

LARS NORDBERG
AND
GÖSTA PERSSON

THE NATIONAL GROUNDWATER
NETWORK OF SWEDEN

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Abstract

The authors give an account of the background and objective of the International Hydrological Decade (IHD) and outline the establishment of a national groundwater network in Sweden within the framework of the IHD.

The main features of the network are presented, and 51 observation areas are briefly described as to location, geology, hydrogeology and hydrology. Salient points of information are given from all stations in tables. Diagrams from

the observation areas showing the variation of the groundwater level, chemical composition, tritium concentration and temperature of the groundwater in various geological settings are presented and commented upon. The variations are related to the variations of precipitation, and, for certain stations, snow cover and depth of frost penetration.

A tentative approach to a regional zonation of Sweden according to the relative groundwater level position is made.

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Preface

Within the framework of the International Hydrological Decade (IHD) a national groundwater observation network has been established by the Geological Survey of Sweden. The main objective of the project is to study the natural quantitative and qualitative long-term variations of the groundwater in selected areas in Sweden, and to explain these variations in relation to the geology, topography and climate of the areas.

Observations of groundwater level, groundwater temperature, frost penetration and snow cover, and sampling for the chemical analysis of groundwater are regularly made in a great number of observation areas in Sweden. Observations and samplings are performed by hired field assistants without whom the project could not be successful. We want to express our gratitude to all assistants for their loyal and scrutinizing work under all types of weather conditions. Up to 1974 the following assistants have been working with the network:

Area	1	Martin Andersson and Frank Jensson
„	3	Ingrid Andersson, Agne Andersson, Karl-Erik Nilsson, Gunnar Klingwall and Elisabeth Persson
„	4	Lennart Petersson
„	5	Jan-Åke Gustafsson, Rolf Nylander and Jan Risberg
„	7	Evald Petersson
„	8	Josef Eriksson and Gillis Ulmstedt
„	9	Nils Lindström
„	10	Erik Stridsberg
„	11	Lennart Lyth and Johan Klintbom
„	12	Josef Enström
„	13	Gösta Claesson and Bengt Stehnsson
„	14	Per-Olof Uhrwing and Wiking Larsson
„	15	Per-Olof Johansson, Bertil Strand, Bo Lundblad and Bengt Ottosson
„	16	Weit Sandgren, Lennart Persson and Sune Lindström
„	17	Bernt Karlsson
„	18	Hans Andersson, Walter Swartling and Brynolf Fogelström
„	19	Johnny Sundell, Karin Karlsson and Arne Karlsson
„	20	Ingemar Cederwall
„	21	Daniel Toth and Mats Wretler
„	23	Rikard Eriksson, Ragnar Bölja and Lennart Johansson
„	24	Erik Bratt
„	26	Tage Söderberg
„	27 and 28	Elis Magnusson, Gösta Gustafsson, Ulf Gradin, Per-Erik Hedén, Björn E. S. Malm, Sven-David Svensson and Raoul Stigård
„	29	Erik Ögren
„	30	Edvard Åhlander, Mats Persson and Hjalmar Flodin
„	31	Rune Sjögren
„	32	Sture Eriksson

Area	33	Sigvard Granberg
„	34	Erik Ståhlberg and Harry Wikström
„	35	Sven-Olov Johansson
„	36 and 37	Eskil Nyström
„	38	Signar Östnell
„	39	Axel Eriksson, Bojan Eriksson, Margareta Redin and Edit Palovaara
„	40	Bodil Uddberg and Thore Uddberg
„	41	Per Thorell
„	42	Gun Marklund and Valentin Marklund
„	43	Thure Johansson
„	44	Rune Rosell
„	45—49	Gunnar Johansson and Erik Nilsson
„	50	Arne Bladh
„	51	Leif Carserud and Svante Björk

We owe special gratitude to the water engineering offices of the towns of Kristianstad (area no. 3), Kalmar (area no. 6), Varberg (area no. 13), Hallsberg (area no. 17), Nyköping, formerly Näveklarn (area no. 18), Karlstad, formerly Molkom (area no. 19) and Sundsvall (area no. 25), who all have furnished us with results of the observations of groundwater and other information. We also want to express our thanks to Gulsele Kraft AB and Ångermanälvens Regleringsföretag for their important observation work at Hälla (area no. 32) and at river Ångermanälven (areas nos. 45—49), respectively.

The groundwater networks in the representative IHD basins Velen (area no. 16), Kassjöån (area no. 26) and Lappträsket (area no. 37) are run in collaboration with the Swedish Meteorological and Hydrological Institute (SMHI), the Division of Hydrology of which organizes the field observations in these basins. All precipitation data have also been obtained from SMHI. We want to acknowledge this rewarding collaboration with great gratitude.

We also want to extend our thanks to Dr. Gustaf Sandberg, the former head of the Abisko Natural Science Research Station, and Mr. Nils-Åke Andersson for their contribution of groundwater data from the Abisko area. To Dr. Gert Knutsson we owe great gratitude for his kind permission to use parts of his collected field data from Emmaboda, and for his constructively supporting attitude to our work. Also our collegiate thanks go to Dr. Ove Gustafsson and Mrs. Marianne Teeling at the Geological Survey of Sweden for their collection of groundwater data and samples and for geological information about some of the observation areas in Skåne (nos. 1, 2, 44).

The project started under the former director general of the Geological Survey, Mr. Karl Albert Lindbergson who constructively supported its creation. The present director general Mr. Gunnar Ekevärn has followed the progress with interest.

The project is skillfully headed by Dr. Åke Hörnsten, chief geologist of the Geological Survey, and we are deeply grateful for his stimulating comments and remarks concerning current and planned activities within the network.

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Many problems of practical and technical nature arising in the work have been solved by Mr. Olof Jonasson, engineer, who is in charge of the various field arrangements in connection with the observation network. Mr. Gunnar Ekman and Mr. Leif Särnblad have also participated in the field work. The vast amount of data continuously emerging from the network is skillfully handled by Mrs. Kerstin Tötterström and Miss Barbro Jansson. Geological mapping and other geological and hydrogeological investigations in several areas have been done by Mr. Jan-Erik Andersson, Mr. Thomas Aneblom, Mr. Leif Bjelm, Mr. Leif Carsrud and Mr. Klas Österberg. The drawing of maps and dia-

grams has been done by Miss Anne-Christine Sjöberg, and the typing of the manuscript by Miss Gunilla Jurgelius, Mrs. Kerstin Brodén and Miss Aurora Gadd. Dr. Ernest Magnusson has read the manuscript and contributed several valuable remarks. The English manuscript has been corrected by Mrs. Carol Nordberg. To all these collaborators we want to express our appreciation of their contribution to this publication.

Geological Survey of Sweden, Stockholm, June, 1974.

Lars Nordberg

Gösta Persson

1. INTRODUCTION

At a "preparatory meeting on the longterm programme of research in scientific hydrology" at Unesco in Paris, May 20—29, 1963, the outlines of the International Hydrological Decade (IHD) were drawn. The main results of the meeting are compiled in a report (UNESCO/NS/181, Paris, 12 July, 1963). The proper background to the project is expressed in the following excerpts.

II. NEED FOR, AND OBJECTIVES OF, AN INTERNATIONAL HYDROLOGICAL DECADE

The Meeting expressly reaffirmed the need for a Hydrological Decade and defined the general aims of the latter in the following terms :

The accelerating growth of human populations and the desire for increased standards of living in all countries have led to increased water use for agriculture and for industrial, municipal and domestic purposes, to the extent that the availability of water has become a critical factor limiting development not only in arid lands but also in many other climatic regions of the world.

With increased water use, shortages have become more frequent and constitute a danger to human welfare through the disruption of production and through health hazards. The growing intensity of land use by human populations more and more interferes with the original balance of nature and has led to soil erosion, increased liability of flooding, and increased devastation by floods in productive and densely populated river valleys.

The absolute necessity of increasing the degree of rational management of water as a vital element of the human environment is therefore recognized. For this it is essential that an adequate body of reliable data should be available in each country, and that water use and management should be based on scientific principles established for all the branches of hydrology. In order that a progressive approach may be maintained as new problems arise, further scientific research in hydrology and extensions and improvements of basic data are also essential.

Hydrology is the science which deals with waters of the earth, their occurrence, circulation and distribution on the planet, their physical and chemical properties and their interactions with the environment, including their responses to human activity.

The overall objective of an international programme in the field of hydrology is to accelerate the study of the regimen and resources of waters with a view to their rational management in the interest of mankind, to promulgate the need for hydrological research and education in all countries and to improve their ability to evaluate and utilize their resources in the best possible way. That is, the programme will focus on science but will give strong consideration to utilitarian factors.

The need for such an international programme is reinforced by the very nature of hydrological phenomena which are re-

lated to the planetary circulation of the atmosphere and the distribution of land and sea and which in many cases involve consideration of very large areas. This implies that data should be properly collected from points on a network of observation stations which must be of adequate density and comparable standard in all countries. All countries have important problems relating to the estimation, conservation and rational management of their water resources, but there are many deficiencies in hydrological services in relation to data collection, data processing, research and water use which call for collaboration and mutual assistance between States. The fact that problems of water-resource development occur throughout the world, that deficiencies must be overcome quickly, and the scarcity of highly specialized research workers, who will often have to work outside their own countries, constitute additional reasons for an international co-ordinated approach.

The International Hydrological Decade will focus primarily on water in the land areas of the globe. It will be concerned with oceanic waters only in relation to specific problems in land areas. Likewise the programme will not be concerned with meteorology as such but will involve study of precipitation as a major element of the hydrological cycle in land areas.

The programme planned for the Hydrological Decade should therefore be centred upon continental waters (including islands) and should include seven basic components :

- (a) appraisal of the state of our knowledge of the hydrology of the world and identification of the principal gaps in it;
- (b) standardization of observations, techniques and terminologies for collection, compilation and reporting data;
- (c) establishment of basic networks and the improvement of existing networks to provide fundamental data on hydrological systems varying in size from small watersheds to the world as a whole;
- (d) research on unique or critical hydrological systems in selected geological, geographical, topographical and climatic environments, constituting what may be called "representative basins";
- (e) research on specific hydrological problems whose urgency and special nature call for a considerable effort at international level;
- (f) education and training in hydrology and related domains;
- (g) systematic exchanges of information.

For a programme to be truly international it must contain elements which interest most nations. A programme consisting only of advanced scientific studies and extensive collection of complex data might hold little interest for countries which are not highly developed, either scientifically or economically, because immediate practical problems might have priority of demand for funds and technical personnel. Conversely, a programme consisting largely of the establishment of conventional hydrological networks and routine data collecting would not satisfy the interests or meet the needs of highly developed countries. Nevertheless, the participation of many countries —

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large or small, developed or underdeveloped — can be secured by means of an appropriate compromise and combination between the two types of activities indicated above.

The general principles of the proposed international programme and the conditions of its execution show clearly the wide range of problems covered and the need to deal with them on a long-term basis. Owing to the variability of hydrological regimes, many hydrological factors cannot be correctly analysed unless observation data stretching at least over five to ten years are available. Thus the essential aim of collecting data on a world-wide scale would thus not be achieved by a short-term programme.

To be fully effective and to have the desirable coverage, the proposed long-term programme should be spread over a minimum period of ten years, from 1965 onwards and this is why the programme should be named the "International Hydrological Decade".

(a) Basic data and observation networks

The natural sciences rely, first and foremost, on the patient accumulation of a host of basic observation data, the classification, analysis and systematic interpretation of which enable the research worker gradually to formulate the basic principles governing natural phenomena and the theories making it possible to foresee them. The practical application of these basic principles and theories opens up new prospects and becomes the key to all rational development of natural resources.

The fact that basic data may lead to practical applications does not prevent their being of scientific value, and vice-versa. Nevertheless, in the field of hydrology, the systematic collection of these data has often been regarded — quite wrongly — as a routine operation devoid of real scientific interest, and it has not always been accorded the vital importance it deserves. Furthermore, observations and measurements are often carried out a long way from any institute or laboratory by staff without adequate training and — a more serious matter — without adequate supervision. The research or practical worker subsequently using these data often finds his research or studies crippled by the poor quality of the results obtained (inaccuracies, gaps).

It is felt essential that one of the major objectives of the International Hydrologic Decade should be to do everything to ensure that, at least in connexion with this programme, the collection of data be organized on the soundest possible basis so as to provide scientific research the material it absolutely requires and the data which hydraulic engineers need for their work.

The procedures for carrying out the program included the formation of national committees for the IHD. The Decade started in 1965.

The program was to concentrate on water balance studies; geochemistry of natural waters; erosion, stream bed evolution, transport and deposition of sediments; influence of man on hydrological phenomena. Under the first heading, the need for the creation of groundwater observation networks was recognized.

In Sweden several institutions participated from the start in the IHD work, and most branches of hydrology were involved in the increased activities. The projects were financed mainly through allocations from the Swedish Natural Science Research Council. From the start the Swedish National Committee for the IHD took an interest in supporting the creation of a groundwater network in Sweden.

The Geological Survey of Sweden (SGU) started to establish a groundwater observation network in 1966 with funds from the Swedish Natural Science Research Council through the Swedish National Committee for the IHD, but a systematic construction of the network had to wait until 1967—68. From July 1, 1969, the observation network is financed as an ordinary project within the Geological Survey of Sweden (Nordberg & Persson, 1970). A close co-operation with corresponding institutions in the other Nordic countries was initiated and soon proved to be very rewarding. The project has been discussed several times by the IHD Nordic working group for hydrogeology and groundwater (NAG 1) and certain recommendations regarding the network have evolved from these discussions.

The objective of the groundwater observation network is to enable a study of the natural quantitative and qualitative variations of groundwater in various geological, topographical and climatological environments, and to formulate the relationship between groundwater and other factors. The study is of necessity a long-term project, as only after a great number of years can important multiannual trends be detected and defined.

The collected data will constitute a valuable reference material for future investigations concerning water supply and reservoir developments, extraction of sand and gravel, mining, various construction projects and other projects where the groundwater conditions are bound to be influenced.

The increased knowledge of the occurrence, movement and composition of groundwater is also of great importance to forestry and agriculture.

Regular observations of the groundwater levels will be an aid in the evaluation of available water volumes in aquifers discharging into, or upstream from, hydroelectric power reservoirs. In northern Sweden, e. g., the main increment of the power reservoirs in the winter is attributed to seepage from the till and peat aquifers within the watershed. A knowledge of the current groundwater situation compared to previous years' will aid in the issuing of forecasts for the supply of water to the reservoirs.

The groundwater data collected from the observation

network will, after due processing, play an important part in the study of the hydrological cycle and in the calculations of water budgets for selected areas. In this respect, the groundwater data constitute an integral cell in the IHD body of representative and experimental basins. Data from the network are also necessary elements which support other basic research projects within and outside the IHD.

Within the framework of the groundwater observation network a number of special research projects have been and will be conducted, e. g., on the effective porosity of till, the fissure porosity of limestone, the groundwater recharge in large glaciofluvial aquifers, the penetration of frost into the ground, the effects of agricultural measures on the chemical composition of groundwater, the response function precipitation — groundwater level etc.

From 1975 the IHD work is planned to continue for the future as an International Hydrological Program (IHP).

Guidance in the planning and designing of the networks was given by WMO/IASH (Symposium on Design of Hydrometeorological Networks, Quebec, Canada, 1965) and by the IHD Coordinating Council (Panel of Experts on Network Planning and Design, Paris, 1967).

However, at the start of the International Hydrological Decade, the special design of a groundwater observation network was not clearly defined. Therefore, the Geological Survey of Sweden started its network with a very practical point of view. With the assistance of the local authorities in the counties (Swedish: *län*), information about previous and current groundwater investiga-

tions was collected. The collection was restricted to investigations and areas where observation wells had been established by consulted engineering firms and where no water extraction had started. Other desired prerequisites were the following: a minimum number of wells (5—10 within a defined area), great probability for the area to remain undisturbed by water extraction for at least ten years, proximity to reliable weather stations. The collected information on suitable investigations and areas was examined, and a number of observation areas were established. Due to the nature of the investigations (search for possible water well sites) most areas were made up of glaciofluvial gravel and sand. Because of very restricted funds during the first years of operation of the network, no complementary observation points in other geological material could be established. Thanks to the co-operation with the Swedish Meteorological and Hydrological Institute, the groundwater networks of the three representative IHD basins Velen, Kassjöån and Lappträsket have been incorporated in the national network. From 1969 a systematic improvement of the national network has taken place in as much as several observation points have been established in till, fine and coarse sediments, and in crystalline and sedimentary bedrock. In 1974, most parts of Sweden had observation areas, and many types of geology, topography and climate are represented in the network. A continuous updating of the network is done annually to secure relevant and reliable observation points.

All observation points are classified with respect to location, geology, topography, aquifer characteristics etc. in a system adapted for computer processing.

2. OBSERVATION STATIONS AND PROGRAM

2.1. Introduction

In Fig. 1 the geographical distribution of the observation areas is shown. Observations are made in most parts of Sweden, although the distribution is somewhat uneven. The number of stations within the individual areas ranges

from 1 to 45 with an average of 10. A synopsis of the geological setting of the stations and the observation program within the areas is presented in Fig. 2. A description of the areas in greater detail follows in chapter 3.

2.2. Observed parameters

2.2.1. Groundwater level

For the most part the observation stations for groundwater level consist of screened, iron tubes which have a diameter of 50 mm. Observations are also made in drilled or dug wells of larger diameter. Measurements are generally performed with tapemeasures equipped with an acoustic sounding device; the tapemeasures have a gauging accuracy of ± 10 mm. Manual measurements are generally made in intervals of 14 days. In about half of the number of the observation areas, the manual measurements are supplemented with automatic recorders. In cases where the recorders are installed on tubes which have a diameter of 50 mm the accuracy is less than with manual measurements, but the accuracy is higher when tubes which have larger diameters are used.

2.2.2. Groundwater temperature

To obtain information about the regional variation of groundwater temperature in different geological and climatological environments, measurements of the groundwater temperature are performed. Valuable information concerning time lag and suppression is also obtained. The temperature readings are generally made in one of the tubes used for the groundwater level observations in each area. The equipment consists of a mercury thermometer in a metal container, usually placed just above the bottom of the tube. The container is connected to the lid of the tube with a nylon string. The thermometer in its container is hoisted to the surface when readings are made. The accuracy of the temperature readings is $\pm 0.1^\circ\text{C}$. The arrangement with stationary thermometers placed in the tubes between measurements was introduced successively in 1970 and 1971. Prior to this the thermometers were lowered into the water in the tubes for a few minutes only at the time of measurement. With this procedure the accuracy

proved to be considerably less than with the present stationary equipment.

2.2.3. Penetration of frost and thickness of snow cover

During the winter when the ground is frozen, no or insignificant volumes of water can percolate to the groundwater. Therefore it is of great importance to know the length of this period. The interpretation of the fluctuations of groundwater levels is facilitated by access to information about the penetration of the frost, the thawing processes and the thickness of the snow cover.

Measurements of the penetration of the frost and of the thickness of the snow cover are made at 1—4 stations in each of thirteen observation areas.

The penetration of the frost is measured with a Gandahl probe (Gandahl, 1957). This consists of a transparent plastic tube filled with water which is dyed with methylene blue. Below the freezing point the blue liquid changes into colorless ice. The inner tube is contained in an outer tube which is inserted vertically into the ground. The inner tube is raised from the outer tube to allow for readings of the frost limits. The readings are made regularly throughout the winter with intervals of 14 days, except for the period of thawing when more frequent measurements are made. The thickness of the snow cover is gauged at the frost penetration stations with a measuring-rod.

In the two representative IHD basins Velen (no. 16) and Lapträsket (no. 37) more extensive observations of the penetration of the frost and snow cover are performed by the Swedish Meteorological and Hydrological Institute (SMHI).

2.2.4. Composition of groundwater

Sampling of groundwater for chemical analysis is done in 21 areas. Most sampling stations consist of natural

springs, but a few stations are made up of plastic tubes penetrating into the aquifers. Drilled and dug wells are also used. The samples, usually collected every third month, are transported in polyethene bottles to the laboratory for analysis. A standard analysis consists of the following parameters and elements: pH, electric conductivity, alkalinity, sulphate, chloride, nitrate, fluoride, sodium, potassium, calcium, magnesium, iron, manganese, aluminium, lead, copper, molybdenum, nickel, cobalt, chromium and tritium. The groundwater temperature is also measured in connection with the sampling. In certain cases oxygen, pH and electric conductivity are measured in the field at the moment of sampling.

The samples taken for chemical analysis are also used for the determination of tritium contents. These deter-

minations can give valuable information on the residence time of the groundwater in certain aquifers.

2.2.5. Precipitation and air temperature

Information on daily precipitation and air temperature within or close to the groundwater observation areas is obtained from the national network of weather stations of the Swedish Meteorological and Hydrological Institute (SMHI). In the representative IHD basins Velen (area no. 16), Kassjöån (area no. 26) and Lappträsket (area no. 37), a more extensive collection of meteorological data is organized by SMHI. In three areas, Hemse (no. 8), File Hajdar (no. 11) and Tärnsjö (no. 23), the observations of SMHI are supplemented with continuous recording of precipitation during the summer.

2.3. Processing of data

Once a month data on groundwater level, temperature, frost penetration and snow cover are dispatched from the field assistants to the groundwater network office of the Geological Survey of Sweden in Stockholm. These observation data and results of the chemical analysis are checked and regularly adapted for computer processing.

Computation of the groundwater level variations in relation to selected reference levels is done, and comparison between different measurements, seasons and years is performed. Mean values, standard deviation and mean error of the observed groundwater levels are computed for different periods. The patterns of variation can be referred to geology, geomorphology, altitude, etc. Computer plotting of the variations of the groundwater levels from the observation areas is done. Special programs for the study of the amplitude of annual and shorter variations in relation to the thickness of the unsaturated zone and the geological composition of the aquifer are also being utilized.

Computer processing of data from the chemical analyses includes calculation of mean values and equilibria. Plotting of variations in the concentration of certain ions in the groundwater is also done.

The relationship of various observed parameters is examined with the help of computer programs. When, in the future, the period of observations is considerably longer, a time series analysis of all measured parameters will be executed.

Besides the computer processing of obtained data, a simple manual control of current data is performed for all stations. For selected stations, diagrams are compiled and successively brought up-to-date. These diagrams give easily accessible information on the current groundwater situation in the whole country. The diagrams are of the same type as those presented in chapter 3.

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GROUNDWATER NETWORK
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● *OBSERVATION AREA*
(with identification number)

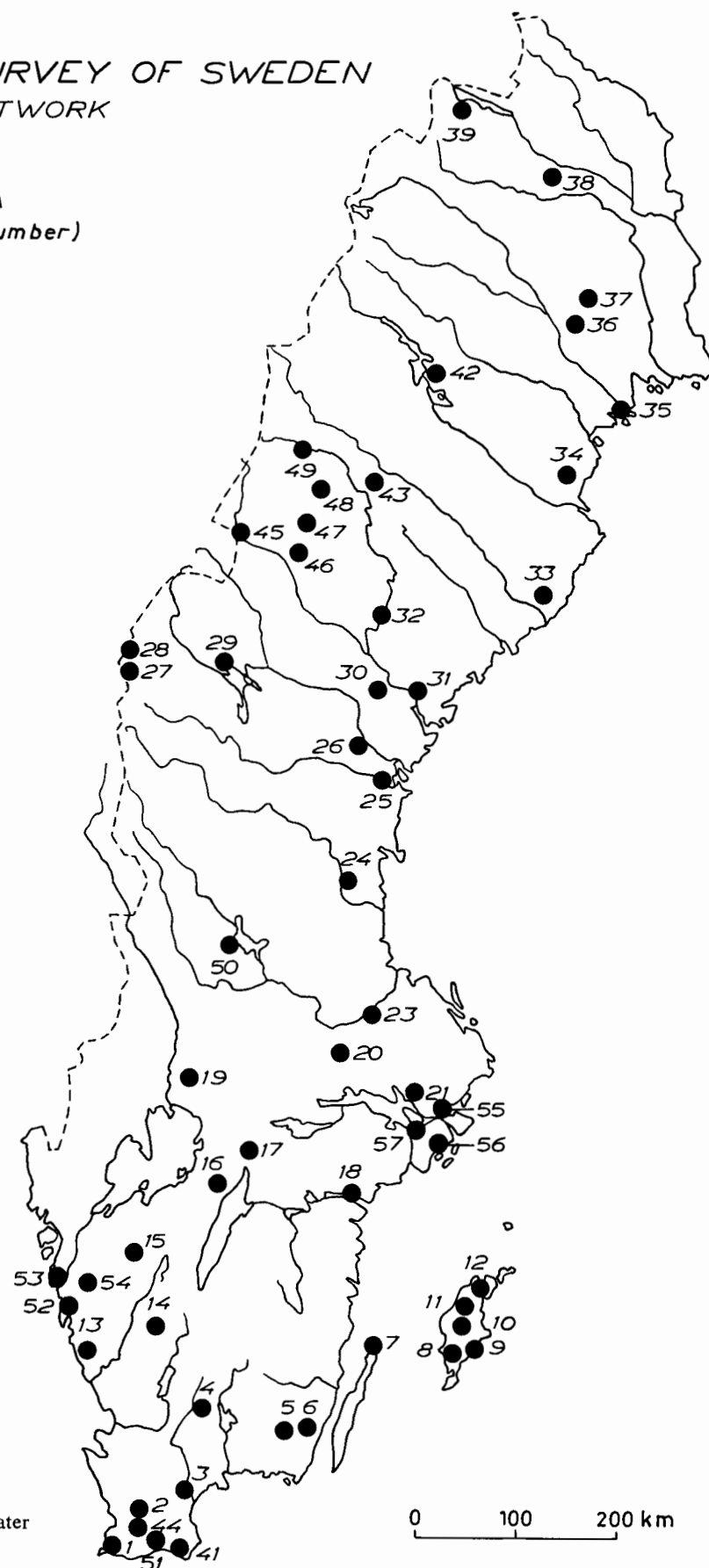


Fig. 1. Map showing the groundwater network of Sweden.

GEOLOGICAL SURVEY OF SWEDEN, GROUNDWATER NETWORK, JANUARY 1, 1974

OBSERVATION AREA	GROUNDWATER LEVEL					GROUNDWATER CHEMISTRY AND TRITIUM					PENETRATION OF FROST					GW TEMP.				
	NUMBER OF STATIONS	GEOLOGICAL SETTING OF STATIONS				START OF OBSERVATIONS	NUMBER OF STATIONS	GEOLOGICAL SETTING OF STATIONS				START OF SAMPLING	NUMBER OF STATIONS	GEOLOGICAL SETTING OF STATIONS				START OF OBSERVATIONS	NUMBER OF STATIONS	
		BEDROCK	TILL	GLACIOFLUVIAL DEPOSITS	OTHER LOOSE DEPOSITS			BEDROCK	TILL	GLACIOFLUVIAL DEPOSITS	OTHER LOOSE DEPOSITS			BEDROCK	TILL		GLACIOFLUVIAL DEPOSITS			OTHER LOOSE DEPOSITS
1 VELLINGE	6	3	3			1970	2	2				1972							1	
2 RÖVAREKULAN							1				1	1968								
3 KRISTIANSTAD	8	1	3		4	1963	13	9		1	3	1963								
4 LIATORP	10		3	7		1968							2		1	1		1971	1	
5 EMMABODA	11		11			1961	2		2			1968	2		2			1971	1	
6 NYBROÅSEN	9			6	3	1957														
7 BODA	12	1		10	1	1968							1			1		1971	1	
8 HEMSE	1	1				1966														
9 LAU							1	1				1969							1	
10 ISUMS	1	1				1967														
11 FILE HAIDAR	8	8				1967														
12 HANGARS							1	1				1969								
13 DJURARPSDALEN	4			4		1957	1			1		1968								
14 NISSAFORS	11	1	2	8		1968	1		1			1970	1			1		1971	1	
15 ÖLANDA	8		2	6		1968													1	
16 VELEN	41	1	34	4	2	1966	4		2	2		1970							4	
17 VISSBODA	8			8		1967	2			2		1968								
18 DAMMTORP	5		4	1		1968													1	
19 BRÄTTFORSHEDE	10			10		1968	1			1		1968							1	
20 SATRABRUNN	5		1	4		1965	3				3	1969								
21 BÄRMÖ			6			1965	2			1	1	1969							1	
22 UGGLEVIK	A B A N D O N E D																			
23 TARNSJÖ	17	2	2	6	7	1965	11		2	3	6	1968	4			1	3	1969	3	
24 RENGSJÖ	4			4		1969							3			3		1970	1	
25 TUNABY	16			16		1953														
26 KASSJÖAN	29	1	25	2	1	1967													1	
27 RUNDHÖGEN							2			2		1968								
28 VISJÖVALEN	5		5			1968													1	
29 YTTERÅN	7		2	5		1968													1	
30 VIKSMÖN	5			5		1968							4			4		1970	1	
31 LÖ-FRÖK	3	3				1968													1	
32 HALLA	13		1	1	11	1958														
33 SÄVARHEDEN	5			3	2	1968							3			1	2	1970	1	
34 DRÅNGSMARK	12			12		1968	1			1		1968	4			4		1970	1	
35 KALLAXHEDEN	7			7		1968							2			2		1970	1	
36 MÅRDUDDEN							1		1			1968								
37 LÄPPTRÄSKET	44	1	33	8	2	1968	1			1		1970							3	
38 SVAPPÅVAARA	12		2	10		1968	1			1		1968							1	
39 ABISKO	2		2			1955							2		2			1972	1	
40 SKANÖR-FÄLSTERBO	A B A N D O N E D																			
41 SANDHAMMAREN	8		2	3	3	1970	1				1	1971							1	
42 ARJEPLOG	10		3	7		1971							4		2	2		1971	1	
43 STENSELE	12		6	6		1971							4		2	2		1971	1	
44 HYBY	1				1	1970	1	1				1972								
45 STRÖMS VATTUDAL	9		9			1972														
46 FLÅSJÖN	8		8			1972														
47 TÄSJÖN	5		5			1972														
48 ORMSJÖN	15		15			1972														
49 MALGOMAJ	10		10			1972														
50 SILJANSFORS	13		11	2		1972														
51 NASBYHOLM	5		3		2	1973	5		3		2	1973								
52 SANDSJÖBACKA	14		12	2		1970														
53 HÅRESTAD	13		13			1971														
54 HÅRSKÖGEN	15		12	3		1970														
55 BOGESUND	19		19			1968														
56 BERGA	18		18			1968														
57 BORN SJÖN	18		18			1968														
TOTAL	538	24	305	170	39		58	14	11	19	14		36		9	22	5		34	

Fig. 2. Table of fundamental information on the groundwater network.

3. DESCRIPTION OF OBSERVATION AREAS AND SELECTED RESULTS

In this chapter a general description of 51 observation areas is given. It includes facts about geographical location, geology and geomorphology, hydrological and hydrogeological features, observation stations, and comments on a diagram from each area. The diagrams contain information about groundwater level, temperature and chemistry, snow cover, frost penetration and precipitation for selected stations. The groundwater level, snow cover and frost penetration are related to the land surface at the observation station. The groundwater temperature is given in degrees centigrade and the precipitation in mm. The chemical composition of the groundwater is given in milliequivalents per liter (meq/l) for the major constituents: sodium (Na), potassium (K), magnesium (Mg), calcium (Ca), bicarbonate (HCO_3), chloride (Cl), sulphate (SO_4) and nitrate (NO_3). The first line above the zero line indicates the sodium content, next line sodium plus potassium, next line sodium plus potassium plus magnesium etc. Below the zero line the major negative ions are added in the same way. In some diagrams some of the eight major constituents have been excluded because of their relatively low concentration. The tritium content is presented in tritium units (TU). Maps of each area showing the location of the stations are also included. Most maps showing the observation areas are excerpts from the topographic map of Sweden. The identification symbols for the used map sheets are given in the figure captions. The description of the stations is made up of a table with salient points of information. The main features of the tables are presented in a brief form in which abbreviations and symbols are used according to the explanation below. Areas incorporated with the network after 1973-12-31 are not described in this chapter.

Abbreviations in the tables:

Station no.	Station number (the first two digits are the area number)
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Lat.	Latitude (degrees and minutes north)
Long.	Longitude (degrees and minutes east of Greenwich)
m a. s. l.	Meters above sea level
obs.	Observation
Aq.	Aquifer

Geology

Grav. till	Gravelly till
Gl. fl. mix.	Glaciofluvial material, mixed composition
Gl. fl. grav.	Glaciofluvial gravel
Gl. fl. sand	Glaciofluvial sand
Fluv. silt	Fluvial silt
Litt. sand	Littoral sand
Ma. la. silt	Marine/lacustrine silt
Ma. la. clay	Marine/lacustrine clay
Eol. sand	Eolian sand

Type of station

Tube	Screened tube well, metal or plastic, diameter varying
Dug	Dug well, diameter varying
Drill	Drilled well, diameter varying
Spring	Artesian or non-artesian spring
Frost	Frost penetration probe
RSG	River stage gauge

Observation program

L	Groundwater level
T	Groundwater temperature
C	Groundwater chemistry, including tritium
F	Frost penetration and snow cover

Aquifer

W	Water table conditions
A	Artesian conditions

3.1. Vellinge

3.1.1. Geographical location

The observation area Vellinge is situated in the southwestern part of the province of Skåne, near the coast of

Öresund, between the towns of Malmö and Trelleborg. The altitude of the area ranges from 0 to 35 m a.s.l. (see map, Fig. 3).

3.1.2. Geology and geomorphology

The bedrock of the area consists of Cretaceous (Danian) limestone, but it is not exposed within the area. It is covered by approx. 10 m of clay till from the last phase of the Weichselian glaciation. Glaciofluvial deposits are few and insignificant. Postglacial littoral sandy deposits are found along the shores. The area forms a flat low-land, gently sloping toward the sea.

3.1.3. Hydrological and hydrogeological features

The groundwater in the area can be found in two storeys, the lower one in the Cretaceous bedrock and the upper one in the Quaternary deposits. The general flow direction of the groundwater is toward the coast. The groundwater in the bedrock is under artesian pressure in all parts of the observation area. Artesian flowing wells are found in certain parts of the area.

The pattern of the groundwater flow in the Quaternary deposits is strongly influenced by the local topography. The groundwater level generally appears 1–5 m below the land surface. The hydrogeological features of the area are presented by Gustafsson (1972). The surface water of the area is drained by a great number of small brooks and ditches toward Öresund and the Baltic Sea.

Four large community water supply wells are found within or adjacent to the observation area. These are Bunkeflostrand, Tygelsjö, Vellinge and Räng, and according to Gustafsson (1972) the following volumes of water were extracted in 1969: 154 000, 50 000, 148 000 and 640 000 m³ respectively, corresponding to 5, 1.5, 5 and 20 l/s respectively.

There are two major limestone quarries in the north-western outskirts of the observation area. From the Limhamn quarry approx. 1.5 million m³/year (= 50 l/s) and from the Klagshamn quarry approx. 0.3 million m³/year (= 10 l/s) were extracted by pumping in 1969. Besides the four big community supply wells and the two quarries, a great number of wells for separate households and farms are found in the area. According to Gustafsson (1972), the total extraction from these wells amounts to approx. 0.5 million m³/year (= 16 l/s).

Pumping from the big wells, quarries and small wells has a local influence on the groundwater levels and flow pattern. However, the regional groundwater conditions seem to be influenced only very slightly or not at all by the pumping.

Fig. 3. Map of observation area 1 Vellinge. (Top, map 1 C NV, 2 C SV.)



3.1.4. Observation stations

The main features of the observation stations are presented in the table below.

The locations of the stations are presented on the map, Fig. 3.

Stations nos. 0103—0105 were established by SGU in order to obtain information concerning the groundwater in the loose deposits. Stations nos. 0106—0109 were drilled prior to the groundwater network project and station no. 0110 was drilled in 1972. All these stations were established for groundwater supply reasons, and stations nos. 0109—0110 are at present producing wells. The groundwater level at station no. 0106 is for certain periods of time influenced by pumping at station no. 0110 which is situated approx. 0.5 km from station no. 0106. The well of station no. 0110 was established in 1972 and a test pumping was performed from July, 1972, to October, 1972. The withdrawal during this period was 7—20 l/s. In December, 1972, this well replaced the well at station no. 0109 as the main water supply well for the small town of Tygelsjö. The pumping during 1973 at station no. 0110 has been 2.6 l/s. The pumping at this station has strongly influenced the groundwater level at station no. 0106 (see diagram, Fig. 4).

3.1.5. Comments on the diagram

In the diagram (Fig. 4) all observed parameters are shown from the selected stations.

A systematic sampling of groundwater for chemical analysis started as late as in 1972, and for this reason no conclusions concerning seasonal and multiannual variation can be drawn.

The chemical composition of the groundwater seems to be representative for the area (cf. Gustafsson, 1972). The high concentrations of calcium and bicarbonate are caused by the large contents of calcium carbonate in the local bedrock and soil.

According to Gustafsson (1972), the tritium contents of the groundwater in the producing wells of the area range from 3 to 15 TU. There is no great difference between the tritium contents of the water from the high-producing wells and of that from the low-producing wells. Therefore Gustafsson concludes that the infiltration conditions are not influenced by the large extractions from certain wells. The rather low concentrations of tritium in the groundwater indicate a long residence time of the water.

The tritium content in the water from station no. 0109 ranges from 3 to 17 TU. The lowest value (3 TU) was found in the spring of 1973 after establishing well no. 0110 and when the pumping from well no. 0109 had almost ceased. Changes in flow pattern due to the changed pumping conditions in December probably have caused the decrease in tritium content in 1973.

The pattern of the seasonal variations of groundwater levels in limestone and clay till are very similar — an annual amplitude of 1—1.5 m in the limestone and 1.3—2.2 m in the till. The great similarity in the patterns of the variations seems to indicate a close relationship between the two aquifers. It can be supposed that all or almost all recharge to the limestone aquifer takes place through the overlying till. The groundwater reaches its highest level in late winter or early spring, and the lowest levels appear in October—November. In the area the ground is neither frozen nor covered permanently with snow in the winter. This means that infiltration and percolation usually can take place throughout the winter. During the long period of intensive plant growth that prevails in this area, the level of the groundwater sinks steadily to a minimum in October—November.

