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Description of recipient areas related to final storage of unreprocessed spent nuclear fuel

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ABSTRACT

A comprehensive study of recipient areas in Fjällveden, Voxnan, Gideå and Kamlungekölen is accomplished. Besides general conditions in Finnsjön and Sternö are discussed.

The recipient areas are defined and their climate, hydrology, bedrock, soil, vegetation, land use and yield from arable land are described as well as the yield of fish for the surface water of interest. The potential exposure pathways and model system at the different areas are defined.

Long-term variations of geology, climate, hydrology, land-use, acidification and evolution are described. The possible development of the recipient areas is also discussed.

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1 INTRODUCTION

To be able to calculate the doses from release of radionuclides from a final repository of spent nuclear fuel the leakage and migration of the different radionuclides must firstly be known. Secondly the recipients and exposure pathways to man must be defined. This report deals with the definition of possible recipient areas and their characteristics in Fjällveden, Voxnan and Gideå. Besides the areas of Finnsjön and Sternö are discussed. The sites are situated in Sweden as shown in Figure 1.1.

Relevant data for recent conditions are presented and their variations are also discussed. These data will be utilized in the dose calculation code BIOPATH, which is based upon compartment theory to be able to calculate the turnover of nuclides in the biosphere and the resulting dose to man /38/.

2 DESCRIPTION OF THE RECIPIENT AREAS

2.1 The Fjällveden area

2.1.1 General description

The Fjällveden area, 58° 56' N, 16° 56' E, is situated about 20 km north-west of Nyköping, Södermanland, see Figure 2.1.1.

2.1.1.1 Climate

The area belongs to the cold snow-forest climate without dry season, Dbf, according to the Köppen classification. The small letters b and f stand for that the warmest month is below +22°C, respectively no dry season.

The annual mean air-temperature for Nyköping is +5.7°C. For January the mean temperature is -3.6°C and for July it is +16.5°C.

The mean precipitation (1931-60) is 603 mm (uncorrected). However, this value is too low because of wind deficit, wetting, evaporation etc. The correction for Södermanland is +19 % /1/. This means that the corrected value is 718 mm. The corrected mean value for Södermanland is 675 mm.

2.1.1.2 Hydrology

The average annual runoff for Södermanland is 205 mm /1/, equal to 6.5 l/s, km^2. This value is close to the value of the Nyköpingsån (1909-38) which is 6.8 l/s, km^2 /2/, see table 2.3.

The potential evapotranspiration was defined as "the water loss which will occur if at no time there is a deficiency of water in the soil for the use of vegetation" by Thornthwaite /3/. Thus this will represent the highest possible evaporation from the soil and vegetation. The potential evapotranspiration has been calculated for the whole country /4/. The mean value for Nyköping is 563 mm/year. For Södermanland as a whole the value is around 575 mm/year.

2.1.1.3 Bedrock and soil

The solid rock consisting archean bedrock, that covers most of Sweden, is of veined gnessies (mainly sedimentary gnessies) /5/.

The soil region in Fjällveden is within the Södermanland-Närke land-scapes glacial till and clay area. Bare rock, glacial till and clay cover about 25 % each within this region /5/.

The whole area is situated below the highest shoreline.

2.1.1.4 Vegetation

The vegetation normally reflects the condition of the nature. Because of that it is important to include the vegetation in a description of part of a landscape. Fjällveden belongs to the so called Boreo-nemoral zone /6/.

2.1.2 Recipients

The migration of radionuclides from the eventual repository to the biosphere will be calculated within an other project. Because of that we have had to define different alternatives of recipients outgoing from the fracture zones around the test site.

The recipients we have chosen are small lakes within or close to the fracture zones, water courses as creeks or rivers, lakes further down in the water system on its way down to the Baltic.

2.1.2.1 Drainage areas, lakes and discharge

Two main recipient areas have been considered around the test site. One eastern area that belongs to the drainage basin of Svärtaån, see Figure 2.1.2. The other one is drained to the west and is a part of the drainage basin of Nyköpingsån, with Morpasjön as the primary recipient, a lake poor in nutrients i.e. oligotrophic. Sågsjön has the same position in the eastern drainage basin.

The drainage areas are summarized in table 2.1.1

Table 2.1.1 Drainage areas - Fjällveden

Drainage basin	Area (km^2)	Lake Percentage (%)
Morpasjön	4.5	9.3
Båven	771	15.6
Lidsjön	827	15.6
Långhalsen	3578	14.0
Nyköpingsån	3622	13.8
Sågsjön	8.3	4.2
Glottran	1.4	28.5
Kappstasjön	55	10.5
Likstammen	61	20.5
Runnviken	247	10.8
Svärtaån	342	8.3

Sources: Reference /7/ and STUDSVIK calculations

Lakes within the two drainage basins have been studied in respect to area and depth. Sounding has been done in some of the lakes. The depth has been estimated for the others, outgoing from sourrounding lakes and topography. The area of the lakes has been obtained from Fisheries Committee. The above mentioned values are shown in table 2.1.2.

Table 2.1.2. Lakes - area, depth and volume

	Area (km^2)	Depth (m)	Volume (m^3) x 10^6
Nyköpingsån			
Morpasjön	0.4	8	3.2
Lidsjön	8.1	9	72.9
Båven	67.3	15*	1009.5
Långhalsen	31.0	10*	310.0
Nyköpingsfjärden	9.5	2	19.0
Svärtaån			
Sågsjön	0.2	6	1.2
Glottran	0.4	6	2.4
Kappstasjön	1.1	5*	5.5
Eknaren	2.4	5*	12.0
Ludgosjön-Runnviken	5.7	4*	22.8

* estimated value

Available discharge data in the Fjällveden area are found for Nyköpingsån /2, 8/ and in the source area of Svärtaån /2/. Besides the runoff map of Sweden gives values for the period 1931-60 /9/.

Table 2.1.3 Characteristic values for discharge and runoff in Nyköpingsån and Svärtaån

	Nyköpingsån 1909-38		Svärtaån 1934-50,1952-54 1958-1975	
	m^3/s	$l/s,km^2$	m^3/s	$l/s,km^2$
Highest highwater flow	104	29	2.36	39
Average highwater flow	53	14.8	1.07	17.5
Highest annual flow	41	11.5	0.67	10.9
Longterm average flow	24	6.8	0.40	6.6
Lowest annual flow	10.7	3.0	0.14	2.3
Average lowwater flow	8.7	2.4	0.11	1.8
Lowest lowwater flow	2.1	0.6	0.00	0.0

The characteristic values of Nyköpingsån represent almost the whole water course. The river has a high lake percentage of 14.0. Of Sweden´s total area 8.6 % consists of lakes /10/.

The discharge values of Svärtaån come from the north-east part of the river basin, covering an area of 61 km^2 with a very high lake percentage of 20.5. The whole drainage basin is 342 km^2 with a lake percentage of 8.3. This means that the high- and lowwater flow will differ from those given in table 2.3. However it is possible to calculate the average high- and lowwater according to the Bergstens formulas /11/. These values becomes 33 and 1 l/s, km^2 respectively. The longterm average runoff is almost equal for the two basins. However, one has to be careful when comparing them, because they stand for different periods. However, these values are consistent with the average annual runoff for the period of 1931-60, that is around 6.5 l/s, km^2 equal to 205 mm.

A calculation for a small drainage area as Morpasjön shows that average highwater will be about 12 times higher than the average flow.

This is also valid for the primary recipients in Voxnan and Gideå.

The average lowwater is about 15-20 times lower than the average flow.

However the variation of the annual average flow for the larger areas is a factor of ±2. That means that turnover time will be affected to the same extent.

Gottschalk /12/ has studied monthly river runoff for rivers all over Sweden. Nyköpingsån is one of them. He found that the runoff varied between 4 to 11 l/s, km^2. The variation and skew coefficients are 0.36 - 0.66 respectively 0.20 - 1.69. During the period 1974-1981 values of the runoff in Nyköpingsån are available /8/. The mean for this period is 5.9 l/s, km^2 i.e somewhat lower than for the period 1909-1938. The low value is explained by the very dry year 1976 when the runoff was only 0.8 l/s, km^2.

The runoff value of 6.5 l/s, km^2 has been used to calculate the turnover times for the different recipients. These values are summarized in table 2.1.4.

Tabel 2.1.4 Turnover time

Recipient	Turnover time (days)
Nyköpingsån	
Morpasjön	1 280
Lidsjön	145
Båven	2 340
Lidsjön	145
Långhalsen	145
Nyköpingsfjärden	8
Svärtaån	
Sågsjön	260
Glottran	2 960
Kappstasjön	185
Eknaren	260
Ludgosjön-Runnviken	185
Likstammen	1 570

An estimate of the turnover time of a channel reach of Nyköpingsån south of Långhalsen showed that water is exchanged very fast. The calculated turnover time was around 12 hours. The Manning equation and the following relation for the turnover time have been used

$$T = \frac{l}{v}$$

T = turnover time
l = channel reach
v = water velocity

2.1.2.2 Physical and chemical characteristics

The water quality of a recipient is determined by its physical and chemical characteristics. The most important physical characteristics are temperature, colour, turbidity, suspended material, conductance and odour.

The chemical characteristics are besides the major constituents (calcium, sodium, magnesium, potassium, iron, bicarbonate, carbonate, sulfate, chloride, nitrate), pH, alkalinity, total hardness, oxygen content, and permanganate oxygen consumption.

Data of the above mentioned characteristics have been obtained from Nyköping Association for Water Conservation /8/, Public Health Office in the community of Nyköping /13/ and from our own measurements.

Within the drainage basin of Nyköpingsån results from the outlet of Lidsjön (Husbyån) and the outlet of Nyköpingsån in Nyköping have been obtained. The period studied is from 1974 to 1981, see table 2.1.5.

Table 2.1.5 Average value and coefficient of variation of physical and chemical data from Nyköpingsån and Husbyån 1974-1981

Parameter	Nyköpingsån Average	Nyköpingsån Coefficient of variation	Husbyån Average	Husbyån Coefficient of variation
pH	7.1	0.04	7.1	0.05
$KMnO_4$ mg/l	34.1	0.07	23.3	0.13
Total-P mg/l	0.064	0.31	0.044	0.57
Total-N mg/l	1.1	0.06	0.8	0.21
Oxygen mg/l	10.1	0.11	10.7	0.06
Conductance mS/m	17.0	0.09	14.8	0.09
Turbidity FTU	6.0	0.20	6.1	0.56
Suspended material mg/l	7.4	0.28	6.1	0.48

The values do not differ much between the two stations. However, Nyköpingsån has a higher content of the different constituents. The variation between different years is highest in Husbyån.

The annual mean transport of different constituents in the outlet of Nyköpingsån is found in table 2.1.6.

Table 2.1.6 Annual transport of suspended materials, organic material, phosphorous and nitrogen, Nyköpingsån 1974-1981

Parameter	Average	Coefficient of variation
Discharge m^3/S	21.5	0.42
Suspended material ton/year	5700	0.56
Organic material ton/year	23130	0.43
Total-phosphorous ton/year	45	0.59
Total-nitrogen ton/year	783	0.45

A comparison between Nyköpingsån and Svärtaån /12/ showed higher content of constituents in Svärtaån. This is, among other things, shown by the turbidity of 40.5 in Svärtaån. The correspon-ding value in Nyköpingsån is 9.1.

At our field survey in Fjällveden we measured pH and conductance at some different places within the area.

In Figure 2.1.2 the different sampling points are shown and the results from the survey 82-06-22 are found in Table 2.1.7.

Table 2.1.7 Conductance and pH in Fjällveden 820622

Sampling point	Type	pH	Conductance mS/m
Lidsjön	Lake	7.2	13.6
Morpasjön	Lake	7.0	9.2
Sågsjön	Lake	5.6	5.2
Glottran	Lake	7.3	11.9
Kappstasjön	Lake	6.3	11.2
-	Brook	6.9	11.6
Tallmon	Spring	4.3	3.9
Lövhagen	Well	5.1	9.9
Sågsjön	Drilled well	7.5	24.9
Svista	Well	6.6	45.8

2.1.2.3 Water utilization

The water is a resource that is used for many purposes, as for water supply, waste water discharge, water power, recreation, navigation, fishery and irrigation. In respect to this study the consumption of drinking water, fishery and irrigation are the most important demands of water to discuss.

Within the Fjällveden area the drinking water is taken from wells. They can be drilled or dug. No surface water is used for municipal supply further down in the water courses. The water supply for Nyköping is arranged by infiltration of surface water from Yngaren to a groundwater reservoir in glacialfluvial materials. In Södermanland only 6 % of the municipal water comes from surface water /14/. The average for the whole Sweden is 52 %.

The interest of irrigation of arable and pasture land has increased in recent years. In Södermanland 29.2 km^2 was irrigated 1975 /15/, i.e. 1.4 % of the arable land. The distribution among different crops is presented in table 2.1.8.

Table 2.1.8 Irrigation, Södermanland county 1975

Crops	Percentage
Grain	36.3
Ley	20.9
Pasture	20.2
Oleiferous crops	15.8
Potatoes	3.8
Horticulturals	1.7
Others	1.3

It has not been possible to find the yield of freshwater fish in the lakes and the rivers. However, a rough estimate of the average yield can be done if the yearly catch is divided by the water area, this gives a value of 2.6 kg/ha, year /16/. This value must however be an underestimate for eutrofic lakes in the Fjällveden area.

2.1.3 Land use

The different types of land in Södermanland are found in table 2.1.9

Table 2.1.9 Types of land according to the National Forest Survey 1973-1977 Södermanland

Type	Area (km^2)	Percentage
Forest land	3360	55.4
Arable land and pasture	2070	34.2
Swamp	80	1.3
Rock surface	360	5.9
Other land	190	3.1

Source: SCB /16/

Table 2.1.10 Use of arable land in Södermanland 1981

Crops	Area (km^2)
Cereals	725
Oleiferous	114
Fodder	299
Peas and beans	6.3
Potatoes	3.4
Horticultural plants	1.9

Source: SCB /15/

2.1.4 Yield from arable and horticultural land

The yield of cereals, ley and potatoes have been found for the different counties. Concerning the horticultural plants the total yield for the whole county is given.

