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Additional geological and hydrogeological studies in the Botnsheiði-Breiðadalur tunnel area

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ADDITIONAL GEOLOGICAL AND HYDROLOGICAL STUDIES IN THE BOTNSHEIÐI-BREIÐADALUR TUNNEL AREA

1. INTRODUCTION

These notes are a short addition to our earlier report of August 9th, 1993 (Sæmundsson et.al., 1993). We report here the outcome of field studies that were suggested and carried out. Furthermore we review the hydrological conditions in the tunnel area, taking notice of additional data and information obtained during the last four weeks. Finally, a new prediction is shown for flowrates at the Breiðadalur face inflow zone.

2. REVISION OF FAULT TRACES AND DIPS

In accordance with an earlier proposal (Sæmundsson et.al., 1993), some further geological observations were carried out in the Botnsheiði-Breiðadalur area. The main purpose of the study was to determine the trace and dip of faults with regard to the tunnel routes. The accompanying map (Figure 1) is a revision of former structural maps, focusing on the area nearest to the tunnel routes. The size of the faults shown is given in metres. Their dip is shown by bars pointing towards the downfaulted block. The dip of the fault planes was measured in several places, and was found to be 80-85° over longer intervals (tens of metres), but greater spread occurred if the dip measurements were made over short intervals (metres scale) at the exposure. Fault breccias frequently accompanied the faults studied. Some of the faults were seen to form steps or branches over an horizontal interval of 5-20 m.

Modifications of older structural maps are mainly confined to the area around Mt. Búrfell. The most prominent fault in this area is found in Mt. Kistufell, north of Búrfell. The throw is 20-25 m to the SW and the trend is NW-SE. This fault, or branches of it, have already been intersected by the Tungudalur tunnel leg. No serious inflow of water occured there. Farther west in Mt. Kistufell, an 8-10 m fault is seen, throwing east and trending north-south. This fault passes west of Búrfell and will be intersected by the tunnel at approximately 1600 m from the Botnsdalur entrance. Another parallel fault of 3 m, throwing also to the east, cuts through the NW shoulder of Mt. Búrfell. This fault will also be intersected by the tunnel at some 1900 m from the Botnsdalur entrance. A small N-S trending fault of about 1 m throw to the west, is seen farther south in the steep cliffs of Mt. Búrfell. The tunnel will presumably intersect this fault at 2000-2050 m from the Botnsdalur entrance.

A rather prominent 5 m fault that cuts through the SW shoulder of Búrfell trends parallel to the Botnsdalur leg and runs down the west side of Búrfell towards Botnsdalur. As the fault plane dips 80-85° to the SW and the fault lies entirely SW of the tunnel, there is little chance of direct intersection, though increased leakage may show up through permeable, horizontal formations. This fault was intersected in the Breiðadalur leg at 160 m from the triple junction without considerable water inflow. A small fault of approximately 1 m throw was found on the SW edge of Mt. Búrfell, trending NW-SE and throwing to the NE. This fault runs parallel and very close to the Botnsdalur leg at its present inner face. It may already contribute to the leakage in the inner part of the Botnsdalur tunnel by way of horizontal formations. The strike is poorly constrained and an itersection can not be excluded.

The section of the Botnsdalur leg which is still to be excavated will run through the above described fault zone. The likelihood of increased water flowrates is substantial at and near the fault/tunnel intersections, and along stretches where the tunnel leg parallels some of the faults at small distances.

Field mapping in the area around the Breiðadalur leg revealed a fracture trending NNW-SSE some 100 m west of the present face. This is probably a fault throwing to the west. It is marked by a pitted furrow of considerable length like most of the faults already defined in the vicinity. A magnetic survey on a single line across this area was carried out in order to determine the origin of the furrows. The line showed no sign of dyke anomalies connected to furrows. Some weak fault-type anomalies were, however, seen in the measured profile, indicating that faults are more likely associated with them.