There is a very distinct falling trend in the annual maximum groundwater levels of stations no. 0105 and no. 0108 from 1970 to 1972. The yearly decrease of the annual maximum levels for station no. 0105 (till), is 0.45 m, and for station no. 0106 (limestone), 0.35 m. In

Station no.	Lat.	Long.	Land surface m a.s.l.	Geology	Depth of well m	Type of station	Obs. program	Aq.	Start of obs.	Remarks
0103	5527	1301	14	Clay till	8	Tube	LT	W	1970	
0104	5524	1302	13	„ „	8	„	L	W	1970	
0105	5526	1300	9	„ „	7	„	L	W	1970	
0106	5531	1300	23	Limestone	34	Drill	L	A	1969	Temporarily influenced by pumping
0107	5531	1300	29	„	15	„	L	A	1969	
0108	5532	1300	32	„	39	„	L	A	1969	
0109	5531	1300	28	„	50	„	C	A	1972	Producing well
0110	5531	1300	20	„	59	„	C	A	1973	Producing well

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AREA 01 VELLINGE

Groundwater level: Station 0105 (clay till) and 0106 (Cretaceous Limestone covered by clay till)
Groundwater temperature: Station 0103 (clay till), measuring depth 7 m below land surface
Groundwater chemistry: Station 0109 (Cretaceous Limestone covered by clay till)
Precipitation: Station SMHI 5223 Falsterbo
Mean yearly precipitation 1931-60: 531 mm

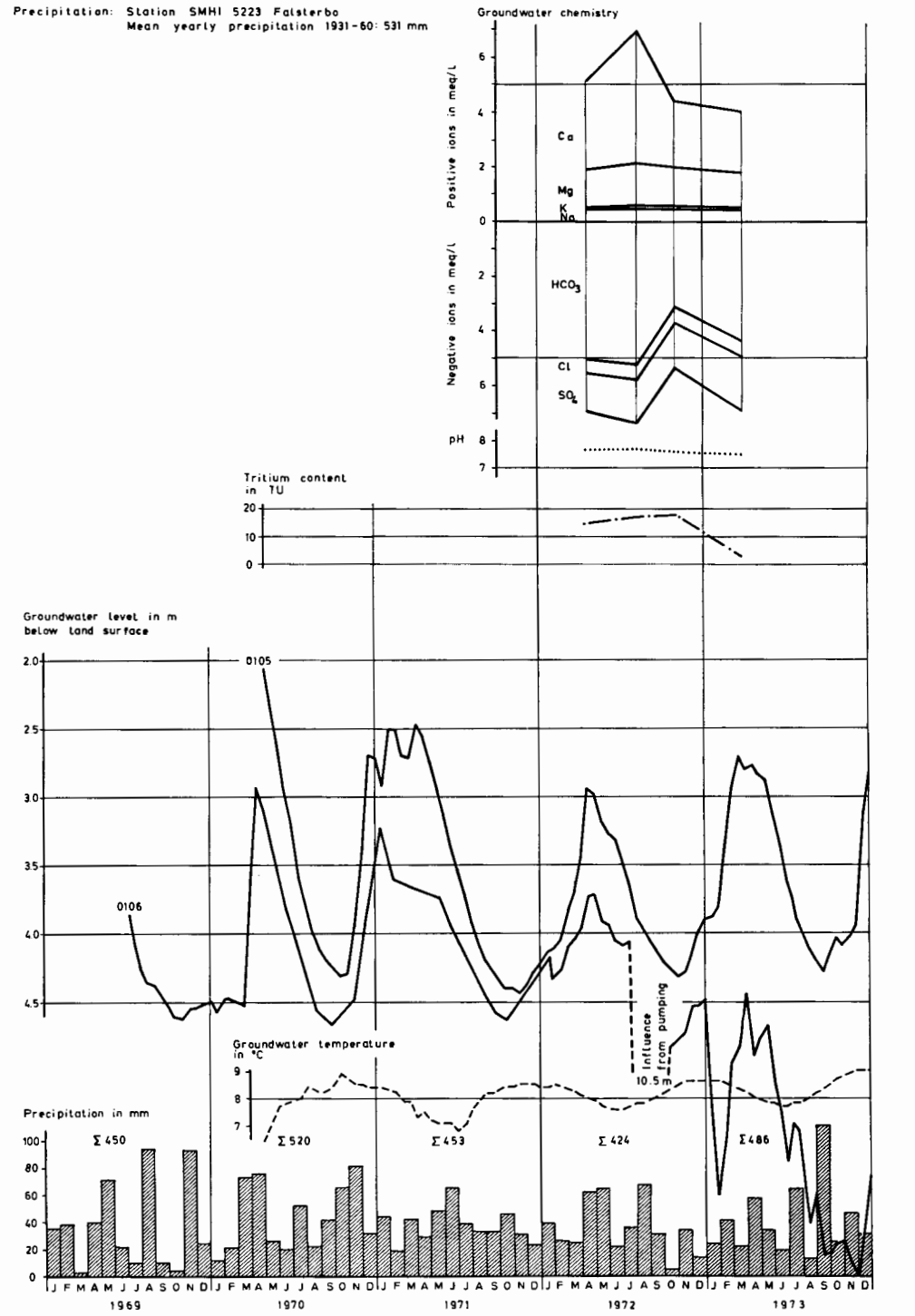


Fig. 4. Diagram from observation area 1 Vellinge.

1973 the levels at no. 0105 rise somewhat again. The very low levels at station no. 0106 are due to the influence from pumping (see page 16). The trend is probably caused by low precipitation in 1971 and 1972.

During the observation period the temperature of groundwater in clay till, seven meters below the land surface, ranges from 6.5 to 8.9 with a mean of 8.1 °C. The annual amplitude is 1.0–2.4° C with the minimum

temperature in June–July and maximum temperature in the winter. Due to an unsatisfactory measuring technique in 1970–71, the curve, for this period, shows irregularities which are assumed not to be representative for the true situation. The recorded annual amplitudes are, for the same reason, probably too large for the years 1970 and 1971.

3.2. Rövarekulan

3.2.1. Geographical location

The observation area Rövarekulan is situated in the central part of the province of Skåne, 6 km south of Lake Ringsjön. The area is shown on the map, Fig. 5.

3.2.2. Geology and geomorphology

The bedrock of the area consists of Silurian shales, generally covered by 1–5 m of clayey sandy till from the Weichselian glaciation. The river Bråån flows through the area in a 20–30 m deep valley cut down into the Silurian shales. The stratigraphy of the upper parts of the shale and of the overlying Quaternary deposits can be studied along the steep slopes of the valley. On some localities a layer of sand about 0.5 m thick is found between the shales and the till.

3.2.3. Hydrogeological features

Several small springs are found on the slopes of the Bråån valley. The outflow of the groundwater from the surrounding moraine terrain is localized to the sand layer above the Silurian shales which are almost impermeable. On the slopes of the valley where groundwater comes to the surface, the formation of peat and travertine takes place.

3.2.4. Observation station

The main features of the observation station are presented in the following table:

Station no.	Lat.	Long.	Land surface m a.s.l.	Geology	Type of station	Obs. program	Start Aq. of obs.
0201	5547	1330	103	Sand covered by till	Spring	C	W 1968

The largest spring in the area has been selected as an observation station. The discharge from this spring is about 0.1 l/s.

3.2.5. Comments on the diagram

The chemical composition and tritium content of the groundwater from station no. 0201 are shown in the diagram (Fig. 6). No distinct, seasonal or multiannual variations in chemical composition can be found. The high concentrations of calcium and bicarbonate are caused by a relatively large content of calcium carbonate in the till of the area. The concentration of nitrate is unusually high. This is probably caused by the use of fertilizer on the surrounding fields in the moraine terrain. The high content of tritium in the groundwater indicates a short residence time.

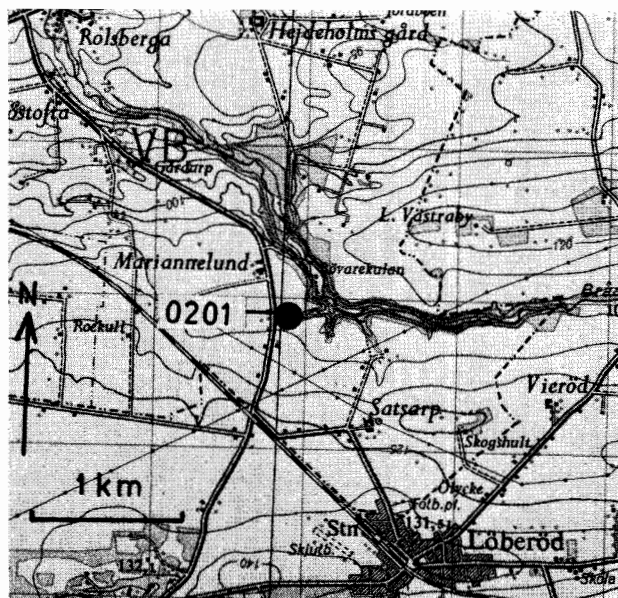


Fig. 5. Map of observation area 2 Rövarekulan. (Top. map 2 D NV.)

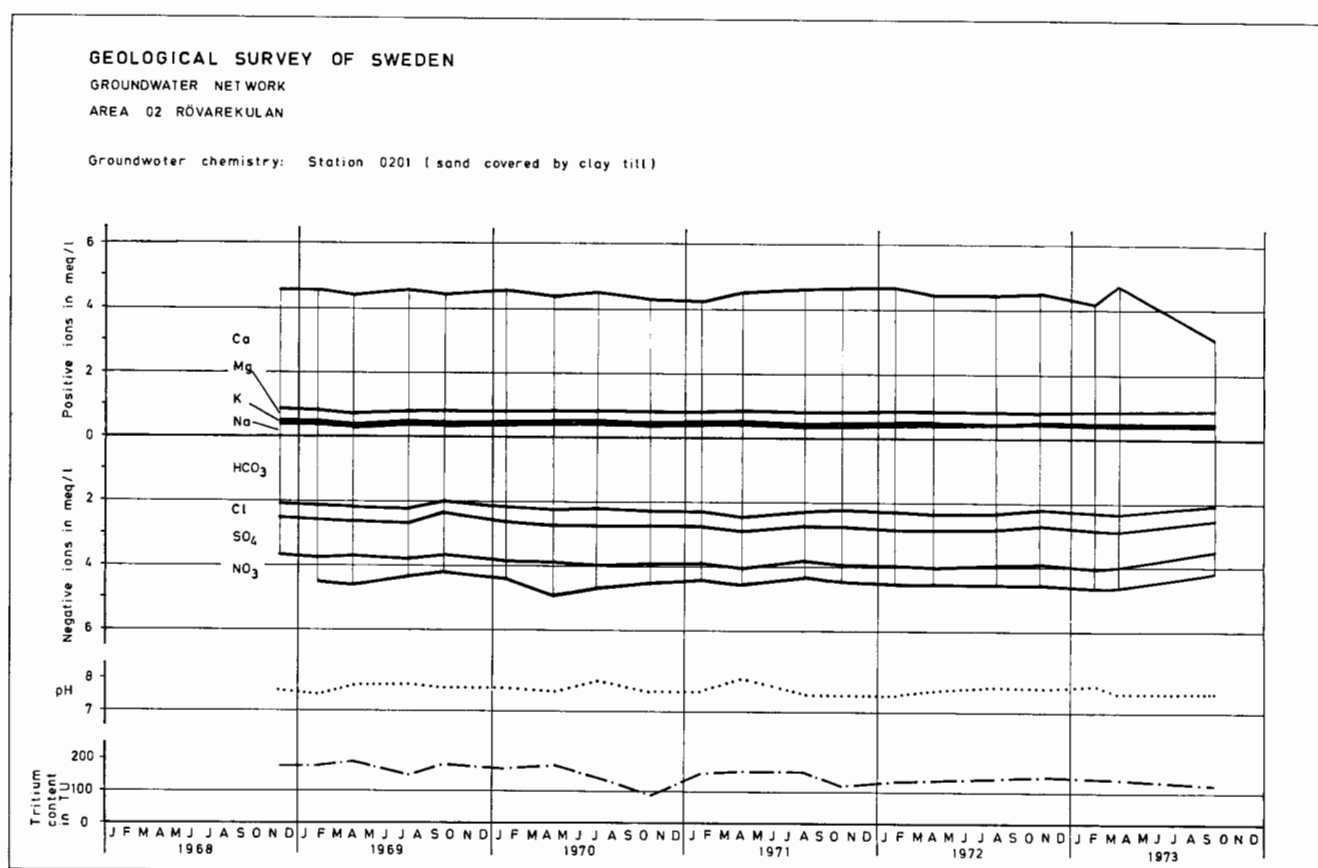


Fig. 6. Diagram from observation area 2 Rövarekulan.

3.3. Kristianstad

3.3.1. Geographical location

The observation area Kristianstad is situated in the northeastern part of the province of Skåne, around the town of Kristianstad. The altitude of the area ranges from 0 to 40 m above sea level.

3.3.2. Geology and geomorphology

The observation area (see map, Fig. 7) is made up of part of the Kristianstad plain which is a flat to gently rolling lowland bordering the Baltic Sea. The northern border is of an erosional character, and the western and southern borders are faults. The plain is underlain by Cretaceous (Senonian) deposits which have in most parts of the plain a thickness of approx. 100–200 m and consist of limestones, sandy limestones, sandstones and calcareous sandstones. Some of the latter are poorly consolidated, especially the so-called glauconitic sandstone generally found in the lower part of the Cretaceous

sequence. This sandstone has been formed near the shore of a transgressing sea. In the upper part of the sequence, limestones predominate. These were probably formed at a greater depth in the sea. The Cretaceous deposits rest on a strongly weathered Precambrian bedrock of gneisses and granites. The Precambrian bedrock is exposed at the noncoastal borders of the Kristianstad plain.

The sedimentary rocks of the Kristianstad plain are covered by glacial drift which consists mainly of till containing significant amounts of clay and silt, and glaciofluvial sandy deposits. Glacial clay, commonly varved, is found in many places of the area. After the deglaciation the area, or part of it, was inundated several times by the waters of glacial lakes and the sea. An extensive wave-washing of the till, the glacial clay and the glaciofluvial deposits took place and resulted in a widespread accumulation of sand and clay.

In the vicinity of the town of Kristianstad the total

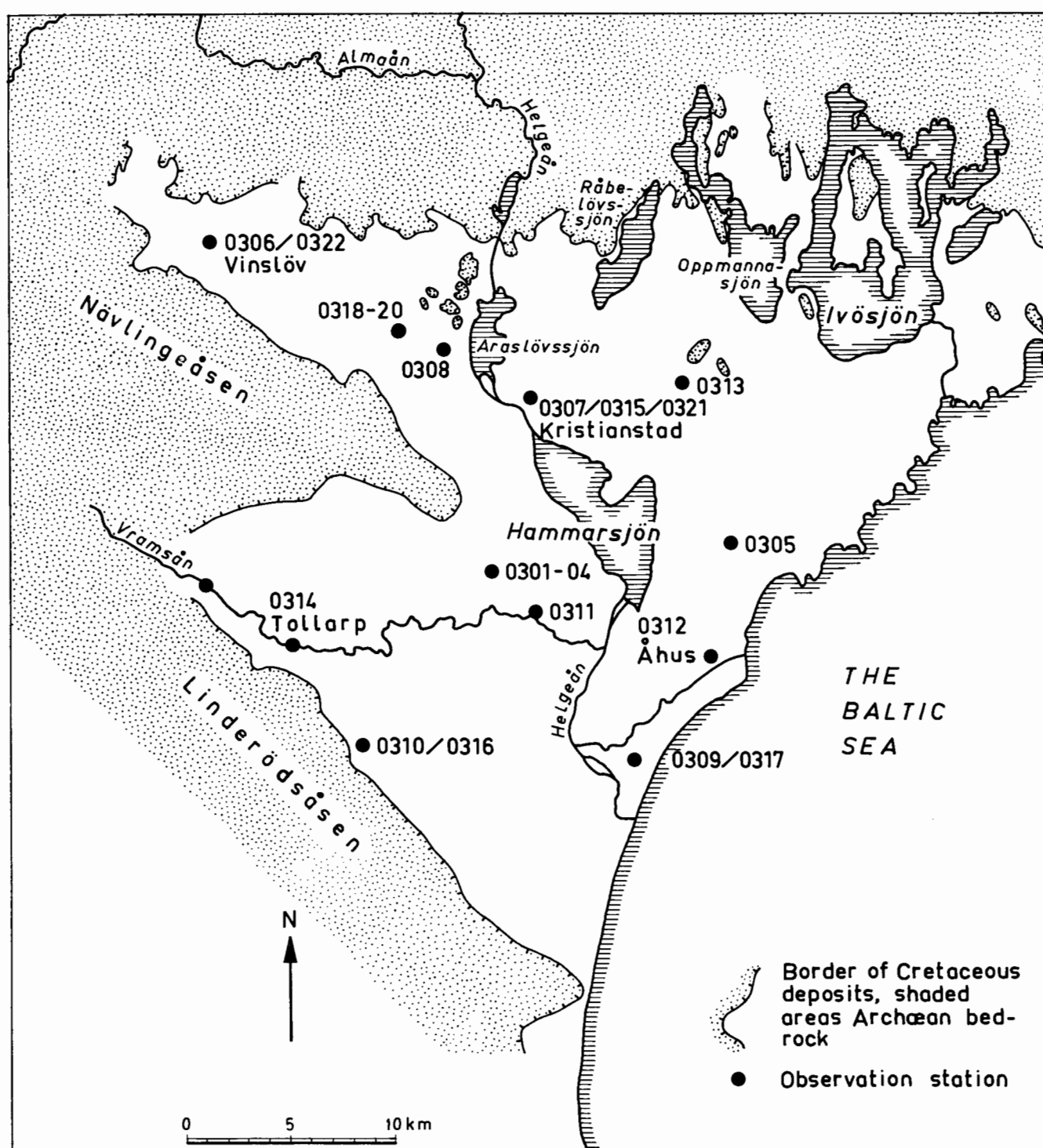


Fig. 7. Map of observation area 3 Kristianstad.

thickness of the Quaternary deposits ranges from 7 to 35 m. The greatest recorded thickness, 82 m, has been found in Yngsjö in the southeastern part of the area.

The geology of the Kristianstad plain is described in greater detail by Nilsson (1966).

3.3.3. Hydrological and hydrogeological features

The surface water of the Kristianstad plain is drained by the river Helgeån and its numerous tributaries, among which the river Vramsån is the largest. Helgeån flows through two shallow lakes, Araslövssjön and Hammarsjön, on its way to the Baltic Sea. In the northeastern part of the area, in the border zone between the plain and the Precambrian upland, there are three major lakes — Råbelövssjön, Oppmannasjön and Ivösjön. Råbelövssjön belongs to the Helgeå drainage system. The other two lakes are drained by the river Skräbeån.

The flow of the groundwater in the Cretaceous rocks is directed toward the Hammarsjö area in the central part of the plain and toward the sea. The groundwater in the Quaternary deposits has the same general flow pattern, but has local deflections due to the topography. In the central part of the plain the levels of the groundwater in the Cretaceous, as well as the Quaternary aquifers, are generally found within a few meters from the surface.

A great number of drilled producing wells are in operation in the observation area. Most of these extract water from the glauconitic sand and sandstones in the basal part of the Cretaceous sequence. These deposits constitute the main aquifer of the area. Kristianstad is supplied with water from several wells within a very restricted area. The total annual extraction for the town of Kristianstad is more than 5 million m³ (= 160 l/s). Due to the pumping, a cone of depression with a diameter of approx. 5–10 km has been created beneath Kristianstad.

Other big wells producing from the Cretaceous aquifer are found in Åhus (400 000 m³/yr = 13 l/s), Vinslöv (200 000 m³/yr = 6 l/s) and Fjälkinge (100 000 m³/yr = 3 l/s). In Åhus the water is extracted from the Åhus sandstone in the upper part of the Cretaceous sequence, whereas the other two towns extract water from the glauconitic sand.

The largest extraction of water from a single well in the Quaternary deposits is found in Tollarp. A volume of approx. 325 000 m³ is pumped each year (= 10 l/s) from sand and gravel accumulated in a canyon in the Cretaceous rock covered by clayey silty till.

Besides the big community water supply wells, a mul-

titude of small wells that supply homes, farms, industries and small towns are found in the area.

Pumping from the big and small wells has a local influence on the groundwater levels and flow pattern. The regional groundwater conditions seem to be influenced mainly by the extraction of water in Kristianstad. Due to the increasing volumes of water extracted from the wells in Kristianstad, the influence on the regional groundwater flow pattern has been growing and is assumed to continue to grow.

A report on the hydrology and hydrogeology of the Kristianstad plain has been compiled by Weijman-Hane and Hörberg (1969). Other reports which concern the groundwater conditions of the Kristianstad plain, have been presented by Viak (1970, 1973).

3.3.4. Observation stations

The main features of the observation stations are presented in the table on page 22.

Stations nos. 0306—0317 and nos. 0321—0322 are all producing wells. In the program for chemical analysis for these stations, only the determination of the tritium content and the concentrations of sodium, potassium, calcium and chloride were included during the period 1963—1971. Since 1971 the program includes all parameters and elements mentioned in chapter 2.2.4. The locations of the stations are presented on the map, Fig. 7.

Station no. 0301 was established in connection with an investigation of the hydrology of the Kristianstad plain during the period 1955—1966 (Weijman-Hane and Hörberg, 1969). Nine producing wells (nos. 0306—0314) within the area were also selected as sampling stations in order to investigate the variations in tritium content of the groundwater. Three of these stations (nos. 0307, 0309 and 0310) have since then been replaced by new wells (nos. 0315, 0317 and 0316). When the investigation on the hydrology of the Kristianstad plain was brought to an end in 1966, SGU continued the measurements and the sampling at these stations. Stations nos. 0302—0304 were established by SGU in 1970 in order to get more information about the variation pattern of the groundwater level in the Quaternary deposits. Station no. 0305 was established for groundwater supply purposes, but it is no longer used for this purpose. Since 1972 this well is used for observation of the variations in groundwater level in the Cretaceous aquifer. The groundwater level at this station is for shorter periods of time influenced by extensive pumping for irrigation purposes from nearby wells. Stations nos. 0318—0320 were established by SGU in connection with a research project

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Station no.	Lat.	Long.	Land surface m a.s.l.	Geology	Depth of well m	Type of station	Obs. program	Aq.	Start of obs.	Remarks
0301	5557	1407	18	Litt. sand	2	Tube	L	W	1963	The sand is covered by till
0302	5557	1406	21	Sand	7	"	L	A	1970	
0303	5557	1406	24	"	6	"	L	A	1970	
0304	5557	1406	23	"	4	"	L	A	1970	
0305	5559	1419	10	Limestone	36	Drill	LT	A	1972	No sampling since 1965
0306	5606	1355	28	Sandstone	26	"	C	A	1963	
0307	5602	1409	4	"	106	"	C	A	1963	
0308	5603	1405	11	"	47	"	C	A	1963	No sampling since 1966
0309	5552	1413	3	Limestone	102	"	C	A	1963	
0310	5553	1401	35	Sandstone	125	"	C	W	1963	No sampling since 1967
0311	5556	1409	6	"	92	"	C	A	1963	No sampling since 1971
0312	5555	1418	21	"	21	"	C	A	1963	
0313	5602	1416	13	"	81	"	C	A	1963	
0314	5555	1358	32	Sand	29	"	C	A	1964	
0315	5602	1409	4	Sandstone	100	"	C	A	1965	
0316	5553	1401	38	"	52	"	C	W	1968	
0317	5552	1413	3	Limestone	57	"	C	A	1967	
0318	5603	1403	7	Ma. la. clay	3	Tube	LC	A	1973	
0319	5603	1403	7	Sand	2	"	LC	A	1973	
0320	5603	1403	7	"	1	"	LC	W	1973	
0321	5602	1409	4	Sandstone	76	Drill	C	A	1973	
0322	5605	1354	35	"	62	"	C	A	1973	

concerning the effects of agricultural measures on the quality of ground- and surface water. The investigations are carried out in co-operation with Lantbrukshögskolan (The Agricultural College of Sweden) and Naturvårdsverket (The National Swedish Environment Protection Board) (cf. stations nos. 5101—5105).

3.3.5. Comments on the diagram

In the diagram (Fig. 8) all observed parameters are shown from selected stations.

A systematic sampling of groundwater for chemical analysis started as late as 1971, and for this reason no conclusions regarding the seasonal and multiannual variations can be drawn.

The chemical composition of the water from the presented station (no. 0308) seems to be representative for the water from the Cretaceous rock in this area.

The high concentrations of calcium and bicarbonate are caused by the large amount of calcium carbonate in the local rocks.

Since the sampling started in 1963, the tritium content in the groundwater from the presented station (no. 0308) has increased from 5 to 51 TU. Tritium concentrations

which increase during this period have been found in many of the producing wells used as sampling stations (nos. 0306, 0307, 0308, 0310, 0312, 0313, 0315 and 0316), (see diagram, Fig. 9). In contrast with these wells, the concentrations of tritium in some of the other wells (stations nos. 0309, 0311, 0314 and 0317) have been very low (generally less than 3 TU) during the whole period.

The low concentrations of tritium in some of the deep and low-producing wells (nos. 0309, 0311, 0317) in the main Cretaceous aquifer indicate a very long residence time of the water in this aquifer. The increasing concentrations of tritium in some wells indicate a shorter residence time in the upper (nos. 0308, 0312) and peripheral (nos. 0306, 0310, 0316) parts of the aquifer. In connection with extensive pumping a rather short residence time is also indicated locally (nos. 0307, 0315) in the basal parts of the aquifer. More information concerning the stations nos. 0306—0317 and the variations of tritium content are presented by Persson (1974).

The variations of the groundwater level at stations in three aquifers are shown in Fig. 8. Station no. 0301 is situated in a non-artesian sand aquifer. In this aquifer

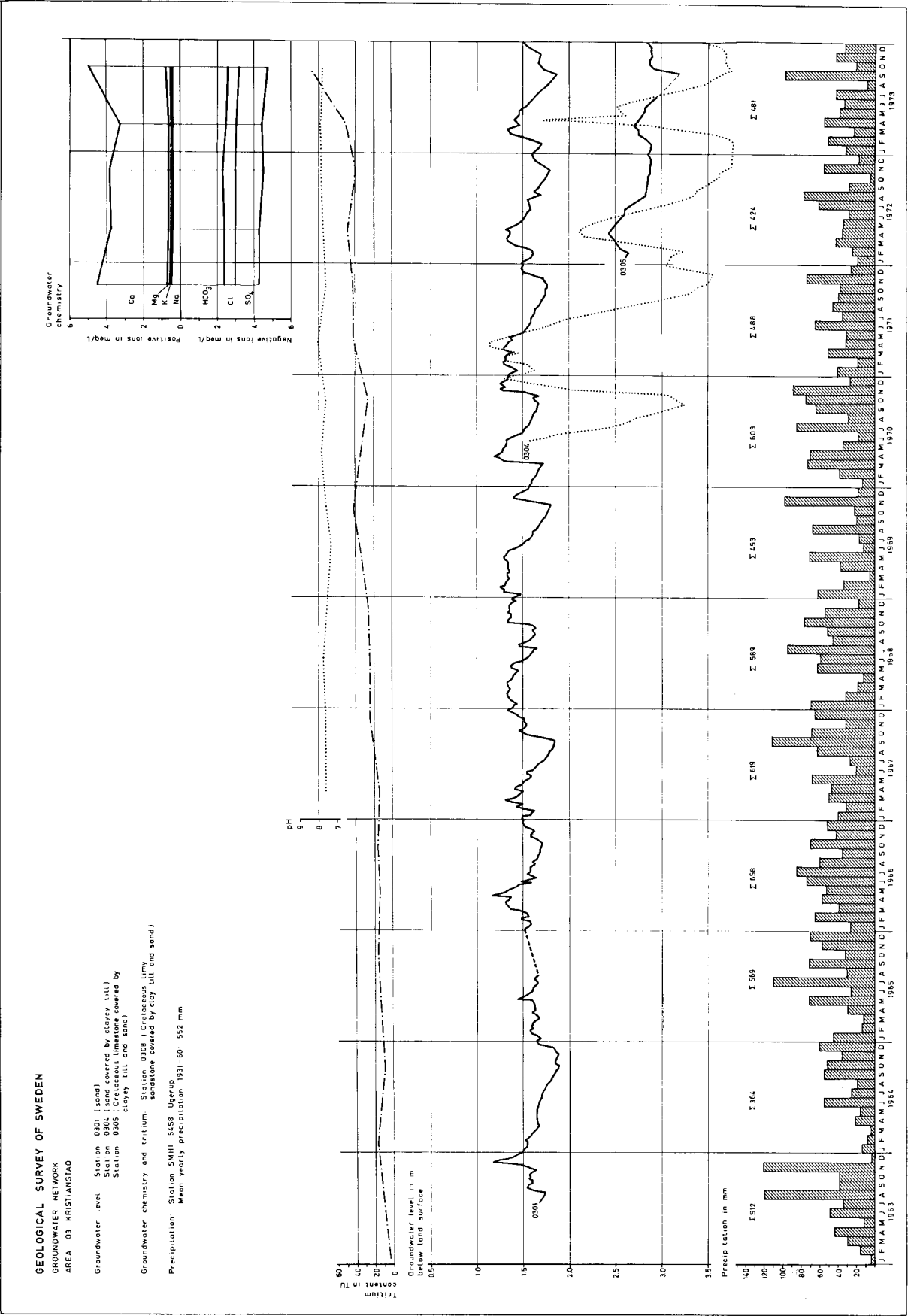


Fig. 8. Diagram from observation area 3 Kristianstad.

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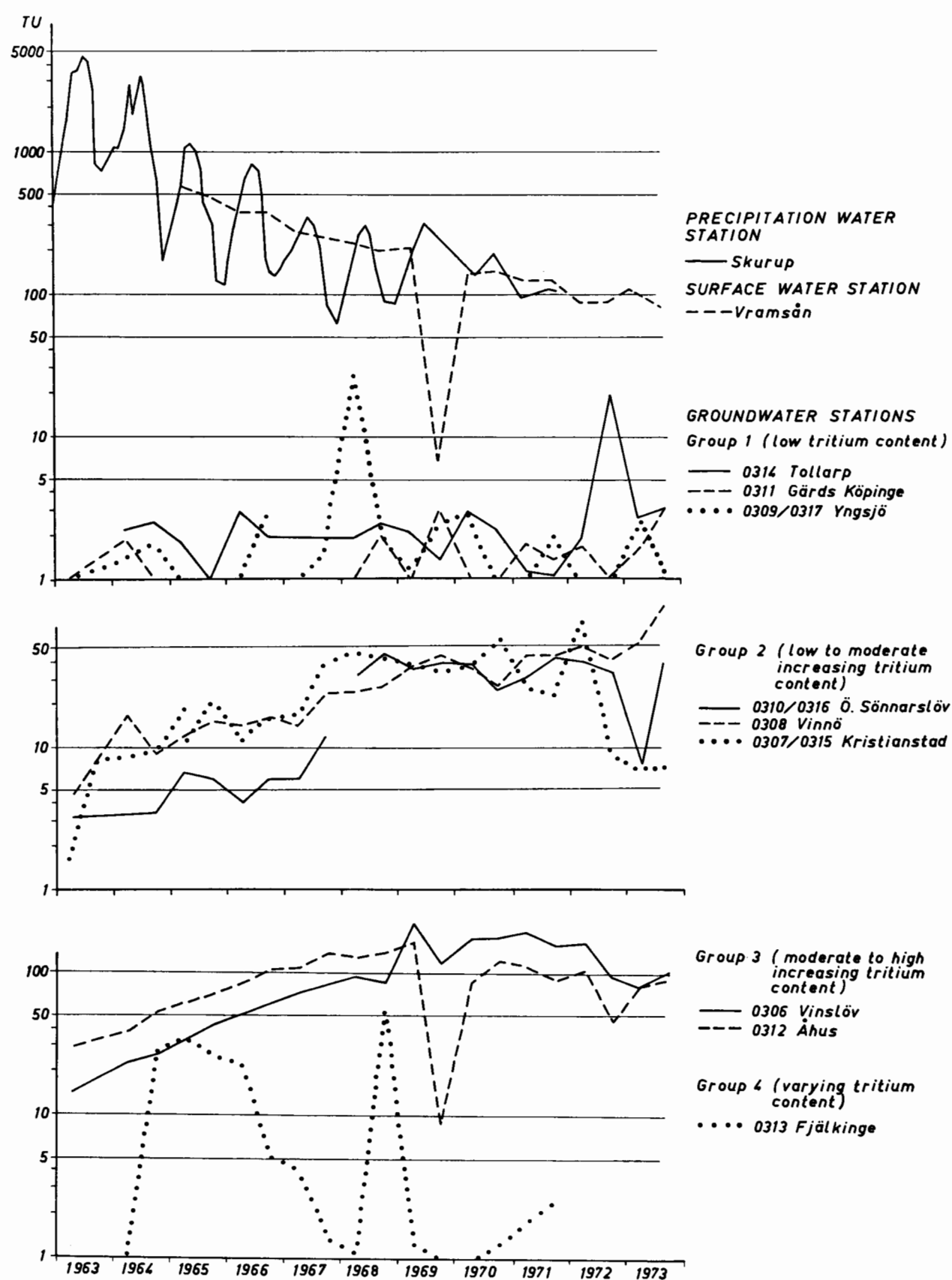


Fig. 9. Diagram showing the variation of tritium content from stations in area 3 Kristianstad. From G. Persson, 1974, supplemented with data for 1973.

the groundwater generally reaches its highest level in late winter or early spring, and the lowest levels appear in September—October. In some years a minor maximum is found in November—December. The annual amplitude is about 0.5 m. No distinct, multiannual trends are found during the observation period, but in some years extreme precipitation conditions seem to have influenced the groundwater level (e. g. the high precipitation in November, 1963, and the low precipitation in 1964).

Station no. 0304 is situated in a confined aquifer (sand covered by till). The groundwater level seems to reach

the maximum and minimum extremes at the same time as at station no. 0301. However, in the former aquifer the annual amplitude is much larger, 1.5—2.5 m. Since the observations started in 1970, a falling trend in both the annual maximum and minimum levels is found.

Station no. 0305 is situated in the Cretaceous aquifer. The observation period for this station is too short to allow any conclusions about multiannual trends. The seasonal variations seem to be similar to those at station no. 0301.

3.4. Liatorp

3.4.1. Geographical location

The observation area Liatorp is situated in the south-western part of the province of Småland in south Sweden, approx. 45 km southwest of the town of Växjö. The altitude of the area ranges from 150 to 156 m a.s.l. A map of the area is shown in Fig. 10.

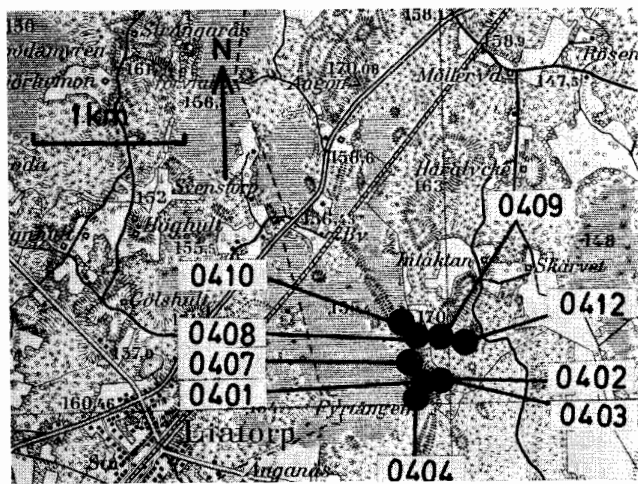


Fig. 10. Map of observation area 4 Liatorp. Station no. 0413 is situated immediately south of the map border.

3.4.2. Geology and geomorphology

The area is underlain by Precambrian bedrock consisting mainly of schistose gneisses. These are not exposed anywhere within the observation area as they are covered by glacial drift from the latest glaciation. The most common constituent of the drift is normal sandy till, the petrographic composition of which is shown in Fig. 11. The material of the till is derived wholly from the Precambrian bedrock. The superficial boulder frequency is intermediate, although, in localized spots a high fre-

quency of large boulders can be found. The thickness of the till is assumed to be 3—5 m. The moraine geomorphology is flat — gently hummocky. A narrow, winding esker, formed above the highest shore line, runs approx. NW—SE through the area. The esker consisting mainly of sand rises 2—6 m above the surrounding terrain. The lower parts of the area, particularly west of the esker, are occupied by organogenic deposits. An extensive bog is situated immediately to the west of the esker.

3.4.3. Hydrological and hydrogeological features

The groundwater, as well as the surface water, of the area is drained through minor brooks toward the low parts of the area and, finally, to the lake Möckeln and the Helgeå drainage system. Groundwater from the esker has been found by comparative temperature readings to seep to the nearby brooks east and south of the esker. The general flow pattern of groundwater in the esker is from the northwest toward the southeast. The gradient is approx. one per cent. A flow of groundwater from the bog west of the esker, transversely or diagonally through the esker, has been assumed in a report by Orrje & Co. (1966). In the same report it is stated that the major part of the groundwater is to be found in the sandy deposits just east of the crest of the esker. Nothing contradicts these assumptions. However, it is quite obvious that a considerable, longitudinal flow of groundwater takes place through the esker. Due to the small size of the esker the total volume of groundwater in it is relatively inferior. No pumping tests have been performed. In the report by Orrje & Co. it is stated that neither the available quantity nor the quality of the groundwater is acceptable for water supply purposes.

The groundwater conditions of the bedrock have not been investigated.

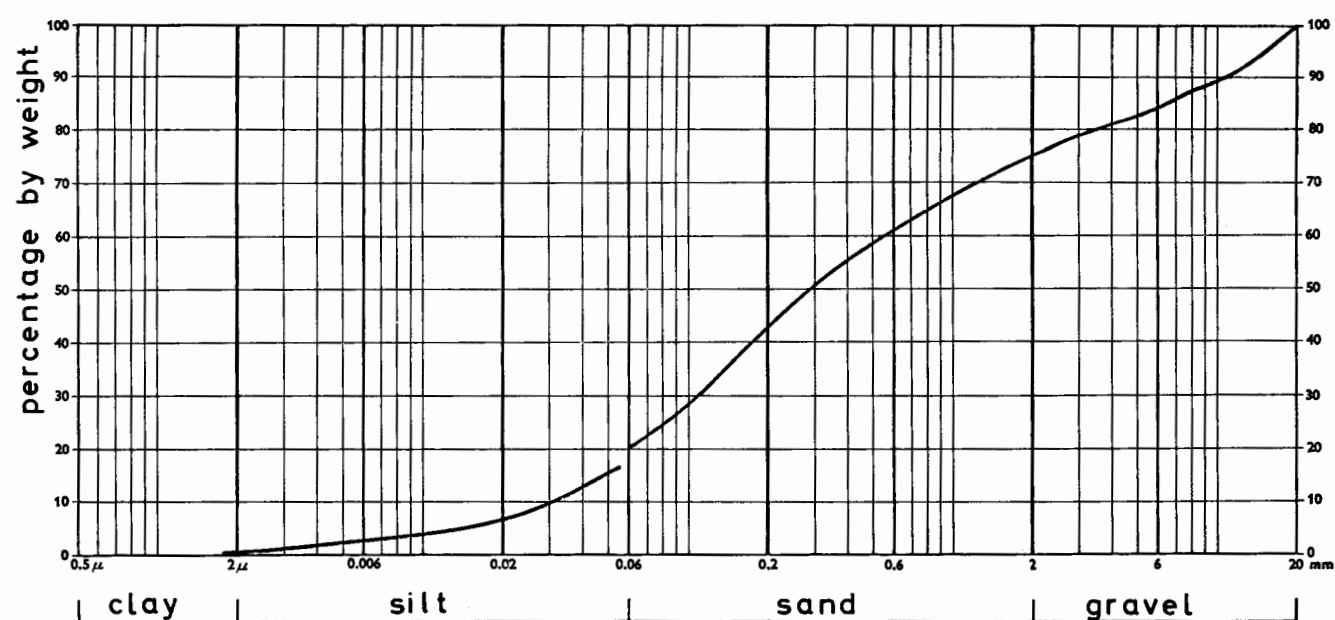


Fig. 11. Grain size distribution of till. Sampling 0.5 m below ground surface, 350 m E of Spånghult, area 4 Liatorp.

There is no extraction of groundwater by pumping within, or close to, the observation area.

3.4.4. Observation stations

The main features of the observation stations are presented in the table below.

The locations of the groundwater stations are presented on the map, Fig. 10. It can be seen that all stations are well concentrated within a limited area; the distance between the outermost stations is only 2.4 km. None of the stations are influenced by pumping.