Table 2.1.11 Yield of cereals, ley and potatoes in Södermanland county 1981

	Yield kg/m^2
Wheat and rye	0.38
Barley and oats	0.42
Ley	0.51
Potatoes	2.9

Source: SCB /15/

In 1981 the yield was 5-10 % above the average of the last five years.

The yield of winter wheat for the whole country has increased with about 0.006 kg/m^2, year during 1925-1975. The corresponding figure for barley is 0.004 kg/m^2, year. Then the yield has stagnated around 0.45 kg/m^2 for winter wheat and 0.35 kg/m^2 for barley.

A rough estimate shows that a change in mean air temperature of 1 ^{o}C will change the yield of cereal with about 10 %.

Table 2.1.12 Weighted yield of vegetables, fruits and berries in Sweden 1976

	Yield (kg/m^2)
Vegetables	3.1
Fruits	0.90
Berries	0.45

Source: SCB /15/

The carrots dominate the yield of vegetables. The apples stand for about 3/4 of the fruits and are as dominating as the strawberries are for the berries.

It can be mentioned that the estimated annual supply of wild berries are 0.0018 kg/m^2 /14/.

2.1.5 Model description

2.1.5.1 Model system

The model system as defined in Figure 2.1.3 is obtained from the study of the recipient area in Fjällveden.

Morpasjön constitutes the primary recipient. Except the water reservoir two sediment boxes are used, one with exchange with the waterbox, the other acting as a sink. From Morpasjön the water flows into the lake system of Lidsjön and Långhalsen. Finally the water is transported through Nyköpingsån and Nyköpingsfjärden to the Baltic. From the reservoir Lidsjön-Långhalsen water is taken for irrigation of farming-land. The irrigated area of the drainage area is thereby the same as for the county of Södermanland, namely 1.4 %. The elements brought by the irrigation is then infiltrating down through the two soil-reservoirs before reaching the ground water. The nuclides are transported back to the surface water reservoir by runoff from the groundwater. All surface water reservoirs have two sediment reservoirs in connection to be able to simulate both the transport back to the water as well as the dispersion out from the system. In table 2.1.9 the sizes and the transfer coefficients related to the turnover of surface water in the model system are shown.

2.1.5.2 Reservoir sizes and transfer coefficients

The volumes of the surface water reservoirs and the transfer coefficients which describe the water turnover in them are summarized in table 2.1.9.

Table 2.1.9 Reservoir volumes and transfer coefficients for the water reservoirs in Fjällveden area

Reservoir	Volume (m^3) x 10^6	Transfer coefficient ($year^{-1}$)
Morpasjön	3.2	0.3
Lidsjön-Långhalsen	382.9	2.5
Nyköpingsfjärden	19.0	45.6

The sizes of the influenced soil reservoirs are determined by the irrigation intensity.

The transfer rate caused by irrigation has been calculated by use of the following assumptions.

- The locally situated landareal which can be influenced by irrigation is about 290 km^2.

- The farming land is the same fraction as for the whole county, namely 34 %.

- The irrigated areal is the same fraction of the total arable land as for the whole county, namely 1.4 %.

- 100 mm per year is added by irrigation.

That will give an annual addition of 1.4×10^5 m^3 water.

The volume of the water reservoir is 383×10^6 m^3 which will give a transfer rate of 3.7×10^{-4} $year^{-1}$.

The irrigated area is then 1.4 km^2.

The dry density of soil can be estimated to be about 1.4 g/cm^3. The upper soil reservoir has a depth about 30 cm and for the lower or deeper soil the corresponding value is 2 m.

The derived values are shown in table 2.1.10.

In the same table the relevant permeability for the area is also shown.

Table 2.1.10 Reservoir size and permeability value for the soil reservoirs in the Fjällveden area

Reservoir	Mass (kg)x10^6	Permeability (m/s)
Upper soil	5.9×10^2	10^{-7}
Deeper soil	3.9×10^3	5×10^{-8}

The size of the upper two sediment reservoires is derived by the areal of the lake, a mean depth of 10 cm and a density of 1.2 g/cm^3. As the deeper sediment reservoir only acts as a sink, it is not necessary to specify any values.

The groundwater has an estimated volume of 1.4×10^6 m^3.

2.1.6 Exposure pathways

For all areas the occurence of a well and the corresponding exposure pathways are not treated in this report. For the Fjällveden area the primary recipient for the groundwater borne nuclides is supposed to be the Morpasjön, which is a small lake mostly surrounded by forests. Some small houses are in the north of the lake and in the south there are some summer-houses. Possible exposure pathways have then been judged to be by eventual utilization of the water in Morpasjön for consumption by man and animals. Naturally the exposure from consumption of fish taken from Morpasjön is also included.

At present there is no evidence for including further exposure pathways according to the conditions at Morpasjön.

The Lidsjön-Långhalsen region which is the next receiver of the nuclides (transported by the water) the whole span of exposure pathways are represented. The water is used for irrigation which implies that all the terrestial exposure pathways according to the BIOPATH code are applicable.

The exposure pathways are:

inhalation
drinking water
milk
meat
cereals
vegetables
root-fruits
egg.

Also consumption of fish caught in the area is another possible exposure pathway.

The next reservoir is the Nyköpingsfjärden where the dominating exposure pathway is consumption of marine food-stuffs. Some few cows can during the summer be seen along the shore, but contribution from milk or meat from those animals cannot have any influence upon the collective doses.

2.1.7 Classification

An area can be classified in many respects. For example the Fjällveden area belongs to a hydrological region called "The rivers of Southern Sweden - eastern rivers" (Fa)according to Melin /12/. In the Fa-region the snowmelt or a combination of rain and snowmelt form the main runoff in the spring. In summer and autumn the runoff is low. The winterflow is moderate.

Another way of classifying the area is with respect to the physical water quality and suspended material transport. This has been done by Brandt /17/. The transport of suspended and dissolved matter is determined by discharge, physiography, geology, land use and human impact, i.e. these transports reflect what type of landscape the water courses pass. Sweden is divided into 8 main regions. Fjällveden belongs to region 5 - Central Sweden around the lakes Mälaren-Hjälmaren and the Östergötland district.

The transport of matter is around 5 ton/km^2, year for large areas (Fyrisån). The dissolved matter is 20-60 ton/km^2, year. The mean of conductivity is around 10 mS/m.

A report by a working group, established by the Nordic Council of Ministers, has divided Norden into physical geographic regions /6/. The vegetation has been the basic criteria for the subdivision, because it reflects the properties of soil and climate. Other important parameters except the three mentioned are geology, geomorphology, land use etc.

The Fjällveden area belongs to region 24 - Fissure Valley Landscape of Eastern Svealand.

2.2 The Voxnan area

2.2.1 General description

The Voxnan area, 61° 20'N, 15° 30'E, is situated 75 km west of Söderhamn in Hälsingland.

2.2.1.1 Climate

The climate zone is Dcf according to the Köppen classification. This means the cold snow-forest climate with no dry season and maximum three months with a mean temperature of +10^{o}C.

The annual mean air temperature in Edsbyn, 20 km east of Voxnan, is +3.8^{o}C. In January and July the mean temperature is -7.2^{o}C respectively +15.8^{o}C.

The annual mean precipitation (1931-60) is 561 mm (uncorrected) for Edsbyn. According to Eriksson /1/ the correction for Hälsingland is +24 %, i.e. the corrected precipitation is 696 mm. This value is close to the mean value of Hälsingland that is equal to 691 mm.

2.2.1.2 Hydrology

The average annual runoff for Hälsingland is 300 mm, equal to 9.5 l/s, km^2. The value of Voxnan is approximately the same, 9.9 l/s, km^2, see table 2.2.3.

The potential evapotranspiration in Edsbyn is calculated to 528 mm/y /4/. The calculated evaporation for Hälsingland is 414 mm. The evaporation value shall be lower than the potential evapotranspiration because of water deficit.

2.2.1.3 Bedrock and soil

The rock is the same as in Fjällveden, i.e. sedimentary gneiss.

Voxnan is situated in the Inland glacial till and bog area. This region covers the interior of

Sweden from Lake Vättern to the northern part of Sweden.

The highest part of Voxnan is close to the highest shoreline.

2.2.1.4 Vegetation

The vegetation zone is Intermediate Boreal, weakly continental, i.e. coniferous forest dominates.

2.2.2 Recipients

2.2.2.1 Drainage areas, lakes and discharge

The Voxnan area has also been divided into two main recipient areas. The eastern part is drained by Älmån to Voxnan. Brynåsbäcken drains the western part, see Figure 2.2.2, where Norra Brynåssjön is primary recipient. The correspon-ding recipient in the drainage area of Älmån is the oligotrophic Älmessjön. The drainage areas are found in table 2.2.1.

Data of the lakes with the drainage areas are shown in table 2.2.2.

Table 2.2.1 Drainage areas - Voxnan

Drainage basin	Area (km^2)	Lake Percentage (%)
Northern Brynåssjön	7.1	6
The outlet of Brynåsbäcken into Voxnan	13.1	4.2
The outlet of Älmessjön	6.0	5.8
Älmån upstream Älmessjöbäcken	47	-
The outlet of Älmån into Voxnan	67	5.4
Voxnan upstream Älmån	2341	6.0
Voxnan at Alfta	3140	6.3
The outlet of Voxnan into Ljusnan	3710	6.1
Ljusnan over Varpen	15230	3.1
The outlet of Ljusnan into the Bothnian sea	19820	4.1

Sources: /7/, /18/ and STUDSVIK calculation

Table 2.2.2 Surface water - area, depth and volume

	Area (km^2)	Depth (m)	Volume (m^3)
Brynåsbäcken			
Northern Brynåssjön	0.17	2	3.4×10^5
Älmån			
Älmessjön	0.32	3	9.6×10^5
Voxnan - river including lakes	10.8	3*	3.2×10^7*
Norrsjön in Voxnan	2.4	3*	7.2×10^6
Ljusnan river including lakes	69.5	7*	4.9×10^8

* estimated value

The discharge for the two main rivers Voxnan and Ljusnan are presented in table 2.2.3

Table 2.2.3 Characteristic values of discharge and runoff in Voxnan and Ljusnan

	Voxnan, Nybro 1914-25, 1940-43		Ljusnan, Ljusdal 1939-61	
	m^3/s	$l/s,\ km^2$	m^3/s	$l/s,\ km^2$
Highest highwater flow	242	107	1 386	107
Average highwater flow	99	44	840	62
Highest annual flow	39	17.3	224	16.5
Longterm average flow	22	9.9	167	12.3
Lowest annual flow	14.2	6.3	102	7.5
Average lowwater flow	4.9	2.2	46	3.4
Lowest lowwater flow	2.0	0.89	24	1.8

The station Nybro in Voxnan is situated between the outlets of Brynåsbäcken and Älmån. Its drainage area is 2 252 km^2. The river Voxnan is thus recipient for the two alternative streams. Voxnan itself enters Ljusnan at Bollnäs. It is about 50 km from Bollnäs down to the coast of Bothnian Sea. The river Ljusnan runs through the two large lakes Bergviken and Marmen on its way to the sea.

The station Ljusdal is situated 60 km north of the confluence of Ljusnan and Voxnan. The drainage area is 13 605 km^2, with a low lake area of 2.7 %.

The runoff value of 10 $l/s,\ km^2$ has been used for calculations of the turnover time, see table 2.2.4.

Table 2.2.4 Turnover time

Recepient	Turnover time (days)
N Brynåssjön	55
Älmessjön	185
Norrsjön in Voxnan	2.8
Voxnan-river, including lakes	14
Ljusnan-river including lakes	24

2.2.2.2 Physical and chemical characteristics

Physical and chemical data have been obtained from Voxnan-Ljusnans Association for water conservation /19, 20/. However, these values only show the conditions at the time of sampling. No time series have been found that could tell about eventual trends.

Table 2.2.5 Physical and chemical parameters within the drainage area of Voxnan

Watercourse	Date	pH	Alcalinity mekv/l	Conductance mS/m	Colour
N Brynåssjön	810301	6.2	0.15	4.0	90
Älmessjön	810312	6.2	0.18	4.3	110
Älmån	800703	6.8	0.19	3.9	120
Norrsjön	800821	6.9	0.17	3.5	55

2.2.2.3 Water utilization

No water is used for consumption or irrigation in the primary recipients. The drinking water is taken from wells. The water in Voxnan is used for irrigation and an increased withdrawal is expected. Water from Norrsjön at Alfta is infiltrated into the ground to form groundwater for consumption. The permitted withdrawal is 1 100 m^3/d.

The irrigated area in Gävleborg county 1975 was only 4.5 km^2, equal to 0.3 % of the arable land. The distribution among the different crops is shown in table below.

Table 2.2.6 Irrigation, Gävleborg county 1975

Crops	Percentage
Grain	8.9
Ley	13.3
Pasture	44.4
Potatoes	17.8
Horticulturals	8.9
Others	6.7

2.2.3 Land use

No special study of the distribution of type of land within the Voxnan area has been done. However, the available distribution of land in Gästrikland is applicable to this area, see tables below.

Table 2.2.7 Type of land according to the National Forest Survey 1973-77, Gävleborg county

Type	Area (km^2)	Percentage
Forest land	14 770	81.2
Arable land and pasture	1 350	7.4
Swamp	1 550	8.5
Rock surface	210	1.2
Other land	310	1.7

Table 2.2.8 Use of arable land in Gävleborg county 1981

Crops	Area (km^2)
Cereals	367
Oleiferous	2
Fodder	354
Peas and beans	0.6
Potatoes	6.6
Horticultural plants	0.6

2.2.4 Yield from arable land

The yield of cereals, ley and potatoes in the Gävleborg county is shown in table 2.2.9. Concerning the horticultural plants, see table 2.1.12.

