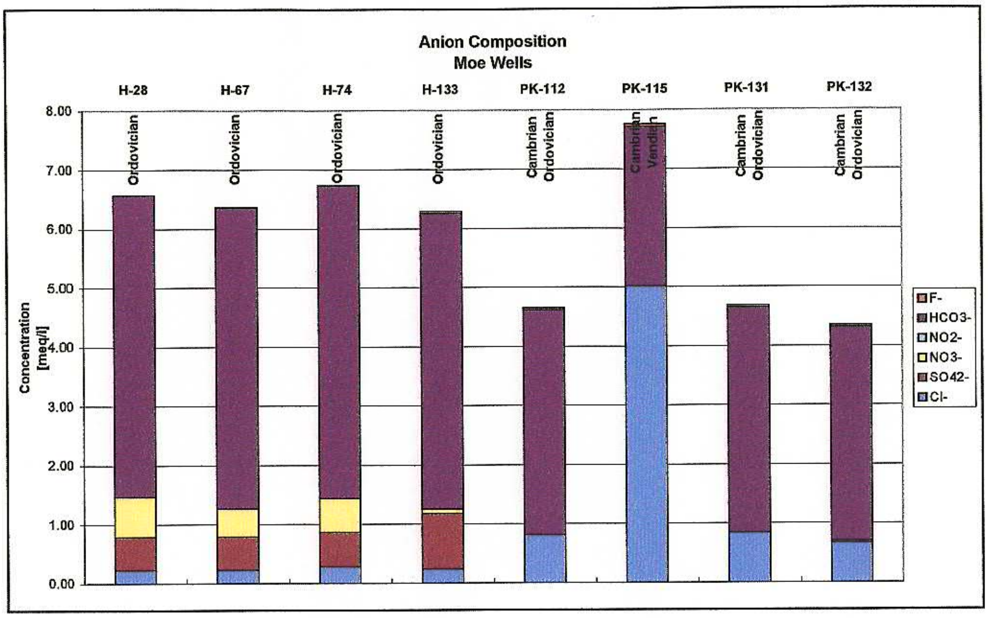


Figure 4.2 Anion composistion

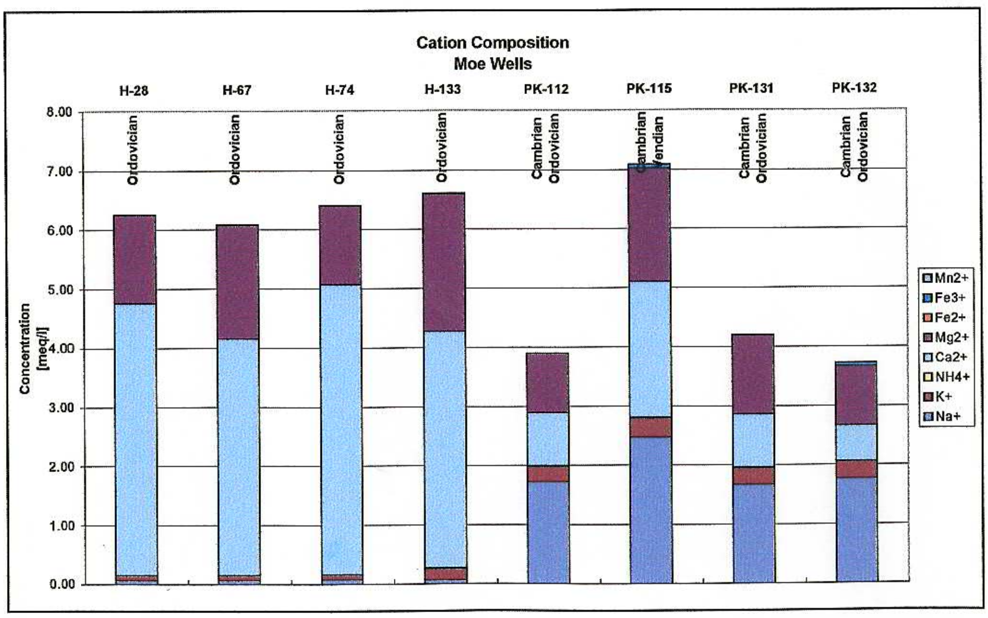


Figure 4.3 Cation composistion

Table 4.3 Quality of water ranked by Excellent, Good, Satisfying, Not acceptable

Well	Quality according to Estonian drinking water standards	Most Critical Parameter
H-28 (Moe I)	Not acceptable	COD
H-67 (Moe I)	Satisfying	Nitrate
H-74 (Moe I)	Satisfying	Nitrate
H-133 (Moe II)	Good	Iron

The wells PK-112, PK-131 and PK-132 are all located in the Cambrian-Ordovician groundwater complex (II). The anion and cation composition of the wells are shown in Figure 4.2 and 4.3. Compared with the upper laying Ordovician groundwater complex (I) it can be seen that the water through its downward transport has undergone ion exchange. In general, the ion content is lower and calcium has been exchanged with sodium. The anion composition is not affected in the same manner although the chloride content is raised compared to the Ordovician aquifer (I). In the deepest well PK-115, located in the Cambrian-Vendian groundwater complex (III), the ion exchange is even more pronounced. The layer of Cambrian "blue clay" separating the Cambrian-Ordovician complex (II) from the Cambrian-Vendian (III) is of marine origin. This is reflected in the rise of the chloride content which is clearly seen in PK-115 compared to PK-112, PK-131 and PK-132. The general quality of the water from wells is shown in Table 4.4.

Table 4.4 Quality of water ranked by Excellent, Good, Satisfying, Not acceptable

Well	Quality according to Estonian drinking water standards	Most Critical Parameter
PK-112 (Tapa)	Good	Ammonia
PK-115 (Tapa)	Not acceptable (Good)	Iron (Ammonia, COD)
PK-131 (Tapa)	Good	Ammonia
PK-132 (Tapa)	Not acceptable (Good)	Iron (Ammonia)

For PK-115 and PK-132 the water quality is stated as not acceptable due to the iron content. This can be overcome by simple treatment in a treatment plant with aeration and filtration. This will probably also reduce the ammonia and COD content.

5 ENVIROMENTAL ASSESSMENT

The main threat to the groundwater source in the area is the contamination from Tapa airbase. Assessments of the jet fuel contamination at Tapa airbase accomplished between 1992 and 1994 show that free phase jet fuel has migrated on the watertable of the upper ordovician aquifer on an area of approximately 6 km^2 /1,2/. The oil accumulation measured in the investigation wells varies in thickness from only a few centimeters to more than 3 meters. Chemical analyses show that a dissolved oil plume has migrated to the east, north and the west of the airbase, covering an area of 16 km^2. Figure 2.1 shows the estimated distribution of free phase jetfuel and dissolved oil plume.

Chemical analyses of water samples collected in the period 1992-1996 indicate, that the dissolved oil plume has reached steady-state conditions, not expanding or migrating further downgradient, although fluctuations in the oil contents were observed.

Oil components are mainly found in the upper aquifers of the Ordovician groundwater complex (I), and are only detected sporadicly in deeper aquifers. Table 5.1 present the result of analyses of water samples from Tapa water supply wells. Samples taken before April 1993 are not included in Table 5.1 due to use of a highly unreliably analytical method (the Spectoflurometric method).

According to Table 5.1 oil products have been detected in samples from three wells (marked with shadow): PK-108, PK-115 and PK130. In well PK-108 belonging to the Ordovician groundwater complex (I), the contents of jet fuel exceeds the Estonian standards for drinking water. Jetfuel and BTEX were not detected in samples taken from this well since February 1994.

Table 5.1 Water Analyses from Tapa Water Supply

		Gas Cromatographic Analyses, µg/l		
Well no.	**Aquifer**	**BTEX**	**Jetfuel**	**Date**
PK-101	C-O	n.m.	< 10	14.04.93
PK-102	C-O	n.m.	< 10	14.04.93
PK-105	C-O	n.m.	< 10	14.04.93
PK-108	O	n.m.	< 10	14.04.93
		n.m.	140	29.04.93
		1,0[1]	32,3	09.02.94
		<0,1	< 10	10.09.95
		<0,1	< 10	06.09.96
PK-112	C-O	n.m.	< 10	14.04.93
		<0,1	< 10	27.01.94
		<0,1	< 10	09.02.94
		<0,1	< 10	28.05.95
		<0,1	< 10	10.09.95
		<0,1	< 10	06.09.96
		<0,1	< 10	03.03.97
PK-115	C-V	n.m.	< 10	29.04.93
		<0,1	< 10	27.01.94
		<0,1	< 10	09.02.94
		1,5[2]	< 10	28.05.95
		<0,1	< 10	10.09.95
		<0,1	< 10	03.03.97
PK-127	C-O	n.m.	< 10	29.04.93
		<0,1	< 10	09.02.94
		<0,1	< 10	10.09.95
PK-128	C-O	n.m.	< 10	29.04.93
		<0,1	< 10	27.01.94
		<0,1	< 10	09.02.94
		<0,1	< 10	10.09.95
		<0,1	< 10	06.09.96
PK-130	C-O	n.m.	< 10	29.04.93
		<0,1	< 10	27.01.94
		<0,1	< 10	09.02.94
		<0,1	< 10	28.05.95
		0,16[2]	< 10	10.09.95
		<0,1	< 10	06.09.96
PK-131	C-O	n.m.	< 10	29.04.93
		<0,1	< 10	27.01.94
		<0,1	< 10	09.02.94
		<0,1	< 10	28.05.95
		<0,1	< 10	10.09.95
		<0,1	< 10	03.03.97
PK-132	C-O	<0,1	< 10	19.03.97

n.m.: not measured
[1]: 0,5 µg/l Toluene, 0,5 µg/l Xylene
[2]: Xylene

In well PK-115 (C-V (III)) and PK-130 (C-O (II)) toluene was detected in May 1995 and September 1995 respectively. In well PK-115 the contents of toluene was above the Estonian standards for drinking water.

The occasional presence of jet fuel, toluene and xylene in the lower part of the Ordovician and Cambrian-Ordovician groundwater complex is probably caused by the intensive exploitation of these groundwater resources. This has locally caused a leakage of oil containing water from the upper groundwater aquifers into the wells.

The detection of xylene in well PK-115 could be a result of analytical problems at the laboratory, unfavorable handling of the sample, or caused by the use of oil containing products in connection with repairment of installations. The oil contents in well PK-115 was not verified by other analyses.

The monitoring programme shows that no oil product or BTEX is present in the deep wells of Tapa since September 1995. In addition the results of the last monitoring round indicate that chlorinated solvents are not present in the groundwater.

6 RISK ASSESSMENT

The development of new well fields in the Moe area or a more intensively exploitation of the deep Cambrian-Vendian groundwater complex in Tapa will increase the risk for the oil plume to migrate further downgradient and/or increase the risk for deeper infiltration of oil components. However, chemical analyses indicate that the oil plume has reached steady-state conditions and will not migrate any further. This could be a result of intrinsic bioremediation.

To assess the impact of the proposed groundwater abstraction at Moe I and Moe II, simulations of different pumping scenarios will be presented and discussed in Section 6.1. An assessment of the risk for contamination of the existing water supply wells will be included in Section 6.2.

6.1 Risk Assessment, Moe Well Fields

Different pumping scenarios have been simulated by means of a mathematical groundwater model to assess the risk of affecting the groundwater quality at the proposed new well fields at Moe I and Moe II. The model setup, the model calibration and the simulated scenarios are included in Enclosure 4

Based on the established groundwater model, the simulation of two different pumping scenarios was carried out, aiming to predict the impact of the water intake at the well fields. The simulated pumping scenarios were following:

- Scenario 1 - pumping from Moe I well field with the abstraction of 13,400 m^3/day (3 remediation fields active)
- Scenario 2 - pumping from Moe II well field with the abstraction of 13,400 m^3/day (3 remediation fields active).
- Scenario 3 - pumping from Moe I well field with the abstraction of 4,000 m^3/day (3 remediation fields active)
- Scenario 4 - pumping from Moe II well field with the abstraction of 4,000 m^3/day (3 remediation fields active).

The resulting heads of scenario 1 are shown in Enclosure 4, Figure 1 - 2 and simulated drawdown pattern is presented on Figure 3 - 4. The resulting heads of scenario 2 are shown in Enclosure 4, Figure 5 - 6 and simulated drawdown pattern is presented on Figure 7 - 8. The resulting heads of scenario 3 are shown in Enclosure 4, Figure 9 - 10 and simulated drawdown pattern is presented on Figure11 - 12. The resulting heads of scenario 4 are shown in Enclosure 4, Figure 13 - 14 and simulated drawdown pattern is presented on Figure 15 - 16.

The simulated drawdown pattern in scenario 1 and 2 indicates that the area of influence of groundwater abstraction reaches Tapa town and the contamination area at the airfield territory. The max. lowering of the water table in scenario 1 and 2 has been simulated at 0.9 m and 1.3 m respectively.

The simulated drawdown pattern in scenario 3 and 4 indicates that the area of influence of groundwater abstraction will not include the contaminated area.The max lowering of the water table in scenario 3 and 4 has been simulated at 0,05 m and 0, 2 m respectively.

From the simulations it can be concluded that a proposed groundwater abstraction of 13,400 m^3/day at Moe I and Moe II will have an impact on the groundwater flow in the contaminated area. However, the impact will be limited, as the simulated lowering of the groundwater in the marginal part of the oil plume will be approx. 20 cm. With a proposed groundwater abstraction of 4,000 m^3/day at Moe I or Moe II the affect on groundwater in the contaminated area will be insignificant.

No attempt has been made to simulate the spread of the oil plume by means of particle tracking. Previously, simulations have been performed with conservative tracer in order to assess the spread of the plume /2/. These simulations were based on very few data. The available data covering 5 years of monitoring indicates, that the dissolved oil plume has reached steady-state conditions with no expantion or further migration downgradient. As mentioned earlier this could be a result of intrinsic bioremediation. The processes that might have an influence on the spread of the plume are not sufficiently described, although observations and some analytical data indicate that a biological degradation do take place. Presently, simulations of oil plume spread will be subject to uncertainty, and there would be a risk of drawing erraneous conclusions.

The risk of spread of the oil plume by a proposed groundwater abstraction of 4,000 m^3/day at Moe I or Moe II is assessed to be insignificant. However, the initial data from Moe II well field is sparse and assumptional parameters have been used. Consequently the assessment has to be regarded as a preliminary assessment. The risk of contamination of the well fields at the max. exploitation of 13,400 m^3/d will obviously be larger, especially in case of low water level in the river.

Other potential sources of pollution in the vicinity of the proposed well fields includes the railway enterprises in Tapa town, the Moe distillery and a gasoline station. All together, establishment of a well field at Moe I or Moe II will demand establishment of a reliable monitoring programme covering the groundwater quality, especially along the southwestern boundary of the well fields.

6.2 Risk Assessment, existing Water Supply Wells

It is assessed that the Ordovician groundwater complex (I) below Tapa Town in the long term must be excluded as a source for drinking water. The reason is that the Ordovician aquifers is vulnerable towards the contamination from Tapa Airbase, and that a continued cleaning-up of the free oil phase does not seem to cause a significant improvement of the groundwater quality in the upper aquifers within the nearest future.

For the Cambrian-Ordovician groundwater complex (II) there is a long-term risk of contamination, as this groundwater complex is only protected by a relatively thin aquitard. The risk of contamination is found to be most pronounced in the fracture zones and close to the wells where downward leakage could take place. An increased abstraction from the Cambrian-Ordovician complex also increase the risk of contamination.

The Cambrian-Vendian groundwater complex (III) is assessed to be well-protected due to the overlying 20-40 m layer of Cambrian clay ("blue clay"). Investigations of the age of the groundwater in this complex show an age of approx. 10,000 years /3/. This age of the groundwater supports the assumption of the Cambrian-Vendian groundwater being well-protected against contamination, and exclude leakage from overlying aquifers. However, there is a risk for contamination around the Cambrian-Vendian wells with corroded casing.

6.3 Remediation Strategy

Various remediation scenarios have been simulated in the "Tapa Airbase Groundwater Contamination Project"/5/. These scenarios show that the groundwater flow is only slightly affected by the remediation measures. The implemented remediation strategy is therfore assessed to be the most appropriate, as long as a large amount of free jetfuel phase is present. A possible intensified effort for the remediation should focus on stimulation of the biological degradation of the contamination.

7 RECOMMENDATIONS

Based on the conclusions from the groundwater study the following recommendations are given regarding establishment of an emergency water supply for Tapa:

- An emergency water supply plan including the Moe II well field should be initiated. Prior to this, a well field investigation including a riskassessment has to be worked out. If the riskassessment confirms a safe yield, a detailed design plan, including economy, time schedule and tender material have to be prepared.

- Well PK-113 C-V (III) should be rehabilitated and an examination of the remaining C-O (II) and C-V (III) water supply wells should be carried out in order to assess the state of the well installations. Especially the physical condition of lining and screens will have to be examined.

- To reduce the exploitation of the Cambran-Ordovician aquifers C-O (II), the water from these aquifers should not be used for industrial purpose in the future.

- The current monitoring programme should be altered and include sampling and analysis at regular intervals (at least once a year) from all water supply wells. The monitoring programme requires a capability of analyzing oil components at a sufficiently low detection limit, maximum 0,1 μg/l for each component.