3.4.5. Comments on the diagram

In the diagram (Fig. 12) all observed parameters are shown from selected stations.

A very distinct, seasonal cyclicality is seen in the pattern of groundwater variation. The highest level is usually reached in April—May. After that, the groundwater level falls rather steadily until October—November when the autumn recharge starts. A secondary peak usually occurs during the first half of the winter. In late winter and early spring, before the spring rise which causes the highest peak levels in April—May to occur, there is a minor fall

Station no.	Lat.	Long.	Land surface m a.s.l.	Geology	Depth of well m	Type of station	Obs. program	Aq.	Start of obs.	Remarks
0401	5640	1418	152	Gl. fl. sand	4	Tube	LT	W	1968	Temp. 1968—70
0402	5640	1418	152	" " "	5	"	LT	W	1970	
0403	5640	1418	152	" " "	6	"	L	W	1970	Contin. recording
0404	5640	1418	151	Sandy till	4	"	L	W	1970	
0405	5640	1418	152	Gl. fl. sand	4	"	L	W	1968	Ended 1970
0406	5640	1418	153	" " "	4	"	L	W	1968	Ended 1970
0407	5640	1418	154	" " "	4	"	L	W	1968	
0408	5640	1418	155	" " "	6	"	L	W	1968	Contin. recording 1968—70
0409	5640	1418	155	Sandy till	3	"	L	W	1970	
0410	5640	1418	156	Gl. fl. sand	3	"	L	W	1968	
0411	5640	1418	151	" " "	3	"	L	W	1968	Ended 1970
0412	5640	1418	152	Sandy till	2	"	L	W	1970	
0413	5639	1418	154	Gl. fl. mix.	4	"	L	W	1970	
F 24	5640	1418	152	" " sand	—	Frost	F	—	1971	
F 25	5640	1418	152	Sandy till	—	"	F	—	1971	

THE NATIONAL GROUNDWATER NETWORK OF SWEDEN

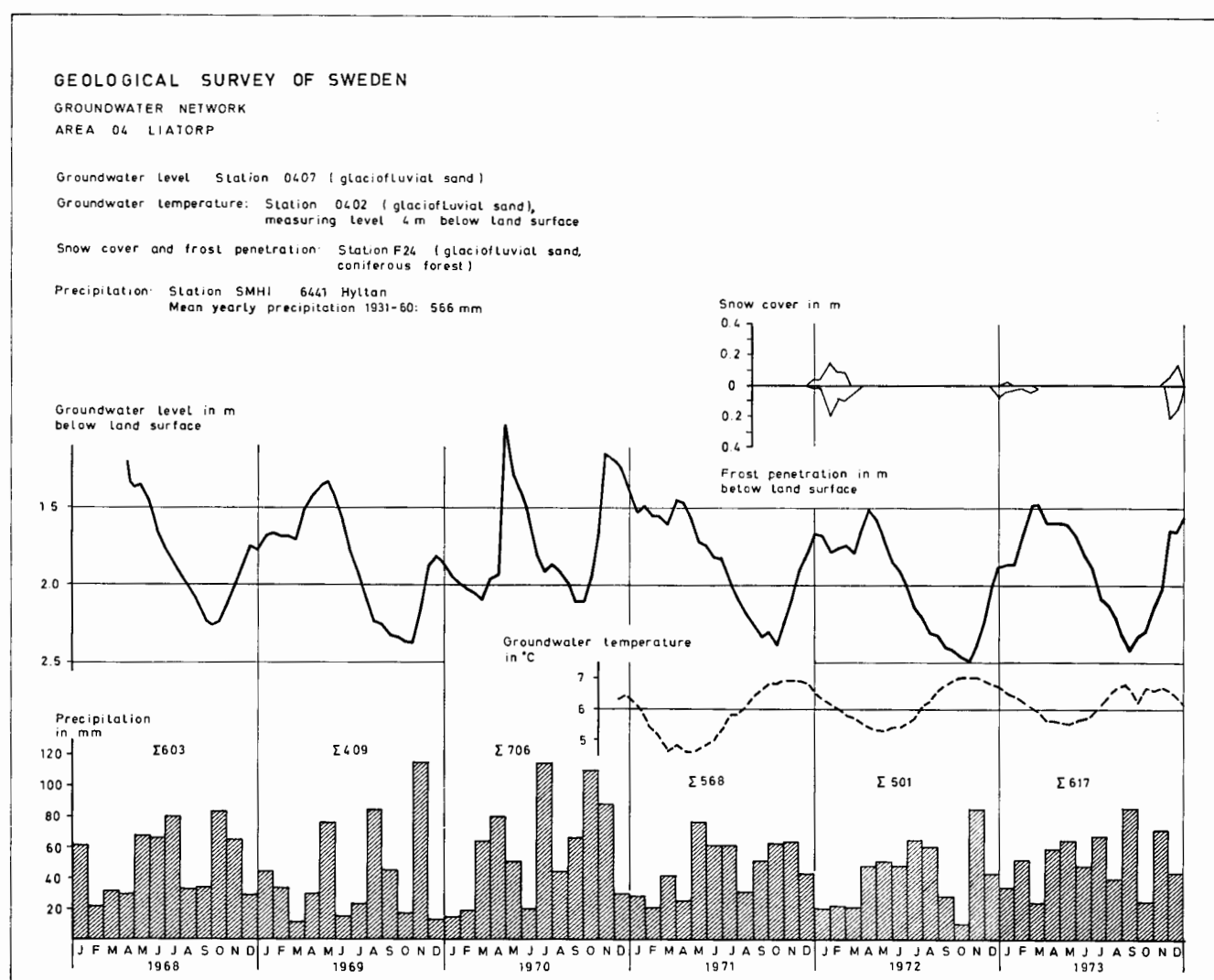


Fig. 12. Diagram from observation area 4 Liatorp.

in the groundwater level. Thus, substantial recharge of the groundwater reservoir takes place in late autumn and spring. The summer period is characterized by a major fall of groundwater levels caused by high evapotranspiration during the period of intensive plant growth. Even in summers with large amounts of precipitation there is no, or only very limited, alimention of the groundwater reservoir. The groundwater fall in the winter, on the other hand, is much less pronounced since the evapotranspiration is insignificant. The annual amplitude is approx. 1 m.

In the years from 1970 to 1973 a falling trend can be seen in the diagram; this trend refers to both peak and bottom levels. The high amount of precipitation in 1970, particularly during the recharge periods, is assumed to be the reason for the high levels that year. Decreasing annual precipitation in 1971 and 1972 is reflected by

the falling trend of groundwater levels.

The groundwater temperature at a depth of 4 m below land surface shows a smooth seasonal variation with maximum values in October—November and minimum values in May. The annual amplitude is approx. 2.0° C. The mean temperature for the observation period is 6.1° C.

The depth and duration of frost penetration and snow cover have been recorded for three winters. The ground is frozen with only a very slight vertical extension, generally less than 20 cm, for approx. three months. The snow cover in the three winters has exceeded 20 cm only once. Due to the low values of frozen ground and snow cover the groundwater conditions are influenced only slightly by these parameters. The decreasing groundwater level in January, 1972, is assumed to be caused by the frost which has impaired the recharge.

3.5. Emmaboda

3.5.1. Geographical location

The observation area Emmaboda is situated in the south-eastern part of the province of Småland in southeast Sweden. The elevation of the area ranges from approx. 110 to 150 m a.s.l. The area is shown on the map, Fig. 13.

3.5.2. Geology and geomorphology

The area is situated in a region of genuine moraine terrain. Two general types of the terrain can be distinguished: (1) A rather flat, high-lying landscape where the till is sandy and compacted. It contains numerous thin layers of stratified sand and gravel. These layers are generally relatively extensive. This landscape contains several drumlins. (2) A hummocky moraine where the till is sandy but rather loose. The boulder frequency is higher than in type (1). The upper part of the till is usu-

ally coarse. Lenses of sorted sand are rather common in the lower part of the till. These lenses, though, are of very limited extension.

The two types of moraine terrain exist side by side, with or without transitional zones. It is assumed that the topography of the underlying bedrock, Precambrian granite, controls the terrain types. A high-lying bedrock surface is generally accompanied by drumlins and similar terrain, whereas low-lying terrain is better characterized by hummocky moraine types. Small patches of the bedrock are exposed in the high parts of the area.

The petrographical composition of the till is characterized by the local bedrock. Therefore, granitic material dominates in the till.

The till was deposited well above the highest level of Late- and Postglacial lakes and seas. Therefore the area has not been subject to any extensive wave-washing. In the Lyckebyån river valley wave-washed till and sorted

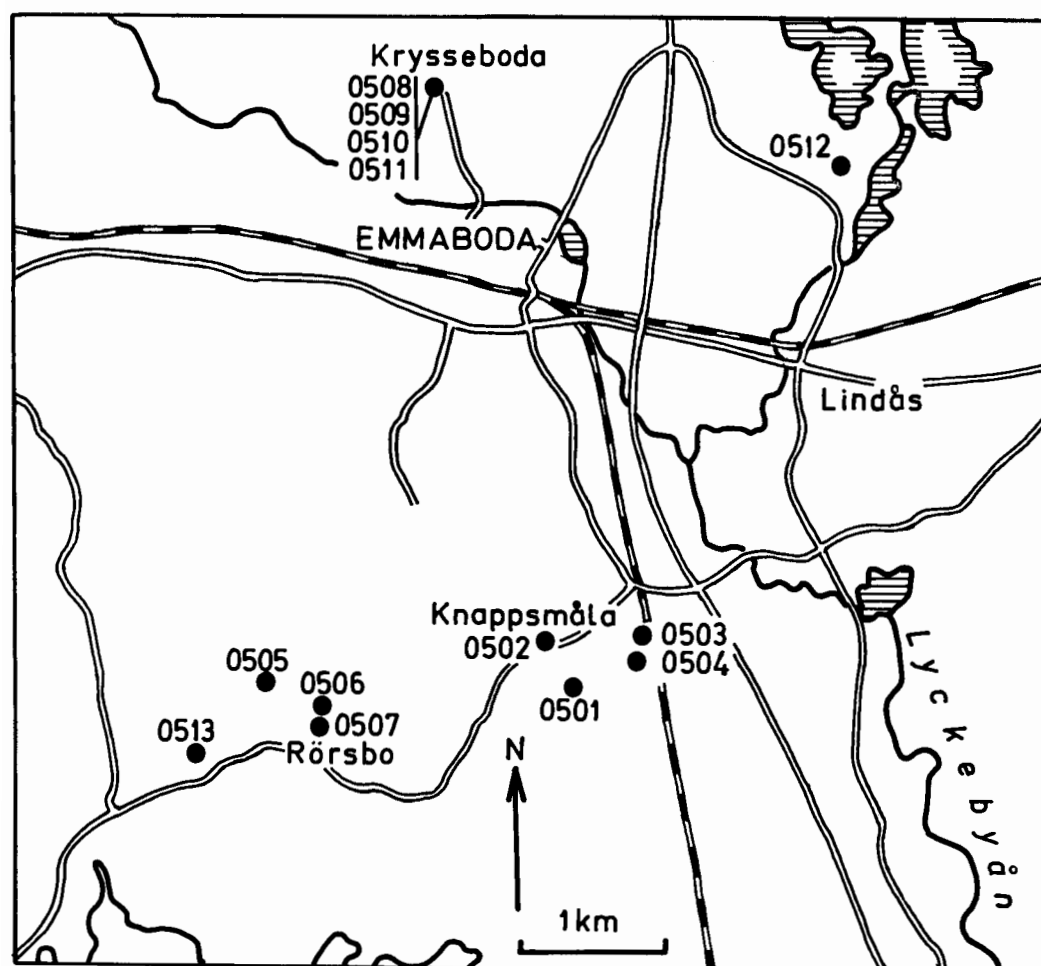


Fig. 13. Map of observation area 5 Emmaboda.

sediments deposited in small ice-dammed lakes are found locally.

A subaerially formed esker is found in the Lyckebyån river valley along the eastern margin of the area. No other glaciofluvial deposits are known from the observation area.

Peat is found in several places in the area, mainly in the low parts of the hummocky moraine terrain. The thickness of the peat is moderate.

3.5.3. Hydrological and hydrogeological features

The hydrogeology, as well as the geology, of the Emmaboda area has been investigated thoroughly by Knutsson (1971). The main drainage channel of the area is the river Lyckebyån at the eastern margin of the area. The Lyckebyån collects water from the entire area and discharges into the Baltic Sea close to the town of Karlskrona.

The direction of the general groundwater flow in the area is in accordance with the moraine topography. Sandy layers in the till, particularly in drumlin terrain, act as conduits for water. On the slopes of such terrain, springs and groundwater seepages can be found. These give rise to swampy ground. Many of the drumlins are cultivated and there are farm houses on the slopes. Dug wells supply water to the homes in this type of terrain. The supply is fairly good. In the hummocky type of terrain the water supply is less good, except in the hollows where precipitation water is collected. Many of the hollows have no surface runoff.

Knutsson has performed short pumping tests in several dug wells and in tubes of 50 mm diameter. The

obtained yield for various stations is in the order of 0.01—0.2 l/s, (personal communication). However, several springs yielding 2—3 l/s are found in the area.

None of the observation stations are assumed to be influenced by withdrawal of water from adjacent wells as the numerous till aquifers have no hydraulic connection with each other.

3.5.4. Observation stations

The main features of the observation stations are presented in the table below.

Stations nos. 0501—0511 are selected from a local network of observation stations established by Knutsson. He collected data up until 1967 when SGU took over the task. Some improvements of the stations have been done by SGU, which also established the other stations. Stations nos. 0512 and 0513, however, had also been under temporary observation by Knutsson prior to the first SGU observation.

3.5.5. Comments on the diagram

The variations in the groundwater composition at station no. 0512 is shown in the diagram (Fig. 14). The groundwater is characterized by a low salt content. Dominating ions are chloride, sodium and calcium. The low salt concentration, as well as the high tritium content, indicates a short residence time of the groundwater.

A falling trend reflecting the decreasing tritium content in the precipitation can be seen in the diagram showing the tritium content. No other distinct trends or regular patterns of variations can be seen in the water composition graphs of the area.

Station no.	Lat.	Long.	Land surface m a.s.l.	Geology	Depth of well m	Type of station	Obs. program	Aq.	Start of obs.	Remarks
0501	5636	1533	121	Sandy till	3	Tube	L	W	1962	
0502	5636	1533	122	" "	3	Dug	L	W	1962	
0503	5636	1533	118	" "	7	Tube	LT	W	1967	Continuous recording. Temp. 1968—69
0504	5636	1533	118	" "	4	"	LT	W	1962	Temp. since 1969
0505	5636	1530	140	" "	4	"	L	W	1962	
0506	5636	1530	145	" "	3	"	L	W	1962	
0507	5636	1530	144	" "	3	"	L	W	1962	
0508	5638	1532	133	" "	2	"	L	W	1961	
0509	5638	1532	134	" "	2	"	L	W	1961	
0510	5638	1532	133	" "	2	"	L	W	1961	
0511	5638	1532	134	" "	3	"	L	W	1961	
0512	5638	1534	124	" "	—	Spring	C	W	1968	
0513	5636	1530	136	" "	—	"	C	W	1968	
F 30	5636	1533	121	" "	—	Frost	F	—	1971	
F 31	5636	1533	121	" "	—	"	F	—	1971	

In the diagram (Fig. 14) the variations of groundwater level are shown from station no. 0501. The station is selected from a group of eleven stations in the Emmaboda area. The stations, located at a maximum distance of 5 km from each other, show almost perfect identity in detail and at large, concerning the variation of the groundwater level. Therefore, the selected station is representative for the whole area and probably even for the surrounding region.

There is a distinct pattern of the seasonal fluctuations of the groundwater level. The highest level generally is reached in late winter and early spring, after the period of snow-melting and thawing of frozen ground and before the intensive period of plant growth. During the latter period the groundwater level falls to a minimum in late summer and early autumn, i. e., August—October. In the autumn the major recharge period starts. It lasts until November—December when winter conditions interrupt the replenishment of the groundwater reservoir for 1—3 months. During the winter the groundwater level falls somewhat until the snow-melting and frost-thawing restart the alimentation of the reservoir.

The falling groundwater levels may be interrupted by

rising levels due to heavy rainfalls. This is clearly noticeable particularly in 1965, 1968 and 1970. The yearly amplitude is 1.0—2.0 m. The maximum levels are almost the same from year to year due to the limiting effect of drainage in the upper zone close to the surface. On the contrary, the minimum levels vary considerably from year to year and are a good reflection of the climatological conditions during the year. A slightly falling trend in the minimum values is seen from 1966 to 1971 and is temporarily interrupted in 1968 and 1970.

The groundwater temperature has been recorded since December, 1968, at first with a regular thermometer being lowered into the tube and hoisted to the surface for reading, and later with a stationary thermometer in the tube 3 m below the ground. The very distinct pattern of seasonal fluctuations in 1969, 1970 and 1971 reflects not only the groundwater temperature but also the air temperature at the moments of thermometer reading. Therefore, the temperatures after July, 1971, are more representative of the groundwater temperature. The yearly amplitude at a depth of approx. 3 m is 2.5—3.0°C, and the mean temperature for the whole period of observation 7.1°C.

3.6. Nybroåsen

3.6.1. Geographical location

Observation area Nybroåsen is situated in the province of Småland in southeast Sweden, 10—20 km west and southwest of the town of Kalmar. The altitude of the area ranges from 13 to 75 m a.s.l. The area is shown on the map in Fig. 15.

3.6.2. Geology and geomorphology

The observation area consists of a part of the Nybro esker, which trends in a northwest-southeast direction. In the northern part of the area the esker is 0.5—1.0 km wide and is surrounded by moraine. In the southern part, the width of the esker is 1.0—1.5 km, and the adjacent lowlands consist of fine-grained sediments, partly covered by peat. At Vassmolösa, in the southeastern part of the esker, a small tributary esker joins the Nybro esker in a north—south direction. Southeast of Vassmolösa the esker widens into the "Hagby massive", a broad and relatively flat area of sediments. South of this, and connected to the "Hagby massive", there is a narrow ridge of sediments running in a north—south direction parallel with and close to the coast.

The Nybro esker rises 15—20 m above the surround-

ing sediment plains in the southern part of the observation area. In the northern part of the area where the esker runs in moraine, the relative relief is generally less.

In parts of the area the esker appears as a network of anastomosing ridges separated by narrow trenches. In many places the relief is very steep with a difference of elevation of more than 15 m.

After the formation of the esker system the area was inundated by the Baltic Ice Lake. The glaciofluvial morphology was altered by abrasion and accumulation from which beach notches, beach ridges and wave-washed sandy flats resulted. There are also parts of the esker system that remained completely uninfluenced by abrasion. This is especially the case with the Tvärskog portion, in the middle of the observation area, where several narrow glaciofluvial ridges are found. Peat developed in Postglacial time in many hollows and low-lying flats, partly fed by groundwater seepage. Eolian redeposition of sand has influenced the top layer in several places.

The cores of the eskers consist of coarse material such as sand, gravel and stones, whereas the distal parts consist of finer material.

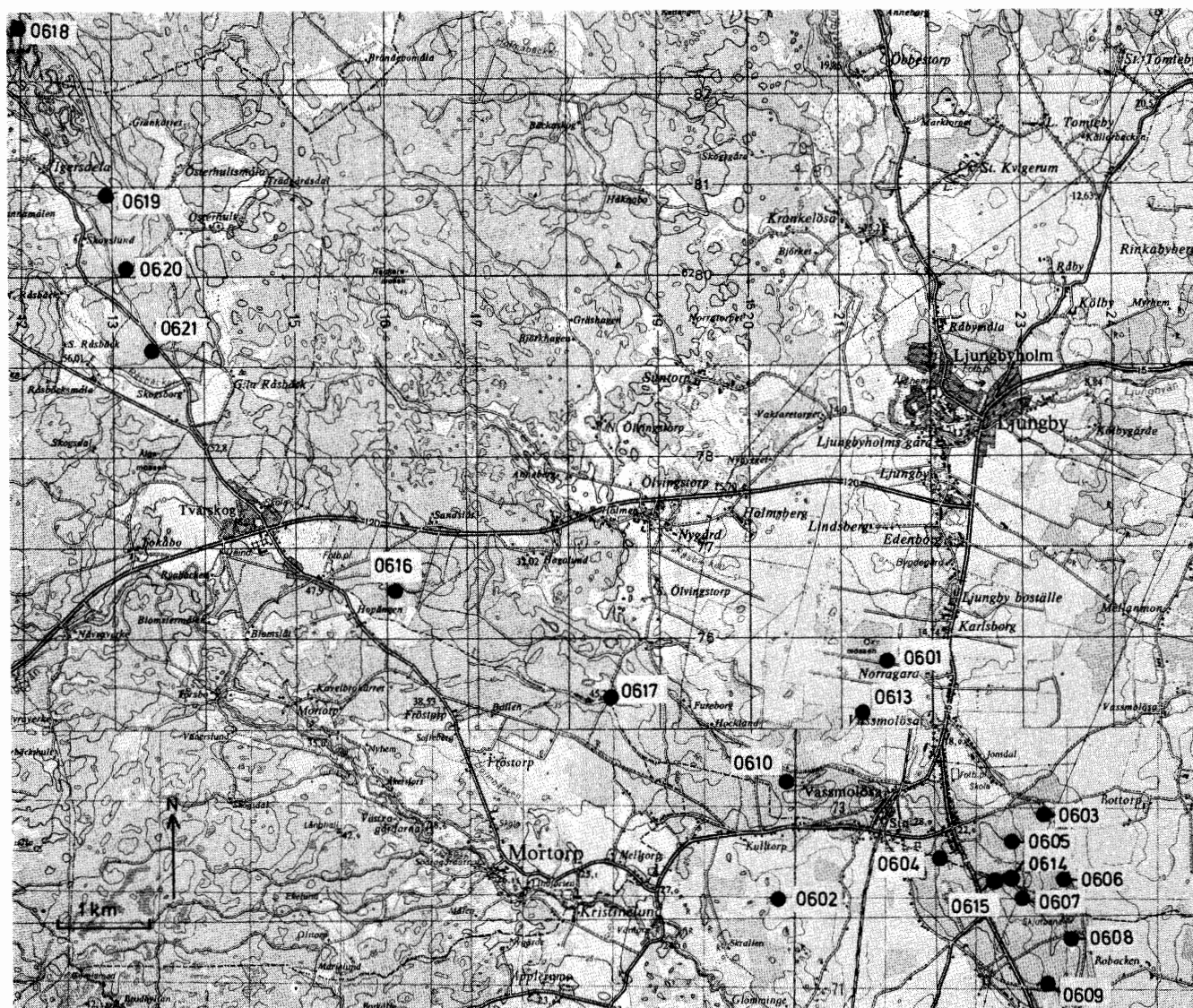


Fig. 15. Map of observation area 6 Nybroåsen. (Top. map 4 G SV, 4 G NV.)

The loose deposits in the northwestern part of the area are underlain by Småland granites, and in the southeastern part, by Cambrian sandstone. The bedrock outcrops in only a few places in the northwestern part of the observation area, and in the southeastern part there are no bedrock outcrops.

The geology of the Nybro esker has been described by Knutsson (1966 b) in a report from Sydsvenska Ingenjörbyrå AB (SIB) on the future water supply of the Kalmar—Nybro region and Öland.

3.6.3. Hydrological and hydrogeological features

The aforementioned report presents a review of the hydrology and hydrogeology of the Nybro esker. The following information is partly derived from that report.

The groundwater in the esker has been found to flow transversely or obliquely through the esker in the northwestern part. The gradient of the groundwater, from the western edge of the esker to the eastern, is 1.0—1.5 per cent. Several springs can be found outside the eastern margin. Individually, they yield rather small volumes of water. In the northwestern part of the area the groundwater level is found 15—20 m below the highest parts of the esker.

In the southeastern part of the area (southeast of Tvärskog) the groundwater flow is mainly longitudinal in respect to the esker. The water flows southeastward toward the big esker junction, the "Hagby massive". There is a secondary flow of groundwater directed away from the esker. From the "Hagby massive" the water is

drained eastward to the Baltic Sea and southward toward the river Hagbyån. There are, at present, only few springs in the southeastern part of the esker system. The groundwater is found 10—20 m below the highest parts of the esker.

The surface runoff of the observation area is collected into brooks flowing into the river Ljungbyån north of the esker and the river Hagbyån south of the esker. Brooks are also crossing the esker from west to east at a few places.

Five major producing wells are situated within the observation area. They were established for the purpose of water supply for the towns of Kalmar and Nybro. Four of them are situated in the southeastern part of the area: Bottorp in the "Hagby massive", Vassmolösa, Ölvingstorp, and Råsbäck on the eastern side of the esker. In the northernmost part of the observation area the town of Nybro has a producing well, Gårdsryd, which yields approx. 40 l/s (in 1972). The extraction from this well does not influence the groundwater at any of the observation stations.

The largest producing well, Bottorp, is situated in the center of the "Hagby massive". In 1972 approx. 100 l/s were withdrawn from this well (it actually consists of 6 tube wells). The pumping relies upon artificial recharge at points 0.5—1.0 km from the well site. The artificial recharge rate is approx. 120 l/s. The water for recharge is taken from the river Hagbyån at Vätörp. The extraction of water at Bottorp has increased, and in the 1960's the mean extraction was approx. 80 l/s.

At Vassmolösa the withdrawal of water was approx.

7 l/s in 1972 which is a decrease since the early 1960's when the extraction was 10—17 l/s.

The well at Ölvingstorp produced approx. 16 l/s in 1972. This rate of production has been constant since 1960.

The well at Råsbäck yielded approx. 30 l/s in 1972. The yield has been of the same magnitude since 1960.

The wells at Vassmolösa, Ölvingstorp and Råsbäck are situated at sites of formerly flowing springs. The groundwater levels are only slightly lowered by pumping.

3.6.4. Observation stations

The main features of the observation stations included in the national groundwater network are presented in the table below.

The locations of the listed stations are shown on the map, Fig. 15. Some stations were excluded from the national groundwater network in 1967 due to an assumed influence from human activities. Besides these stations, a number of other stations have been in use (and are still in use) for observations by the water works offices of the towns of Kalmar and Nybro. Many of the other stations are situated so that they are strongly influenced by artificial recharge and pumping. Most stations were established by Sydsvenska Ingenjörbyrå AB in the 1950's as part of investigations for the future water supply for Kalmar and Nybro. The investigations have been presented in a number of reports from SIB.

Of the stations in operation in 1972, stations nos. 0601 and 0610 are assumed to become slightly influenced in the future by increasing artificial recharge and pumping

Station no.	Lat.	Long.	Land surface m a.s.l.	Geology	Depth of well m	Type of station	Obs. program	Aq.	Start of obs.	Remarks
0601	5636	1610	14	Litt. sand	9	Tube	L	W	1962	
0602	5635	1608	19	" "	7	"	L	W	1965	Excluded in 1967
0603	5635	1611	14	Gl. fl. mix.	6	"	L	W	1962	" " "
0604	5635	1610	25	" " "	20	"	L	W	1966	" " "
0606	5635	1611	16	" " "	16	"	L	W	1962	" " "
0607	5635	1610	22	" " sand	23	"	L	W	1962	" " "
0608	5634	1611	11	" " "	16	"	L	W	1962	" " "
0609	5634	1611	26	" " "	29	"	L	W	1962	" " "
0610	5635	1608	19	" " "	12	"	L	W	1962	
0613	5636	1609	13	Litt. sand	4	"	L	A	1957	
0614	5635	1610	15	Gl. fl. sand	18	"	L	W	1962	Excluded in 1967
0615	5635	1610	13	" " mix.	13	"	L	W	1962	" " "
0616	5636	1604	44	Ma. la. silt	5	"	L	W	1964	
0617	5636	1606	41	Gl. fl. sand	18	"	L	W	1964	
0618	5640	1600	62	" " "	6	"	L	W	1964	
0619	5639	1601	74	" " mix.	20	"	L	W	1964	
0620	5638	1601	65	" " "	18	"	L	W	1964	
0621	5638	1601	54	" " "	14	"	L	W	1964	

at Bottorp. Possibly, this could also be the case with station no. 0613. The rest of the stations will remain uninfluenced by human activities for the near future.

The observations of the groundwater levels in Nybroåsen are carried out by the waterworks offices of Kalmar (main part of the observation area) and Nybro (a limited portion of the northwestern edge of the esker).

3.6.5. Comments on the diagram

The variation of groundwater levels from two stations, nos. 0613 and 0618, are presented in the diagram (Fig. 16). Station no. 0613 is situated outside the esker, just north of the "Hagby massive". The aquifer consists of sand which is covered by peat rendering the aquifer artesian characteristics. Observations have been going on since 1957, but there have been several interruptions for technical reasons.

The pattern of fluctuation of the groundwater level at station no. 0613 is rather jagged. This is assumed to be caused by meteorological influence on the confined aquifer. Due to the many interruptions in the observation series and to the jagged configuration of the curve the seasonal pattern is not very distinct. However, the

groundwater generally reaches its lowest level in late summer, while the highest level generally occurs in the winter. The annual amplitude is 40–80 cm. A multi-annual trend of falling groundwater level is present from 1960 to 1964. There are no clear trends in the curves from 1957 to 1960, nor from 1964 to 1973.

Station no. 0618 is situated in the northwestern part of the esker, at the bottom of a trench between glacio-fluvial ridges. Measurements have been performed since 1964 with several interruptions. The seasonal fluctuations of the groundwater level at station no. 0618 have a pattern which has a rising level in the spring, a peak usually reached in May–June, a general falling level throughout the summer, a recharge period starting in late autumn and continuing throughout the winter, and levels reaching the maximum extreme again in May–June. The annual amplitude is 70–160 cm. From the minimum extreme in December, 1964, caused by a low amount of rainfall that year, the groundwater rose to a peak level in May, 1966. Since then a weak falling trend has been present. In December, 1971, the same minimum extreme level was reached as that which was recorded in December, 1964.

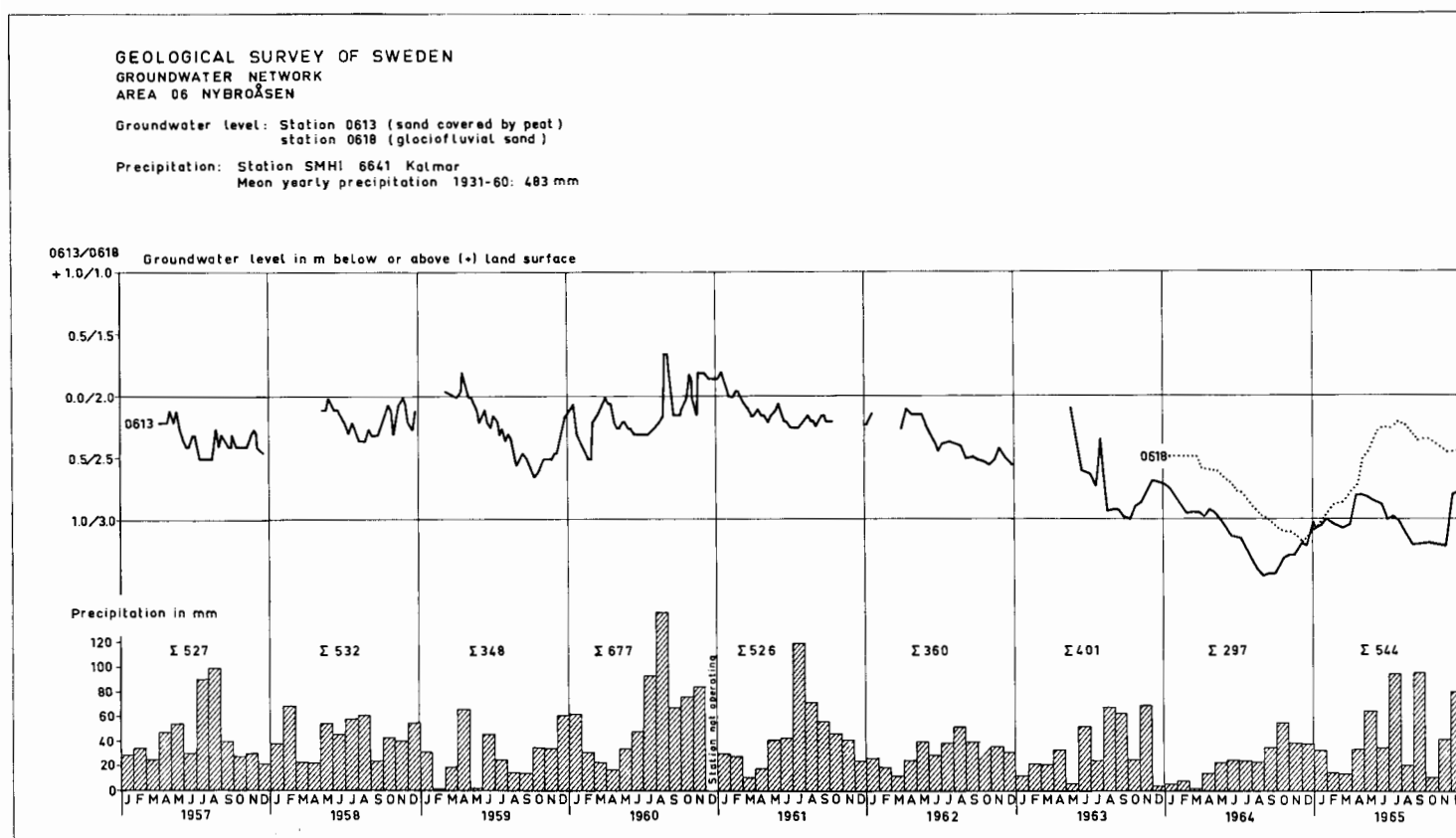


Fig. 16. Diagram from observation area 6 Nybroåsen.

3.7. Böda

3.7.1. Geographical location

The observation area Böda is situated in the northernmost part of the island of Öland, off the coast of the southeastern Swedish mainland (see map, Fig. 17). The altitude of the area ranges from 10 to 20 m a.s.l.

3.7.2. Geology and geomorphology

The bedrock of the observation area consists of Ordovician limestone. It is covered by glacial drift which is strongly modified by the wave-action of Late- and Post-glacial lakes and seas.

The most important geological feature of the area is the so-called Böda esker and the surrounding sand deposits. The esker is made up of six flat crests separated by hollows. They trend in a, generally, northwest—southeasterly direction. The central part of the esker consists of sand and gravel including stones. This part is surrounded by sand and silt. Clay is found in local spots. These deposits are overlain by wave-washed and redeposited sand and gravel. In the central part the Quaternary deposits have a thickness of 10–12 m. The thick-

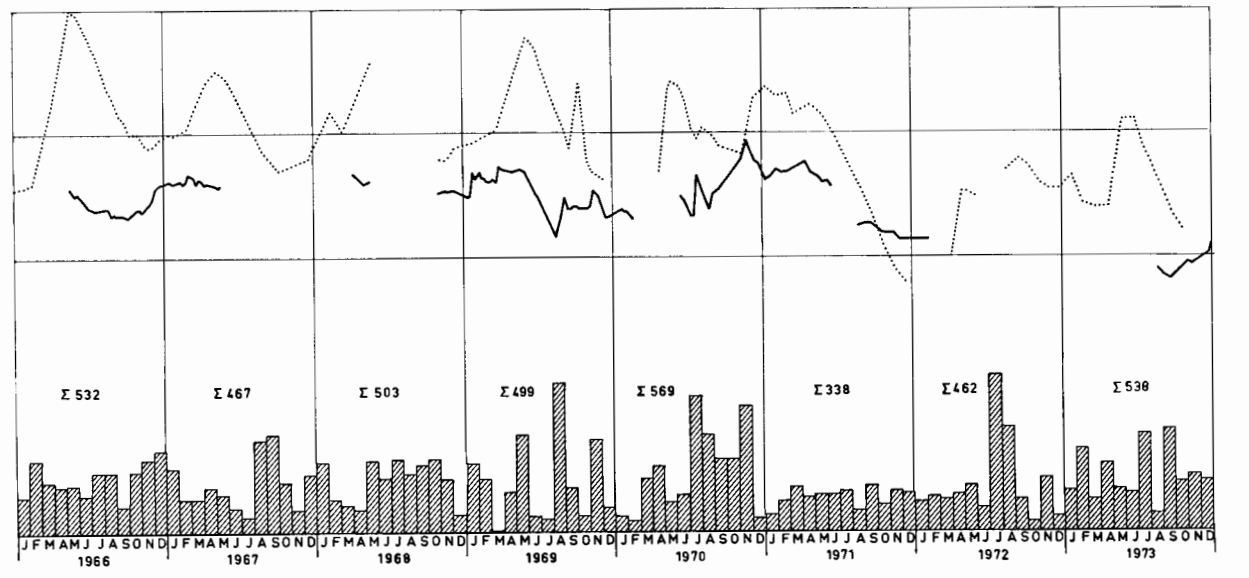
ness decreases in directions from the central core part. Till has not been found under the glaciofluvial and lacustrine/marine deposits within the observation area.

Considerable erosion and redeposition of glaciofluvial material have taken place after the glaciation. Both lakes and seas have covered the area for long periods of time. By wave action at times when the area was close to the surface of the water, part of the esker was heavily eroded and the material was transported and redeposited away from its primary location. Littoral features like beach ridges etc. developed in the redeposited material. The top layer of the sand is also influenced by recent eolian activity.

The geology of the area has been described by Knutsson (1966 a) in a report on the geohydrology and the Quaternary geology.