Table 2.2.9 Yield of cereals, ley and potatoes in Gävleborg county 1981

	Yield (kg/m^2)
Barley and oats	0.30
Ley	0.54
Potatoes	2.1

2.2.5 Model description

2.2.5.1 Model system

The study of recipient areas in Voxnan has led to the model system that is found in Figure 2.2.3. The chosen primary recipient is Älmessjön, with two sediment layers, one with exchange with the lake water, the other representing a sink.

The river Voxnan is the next reservoir, where the water is used for irrigation. After transport by the irrigation water to farming-land the nuclides are migrating through the two soil-layers before entering the groundwater zone. The runoff of groundwater carries the nuclides back to the Voxnan reservoir. The next recipient is Norrsjön where the water withdrawl is used for infiltration. The recharge area and the groundwater are illustrated by two reservoirs, see fig 2.2.3.

Finally the discharge goes into Ljusnan and out into the Bothnian Sea.

No sedimentation is expected in the river reach. The most important sedimentation is assumed to take place in the different lake systems.

2.2.5.2 Reservoir sizes and transfer coefficients

The volumes and transfer coefficients of the surface water system of the Voxnan area are summarized in table 2.2.9.

Table 2.2.9 Reservoir volumes and transfer coefficients of the different surface water reservoirs in the Voxnan recipient area

Reservoir	Volume $(m^3)x10^6$	Transfer coefficient $(year^{-1})$
Älmessjön	9.6×10^{-1}	2.0
Voxnan	3.2×10	26
Norrsjön	7.2	130
Ljusnan	4.9×10^2	15

From Voxnan we assume that water is taken for irrigation of pasturage and potatoes. The agriculture in the surroundings of the river is not at all of such dignity as in the south of Sweden.

The area influenced by future irrigation has been received as follows:

- The length between the inflow of Älmesån to Voxnan and down to Norrsjön has been estimated to be about 15 km.
- 500 m at each riverside is supposed to be eventually influenced.
- 30 % of that area is supposed to be farming-land.
- 10 % of the farming-land is assumed to be irrigated with water from the river.
- Annual amount of water added by irrigation is 100 mm.

This will give an irrigated area of 0.45 km^2 and the transfer coefficient will be 1.4×10^{-3} $year^{-1}$.

The masses of the corresponding reservoirs are shown in table 2.2.10 where also the permeability values used for calculation of the nuclide-specific transfer coefficients are shown.

The volume of the groundwater is estimated to be 4.5×10^5 m^3.

From Norrsjön water is taken to a recharge area estimated to be about 650 m^2. Such a recharge area constitutes of an upper rather course material which can have a depth of about 0.5 m. The permeability is rather high, an estimated value of 5×10^{-5} m/s seems reasonable.

Table 2.2.10 Resevoir size and permeability values for the soil reservoirs influenced by irrigation from Voxnan

Reservoir	Mass(kg)x10^6	Permeability (m/s)
Upper soil	1.9×10^2	10^{-7}
Deeper soil	1.3×10^3	5×10^{-8}

2.2.6 Exposure pathways

The primary recipient for the groundwater borne nuclides in the Voxnan area has been supposed to be Älmessjön. This lake is not utilized for any drinking water as there are wells situated in a nearby esker which satisfies the need of water for the people living there.

Concerning animals there are at present sheep grazing near the lake which of course can use the water for consumption. These ought to be of minor importance relative to animals fed for the purpose of producing milk.

This has implied that the only relevant exposure pathway has been deemed to be the consumption of fish caught in the lake. From the primary recipient the nuclides are transported further by the water-turnover to the Voxna.

At present this river is mainly used for fishing, but there is a strong possibility that in the near future the water will to a greater extent be used for irrigation of pasturage and potatoes. So the follwing terrestrial exposure pathways will be taken into consideration for the Voxna region:

- inhalation
- milk
- meat
- potatoes.

Naturally fish caught in the river will also be included.

Further down in the water system there are some small lakes formed. One of them is included in the model system, namely Norrsjön. From that lake water is taken to a recharge area for purification before utilized as drinking-water. Consequently the exposure from this area is only through the two exposure pathways, drinking-water respectively consumption of fish. The drinking water is naturally taken from the groundwater-reservoir coupled to the recharge area.

The last region before the Bothnia sea is the Ljusnan river. The only relevant exposure pathway there is the overall presented consumption of fish.

2.2.7 Classification

Hydrologically the Voxnan area can be classified as belonging to region D - Mountain and Forest Rivers in the south of Norrland and north of Svealand /12/. The snow melt runoff is more pronounced in this region compared to the Fa-region which Fjällveden belongs to. The coefficient of monthly variation is rather high, 0.44 for Ljusnan,and the skewness is around 1.0.

The water quality and suspended material transport classification /17/, see paragraph 2.1.6, for Voxnan, is 2B - the interior of southern Norrland. In this region the following is valid:

Suspended total material	4-10 mg/l
Suspended inorganic material	2- 6 "
Dissolved matter	15-50 "
Conductivity	2- 5 mS/m
Colour	10-40 mg Pt/l

Transport of suspended material: 2-3 ton/km^2
Transport of dissolved material: 8-20 "

The physical geographic region is <u>28b - Hilly lands of the southern boreal region.</u> The southern limit of this region mainly follows the "limes norrlandicus". The terrain is undulating hilly with fine sediments in between.

2.3 The Gideå area

2.3.1 General description

The Gideå area, 63° 30'N, 19° 05'E, is situated 30 km north-east of Örnsköldsvik, Ångermanland.

2.3.1.1 Climate

The climate zone is Dcf, i.e. the same as for Voxnan. The closest climate station is Umeå, with an annual mean air temperature of $+3.2^{\circ}C$ (1931-60). In January the mean air temperature is $-7.8^{\circ}C$ and for July $+16^{\circ}C$.

The annual mean precipitation (1931-60) in Umeå is 602 mm (uncorrected). The correction for Ångermanland is +20 % and +22 % for Västerbotten. Thus the corrected value will become around 730 mm.

2.3.1.2 Hydrology

The average annual runoff for Ångermanland is 320 mm, equal to 10.2 l/s, km^2.

The potential evapotranspiration in Umeå is calculated to 450 mm/y /14/. The calculated evaporation in Ångermanland county is 376 mm/y.

2.3.1.3 Bedrock and soil

The bedrock in the Gideå area is the same as in Fjällveden and Voxnan, i.e. sedimentary gneiss.

The soil region is "The coastal zone of Norrland". Glacial till is the dominating soil type. Bare rock covers about 20 % of the area.

2.3.1.4 Vegetation

The vegetation zone is "Intermediate Boreal", i.e. the same as in Voxnan.

2.3.2 Recipients

2.3.2.1 Drainage areas, lakes and discharge

The Gideå area is drained by the two main water courses Gideåälven and Husån, see Figure 2.3.2. The primary recipient that has been chosen is the dam in Gideåälven at Gideå Bruk. The recipient is poor in nutrients, i.e. oligotrophic. No natural primary recipient in the eastern area has been found, eventually Skademarkssjön could be used.

A coastal recipient where Gideälven and Husån have their outlets is also included.

Tables 2.3.1 and 2.3.2 summarize the different drainage areas and the data for the surface water.

Table 2.3.1. Drainage areas - Gideå

Drainage basin	Area (km^2)	Lake Percentage (%)
Western outlet of the test-site area into Gideälven	6.3	0.0
Eastern outlet of the test-site area into Husån	9.0	0.0
Skademarkssjön	3.6	6.9
Gideälven	3 430	5.1
Husån	580	8.0

Table 2.3.2 Surface water - area, depth and volume

	Area (km^2)	Depth (m)	Volume (m^3)
Gideälven			
Dam at Gideåbruk	0.45	5	2.3×10^6
Reach downstream Gideåbruk	0.20	3*	6.0×10^5
Husån			
Skademarkssjön	0.25	3	7.5×10^5
Reach downstream Västersjön	0.10	2*	2.0×10^5
Coastal area	3.5	9	3.1×10^7

* estimated values

Characteristic discharge values for Gideälven are presented in table 2.3.3.

Table 2.3.3. Characteristic values for discharge and runoff in Gideälven

Characteristic values	Björna 1923-75 m^3/s	Björna 1923-75 $l/s, km^2$
Highest highwater flow	382	127
Average highwater flow	174	58
Highest annual flow	49	16.2
Longterm average flow	32	10.5
Lowest annual flow	19.8	6.6
Average lowwater flow	6.4	2.1
Lowest lowwater flow	2.8	0.9

The discharge station Björna is situated upstream Gideå with a drainage basin of 3 017 km^2.

The river reach of Gideälven downstream Gideå is about 16 km, and Husån is approximately 20 km downstream Skademarkssjön.

A runoff of 10 l/s, km^2 has been used to calculate the turnover times, see table 2.3.4.

The water exchange in the coastal bay is dominated by the freshwater inflow. Because of that the river discharge has been used to calculate the turnover time.

Table 2.3.4 Turnover time

Recipient	Turnover time (days)
Dam at Gideå bruk	0.8
Reach downstream Gideå	0.2
Skademarkssjön	241
Coastal area	9

2.3.2.2 Physical and chemical characteristics

It has been difficult to find relevant data within or in the vicinity of the area. A report of the acidification /21/ gives some information.

In table 2.3.5 measurements from a field survey and from reference 21 are presented.

Table 2.3.5 Physical and chemical data within the drainage area of Voxnan and Husån

Watercourse	Date	pH	Conductivity mS/m	Alcalinity mekv/l	Colour mg Pt/l
Gideälven	820821	6.2	2.2		
Western stream	"	4.5	4.1		
Husån	"	6.1	2.5		
Eastern stream	"	5.9	2.3		
Skademarkssjön	Nov 1976	6.2	3.5	0.14*	31*

* reference /21/

2.3.2.3 Water utilization

The water from the rivers is not used for either consumption or irrigation.

The only interesting utilization of water is fishing. In Gideälven the annual fish yield is as high as 40 kg/ha. The corresponding value in Husån is around 25 kg/ha.

2.3.3 Land use

The land types of Västernorrland are presented in table 2.3.6. This distribution is roughly correct for Gideå. However, the arable land and pasture area are smaller and the swamp area is larger.

Table 2.3.6 Type of land according to the National Forest Survey 1973-77 Västernorrland county

Type	Area (km^2)	Percentage
Forest land	17 320	79.5
Arable land and pasture	1 380	6.3
Swamp	2 000	9.2
Rock surface	690	3.2
Other land	390	1.8

Table 2.3.7 Use of arable land in Västernorrland 1981

Crops	Area (km^2)
Cereals	202
Fodder	367
Peas and beans	0.5
Potatoes	7.9
Horticultural plants	0.9

2.3.4 Yield from arable land

Table 2.3.8 shows the yield in Västernorrland county.

Table 2.3.8 Yield of cereals, ley and potatoes in Västernorrland county 1981

	Yield (kg/m^2)
Barley and oats	0.33
Ley	0.47
Potatoes	2.3

2.3.5 Model description

2.3.5.1 Model system

The model system of Gideå, Figure 2.3.3, is simple compared to the other two areas. The system consists of a primary recipient, a dam in Gideälven with two sediment reservoirs, the Gideälv itself and a coastal area also including two sediment reservoirs.

2.3.5.2 Reservoir sizes and transfer coefficients

The size of the different rservoirs in the Gideå recipient area are summarized in table 2.3.9. The transfer coefficients for describing the water-turnover are also included.

Table 2.3.9 Reservoir volumes and transfer coefficients for the Gideå area

Reservoir	Volume (m^3)	Transfer coefficient ($year^{-1}$)
Dam at Gideå bruk	2.3×10^6	456
Sediment underlying the dam	4.5×10^4	
Gide älv	0.6×10^6	1 825
Coastal area	3.1×10^7	41
Sediment underlying the coastal area	3.5×10^5	

2.3.6 Exposure pathways

The Gideå recipient area constitutes mostly of forest which is typical for the north of Sweden. The primary recipient is a dam situated at Gideå. There are some small houses situated thereby, so there is a possibility for using the water from the dam for consumption both of man and animals. That has implied that the following exposure pathways can be included:

- drinking water
- milk and meat contaminated by the animals drinking water.

Naturally the consumption of fish is also included.

By the transport of the nuclides further on in Gideälven exposure is also possible from fish caught there.

Finally, as the nuclides are transported to the coast, they can reach man via consumption of marine food-stuffs.

2.3.7 Classification

Hydrologically the Gideå area belongs to region E - Forest and Coastal Rivers of Norrland /12/. The maximum discharge is in May, around 30-35 l/s, km^2. The coefficients of variation and skewness are somewhat higher than for example Ljusnan, but are more evenly distributed over the year.

The water quality and transport classification of the Gideå area is 3A - Coastal Area of Norrland, Northern Part.

Relevant values of this region are:

Suspended total material	3 - 8 mg/l
Suspended inorganic material	1 - 5 "
Dissolved matter	30 - 50 "
Conductivity	2 - 6 mS/m
Colour	40 - 90 mg Pt/l

Transport of suspended material	1 - 28 ton/km^2
Transport of dissolved material	8 - 20 "

The physical geographic region is 29a - Coastal Plains and Valleys with Marine Sediments at the Gulf of Bothnia. The landscape is characterized by plains and undulating terrain with low hills.

2.4 The Kamlungekölen area

2.4.1 General description

The Kamlungekölen area, 66° 07' N, 22° 55' E, is situated about 70 km north-east of Luleå in the county of Norrbotten, see Figure 2.4.1.

2.4.1.1 Climate

The climate zone of Kamlunge is Dcf, according to the classification by Köppen.