- The current remediation programme should be continued to reduce the free jetfuel phase in the hot spot area. A possible intensified effort for the remediation should focus on stimulation of the biological degradation of the contamination.

8 EMERGENCY IMPLEMENTATION PLAN

8.1 General Remarks

In order to reduce the risk of contamination of the groundwater resources in the Cambrian-Ordovician C-O (II) aquifers below Tapa Town, it is recommended to reduce the water withdrawal from the wells in the town area. On a long-term basis it is proposed to establish new well fields outside Tapa to meet the total water demand for household and industry purposes in the Tapa Town area.

On a short-term and emergency basis it is proposed to establish a new well field at Moe II. The new well field must have a capacity enabling it to replace the water withdrawal from wells connected to the city network. From the new well field at Moe II the groundwater is pumped to the existing pumping station at Rakvere Tee and from there distributed to the town's pipeline network.

In addition it is proposed to rehabilitate the Cambrian-Vendian well PK-113.

8.2 Water Demand

The present water consumption of the town, considering individual users and industrial water, is approximately 4,000 m^3/day corresponding to 1,460,000 m^3/year according to /3/.

The actual average daily production rate of the town pipeline network supplied by wells belonging to Tapa Vesi and private owned wells is 1,990 m^3/day corresponding to an annual production rate of approximately 725,000 m^3. Consequently, the future wells at the new Moe II well field must, on a short-term and emergency basis, have a production capacity of 725,000 m^3/year.

As only figures from Tapa Vesi wells are available considering fluctuations in the water demand throughout the year and no figures are available considering fluctuations during the day, the design of water demands in Tapa is estimated and based on experience.

A ratio of 1:1.6 between average daily and maximum daily for the total water demand and a ratio of 1:1.4 between the average hourly and the maximum hourly water demand are considered realistic for a predesign purpose.

Based on an annual water demand of 725,000 m^3 and the above assumptions regarding daily and hourly water demand variations the following demand figures are estimated:

average daily demand:	2,000 m^3/day
maximum daily demand:	3,200 m^3/day
maximum hourly demand:	185 m^3/hour

8.3 Well Field

Based on the preliminary investigations of the existing well at Moe II well field, a capacity of at least 30 m^3/hour must be expected. The investigations indicated that only a minor drawdown of the watertable must be expected.

Assuming that the submerged pumps in the wells operate for 20 hours per day, water must be pumped from 5 wells in order to meet the demand for a future maximum daily withdrawal of 3,200 m^3. A distance of 50 meters between each well is proposed. Each well must be equiped with a submerged pump with a capacity of approx. 35 m^3/hour, e.g. Grundfos SP45.

At each well head a locked underground small chamber for valve operation, electrical installations, control unit, water sampling and with provision for metering must be established.

In order to prevent accidental damage of pumps and other equipment installed in the wells as well as to avoid an immediate danger of water pollution in the vicinity of the wells the well site should be placed within an area protected by a fence. Besides, it is recommended to impose certain restrictions to the land use in areas, in which wells are located.

8.4 Transmission Line

From the proposed well field at Moe II a transmission line connecting the new wells and the excisting town pipe system at the pumping station at Rakvere Tee must be established.

The transmission line is designed for a maximum flow of 6,500 m^3/day and an operation time for the submerged pumps of 20 hours per day. Designing the transmission line for a daily maximum flow of 6,500 m^3 allows an increase of the water demand from approx. 775,000 m^3/year to approx. 1,500,000 m^3/year.

Based on the above design criteria it is proposed to construct a transmission line at a size of 315 mm.

8.5 Reservoir and Water Treatment

At the Rakvere Tee pumping station is a reservoir with a capacity of 1,000 m^3. As the reservoir volume is able to cover approx. 30% of the maximum daily water demand for a total water consumption of 725,000 m^3/year, the reservoir capacity is sufficient.

The preliminary investigation of the ground water quality at Moe II shows that the iron content is about 0.27 mg/l which is slightly above other wells in the Ordovician aquifer in the Tapa area. Detailed investigations at the proposed well field at Moe II will clarify whether simple water treatment like aeration and filtration will be needed. In case water treatment is needed a treatment capacity of 160 m^3/h has to be installed in the Rakvere Tee pumping station.

8.6 Estimated Construction Costs

Estimated construction costs for establishing a new well field at Moe II and a transmission line to the existing pipe network at Rakvere Tee

Well field investigation:	900,000 EKK
Detail design work:	600,000 EKK
Building and construction of the well field:	3,600,000 EKK
Construction of transmission line(2km):	3,000,000 EKK
Water treatment:	1,200,000 EKK
Rehabilitation of well PK-113:	200.000 EEK
Unforeseen expenses:	1,000,000 EKK
Total cost:	10,500,000 EKK

8.7 Economic Advantages

Although the establishment of a new well field at Moe II is made only from environmental considerations the cost of pumping water from Moe II to the pipe network in Tapa is expected to be considerably lower than pumping from the existing deep wells supplying Tapa today.

The water table in the existing deep wells in Tapa is 60 to 70 meters below ground level, whereas the water level in the well at Moe II is approx. 5 meters below ground level. As the ground level at Tapa and Moe II is at approximately the same level above sea the cost of energy if pumping groundwater from the aquifer at Moe II through the transmission line to Tapa only amounts to 10% of the cost if pumping from the deep wells in Tapa.

9 REFERENCES

/1/ Hedeselskabet, 1992, Investigation of Oil Pollution at the Tapa Military Airfield.

/2/ Hedeselskabet, 1994, Tapa-Airbase, Estonia.Groundwater Contamination, Phase 2.

/3/ Maves A/S, 1992, Determing Measures for Eliminating Jetfuel Contamination at the Tapa Military Airfield.

/4/ Hofman Andersen & Partners, 1997, Project Preparation Mission Report for Small Municipality Water Supplies and Wastewater Project., Towns of Keila, Tapa and Aruküla, Estonia. Draft Report.

/5/ Maves A/S, 1996, Tapa Airbase Estonia. Groundwater Contamination phase III

/6/ The USSR Geological Survey, 1981, Well Field Investigation at Moe.(In Russian)

10 ABBREVIATIONS

DEPA	Danish Enviromental Protection Agency
EME	Estonian Ministry of Enviroment
HEED	Hedeselskabet, Enviromental and Energy Division
EERC	Estonian Enviromental Research Center
HL	Hedeselskabet's Laboratory
O (I)	Ordovician Groundwater Complex
C-O(II)	Cambrian-Ordivician Groundwater Complex
C-V(III)	Cabrian-Vendian Groundwater Complex

Enclosures

Enclosure 1
Chemical Analysis

Chemical analyses from Tapa and Moe watersupply wells

D: Standard analyses for groundwater quality

Drill well, Drill hole	Date of sampling and analysing	Total solids g/l	Na^+	K^+	NH_4^+	Ca^{2+}	Mg^{2+}	Fe^{2+}	Fe^{3+}	Cl^-	SO_4^{2-}	NO_3^-	NO_2^-	CO_2 free	HCO_3^-	F^-	P	Mn	Total hardness	Carbonate hardness	Non-carbonate hardness	pH	COD	Bacteriolocical test: Aerobic viable at 37°C	Bacteriolocical test: Coliform bacteria	Bacteriolocical test: Thermotolerant coliform bacteria
			mg/l																mg-ekv/l				mgO/l	nests/100 cm^3		
H-28	07.03.97. 10.03.97.	0.338	2.5	2.0	<0.01	92	18	0.05	0.008	8.0	27.0	15.73	<0.001	0	311	0.08	0.006	<0.02	6.1	5.1	1.0	8.25	4.2	13	0	0
H-67	06.03.97. 10.03.97.	0.312	2.5	2.0	<0.01	80	23	0.12	0.052	8.0	27.0	10.85	<0.001	0	311	0.16	0.006	<0.02	5.9	5.1	0.8	7.7	1.8	2	0	0
H-74	05.03.97. 10.03.97.	0.366	3.0	2.0	<0.01	98	16	0.025	0.005	10.0	28.0	13.07	<0.001	0	323	0.12	0.012	<0.02	6.2	5.3	0.9	7.6	1.4	1	0	0
H-133	04.03.97. 05.03.97.																							5	0	0
H-133	05.03.97. 10.03.97.	0.336	2.5	4.5	0.10	80	28	0.25	0.019	8.3	45	1.90	0.01	0	305	0.58	0.009	<0.02	6.3	5.0	1.3	7.6	<1.0	3	0	0
PK-112	10.03.97. 11.03.97.	0.222	67	6.0	0.15	18	12	0.071	0.005	28.6	<1.0	<0.02	<0.001	0	232	0.66	<0.002	<0.02	1.9	3.8	-	8.25	<1.0	n.a.	n.a.	n.a.
PK-115	05.03.97. 10.03.97.	0.466	96	7.5	0.19	46	23	0.028	1.2	178	<1.0	<0.02	<0.001	0	165	0.71	<0.002	0.06	4.2	2.7	1.5	8.0	1.8	0	0	0
PK-131	10.03.97. 11.03.97.	0.196	65	6.5	0.15	18	16	0.062	<0.005	30.0	<1.0	<0.02	<0.001	0	232	0.64	<0.002	<0.02	2.2	3.8	-	8.2	<1.0	n.a.	n.a.	n.a.
PK-132	19.03.97. 21.03.97.	0.232	69	6.5	0.15	12	12	0.095	1.0	23.6	1.8	<0.02	0.003	0	220	0.68	0.02	<0.02	1.6	3.6	-	8.5	<1.0	n.a.	n.a.	n.a.
Drinking water quality classes	Excellent	1	-	-	0	-	-	0.1		100	100	1.0	0	-	-		-	0.05	5	-	-	6.5-8.5	1.0	-	0	0
	Good	1	-	-	0.5	-	-	0.3		250	250	10.0	0.01	-	-		-	0.1	7	-	-	6.0-9.0	2.0			
	Satisfying	1.5	-	-	1.0	-	-	1.0		350	500	45.0	0.1	-	-		-	0.2	10	-	-	6.0-9.0	4.0			

n.a. - the sample is not analysed

Drinking water quality classes are from EVS 663:1995 (Drinking Water)

Chemical analyses from Tapa and Moe watersupply wells

A: Jet fuel and BTEX

Drill well Drill hole	Depth, m	Water level absolute elevation, m	Date	Pumping time	Benzene	Toluene	Ethyl-benzene and Xylene	Jet fuel	Date of sampling and analysing	Notes
					µg/l					
H-28	87	92.06	07.03.97.	10.05-12.05	<0.1	<0.1	<0.1	<10	07.03.97. 10.03.97.	Russian pump: НЦ-70
H-67	30	n.m.	06.03.97.	14.40-19.40	<0.1	<0.1	<0.1	<10	06.03.97. 10.03.97.	Russian pump: НЦ-70
H-74	30	n.m.	06.03.97.	14.30-16.30	<0.1	<0.1	<0.1	<10	05.03.97. 10.03.97.	Russian pump: НЦ-70
H-133	30	89.17	04.03.97.	17.15-9.00	<0.1	<0.1	<0.1	<10	05.03.97. 10.03.97.	Grundfoss: SP 8A-5NE
PK-112	160	~27	09.1992.	-	<0.1	<0.1	<0.1	<10	10.03.97. 10.03.97.	Tapa water supply well
PK-115	318	n. m.	-	-	<0.1	<0.1	<0.1	<10	05.03.97. 10.03.97.	Tapa water supply well
PK-131	167	n. m.	-	-	<0.1	<0.1	<0.1	<10	10.03.97. 10.03.97.	Tapa water supply well
PK-132	166	~22.5	19.03.97.	11.00-13.10	<0.1	<0.1	<0.1	<10	19.03.97. 20.03.97.	Tapa water supply well, in reserve. Grundfoss pump: JS3-0.8
Concentration Limits in Water, µg/l	Reference Value				0.2	0.5	0.5	20*	Regulation of EV Covernment no. 179. 11.04.1995.	*) Oil products total
	Remediation Investigation Value				5	50	60	600*		*) Oil products total

n.m. - the value is not measured

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Registernr.:	433828
Kundenr.:	70910
Ordrenr.:	416653
Modt. dato.:	1997.03.12
Sidenr.:	1 af 2

ANALYSERAPPORT

Rekvirent.....: MAVES Ltd.
Marja 4D, EE0006 Tallinn, Estonia,
Prøvested.....:
Prøvetype.....: Grundvand
Prøveudtagning:
Prøvetager....: Marti Saln

Analyseperiode: 1997.03.12 - 1997.04.01

Udførte analyser	H-133 Resultat	H-67 Resultat	PK-115 Resultat	PK-3 Resultat	Enheder	Metoder
Polychlorerede biphenyler			<0.01		mg/l	GC/FID
Klorerede opløsningsmidler						GC/ECD
Kloroform	0.04	0.04	0.07	0.05	µg/l	GC/ECD
Tetraklormethan	<0.01	<0.01	0.03	<0.01	µg/l	GC/ECD
Triklorethylen	<0.01	0.01	0.01	0.01	µg/l	GC/ECD
Tetraklorethylen	0.01	<0.01	<0.01	<0.01	µg/l	GC/ECD
Triklorethan	<0.01	<0.01	<0.01	<0.01	µg/l	GC/ECD

Tegnforklaring:
< : mindre end. i.p. : ikke påvist.
> : større end. i.m. : ikke målelig.

den 02. April 1997

Birgit Pedersen

Enclosure 2
Aquifer Test

Aquifer Test

Description of Wells

The wells H-67 and H-74 are screened in the Ordovician groundwater complex from 5 to 30 meters b.g. (O3nbS Upper Ordovician limestone). Well H-28 is screened over a significantly larger interval than the wells H-67 and H-74. The interval of H-28 spread from 6 to 87 meters b.g., and does consequently also include lower groundwater deposits in the Ordovician groundwater complex.

In connection with establishment of well H-133 a gamma log, a caliber log and a flowmeter log were carried out. The results of these logs appear from Enclosure 2. It appears that the main inflow of water takes place in the interval 7 to 22 m b.g. In this interval the flow log showed an inflow in the region of 16 m^3/h. The aquifer clearly appears in the gamma log, in which a significant change in the signal is observed 7 respectively 22 meters b.g. The reservoir rock type is an O3nbS limestone formation from Upper Ordovician. The same limestone formation constitutes the uppermost aquifer at Moe I wellfield.

On 12 March, 1997 the water table in the wells has been sounded. In the wells H-28 and H-67 the water table lies at approx. 0.5 m below the water table of the river. In well H-72 an overflow has been observed. It is assessed that the wells H-28 and H-67 are semi-artesian and well H-72 is artesian.

The water table in well H-133 (Moe II) and in the nearby river have also been sounded on 12 March, 1997. The water table 1.04 meters below the water table in the river, and the well is assessed to be semi-artesian.

Test Pumping Moe I

A test pumping has been performed in well H-67. The well has been reported to have a capacity of approx. 90 m^3/h. The pump equipment used could with the given screen dimension and the given pressure conditions pump maximum 60 m^3/h. With this performance a momentary drawdown of approx. 15 cm was observed. This drawdown is due to well storage. The registered drawdown curve appears from the figure in this enclosure.