3.7.3. Hydrological and hydrogeological features

The aforementioned report contains a map with equipotential lines for the groundwater level. It can be seen that in the central part of the area the groundwater is



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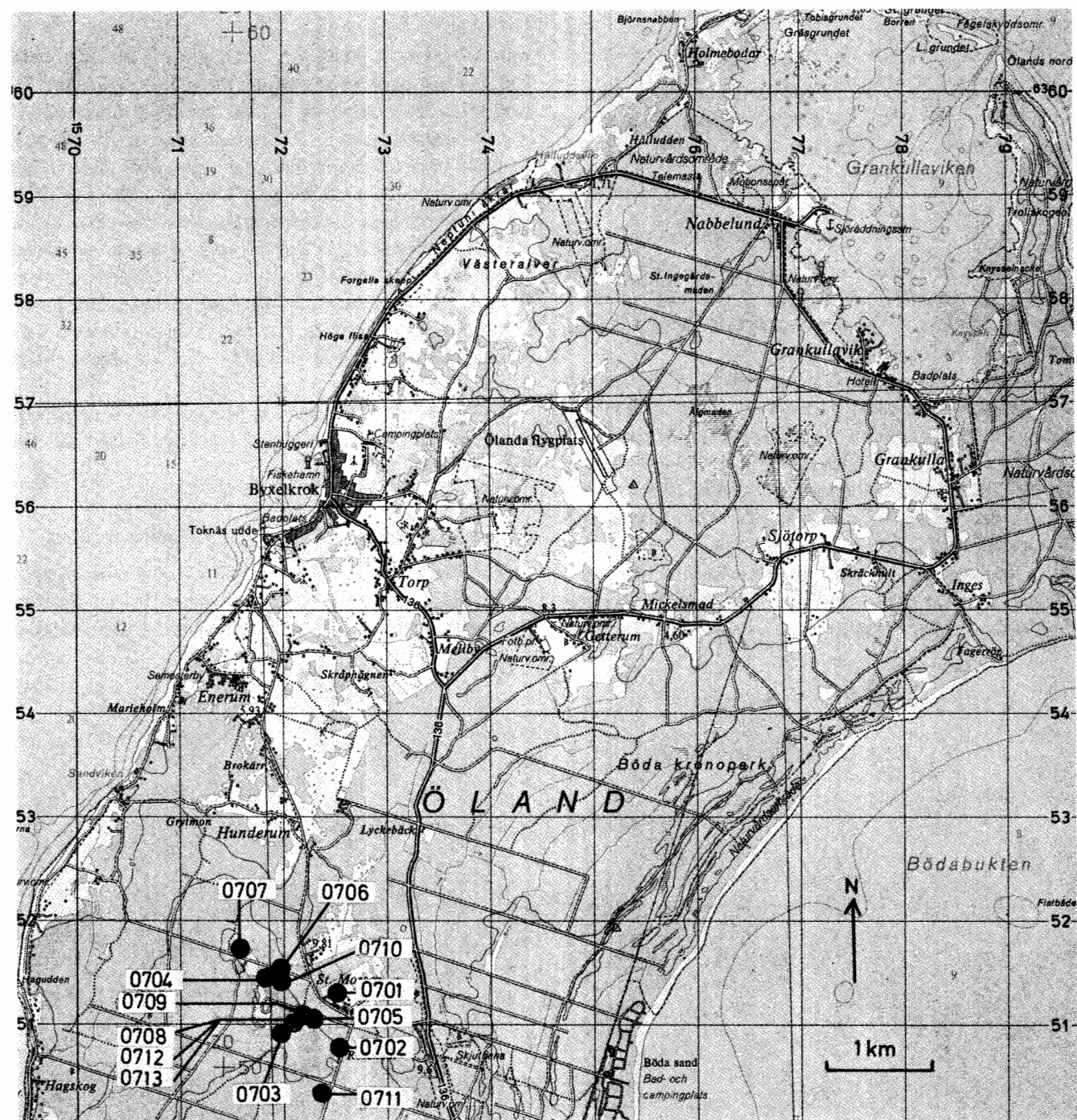


Fig. 17. Map of observation area 7 Böda. (Top. map 6 H SV.)

found 5—9 m below the land surface. The groundwater flows radially in all directions from a central plateau and discharges into shallow brooks and ditches. The recharge area is assumed to coincide with the observation area.

There is no, or only insignificant, withdrawal of groundwater by pumping within the area. At the east edge of the area a few small wells for separate households are in use.

3.7.4. Observation stations

The main features of the observation stations are presented in the table below.

The locations of the groundwater stations are shown in Fig. 17. Stations nos. 0701—0712 were established by SIB in connection with an investigation for Ölands Vattentäktförbund and were intended to help to evaluate the possibilities for future water supply schemes. So far no wells have been established within the area. Stations nos. 0712—0713 were made by SGU in order to obtain information about the relationship between groundwater in the loose deposits and that in the bedrock. It is assumed that the two aquifers are completely interconnected since the two patterns of groundwater fluctuations are identical, as seen from recorder charts. Also, the levels coincide perfectly. This indicates that there are no sealing fine sediments or till between the bedrock and the loose deposits.

3.7.5. Comments on the diagram

In the diagram (Fig. 18) all observed parameters are shown from the selected stations.

The seasonal fluctuations of groundwater levels have a

distinct pattern. The highest levels are attained in May—June, and the lowest levels are reached in late winter. The main recharge of the groundwater takes place in the spring. In 1970 there was a considerable recharge also in the autumn. The annual amplitude ranges from 30 to 58 cm for the years 1968—1973 with a mean of 43 cm. A remarkable absence of recharge in 1972 is to be noted. This is due to the low precipitation that year. Also the preceding year had a low amount of precipitation which caused the groundwater level to fall steadily from May, 1971, to February, 1973. The low level at the end of 1973 is the absolute minimum extreme for the observation period. Except for the decrease in 1971—1973, no clear multiannual trend is found in the variation of the groundwater level.

The groundwater temperature at a depth of 6—9 m below the land surface varies in a distinct seasonal pattern. The lowest temperature is found in May—June and the highest in November—December. The annual amplitude is generally 1.0—1.5°C. The somewhat higher amplitudes in 1969 and 1970 are probably due to an unsatisfactory measuring technique. The mean temperature for the whole observation period is 7.3°C.

The penetration of frost and the snow cover have been measured since December, 1971. The ground was frozen from late December, 1971, to late March, 1972, to a maximum depth of only 16 cm. The snow cover, too, was very thin, and it lay on the ground for less than two months. In the winter of 1972—1973 neither frost penetration nor snow cover was reported. Thus, the frost has influenced the groundwater recharge only to a very slight degree.

Station no.	Lat.	Long.	Land surface m a.s.l.	Geology	Depth of well m	Type of station	Obs. program	Aq.	Start of obs.	Remarks
0701	5717	1700	10	Litt. sand	2	Dug	L	W	1968	
0702	5716	1700	13	Gl. fl. sand	5	Tube	L	W	1968	
0703	5716	1700	17	" " "	10	"	L	W	1968	
0704	5717	1659	19	" " grav.	11	"	L	W	1968	
0705	5716	1700	15	" " sand	8	"	L	W	1968	
0706	5717	1659	16	" " "	8	"	L	W	1968	
0707	5717	1659	18	" " "	11	"	L	W	1968	
0708	5716	1700	18	" " "	11	"	L	W	1968	
0709	5716	1700	17	" " "	10	"	LT	W	1968	
0710	5717	1659	16	" " "	8	"	L	W	1968	
0711	5716	1700	11	" " "	6	"	L	W	1968	
0712	5716	1700	18	" " "	12	"	L	W	1971	Continuous recording
0713	5716	1700	18	Limestone	37	Drill	L	W	1971	Continuous recording
F 35	5716	1700	18	Gl. fl. sand	—	Frost	F	—	1972	

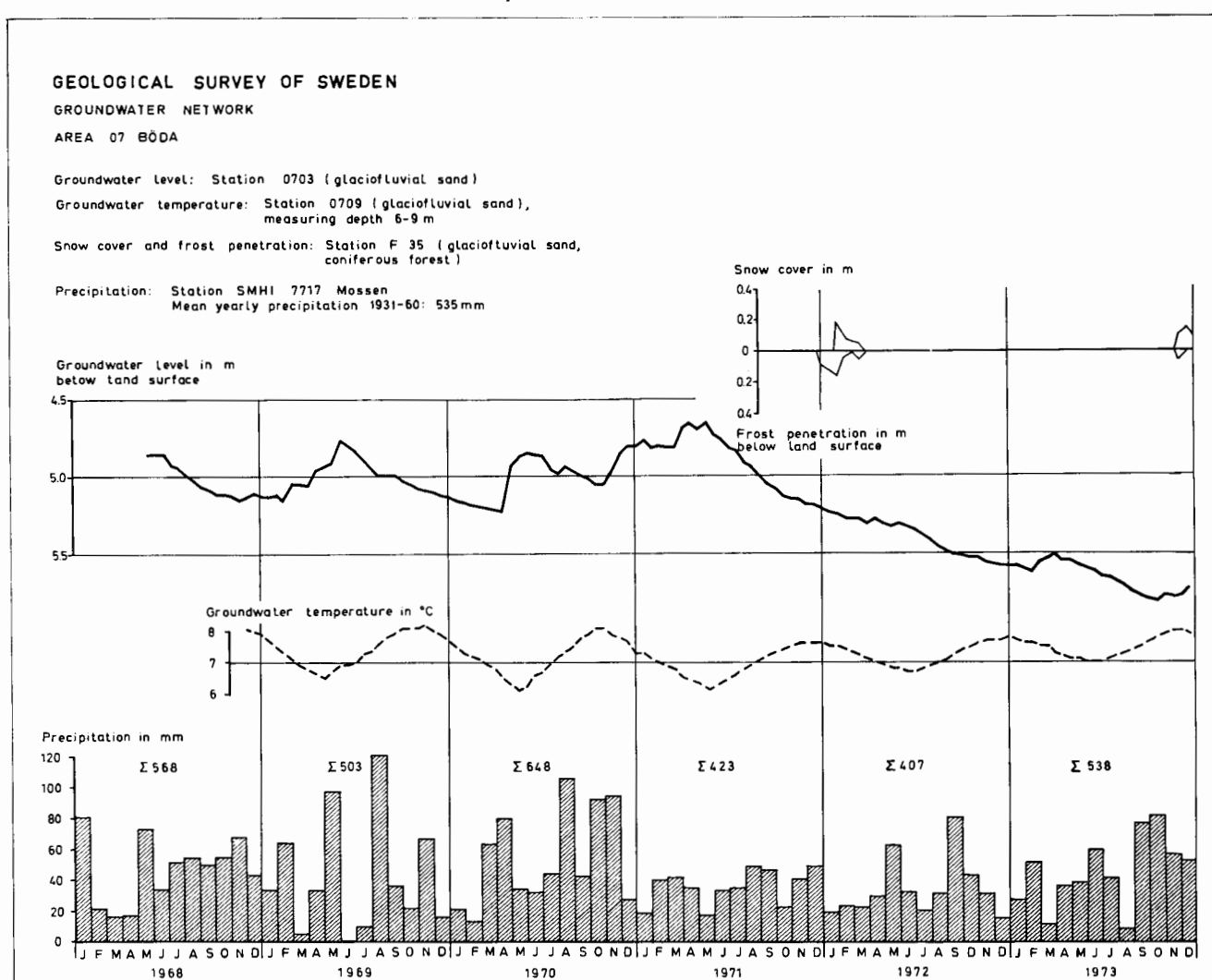


Fig. 18. Diagram from observation area 7 Böda.

3.8. Hemse

3.8.1. Geographical location

The observation area Hemse is situated in the southern part of the island of Gotland. A map of the area is shown in Fig. 19.

3.8.2. Geology and geomorphology

The Hemse area is a flat lowland. The bedrock of the area, consisting of Silurian marlstone, is partly covered by Quaternary deposits mainly made up of till and littoral sand and gravel.

3.8.3. Hydrological and hydrogeological features

The main water divide between the eastern and western parts of Gotland is situated in the Hemse area. Therefore, the surface water of the area is drained both east-

wards and westwards to the Baltic Sea. The groundwater divide is probably situated in the same area, perhaps a few kilometers east of the surface water divide. The main aquifer of the area is the Silurian rocks. There is no important extraction of groundwater within the area.

3.8.4. Observation stations

The main features of the observation stations are presented in the table on next page.

The observation wells are situated a few hundred meters west of the surface water divide. The wells were established as producing wells for the water supply of the town of Hemse. However, Hemse is now supplied by surface water, and the wells are no longer used for their original purpose. When station no. 0801 was destroyed

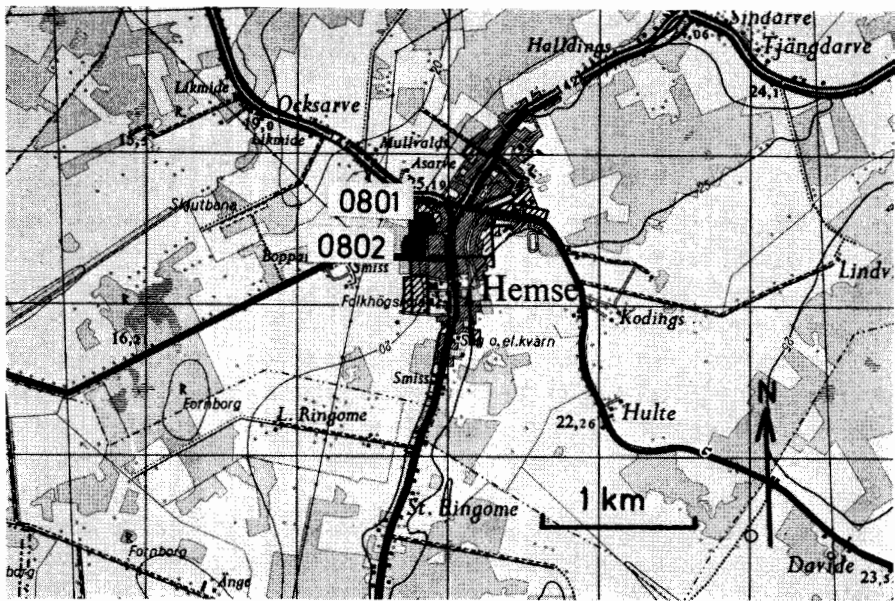


Fig. 19. Map of observation area 8 Hemse. (Top. map 5 J NV.)

Station no.	Lat.	Long.	Land surface m a.s.l.	Geology	Depth of well m	Type of station	Obs. program	Aq.	Start of obs.	End of obs.
0801	5714	1822	19	Marlstone	20	Drill	LT	A	1966	1972
0802	5714	1822	20	"	20	"	LT	A	1972	

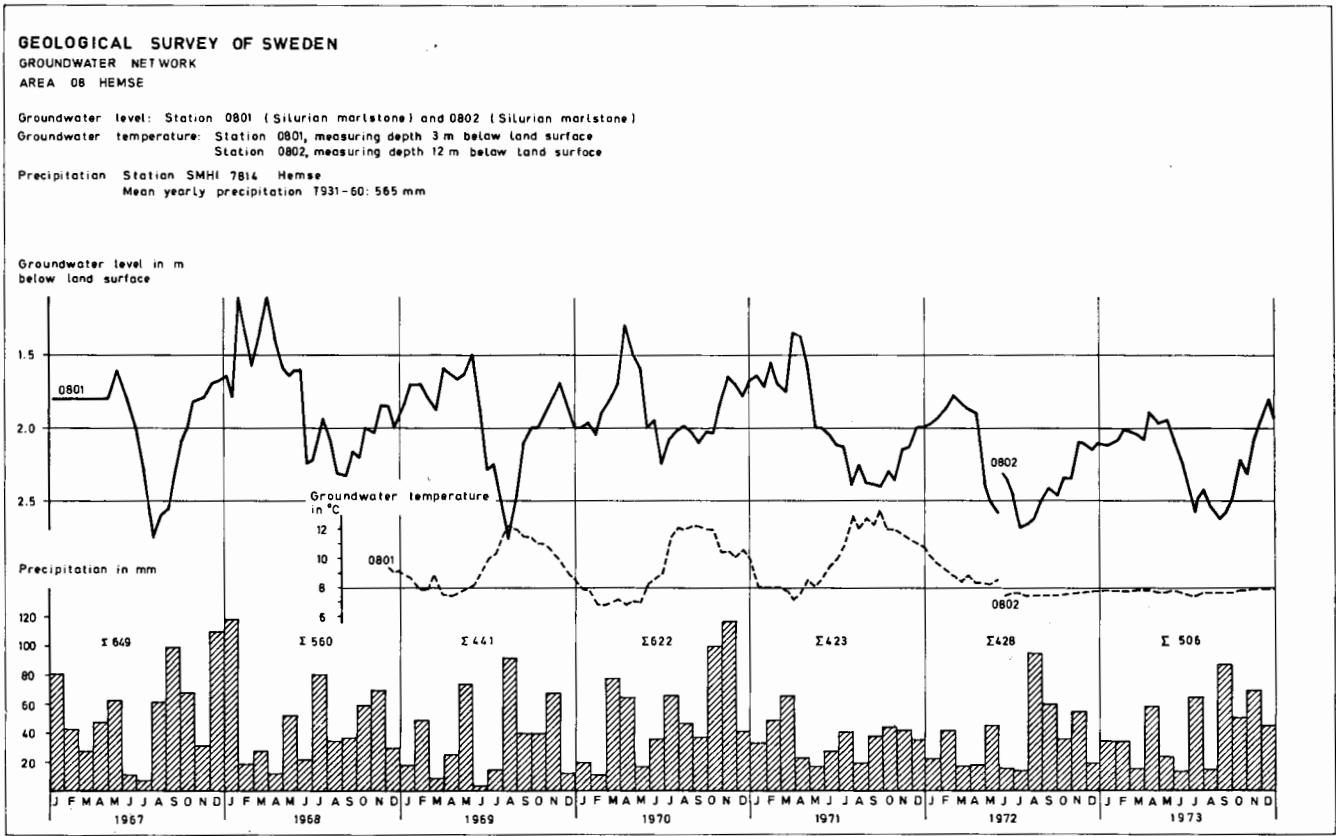


Fig. 20. Diagram from observation area 8 Hemse.

through construction works in 1972, measurements were started in station no. 0802, situated only about one hundred meters from station no. 0801.

3.8.5. Comments on the diagram

In the diagram (Fig. 20) all observed parameters are shown from the two stations.

The seasonal variations of the groundwater level has an annual amplitude of 0.9–1.2 m.

The groundwater reaches its highest level in late winter or early spring. Percolation to the marlstone aquifer can usually take place throughout the winter. In the area the ground is neither frozen nor covered permanently with snow in the winter.

During the vegetation period, when intense evapotranspiration prevails, the groundwater level sinks to its minimum extreme, generally reached in late summer.

Beside the seasonal variations there are a great number of minor fluctuations in the groundwater level. These fluctuations can, in most cases, be correlated with short

periods of heavy rainfall or droughts. The extensive areas of outcropping bedrock adjacent to the observation area probably facilitate a rapid infiltration of water directly to the marlstone aquifer. Differences in barometric pressure probably exert an influence of the rapid fluctuations in the groundwater level in this artesian aquifer. No clear multiannual trend can be found in the diagram.

The groundwater temperature at station no. 0801, 3 m below land surface, has a mean value of 9.4°C and an annual amplitude of 5–6°C. This value is probably not representative for the groundwater of the area. Station no. 0801 was a well situated inside a house and the temperature values are probably too high. The annual temperature maximum is reached in August–September and the minimum in March. The temperature measurements at station no. 0802 are performed at a greater depth (12 m below land surface), and the annual amplitude is much less than that at station no. 0801, only 0.4°C. The mean value is 7.6°C. The minimum temperature is reached in the summer and the maximum in March.

3.9. Lau

3.9.1. Geographical location

The observation area Lau is situated in the southeastern part of the island of Gotland, 1 km from the coast of the Baltic Sea (Fig. 21).

3.9.2. Geology and geomorphology

The main geomorphologic feature of the area is Lau-backar, a plateau with an altitude of about 20 meters above the surrounding lowland, which slopes gently

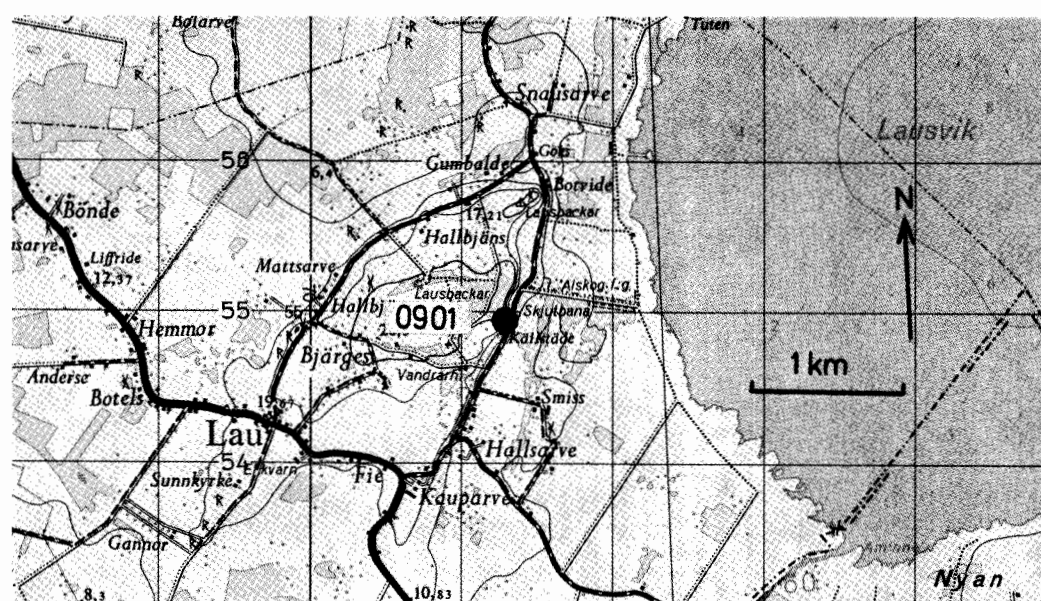


Fig. 21. Map of observation area 9 Lau. (Top map 6 JSV.)

toward the Baltic Sea. Laubackar is made up of Silurian limestone resting on Silurian marlstones which outcrop in the surroundings. The Quaternary deposits are thin and consist mainly of littoral sand and gravel.

3.9.3. Hydrogeological features and observation station

Along the steep slopes of Laubackar, groundwater leakage can be found. The most important spring, yielding approx. 1 l/s, is situated at the eastern slope of Laubackar. This spring was selected to be an observation station. The main features of the station are presented in the following table:

Station no.	Lat.	Long.	Land surface m a.s.l.	Geology	Type of station	Obs. program	Aq. of obs.	Start of obs.
0901	5717	1839	13	Limestone	Spring	C	W	1969

3.9.4. Comments on the diagram

The chemical composition and tritium content of the groundwater from station no. 0901 are shown in the diagram (Fig. 22). A distinct, seasonal variation in the composition of the water can be seen, as samples collected in the spring have a lower content of calcium and bicarbonate than samples from other seasons. This is probably due to an intense groundwater recharge during the time of the year when the evapotranspiration is very low. A dilution of the old groundwater by infiltrated rainwater, having a low salt content, takes place.

The high concentrations of calcium and bicarbonate in the groundwater are caused by the very high content of calcium carbonate in the bedrock of the area.

The high content of tritium and the seasonal variations in chemical composition indicate a short residence time.

The concentration of tritium in the groundwater has decreased since the sampling started in 1969. This is due to the decreasing tritium concentration in the precipitation.

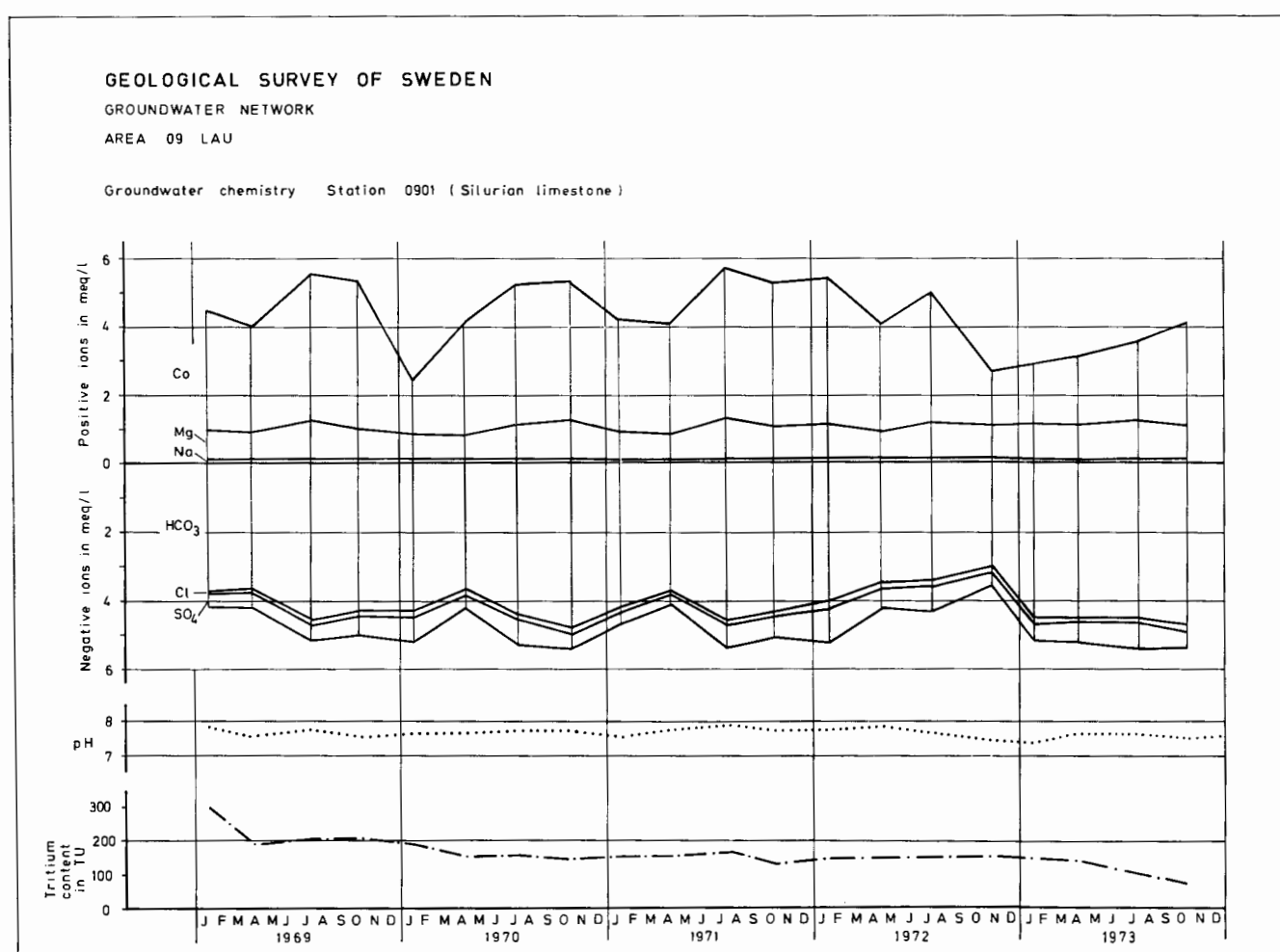


Fig. 22. Diagram from observation area 9 Lau.

3.10. Isums

3.10.1. Geographical location

The observation area Isums is situated in the central part of the island of Gotland, about 15 km SSE of the town of Visby. A map of the area is shown in Fig. 23.

3.10.2. Geology and geomorphology

The bedrock of the area consists of Silurian marlstone. It is covered by Quaternary deposits mainly made up of till. The area is a flat lowland.

3.10.3. Hydrological and hydrogeological features

The main water divide between the eastern and western parts of Gotland is situated in the Isums area. The surface

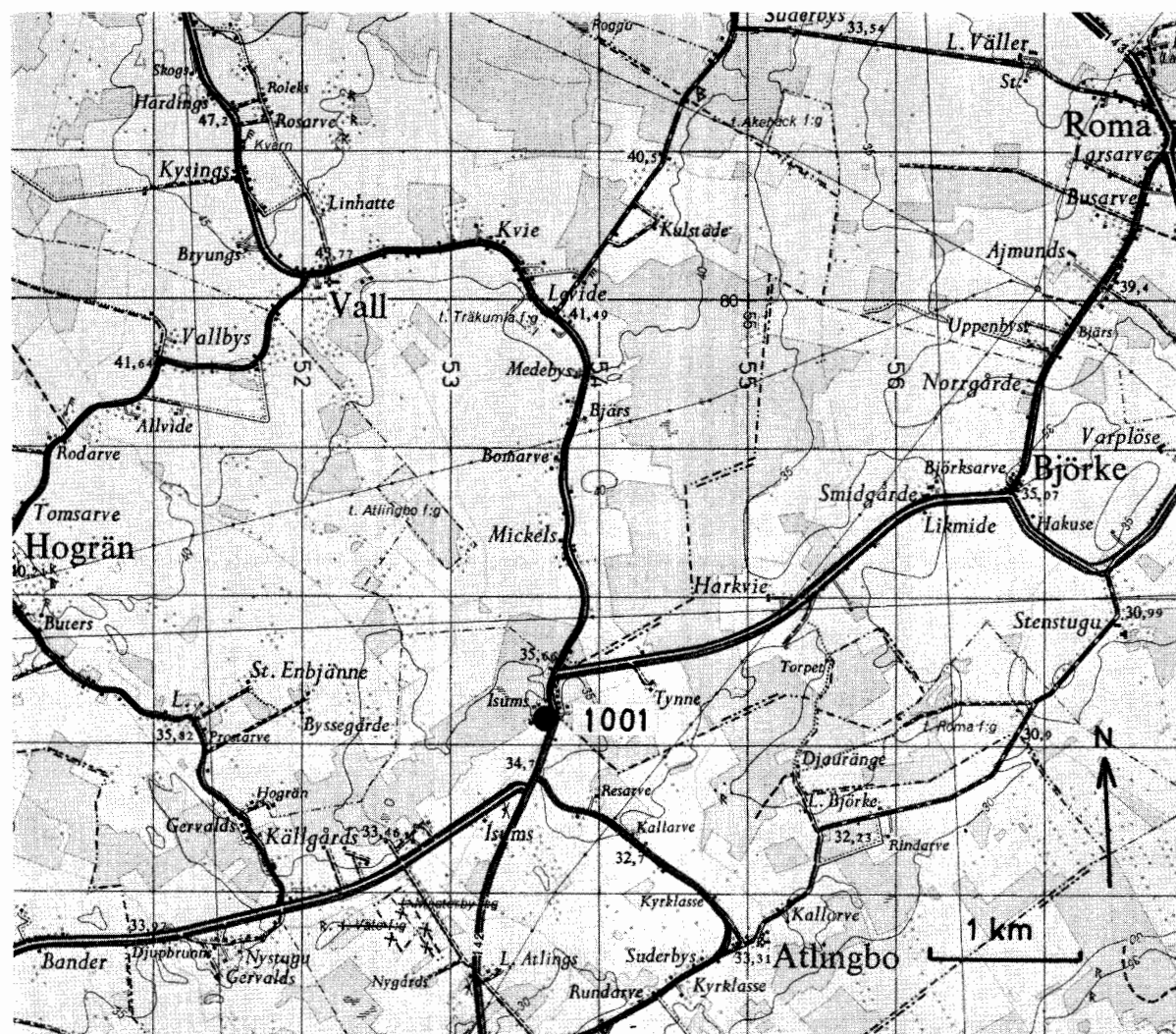
water from the area is drained both eastwards and westwards to the Baltic Sea. The groundwater divide probably has approximately the same location as the surface water divide. The main aquifer of the area is the Silurian rocks.

Producing wells that supply farms and separate households are found in the area. However, no important extraction of groundwater takes place.

3.10.4. Observation station

The main features of the observation station are presented in the table on next page.

The observation well was established for water supply



Station no.	Lat.	Long.	Land surface m a.s.l.	Geology	Depth of well m	Type of station	Obs. program	Aq.	Start of obs.
1001	5729	1822	34	Marlstone	22	Drill	L	A	1967

but is no longer used for this purpose. The well was drilled at the bottom of an old dug well. The station is situated less than one kilometer west of the surface water divide.

3.10.5. Comments on the diagram

The variations in groundwater level at station no. 1001 are shown in the diagram (Fig. 24).

The annual amplitude of the groundwater level variations is 1.2–2.2 m, with a maximum in winter or early spring and a minimum in late summer or autumn.

In the area the ground is neither frozen nor covered with snow permanently in the winter. This means that percolation through the Quaternary deposits can take place throughout the winter and cause a high groundwater level. During the period of vegetation, when intense evapotranspiration prevails, almost no groundwater recharge takes place. This results in a falling groundwater level.

No multiannual trend can be found in the diagram. The unusually low groundwater level in the autumn, 1971, and the winter, 1972, was caused by the low precipitation in 1971.

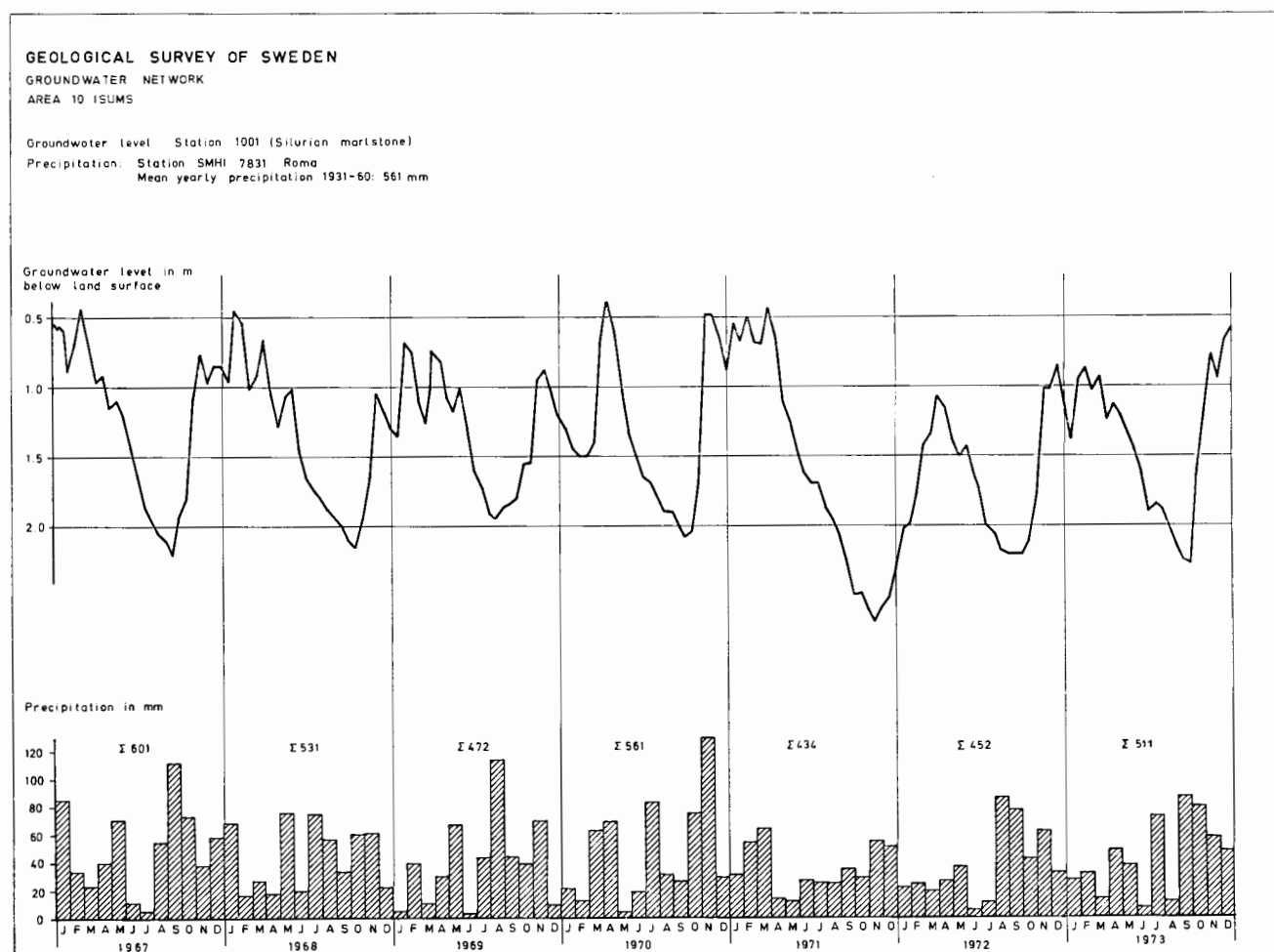


Fig. 24. Diagram from observation area 10 Isums.

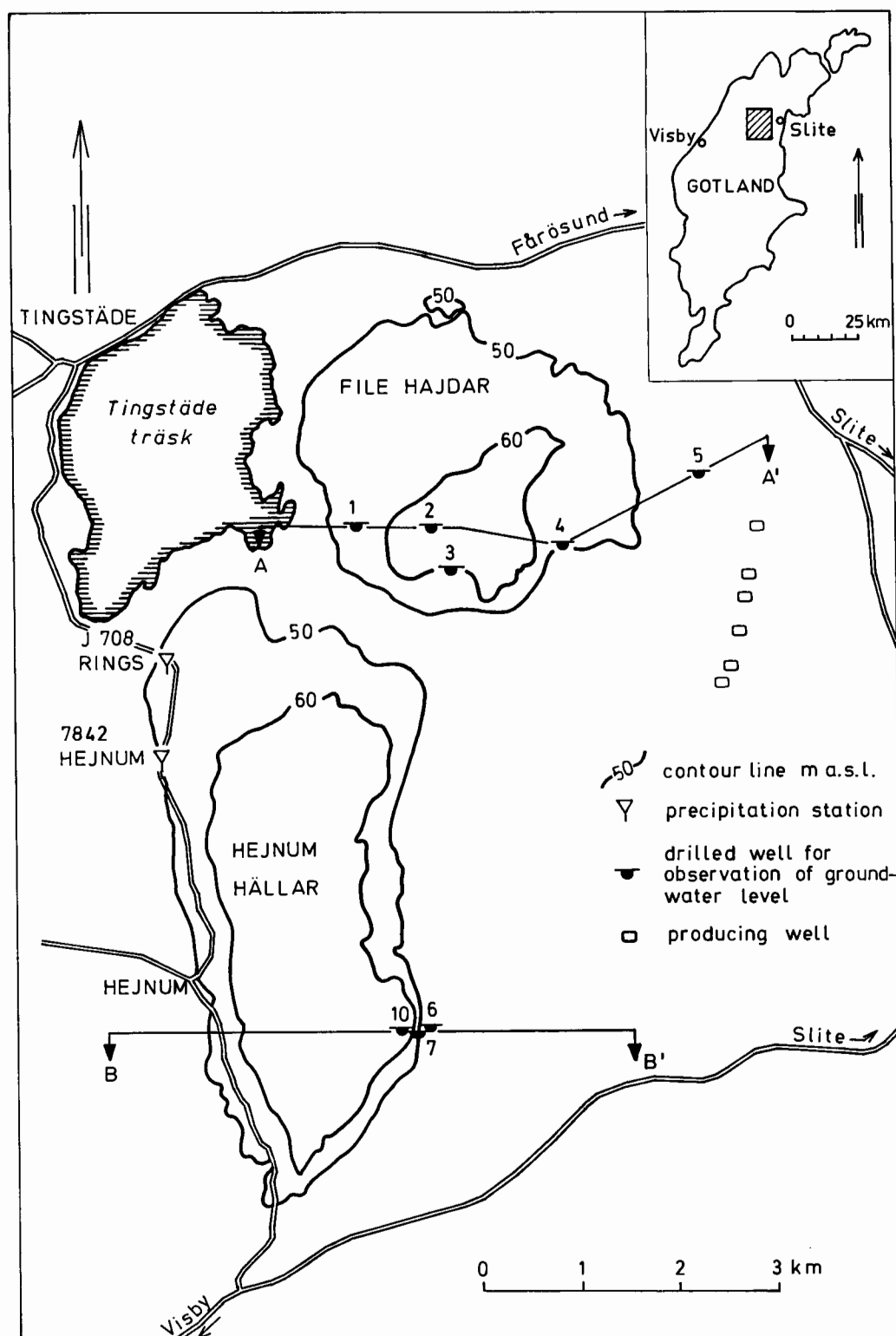


Fig. 25. Map of observation area 11 File Hajdar. Station numbers for drilled wells (1—10) correspond to station numbers 1101—1110 of the groundwater network. From Fagerlind and Nordberg, 1973.

3.11. File Hajdar

3.11.1. Geographical location

The observation area File Hajdar is situated in the northeastern part of the island of Gotland, which is the largest island in the Baltic Sea. The altitude of the area ranges from 30 to 75 m a.s.l. Maps and sections of the observation area are presented in Figs. 25, 26 and 29.

3.11.2. Geology and geomorphology

The bedrock of the area consists of Silurian limestone belonging to the so-called Slite group. It is made up of reefs and stratified deposits, including marlstones. Two major plateaux constitute the observation area: File Hajdar proper and Hejnum Hällar. They rise 20–40 m above surrounding lowlands. On the plateaux the bedrock is only partly covered by soil, a product of weathering, consisting of clayey gravel with chips of limestone and lake marl. The rest of the plateaux has hardly any

loose deposits. The vegetation in the plateau areas has a steppe-like character (Swedish: *alvar*) with groves of low pines and junipers. A relatively thin cover of glacial drift, generally reworked by Postglacial transgressions and regressions of the sea, is found in the lowlying areas outside the plateaux. The general character of the area is shown by a photo, Fig. 27.