The annual mean air temperature in Haparanda, 60 km east of the test site, is +1.6 $^{\circ}$C. In January and July the mean temperature is -10.6 $^{\circ}$C respectively +16.3 $^{\circ}$C.

The annual mean precipitation (1931-60) is 552 mm (uncorrected). According to Eriksson /1/ the correction is +23 %, i.e. the corrected precipitation is equal to 680 mm. The corrected value for the whole Norrbotten is 630 mm.

2.4.1.2 Hydrology

The average annual runoff for Norrbotten is 300 mm, equal to 9.5 l/s, km^2. The runoff value of Sangisälven is somewhat higher 10.7 l/s, km^2.

The potential evapotranspiration in Haparanda is 350 mm. The calculated evaporation for Norrbotten is 334 mm.

2.4.1.3 Bedrock and soil

The rock in Kamlunge is dominated by the Lina granites.

Kamlunge is situated in the Inland glacial till and bog area.

2.4.1.4 Vegetation

The vegetation zone for Kamlunge is "Intermediate Boreal".

2.4.2 Recipients

2.4.2.1 Drainage areas, lakes and discharge

The Kamlungekölen is divided into two main recipient areas. The eastern part is drained to Korpikån and Sangisälven. The recipient of the western part is the Kalixälven, see Figure 2.4.2. The western primary recipient is Idträsket, a small tarn. Because of the growth of vegetation nowadays in the tarn, it will vanish in the near future. Idträskbäcken flows into the Granträsket, which could be an alternative to Idträsket.

Häggmantjärnen in the eastern part is also a small, shallow tarn. It is also possible that it will disappear in the future. It does not exist an alternative recipient in the eastern part that is drained to the Sangisälv. However, Stor-Lappträsket is thc best alternative for the whole area, because two main fracture zones encounter each other there. The drainage areas are found in table 2.4.1.

Table 2.4.1 Drainage areas - Kamlungekölen

Drainage basin	Area (km^2)	Lake Percentage (%)
Idträsket	3.2	
St Lappträsket	15.0	
Häggmantjärnen	0.7	10.0
Korpikån	395	2.1
Sangisälven	1250	6.2
Kalixälven at Räktfors	22999	2.9

Table 2.4.2 Surface water - area, depth and volume

Lake	Area (km^2)	Depth (m)	Volume (m^3)
Häggmantjärnen	0.08	2.5*	2.0×10^5
Idträsket	0.15	2*	3.0×10^5
Granträsket	0.8	7	5.6×10^6
St Lappträsket	4.1	8	3.3×10^7
Lower Kalix älv, smooth water-reach	7.5	2*	1.5×10^7
Lower Kalix älv, rapids	0.5	0.5*	2.5×10^5
Repskärsfjärden	64	6	3.8×10^8

* estimated value.

The discharge of the two main rivers, Kalixälven and Sangisälven are presented in table 2.4.3.

Table 2.4.3. Characteristic values of discharge and runoff in Kalixälven and Sangisälven

Characteristic values	Kalixälven, Räktfors 1937-75		Sangisälven, Kukkasjärvi 1924-68	
	m^3/s	$l/s, km^2$	m^3/s	$l/s, km^2$
Highest highwater flow	2000	87	49	98
Average highwater flow	1392	61	30	59
Highest annual flow	364	15.8	8.5	16.9
Longterm average flow	276	12.0	5.4	10.7
Lowest annual flow	193	8.4	3.0	6.0
Average lowwater flow	49	2.1	0.5	1.0
Lowest lowwater flow	30	1.3	0	0

The discharge gauging station Räktfors in Kalixälven is close to the outlet from Granträsket.

The station Kukkasjärvi is situated north of the conjunction of Korpikån and Sangisälven. The drainage area is 502 km^2.

The runoff value of 12 $l/s, km^2$ has been used for the calculations of turnover time, see table 2.4.4.

Table 2.4.4 Turnover time

Recipient	Turnover time (days)
Häggmantjärnen	300
Idträsket	90
St Lappträsket	2120
Lower Kalix älv	1
Repskärsfjärden	10

2.4.2.2 Physical and chemical characteristics

Data concerning water chemistry etc have been obtained from the County Administration of Norrbotten. Values representing some different periods are found in the table below. There are unfortunately no available time series representing the annual variations.

Table 2.4.5 Physical and chemical data of surface water

Water course	Date	pH	Alcalinity mekv/l	Conductance mS/m	Colour Pt mg/l
Kalixälven, Kalix	610320	7.3		6.0	11
- " -	610620	6.8		2.9	33
Kalixälven, Kamlunge	800325	6.8		6.4	-
- " -	800826	7.1		4.3	20
- " -	810331	6.7		6.4	35
- " -	810825	7.0		3.1	80
- " -	820330	7.0		6.4	35
Sangisälven, Sangis	800325	6.4		15.2	-
- " -	800826	6.6		9.5	85
Häggmanstjärnen	780731	6.9	0.078	2.6	20
Stor-Lappträsket	780731	7.2	0.116	3.4	25

Sources: Hydroconsult AB and County Administration of Norrbotten.

The transport of suspended material in Kalixälven has been measured during long time. In the beginning of 1960s duration curves were calculated for Kalixälven. These curves show that during 50 % of the time the concentration is greater than 15 mg/l at Kalix, during 10 % of the time greater than 40 mg/l.

2.4.2.3 Water utilization

No surface water is used for consumption or irrigation in the different recipients of interest.

The yield of fishery in Kalixälven is 25 kg/ha in the rapids and 10-15 kg/ha in the smooth water-reaches.

In Sangisälven the yield is somewhat lower, 15 kg/ha in the rapids and 10 kg/ha in the smooth water-reaches.

Irrigation is uncommon in the Norrbotten county, only 0.1 % of arable land. It is mainly potatoes, more that 50 % of the irrigated area. Horticulturals stand for about 30 %.

2.4.3 Land use

No special study of the distribution of type of land within the Kamlungekölen area has been done. However, the available data of distribution of land in Norrbotten is applicable to this area, except for the high mountain area, see table below.

Table 2.4.6 Type of land according to the National Forest Survey 1973-77, Norrbotten county

Type	Area (km^2)	%
Forest land	40530	41
Arable land and pasture	1120	1
Swamp	17410	18
Rock surface	720	1
High mountain	27980	28
Other land	11140	11

Table 2.4.7 Use of arable land in Norrbotten county 1981

Crops	Area (km^2)
Cereals	99
Fodder	287
Potatoes	9
Horticultural plants	2

2.4.4 Yield from arable land

The yield of cereals, ley and potatoes in the Norrbotten county is found in table 2.4.8.

Table 2.4.8 Yield of cereals, ley and potatoes in Norrbotten county 1981

	Yield (kg/m^2)
Barley and oats	0.27
Ley	0.46
Potatoes	1.9

2.4.5 Model description

2.4.5.1 Model system

The model system as defined in Figure 2.4.3 is obtained from the study of the recipient area in Kamlungekölen.

Stor-Lappträsket south of the test site constitutes the primary recipients. One water reservoir with two underlying sediment reservoirs are used. The water flows from the lake into Kalixälven. The reach of the river is 17 km long from Pataudden to the Bothnian Bay. The river mainly constitutes of smooth water-reaches interrupted by rapids of different length and fall.

The reach is the next reservoir in the model system. In this part of the Kalixälven river sediments are seldom occuring, mainly because of the relatively high sedimentation in the lake Räktjärv, Hjorth /39/. However, at the river-mouth finer material can be found. Deep erosion will also take place in this part of the river. The river will erode the old bay sediment because of the shore displacement, around 0.9 cm/year. Beacause of these conditions only one sediment reservoir with relatively short turnover time is used in the river.

Outside the river-mouth a coastal water reservoir with two underlying sediment reservoirs are used in the model.

2.4.5.2 Reservoir sizes and transfer coefficients

The volumes and the transfer coefficients which describe the water turnover are found in table 2.4.9.

Table 2.4.9 Reservoir volumes and transfer coefficients for the water reservoirs in Kamlungekölen

Reservoir	Volumes $m^3 \times 10^7$	Transfer coefficient (year^{-1})
Stor-Lappträsket	3.3	0.17
Sediment underlying the lake	0.4	
Kalix älv	1.5	365
Sediment underlying the river	0.8	
Coastal area	38.0	36.5
Sediment underlying the coast area	6.4	

Irrigation is not used within the area of interest and will probably not be relevant in the future.

2.4.6 Exposure pathways

The landscape around Kamlunge is dominated by forests and swamps. At the lake some farms can be found, e.g. at the primary recipient Stor-Lappträsket. Water for consumption is nowadays taken from wells, but it is possible to use the lake water as drinking water. Lake water is also used by the animals.

Fish is caught in the lake, the river and coastal area.

Thus the following exposure pathways are identified:

- via drinking water
- via milk and meat contaminated by the animals drinking water
- via freshwater fish
- via marine food-stuff.

2.4.7 Classification

Hydrologically the Kamlunge area is found within region A - "Polar Rivers", represented by Kalix älv. The main runoff forming factor is snowmelt and the maximum discharge values are observed in May and June for the lowland, Gottschalk /12/. The coefficient of variation shows small variations throughout the year. It is 0.34 for Kalixälven at Morjärv. The skewness does not show any regular pattern.

The water quality transport classification of Kamlunge is 3A - "Coastal Area of Norrland", Northern Part, i.e. the same as for Gideå. The quarterly means vary between 5-20 mg/l, Brandt /17/. A duration-curve of the suspended material at Kalix shows a 95 % value of 10 mg/l, the 50 % and 10 % values are 15 mg/l and 35 mg/l. The dissolved material is 30-50 mg/l.

The physical geographic region is 30b - Hilly middle boreal woodlands. The area is hilly in some parts, with moderately high swamp percentage.

3 GENERAL DESCRIPTION OF FINNSJÖN AND STERNÖ

Many different investigations concerning the Finnsjö area have been done. The bedrock has a complicated geological pattern. Rock with granodioritic-granitic composition dominates /22/. Large areas are dominated by the rock. Between the rock the soil mainly consists of sandy silty till and peat /23/.

Concerning the hydrology three different reports can be mentioned. One of them deals with hydrological surveying /24/ and another one is an inventory of wells /25/. Parts of the third report contains surface water chemistry /26/.

Finnsjön is a part of the drainage area of Forsmarksån, with a total drainage basin of 387 km^2 and a lake area of 5.5 % /27/. The drainage area of Finnsjön itself is 117 km^2 and has a lake area of 6.7 %. The runoff in northern Uppland landscape is around 7 l/s, km^2 /9/.

Finnsjön has a lake area of 4.3 km^2 /27/. The depth is estimated to be 2 m. This gives a turnover time for the water of 0.33 year.

The hydrological region is Fa, i.e. the same as Fjällveden.

Concerning sedimenttransport and water quality it belongs to region 5, the same as for Fjällveden.

Finally the physical geographic region is 26 - Woodland south of "limes norrlandicus". This region is low-lying and flat with forests. Bogs are fairly frequent.

The only probable recipient of釜Sternö is a part of the sea, Pukaviksbukten. However, the mean runoff is 6 l/s, km^2 /9/. The turnover time for water in the coastal areas of that type surrounding Sternö could be of an order of 5-10 days /28/. These figures are rough and are dependent of how the size of recipient data is defined. It has not been possible within this project to estimate this more exactly.

The physical region is 9 - Fissure valley landscape and oak woods of Blekinge.

4 SUMMARY OF THE CHARACTERISTICS AND GENERALITY OF THE RECIPIENT AREAS

The five different recipient areas from Sternö in the south to Gideå in the north are separated by a distance of roughly 850 km. This means naturally that great differences exist between them concerning climate, hydrology, vegetation etc.

The five areas represent five different physical geographical regions out of around 30 regions in Sweden.

In table 4.1 the most important characteristics are summarized. The abbreviations and classifications are explained in the chapters concerning each recipient area.

Table 4.1 Summary table

Parameter	Recipient area					
	Fjällveden	Voxnan	Gideå	Finnsjön	Sternö	Kamlung
Mean air temperature (^{o}C)	+5.7	+3.9	+3.2	+5.8	+7.6	+1.6
Precipitation, corrected (mm)	720	695	720	755	700	680
Evaporation (mm)	475	415	375	470	490	335
Runoff (l/s, km^2)	6.5	10	10	7	6	12
Turnover time in primary recipient (days)	1280	185	1	120	ca 5-10	2120
Hydrological region	Fa	D	E	Fa	Fa	A
Sedimenttransport region	5	2B	3A	5	6	3A
Physical geographic region	24	28b	29a	26	9	30b

In Sweden 8 different hydrological regions are defined. Four of them are represented by the recipient areas. The Fa-region covers the eastern part of Götaland and Svealand. Region D represented by Voxnan stands for the middle of Sweden. Finally Gideå represents the coastal areas of Norrland.

Concerning the sediment transport and water quality Sweden is divided into 10 regions. The region 2B represents the southern part of of the interior of Norrland, Dalarna and Värmland. Region 3A is the northern part of the coastal zone of Norrland. Finally region 5 covers the Mälaren-Hjälmaren region and the plain of Östergötland.

As can be seen the hydrological and water quality regions are fairly good represented in the eastern parts of Sweden by the recipient areas. The south-western and northern parts are not covered by these areas.

From the physical geographic regions point of view the eastern parts of Svealand are represented by Fjällveden (24) and Finnsjön (26). Besides the interior of Värmland, Dalarna and Hälsingland is covered by region 28b, Voxnan. The region 29a, Gideå, is a coastal zone, within about 40 km from the coast, limited by Gideälven in the south and Piteälven in the north.

Concerning the exposure pathways from the different recipient areas there is quite a difference between them especially for the regions. There is a gradual change from a pronounced farming-land in the south to a typical forest area in the north. Different exposure pathways are summarized in table 4.2 and 4.3 where the local area constitutes of the primary recipients. The regional area includes the rest of the influenced areas before the Baltic.