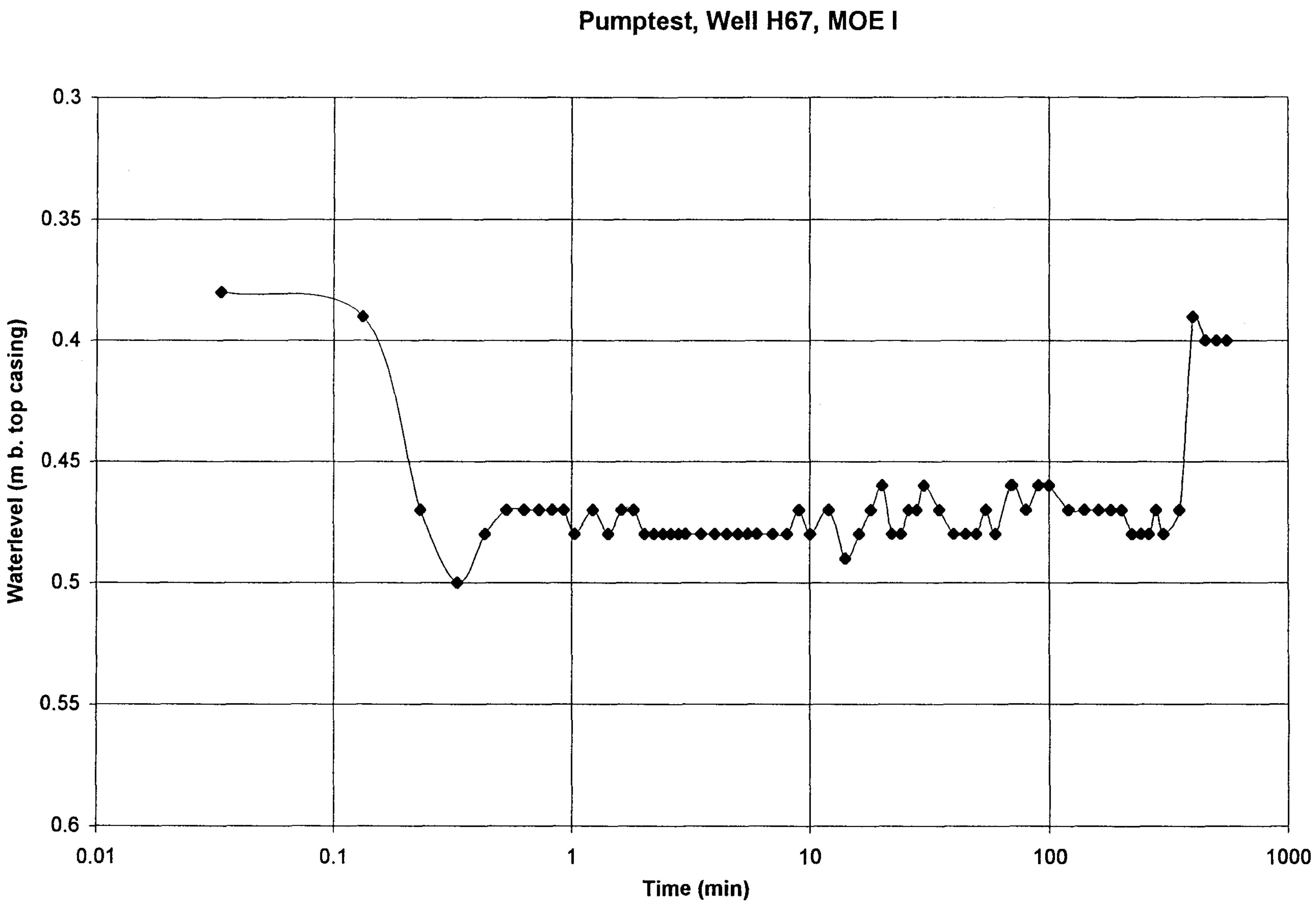
Well H-28 was established as an investigation well with a small screen dimension. In this way it was only possible to use a smaller submerged pump able to yield approx.10 m^3/h. With this yield a momentary drawdown of approx. 4 cm was observed. This drawdown is also due to well storage.

In well H-74 no real test pumping could not be performed due to overflow in the well during the test period. In spite of a pumping of 60 m^3/h from the well an overflow was still observed.

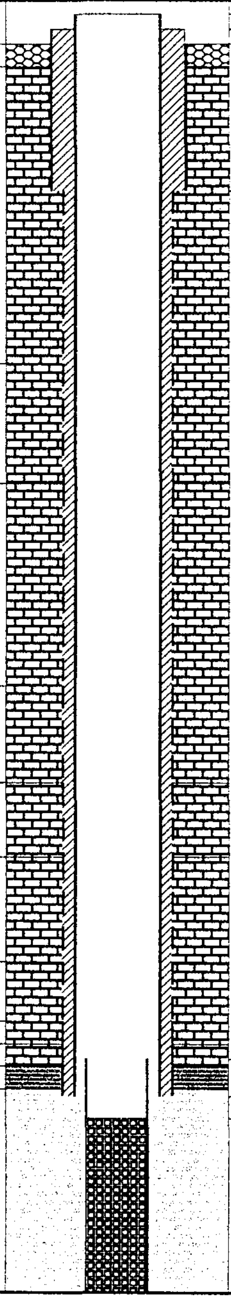
The tests indicate that the wells H-28, H-67 and H74 have a very high capacity, and the maximum capacities of the wells are assessed to be at a level corresponding to those previously assessed in /6/. All the wells are situated immediately by the river, and consequently they can not be regarded respresentative for the whole Moe I well field. When comparing the previously performed tests /6/ with the tests performed in this study, it is assumed that the water yield registered in connection with previous test pumpings /6/ are still valid. This, however, is not fully confirmed by the performed tests due to physical conditions around the well installations and the pump equipment.

Test Pumping Moe II

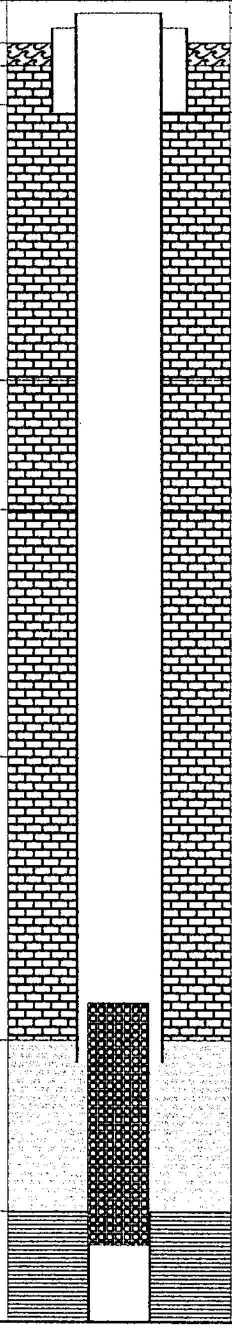
A preliminary 1-day test pumping has been performed in well H-133. The well has been established as a small diameter well, primarily made for water sampling. The used pump equipment could with the given screen dimension and the given pressure condition pump with a capacity of maximum 12 m3/h and a drawdown of approx. 8 cm. This drawdown is due to well storage. The well is located in the same aquifer as in Moe I well field. The maximum capacity of well H-133 is, consequently, assessed to be significantly higher, around 20-30m^3/h, than the 12 m^3/h that were measured during the performed test. Further description of the groundwater conditions in the Moe II well field requires establishment of large diameter pump wells and long-range pump tests.

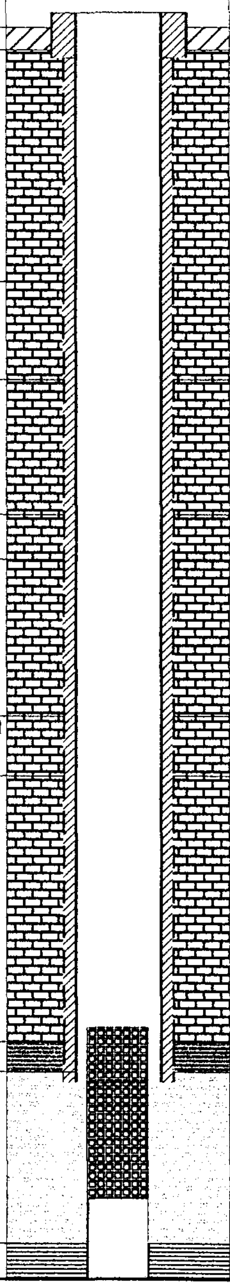

Pumptest, Well H67, MOE I
Waterlevel (m b. top casing)
0.3
0.35
0.4
0.45
0.5
0.55
0.6
0.01
0.1
1
10
100
1000
Time (min)

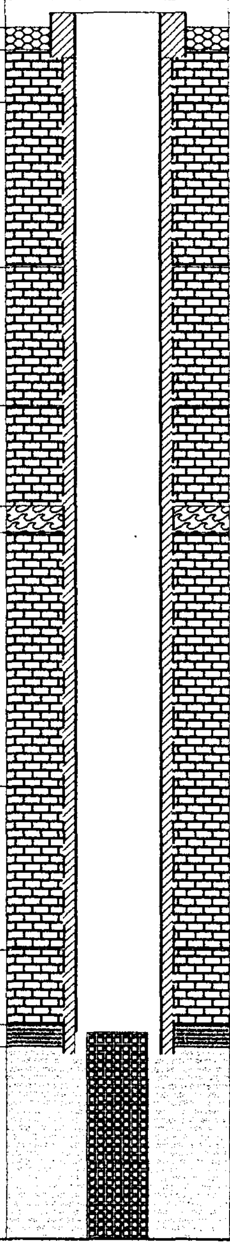
Enclosure 3
Well Construction
and Well Logging

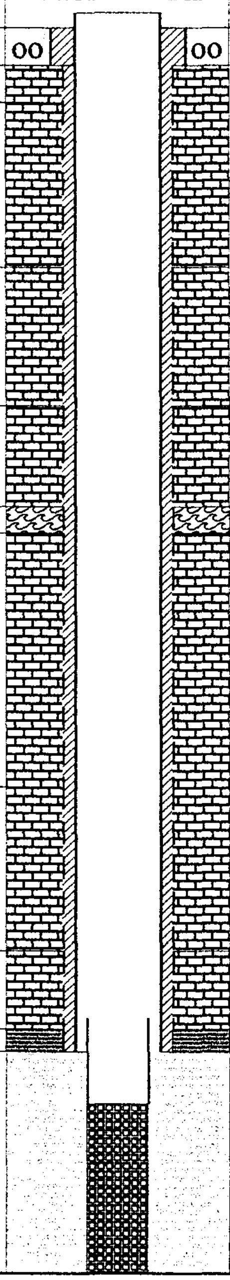
Construction of drill well PK-112				TAPA	59°16' north latitude 25°57' east longitude		
Geol. index	Bottom depth, m	Layer thick-ness m	Description of soils	Abs. Elevation 98.00 m	Interval length m	Casing tube Ø mm	Water level m 01.85
	0.00				0.20 0.30		
Q_{III}^{gl}	0.40	0.40	Limestone rubble		17.00	14" and 10"	
O_3 vr- O_3 nb	40.00	36.60	Limestone containing pyrite				40.20
O_2 rk	56.00	16.0	Limestone, crystalline				
O_2on- O_2 id	83.00	27.00	Limestone with intermediate marl layers		114.00	10"	
O_2 kk	96.00	13.00	Bituminous limestone with intermediate kukersite layers				
O_2 tl	106.00	10.00	Marly limestone				
O_2 tl- O_2 as	120.00	14.00	Hard limestone with iron grains in lower section				
O_1kn	128.00	8.00	Limestone with interm. marl layers				
O_1vl	130.00	2.00	Glauconite limestone				
O_1lt	132.00	2.00	Glauconite limestone and clay				
O_1pk	134.00	2.00	Dictyonema shale		4.50	10",8"	
O_1pk- $Є_1$pr	160.00	26.00	Fine - grained sandstone Aquifer		1.90	8"	
					23.60	8" filter	

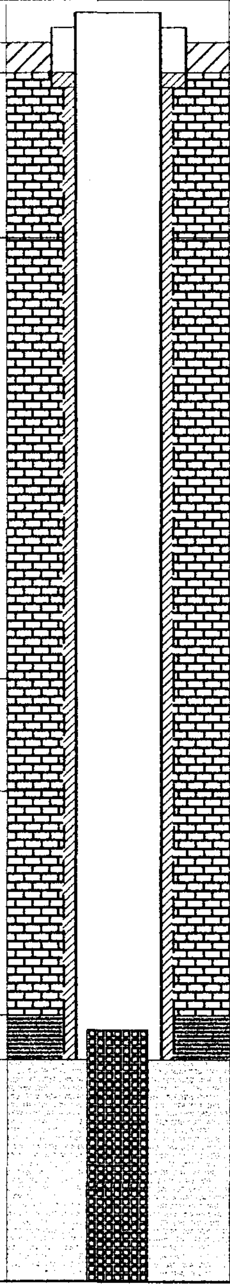
Construction of drill well PK-127 — TAPA

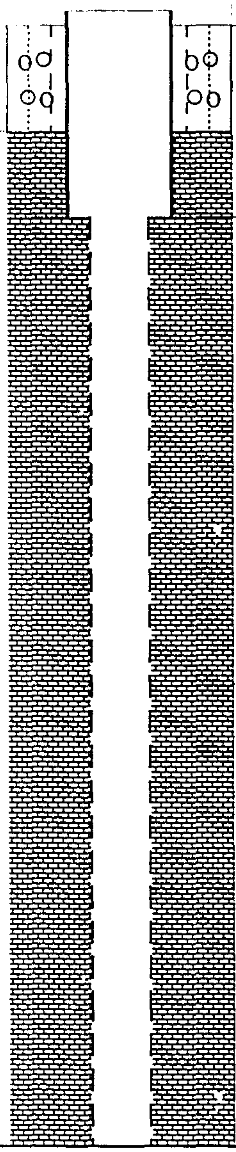
Geol. index	Bottom depth, m	Layer thick-ness m	Description of soils	Abs. Elevation 91.50 m	Interval length m	Casing tube Ø mm	Water level m 05.81
					0.20 0.30		
Q_{III}	0.50	0.50	Soil		6.3	16"	
O_3	5.70	5.20	Karst limestone				
O_3	42.00	36.30	Hard limestone		113.70	10"	45.50
O_3	59.00	17.00	Limestone, crystalline				
O_2	92.00	33.00	Hard, marly limestone				
O_{2-1}	130.00	38.00	Dolomite limestone		5.00	10",6"	
					8.00	10", 6"fil.	
O_1pk	153.00	23.00	Limestone with intermediate clay layers		24.50	6" filter	
$Є_1ln$	168.00	15.00	Blue clay		10.5	6"	

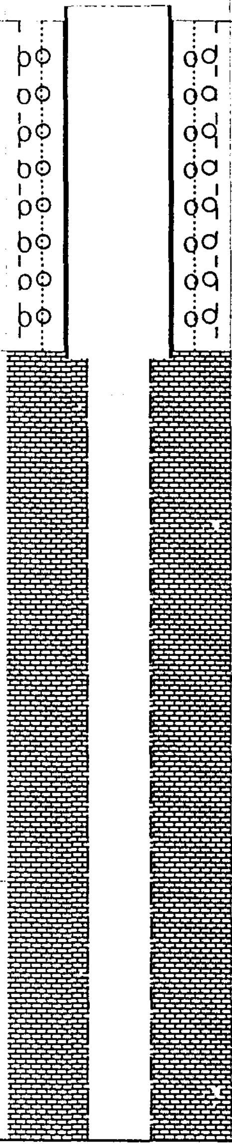
Construction of drill well PK-128				TAPA	59°16' north latitude 25°59' east longitude		
Geol. index	Bottom depth, m	Layer thick-ness m	Description of soils	Abs. Elevation 100.00 m	Interval length m	Casing tube Ø mm	Water level m 02.81
	0.00				0.20		
Q_{III}^{gl}	1.50	1.50	Sandy loam with limestone shingles		2.10	14"	
O_3vr-O_3nb	32.00	30.50	Limestone with intermediate marly limestone layers in upper part				
O_3nb	45.00	13.00	Marly limestone				
O_3rk	63.00	18.00	Limestone				57.80
	69.00	6.00	Marly limestone		129.55	10"	
O_2on	90.00	21.00	Limestone and marly limestone				
O_2kl-O_2id	98.00	8.00	Limestone and marly limestone with intermediate oil shale layers				
O_2kk	133.00	35.00	Limestone				
O_1lt-O_1pk	137.00	4.00	Glauconite clay and dictyonema shale		6.75	10",6"	
O_1pk-Є$_1$pr	160.00	23.00	Sandstone with intermediate clay layers in lower part		15.60	6" filter	
Є$_1$ln	165.00	5.00	Clay		11.00	6"	

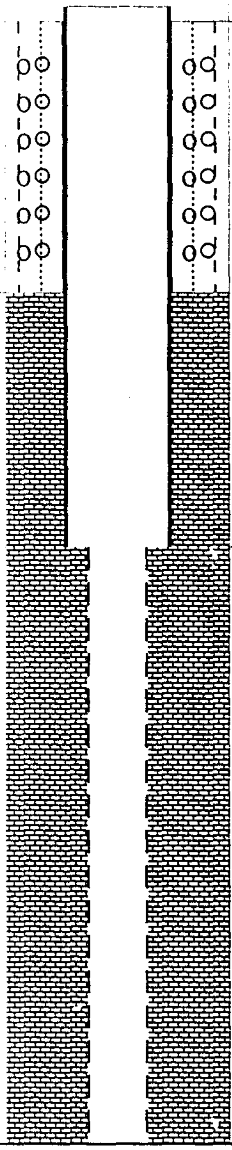
Construction of drill well PK-130				TAPA	57°16' north latitude 25°57' east longitude		
Geol. index	Bottom depth, m	Layer thick-ness m	Description of soils	Abs. Elevation 99.00 m	Interval length m	Casing tube Ø mm	Water level m 03.85
	0.00				0.50	324,219	
Q_{III}^{al}	2.00	2.00	Limestone shingles		2.50		
O_3vr	10.00	8.00	Marly limestone				
O_3nb	32.00	22.00	Limestone				
O_3nb	50.50	18.50	Limestone and marly limestone				
O_3rk	64.00	13.50	Limestone				59.60
O_2on	67.50	3.50	Marl		132.50	219	
O_2kl- O_2kk	101.5	34.00	Limestone with intermediate layers of marly limestone and, in the lower part, kukersite				
O_2tl- O_2as	123.50	22.00	Limestone with intermediate layers of marly limestone				
O_1kn- O_1vl	134.00	10.50	Marly limestone and glauconite limestone				
O_1lt-O_1pk	137.00	3.00	Glauconite clay and dictyonema shale		3.00	219,168	
O_1pk- $Є_1$pr	163.00	26.00	Sandstone with intermediate layersof aleurolite and, in the lower part, clay		25.00	168 filter	