The Breiðadalur leg will intersect the above mentioned fault some 100 m west of the present face. Another 10 m fault, seen in the east escarpment of Mt. Þverfjall, will be intersected some 400 m further ahead of the face. After this fault is passed, no sign of major faults were observed on surface along the proposed Breiðadalur leg.

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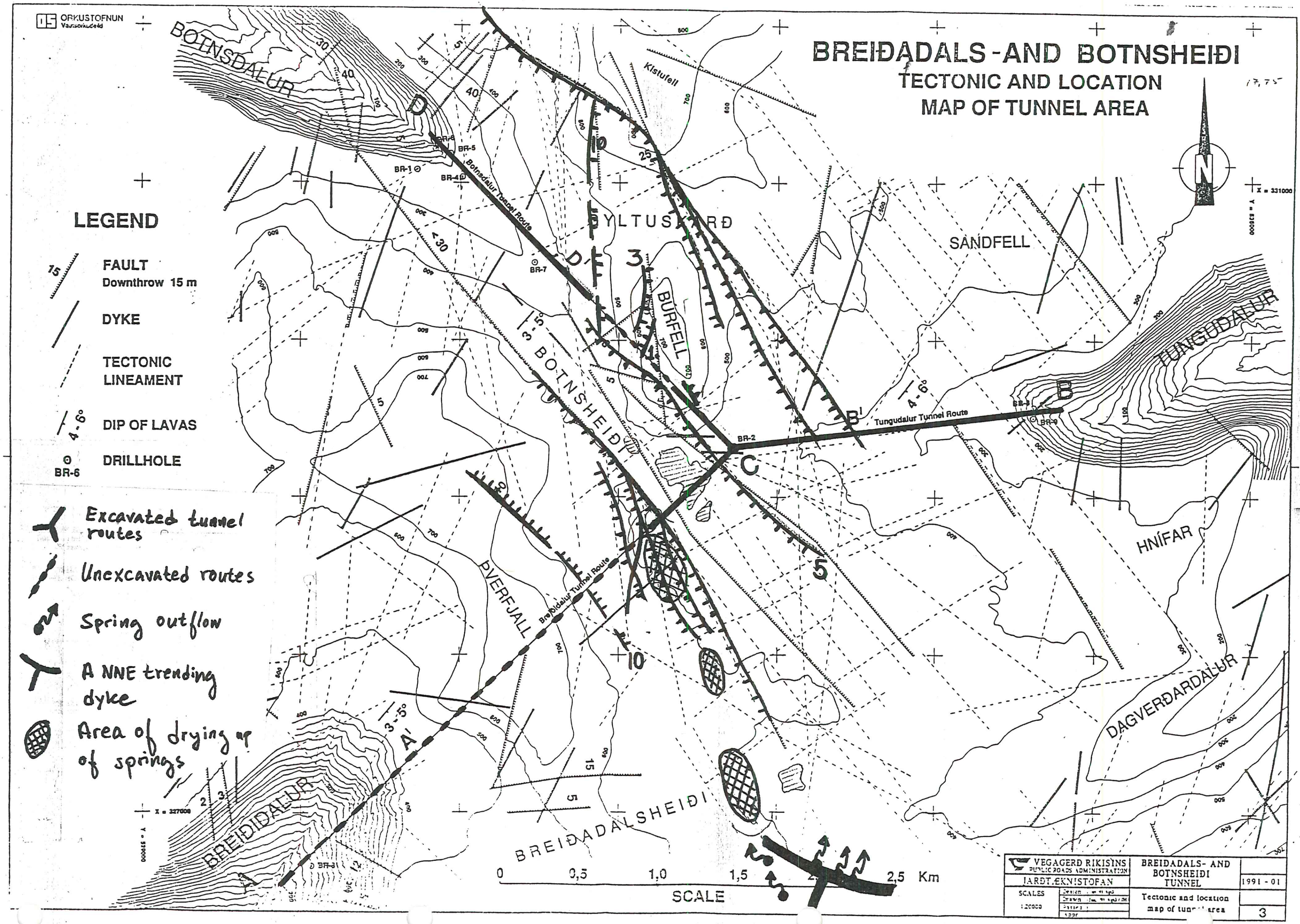
Figure 1: *A revised structural map of the Breiðadals-Botnsheiði area in the vicinity of the tunnel routes. Spring areas which have dried up (blue) occur in a NW-SE trending zone extending 2 km between the present Breiðadalur face and Heiðarvatn. No decline in outflows has been observed in springs emerging from a thick, branching dyke south of Heiðarvatn.*