The geology of Gotland has been dealt with by Munthe et al. (1925).

3.11.3. Hydrological and hydrogeological features

The plateaux are very dry in the summer and no surface runoff has been found. During the rest of the year, the weathered topsoil is generally saturated, and the depressions are filled with water. Surface runoff can be found outside the plateaux, and the drainage is toward the Baltic Sea in the east and the lake Tingstäde Träsk in

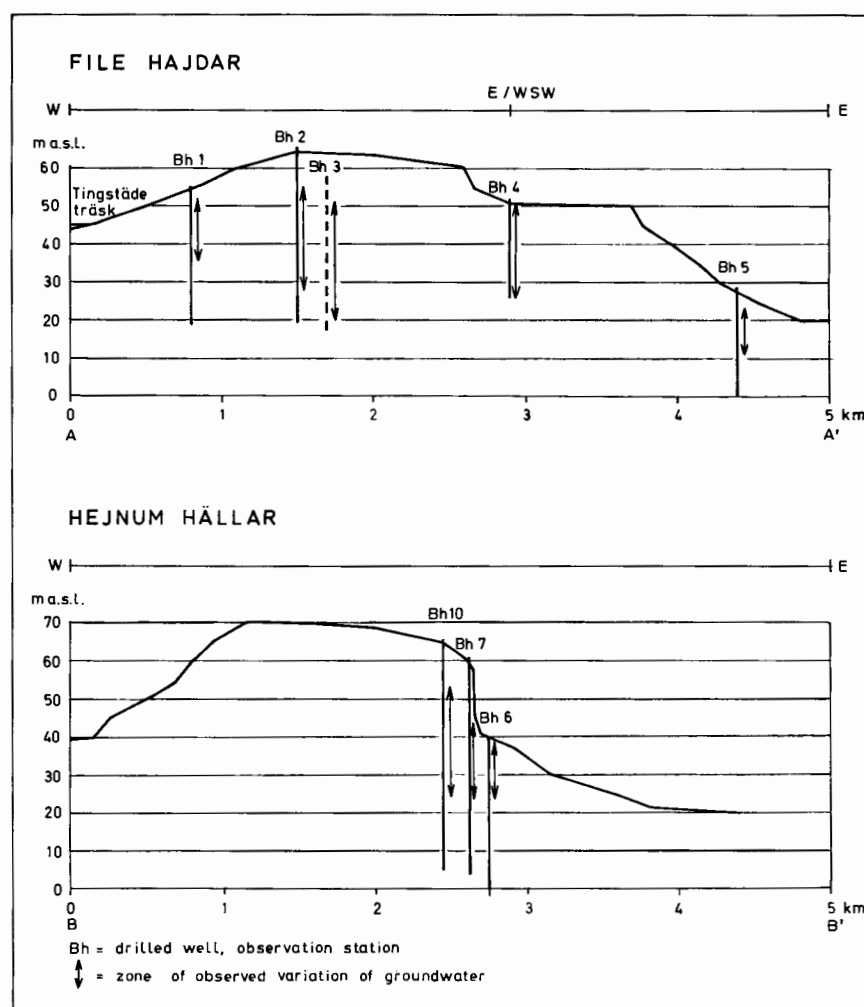


Fig. 26. Section across File Hajdar and Hejnum Hällar. Station numbers for drilled wells (Bh 1—Bh 10) correspond to station numbers 1101—1110 of the groundwater network. From Fagerlind and Nordberg, 1973.



Fig. 27. The general character of the sparsely forested landscape close to station no. 1104. Photo G. Persson 1973.

the west. The groundwater of the plateaux is drained mainly to the east. A small portion of the flow is directed westwards.

The groundwater regime of the plateaux is characterized by very large and rapid fluctuations. Thus, the groundwater level has been found to rise 20–25 m in less than a day in connection with precipitation. The hydrological and hydrogeological features of File Hajdar have been presented by Fagerlind and Nordberg (1973).

Extraction of water by pumping from wells takes place east of File Hajdar (see Fig. 25). The yearly extraction is approx. 300 000 m³ (9.5 l/s). Prior to the pumping, flowing springs could be found at the location of the producing wells.

3.11.4. Observation stations

The main features of the observation stations are presented in the following table:

Station no.	Lat.	Long.	Land surface m a.s.l.	Geology	Depth of well m	Type of station	Obs. program	Aq.	Start of obs.	Remarks
1101	5743	1840	56	Limestone	34	Drill	L	W	1967	
1102	5743	1840	64	„	43	„	L	W	1967	
1103	5743	1841	58	„	39	„	L	W	1967	
1104	5743	1842	50	„	23	„	L	W	1967	
1105	5743	1843	29	„	25	„	L	W	1967	
1106	5740	1840	39	„	41	„	LT	A	1967	
1107	5740	1840	58	„	55	„	L	W	1970	
1110	5740	1840	64	„	59	„	L	W	1970	Continuous recording

The location of the stations can be seen in Figs. 25 and 29.

The observation stations are selected from a network of boreholes that were drilled by Slite Cement och Kalk-aktiebolag in the search for limestone suitable for the production of cement. No operating quarries have yet been established within the observation area.

3.11.5. Comments on the diagram

Measurements of groundwater level and temperature have been performed since 1967, with exception of interruptions for technical reasons during the first winters (see diagram, Fig. 28). The pattern of seasonal groundwater level fluctuations is quite distinct. Generally the level is close to its maximum extreme from September—October to April—June. During the summer the level is close to its minimum extreme. It is remarkable that only a few measurements show the level in an intermediate position. The annual amplitude is approx. 25

m. It has been shown that the rises in groundwater level are extremely rapid in connection with precipitation. The fall of the groundwater level is considerably slower. A rise of 20—25 m in less than a day commonly occurs in several boreholes at File Hajdar. The relationship between precipitation and groundwater response at File Hajdar has been treated by Fagerlind and Nordberg (1973). By a calculation performed by them, it is concluded that the effective fissure porosity of the limestone within the zone of the groundwater variation ranges from only 0.06 to 0.47 per cent. The zone of variation is assumed to be limited both upwards and downwards by bedrock with quite different aquifer characteristics.

The local peculiarities of the observation area may conceal any weak multiannual trends in the movement of the groundwater level. The very low amounts of precipitation in 1971 and 1972 are not reflected in any lower groundwater levels for corresponding years. The extreme levels are almost identical from year to year. The difference is the duration of the extreme situations.

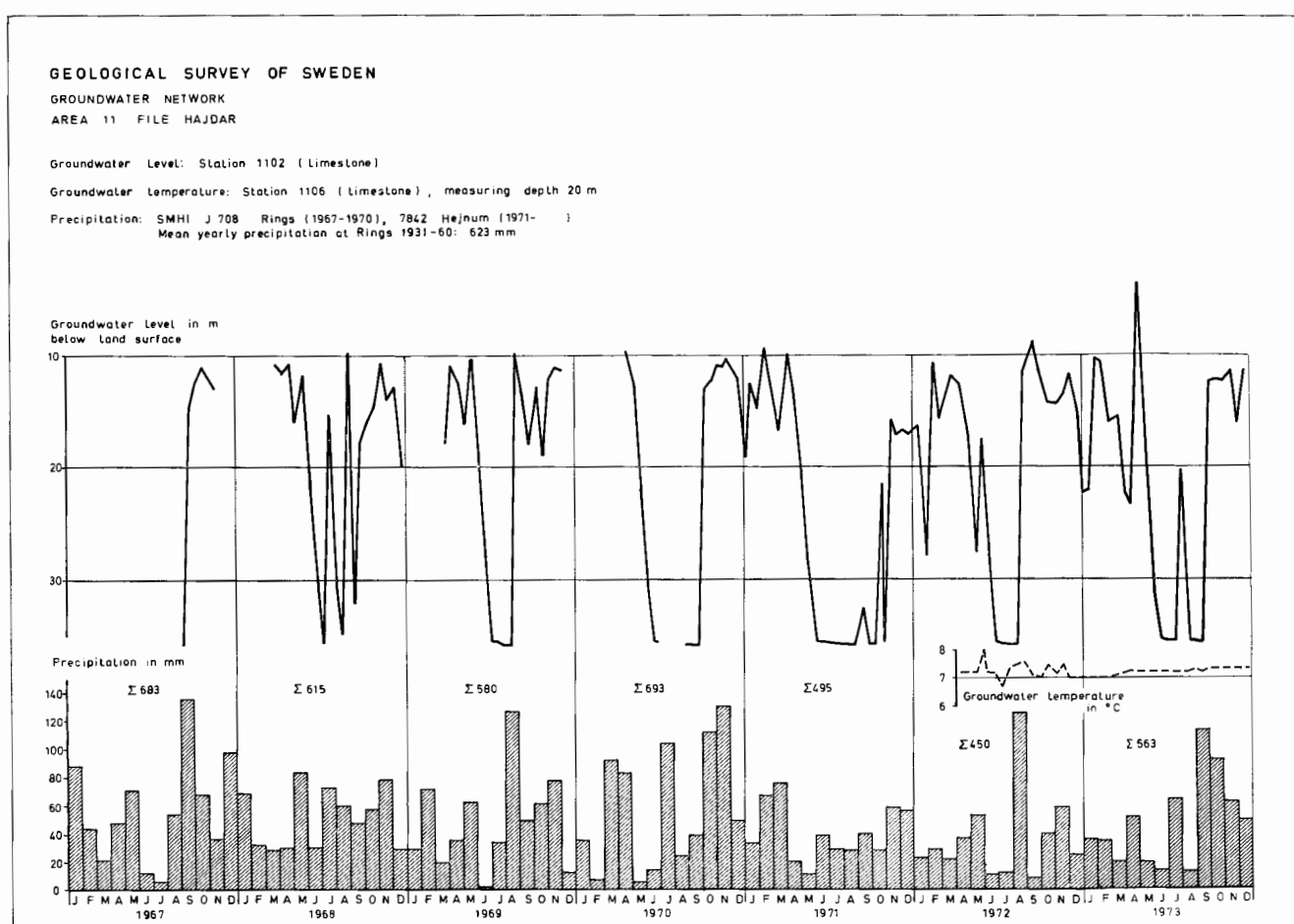


Fig. 28. Diagram from observation area 11 File Hajdar.

LARS NORDBERG AND GÖSTA PERSSON

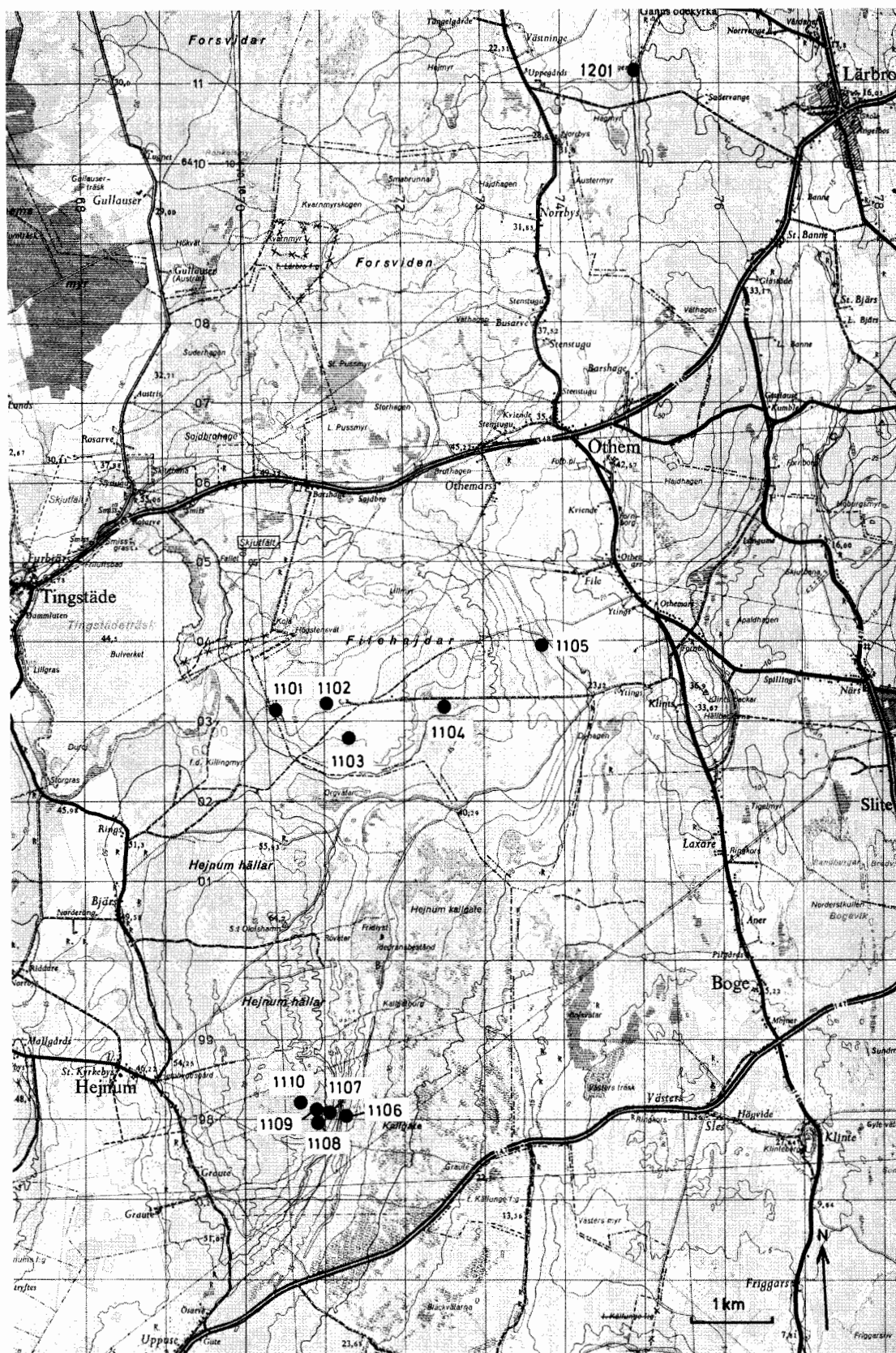


Fig. 29. Map of observation areas 11 File Hajdar and 12 Hångars. (Top. map 6 J NV, 6 J NO, 7 J SV, 7 J SO.)

There is a very strong correlation between weather, vegetation and groundwater levels. The pattern of recharge and discharge reflects the weather and plant growth conditions very well.

The variation of groundwater temperature has been measured only since April, 1972. The presented curve is remarkably uneven for deriving from measurements 20

meters below land surface. The irregularities are assumed to be connected with the very rapid and large changes in groundwater level. Also they may be caused in part by the unsatisfactory measuring technique used in 1972. No seasonal pattern of fluctuation can be found. The annual amplitude is 1.3°C with a mean value of 7.2°C .

3.12. Hångars

3.12.1. Geographical location

The observation area Hångars is situated in the northern part of the island of Gotland (Fig. 29). For the sake of identification, the area File Hajdar (no. 11) is also shown on the map.

3.12.2. Geology and geomorphology

The bedrock of the area consists of Silurian limestones partly covered by a thin layer of Quaternary deposits, mainly till. The area is a lowland gently sloping toward the northwest.

3.12.3. Hydrogeological features and observation station

The only observation station within the area is a spring which yields approx. 3 l/s from fissures in the limestone. The main features of the station are presented in the following table:

Station no.	Lat.	Long.	Land surface m a.s.l.	Geology	Type of station	Obs. program	Start of obs.
1201	5747	1845	21	Limestone	Spring	C W	1969

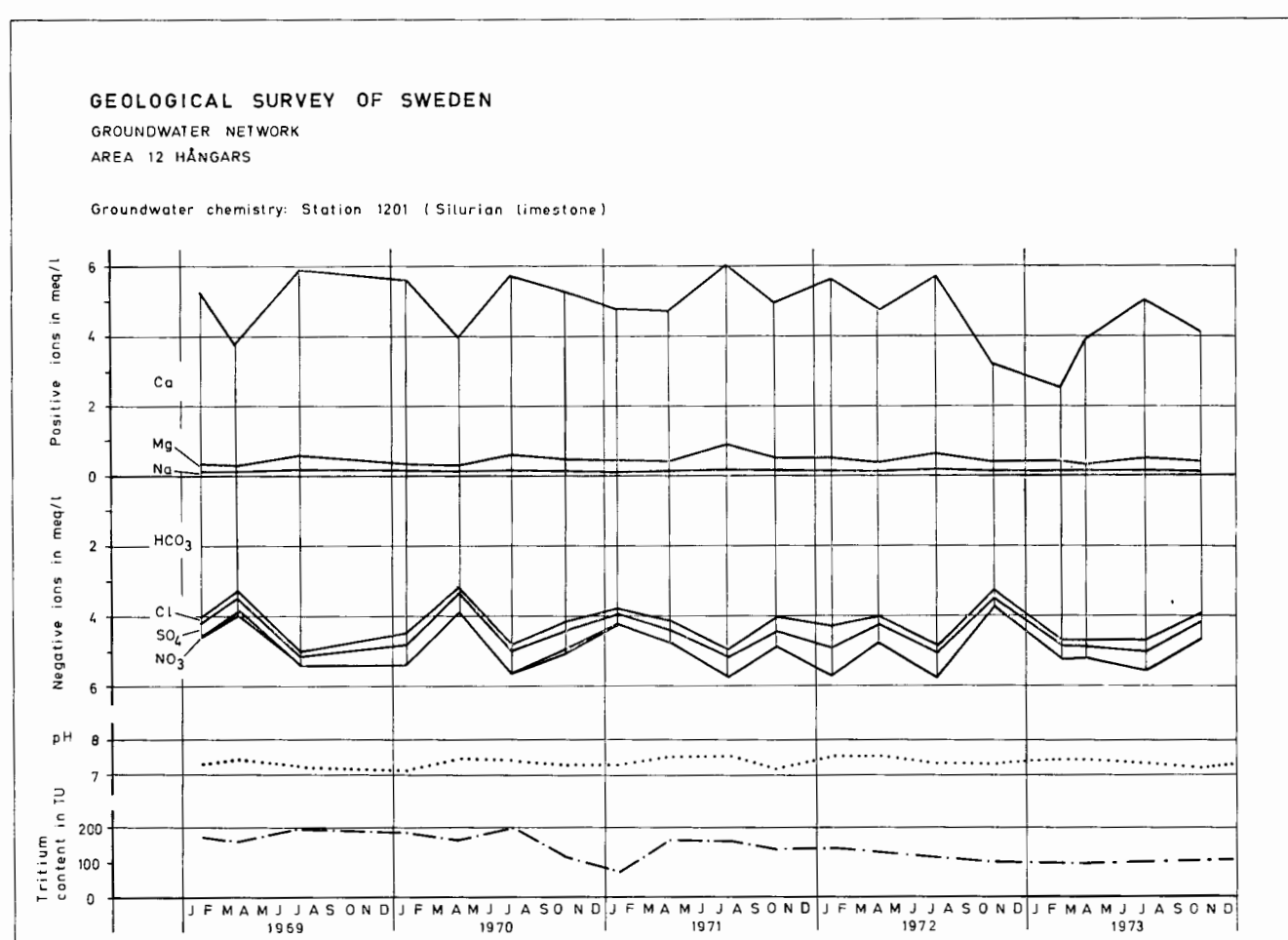


Fig. 30. Diagram from observation area 12 Hångars.

3.12.4. Comments on the diagram

In the diagram (Fig. 30) the chemical composition and tritium content of the groundwater from station no. 1201 are shown. A distinct, seasonal variation in the composition of the water can be seen, as samples collected in the spring have a lower content of calcium, magnesium and bicarbonate than samples from other seasons. The

variation pattern at station no. 1201 is very similar to that of station no. 0901 (see page 41).

The high concentration of calcium and bicarbonate in the groundwater is caused by the very high content of calcium carbonate in the bedrock of the area.

The high content of tritium and the seasonal variations in chemical composition indicate a short residence time.

3.13. Djurarpsdalen

3.13.1. Geographical location

Observation area Djurarpsdalen is situated in the province of Halland in southwest Sweden, approx. 15 km eastnortheast of the town of Varberg.

3.13.2. Geology and geomorphology

The observation area consists of the Djurarp valley, which is 4 km long and has a direction of N—S (see map, Fig. 31). The flat valley floor is around one kilometer wide. The altitude ranges from 25 to 35 m a.s.l. The slopes of the valley are rather steep and the surrounding heights reach altitudes of 100 to 130 m a.s.l. The Djurarp valley forms a tributary valley to the Himleån valley which is several kilometers wide and has a direction of W—E.

The bedrock of the area consists of gneisses which outcrop frequently on the surrounding heights. A thin layer of glacial drift, mainly consisting of sandy till from the latest glaciation, partly covers the bedrock of the area. In the north of the valley, at the village of Skällinge, a large accumulation of glacial drift damming lake Skällingesjö is found. This accumulation, consisting mainly of stratified sand and gravel was built up as a delta in the sea by glaciofluvial streams. The highest Late-glacial sea level in this area reached 70—75 m above present sea level which elevation coincides with the altitude of the flat surface of the delta.

Stratified sand of glaciofluvial origin is also found in the Djurarp valley southwest of the Skällinge delta. These sediments are generally covered by marine clay. The thickness of the sand ranges, in four borings in the valley, from 5 to 36 m and the thickness of the covering clay from 4 to 15 m.

3.13.3. Hydrological and hydrogeological features

The surface water of the observation area is drained by a small rivulet, the Horsabäcken, which flows southwards in the Djurarp valley to Himleån. The lake Skällingesjö has no surface outlet. It is evidently drained by

shore and lake bottom infiltration to the groundwater of the Skällinge delta. The groundwater flow in this aquifer is directed toward the southwestern distal part of the delta. A spring (station no. 1301) discharging a few liters per second is found just outside the foot of the delta.

The delta aquifer probably has a hydraulic connection with the sand deposits below the marine clay in the Djurarp valley. The sand deposits constitute the main

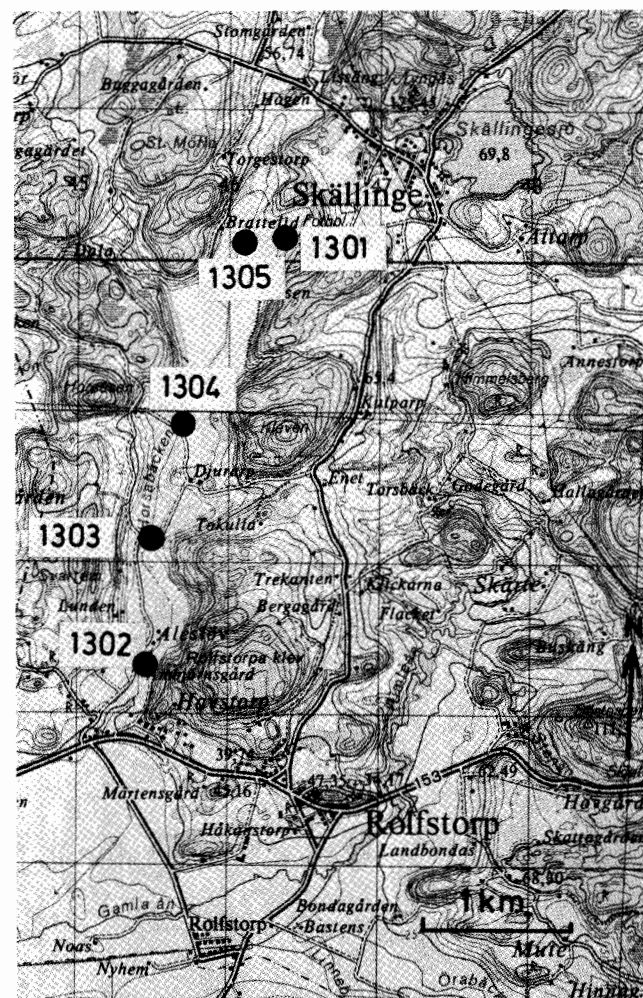


Fig. 31. Map of observation area 13 Djurarpsdalen. (Top. map 5 B NO.)

aquifer of the valley. This aquifer is artesian and the pressure head in the northern part of the valley is situated approx. 2—3 m above the land surface and in the southern part close to the land surface. This aquifer has a groundwater flow southwards and there probably is a flow of groundwater from the Djurarp valley into aquifers of the Himleån valley.

3.13.4. Observation stations

The main features of the stations are presented in the table below.

The locations of the stations are presented on the map, Fig. 31. Station no. 1301 consists of the aforementioned spring, situated in the distal part of the Skällinge delta. Stations nos. 1302—1305 are situated in the Djurarp valley and consist of iron tubes penetrating the marine clay down into the sand aquifer. These stations were established by Sydsvenska Ingenjörbyrå (SIB) in connection with an investigation for the water supply of the town of Varberg. Extensive extraction of groundwater for the water supply of Varberg takes place in the Himleån valley. The pumping, however, does not seem to influence the groundwater conditions in the Djurarp valley.

A small community water supply well for Skällinge is situated 300 m northeast of station no. 1301. The groundwater extraction is only approx. 1 l/s and seems to have no influence on the groundwater conditions at the observation stations.

3.13.5. Comments on the diagram

In the diagram (Fig. 32) all observed parameters are shown from selected stations.

The low salt concentration and the relatively high tri-

tium content in the analyses from station no. 1301 indicate a short residence time for the groundwater in the Skällinge delta. The observation series is too short to allow the drawing of any conclusions concerning seasonal variations and multiannual trends in the chemical composition of the groundwater.

The groundwater has relatively high concentrations of sodium and chloride. This is due to high content of these ions in the precipitation water in the coastal area of southwest Sweden. A distinct, falling trend can be seen in the diagram showing the tritium content. This trend is caused by the decreasing tritium concentration in the precipitation.

The curve for the groundwater level at station no. 1303 shows a distinct, seasonal variation, generally a high groundwater level in the winter and low level in late summer. The amplitude of the annual variations is 0.5—1.5 m. The winter climate of the area is relatively mild; the ground is neither frozen nor covered with snow permanently in the winter. For this reason, groundwater recharge can take place throughout the winter in most years. The main groundwater recharge seems to take place in the autumn and the winter.

In addition to the seasonal variations, there are a great number of minor fluctuations in the groundwater level. As the aquifer is artesian, these short-term fluctuations probably can be explained by changes in the barometric pressure.

Some weak multiannual trends can be found in the diagram. During the years 1959—1963, 1965—1967 and 1969—1971, a trend of rising groundwater level is found. Contrary to this, a falling trend is found in the years 1963—1965, 1967—1969 and 1971—1973. These multiannual trends seem to reflect changes in the yearly precipitation.

Station no.	Lat.	Long.	Land surface m a.s.l.	Geology	Depth of well m	Type of station	Obs. program	Aq.	Start of obs.
1301	5710	1228	37	Gl. fl. sand	—	Spring	C	W	1968
1302	5709	1226	27	„ „ grav.	24	Tube	L	A	1959
1303	5709	1226	29	„ „ sand	16	„	L	A	1959
1304	5710	1227	30	„ „ „	25	„	L	A	1959
1305	5710	1227	32	„ „ „	26	„	L	A	1959

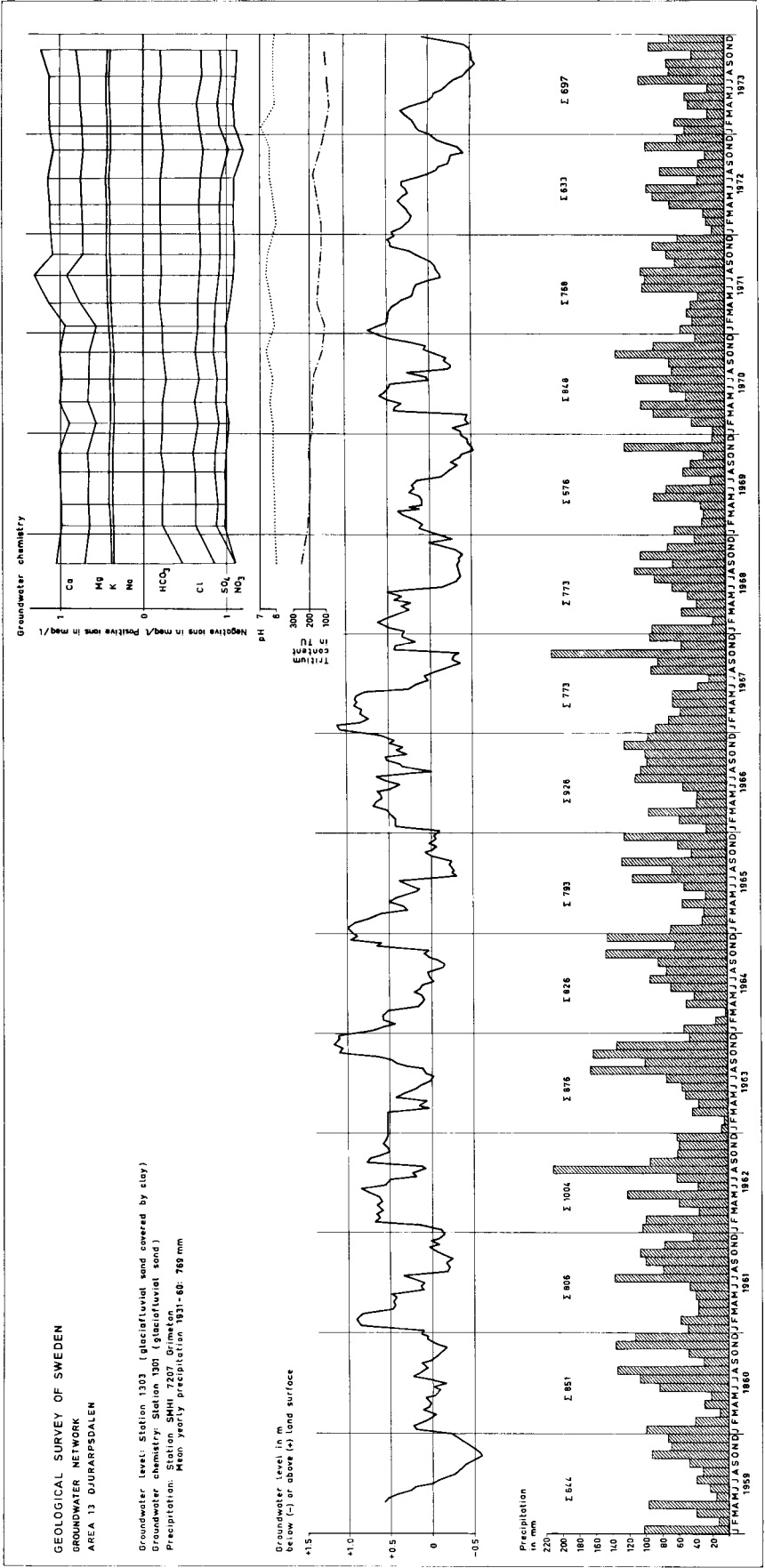


Fig. 32. Diagram from observation area 13 Djurarpssdalen.

3.14. Nissafors

3.14.1. Geographical location

The observation area Nissafors is situated in the western part of the province of Småland in southern Sweden, approx. 50 km southwest of the town of Jönköping. The altitude of the area ranges from 153 to 185 m a.s.l.

3.14.2. Geology and geomorphology

The observation area is situated in the valley of the river Nissan which, in this part of the valley, flows through several lakes (see map, Fig. 33). The bedrock consists mainly of Precambrian gneisses. Rock outcrops are found at only a few localities within the area but are more frequent on the surrounding heights.

The bedrock is generally covered by a sandy till from the latest glaciation. At some localities, e. g., north of Nissafors at the observation stations nos. 1412—1415, moraines of drumlin-shaped character are found.

Extensive areas covered by glaciofluvial sediments are found in the Nissan valley south of Nissafors, both west and east of the lakes Vikaresjön and Stora Gussjön. These accumulations generally have a rather flat surface. According to "Arbetsgruppen för Östbo och Västbo häraders vattenförsörjning" (Working group for the water supply of Östbo and Västbo, Report, 1967), the glaciofluvial sediments have a considerable thickness. A thick-

ness of more than 70 m has been recorded at observation station no. 1410. Loose deposits which have a thickness of 30—50 m are commonly found in the area. The sediments consist mainly of sand and silt; however, coarser material is found at some places.

3.14.3. Hydrological and hydrogeological features

All surface water in the area is drained to the lakes Stora Gussjön and Vikaresjön in the Nissan river system. The river Nissan flows southwestwards to the Kattegatt Sea.

A map showing the groundwater flow in the glaciofluvial deposits of the area is presented in the aforementioned report. The map shows a flow direction toward the lakes Stora Gussjön and Vikaresjön. The gradient of the groundwater surface is rather steep, an average of 15 per mille is found. This indicates that the material of the aquifer is relatively fine-grained. Groundwater seepage is found at several places along the shores of the lakes.

Two groundwater works are found within the area. The one which supplies the village of Nissafors with water is situated one kilometer north of Nissafors. The well is situated in coarse glaciofluvial deposits within a distance of 100 m from the shore of the river Nissan. A volume of 43.500 m³ (= 1.5 l/s) of groundwater was pumped from this well in 1972. This extraction of groundwater probably has only a very local influence on the groundwater level and flow pattern. The other well is situated at Bäckshult on the east side of Stora Gussjön and supplies the small towns of Gnosjö and Hillerstorp with groundwater. From this well 500 000 m³ (= 16 l/s) of water was pumped in 1972. This pumping has a direct influence on the groundwater level and the flow pattern in the area east of the southern part of the lake Stora Gussjön. However, no influence from the pumping from this well has been observed at the observation stations between the well and Nissafors.

3.14.4. Observation stations

The main features of the observation stations are presented in the table on page 54.

The locations of the groundwater stations are shown on the map, Fig. 33. Stations nos. 1401—1411 are situated in the glaciofluvial deposits east and west of the lakes Stora Gussjön and Vikaresjön. They were established by Sydsvenska Ingenjörbyrå AB (SIB) in connection with the investigations for groundwater supply under the auspices of "Arbetsgruppen för Östbo och Västbo hä-

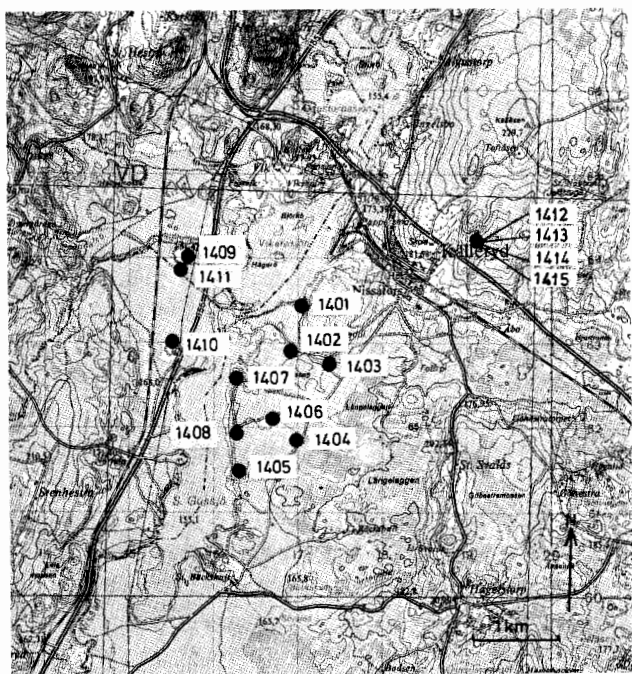


Fig. 33. Map of observation area 14 Nissafors. (Top. map 6 D SV.)

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Station no.	Lat.	Long.	Land surface m a.s.l.	Geology	Depth of well m	Type of station	Obs. program	Aq.	Start of obs.	Remarks
1401	5724	1337	163	Gl. fl. sand	30	Tube	L	W	1967	
1402	5724	1337	167	" " "	19	"	LT	W	1967	Temp. from 1970
1403	5724	1337	171	" " "	14	"	L	W	1967	
1404	5723	1337	169	" " "	23	"	L	W	1967	
1405	5723	1336	169	" " "	29	"	L	W	1967	
1406	5723	1337	170	" " "	15	"	LT	W	1967	Temp. 1968—1969
1407	5723	1336	165	" " "	35	"	L	W	1967	
1408	5723	1336	167	" " "	22	"	LT	W	1967	Temp. 1969—1970
1409	5724	1335	161	" " "	12	"	L	W	1967	
1410	5724	1335	160	" " "	23	"	L	W	1967	
1411	5724	1335	162	" " "	21	"	L	W	1967	
1412	5724	1339	181	Sandy till	5	"	L	A	1970	
1413	5724	1339	183	Gneiss	110	Drill	L	A	1970	
1414	5724	1339	185	Sandy till	4	Tube	L	A	1970	
1415	5724	1339	185	" "	—	Spring	C	A	1970	
F 23	5723	1337	170	Gl. fl. sand	—	Frost	F	—	1971	

radars vattenförsörjning". Stations nos. 1412—1414 were established to supply water to Nissafors. However, the capacity of the drilled well (no. 1413) was too small, and the well has never been used for water supply purposes. These three stations are situated at the foot of a drumlin-like hill and where artesian conditions are present. A spring yielding a few liters per second (station no. 1415) is found here too.

3.14.5. Comments on the diagram

In the diagram (Fig. 34) all observed parameters are shown from the selected stations. The observations of the chemical composition of the groundwater at station no. 1415 started in 1970. The observation period is too short to show any multiannual trends or to permit any conclusions about the character of the observed, seasonal fluctuations.

Precambrian gneisses dominate the rock material in the till aquifer, and due to this fact the groundwater has a relatively low content of calcium and bicarbonate ions and a low pH-value (around 6.0—6.5).

The groundwater has a tritium content of around 150 TU, which indicates a relatively short residence time.

The penetration of frost and the snow cover have been measured since December, 1971. During the winter seasons the ground has been frozen from the beginning of January to the end of March. The maximum depth was only 6 cm in the winter of 1971—1972, 19 cm 1972—1973 and 27 cm in December, 1973. The snow cover was very thin these winters. Thus, the frost has probably influenced the groundwater recharge only to a very slight degree during these winters. In most winters a thicker

snow cover and probably also a deeper frost penetration are present. The groundwater recharge during the winter months is generally quite insignificant. A winter minimum in the groundwater level is found in years like 1968, 1969 and 1970.

The variations of the groundwater levels in three different aquifers are shown in the diagram. The fluctuations of the groundwater levels in the till aquifer at station no. 1412 and in the bedrock aquifer at no. 1413 show great similarities. These stations are situated only about 25 m from each other, and there is probably a relatively good, hydraulic communication between the two aquifers. The yearly amplitudes are at these stations 0.5—1.0 m. The maximum groundwater level is reached in the winter, and the minimum, in late summer or autumn. Variations in barometric pressure have probably caused some of the minor, short-term fluctuations in the groundwater level found at stations nos. 1412 and 1413. The bedrock aquifer and the till aquifer are confined.