Construction of drill well PK-131				TAPA	57°16' north latitude 25°57' east longitude		
Geol. index	Bottom depth, m	Layer thick-ness m	Description of soils	Abs. Elevation 99.00 m	Interval length m	Casing tube Ø mm	Water level m 01.85
	0.00				0.50		
Q_{III}^{gl}	5.00	5.00	Clayey gravel with pebbles		5.00	324,219	
O_3vr	10.00	5.00	Marly limestone				
O_3 nb	32.00	22.00	Limestone				
O_3 nb	50.50	18.50	Limestone and marly limestone				
O_3 rk	64.00	13.50	Limestone				59.80
O_2on	67.50	3.50	Marl		128.60	219	
O_2kl-O_2kk	101.50	34.00	Limestone with intermediate layers of marly limestone and, in the lower part, kukersite				
O_2tl-O_2as	123.50	22.00	Limestone with intermediate layers of marly limestone				
O_1kn-O_1vl	134.00	10.50	Marly limestone and glauconite limestone				
O_1lt-O_1pk	137.00	3.00	Glauconite clay and dictyonema shale		3.40	219,168	
O_1pk-$Є_1pr$	167.00	30.00	Sandstone with intermediate layers of aleurolite and, in the lower part, clay		7.00	168	
					23.00	168 filter	

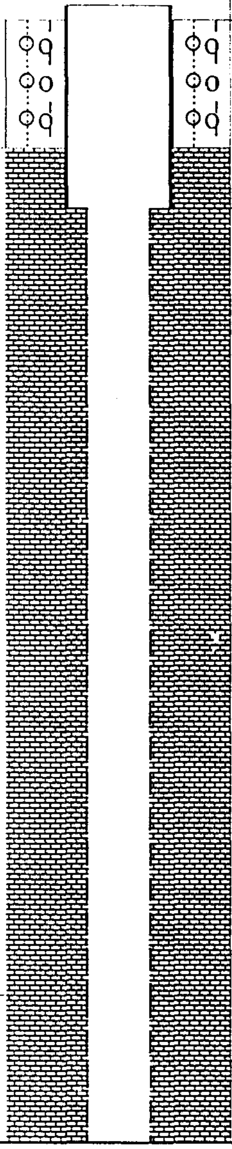
Construction of drill well PK-132				TAPA			
Geol. index	Bottom depth, m	Layer thick-ness m	Description of soils	Abs. Elevation 98.00 m	Interval length m	Casing tube Ø mm	Water level m 03.92
	0.00				0.05 0.25	273	
Q_{III}^{gl}	4.00	4.00	Sandy loam		6.00		
O_3uk	26.00	22.00	Karst limestone				
O_3nb-O_2kl	85.00	59.00	Limestone and marly limestone		126.00	168	68.00
O_2kk	100.00	15.00	Marly limestone				
O_2tl-O_1kn	130.00	30.00	Limestone				
O_1vr	136.00	6.00	Glauconite clay and dictyonema shale		4.00	168,127	
O_1pk-$Є_1lk$	166.00	30.00	Sandstone with intermediate clay lower part		30.00	127 filter	

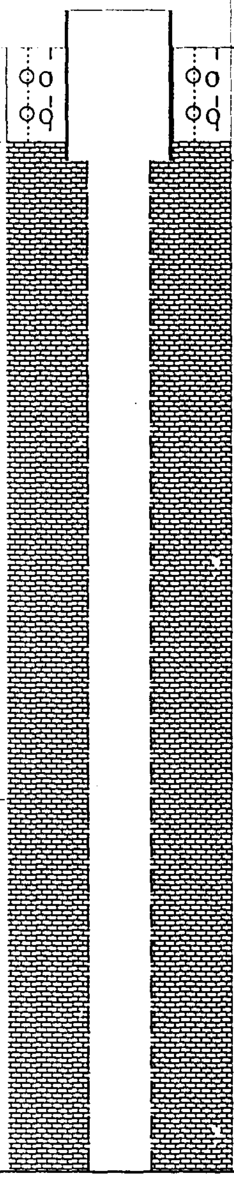
Construction of drill hole H-67				MOE	north latitude east longitude		
Geol. index	Bottom depth, m	Layer thick-ness m	Description of soils	Abs. Elevation 91.97 m	Interval length m	Casing tube Ø mm	Water level m
	0.00				0.18		
$Q_{III}gl$	2.80	2.80	Sandy loam moraine		5.10	219	▼ 1.42 03.79
O_3nbS	26.0	23.2	Limestone		24.90	132	
O_3nbP	30.0	4.0	Clayey limestone				

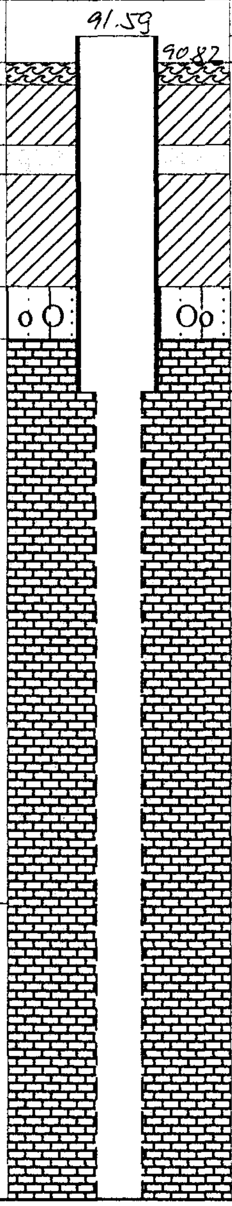
Construction of drill hole H-70-I				MOE	north latitude east longitude		
Geol. index	Bottom depth, m	Layer thick-ness m	Description of soils	Abs. Elevation 91.22 m	Interval length m	Casing tube Ø mm	Water level m
	0.00				0.50		
$Q_{III}gl$	8.80	8.80	Clay loam moraine		9.00	219	▼1.15 09.77
O_3nbS	23.00	14.20	Limestone		21.00	132	
O_3nbP	30.00	7.00	Clayey limestone				

Construction of drill hole H-71-IX				MOE	north latitude east longitude		
Geol. index	Bottom depth, m	Layer thick-ness m	Description of soils	Abs. Elevation 98.01 m	Interval length m	Casing tube Ø mm	Water level m
	0.00				0.20		
$Q_{III}gl$	7.20	7.20	Clay loam moraine		14.00	12"	▼7.65 07.77
O_3vr	14.00	6.80	Limestone				
O_3nbS	30.00	16.00	Limestone		21.00	$11^{3/4}$"	

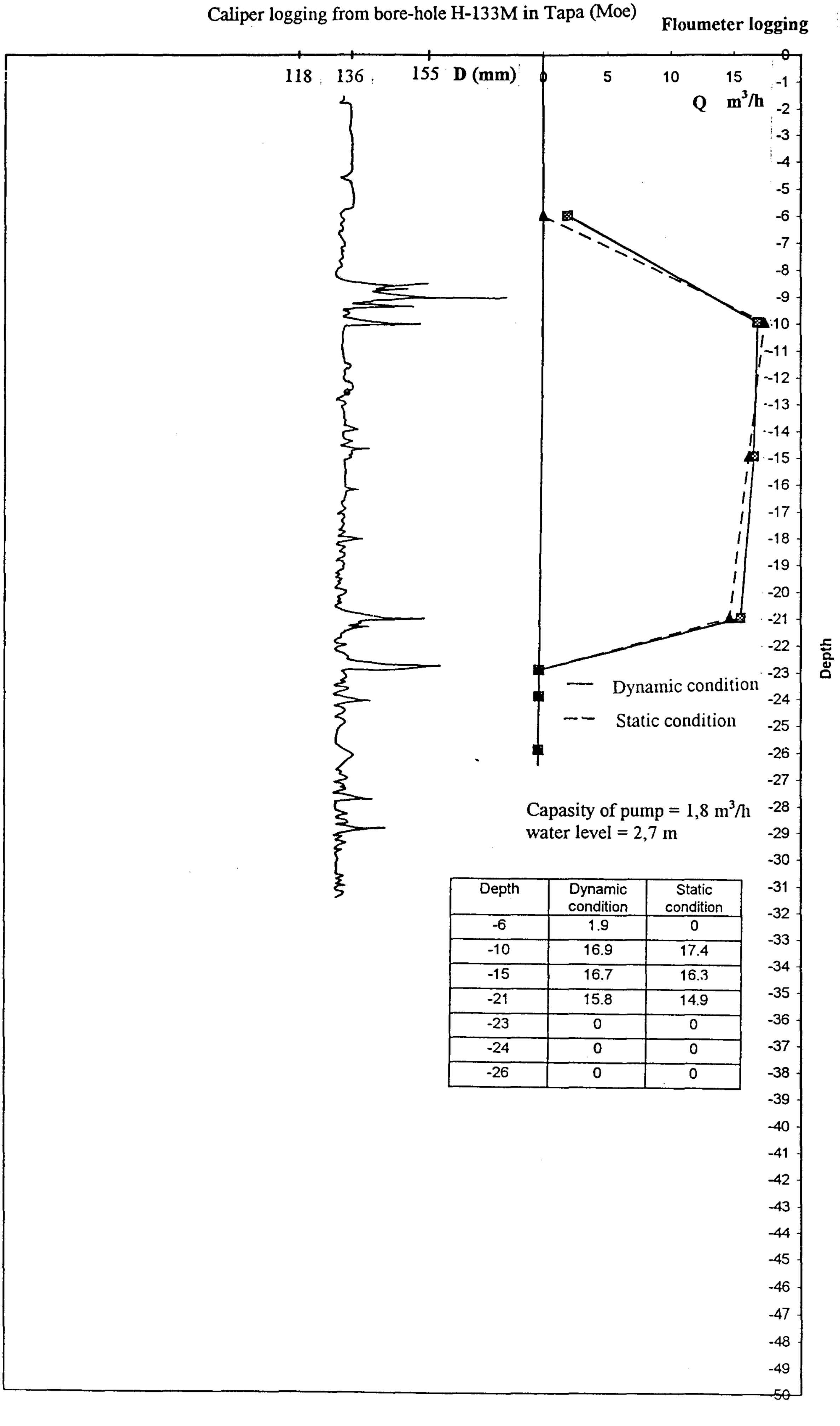
Construction of drill hole H-74				MOE	north latitude east longitude		
Geol. index	Bottom depth, m	Layer thick-ness m	Description of soils	Abs. Elevation 91.31 m	Interval length m	Casing tube Ø mm	Water level m
	0.00				0.20		
Q_3gl	3.40	3.40	Clay loam moraine		5.00	219	0.88 / 03.79
O_3nbS	26.00	22.40	Limestone		25.00	132	
O_3nbP	30.00	4.00	Clayey limestone				



Construction of drill hole H-87				MOE	north latitude east longitude		
Geol. index	Bottom depth, m	Layer thick-ness m	Description of soils	Abs. Elevation 101.59 m	Interval length m	Casing tube Ø mm	Water level m
	0.00				0.50		
Q_3gl	2.50	2.50	Clay loam moraine		3.00	168	
O_3pgM	14.30	11.80	Limestone				9.39 03.79
O_3vr	20.00	5.70	Clayey limestone		27.00	146	
O_3nbS	30.00	10.00	Limestone				

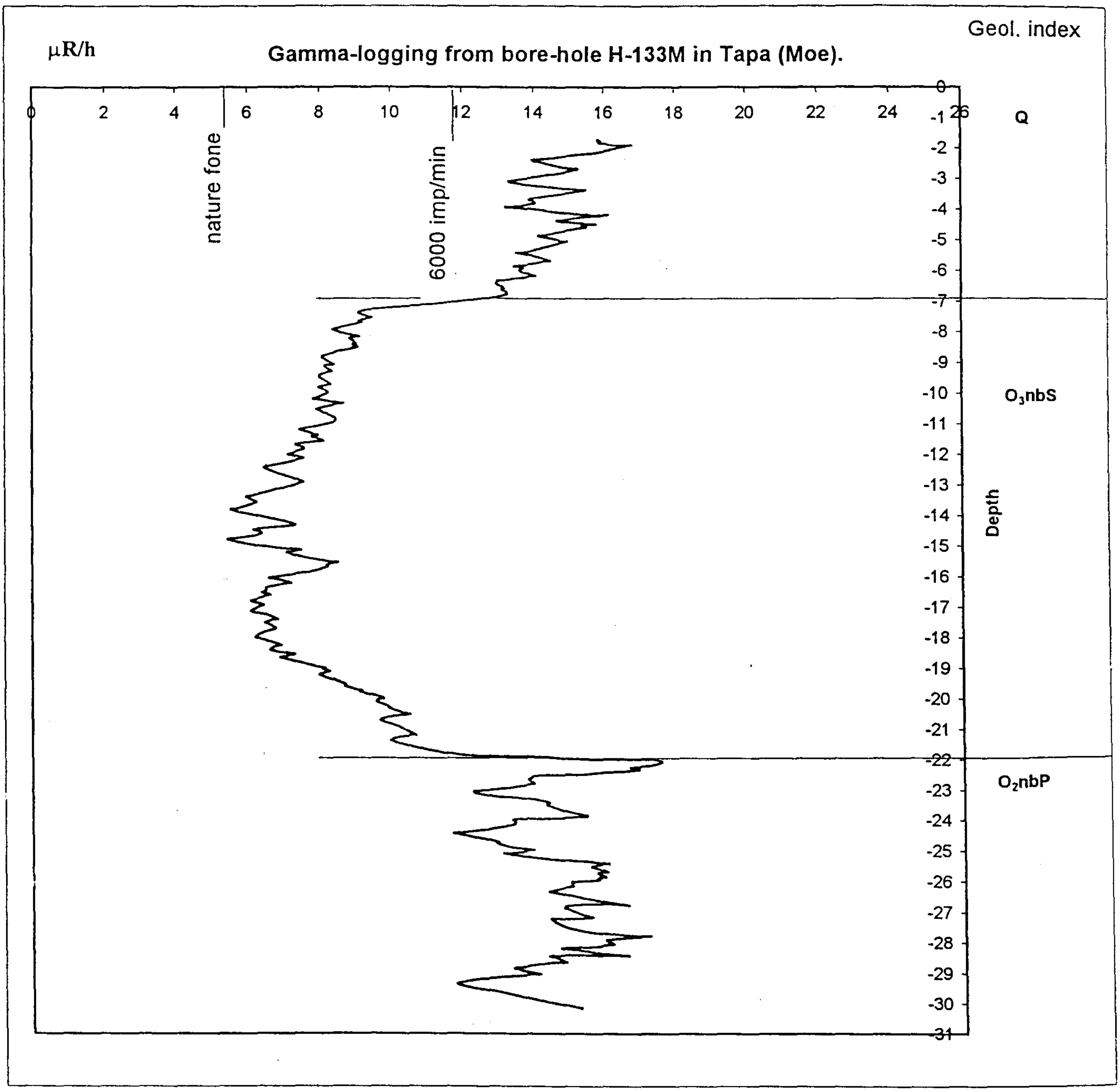
Construction of drill well H-133M				MOE	north latitude east longitude		
Geol. index	Bottom depth, m	Layer thick-ness m	Description of soils	Abs. Elevation 90.82 m	Interval length m	Casing tube Ø mm	Water level m 02.97
					0.70		
Q_{IV}	0.40	0.40	Soil				
$Q_{III}lgl$	2.00	1.60	Sandy loam				1.98
$Q_{III}fgl$	2.60	0.60	Sand with gravel				
$Q_{III}lgl$	5.60	3.00	Sandy loam with intermediate layers of gravelsand		8.30	146	
$Q_{III}gl$	6.90	1.50	Sandy loam moraine				~~7.60~~
O_3nbS	22.00	15.10	Limestone			132	
O_3nbP	30.00	8.00	Clayey limestone with intermediate layers of marl				

Caliper logging from bore-hole H-133M in Tapa (Moe)



Capasity of pump = 1,8 m³/h
water level = 2,7 m

Depth	Dynamic condition	Static condition
-6	1.9	0
-10	16.9	17.4
-15	16.7	16.3
-21	15.8	14.9
-23	0	0
-24	0	0
-26	0	0


Geol. index
μR/h
Gamma-logging from bore-hole H-133M in Tapa (Moe).
0
2
4
6
8
10
12
14
16
18
20
22
24
26
nature fone
6000 imp/min
Q
O3nbS
Depth
O2nbP
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
-11
-12
-13
-14
-15
-16
-17
-18
-19
-20
-21
-22
-23
-24
-25
-26
-27
-28
-29
-30
-31

Enclosure 4
Groundwater Modelling

Groundwater Modelling

Model Setup

The groundwater model is set up using ModFlow software - a fully distributed (3D) groundwater model for estimation of both stationary and transient saturated flow in porous media. The model is developed by United States Geological Survey (USGS) and is distributed by Geraghty & Miller Inc. Modelling Group, Virginia, USA.The ModFlow includes a data interface package, ModelCad, for definition of model area, boundaries, model parameters etc. Further,. the model system includes a number of utility programmes for statistical analysis, water budget calculations and sensitivity analysis.

Model area delineation

The flows and hydraulic heads within the defined model area are calculated in the nodes located in a squared grid. In this model setup the calculation grid has a resolution of 200 m.

The boundaries of the model area have been delineated in order to limit the groundwater flow through the model region. Therefore, the northeastern and southwestern edges of the model area are defined as no-flow boundaries (no groundwater flux). Groundwater enters the model area at southeastern and exits at northern edge, which are defined as general-head boundaries (head-dependent flux).