BREIÐADALS-AND BOTNSHEIÐI
TECTONIC AND LOCATION MAP OF TUNNEL AREA

17,75



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SCALES 1:20000	Tectonic and location map of tunnel area	3

3. DYKES AND THEIR ROLE IN PERMEABILITY

The tunnel has cut through several dykes and occasionally an increased water ingression was observed in connection with these. The only large dykes yet to be intersected are: 1) an E-W trending dyke in the southern part of Mt. Þverfjall which will be cut by the Breiðadalur leg, and 2) a NE-SW trending dyke seen in the northern part of Mt. Þverfjall, which may intersect the Botnsdalur leg. The question of their permeability remains unsolved.

There are already evidence of permeable dykes in the study area. One such may actually serve as an important recharge system to the NW-SE trending fault zone on Botnsheiði. This particular dyke has been traced from the inner part of Önundarfjörður through Kirkjubólsfjall and Langafjall into the upper reaches of Dagverðardalur. Figure 2 shows the location of that dyke. A common thickness of the dyke is 15 m. Spring outflows in the range of 100 l/s were observed and connected to this dyke at both sides of the mountain area between Dagverðardalur and Önundarfjörður. The springs emerge at 280 m a.s.l. on the Önundarfjörður side and at 480 m elevation at the Dagverðardalur (Ísafjörður) side. At Dagverðardalur the dike shifts its trend from NNE-SSW to WNW-ESE where it runs into the NW-SE fault zone. This is also where the major springs at Dagverðardalur well up. It is quite possible that this dyke increases the recharge area of the Botnsheiði fault zone considerably to the south towards Mt. Langafjall.

Some dykes in the tunnel area may act as impermeable barriers. Their low permeability could result in a substantial pressure change from one side of the dyke to the other. This may become important during tunnel work in the Botnsdalur leg.