The glaciofluvial sand aquifer is represented by station no. 1410. The yearly amplitude of the groundwater level fluctuations is 0.3—0.9 m. The patterns of seasonal fluctuation have been different from year to year during the observation period. In the winters of some years (1968, 1969 and 1970) a minimum level is found and in others (1971 and 1973) a maximum. These differences are probably due to variations in the frost penetration and the snow cover, as mentioned above. Contrary to the till and bedrock aquifers at stations nos. 1412 and 1413, the sand aquifer is non-artesian, and no short-term fluctuations caused by variations in barometric pressure can be found. The thickness of the unsaturated zone, which in most places exceeds 5 m, also has an equ-

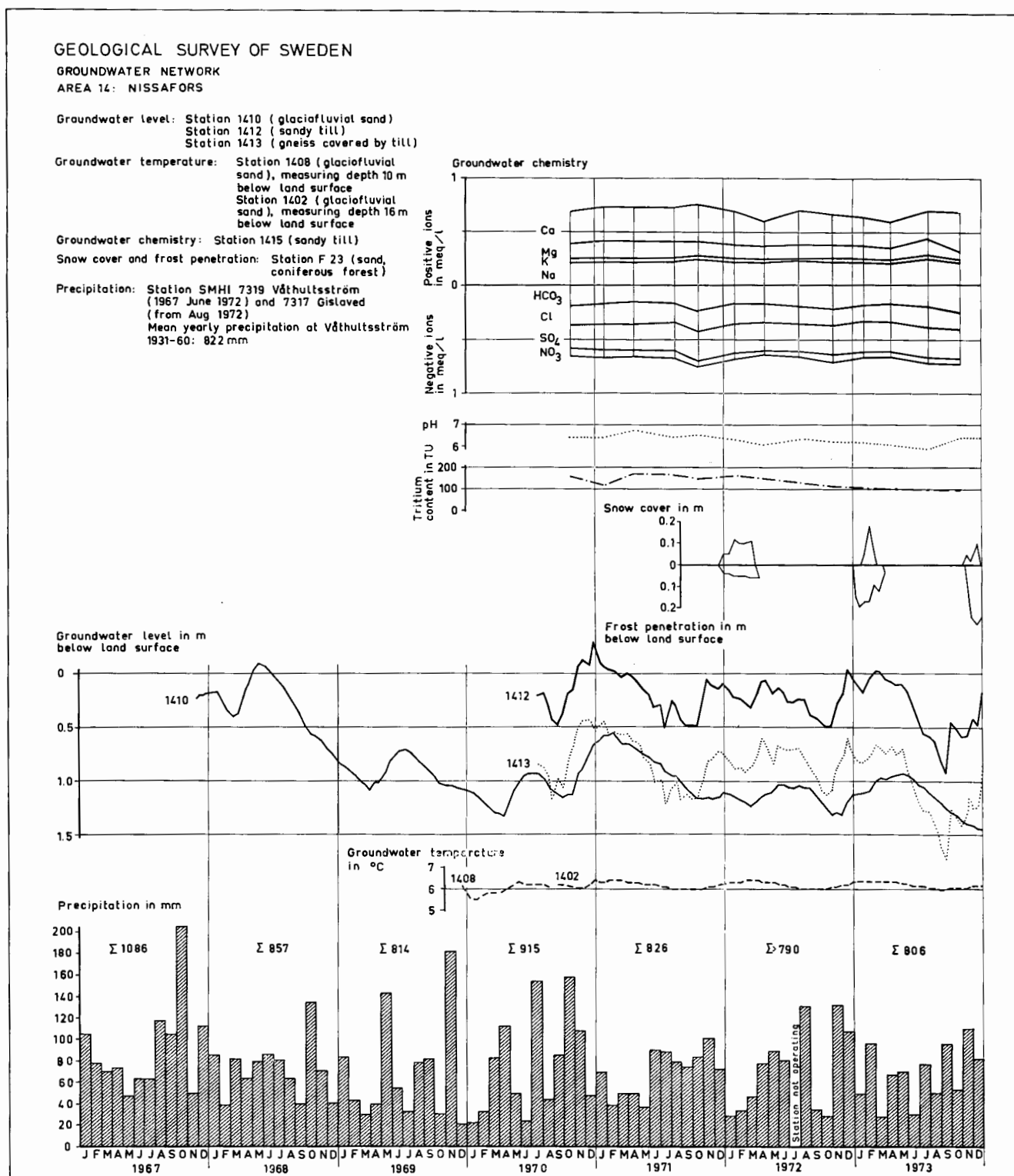


Fig. 34. Diagram from observation area 14 Nissafors.

alizing effect on groundwater level changes caused by heavy, periodic rainfall. The depth to the groundwater level at station no. 1410 refers to the distance from the bottom of a 10–15 m deep gravel pit to the groundwater level. Consequently, the thickness of the unsaturated zone in the surrounding area is 10–15 m.

No multiannual trends can be seen in the curves from stations nos. 1412 and 1413. At station no. 1410, from which a longer observation series is available, a trend of falling groundwater level is found during the years 1968–1970 and a trend of rising levels 1970–1971. These long-term variations are probably caused by the

high sums of precipitation in the years 1967 and 1970. The extreme minimum level for the period of observation occurred in December, 1973.

The groundwater temperature has been measured in some of the tubes in the sand aquifer. Temperature curves from stations nos. 1408 and 1402 are shown in the diagram (Fig. 34). At station no. 1402 a yearly amplitude of 0.4°C is found at a depth of 16 m below land surface. The maximum temperature is found in March and the minimum in August–September. The mean temperature is 6.1°C.

3.15. Ölanda

3.15.1. Geographical location

The observation area Ölanda is situated in the province of Västergötland in southwest Sweden, approx. 90 km northeast of Göteborg. The altitude of the area ranges from 145 m to 160 m a.s.l. The area is shown on the map, Fig. 35.

3.15.2. Geology and geomorphology

The bedrock of the area consists of Precambrian gneisses. They are generally covered by glacial drift. The village of Ölanda is situated on a drumlin-like accumulation. The till, which is sandy, has been found to have a

thickness of 7–8 m. The low-lying ground in the southern part of the area is covered by peat. The swampy area 2 km SSW of Ölanda is a remnant of the former lake Klastorpasjön which was artificially lowered in the 19th and 20th centuries. Glaciofluvial deposits are found in small isolated, sharp-crested hills which rise 5–6 m above the flat peatland in the southern part of the area. The glaciofluvial deposits belong to an esker system with the general direction of NE–SW. In the northeastern part of the area the esker has a well-defined continuity. Southwest of the village of Ölanda, glaciofluvial material also appears in isolated ridges trending NW–SE. The glaciofluvial material consists mainly of sand and gravel.

3.15.3. Hydrological and hydrogeological features

The area is drained by the river Nossan and its tributary Vimleån to Lake Vänern. It is assumed that the separate glaciofluvial deposits have a good hydraulic connection with each other at some depth. The groundwater flow is mainly directed to the south. The groundwater conditions of the Ölanda area were investigated by Viak (1957). A great number of observation tubes were established in order to obtain information on groundwater levels in the glaciofluvial sand and gravel. Most tubes penetrated 5–10 m of loose deposits below which bedrock or large boulders were encountered. A test pumping was performed at the present stations no. 1503 and no. 1505 from March to August, 1957. A safe yield of at least 22 l/s was obtained. The cone of depression was very shallow which indicates a good permeability in the aquifer. The maximum lowering of the groundwater table in the pumping wells was approx. 3 m. A few hundred meters from the pumping wells the lowering of the

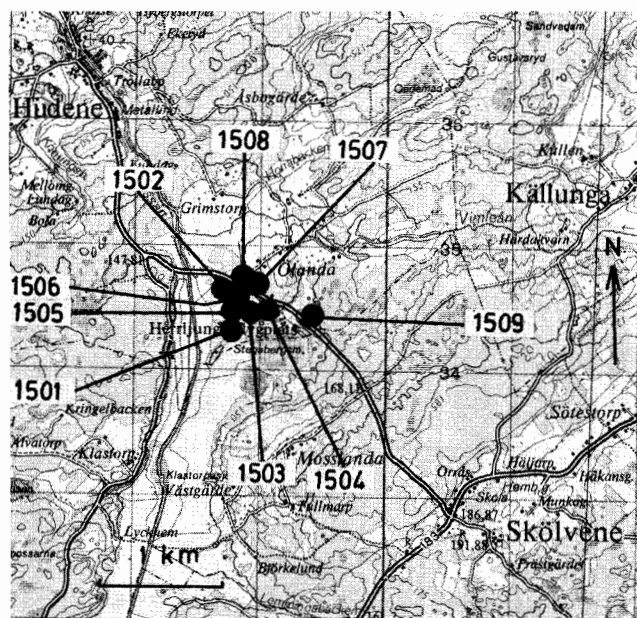


Fig. 35. Map of observation area 15 Ölanda. (Top. map 7 C NO.)

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Station no.	Lat.	Long.	Land surface m a.s.l.	Geology	Depth of well m	Type of station	Obs. program	Aq.	Start of obs.	Remarks
1501	5802	1307	145	Gl. fl. grav.	6	Tube	L	W	1968	Covered by peat
1502	5802	1307	146	" " sand	3	"	L	W	1968	
1503	5802	1307	145	" " grav.	11	"	L	W	1968	Continuous recording from 1970 Covered by peat
1504	5802	1307	146	" " "	6	"	L	W	1968	
1505	5802	1307	145	" " "	10	"	LT	W	1968	Covered by peat
1506	5802	1307	146	" " sand	5	"	L	W	1968	
1507	5802	1307	150	Sandy till	5	"	L	W	1968	
1508	5802	1307	148	" "	4	"	L	W	1970	
1509	5802	1307	147	Gl. fl. grav.	3	"	L	W	1970	

groundwater table was less than one meter. A great deal of the amount of depression can probably be attributed to the natural, seasonal fall of the groundwater in the summer. The investigation by Viak showed that a well, established at Ölanda (close to the present observation stations nos. 1503 and 1505) could yield water sufficient for the calculated requirements of the town of Herrljunga. The quality of the groundwater was good, except for relatively high concentrations of iron and manganese which could be materially reduced by simple means of oxidation and filtration. However, no community water well has been established yet.

The village of Ölanda is supplied with water from separate dug wells. Some of the wells extend into the underlying bedrock. The extraction of water is small.

3.15.4. Observation stations

The main features of the observation stations are presented in the table above.

The locations of the stations are shown on the map, Fig. 35. Stations nos. 1501—1507 were established by Viak in connection with the aforementioned investigation. Station no. 1507 was improved in 1970 by SGU, which also established stations nos. 1508—1509. None of the observation stations are influenced by pumping.

3.15.5. Comments on the diagram

In the diagram (Fig. 36) the variation of groundwater level and temperature is shown in relation to precipitation.

There is a distinct, seasonal cyclicity in the pattern of the groundwater level variations. Normally there are two major periods of recharge each year, one in the spring and one in the autumn. However, the aquifer, consisting of permeable gravel, responds quickly to large rainfalls. Therefore, periods of rising groundwater can occur any time of the year, even in the middle of the summer with high evapotranspiration. Such periods are noticeable in 1971 and 1972. The extreme levels in a year, therefore, may occur any month. The annual amplitude is 1.4—1.8 m. A weak trend of rising minimum levels is discernible from 1968 to 1972. A corresponding trend of maximum levels cannot be found. Consequently, the annual amplitudes have decreased with time.

The temperature of the groundwater has been gauged since 1968. During the first two years, readings were taken 2—3 m below ground surface. Since July, 1970, a stationary thermometer has been placed 9 m below the ground surface in the observation tube. The seasonal pattern indicates that the lowest temperatures occur in the summer and the highest ones in early winter. The annual amplitude is 1.1—2.0°C. The mean temperature for the whole period of observation is 5.4°C.

3.16. Velen

3.16.1. Geographical location

The observation area Velen is situated in the northern part of the province of Västergötland, south central Sweden, between the two large lakes, Lake Vänern and Lake Vättern. The altitude of the area ranges from 120 to 175 m a.s.l. (see map, Fig. 37).

3.16.2. Geology and geomorphology

The area was geologically mapped by Engqvist (1966). The basal bedrock consists of Precambrian granites and gneisses with minor occurrences of basic rocks. Outcrops are found at several localities within the area, although most of them are areally small.

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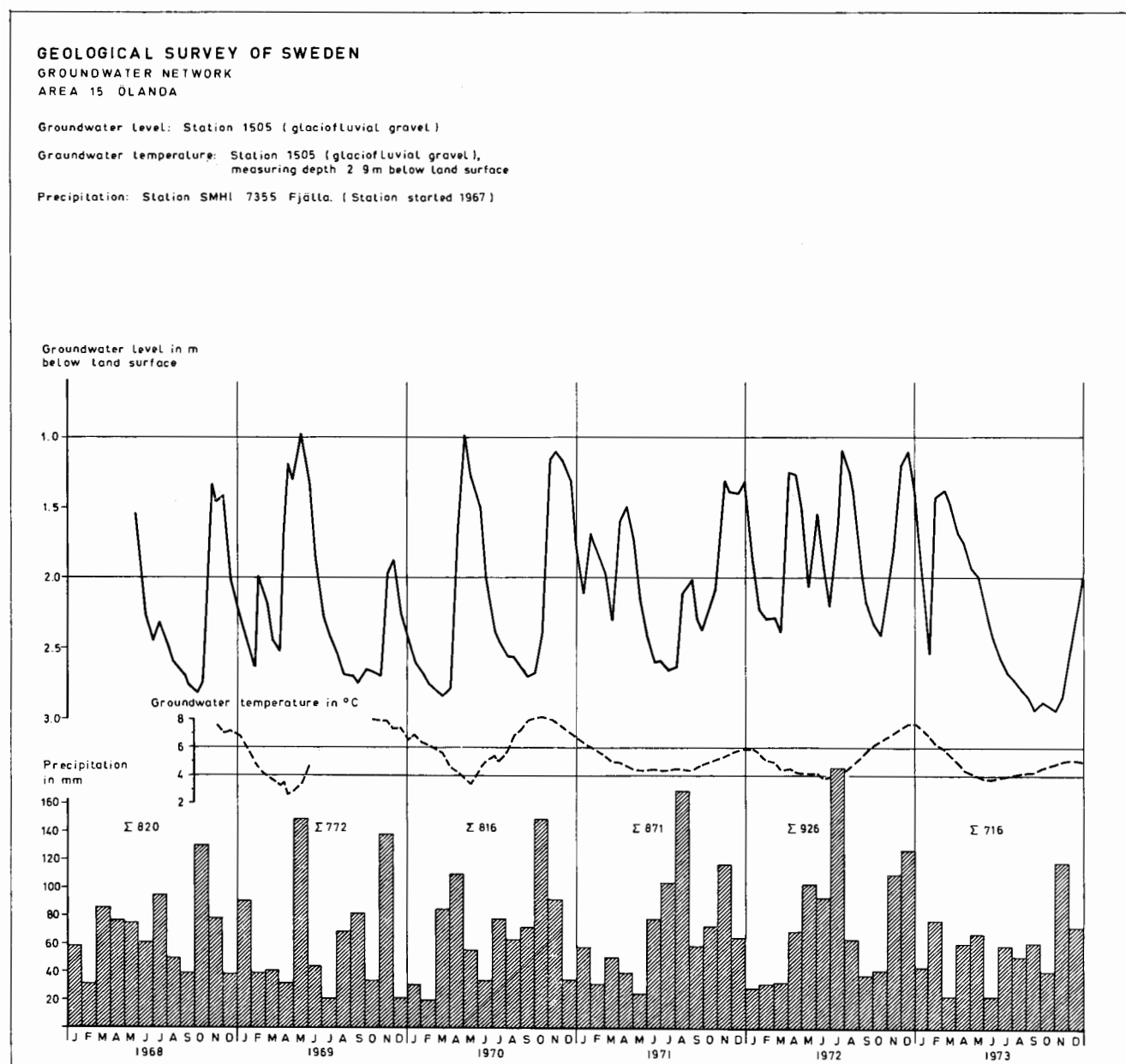


Fig. 36. Diagram from observation area 15 Ölanda.

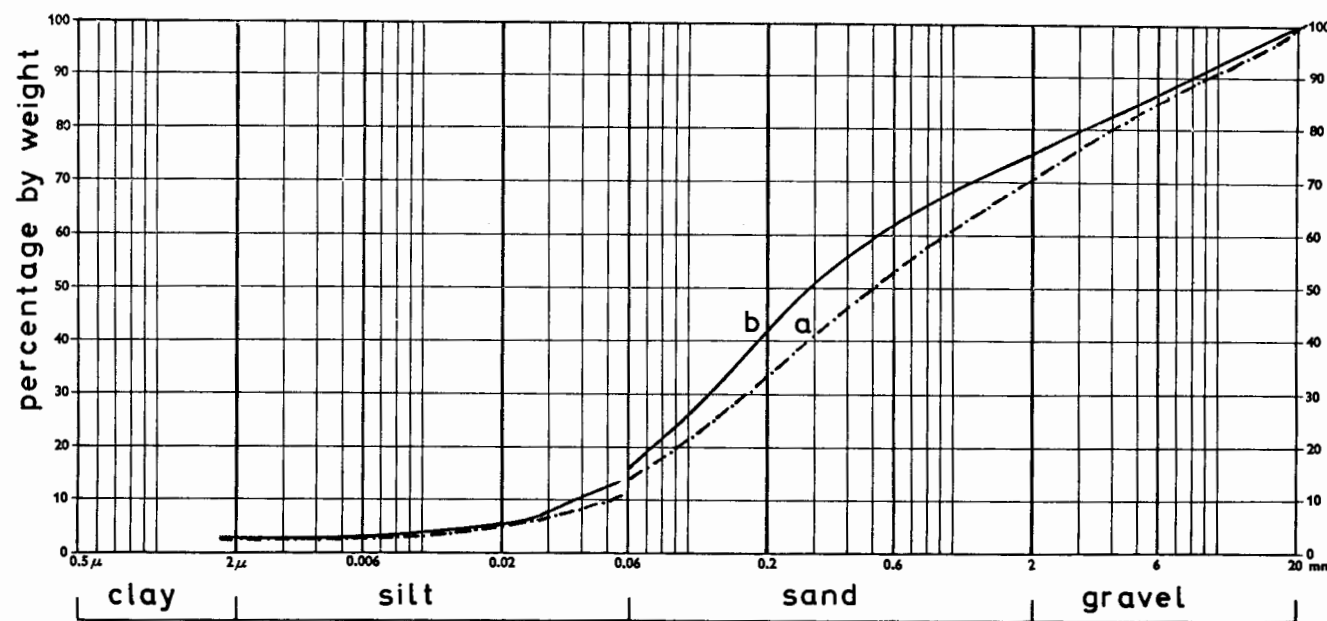


Fig. 38. Grain size distribution of till. Sampling from an excavation 900 m N of the cluster of stations at Sjöängen. Curve a 100 cm below ground surface, curve b 175 cm.

The bedrock is generally overlain by glacial drift. Till is the dominating type of soil in the moraine terrain. The till is sandy, with a very varying boulder frequency. The grain size distribution of some till samples is shown in Fig. 38, and a photo shows an exposed excavation in till in Fig. 39. In many parts of the area the till has a surface morphology of its own. Drumlin-shaped ridges in approx. N—S are found, as well as irregularly hilly terrain.

The thickness of the till cover was investigated by Nordberg and Modig (1973) within a centrally located part of the area. The thickness was determined by seismic and electric resistivity measurements along five lines with the length of 350 m, 400 m, 450 m, 250 m and 90 m, respectively. The mean thickness was 4.6 m, 3.0 m, 3.4 m, 4.4 m and 4.8 m, respectively. As the investigation covered different types of moraine terrain, the obtained values are regarded as representative for a larger area.

Some small glaciofluvial deposits are found in the area. They were formed during the deglaciation. Sand and gravel are the dominating fractions. The deposits have the shape of eskers with a small to moderate height. Some parts of them are steep-sided and crest-ridged, indicating formation subaerially, whereas, other parts show signs of wave-washing, i. e., they were formed subaqueously.

A moderate redeposition of material by wave-washing took place in most of the area after the deglaciation. The sea reached a maximum of 130—140 m above the present sea level. Some minor patches of sandy sediments are found below this level.

After the regression of the sea, the formation of peat started in many low-lying parts of the area. Nowadays, 23 per cent of the area is covered by peat. Some of the bogs have a thickness exceeding 7 m.

3.16.3. Hydrological and hydrogeological features

The area, 45 km², is a well-defined watershed constituting an IHD representative basin. Three major lakes are found in the area, Velen, Sänningen and Alsjön. The ultimate discharge station is situated at the southern tip of the lake Velen, where the river Mossån starts its flow in a southerly direction to the lake Viken. Lake Viken discharges into the river Forsviksån which flows to Lake Vättern which in turn, is drained by the Motala ström to the Baltic Sea. The mean yearly discharge from the basin for the period 1966—1972 is 409 l/s. The range of momentary discharge is very large, from 0 to 3 000 l/s.

The groundwater in the moraine terrain flows in general agreement with the topography, i. e., there are a number of small, local flow systems. Most of the basin

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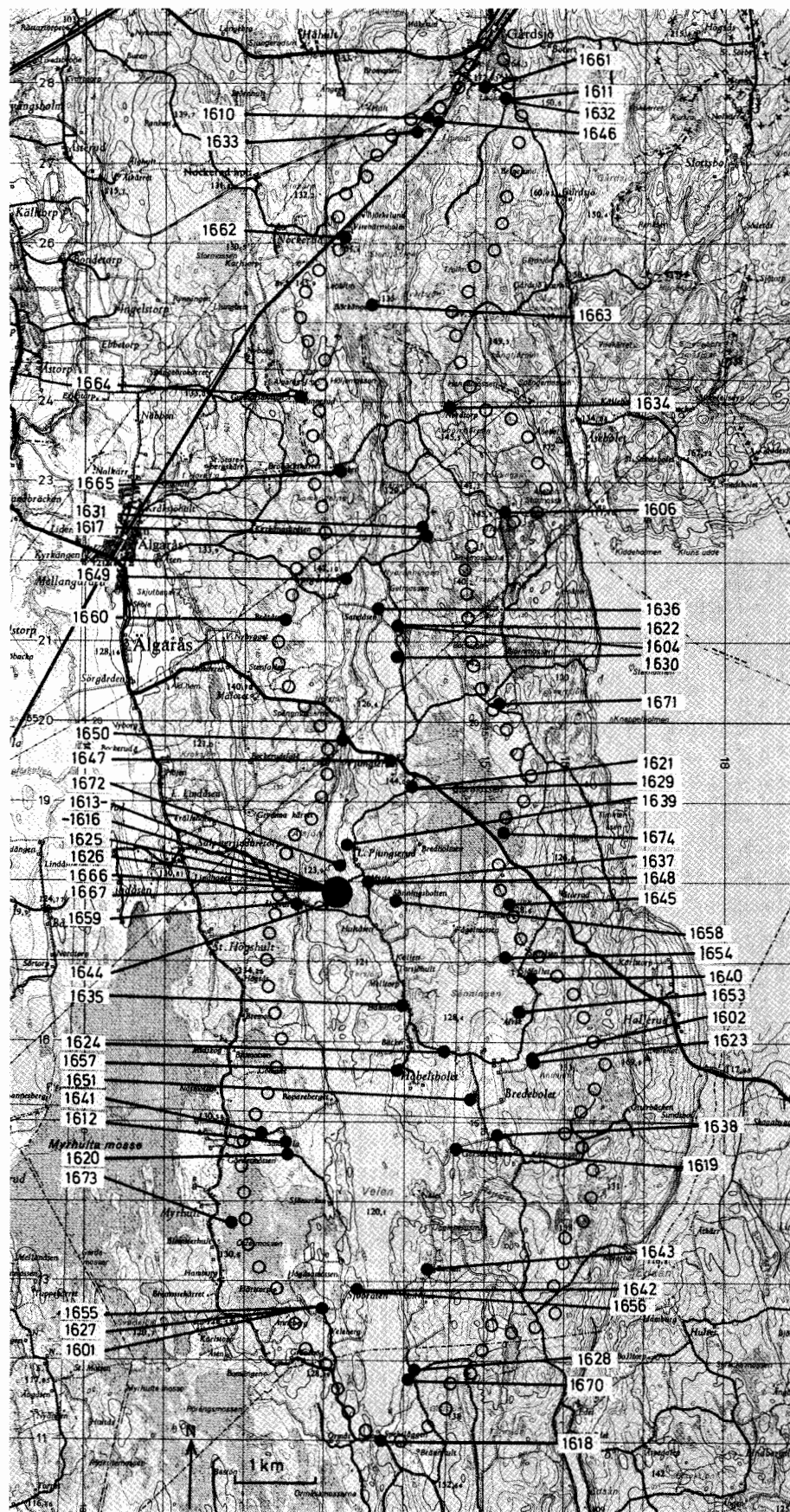


Fig. 37. Map of observation area 16 Velen. Water divide of basin roughly indicated by line of circles. (Top. map 9 E SV, 9 E NV.)

acts as a recharge area, whereas groundwater discharge takes place mainly along lakes, watercourses and other low-lying stretches of land. Some minor springs are found in the area, some of which yield water only at times of high groundwater level.

The aforementioned investigation by Nordberg and Modig (1973) shows that the groundwater in the moraine terrain may be encountered at depths ranging from 0 to more than 5 m. A normal range is assumed to be 0—3 m. The investigation focused on a study of total and effective porosity of the sandy till. The mean value of total porosity measured with a gamma-neutron probe along four vertical profiles through the till is 25.1 per cent; the corresponding mean effective porosity is 5.4 per cent.

There are a number of dug wells supplying water to separate homes in the area. Several of the wells are used only temporarily. The withdrawal of water from the wells is small and has no significant influence on the general groundwater conditions of the basin.

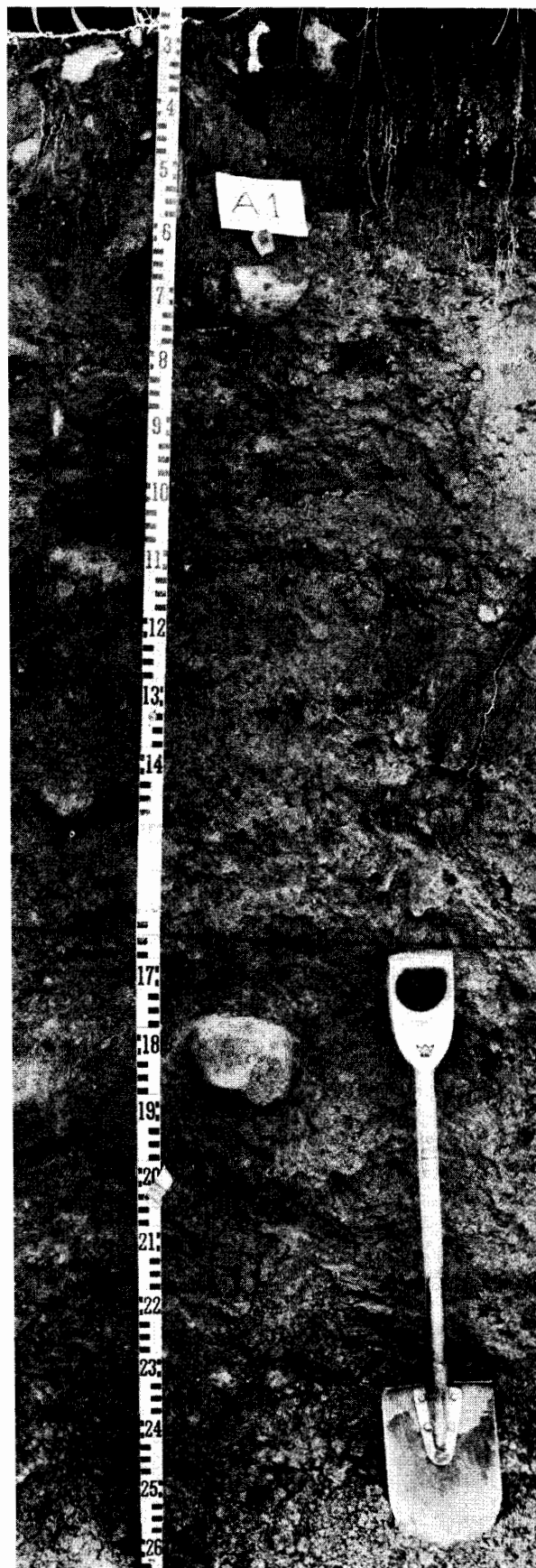
3.16.4. Observation stations

The main features of the observation stations are presented in the table on pages 62—63.

Stations nos. 1601—1622 are iron tubes, installed by the Swedish Meteorological and Hydrological Institute (SMHI) at the time for establishment of the IHD representative basin Velen. SMHI also installed a number of other iron tubes that have been abandoned due to unsatisfactory functioning. Stations nos. 1634—1666 are dug wells that were selected for the measurement of groundwater. At present most of them are withdrawn from the measuring program. Station no. 1667 is a drilled well, established by SMHI for the purpose of studying groundwater in the bedrock. The rest of the stations were established by SGU in collaboration with SMHI in order to improve the station network. Stations nos. 1623—1627 and nos. 1630—1633 are iron tubes that replaced some of the above-mentioned, abandoned tubes. Stations nos. 1628—1629 are plastic tubes, nos. 1670—1671 are natural springs, nos. 1672—1674 are iron tubes.

The observation program for groundwater in the Velen basin is carried out through collaboration between SGU and SMHI. A comprehensive program for hydrological research in the area is executed by SMHI and aims at a better understanding of water balance problems and of hydrological processes.

Fig. 39. Till excavation from which samples were collected for grain size analysis (Fig. 38). Photo S. Modig 1973.



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Station no.	Lat.	Long.	Land surface m a.s.l.	Geology	Depth of well m	Type of station	Obs. pro-gram	Aq.	Start of obs.	Remarks
1601	5843	1418	130	Sandy till	2	Tube	L	W	1967	
1604	5848	1419	134	Gl. fl. sand	1	"	L	W	1967	
1606	5849	1420	143	Sandy till	2	"	L	A	1967	Covered by peat
1610	5851	1420	144	" "	1	"	L	W	1967	
1611	5851	1420	164	" "	2	"	L	W	1967	
1612	5844	1417	134	" "	1	"	L	W	1967	
1613	5846	1418	126	" "	1	"	L	A	1967	Covered by silt
1614	5846	1418	126	" "	1	"	L	A	1967	" " "
1615	5846	1418	126	" "	1	"	L	A	1967	
1616	5846	1418	128	" "	1	"	L	W	1967	
1617	5848	1419	142	" "	1	"	L	W	1967	
1618	5842	1419	122	" "	3	"	L	W	1967	
1619	5844	1420	123	" "	2	"	L	A	1967	Covered by peat
1620	5844	1417	134	" "	1	"	L	W	1967	
1621	5847	1419	145	" "	1	"	L	W	1967	
1622	5848	1419	135	Gl. fl. sand	3	"	L	W	1967	
1623	5845	1421	139	" " mix.	4	"	L	W	1970	
1624	5845	1419	132	Sandy till	6	"	L	W	1970	
1625	5846	1418	128	" "	4	"	L	W	1970	Continuous recording
1626	5846	1418	127	" "	4	"	LT	W	1970	
1627	5843	1418	130	" "	5	"	L	W	1970	
1628	5843	1419	125	Gl. fl. sand	5	"	LC	W	1970	
1629	5847	1419	145	Sandy till	3	"	L	W	1970	
1630	5848	1418	139	" "	3	"	L	W	1970	
1631	5848	1419	142	" "	3	"	L	W	1970	
1632	5851	1420	164	" "	5	"	L	W	1970	
1633	5851	1419	141	" "	3	"	L	W	1970	
1634	5849	1419	157	" "	4	Dug	L	W	1966	Continuous recording
1635	5845	1419	130	" "	3	"	L	W	1966	" "
1636	5848	1418	133	" "	2	"	LT	W	1966	
1637	5849	1418	139	" "	3	"	L	W	1966	
1638	5844	1420	145	" "	4	"	L	W	1966	
1639	5846	1418	132	" "	3	"	L	W	1966	
1640	5845	1420	131	Gl. fl. sand	3	"	L	W	1966	
1641	5844	1417	132	Sandy till	2	"	L	W	1966	
1642	5843	1418	131	" "	3	"	LT	W	1966	
1643	5844	1419	145	" "	3	"	L	W	1966	
1644	5846	1418	128	" "	2	"	LT	W	1966	
1645	5846	1420	140	" "	2	"	L	W	1966	
1646	5851	1419	144	" "	3	"	L	W	1966	
1647	5847	1419	143	" "	7	"	L	W	1966	
1648	5846	1418	128	" "	2	"	L	W	1967	
1649	5848	1418	142	" "	2	"	L	W	1966	
1650	5847	1418	126	" "	1	"	LCT	W	1966	
1651	5844	1419	125	" "	3	"	L	W	1966	
1653	5845	1420	129	" "	3	"	L	W	1966	
1654	5846	1420	129	" "	2	"	L	W	1966	
1655	5843	1418	130	" "	3	"	L	W	1966	
1657	5845	1419	126	" "	3	"	L	W	1966	
1658	5846	1419	138	" "	3	"	L	W	1966	
1659	5846	1417	131	" "	2	"	L	W	1966	
1660	5848	1417	142	" "	2	"	L	W	1966	
1661	5851	1420	161	" "	2	"	LT	W	1966	
1662	5850	1418	134	" "	1	"	L	W	1966	
1663	5850	1420	132	" "	3	"	L	W	1966	
1664	5849	1417	145	" "	2	"	L	W	1966	
1665	5859	1418	135	" "	2	"	LT	W	1967	

Station no.	Lat.	Long.	Land surface m a.s.l.	Geology	Depth of well m	Type of station	Obs. program	Aq.	Start of obs.	Remarks
1666	5846	1418	126	Sandy till	3	Dug	L	A	1967	{ Covered by silt Continuous recording Covered by till Continuous recording
1667	5846	1418	126	Gneiss	50	Drill	L	A	1967	
1670	5843	1419	127	Gl. fl. sand	—	Spring	C	W	1970	
1671	5847	1420	145	Sandy till	—	"	C	W	1970	
1672	5846	1418	126	" "	3	Tube	L	W	1971	
1673	5844	1417	130	Peat	4	"	L	W	1971	
1674	5846	1420	140	"	6	"	I	W	1971	

3.16.5. Comments on the diagram

In the diagram (Fig. 40) the variations of groundwater levels are shown from four separate observation stations. The variation of groundwater temperature is shown from one station. Information on the chemical composition of the groundwater is presented from two stations. The precipitation measured at a station within the basin is also shown.

The groundwater level fluctuates according to a seasonal pattern. Two main periods of net recharge are found each year: spring and autumn. In the spring (March—April) the groundwater rises due to the melting of the snow and the thawing of the frozen ground. The evapotranspiration is relatively low and, consequently, large volumes of water can percolate to the groundwater reservoir. During the summer there is a general fall of the groundwater levels, although it is temporarily interrupted by rises caused by heavy rainfalls. Much of the water is lost through evapotranspiration during the period of intensive plant growth in May—August. The autumn recharge period is generally less pronounced than the spring period. The autumn recharge may last from September to December and is frequently interrupted by short periods of falling levels. During the winter (December—February) the ground may be frozen and precipitation may fall as snow, and then no, or only very small, volumes of water can reach the groundwater reservoir. The result is a fall of groundwater levels. Most winters in this region, though, have frequent periods of mild weather. This facilitates groundwater replenishment.

The yearly amplitude in sandy till is 1—2 m; in glaciofluvial sand in a rather small esker, 0.5 m, and in gneissic bedrock, 0.5—1.0 m. From the diagrams it can be seen that the amplitudes have decreased somewhat

since the first years of observation. The reason for this seems to be — in the last few years — the frequently interrupted summer decline resulting in a less deep minimum level. The interruptions were caused by heavy summer rainfalls. However, in 1973, the summer decline was very large and, consequently, the amplitude for 1973 reached values similar to those of 1967, 1968 and 1969.

No distinct, multiannual trends can be seen in the variations of groundwater levels.

The groundwater temperature, measured at a depth of 2.5 m below land surface, fluctuates seasonally. The highest temperature is present in August—September, whereas the lowest temperature is reached in March—April. The yearly amplitude at this depth, at the bottom of an unused dug well, is as large as approx. 8°C. The mean temperature for the whole period of observation is 6.3°C.

The groundwater chemistry from two stations is shown in the diagram. No great difference in the composition of the groundwater is found at the two stations, representing glaciofluvial sand (no. 1628) and sandy till (no. 1671). No distinct seasonal fluctuations or multiannual trends are found in the chemistry diagrams. However, station no. 1671 (till) seems to show a more irregular fluctuation pattern than station no. 1628 (sand). In the pH-diagrams, for both stations an annual cyclicity can be found, which shows higher pH-values in the winter than in the summer.

The relatively low tritium values and the lack of annual cyclicity in the chemistry diagrams indicate a long residence time of the water in the ground. Despite the long residence time, the salt content of the groundwater is low, probably due to a low chemical affinity of the aquifer material.

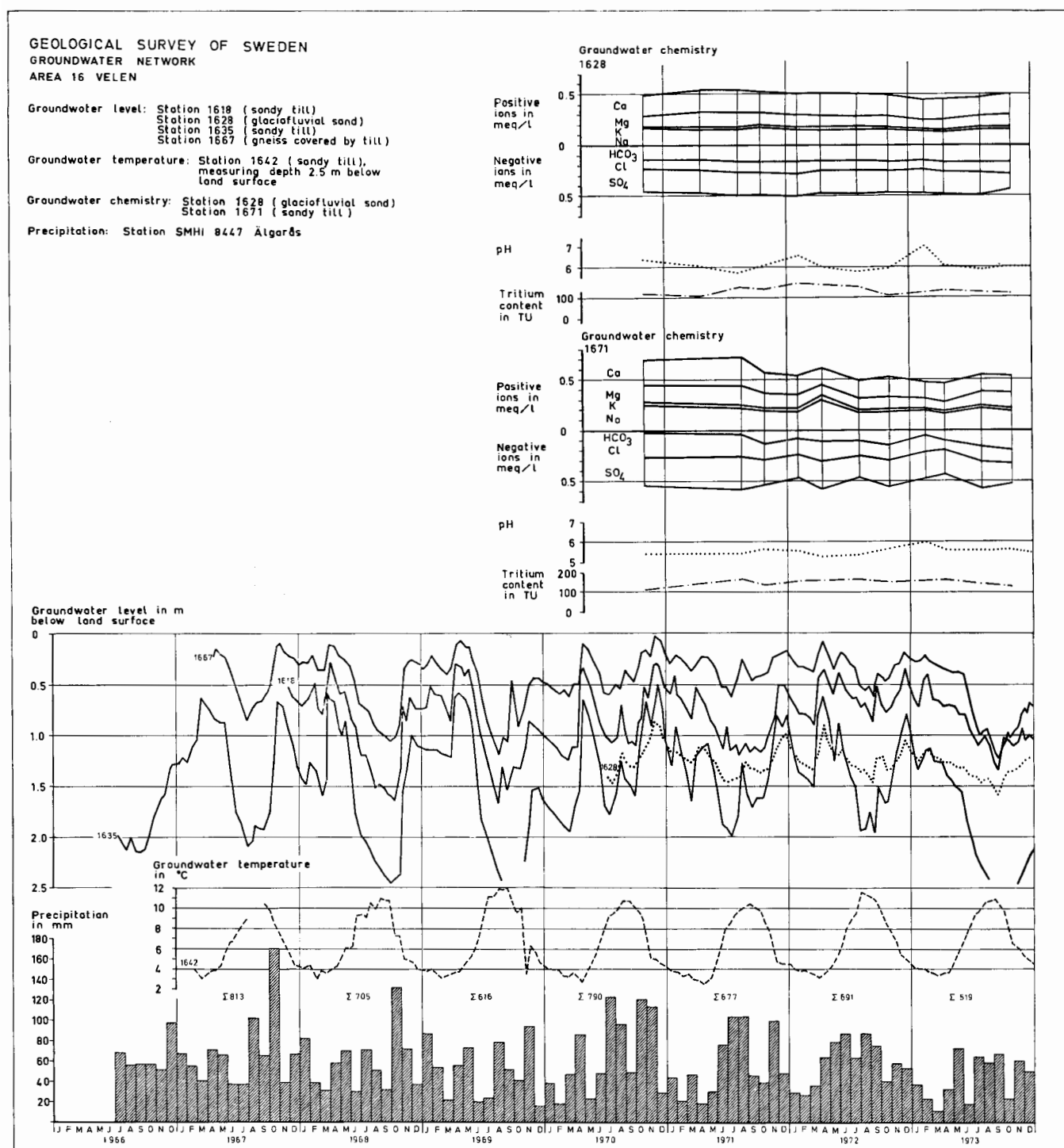


Fig. 40. Diagram from observation area 16 Velen.