Compared with the previous modelling study of the "Tapa Airbase Groundwater Contamination Project" /5/ the modelling area has been expanded westwards up to Soodla River and eastwards to cover the eastern side of Valgejõgi River, in order to decrease the influence of the marginal regions, where the initial data is sparse and assumptional parameters have to be used. The size of the modelled area is 384 km2 with the applied grid size 80x120 cells.

Topography, geology and hydrology

The topography and surface geology in the model area are described in Paragraph 2.1. In this modelling approach, only the upmost 30 m thick fractured and karst-submitted layer of limestone formations (O3 vrS- bnS) are considered, since the deeper layers are of minor importance to the dynamics of the upmost groundwater aquifer, due to very little water exchange between them. The topsoil layer is excluded from the model because of the small thickness and consequently small water amount in this layer

In the model area a groundwater divide is located at the airbase from where the flow direction is northwest (towards Soodla River valley) and north/northeast (towards Valgejõgi River valley). The groundwater contributes to both Soodla and Valgejõgi Rivers by diffuse subsurface base flow. In the central part of the model area Rauakõrve Brook is located, which is draining the groundwater in periods of a high groundwater level and is included in the model as the drain boundary type, active only when the groundwater levels exceed the elevation of the brook.

The recovery tests, carried out during the "Tapa Airbase Groundwater Contamination Project" /2,5/, show much higher horizontal conductivities in the upmost fractured zone of the limestone (up to 300 m/d) than in any other geological formation in the area. Below the upmost fractured layer the limestone is more compact and impervious with hydraulic conductivity less than 2 m/d.

The mean annual precipitation rate for the model area is estimated as 712 mm, which is divided in the following way according to /5/:

· 2% surface runoff
· 60% evapotranspiration
· 38% infiltration, from that:
· 21% discharge via the springs
· 17% deep infiltration.

The amount of deep infiltration was used as the value of groundwater recharge.

The HBV surface water model established in phase III of the "Tapa Airbase Groundwater Contamination Project" /5/ has been used in the initial calibration of the groundwater model.

Model calibration

The calibration of the model has been carried out assuming both stationary and transient flow conditions. The stationary model was calibrated to obtain the groundwater flow pattern, matching the observed heads data. The transient model calibration was used for the simulation of seasonal (monthly) changes of groundwater heads and drawdown pattern.

The model has been calibrated on the observed pressure heads in the monitoring wells and water stage elevations at two river gauging stations, established during the phase III of the "Tapa Airbase Groundwater Contamination Project"/5/.

The observation data has been used for the model calibration in two different ways:

- The values of the observed pressure heads in the monitoring wells were inserted into the model directly using the option Calibration Targets of ModelCad. This option was used for the calibration of a steady-state model setup.

- Data from the river gauging stations were processed with the HBV model to obtain the rate of infiltration into the groundwater (total recharge) and the distribution of the recharge over the monitoring year. The results were evaluated with CalcStats option of ModUtilities package. This procedure was used for setting up the transient model.

Hydraulic conductivity values were derived from the results of test pumpings carried out during the investigation of the Moe I well field /6/ and the results of recovery tests carried out in "Tapa Airbase Groundwater Contamination Project" /2,5/. Hydraulic conductivity is assumed to be higher than the overall value in following areas:

- Large fracture zones in the southwest-northeastern direction. These zones are associated with large regional tectonic zones and their presence is confirmed with the results of a geophysical survey /5/.

- The Valgejõgi River valley between Moe and Tapa. In this area large amounts of groundwater contribute to the river.

- The Airfield area in the surroundings of the remediation fields. Here hig-her hydraulic conductivities are proved by the results of recovery tests, carried out in the "Tapa Airbase Groundwater Contamination Project" /2,5/.

Both steady-state and transient simulations have been carried out during this modelling session. Since the initial data were characterizing mainly the central part of the model domain (Tapa town and Moe I wellfield), the main attention was paid to achieving of a closest possible match of water table elevations in this region.

The resulting pattern of water table elevations shows that both rivers - Valgejõgi and Soodla - on the borders of the model area are draining the groundwater. Water table elevations are descending towards the rivers. Rauakõrve Brook is "active" only during the period of a high groundwater level - that is also corresponding to the real situation. The overall slope of groundwater heads is towards north, northwest and northeast. The simulated flow pattern around the contaminated area is towards north and northeast.

The changes of watertable elevations during the transient simulation were achieved by prescribing monthly variable recharge rates to the model based on the results of HBV modelling.

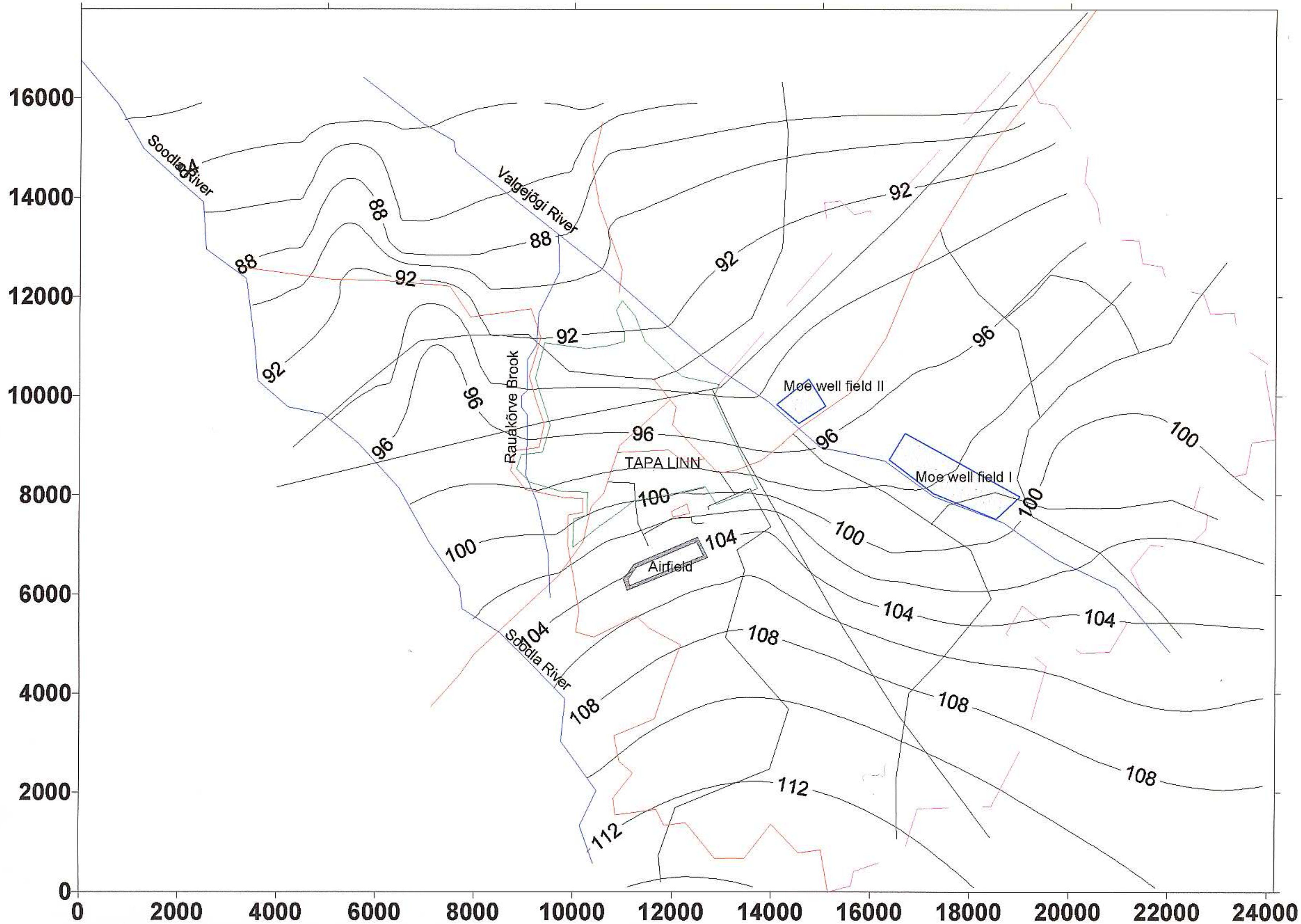


Figure 1 Transient simulation: watertable elevation of Tapa-Moe region
Moe well field I working at 13 400 m3/d abstraction rate, remediation fields activated
Stress period 7 - July
Axis scale in meters, watertable drawdown in meters

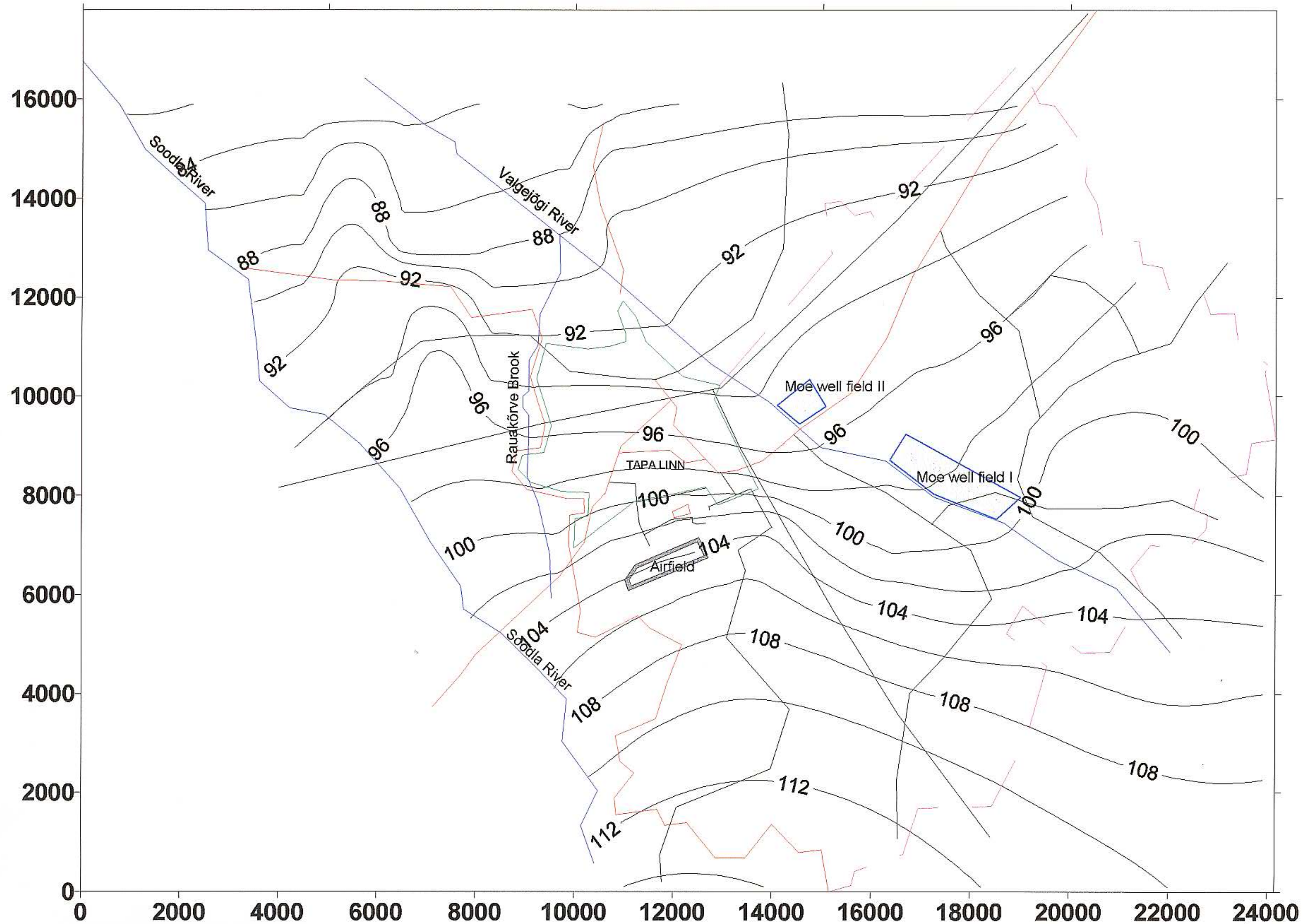


Figure 2 Transient simulation: watertable elevations of Tapa-Moe region
Moe well field I working at 13 400 m3/d abstraction rate, remediation fields activated
Stress period 12 - December
Axis scale in meters, watertable elevation in meters

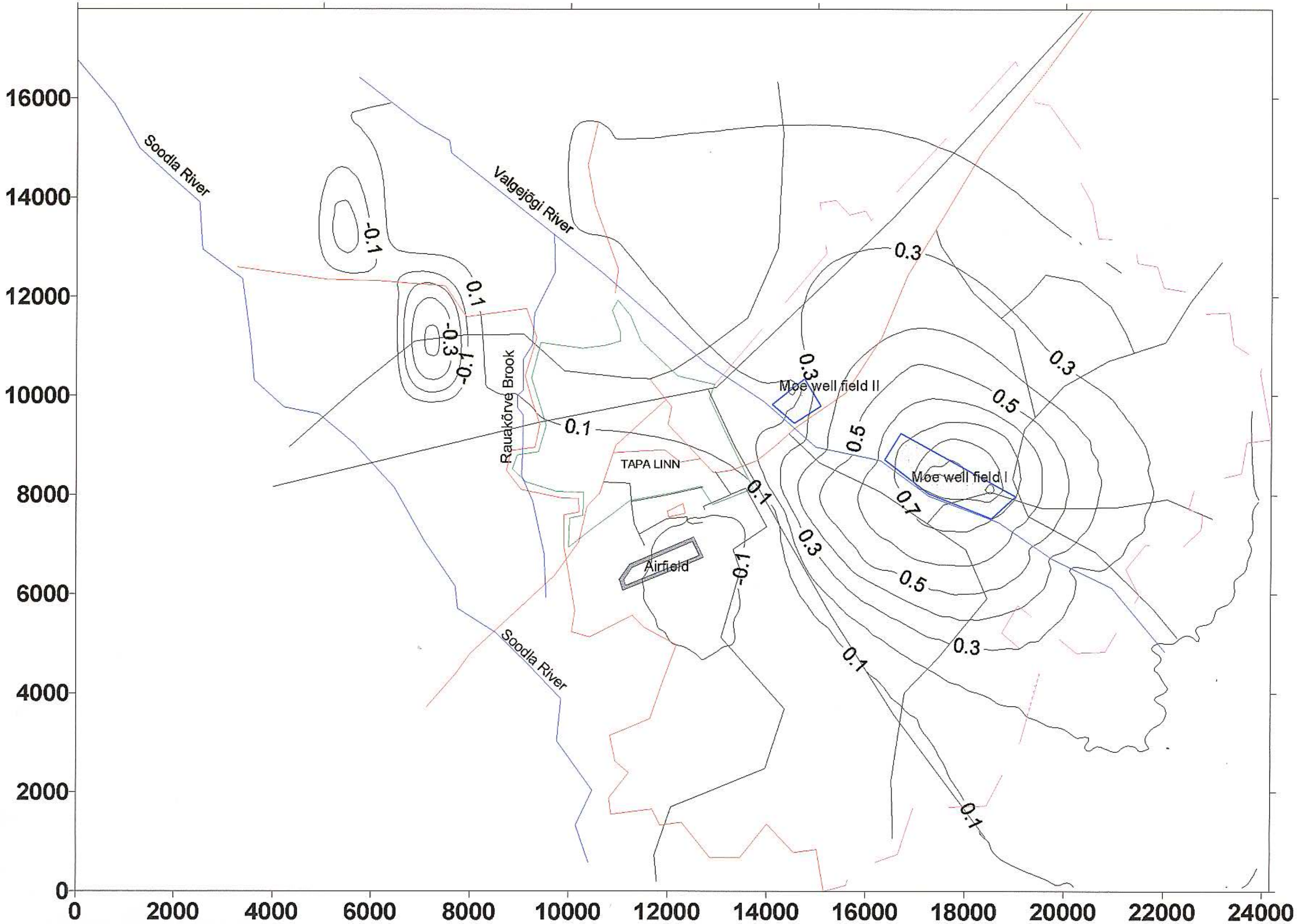


Figure 3 Transient simulation: watertable drawdown at Tapa-Moe region
Moe well field I working at 13 400 m3/d abstraction rate, remediation fields activated
Stress period 7 - July
Axis scale in meters, watertable drawdown in meters