Table 4.2 Exposure pathways considered for the local area in the different recipient areas

	Area			
Exposure pathway	Fjällveden	Voxnan	Gideå	Kamlunge
Drinking water	x		x	x
Milk*	x		x	x
Meat*	x		x	x
Fish	x	x	x	x

* only considered pathway is the animals consumption of water

Table 4.3 Exposure pathways considered in the regions of the recipient areas

Exposure pathway	Fjällveden	Voxnan	Gideå	Kamlunge
Inhalation	x	x		
Drinking water	x	x		
Milk	x	x		
Meat	x	x		
Cereals	x			
Vegetables	x			
Root-fruits	x	x		
Egg	x			
Fish	x	x	x	x

5 LONG-TERM VARIATIONS

The description of the different recipient areas is based on recent conditions. However, it will take thousands of years before any nuclide will reach the surface water. Thus it is the prevailing conditions at that time, that should be the basis of dose calculations. The assumption of the conditions in the future will however have a considerable uncertainty. A general discussion about these conditions will be done below.

5.1 Geology

According to the theory of continental drift the different continents were united to one super continent called Pangaea in the end of the paleozoic era, about 250 million years ago. During the triassic period, about 200 million years ago, the different shields began to separate. Around 65 million years from now the northern continent started to split up. At that time the North Atlantic started to form and this movement is still going on divering from the Mid-Atlantic Ridge. It has been calculated that the widening is about 1-4 cm/year /29/. This shows that the continental drift is of minor importance when discussing changed conditions in the future in Sweden. Other factors as climate change, new iceages etc will be more important.

5.2 Climate

Studies of the climate during the last 500 million years have shown that the warm periods dominate the history of the earth. The glacial periods have been of fairly short duration /30/. The mesozoicum era, 225-63 million years ago, was a pronounced warm period. No glaciations from that era are known.

The Tertiary period was a warm period, but with decreasing temperature. In Middle Europe the mean air temperature decreased from +21°C to +14°C when the Quaternary period began, about 1 million years ago. The mean temperature was around +10°C, that corresponds to the temperature nowadays /30/.

The Quarternary period is divided into two parts a) Pleiostocene when the glaciations took place and b) Holocene, the time after the glaciations extending over the last 10 000 years. During the Pleistocene epoch there have been four our five glaciations. The four known periods are in Europe called Günz, Mindel, Riss and Würm. The Günz period began 590 000 years ago and lasted for around 40 000 years. Both the Riss and Mindel continued for about 40 000 years. The periods between the three glaciations were 75 000 years respectively 200 000 years long. The latest glaciation period Würm began around 115 000 years B.P and ceased 25 000 B.P.

In the southern part of Scandinavia the ablation began about 20 000 years ago. The end of the Ice Age is located in 6 800 B.P., that is close to the time when the ice left the areas of Voxnan and Gideå around 7 300 B.P. The tongue of the ice sheet disappeared from the Fjällveden area around 8 500 B.P. /31/.

As can be seen from above the climate is changing with varying periodicity. The closer we come recent time the more in detail it is possible to describe these variations. For example during the last 250 years the air temperature in

Stockholm has been recorded. These records show that the winter temperature has fluctuated, but had an increasing trend until 1940 /30/. After 1940 there is a declining trend. The summer temperatures do not have the same increasing trend as the winter temperatures before 1940.

The global mean temperature and winter temperature increased with 0.5 ^{o}C from 1880 to 1940, after this the temperature seems to fall. For how long time will it fall? Are we in a beginning of a new glaciation? What will the future climate become? There are many questions to be answered. There are also many factors affecting the climate variations. The global radiation will primarily determine these variations. Liljequist /30/ divides these factors into two groups, extra terrestrial and terrestrial factors.

The extra terrestrial factors are a) the amount of the heat from the sun, b) absorption and radiation in cosmic dust, c) periodic and non-periodic variations in the orbit of the earth.

The terrestrial factors are a) atmospheric as cloudiness, content of water vapour and CO_2, amount of dust, b) distribution of land and sea, the relief of the earth, c) conditions in the sea as salinity, ice sheets and ocean currents.

How will these factors vary in the future and which one of them can affect the climate? There are many different opinions about that. It is probable that we in the future will have oscillations between warm and cold periods with ablation and glaciation, if not man will affect the environment to such an extent that these variations will be altered. Bolin /32/ has discussed the pollution of the air and its influence on the global mean air temperature. He found that the content of CO_2 is the most important factor. If the content of CO_2 is doubled, which will happen around year 2050 with an annualy increase of 3 % of the emissions, the temperature will rise 1.5 - 4^{o}C. An increase of temperature means that the inland ice will melt and that the sea level will rise with about 1 - 1.5 cm per year, i.e. this could compensate for the land uplift.

Thus the coming climate variations are difficult to forecast both in time and space.

5.3 Hydrology

The long-term water regime has varied a lot depending on variations in global radiation, changes in the relief, the extension of glaciation etc.

The glaciation and ablation periods will of course have the most extreme influence on the discharge. However, between these extremes the discharge can vary as a random phenomenon. Trends or quasi-periodic oscillations of the time series of discharge that can be found, will not permit us to forecast the structure of the discharge in the future /33/. This means that it is almost meaningless to discuss future varations. However, a description of the latest variations can give some information.

A declining trend during the 20th century of the northern rivers has been found by Gottschalk /33/. The decrease is 0.02-0.10 l/s, km^2 per year. This is specially pronounced in smaller drainage basins. Within the high mountain area and in southern Sweden no significant trends are found.

Melin /11/ has studied moving-average variations of discharge from 1910 to 1960. The 30 year movingaverage usually varies with ±5 % around the mean value. The variations are greatest in the southern part of Sweden.

5.4 Land-use

The trend nowadays goes towards increasing forest areas at the expense of the arable land. It is possible in the future, if the climate gets colder, that the arable land areas will increase again, because of lower yields. However, as a whole the variations of the different areas cannot change a lot as the main structure of the landscape will not change that much. Even after a new ice-age this main structure will remain. In year 1900 the forest areas was 50.4 % of the land area compared to 57.3 in the middle of the 1970´s. The corresponding values for arable land and pasture is 12.2 % and 11.8 % respectively.

The maximum land uplift of Sweden is nowadays around 1 cm/year along the coast of the Bothnian Bay. In the southern part of the country it is around zero. However, it is more correct to talk about the displacement of the shorelines because there are different processes as the eustatic and isostatic effects that influence the position of the shoreline /34/.

When the shoreline has moved downward, areas that earlier were sea bottom with different types of sediments, became land. This means that coastal areas and river valleys, especially in the north, have become arable land. In the valleys, deltas at different elevations, i.e. of different ages, can be found. These sediments mainly consist of sand and coarse silt and rest upon finer sediments originating from bottom sediments of the sea.

In the future the shoreline will move downwards but with a reduced velocity, if not other processes will dominate, see 5.2.

Some lakes will in the future be filled up by growth. This process has accelerated during the last decades because of the increased discharge of nutrients to rivers and lakes. This means that old lake areas can be used as arable land or forest areas.

Another form of changed land-use is exploitation of peat for combustion.

5.5 Acidification

The most important influence on the Swedish environment nowadays is the acidification. The increased combustion of fossil fuels has led to increased pollution of the atmosphere, hydrosphere and soil. During the 1970´s this pollution became obvious.

The first evidence was decreasing pH in lakes, specially in the south-west of Sweden. Today about 18 000 lakes are affected. With a pH of around 5.5 the reproduction of roach is disturbed and crayfish dies /35/. If the pH is decreased further many other species will die.

Another important effect is the increased leakage of metals as aluminium, cadmium, zinc, lead and iron. Increased content of mercury in pikes from acid lakes has also been found.

However, the acidification of lakes is a secondary phenomena. Most of the fallout occurs over land and affects the chemical processes in the soil /35/. Low values of pH and high content of metals have been found in the groundwater.

So far the effect on soil has not been as evident as in the water. However, the chemical balance has been changed.

If the release of sulphur in Europe is unchanged and is 50 % lower in Sweden during the 1980´s a prognosis /35/ shows that in 1990:

- the deposition of 1-2 g/m^2, year will be unchanged,
- the pH in precipitation will be the same,
- the arable land will have a continued acidification if not the liming will neutralize the acid supply,
- increased release of acid and nutrients from woodland, specially coniferous forests, will result,
- a local recovery around Swedish sources of surface- and groundwater will be established
- the number of acidified lakes will increase by 3 000.

5.6 Evolution

The man (Homo sapiens) has developed from the mammals. Fossils from the earliest mammals are about 200 million years old. The man belongs to the group of primate, that is an order of the mammals. The first primates are found about 60 million years ago /36/.

Around 10-15 million years ago the anthropoid ape (Hominidae) is thought to appear. The apes had earlier lived in the trees, but now they left the trees and lived on the steppes. The evolution went on with the Australopithecus (2 million years ago), Homo habilis (1.75 million), Homo erectus (1 million), Neanderthaler (0.1 million) and Cro Magnun (0.03 million).

No provable changes of the genetic composition have been discovered during the last 30 000 years. The changes that are found are for example length, form of the nose and colour of the skin.

Because of better care of the descendant not only the strongest have survived and reached reproductive age. This means that the driving force is out.

Another unpredictable factor is the manipulation of genes, that can affect the coming evolution.

Because of what is said above it is not possible to say how the evolution will go on. It is not possible to extrapolate the recent trends. However, it is likely to expect that within the next 10 000 years not very much will happen to man.

In the long perspective, millions of years, there will perhaps be other species that will dominate the world. Perhaps it is the "bockanin" (Ungulagus silvicola) or "skymningstassaren" (Manambulus perhorridus) that is the master of the world. The geologist and palentologist Dixon /37/ describes the life of world 50 million years ahead, that he thinks is the result of a probable evolution.

5.7 Variations related to Fjällveden

When discussing variations of different parameters in the future and the consequences, it is not meaningful to discuss what will happen beyond a time of about 10 000 years. The uncertainties will increase with increasing time.

The most radical influence is the forming of an inland ice covering the whole of Sweden again. After the ice has melted vegetation will return and animals and man will probably follow. The main features of the landscape will presumably be the same, i.e. the arable land will mainly be found on the same places.

If not a new ice-age is forthcoming, the acidification, if it continues, will affect the fish production. If the catch from the recipient goes down, the doses will decrease with the same rate. Parts of the Fjällveden areas are sensitive to acidification. In the lake system Lidsjön-Långhalsen and Nyköpingsån the risk of acidification is very small.

If the land uplift will continue with the same rate Nyköpingsfjärden will become land area within 1 000 years. This means that the sediment in the future can be used as arable land.

5.8 Variations related to Voxnan

There are no direct important variations that can be predicted which will influence the model system. In the future a shallow lake as Norra Brynåssjön or Älmessjön will eventually be filled up and become a bog. This means of course that no fish will be cought. In stead peat can be used from the bog for combustion.

Constructions of water-power plants in the rivers, which is not likely, will influence the fishing.

5.9 Variations related to Gideå

The exposure pathways in Gideå are few and no additional effects other, than those mentioned above, can be predicted.

However, one exposure pathway that is not included and should be mentioned is peat from bogs. Already today a bog is prepared for harvesting peat. Because the bogs are situated in outflow areas, they can become recipient areas for radionuclides in the future. Within the Gideå area there are quite large areas covered by bogs that could be of interest in the future.

5.10 Variations related to Kamlungekölen

It is probable that the Kalixälven will be affected by constructions of water-power plants in a near future. This will of course influence the fishery in a negative way.

Another important process is the redistribution of the sediments in the lower part of Kalixälven. Because of the land uplift the river will erode the sediments and transport the sediments further down to the river mouth or out in the sea. This means that the sediments will be accessible again. This process will be repeated several times.

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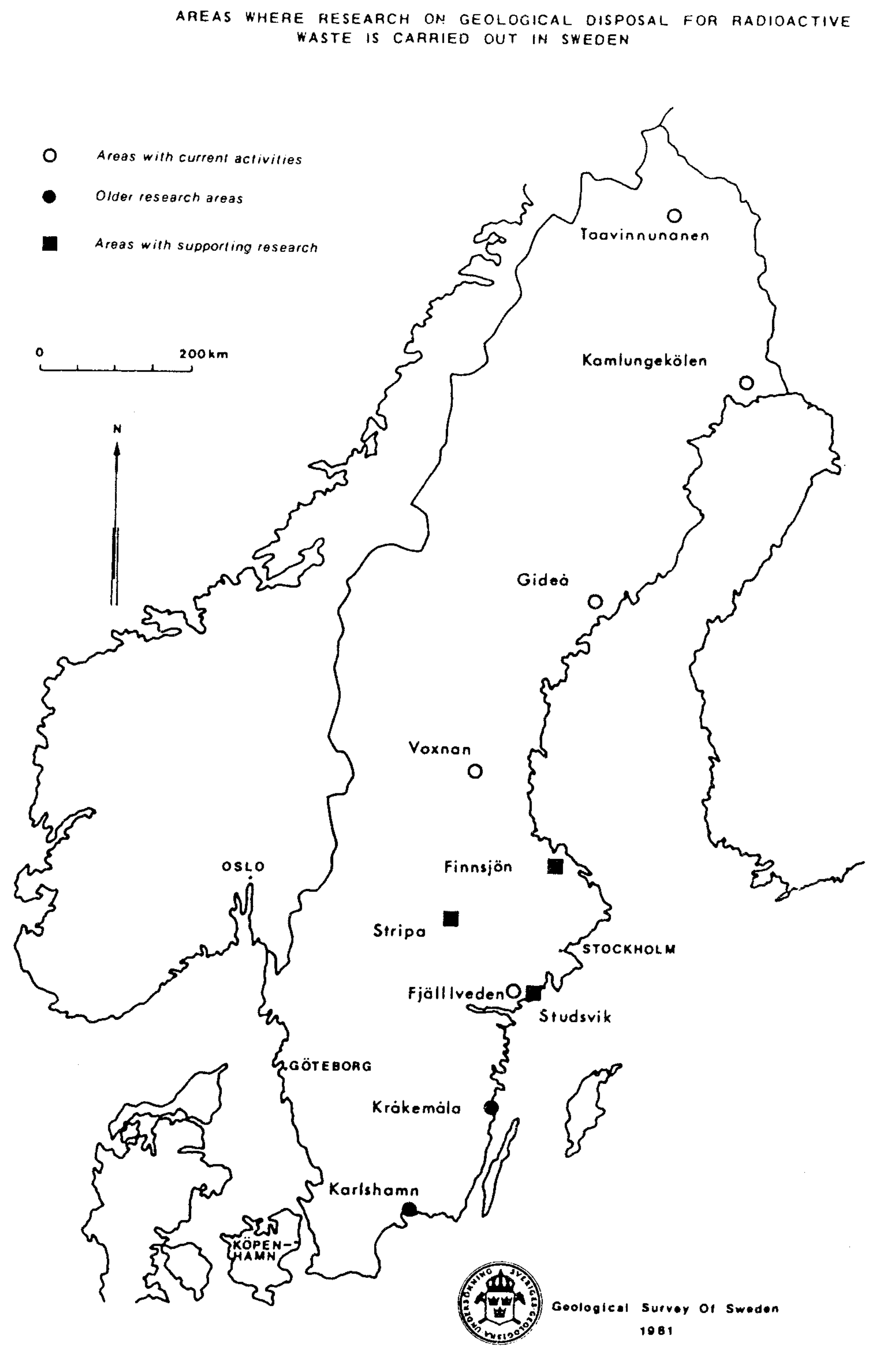