3.17. Vissboda

3.17.1. Geographical location

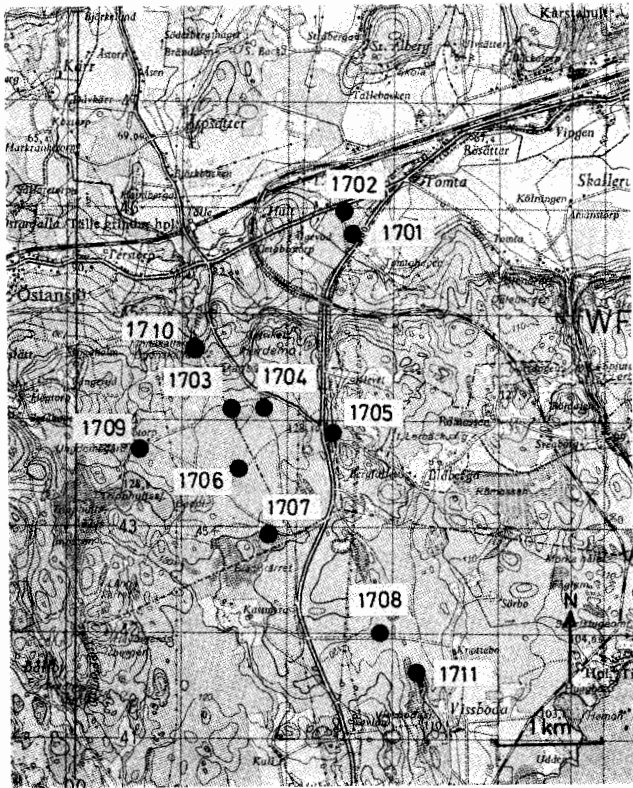


Fig. 41. Map of observation area 17 Vissboda. (Top. map 9 F NV.)

The observation area Vissboda is situated in the province of Närke in south central Sweden, approx. 5 km southwest of the town of Hallsberg. The altitude of the area ranges from 65 to 140 m a.s.l. (see map, Fig. 41).

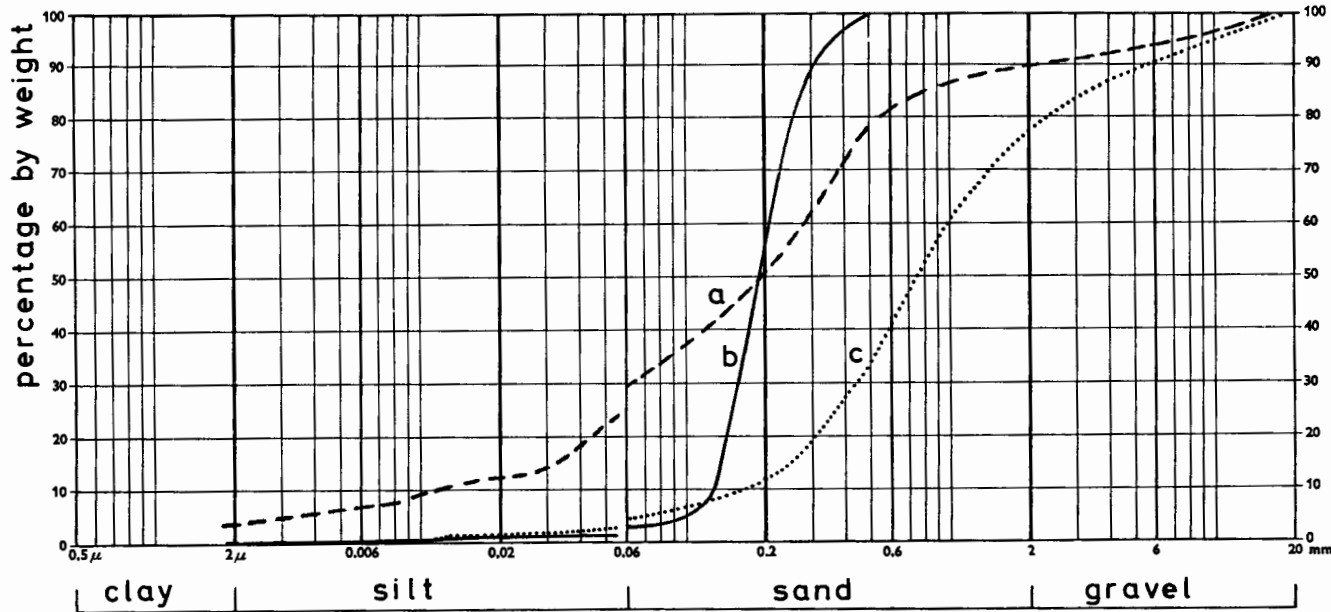
3.17.2. Geology and geomorphology

The main geomorphological feature of the area is an important fault which has a vertical dislocation of about 80–100 m. The fault line runs in an E–W direction and constitutes the south border of the Närke plain.

South of the fault line, the bedrock consists of Precambrian gneisses which outcrop frequently in the area. North of the fault, the Precambrian bedrock is partly covered by Cambrian sandstone. The sandstone in the area is completely covered by Quaternary deposits.

The most important Quaternary deposits in the observation area are glaciofluvial accumulations of sand and gravel, belonging to the Kumla–Hallsberg and Harremo esker systems. The grain size distribution of some samples is shown in Fig. 42. Both north and south of the observation area the eskers appear as narrow ridges (0.1–0.2 km wide), but, within the area, the Kumla–Hallsberg esker widens into the Vissbomon, an accumulation which has a width of 1–2 km and extends from Asbro in the south part of the area to north of the fault line (see map, Fig. 41). The Kumla–Hallsberg esker runs in a SSE–NNW direction south of the fault line, but north of this fault the direction of the esker changes to SW–NE. About 2 km south of the fault line the Harremo esker joins the Kumla–Hallsberg esker in a NNW–SSE direction. The surface of the Vissbomon has an altitude of 125–130 m a.s.l. and is relatively flat

Fig. 42. Grain size distribution of till and sediments. Curve a 300 m NW of station no. 1709, curve b 1 km W of station no. 1711, curve c 500 m SSW of station no. 1711. All samples are taken 0.5 m below ground surface.



with the exception of single ridges and dead-ice hollows in the south part of the accumulation. The smooth surface is probably partly due to wave action in the Late-glacial sea which, after the deglaciation, reached an altitude of about 150 m above present sea level in this area. In connection with the glaciofluvial deposits, areas of wave-washed sand are found. These sand deposits partly cover the till in the moraine terrain surrounding the Vissbomon.

3.17.3. Hydrological and hydrogeological features

In connection with an inventory of the water resources of the Kumla—Hallsberg area, Vattenbyggnadsbyrån (VBB) and Kommunernas Konsultbyrå — LBF have made a hydrogeological investigation of the Vissbomon area. The report presents a map with equipotential lines for the groundwater level. A groundwater divide is found in the area approx. 2.5 km north of Vissboda. South of this groundwater divide, the main direction of the groundwater flow is southwards toward Vissboda and Asbro. Several springs discharging the groundwater from the south part of Vissbomon are found at Vissboda and Asbro.

The surface water of the south part of the Vissbomon area drains through the lake Tisaren and the lake Yngaren to the Baltic Sea.

North of the groundwater divide, the flow is directed northwards toward the Närke plain. In connection with the fault the gradient of the groundwater surface increases considerably. Some springs with a total discharge of 8—10 l/s are found in this area of steep groundwater gradient. Springs are also found in connection with the eskers on the Närke plain north of the fault. The surface water of this part of the area drains through Lake Hjälmaren and Lake Mälaren to the Baltic Sea.

There is no, or only insignificant, withdrawal of groundwater by pumping within the area.

3.17.4. Observation stations

The main features of the observation stations are presented in the table below.

The locations of the stations are shown in Fig. 41. Stations nos. 1701—1708 were established by VBB in connection with the aforementioned investigation of the possibilities for future extraction of groundwater for water supply. No wells have been established within the area so far.

3.17.5. Comments on the diagram

In the diagram (Fig. 43) all observed parameters are shown from the selected stations.

The chemical composition of the groundwater at station no. 1710 shows some minor fluctuations mainly caused by variations in the concentrations of calcium and sulphate. Only four samples are analysed every year, and only a very rough sketch of the fluctuation pattern is obtained. However, there seems to be a correlation of the fluctuations of groundwater level and chemistry in the area. When the groundwater level is high, the salt content of the water discharged from the spring (station no. 1710) is low.

The seasonal fluctuations and the high content of tritium (200—450 TU) indicate a short residence time of the groundwater. The decreasing tritium content in the groundwater reflects the decreasing content in the precipitation water.

A distinct difference in chemical composition of the groundwater is found between station no. 1710 (see diagram, Fig. 43) and no. 1711. At no. 1711 the concentrations of bicarbonate and calcium are twice as high as those at station no. 1710. Contrary to this, sulphate and manganese have concentrations about half of those found at no. 1710. Station no. 1710 is situated north of the water divide in the part of Vissbomon connected with the Hardemo esker, and no. 1711 is situated south of the water divide in connection with the main esker.

Station no.	Lat.	Long.	Land surface m a.s.l.	Geology	Depth of well m	Type of station	Obs. program	Aq.	Start of obs.	Remarks
1701	5903	1502	75	Gl. fl. sand	13	Tube	L	W	1967	
1702	5903	1502	74	" " "	18	"	L	W	1967	
1703	5902	1501	124	" " "	13	"	L	W	1967	Station destroyed 1970
1704	5902	1501	124	" " "	19	"	L	W	1967	
1705	5902	1502	118	" " "	15	"	L	W	1967	
1706	5901	1501	126	" " "	13	"	L	W	1967	
1707	5901	1502	127	" " "	10	"	L	W	1968	
1708	5900	1503	120	" " "	12	"	L	W	1968	
1709	5901	1500	130	" " "	2	Dug	L	W	1967	
1710	5902	1501	104	" " "	—	Spring	C	W	1968	
1711	5900	1503	110	" " "	—	"	C	W	1971	

GEOLOGICAL SURVEY OF SWEDEN
GROUNDWATER NETWORK
AREA 17 VISSBODA

Groundwater level: Station 1706 (glaciofluvial sand)
Groundwater chemistry: Station 1710 (glaciofluvial sand)
Precipitation: Station SMHI 9504, Hallsberg
Mean yearly precipitation 1931-60: 600 mm

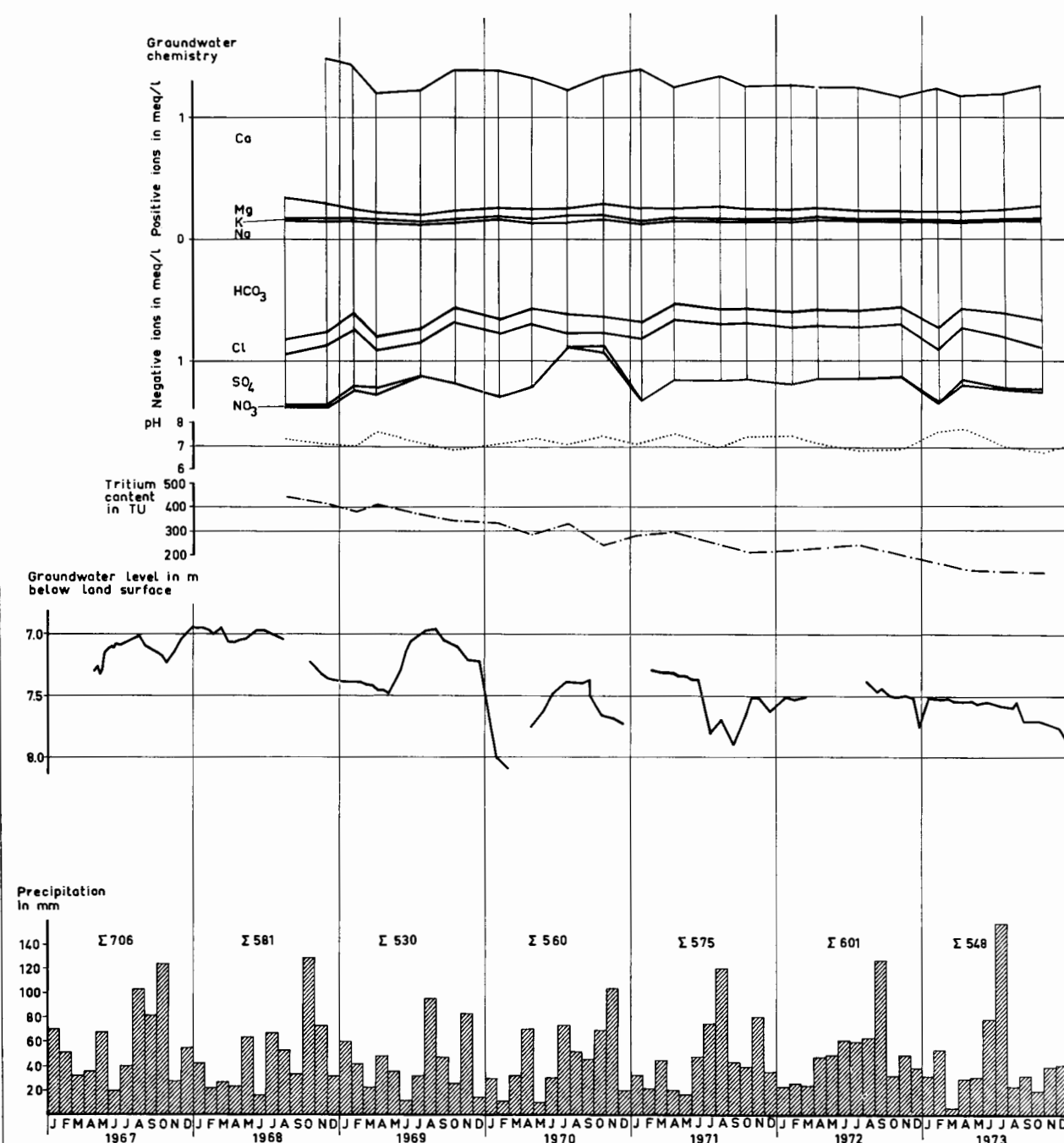


Fig. 43. Diagram from observation area 17 Vissboda.

Probably differences in the composition of the rock material (the proportions between gneisses and Cambrian sandstones, schists and limestones from the Närke plain) in the two eskers cause the observed differences in the groundwater composition at the two stations.

The groundwater level variations at station no. 1706 are shown in the diagram. This station is situated in the central part of Vissbomon near the groundwater divide. The pattern of the seasonal fluctuations is irregular.

During the observation period the groundwater level measurements have been interrupted several times for shorter or longer periods. These interruptions complicate the interpretation of the pattern of the seasonal variations.

A trend of falling groundwater level is found during the years 1968—1973. This trend reflects the low yearly sums of precipitation during this time.

3.18. Dammtorp

3.18.1. Geographical location

The observation area Dammtorp is situated in the eastern part of south Sweden, approx. 110 km southwest of Stockholm. The elevation of the area ranges between 48 and 60 m a.s.l. (see map, Fig. 44).



Fig. 44. Map of observation area 18 Dammtorp. (Top. map 9 G SO, 9 H SV.)

3.18.2. Geology and geomorphology

The area is situated above the main east—west fault along the narrow bay of Bråviken. The bedrock consists of Precambrian supracrustal gneiss, generally migmatized, and is tectonically dissected. Outcrops are found in the moraine terrain. The central part of the observation area is a valley only a few hundred meters wide. The main type of soil in the valley is glacial clay. It has a

recorded maximum thickness of 20 m. In the southeastern part of the area the clay is underlain by sand and gravel, probably of glaciofluvial origin. The thickness of the sand and gravel approaches 10 m. After the glaciation the area was subject to an extensive wave-washing. Thus the sandy till around the valley contributed large volumes of silt and sand to the valley where, consequently the clay became covered by coarser sediments. In the lowest parts of the area organogenic soils are found. The geology of the area has been dealt with by von Brömssen (1968).

3.18.3. Hydrological and hydrogeological features

Von Brömssen (1968) also gave a short description of the hydrology and hydrogeology of the area. The surface water is drained toward a brook in the center of the valley. The bottom of the brook is situated in clay. Therefore, there is no significant hydraulic communication between the brook and the underlying groundwater reservoir. The brook flows from the observation area and into the bay Bråviken by a series of steep waterfalls across the major fault line.

The general flow direction of the groundwater is also toward the center of the valley. Minor springs are found in a transitional zone between the moraine terrain and the clay valley. Where redeposited sediments are found above the clay, an upper secondary groundwater reservoir may be found. The groundwater in the sediments and till under the clay is artesian with temporary pressure heads above the ground surface. The deep groundwater is partially extracted for the village of Nävekvarn from a community well in the southern part of the area. The well penetrates 11 m of clay, 4 m of sandy clay and approx. 15 m of sand and gravel. The water is pumped from the sand and gravel. The main recharge area for the well is assumed to be situated in the eastern moraine terrain which contains strongly wave-washed and re-

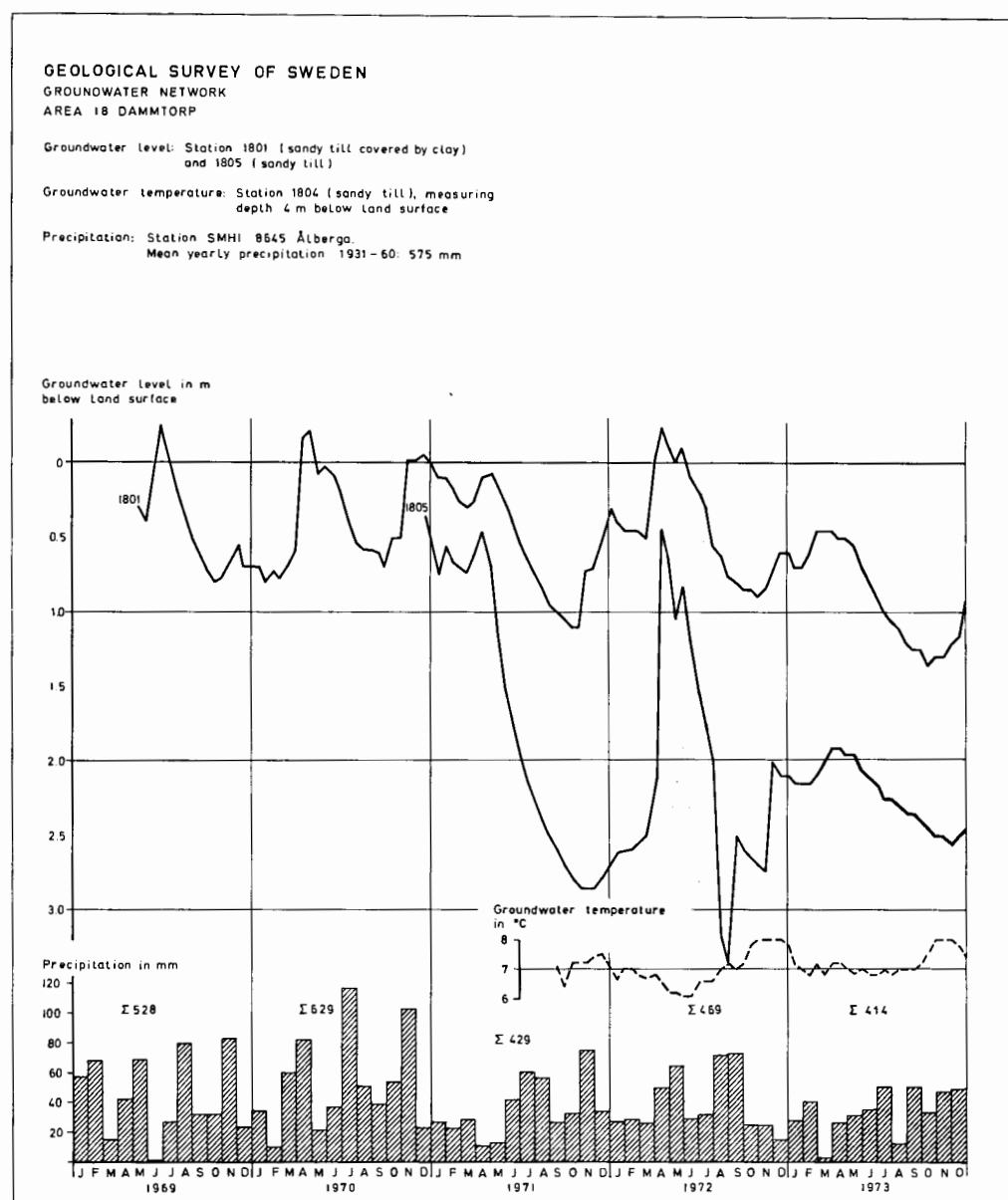


Fig. 45. Diagram from observation area 18 Damm-torp.

deposited till. Pumping tests in 1957–1958 and in 1966 have, according to von Brömssen (1968), indicated a safe yield of 5.5 l/s. The present (1972–1973) extraction of water amounts to approx. 4 l/s. The pumping from the well strongly effects the groundwater regime of the area adjacent to the well. Thus station no. 1803 is situated within the cone of depression, and the other stations are assumed to be uninfluenced by the pumping. A few minor wells within the area supply water to separate households. They do not influence the groundwater flow pattern.

3.18.4. Observation stations

The main features of the observation stations are presented in the table on page 70.

Stations nos. 1801–1803 were established in 1965 and 1966 in connection with a water supply investigation. The other two stations were erected in 1970 by SGU for the national groundwater network. The locations of the stations are shown on the map, Fig. 44.

3.18.5. Comments on the diagram

In the diagram (Fig. 45) the variation of groundwater level and temperature is shown in relation to precipitation.

A very distinct, seasonal pattern of groundwater level fluctuation is present. Peak levels are reached in April after a major recharge period following the melting of the snow. From the peak level the groundwater is ge-

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Station no.	Lat.	Long.	Land surface m a.s.l.	Geology	Depth of well m	Type of station	Obs. program	Aq.	Start of obs.	Remarks
1801	5839	1639	50	Sandy till	15	Tube	L	A	1969	Covered by fine sediments
1802	5839	1639	50	„ „	17	„	L	A	1969	Covered by fine sediments Continuous recording since 1970
1803	5838	1640	48	Gl. fl. sand	18	„	L	A	1969	Covered by fine sediments
1804	5839	1639	55	Sandy till	5	„	LT	W	1970	Temp. since 1971
1805	5839	1639	59	„ „	3	„	L	W	1970	

nerally falling throughout the summer, and the bottom level is present in October. The autumn recharge in November—December is generally of less importance than the spring recharge. A considerable difference of yearly amplitudes of the two presented stations is seen. This may be attributed to a significant difference of effective porosities at the two stations. It can be assumed that station no. 1801 is characterized by till and the coarse bottom varve of the overlying glacial clay, but station no. 1805 is only till. The yearly amplitudes are at station no. 1801, approx. one meter, and at station no. 1805, 2—2.5 m. The response to precipitation is fairly rapid at both stations. However, during the summer,

rainfall does not contribute to the groundwater recharge, due to a high degree of evapotranspiration.

A weak, falling long-term trend for station no. 1801 can be seen in the diagram. The low sums of precipitation in 1971 and 1972 are not clearly reflected by correspondingly falling groundwater levels. The variation of the groundwater temperature at a depth of 4 m shows an irregular, but seasonal pattern. Highest temperatures are present in late autumn, and lowest temperatures are found in early summer. The yearly amplitude is 1.5—2.0°C, and the mean temperature for the period of observation is 7.1°C.

3.19. Brattforsheden

3.19.1. Geographical location

The observation area Brattforsheden is situated in the province of Värmland in west Sweden, about 30 km north of Lake Vänern. The altitude of the area ranges from 130 to 240 m a.s.l.

3.19.2. Geology and geomorphology

The observation area is situated in the southwestern part of the large glaciofluvial delta, Brattforsheden, which is situated south of the lakes Alstern and Mången (see map, Fig. 46). The delta plain has an extension of several square kilometers. The flat surface of the delta reaches an altitude of about 180—185 m, which is just below the highest Late-glacial shore level in this area (187 m according to G. Lundqvist, 1961). The dominating fraction in the delta sediments is sand. However, thin layers of silt and clay, which are of great hydrogeological importance, have been found in the observation area. North of the delta plain, the moraine terrain

rises to altitudes above 200 m a.s.l. In this area outcrops of bedrock consisting of Precambrian granites, gneisses and hyperites are common.

South of the relatively steep south margin of the delta, extensive areas of silty sediments, partly covered by peat, are found.

Deposits of eolian sand, locally forming dunes, are quite common in connection with the Brattforsheden delta. The geology and geomorphology of the area has been described by Hörner (1927).

3.19.3. Hydrological and hydrogeological features

The surface water of the Brattforsheden area is drained to Lake Vänern through several different river systems. Due to the high infiltration capacity of the sand, no surface water is found on the delta plain. All precipitation water not lost by evapotranspiration percolates to the groundwater. The main flow direction of the groundwater of the delta is toward the margin in the south.

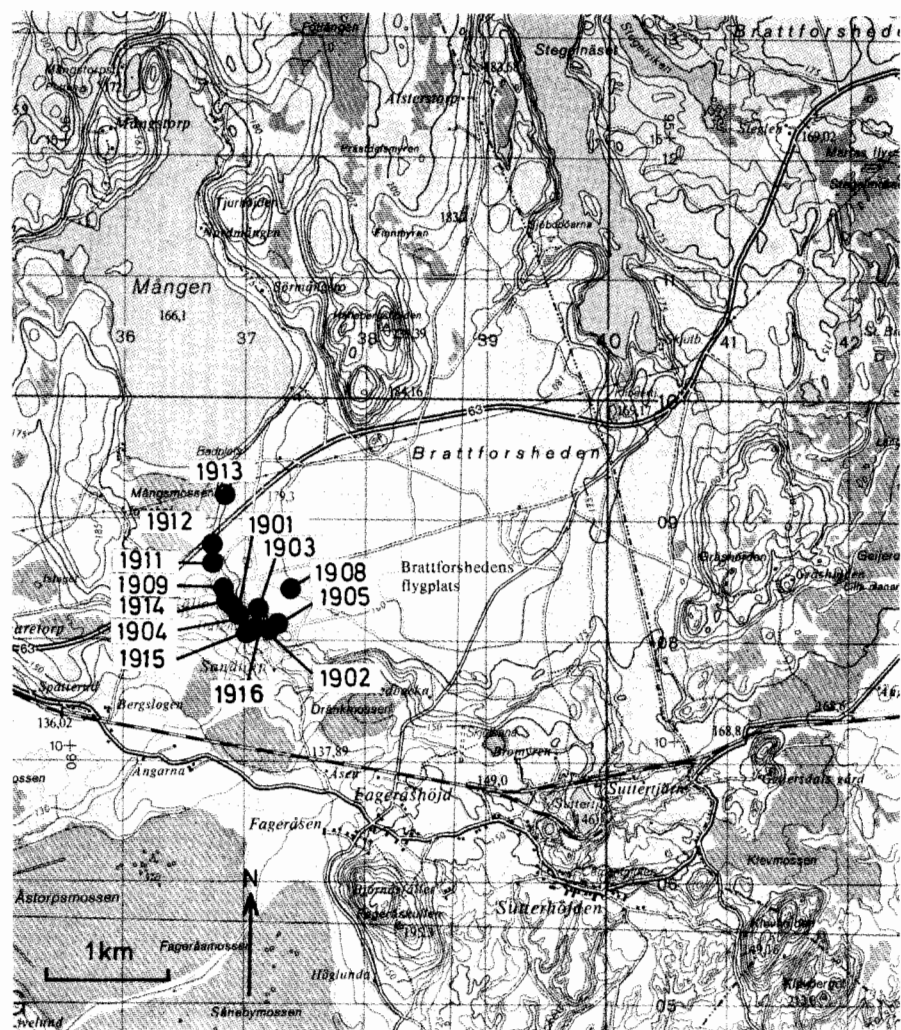


Fig. 46. Map of observation area 19 Brattforsheden. (Top. map 11 D SO.)

Several springs, generally located in small gullies, are found in the marginal parts of the delta.

An exchange of water between the two large lakes of the area, Alstern and Mången, and the delta aquifer takes place. Within the observation area in the south-western part of the delta, natural infiltration of water from the lake Mången into the delta sand generally occurs. A groundwater flow directed southwards from the southern shore of the lake Mången has been found. At the margin of the delta at Tjuvdalen, 1.5 km south of the lake Mången, a spring area yielding 20–25 l/s is found. A profile showing the land and groundwater surfaces between lake Mången and Tjuvdalen is shown in Fig. 47. An upper perched aquifer is found locally in this area. The existence of this perched groundwater is due to the presence of clay and silt layers in the delta sand.

Water from the springs at Tjuvdalen is collected and used for the water supply of the village of Molkom. The

pumping is performed from a small brook running from the springs. This utilization of water has no influence on the groundwater conditions of the observation area.

A few wells supplying single households with water are found in the observation area. The withdrawal of water from these wells does not seem to have any influence on the recorded groundwater levels of the area.

3.19.4. Observation stations

The main features of the observation stations are presented in the table on page 72.

The observation tubes nos. 1902–1909 were established in connection with investigations on the groundwater conditions performed prior to the establishing of the aforementioned water works of Molkom at Tjuvdalen. Stations nos. 1911–1914 were established by SGU for the national groundwater network. Stations nos. 1915–1916 are natural springs.

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Station no.	Lat.	Long.	Land surface m a.s.l.	Geology	Depth of well m	Type of station	Obs. program	Aq.	Start of obs.	Remarks
1902	5936	1353	172	Gl. fl. sand	17	Tube	L	W	1968	
1903	5936	1353	174	" " "	22	"	L	W	1968	
1904	5936	1353	167	" " "	20	"	L	W	1968	
1905	5936	1353	177	" " "	26	"	L	W	1968	
1908	5936	1353	178	" " "	24	"	L	W	1968	
1909	5936	1353	165	" " "	4	"	L	W	1968	Upper aquifer
1911	5936	1353	168	" " "	13	"	L	W	1969	Continuous recording to 1971
1912	5936	1353	170	" " "	14	"	LT	W	1969	
1913	5936	1353	168	" " "	8	"	L	W	1969	
1914	5936	1353	163	" " "	14	"	L	W	1969	
1915	5936	1353	149	" " "	—	Spring	C	W	1968	
1916	5936	1353	149	" " "	—	"	C	W	1968	Sporadical sampling

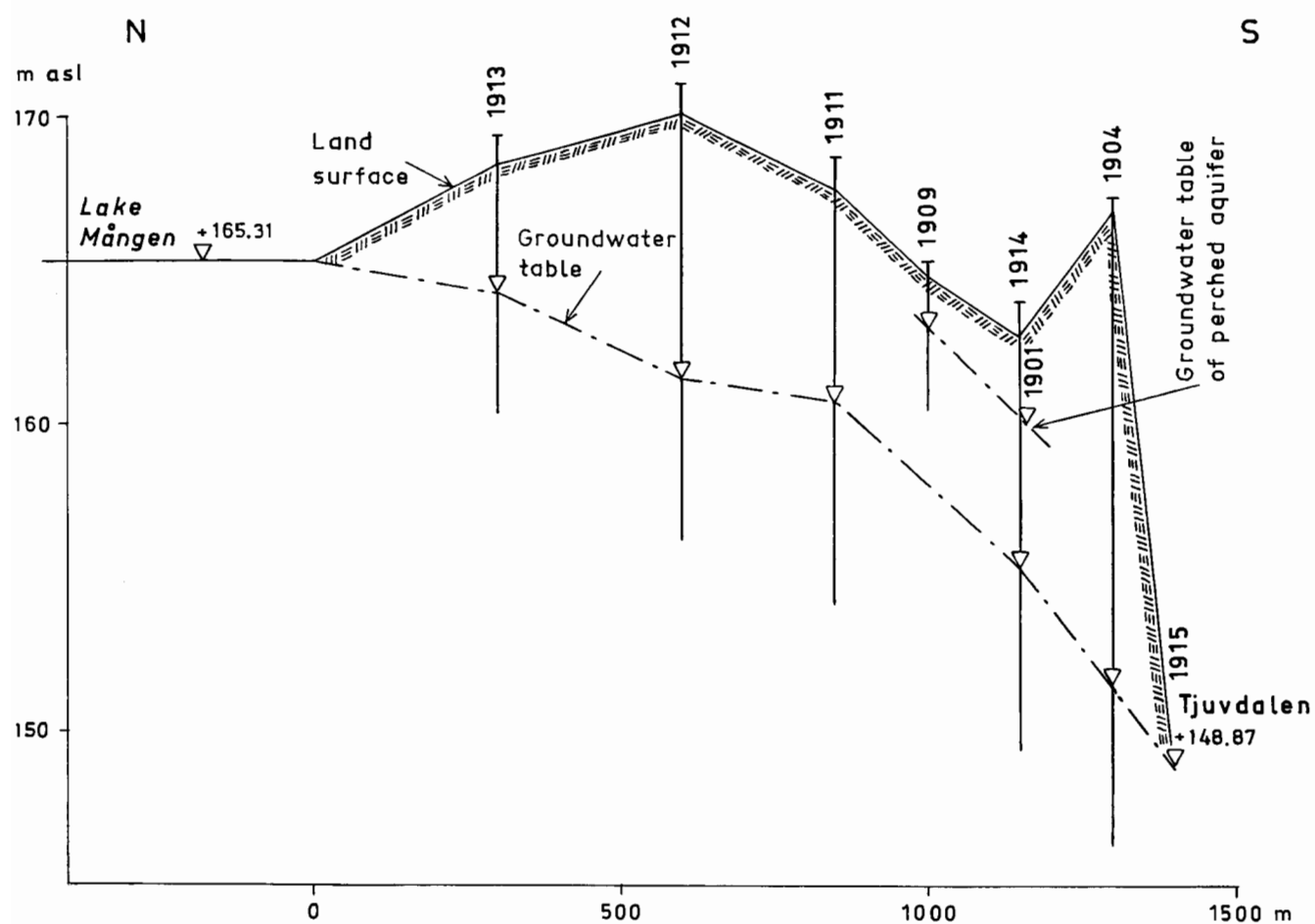


Fig. 47. Section from lake Mängen to Tjuvdalen. Note perched aquifer in part of the section. Station no. 1901 is situated in a sand pit; the station is now destroyed.

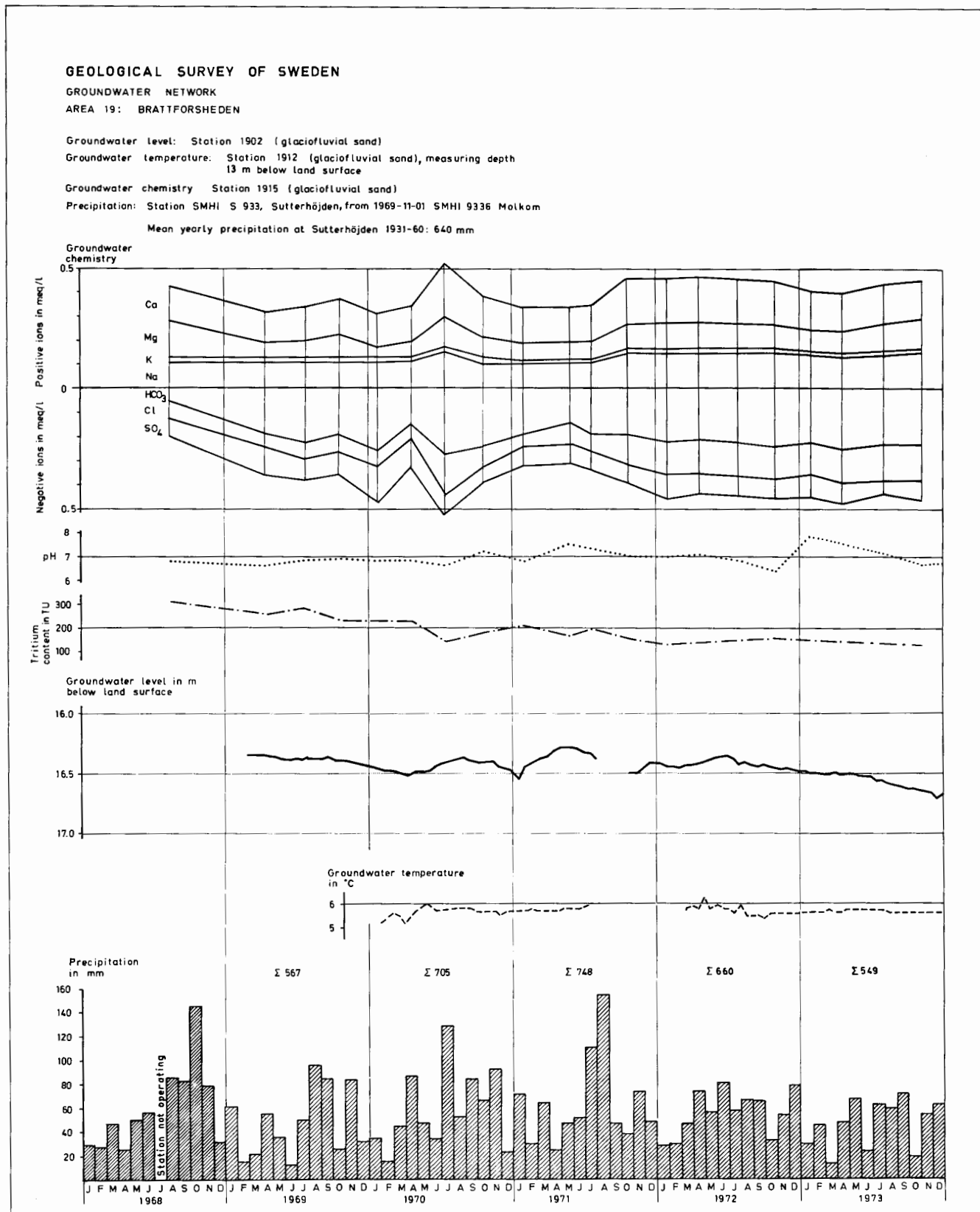


Fig. 48. Diagram from observation area 19 Brattforsheden.

3.19.5. Comments on the diagram

In the diagram (Fig. 48) the variation of observed parameters is shown from selected stations in the main aquifer.

No regular, seasonal fluctuations are found in the diagrams which show the variations in groundwater level and chemical composition.

Some years (1970, 1971 and 1972) a maximum groundwater level is found in the summer and a minimum level in the winter; other years (1969 and 1973) a continuously falling level has been recorded. The maximum yearly amplitude during the observation period is 0.25 m. Some weak, multiannual trends can be found in the diagram. From August, 1968, to April, 1970, and from July, 1972 to the beginning of 1974, a falling groundwater level was recorded. A generally rising groundwater level was recorded from April, 1970, to June, 1972. The periods of falling and rising trends seem to coincide with periods of small and large sums of precipitation.