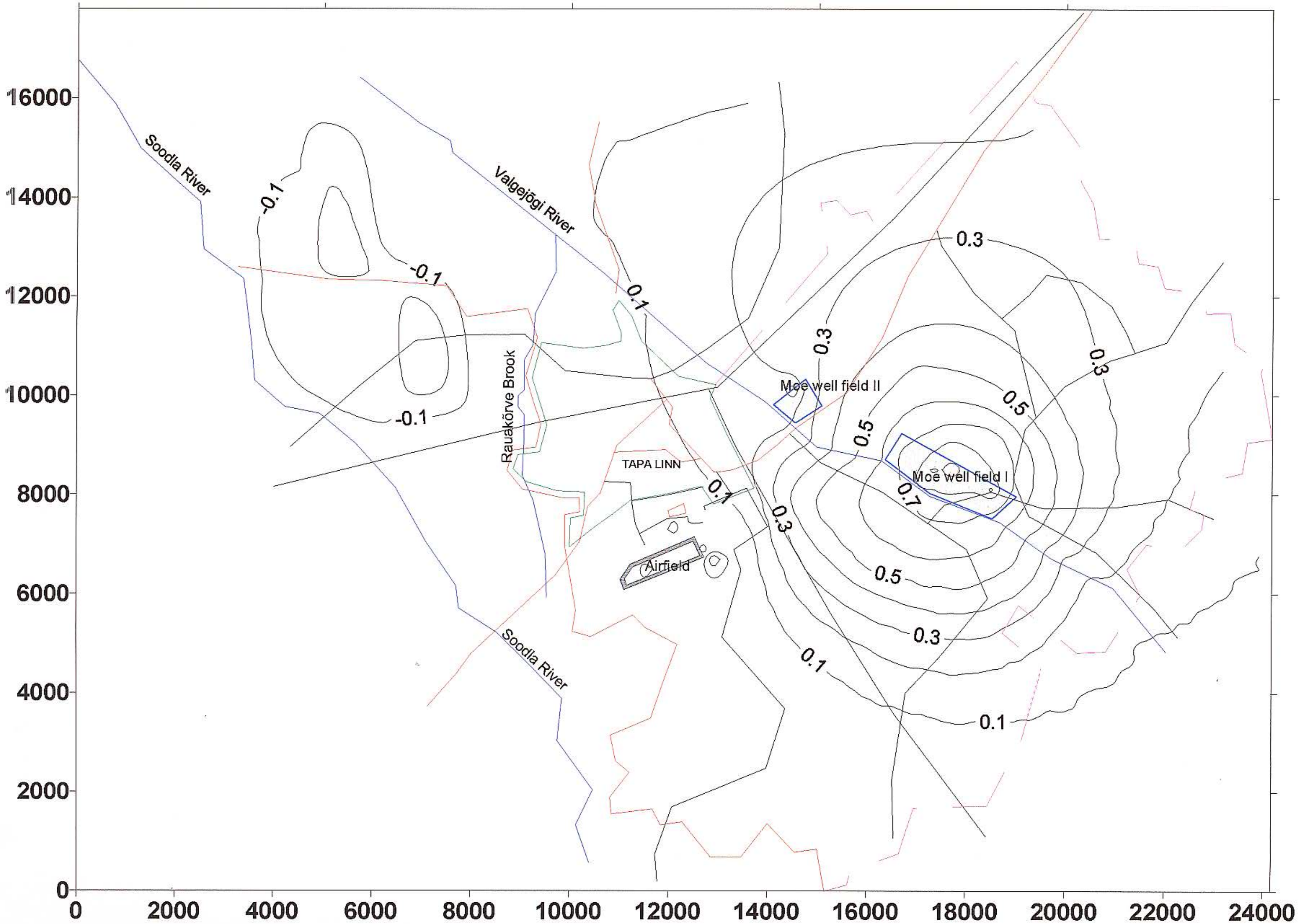


Figure 4 Transient simulation: watertable drawdown at Tapa-Moe region
Moe well field I working at 13 400 m3/d abstraction rate, remediation fields activated
Stress period 12 - December
Axis scale in meters, watertable drawdown in meters

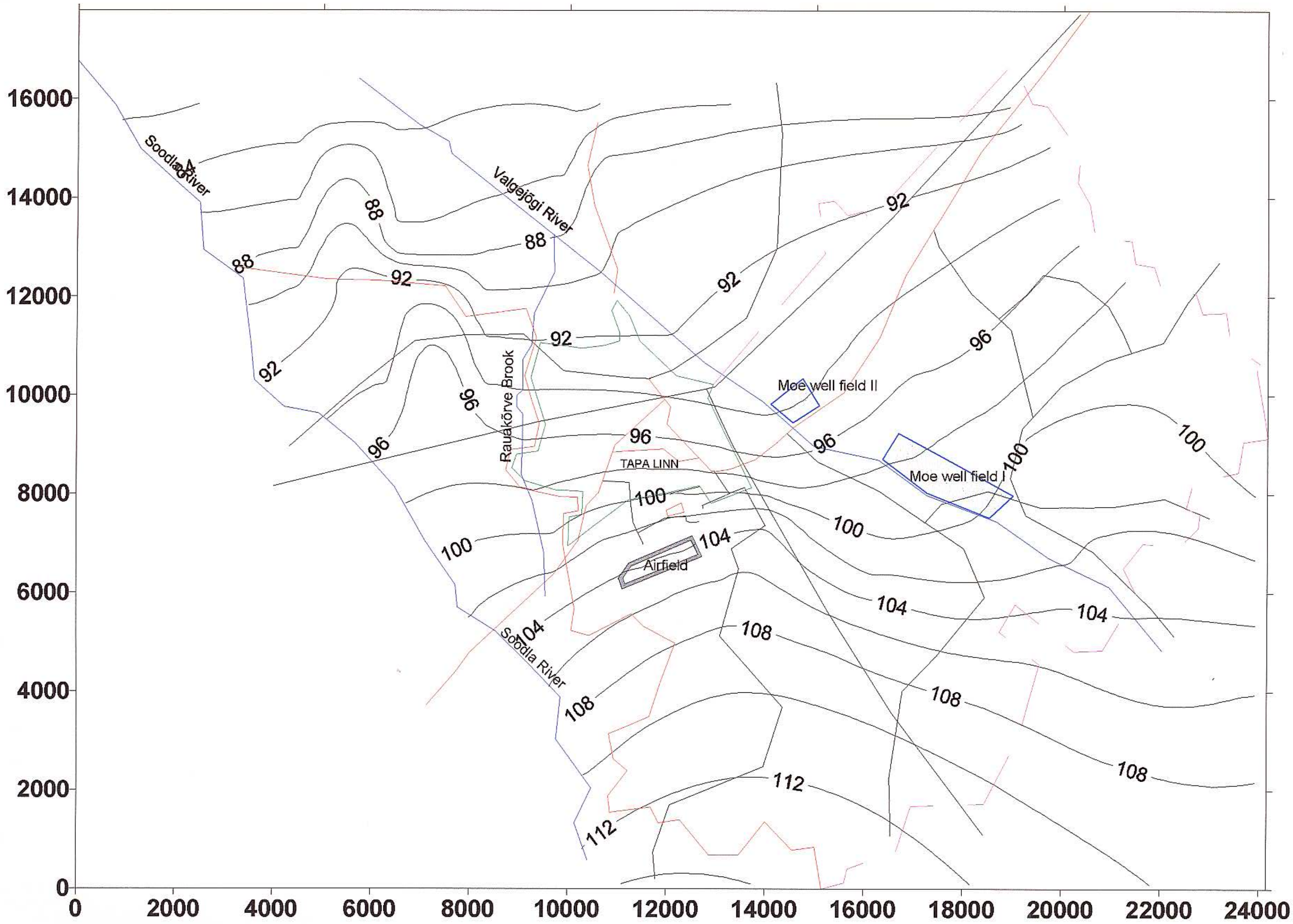


Figure 5 Transient simulation: watertable elevations of Tapa-Moe region
Moe well field II working at 13 400 m3/d abstraction rate, remediation fields activated
Stress period 7 - July
Axis scale in meters, watertable elevation in meters

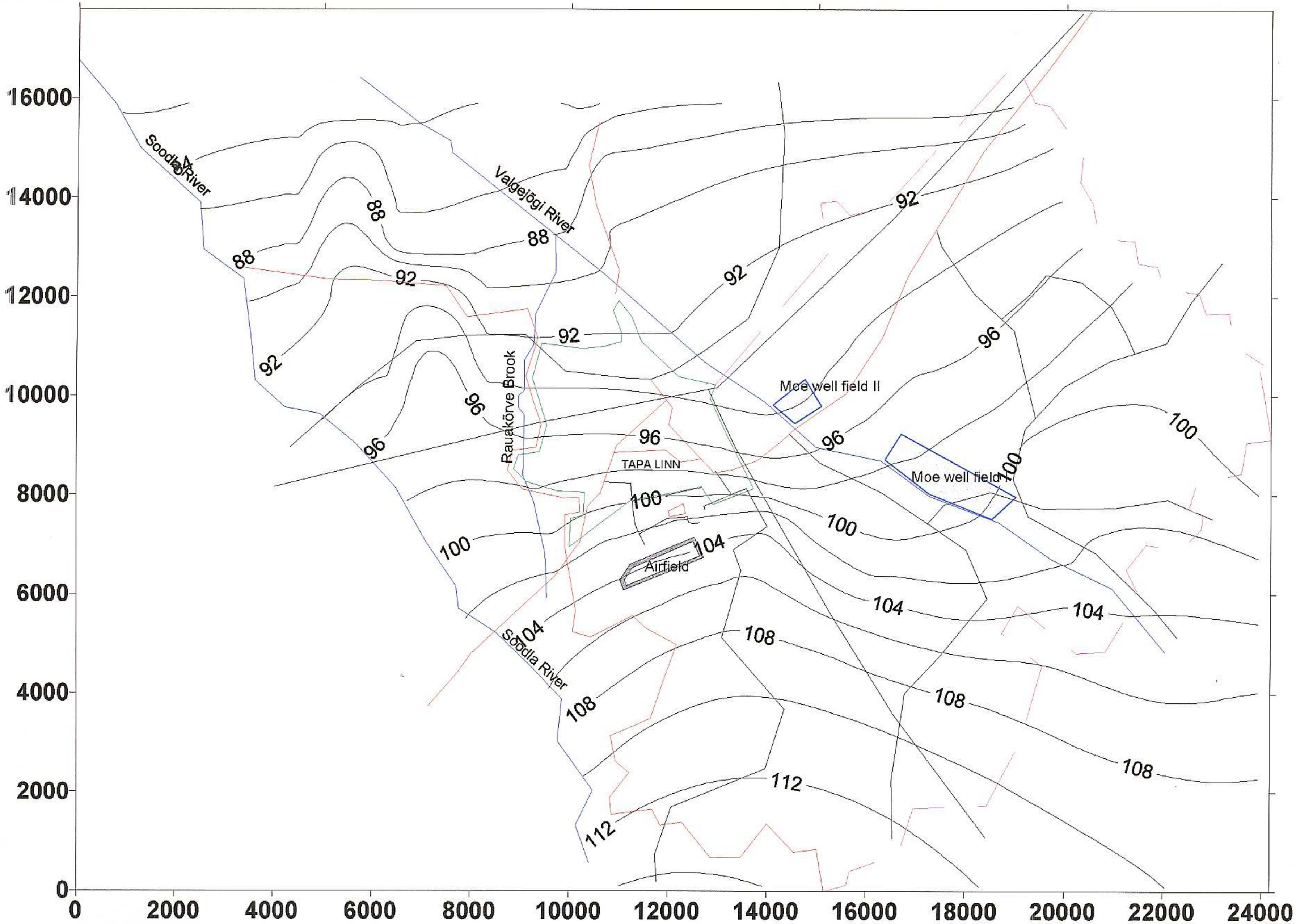


Figure 6 Transient simulation: watertable elevations of Tapa-Moe region
Moe well field II working at 13 400 m3/d abstraction rate, remediation fields acitvated
Stress period 12 - December
Axis scale in meters, watertable elevation in meters

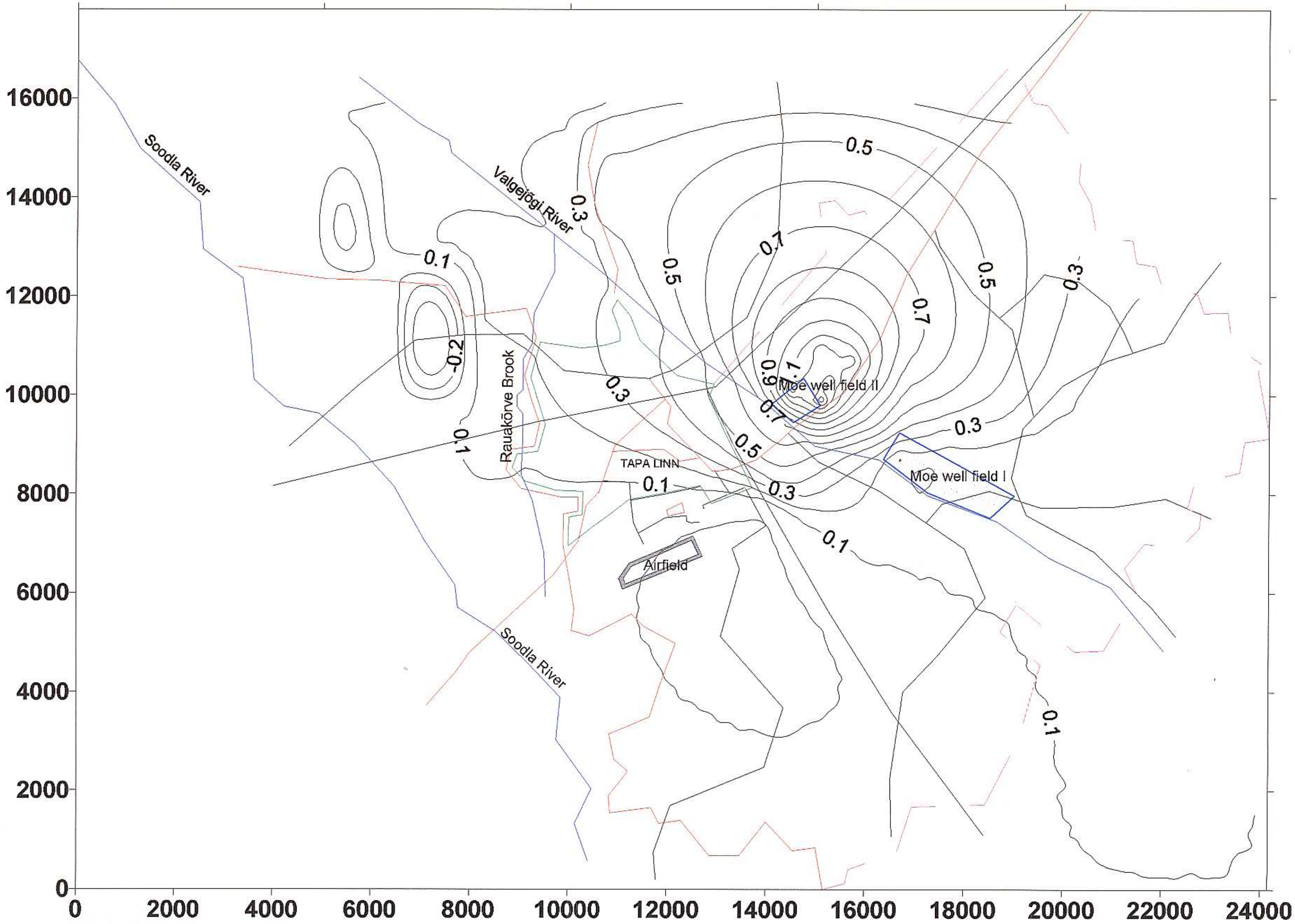


Figure 7 Transient simulation: watertable drawdown at Tapa-Moe region
Moe well field II working at 13 400 m3/d abstraction rate, remediation fields activated
Stress period 7 - July
Axis scale in meters, watertable drawdown in meters