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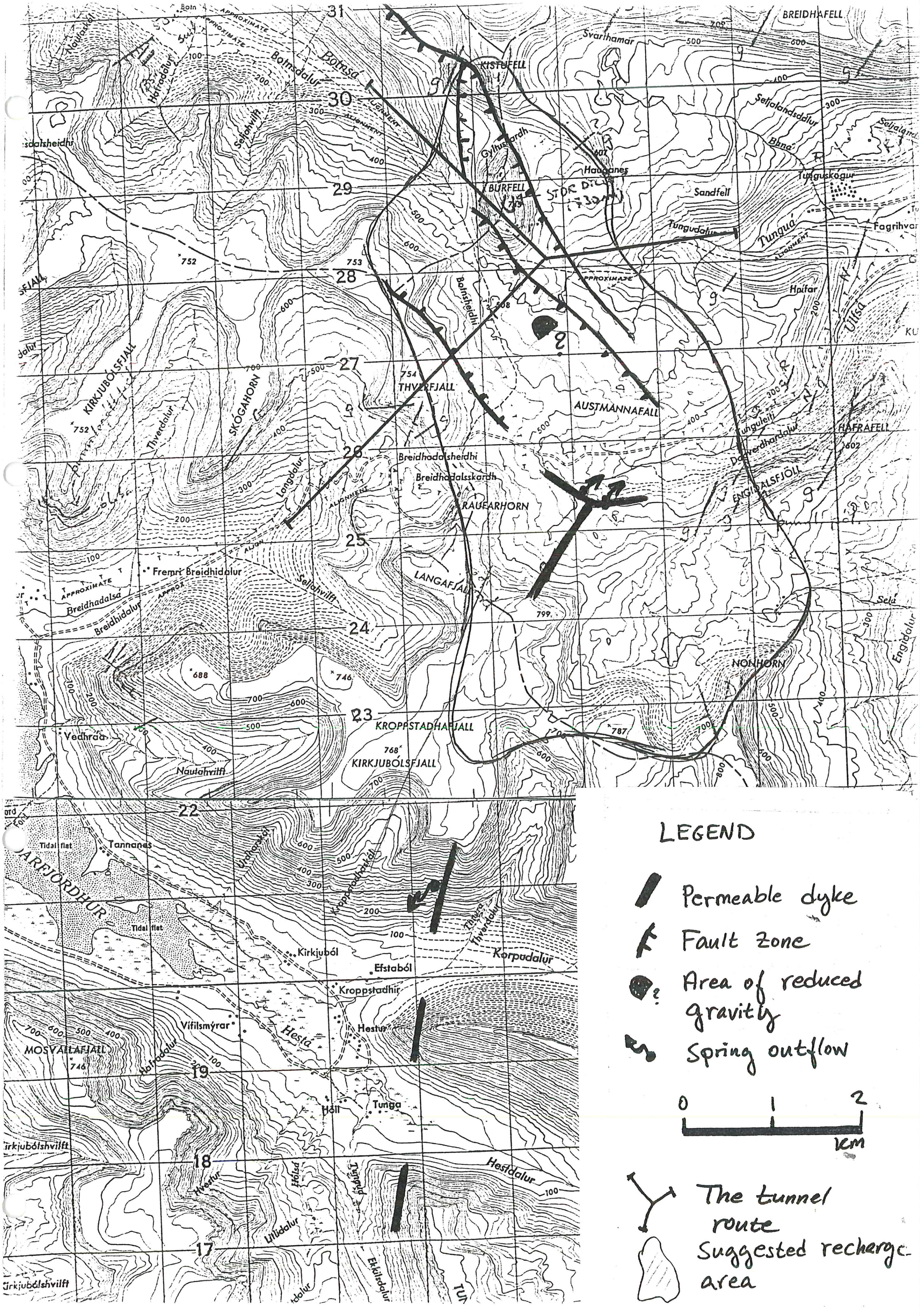
Figure 2: *Probable recharge area of the fault zone feeding the inflow at the face of the Breiðadalur tunnel. A 15 m thick dyke, which is shown by numerous springs to be higly permeable, may feed water into the Botnsheiði fault zone from the south.*


LEGEND
Permeable dyke
Fault zone
Area of reduced gravity
Spring outflow
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1
2
KM
The tunnel route
Suggested recharge area
KISTUFELL
BURFELL
STOR DIL
Botnsdalur
Botnsá
ALIGNMENT
APPROXIMATE
Haugones
Sandfell
Tunguá
Tungudalur
Fagrihvar
Seljalandsdalur
Bhná
Tunguskogur
BREIDHAFELL
Svarthamar
Gylhsardh
Botnsheidhi
THVERFJALL
AUSTMANNAFALL
Hnifar
Úlfsá
HAFRAFELL
ENGIDALSFJÖLL
Dagverdhardalur
Tunguleiti
Breidhadalsheidhi
Breidhadalsskardh
RAUFARHORN
LANGAFJALL
NONHORN
Engidalur
Sela
KIRKJUBÓLSFJALL
SKÓGAHORN
Thverdalur
Langadalur
Fremri Breidhidalur
Breidhadalsá
Breidhidalur
Seljahvilft
KROPPSTADHAFJALL
Vedhraá
Nautahvilft
Hafradalur
Seljahvilft
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4. DRYING UP OF SPRINGS - GRAVITY CHANGES

Up until now springs have vanished on a 2 km long NW-SE trending zone between the Breiðadalur tunnel face and Heiðarvatn (Figure 1). Repeated flow measurements carried out in this area years back, indicate that the present decline in spring outflow amounts to some 200 l/s. The area of dry springs corresponds to the fault bundle that runs nearest to the face of the Breiðadalur leg. No reduction was observed in springs that are feeding the Búrfell-lakes nor in springs in the Búrfell area.