FIGURE 1.1

(From Geological Disposal of Radioactive Waste, Reaserch in the OECD Area 1982)

FIGURE 2.1.1. GENERAL MAP OF FJÄLLVEDEN

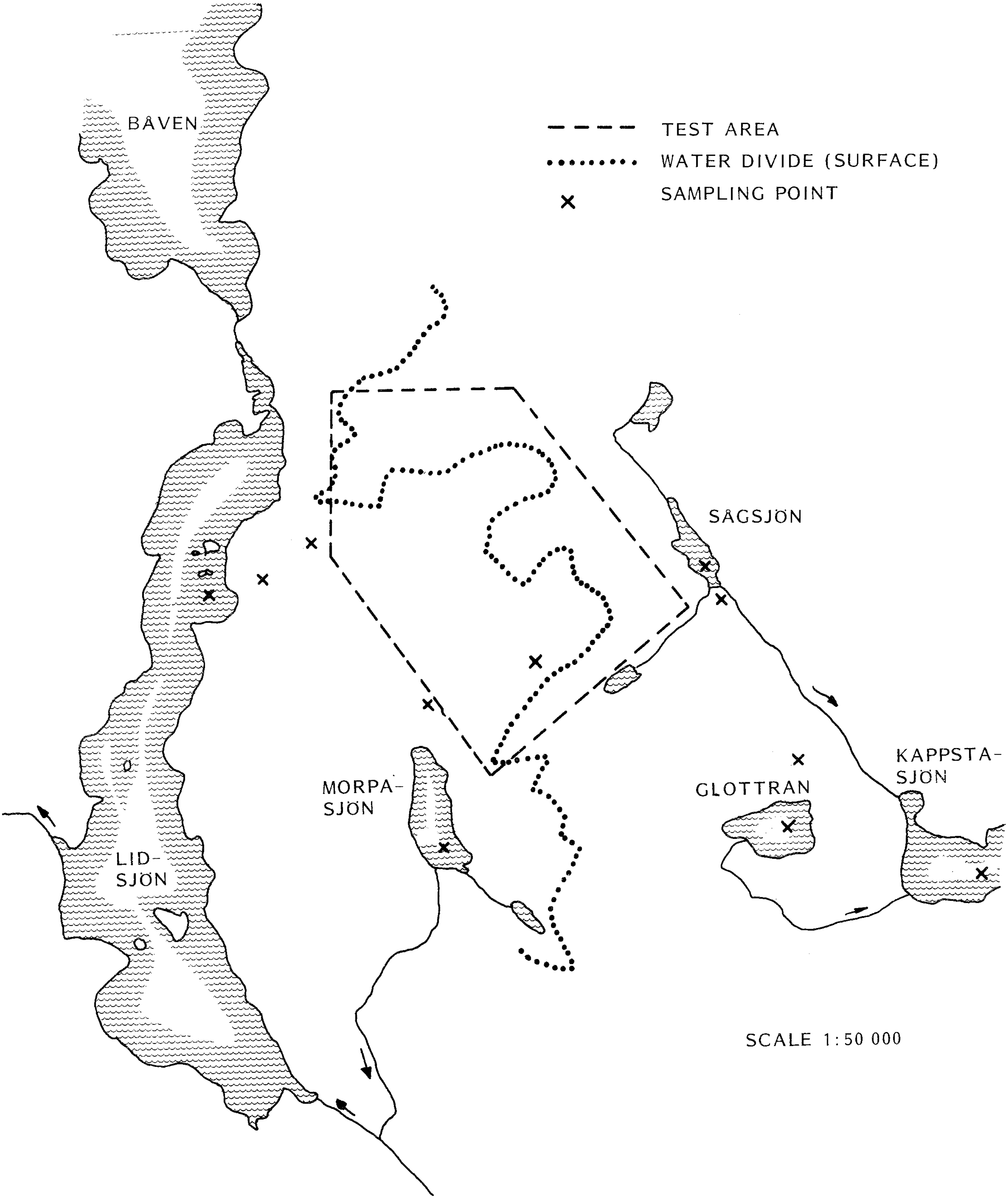


FIGURE 2.1.2 THE FJÄLLVEDEN AREA

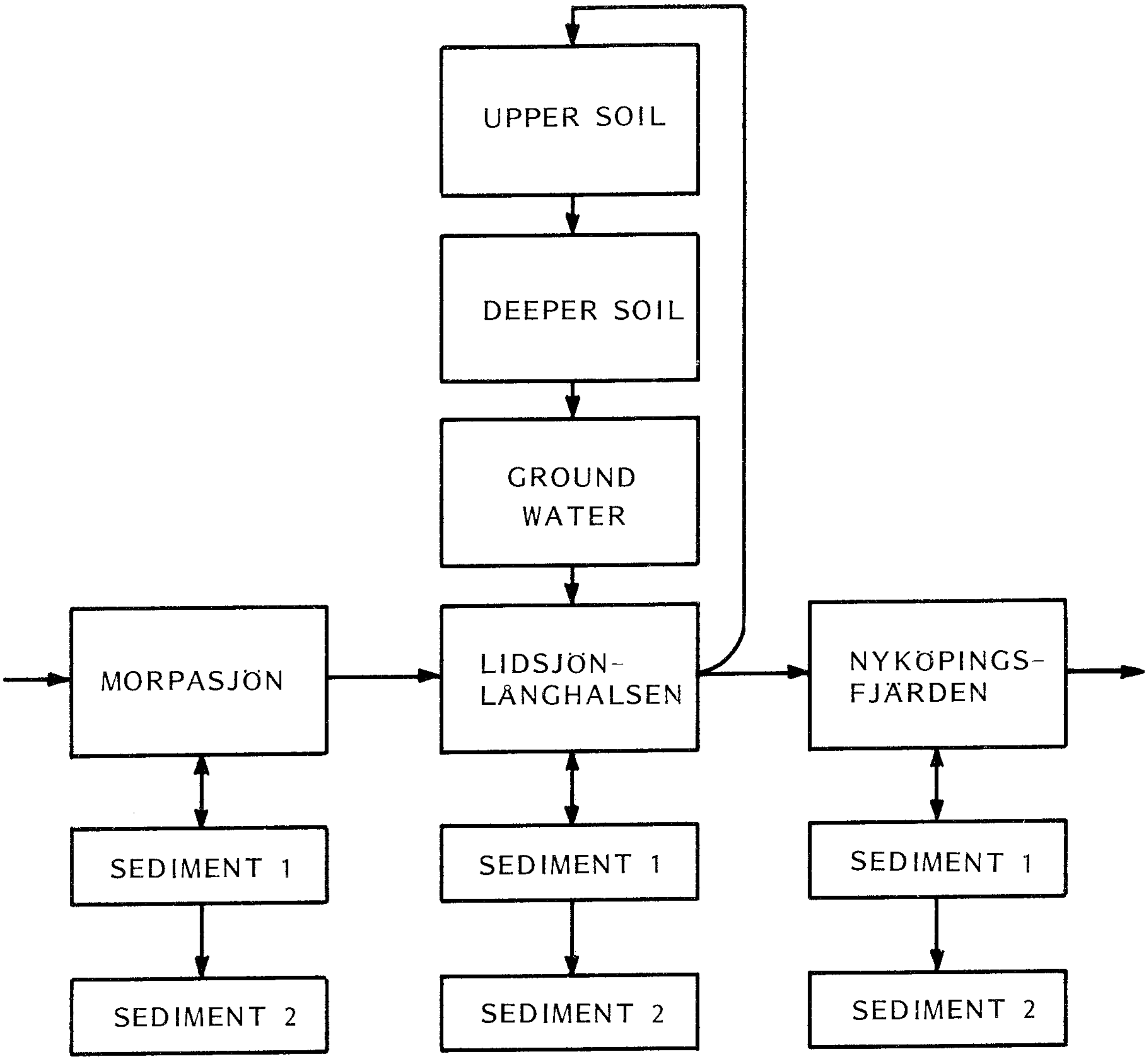
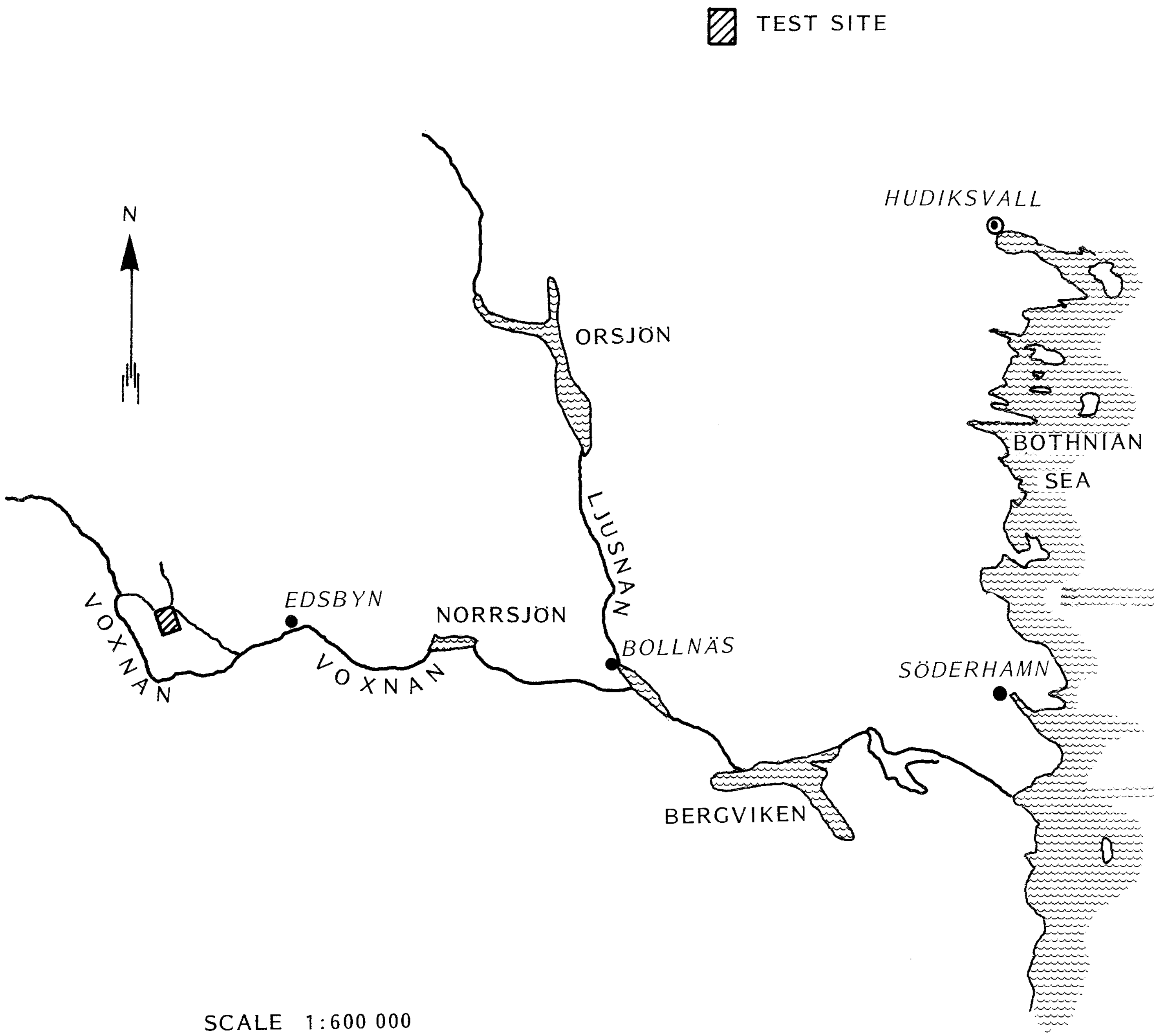
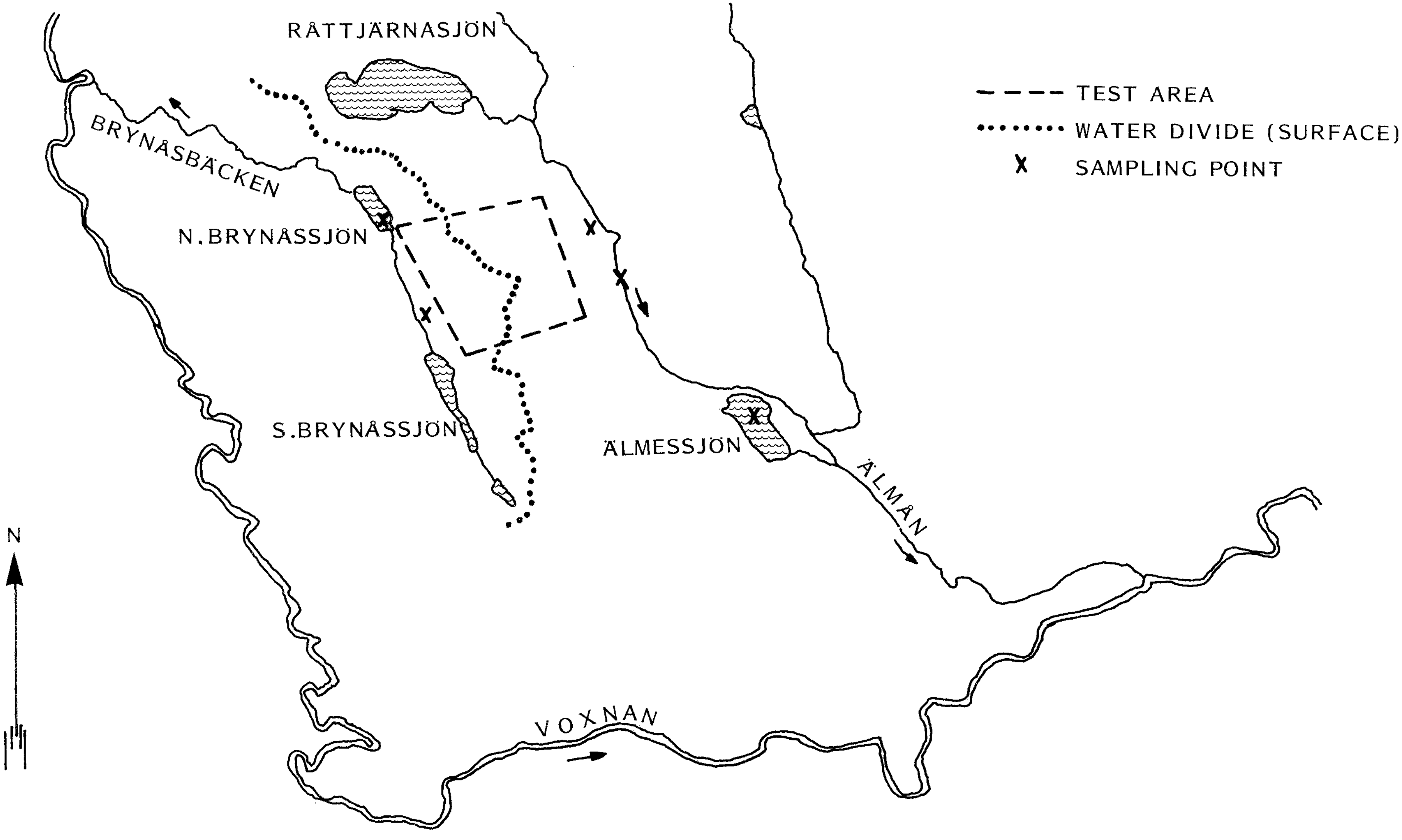