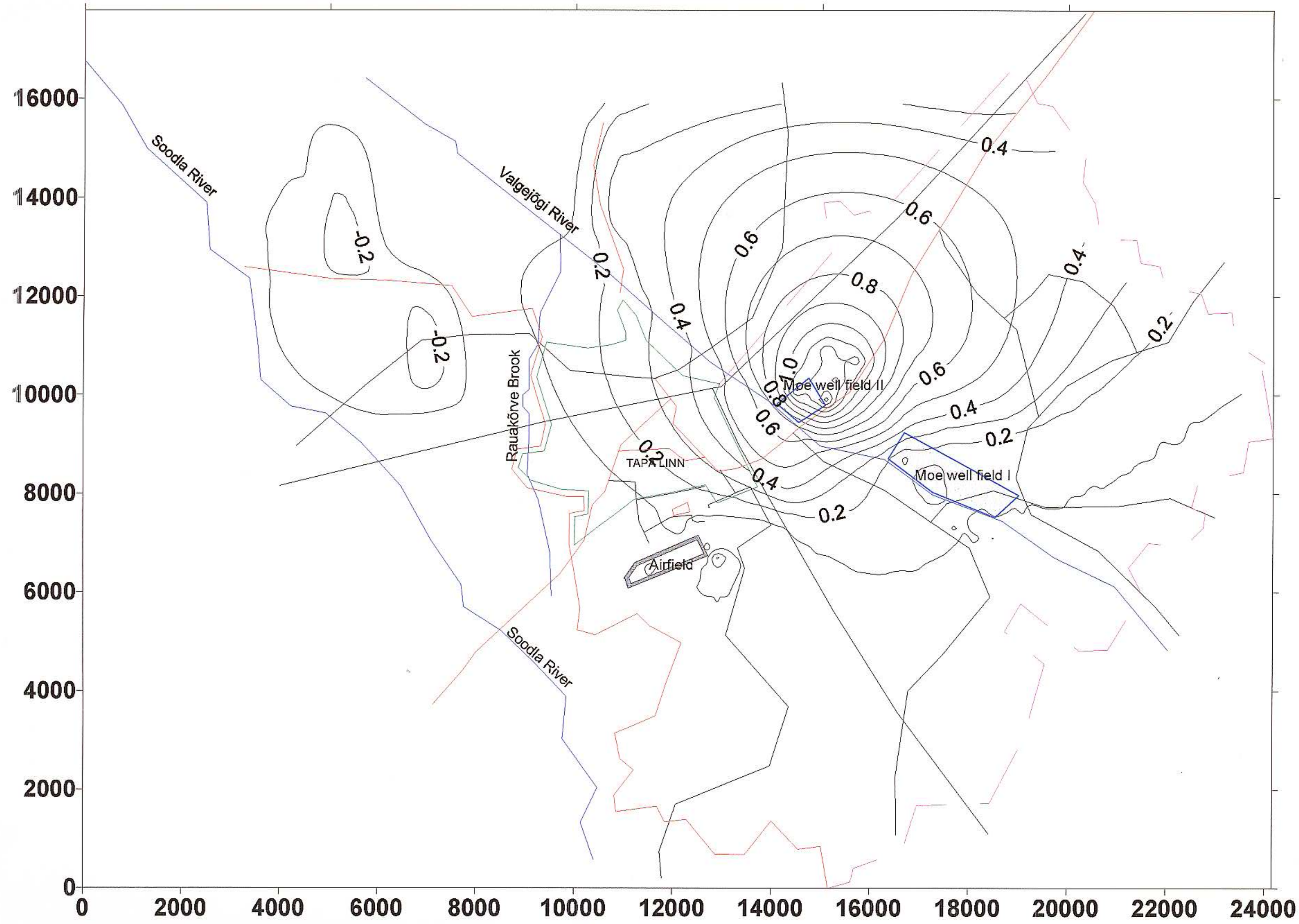


Figure 8 Transient simulation: watertable drawdown at Tapa-Moe region
Moe well field II working at 13 400 m3/d abstraction rate, remediation fields activated
Stress period 12 - December
Axis scale in meters, watertable drawdown in meters

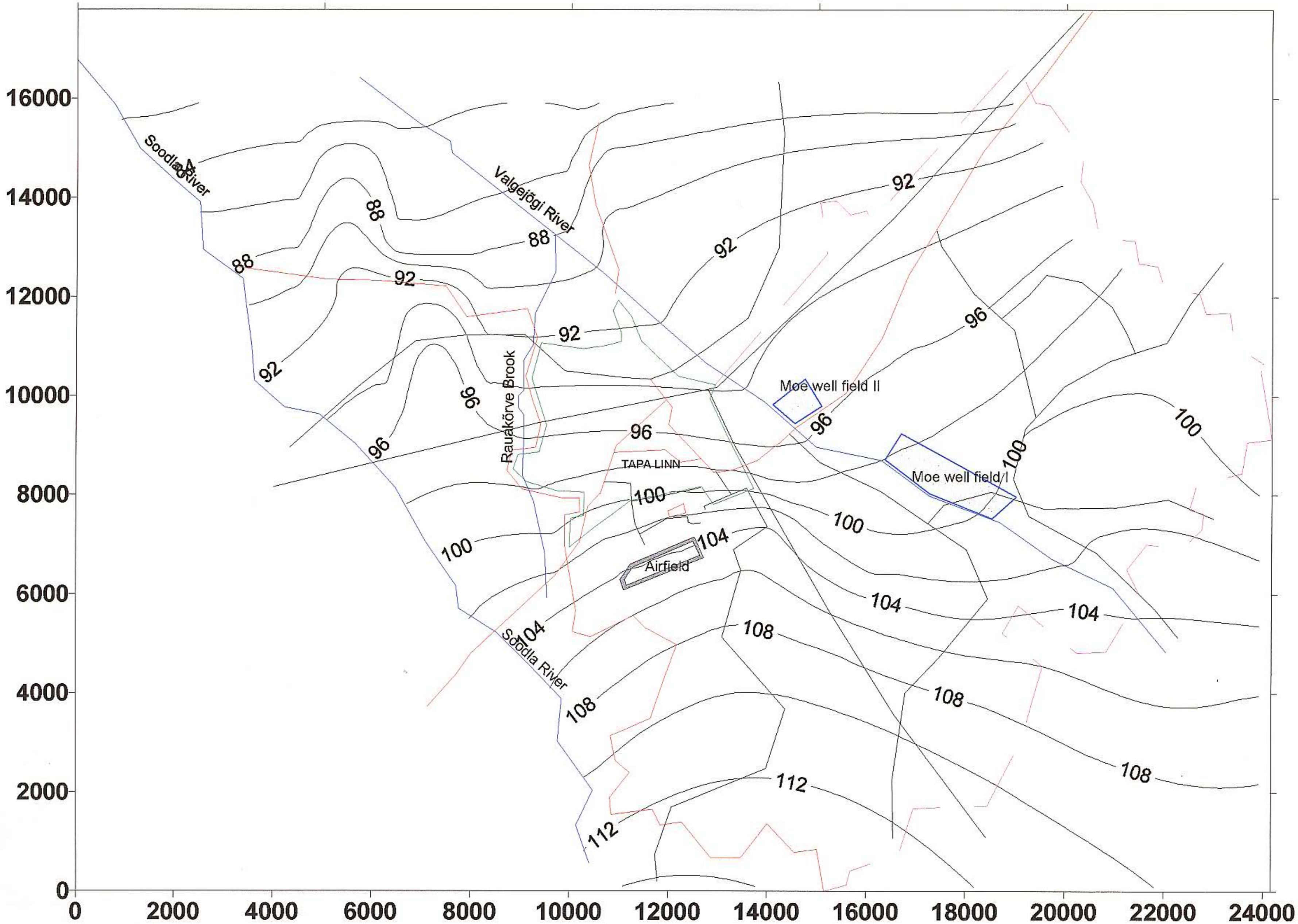


Figure 9 Transient simulation: watertable elevations of Tapa-Moe region
Moe well field I working at 4000 m3/d abstraction rate, remediation fields activated
Stress period 7 - July
Axis scale in meters, watertable elevation in meters

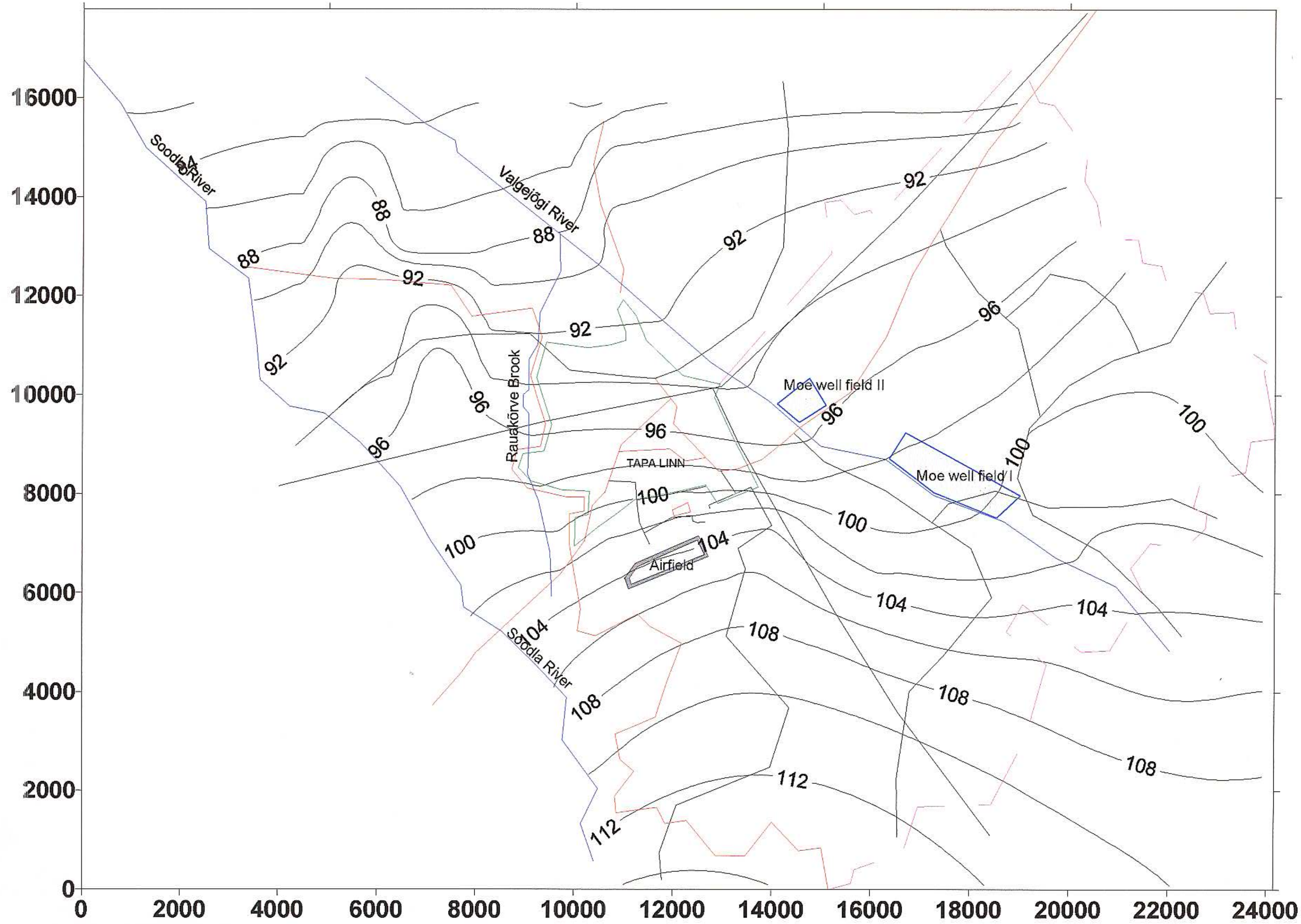


Figure 10 Transient simulation: watertable elevations of Tapa-Moe region
Moe well field I working at 4000 m3/d abstraction rate, remediation fields activated
Stress period 12 - December
Axis scale in meters, watertable elevation in meters

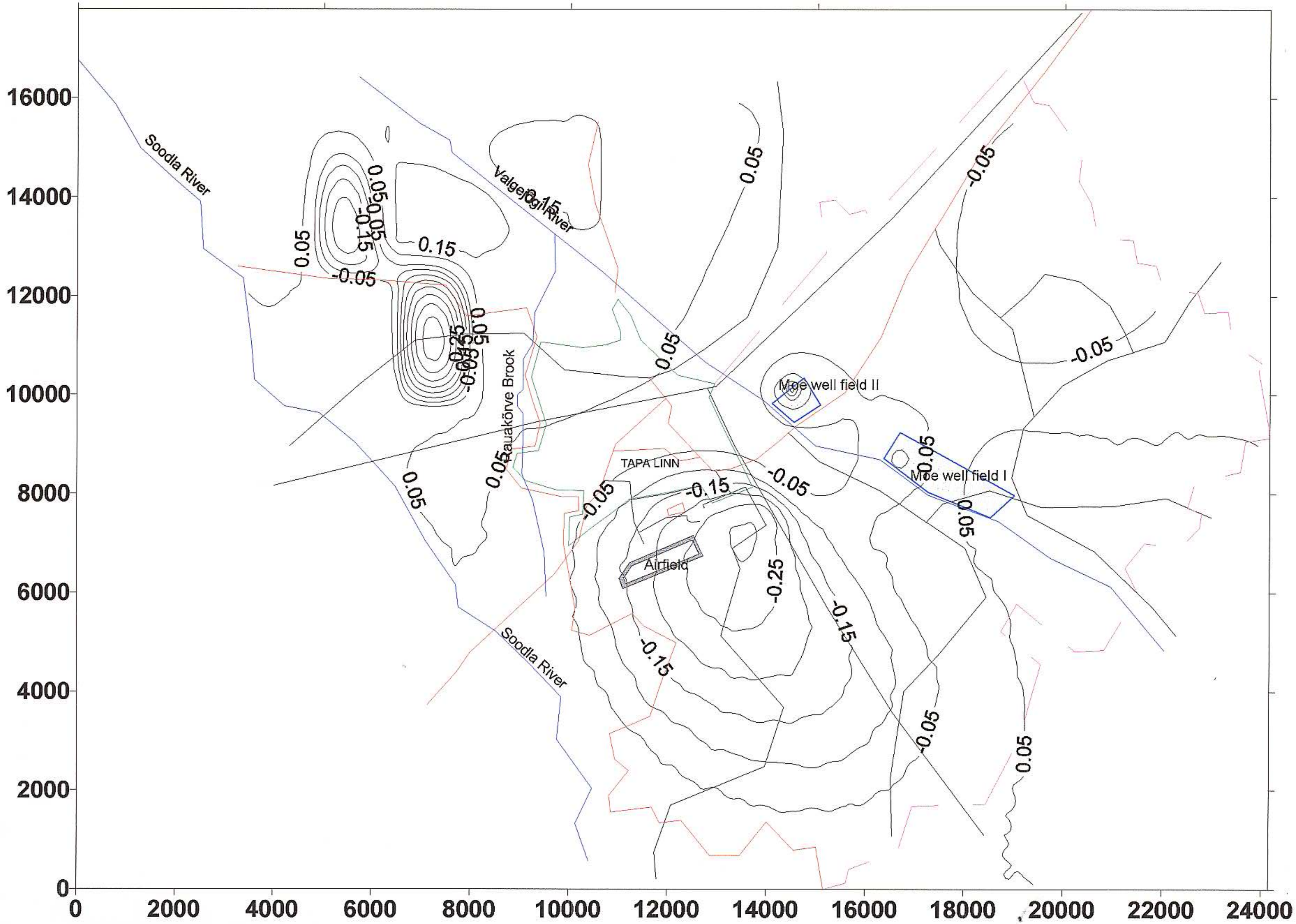


Figure 11 Transient simulation: watertable drawdown at Tapa-Moe region
Moe well field I working at 4000 m3/d abstraction rate, remediation fields activated
Stress period 7 - July
Axis scale in meters, watertable drawdown in meters

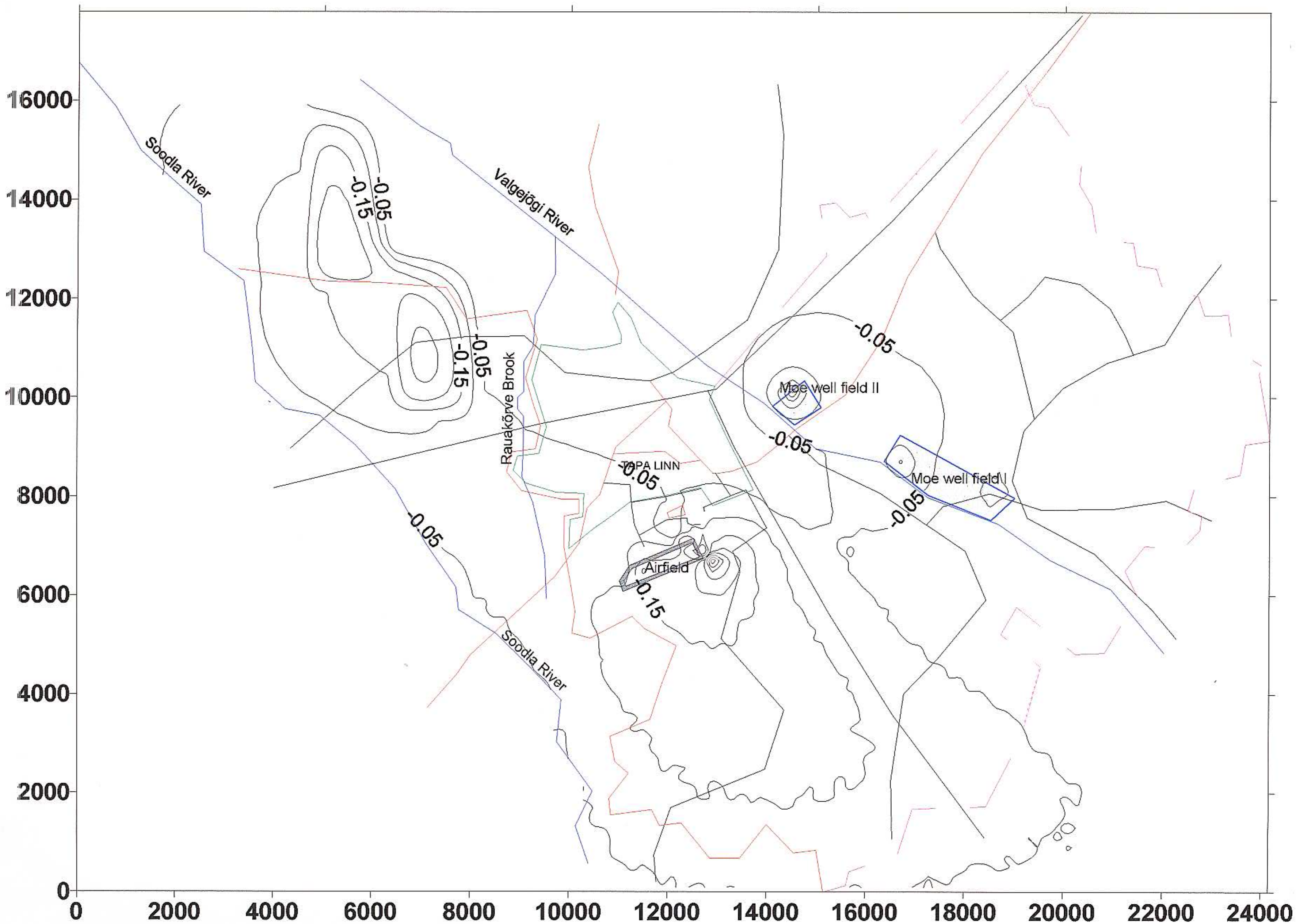


Figure 12 Transient simulation: watertable drawdown at Tapa-Moe region
Moe well field I working at 4000 m3/d abstraction rate, remediation fields activated
Stress period 12 - December
Axis scale in meters, watertable drawdown in meters