In order to monitor groundwater changes in the tunnel area, an extensive gravity grid has been set up and remeasured once. The first survey was carried out in the middle of July and the latter one on September 10-12. No significant changes were observed in the grid area, apart from 2 or 3 stations to the east of Búrfell-lakes (Figure 2). This is on the edge of the initial survey area and, therefore, the grid has now been extended several kilometres to the east (Hjálmar Eysteinsson 1993, personal communication).

Repeated waterlevel measurements in well BR-2 on Botnsheiði show no changes. This is in accordance with negligible gravity changes in this area. The stability in the waterlevel is probably due to an instantanious replacement of the fluid produced into the tunnel, by an inflow from the SE through the fault zone and the NNE trending dyke. However, well BR-7 in Botnsdalur has shown a drop in waterlevel by tens of metres. The most likely reason is a local draining around the tunnel, which has now passed this site. This kind of draining has not yet been possible at the Breiðadalur face due to the high permeability and the rapid recharge from the SE.

5. FLOWRATE ANALYSIS AT THE BREIÐADALUR FACE

Figure 3 shows the flowrate at the face of the Breiðadalur tunnel as a function of time. During the first three weeks shown, a flow decline from ≈ 2700 l/s to ≈ 1700 l/s occurred. Since then the flowrate has stabilized at 1600-1700 l/s. The cumulative mass produced amounted to more than 10 million metric tons by August 30th., 1993. Experience, obtained through the flow measurement process, shows that a 5-10 % error is to be expected in the flowrate data. This is evident by data points, collected in two adjacent cross sections on August 30th. (Figure 3).