FIGURE 2.1.3 MODEL SYSTEM FOR THE FJÄLLVEDEN AREA



SCALE 1:600 000

FIGURE 2.2.1 GENERAL MAP OF VOXNAN



SCALE 1:75 000

FIGURE 2.2.2. THE VOXNAN AREA

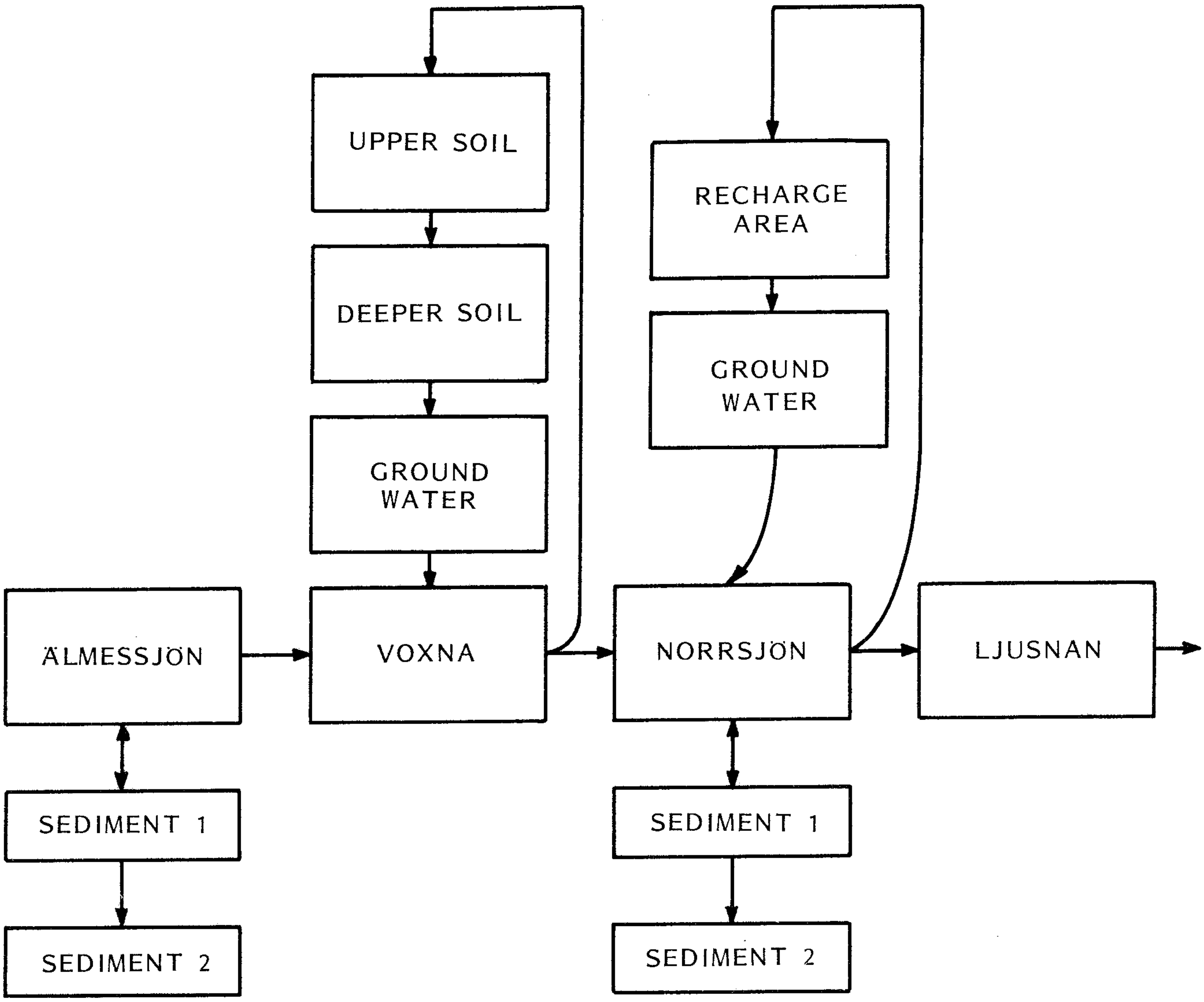


FIGURE 2.2.3 MODEL SYSTEM FOR THE VOXNAN AREA

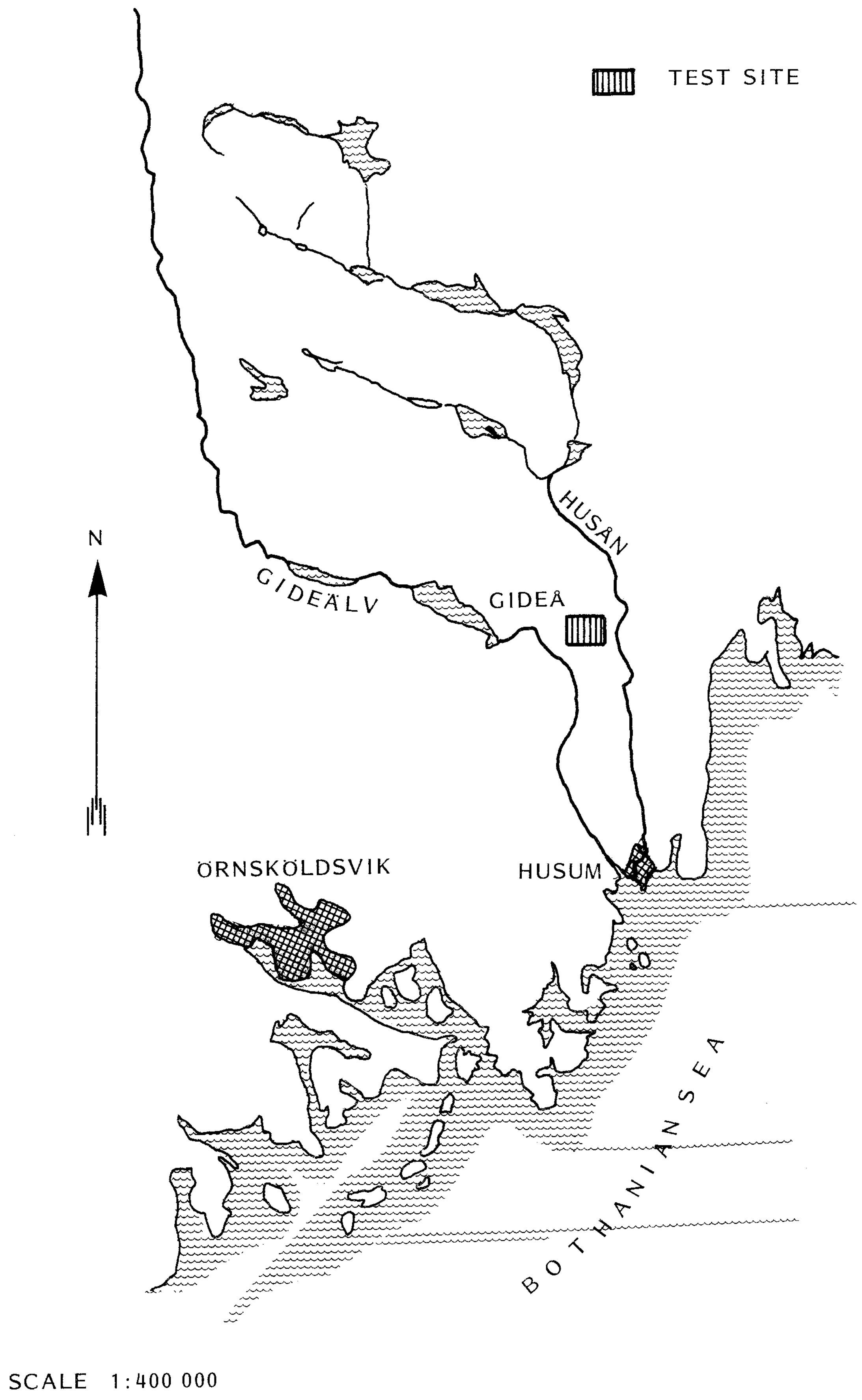


FIGURE 2.3.1 GENERAL MAP OF GIDEÅ

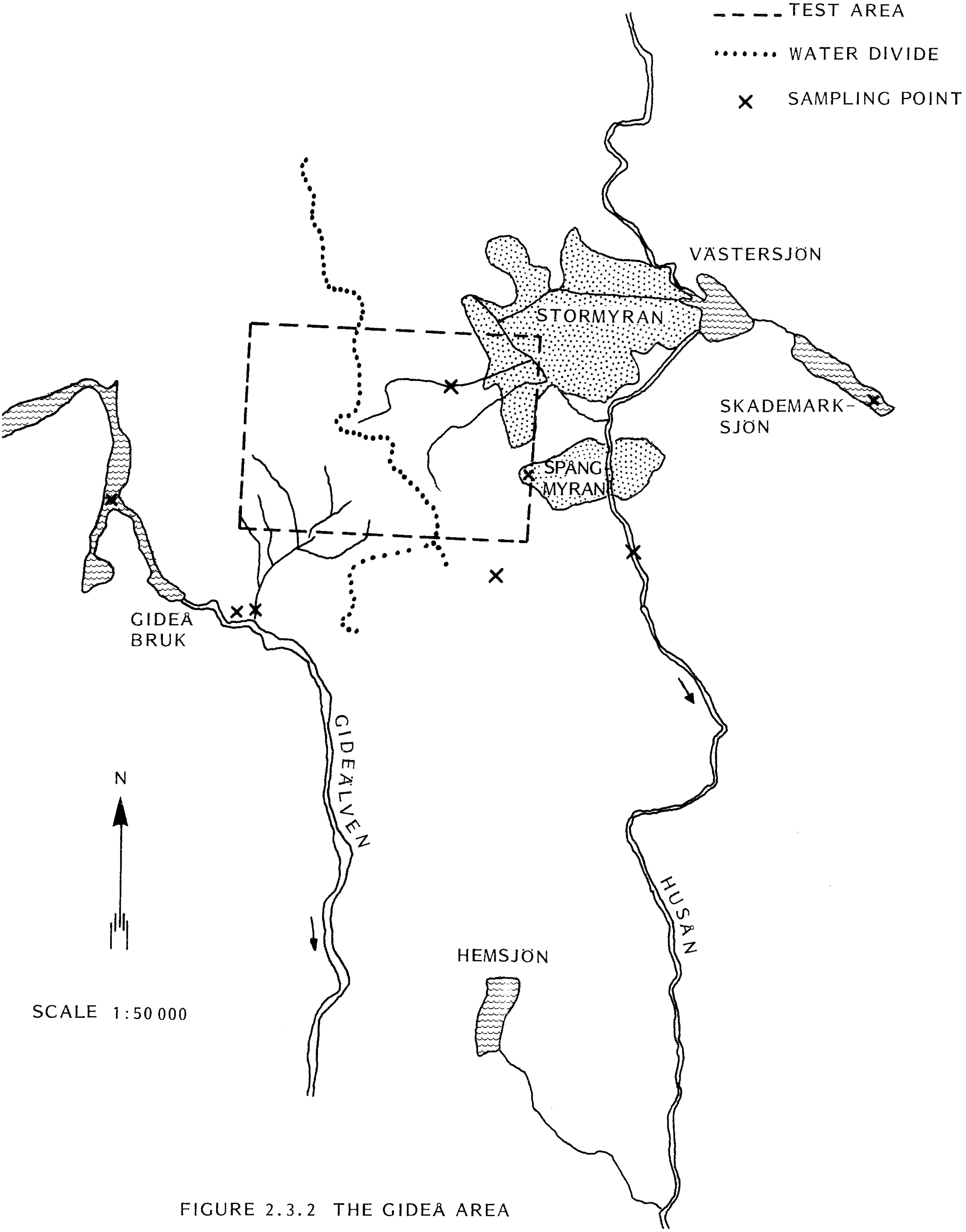


FIGURE 2.3.2 THE GIDEÅ AREA

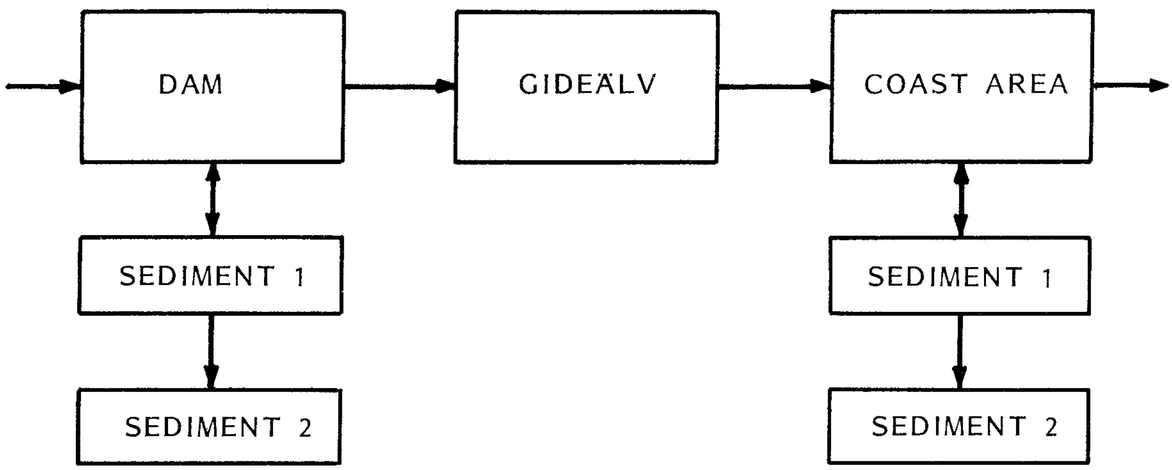