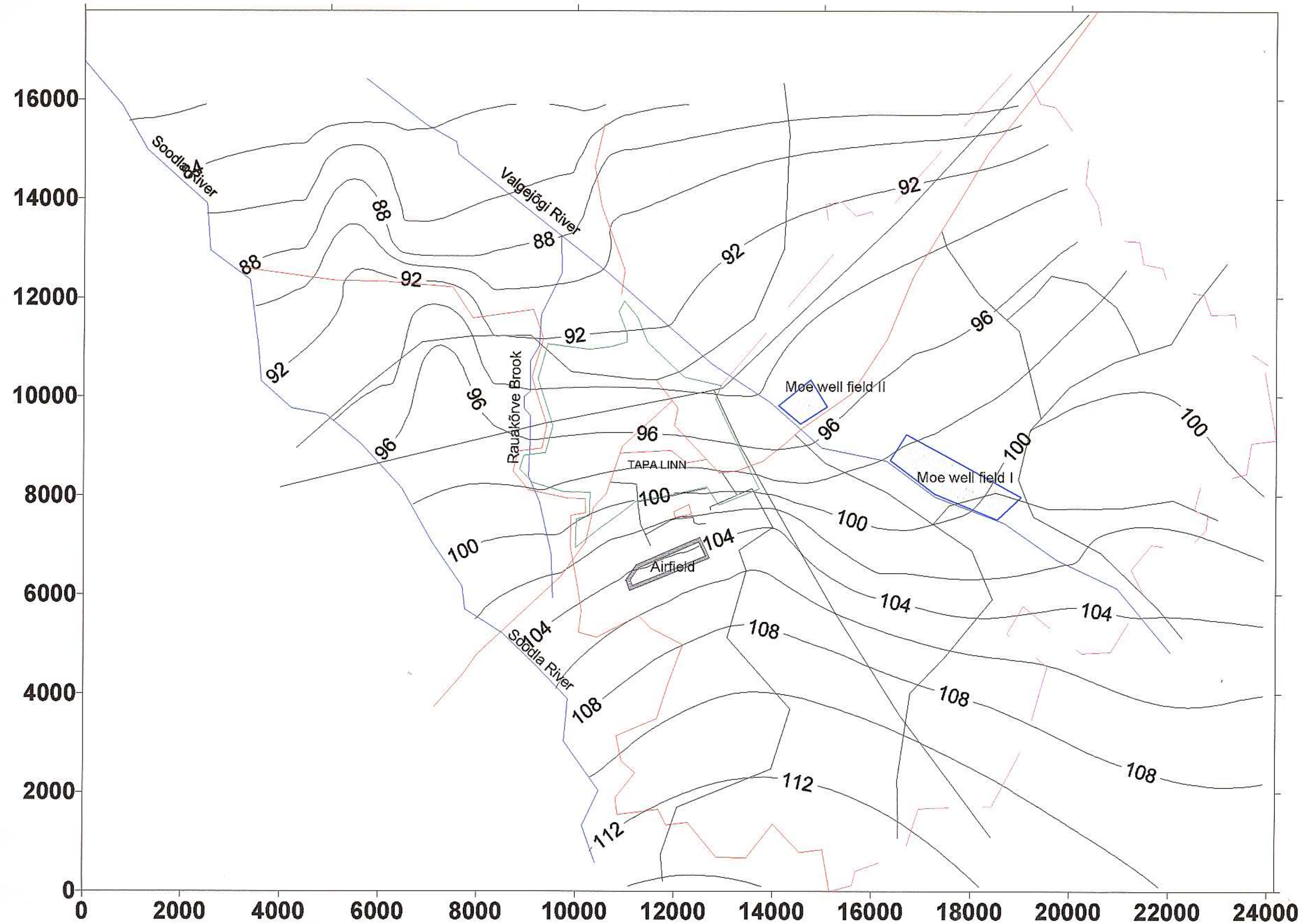


Figure 13 Transient simulation: watertable elevations of Tapa-Moe region
Moe well field II working at 4000 m3/d abstraction rate, remediation fields activated
Stress period 7 - July
Axis scale in meters, watertable elevation in meters

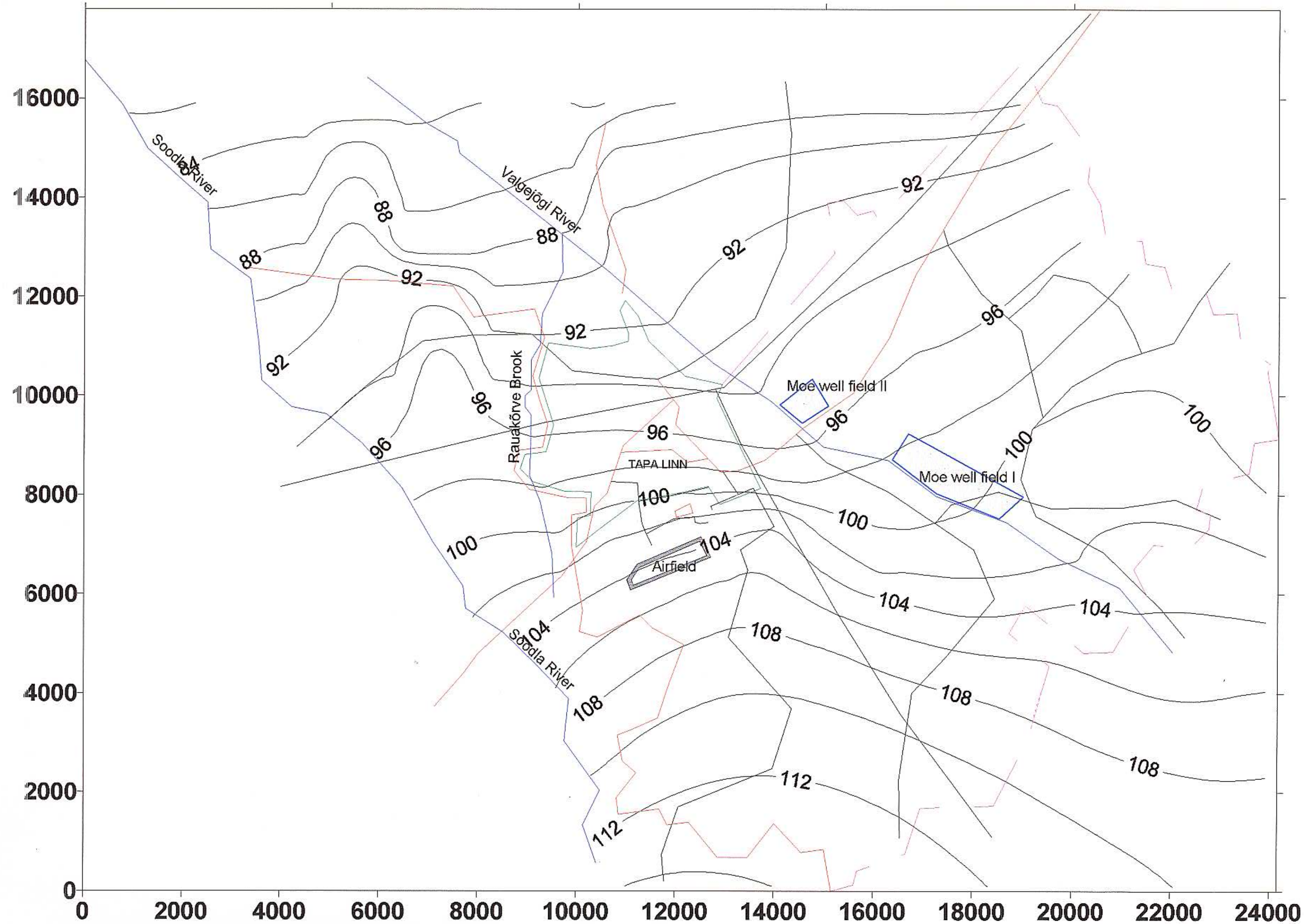


Figure 14 Transient simulation: watertable elevations of Tapa-Moe region
Moe well field II working at 4000 m3/d abstraction rate, remediation fields activated
Stress period 12 - December
Axis scale in meters, watertable elevation in meters

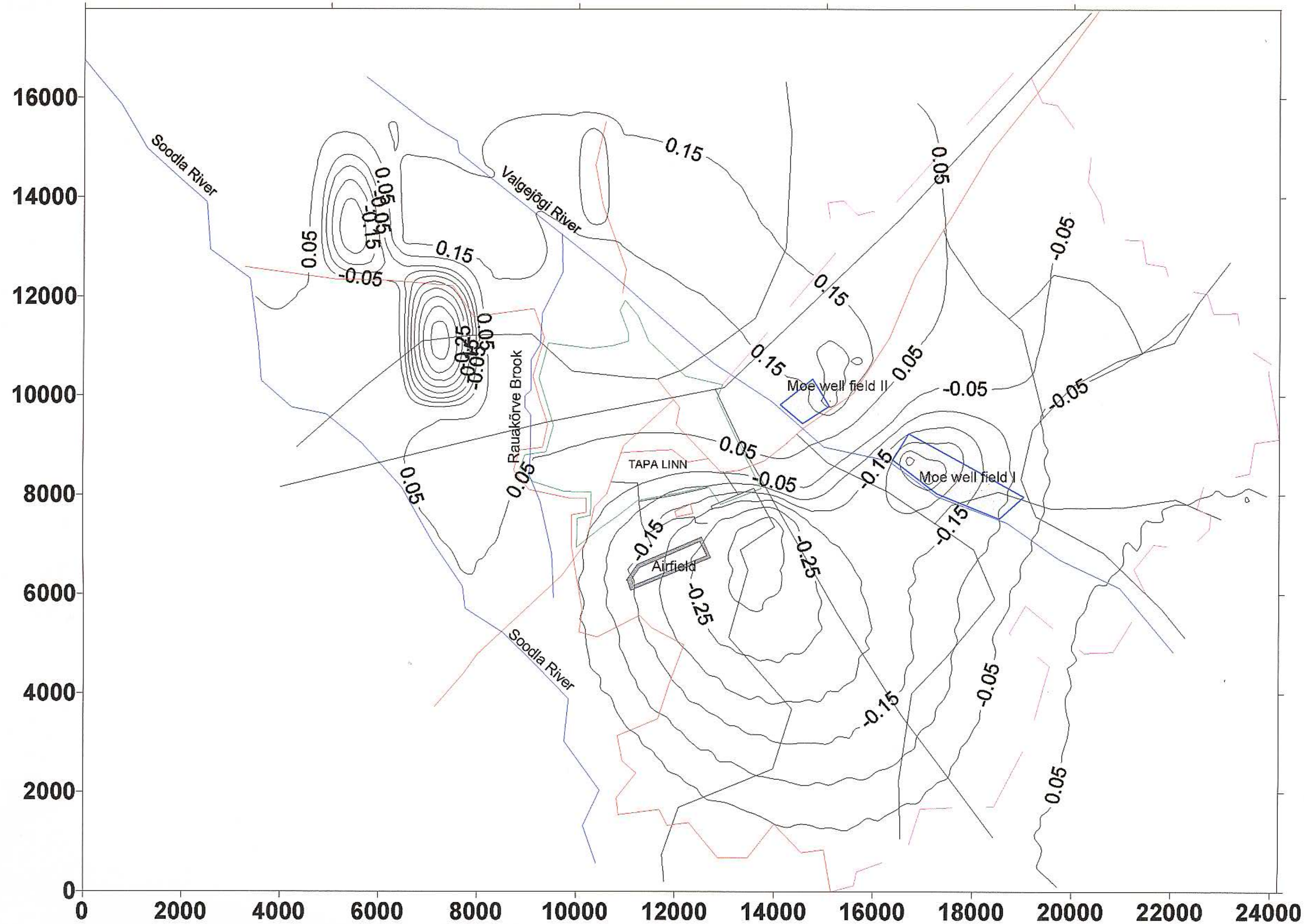


Figure 15 Transient simulation: watertable drawdown at Tapa-Moe region
Moe well field II working at 4000 m3/d abstraction rate, remediation fields activated
Stress period 7 - July
Axis scale in meters, watertable drawdown in meters

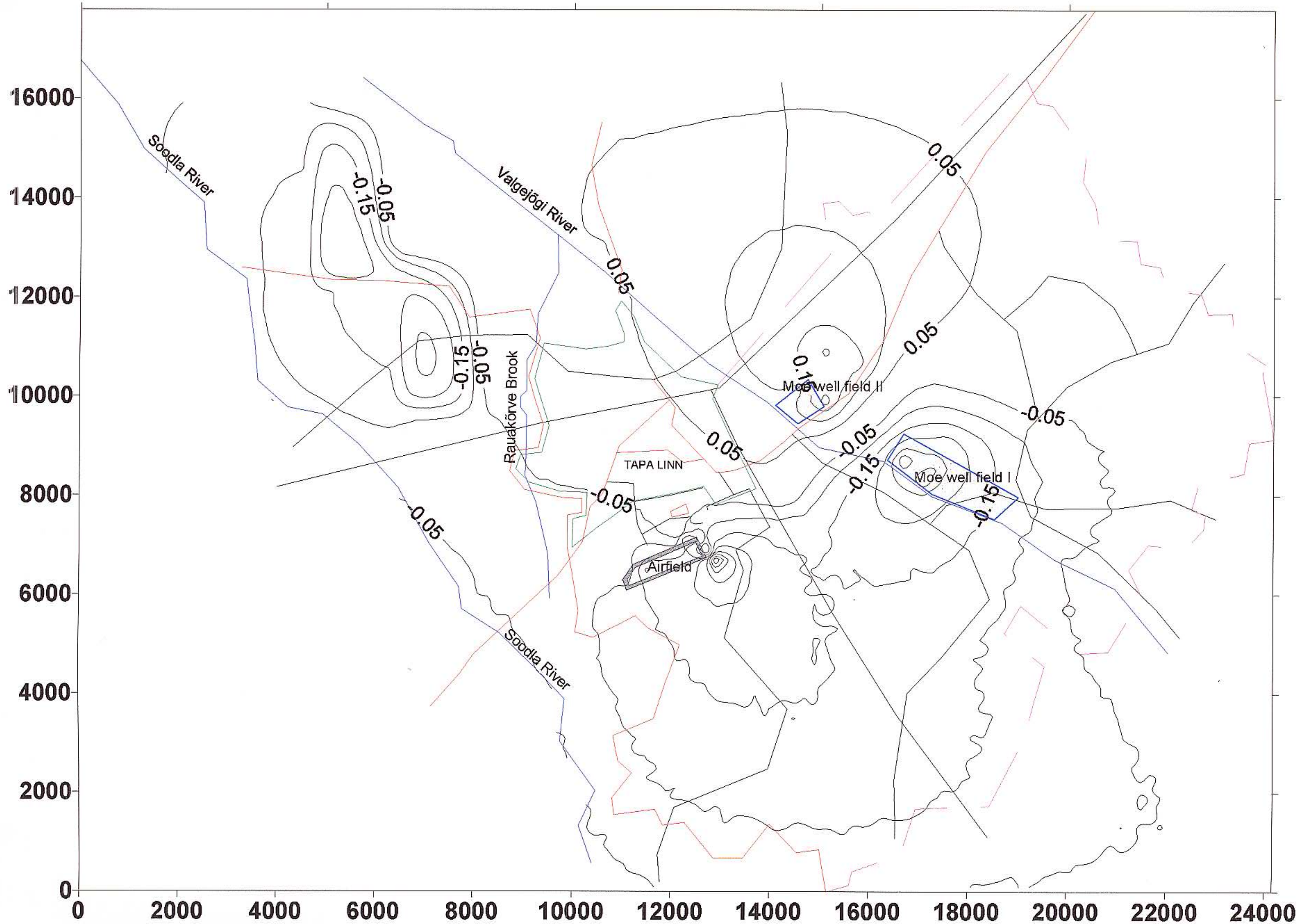


Figure 16 Transient simulation: watertable drawdown at Tapa-Moe region
Moe well field II working at 4000 m3/d abstraction rate, remediation fields activated
Stress period 12 - December
Axis scale in meters, watertable drawdown in meters