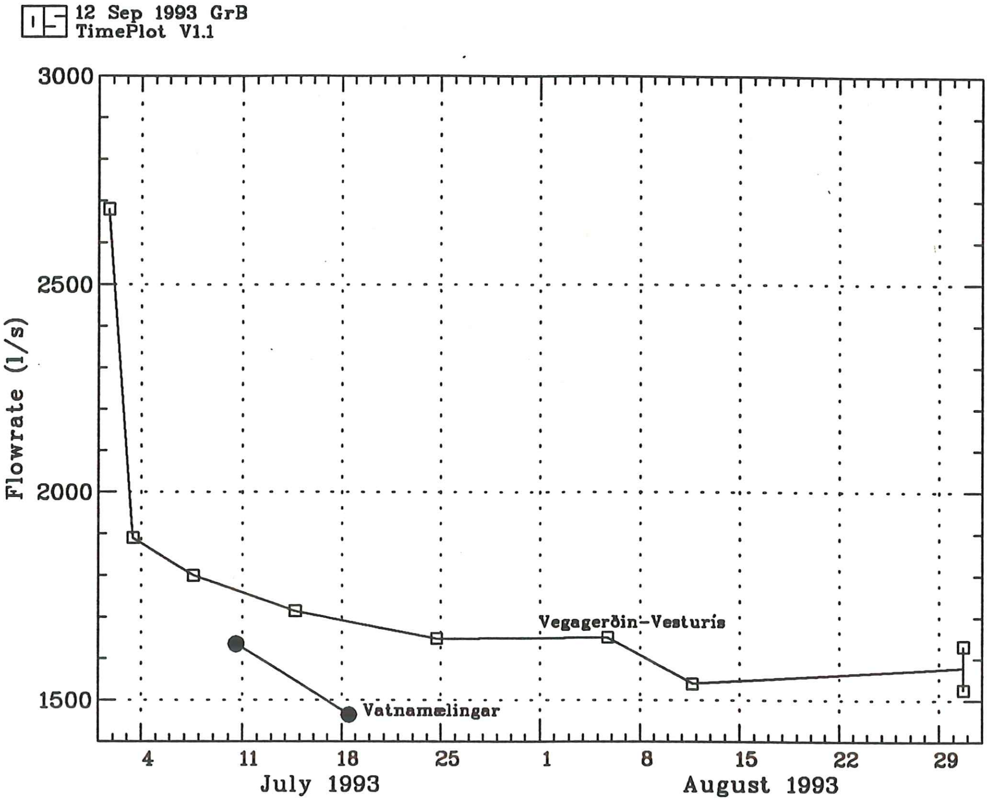

Figure 3: *Inflow history at the Breiðadalur face.*

In a previous report, some predictions were made for flowrates through the faultzone at the Breiðadalur face (Sæmundsson et.al., 1993). In that study two simple groundwater models were considered: 1) a single fracture reservoir with flow history changing linearly by the square root of time; and 2) an infinite, confined reservoir where the flow history is linear with the natural logarithm of time. A revision of the governing pressure/flow equations in the two models above show that the inverse of the flowrate should change linearly with time. Figures 4 and 5 show this. Also shown on the graphs are straight lines which are taken to represent a best fit through the measured data. These lines are, furthermore, extrapolated with time and serve then as predicted flowrate curves. Figure 6 shows finally these two lines converted to real times and flowrates. According to the figure, flowrates above one cubicmeter per second are to be expected at least to the end of 1994.

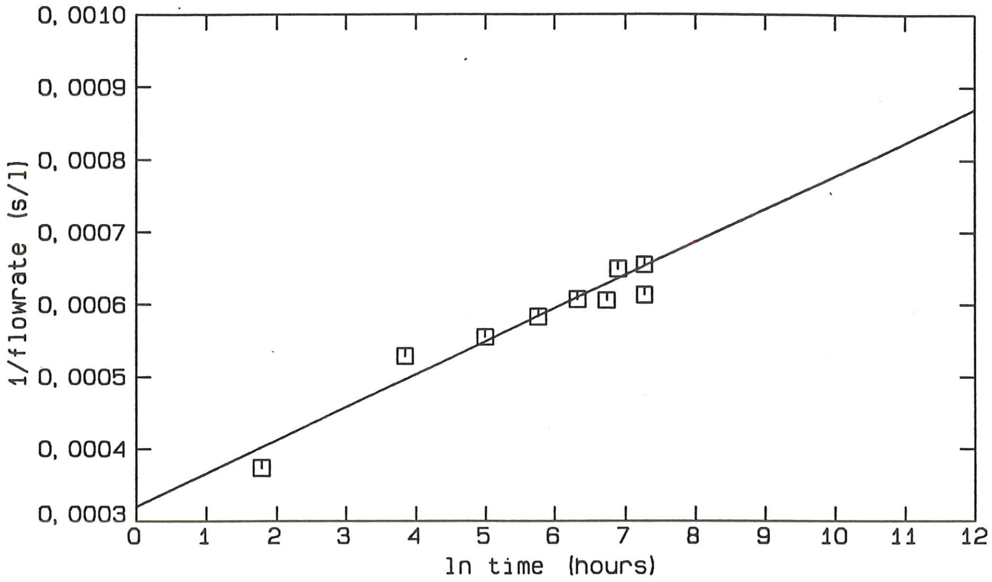

Figure 4: *The inverse of the flowrate at the Breiðadalur face as a function of the logarithm of time. The flowrate data is shown by squared symbols and a best fit is shown by the solid line.*