FIGURE 2.3.3 MODEL SYSTEM FOR THE GIDEÅ AREA

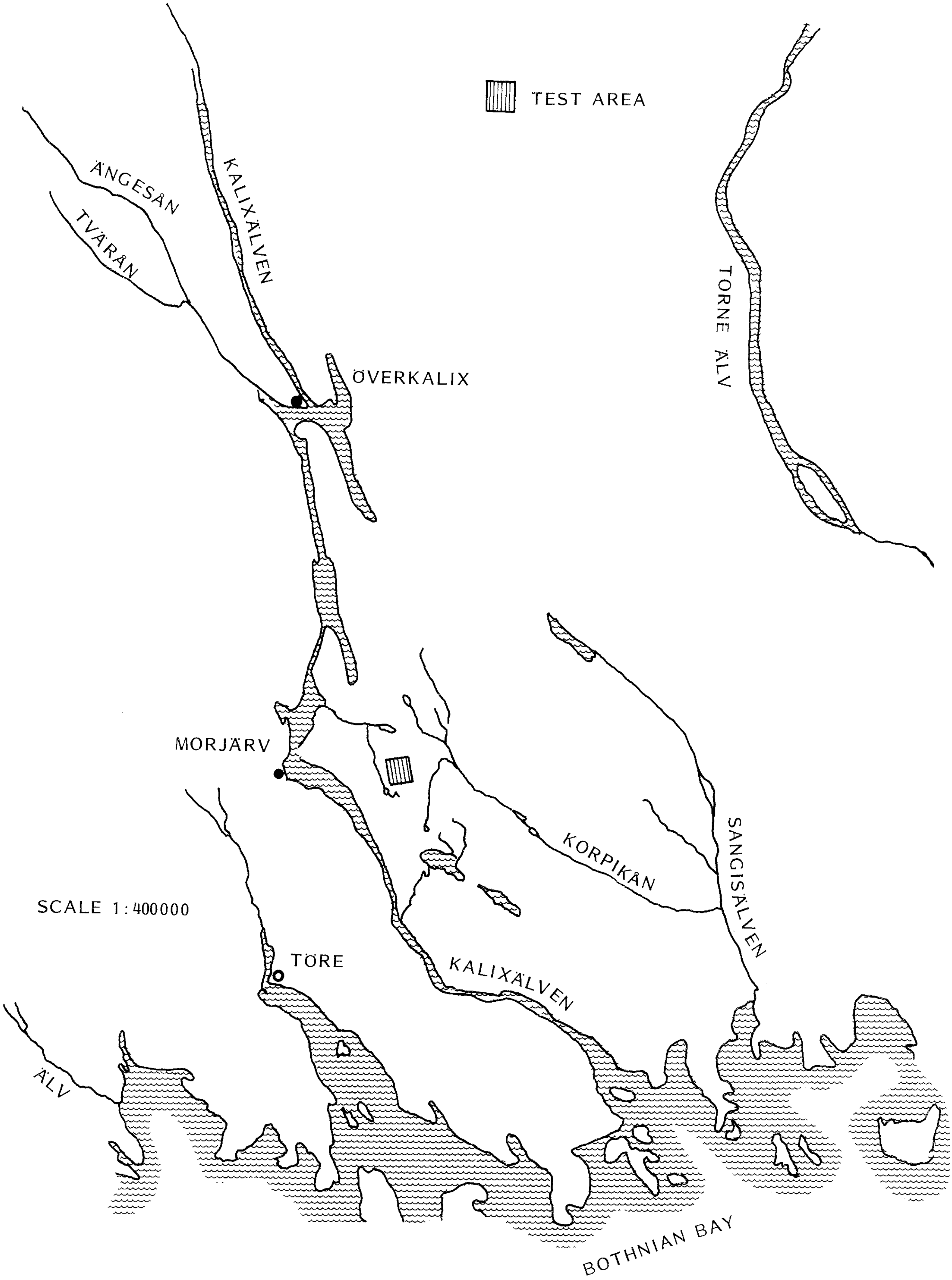


FIGURE 2.4.1 GENERAL MAP OF KAMLUNGEKÖLEN

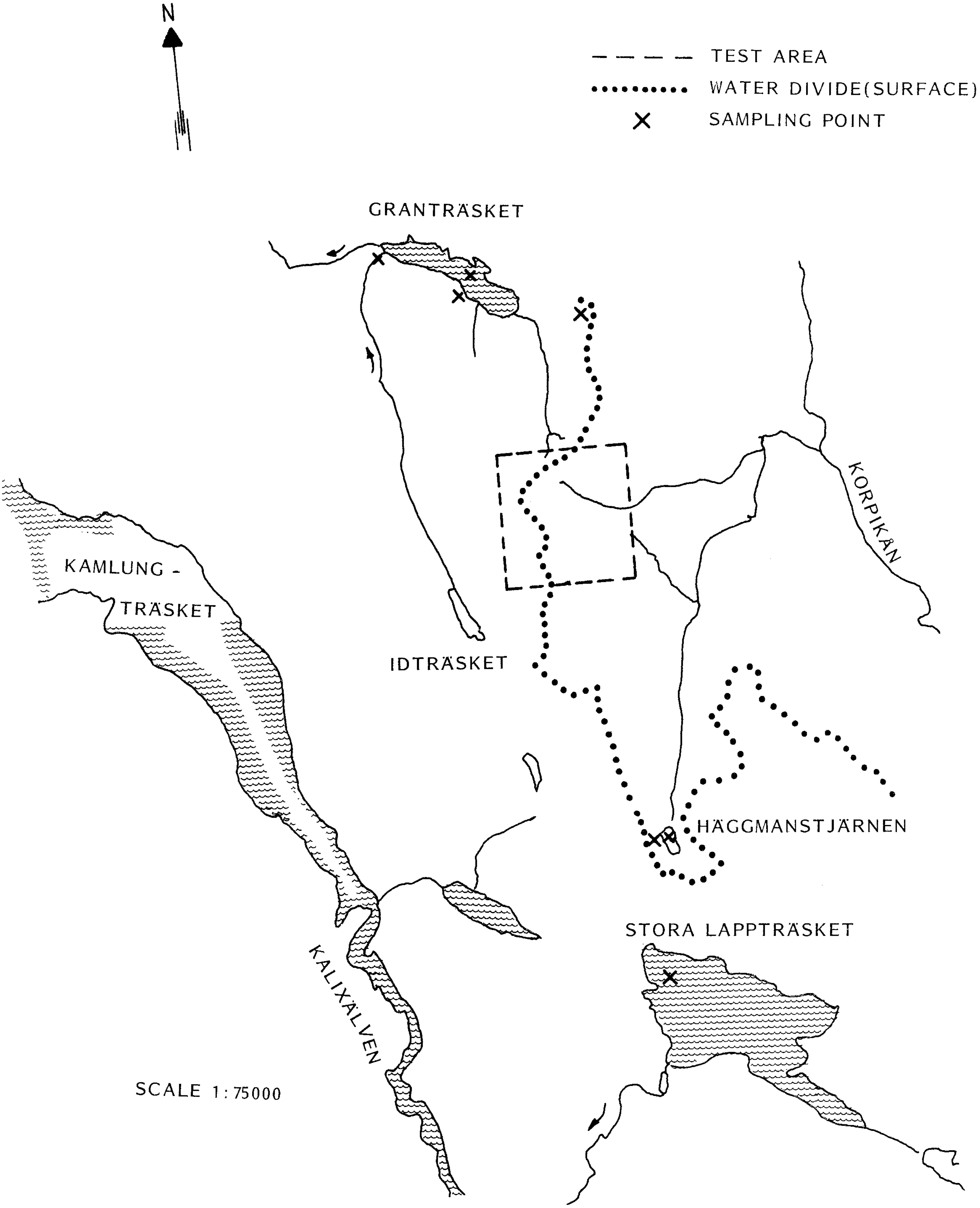


FIGURE 2.4.2 THE KAMLUNGEKÖLEN AREA

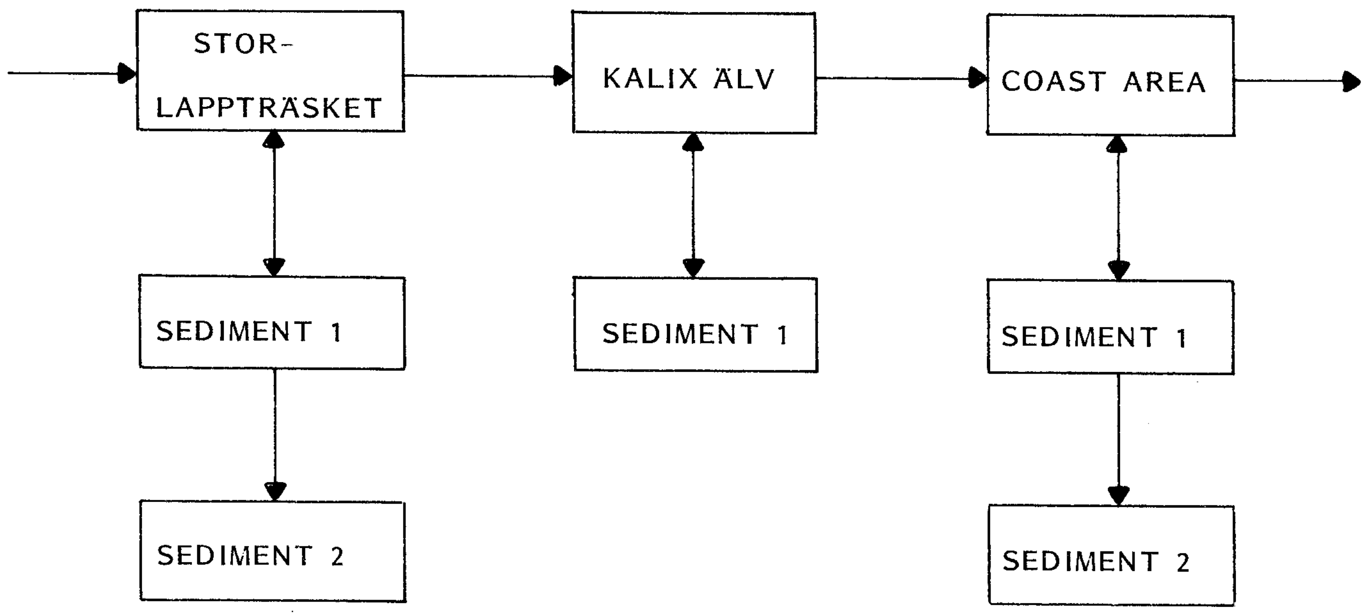


FIGURE 2.4.3 MODEL SYSTEM FOR THE KAMLUNGEKÖLEN AREA

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Compiled by Duwayne M Anderson
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