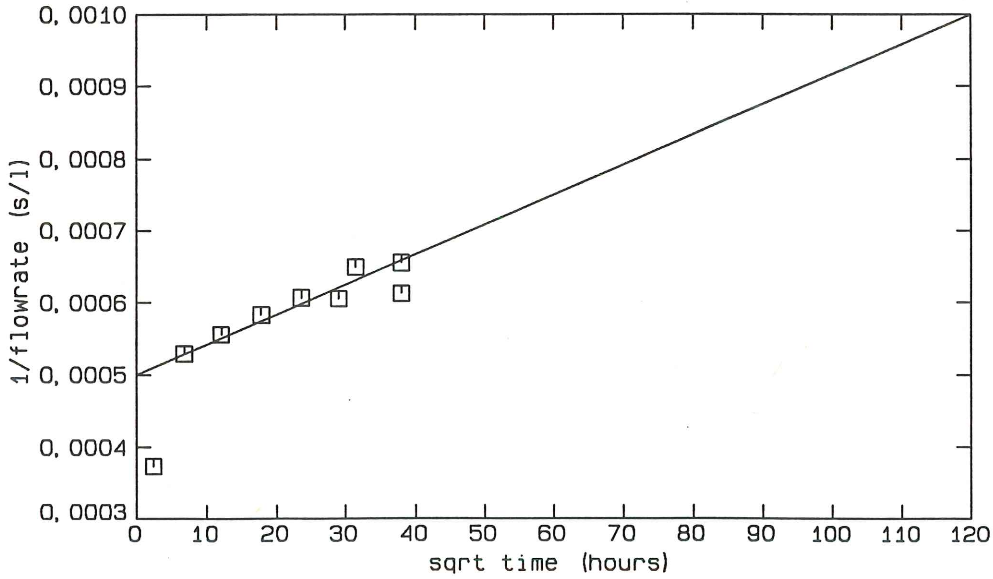

Figure 5: *The inverse of the flowrate at the Breiðadalur face as a function of the square root of time. The flowrate data is shown by squared symbols and a best fit is shown by the solid line.*

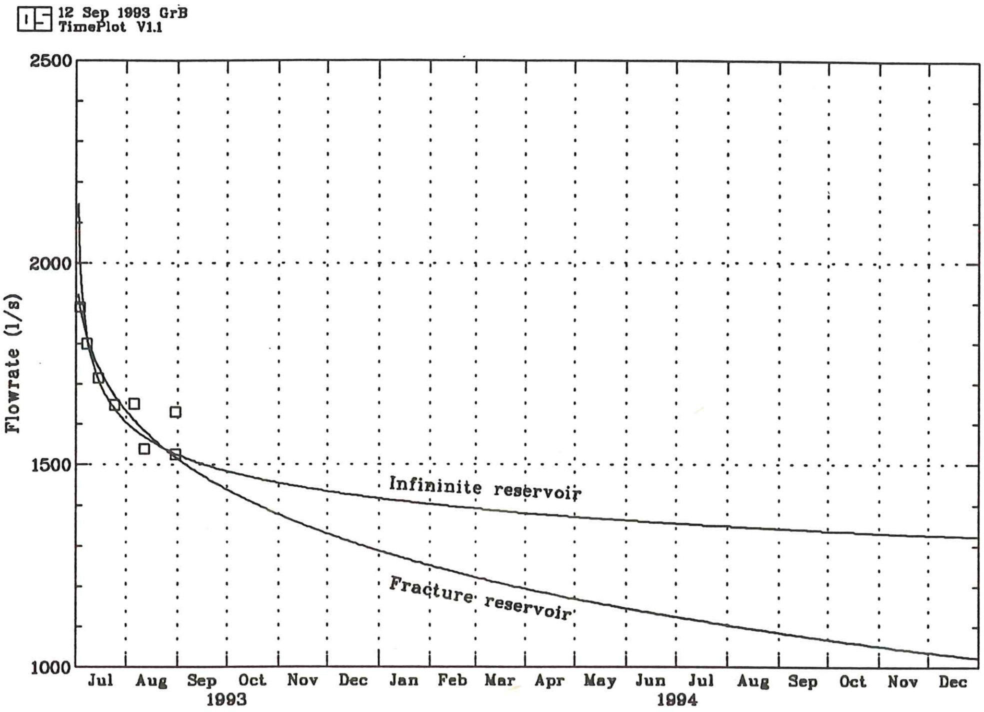

Figure 6: *Predicted flowrates at the Breiðadalur face for the two reservoir models considered. Measured data is shown by squared symbols and the predicted flowrates by solid lines.*

It should be emphasized that the above predictions are based on a limited set of data and that a lot of unknowns are included in the study. The highest uncertainities have to do with the recharge to the groundwater system that is feeding the tunnel inflow. This may result in too high flowrates predicted (Figure 6). As an example, warm temperatures and substantial precipitation have resided since late August in the tunnel area. These two factors could have increased infiltration rates substantially and, hence, stopped the pressure decline in the reservoir feeding the fault zone. Repeated flowrate measurements during the forthcoming winter and spring will provide an answer to this critical question of seasonal changes in the groundwater pressure and tunnel inflow rates.

Figure 7 shows finally the cumulative mass outflow at the Breiðadalur face up til the end of 1994. The former two cases of reservoir models are shown (Figure 6), but also shown are the cumulative masses for stable 200, 400 and 600 l/s infiltration rates into the groundwater system feeding the tunnel. The difference between the total output and the infiltrated mass is the water taken from storage in the reservoir. By the end of 1994, this mass will amount to between 30 and 50 million tons. Assuming a 10 % effective porosity and a total draining of the water in storage, a rock volume of 0.3-0.5 km^3 is required for this purpose. Taking into account the combined area of the NW-SE fault zone and the NNE trending, permeable dyke (> 20 km^2), this volume may actually become available (an average drawdown of 15-25 m).

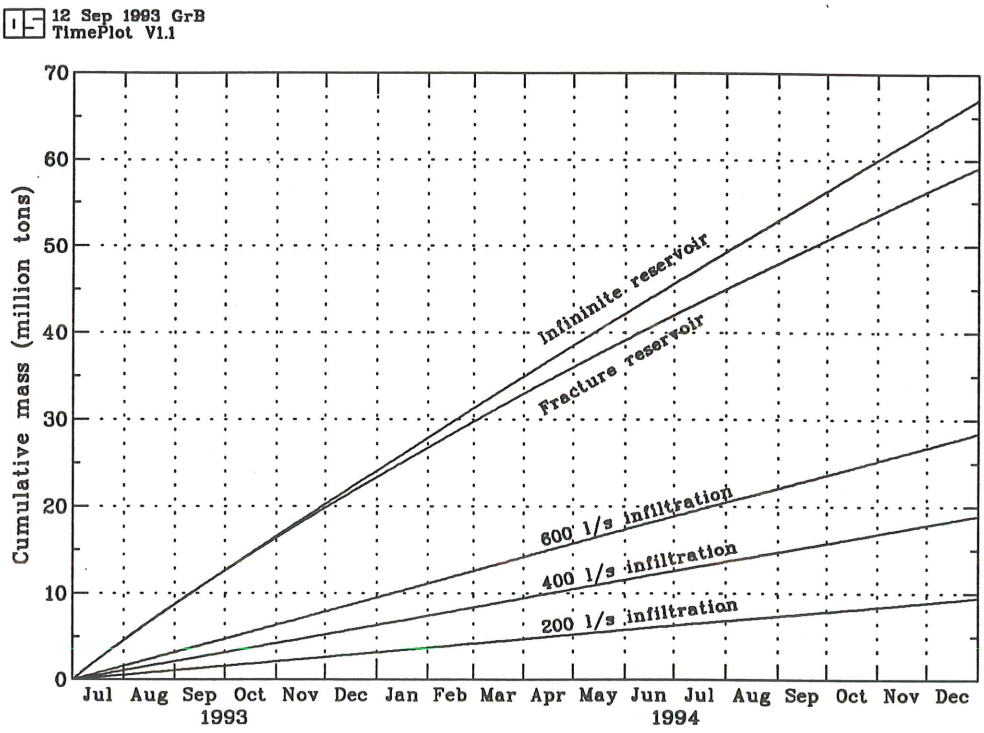

Figure 7: *Cumulative mass outflow of the Breiðadalur-Botnsheiði tunnels for the two predicted flowrate curves shown on figure 5. Also shown is the cumulative mass flow for stable 200, 400 and 600 l/s infiltration rates into the groundwater system.*

REFERENCES

Sæmundsson Kristján, Grímur Björnsson, Ágúst Guðmundsson and Matthías Loftsson, 1993: *Tunnels under Breiðadals- and Botnsheiði. A report on groundwater systems and water flow in connection with faults and dykes.* A report submitted to Vegagerð Ríkisins in August 1993, 27 p.

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