There seems to be a certain agreement between the variation patterns of the groundwater level and of the chemical composition; periods of high groundwater level correspond to periods of low salt content and vice versa. During periods of low groundwater level the flow velocity of groundwater is also low. The residence time of the water in the aquifer is long and this results in a relatively high ion content in the water.

The different residence times of the water in the aquifer during periods of low and high groundwater level are also reflected in the curve showing the tritium content. Decreasing tritium content seems to correspond to falling groundwater level and increasing salt content, and increasing tritium content corresponds to rising groundwater level and decreasing salt content.

No seasonal fluctuations in the groundwater temperature can be seen in the diagram. Most of the recorded variations are probably due to an unsatisfactory measuring technique. The mean temperature of the groundwater during the observation period at station no. 1912, at a depth of 11 m below land surface, is 5.6°C.

3.20. Sättrabrunn

3.20.1. Geographical location

The observation area Sättrabrunn is situated in the province of Västmanland about 25 km north of the town of Västerås. The elevation of the area ranges from 55 to 85 m a.s.l. (see map, Fig. 49).

3.20.2. Geology and geomorphology

The area is characterized by a large esker trending in a NW—SE direction. It is part of the Badelunda esker which can be traced for about 100 km both northwards and southeastwards from the observation area. The esker is of the subaqueous type with a crest, flattened by abrasion. The material of the esker, visible in several pits, consists mainly of stratified sand and gravel. The esker rises about 20 m above the surrounding plain which consists of fine-grained, distal glaciofluvial sediments and material redeposited through wave-washing during Late- and Postglacial time. The sediments are partly covered by peat. The sediment plain occupies a 2—4 km wide zone on each side of the esker. At a greater distance from the esker a rather flat moraine terrain with a great number of outcrops of the Precambrian bedrock is found. A sandy till with a wave-washed surface is typical for this area. The thickness of the till layer is moderate, rarely exceeding a few meters.

3.20.3. Hydrological and hydrogeological features

The area northeast of the esker is drained by the Sagån river system, whereas the area southwest of the esker is drained partly by the Sagån and partly by the Svartån river system. Both rivers discharge into Lake Mälaren.

The sand and gravel deposits of the Badelunda esker form the most important aquifer of the area. There seems to be a groundwater divide in the northwestern part of the esker, probably between stations no. 2003 and no. 2002 (see map, Fig. 49). Southeast of the divide the flow direction of the groundwater is toward the southeast. The gradient of the groundwater level is very slight (about 0.15:1 000), probably due to a rock threshold southwest of station no. 2005. Probably much of the water which has infiltrated into the esker flows toward the sediment plains in the northeast and southwest, where several springs are located. In the surrounding moraine terrain a more irregular, groundwater flow pattern, strongly influenced by the topography, is found.

No important withdrawal of groundwater takes place within the area. Only a number of wells which supply single households with water are found. These wells seem to have no influence on the groundwater conditions at the stations.

At Sättrabrunn, northwest of the observation area, an important spring area is found in connection with the

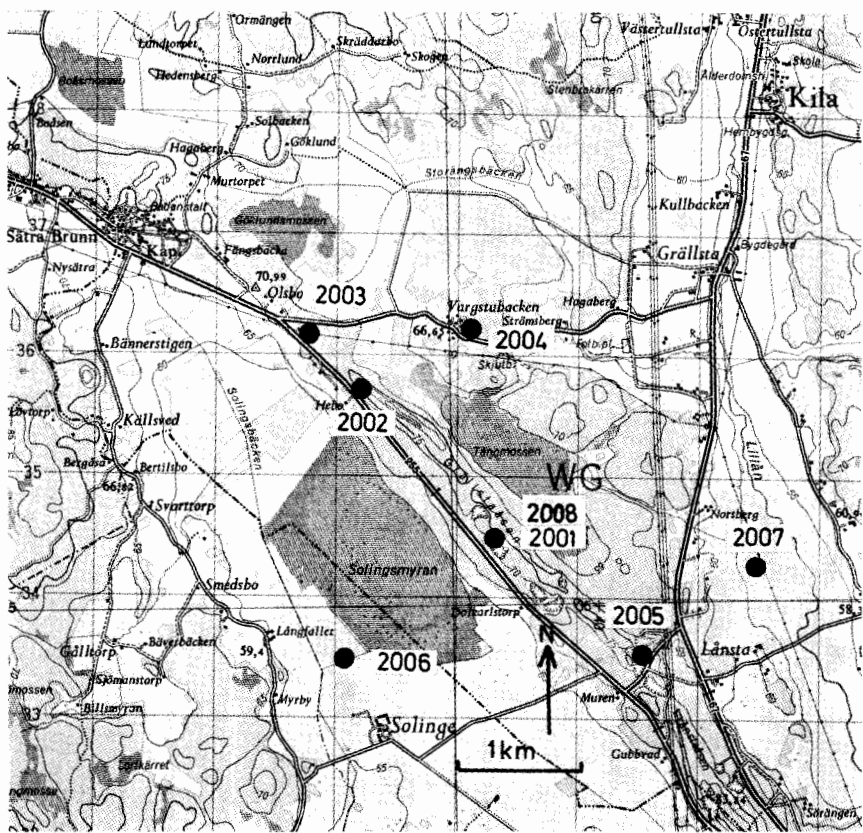


Fig. 49. Map of observation area 20 Sättra-brunn. (Top. map 11 G NO.)

Badelunda esker. Many of the springs have been used for therapeutic reasons because of their high content of iron. The water of the springs is assumed to derive from the major aquifer in the esker.

3.20.4. Observation stations

The observation stations are presented in the table below. The locations of the stations are shown on the map, Fig. 49. Stations nos. 2001, 2004, 2005 and 2008 were established by SGU for the national groundwater network. Stations nos. 2002 and 2003 are wells used only as reservoirs in case of fire. Stations nos. 2006 and 2007 are natural springs.

3.20.5. Comments on the diagram

No trends or seasonal fluctuations can be seen in the diagram (Fig. 50) showing the groundwater chemistry at station no. 2006. The water at this station is characterized by a high salt content. Calcium and bicarbonate ions dominate. The water has a low oxygen and a relatively high iron content. Station no. 2006 is a spring with a discharge of a few liters per second and is situated 1.5 km southwest of the esker. The water derives from a sand layer which is covered by clay and probably hydraulically connected with the esker aquifer. The chemical composition and the low tritium content (20–40 TU) of the water at this station indicate a long residence time in the aquifer.

Station no.	Lat.	Long.	Land surface m a.s.l.	Geology	Depth of well m	Type of station	Obs. program	Aq.	Start of obs.	Remarks
2001	5950	1630	62	Gl. fl. sand	5	Tube	LC	W	1965	Chemistry since 1969
2002	5950	1629	63	„ „ grav.	4	Dug	L	W	1965	
2003	5951	1628	61	„ „ sand	2	„	L	W	1965	
2004	5951	1630	65	Sandy till	4	Tube	L	W	1969	
2005	5949	1631	62	Gl. fl. sand	5	„	L	W	1969	Station destroyed 1973
2006	5949	1628	54	„ „ „	—	Spring	C	A	1969	Covered by clay
2007	5950	1632	53	„ „ „	—	„	C	A	1969	„ „ „
2008	5950	1630	62	„ „ „	4	Tube	L	W	1973	Continuous recording

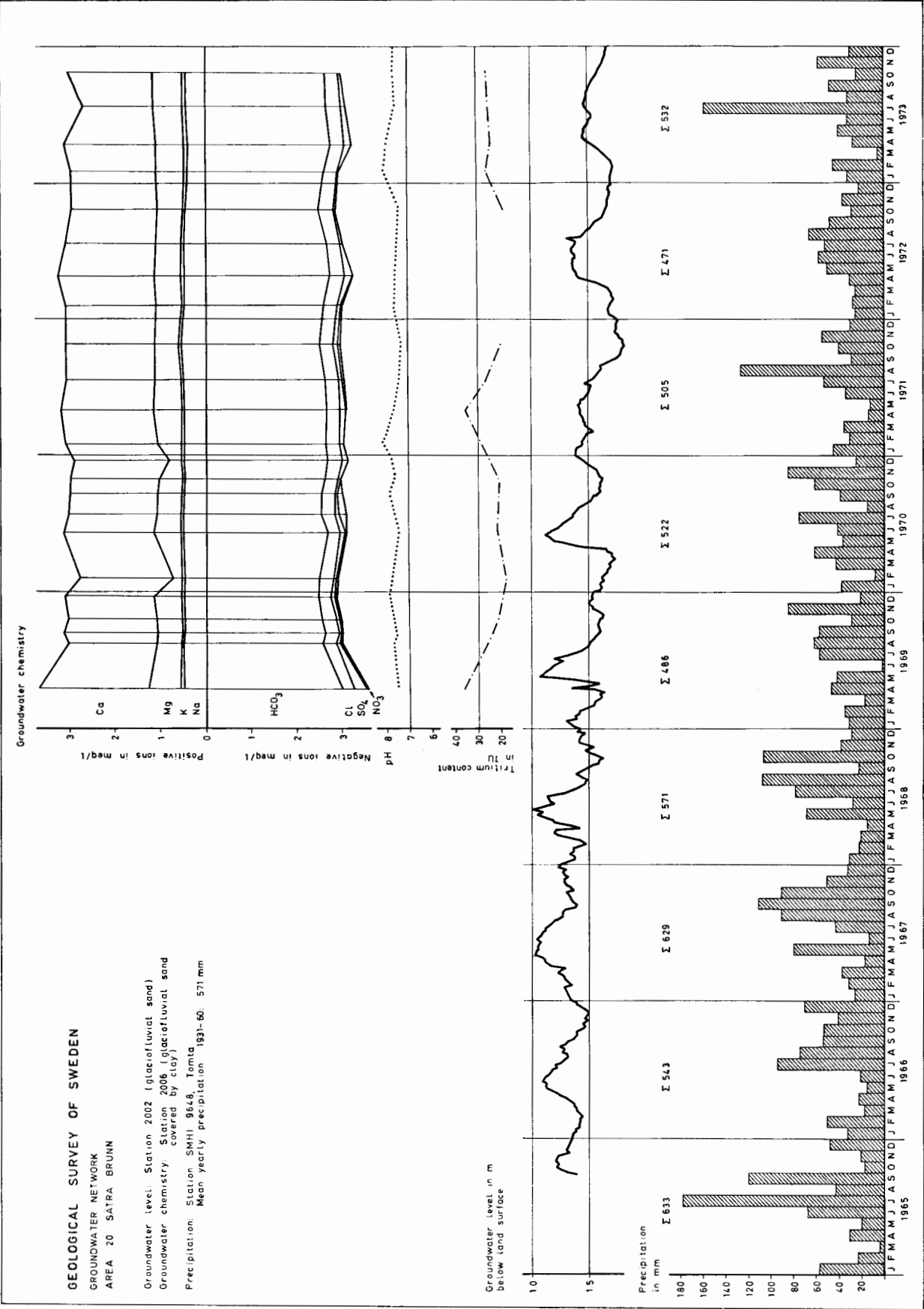


Fig. 50. Diagram from observation area 20 Sättrabrunn.

At station no. 2001, located in the central part of the esker which is a recharge area, the groundwater has a completely different composition. The salt content is about one fifth of that at station no. 2006, and the tritium content is 150—200 TU.

The variations in the groundwater level at station no. 2002, which is situated in the central part of the esker, show a distinct annual cyclicity: high levels in late spring and early summer, and low levels in the winter. The yearly amplitude is about 0.5 m. The periods of major recharge in the spring coincide with the periods of snow-

melting. In connection with heavy rainfall in the summer and autumn and periods of thawing in the winter, minor periods of net recharge may cause rising groundwater level.

In the diagram (Fig. 50) a generally higher groundwater level is found during the first years of observation (1965—1968) than during the rest of the period (1969—1973). During this period of low groundwater level the sums of annual precipitation have been below average each year.

3.21. Bärmö

3.21.1. Geographical location

The observation area Bärnäs is situated in the province of Uppland, 45 km northwest of Stockholm. The elevation of the area ranges from the level of Lake Mälaren at 0.3 m a.s.l. to the highest moraine and bedrock hills nearly 50 m a.s.l. (see map, Fig. 51).

3.21.2. Geology and geomorphology

The observation area is typical for the landscape around Lake Mälaren, made up of a tectonically broken, undu-

lating Precambrian bedrock which is covered by glacial drift. Till predominates in the high parts whereas clay dominates at the surface in the valleys.

The bedrock of the area consists mainly of granodiorite and gneissic metasediments. The bedrock outcrops in the hills surrounding the central Bärmö valley. The bedrock is, in most places, covered by sandy till. In the valleys the till is overlain by glacial and Postglacial clay which have an observed maximum thickness of 22 m. During Late- and Postglacial time the area was inundated by lakes and seas. The till on the hills became wave-

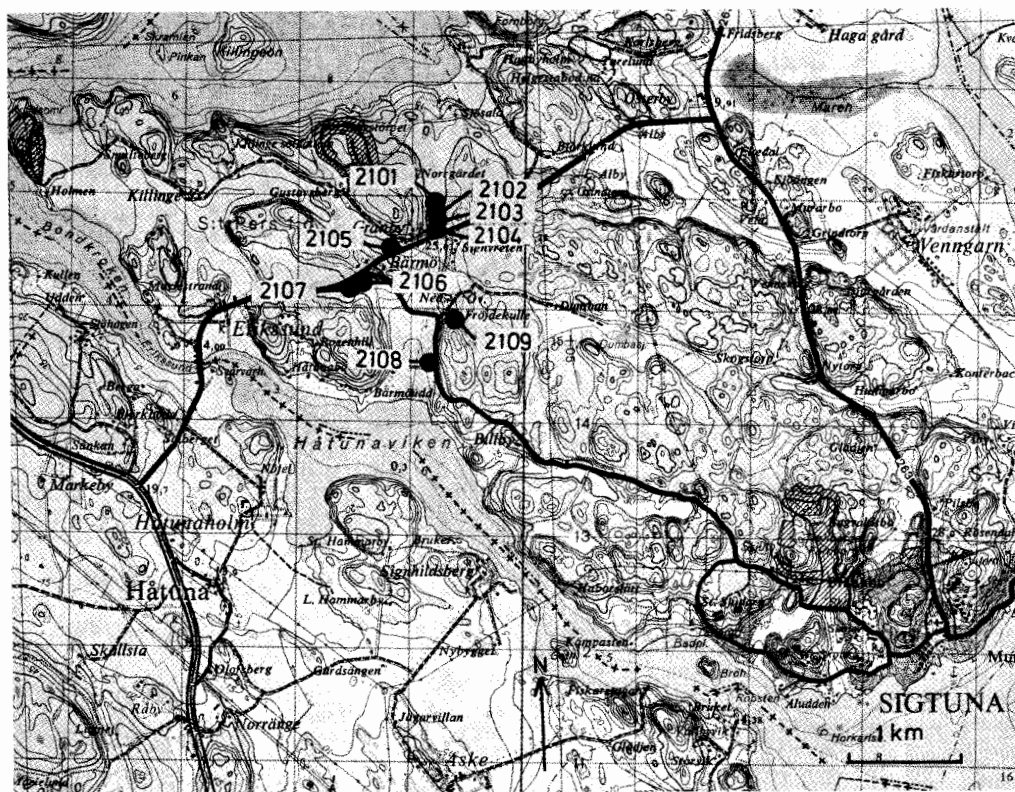


Fig. 51. Map of observation area 21 Bärmö. (Top. map 11 I SV.)

washed and sand from it was redeposited along the slopes of the hills, partly covering the clay in the valleys. Along the shore of Lake Mälaren the clay is covered by gyttja clay.

In the southeastern part of the Bärmö valley, the clay is underlain by glaciofluvial sand and gravel having an observed maximum thickness of approx. 10 m.

The low part of the Bärmö valley has an elevation of 0–10 m a.s.l., and the high part of the valley, where all but one of the observation stations are situated, has an elevation of 20–25 m a.s.l. The surrounding bedrock and moraine hills rise to 40–50 m a.s.l.

3.21.3. Hydrological and hydrogeological features

The observation area is well-defined as to water divides. From the divides on the hills and in the highest part of the valleys the water is drained to a ditch which leads the water to Lake Mälaren. Most of the infiltration in the area takes place in the bedrock and moraine hills. The flow of groundwater is directed toward the central valley where the clay is underlain by till and permeable sand. Therefore, the groundwater is under artesian pressure in the low part of the valley. Where the clay has been punctured by observation tubes, groundwater temporarily flows out of the tubes and is drained as surface runoff. A small natural spring yielding 0.1–1.0 l/s is found in sand on the eastern slope of the main valley.

Prior to 1970 the community of Sigtuna used station no. 2108 for water supply purposes. The mean withdrawal amounted to approx. 3 l/s. After that date, the well has been in operation only for very short periods. At present, it serves temporarily as producing well for the Bärmö farm.

The hydrogeology of the area has been described by Viak AB (1963) and von Brömssen (1968).

3.21.4. Observation stations

The main features of the observation stations are presented in the table below.

At stations nos. 2101–2108 the groundwater under observation refers to till (nos. 2101–2107) and glaciofluvial sand (no. 2108) overlain by clay. Between the till and the clay, thin layers of silt and sand, probably belonging to the bottom varve of the glacial clay, can be found. The thickness of the clay at the stations ranges from 4 m to 8 m.

The observation tubes, except for station no. 2108, were established in 1965 by von Brömssen. Station no. 2108 was established in 1963 by Viak AB in connection with an investigation for a water supply well (see above).

3.21.5. Comments on the diagram

In the diagram (Fig. 52) the variation of observed parameters is shown from selected stations.

No regular, seasonal fluctuations are found in the diagram showing the variations in the chemical composition of the groundwater. The water has a rather high concentration of certain ions (calcium, bicarbonate and sulphate). This is probably caused by influence from the glacial clay, which, in this part of the country, has a high content of calcium carbonate. The tritium content of the water is high, approx. 200 TU, which indicates a short residence time. No multiannual trends can be seen in the diagrams for chemical composition or tritium content.

A very distinct, seasonal cyclicity is seen in the pattern of groundwater level variation. The peak is usually reached in March–May after which the groundwater level falls until late autumn. The bottom level is reached in September–November. Usually, there is a considerable rise of groundwater levels in November–December.

Station no.	Lat.	Long.	Land surface m a.s.l.	Geology	Depth of well m	Type of station	Obs. program	Aq.	Start of obs.	Remarks
2101	5938	1738	22	Sandy till	5	Tube	L	A	1965	Till covered by clay
2102	5938	1738	22	" "	8	"	L	A	1965	" " " "
2103	5938	1738	22	" "	6	"	L	A	1968	" " " "
2104	5938	1738	22	" "	6	"	L	A	1969	" " " "
2105	5938	1738	21	" "	10	"	L	A	1965	" " " "
										Continuous recording
2106	5938	1738	24	" "	4	"	LT	A	1965	Till covered by clay
2107	5938	1738	23	" "	5	"	L	A	1965	" " " "
2108	5938	1738	2	Gl. fl. sand	11	"	C	A	1969	Sand covered by clay
2109	5938	1738	23	Litt. sand	—	Spring	C	W	1972	

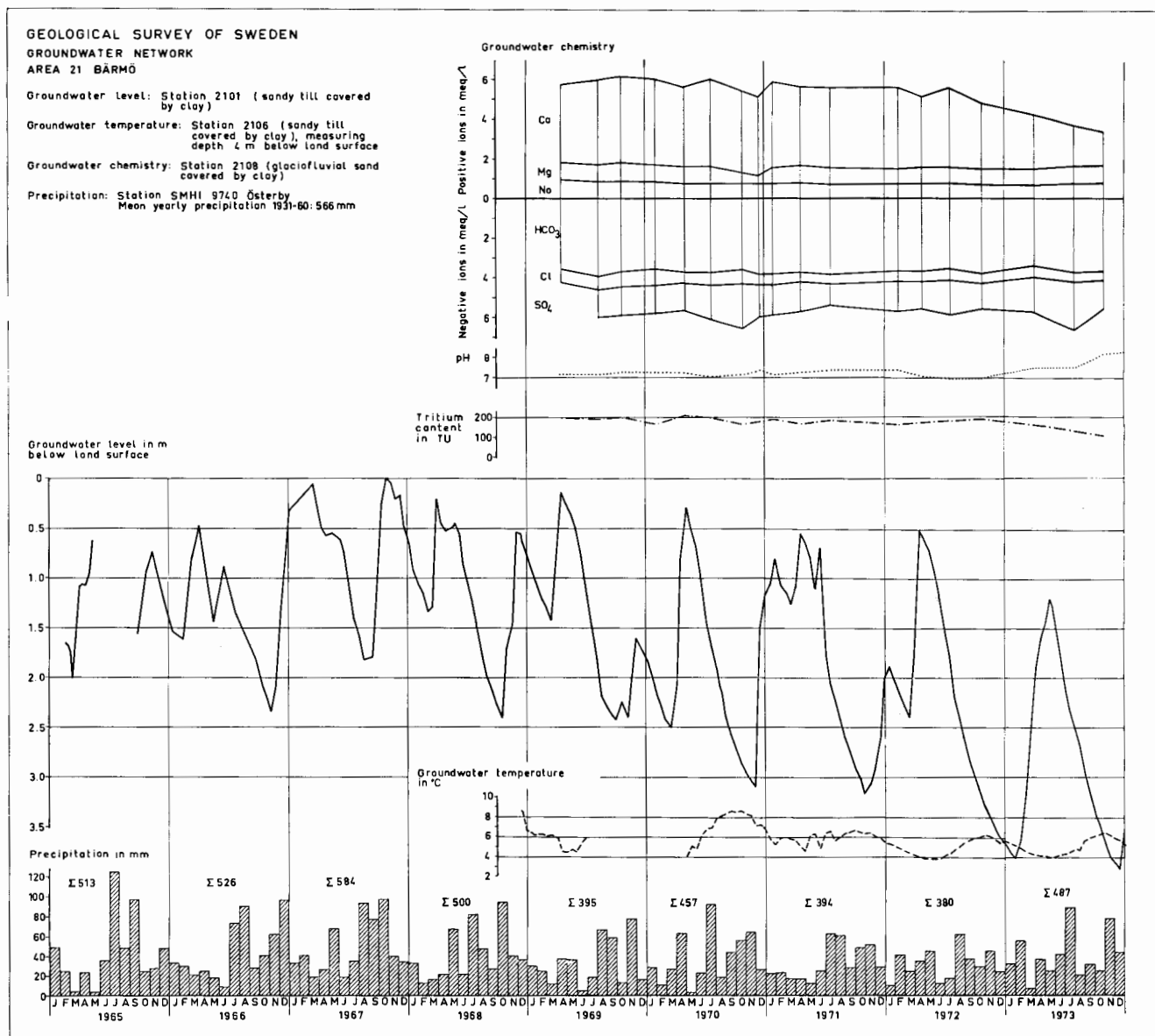


Fig. 52. Diagram from observation area 21 Bärmo.

ber, interrupted in late winter by a period of falling levels. The main rise takes place in the spring in connection with the snow-melting. Thus, the major recharge of the groundwater takes place in the autumn and in the spring. The annual amplitude is 1.8–3.1 m. There is a trend of increasing annual amplitudes with time.

A falling trend, from 1967 to 1973, is seen in the diagram. The trend is clearly discernible both in peak levels and in bottom levels. The fall has been approx. 0.1 m per year for peak levels and 0.2–0.3 m per year for bottom levels. The trend is explained by the low sums of precipitation in the years 1968–1972. As a matter of fact, the precipitation during the presented pe-

riod exceeded the long-term average only once, viz., in 1967.

The temperature of the groundwater has been gauged at station no. 2106 since December, 1968. Measuring depth has been approx. 4 m below land surface. Due to technical difficulties the observations were interrupted from June, 1969 to May, 1970. In the autumn of 1971 an improved measuring technique was introduced, and since then, the curve is relatively smooth. The highest temperature is reached in October–November and the lowest in May–June. The annual amplitude in 1972 was 2.4°C. The mean value for the whole observation period is 5.6°C.

3.22. Ugglevik

3.22.1. Geographical location

The observation area Ugglevik is situated 2 km north of the city of Stockholm (see map, Fig. 53).

3.22.2. Geology and geomorphology

The bedrock of the area consists of Precambrian gneisses and granites, and it frequently outcrops in several small hills which have an altitude of about 25 m a.s.l. In connection with the bedrock outcrops, wave-washed sandy till from the latest glaciation is found. In the small valleys between the hills, the till is covered by clay deposited in Late- and Postglacial lakes and seas.

3.22.3. Observation station

The main features of the observation station are presented in the following table:

Station no.	Lat.	Long.	Land surface m a.s.l.	Geology	Type of station	Obs. of pro-gram	Aq. Obs. period
2201	59°21'	18°04'	3	Sandy till covered by ma. la. clay	Spring	C	A 1969—1971

The observation station is a small spring with a maximum discharge of less than 0.1 l/s in March—April. In the summer and autumn the water in the spring often is almost stagnant. The station is situated in a small valley surrounded by bedrock outcrops. The surface deposits in the valley consist of Postglacial marine clay which covers glacial varved clay and till. The water of the spring probably derives from the water-bearing bottom varve of the glacial clay and/or the till and penetrates to the surface through the punctured clay cover.

3.22.4. Comments on the diagram

A diagram showing the chemical composition of the water at station no. 2201 is presented in Fig. 54. The water has a rather high salt content. Among the ions, calcium and bicarbonate dominate, probably due to the high content of calcium carbonate in the glacial clay of the area. The water also has a remarkably high content of sulphate, which reflects the high content of sulphur in the precipitation in the Stockholm area.

No distinct variations in the chemical composition of

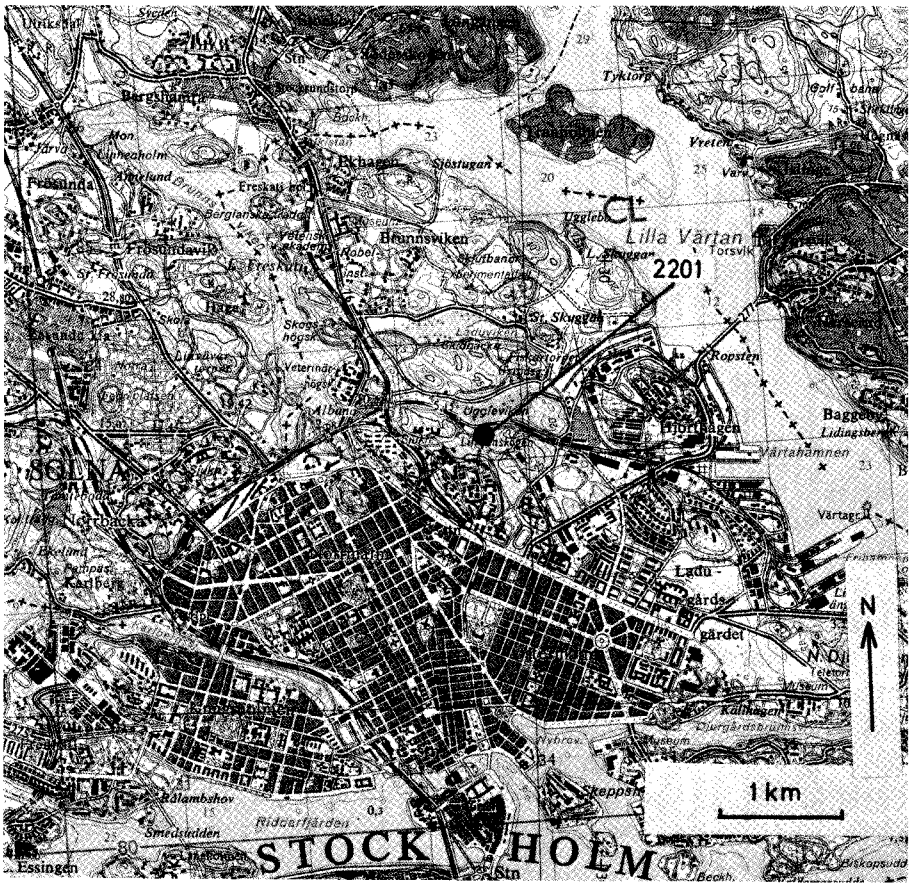


Fig. 53. Map of observation area 22 Ugglevik. (Top. map 10 I NO.)

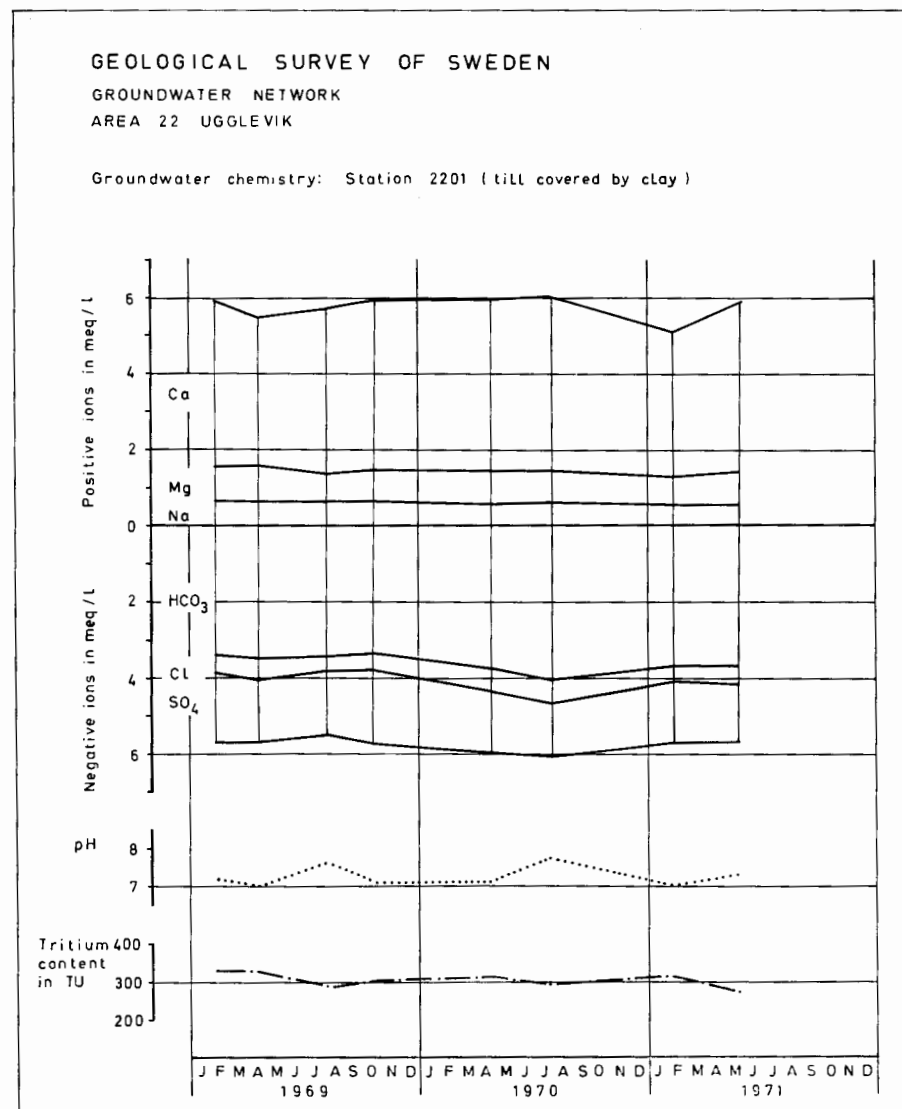


Fig. 54. Diagram from observation area 22 Ugglevik.

the water have been observed during the observation period.

The tritium content of the water is high (around 300 TU), which indicates a relatively short residence time.

The regular sampling at the station ceased in 1971, but from time to time single samples will probably be collected and analysed in the future.

3.23. Tärnsjö

3.23.1. Geographical location

The observation area Tärnsjö is situated in the north-western part of the province of Uppland, approx. 60 km northwest of Uppsala. The elevation of the area ranges from 55 to 85 m a.s.l. (see map, Fig. 55).

3.23.2. Geology and geomorphology

The area is representative of the eastern part of south central Sweden, characterized by large eskers in moraine

terrain which was temporarily inundated after the latest glaciation.

The bedrock of the area consists mainly of Precambrian granites and outcrops frequently in the moraine terrain. It is assumed that the bedrock is tectonically fissured which allows for a relatively good hydraulic communication within localized areas.

The centrally located esker is part of the Enköpingsåsen which can be followed for more than 200 km in generally N—S direction. The esker is split into two

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Fig. 55. Map of observation area 23 Tärnsjö. (Top. map 12 H SV.)

branches within the observation area. They run almost parallel 10–20 km from each other for a distance of approx. 100 km from the point of separation. At this point, and directly south of it, the esker has a width of nearly one kilometer; elsewhere it is generally less wide.

The highest parts of the esker rise 30–50 m above surrounding terrain. Seismic investigations by Kjessler & Mannerstråle AB and by SGU have shown a thickness of the sediments in the central parts of the esker of 15–50 m. The surface of the esker has been smoothed by abrasion. A considerable transportation of sand and gravel has taken place by wave action in a westerly direction across the crest of the esker. This material was redeposited on the western flanks of the esker. Here and

there the redeposition has resulted in very steep slopes. Thus, the esker has a generally asymmetrical transversal profile of gentle slopes facing east and steep slopes facing west. Several beach features can be observed, especially on the west side of the esker. Fine sediments, belonging to the distal accumulations of the outwash can be found in the surroundings of the esker. These generally varved sediments are in most places covered by secondary material, mainly sand, which was redeposited during the abrasion of the esker. The secondary material is found in a zone 1–2 km on either side of the esker. The thickness of this material generally ranges from 0 to 2 m. However, close to the esker it may reach a maximum thickness of more than 10 m.

In the peripheral parts of the observation area till frequently appears at the surface. The till has a thickness of only a few meters, and it conceals most of the bedrock by an undulating cover. At the surface it is wave-washed. The till was deposited during the latest glaciation and is almost exclusively composed of material from the underlying Precambrian bedrock. Sand and gravel dominate in the till. The superficial boulder frequency is high in many places. A correspondingly high boulder frequency is also found locally on the eastern and northeastern slopes of the esker. These boulders are assumed to derive mainly from icebergs that had run aground on the esker. The low parts of the area are locally covered by peat. The formation of the peat seems to be favored by the seepage of groundwater from the sediments.

The geology and geomorphology of the esker have been studied by Lundahl and Perzon (1971).

3.23.3. Hydrological and hydrogeological features

The main surface water divide in the observation area coincides with the crest of the esker and its northeastern branch. West of these, the drainage is directed toward the lake Färnebofjärden of the Dalälven river system, whereas east of the esker, the drainage is toward the lake Tämnaån which is drained by the river Tämnaån. Both rivers have their mouths on the Bothnian Sea which forms part of the Baltic Sea.

The regional surface water divide between the rivers Dalälven and Tämnaån, in the north, and Lake Mälaren, in the south, is situated a few kilometers south of the observation area.

The most important aquifer of the area is the large esker. The main groundwater flow is directed from a groundwater divide at Råsbo, in the south part of the observation area, northwards toward two major discharge areas. The incline of the groundwater level is very slight in the southern part of the flow-system (less than one per mille). The incline increases in the direction of the discharge areas, 2—3 per mille from the point of branching to the springs. The largest discharge is found at Östa (stations nos. 2308, 2317) at the foot of the northwestern branch of the esker, southeast of another groundwater divide that is caused by a high-lying bedrock barrier. The total discharge from the five major Östa springs is 50—100 l/s. Part of the main groundwater flow is directed into the northeastern branch of the esker. Discharge takes place at the Ulebo spring (station no. 2309) with an estimated yield of 30—50 l/s. Another ground-

water divide is found between Ulebo and Tärnsjö. North of Tärnsjö there is a spring (station no. 2315) which yields 30—40 l/s. This spring, which is utilized for the water supply of Tärnsjö, is assumed to obtain the major part of its discharge from the north.

Several minor springs discharging water from the main aquifer of the esker are also found along the flanks of the esker (e. g., stations nos. 2314, 2316, 2328).

As stated in section 3.23.2., the esker is partly covered by redeposited sand and gravel. Glacial clay and silt occur on the flanks of the esker between the primary and the redeposited material. This has caused the formation of a perched aquifer in the redeposited sand and gravel. Several small springs temporarily discharge water from this aquifer (e. g., station no. 2311). The yields of these springs are approx. 1 l/s or less.

In the central part of the esker the groundwater level of the major aquifer is found at a maximum depth of 40 m below the ground surface. Where the upper groundwater aquifer occurs, its level usually is found 7—8 m above the level of the major aquifer of the esker.

The groundwater flow in the surrounding moraine terrain is strongly influenced by the local topography. The yield is insignificant in comparison with the yield of the glaciofluvial aquifer. The groundwater level is found within a few meters from the land surface. Where the till is covered by clay, artesian conditions may be present.

The groundwater flow in the Precambrian bedrock is influenced by the tectonic pattern of the bedrock.

3.23.4. Observation stations

The main features of the observation stations are presented in the table on page 84.

The locations of the groundwater stations are presented on the map, Fig. 55. Stations nos. 2303 and 2304 were established by Viak AB in collaboration with SGU in 1965 in order to obtain information on the groundwater levels of the area. All other tube stations and the drilled wells have been established by SGU exclusively for the national groundwater network. The dug wells are, or have been, producing wells. After due investigation they have been incorporated into the network.

No extraction of water by pumping takes place within the area except minor withdrawals for separate households. Therefore, no influence by pumping on the groundwater flow is present. As mentioned above, the water supply of Tärnsjö is based on a part of the discharge from one single spring (station no. 2315).

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Station no.	Lat.	Long.	Land surface m a.s.l.	Geology	Depth of well m	Type of station	Obs. program	Aq.	Start of obs.	Remarks
2301	6008	1653	69	Litt. sand	5	Dug	LC	W	1965	Lower aquifer
2302	6008	1653	69	" "	4	Tube	L	W	1969	Chemistry since 1969
2303	6006	1652	85	Gl. fl. mix.	16	"	L	W	1965	Lower aquifer
2304	6007	1652	84	" " "	16	"	LT	W	1965	" "
2305	6007	1651	68	Sandy till	3	Dug	LC	W	1965	" "
2306	6007	1651	65	" "	3	"	L	W	1966	Temp. since 1968
2307	6007	1651	69	" "	3	Tube	LC	W	1969	Level 1965—70
2308	6008	1650	61	Gl. fl. sand	—	Spring	C	A	1968	Chemistry 1970—71
2309	6008	1655	60	Litt. sand	—	"	C	A	1968	Covered by clay
2310	6008	1650	65	Gl. fl. sand	9	Tube	L	W	1970	Chemistry since 1971
2311	6006	1652	78	Litt. sand	—	Spring	C	W	1970	Lower aquifer
2312	6007	1652	76	" "	1	Dug	C	W	1970	Covered by peat
2313	6003	1645	63	Sandy till	5	"	LC	A	1971	Lower aquifer
2314	6006	1654	59	Litt. sand	—	Spring	C	A	1971	Covered by peat
2315	6010	1657	57	Gl. fl. mix.	—	"	C	W	1971	Lower aquifer
2316	6008	1650	61	Litt. sand	—	"	C	W	1971	" "
2317	6009	1650	58	" "	—	"	C	A	1971	" "
2318	6008	1656	68	" "	11	Tube	L	W	1971	Covered by peat
2319	6008	1655	66	" "	11	"	L	W	1971	Lower aquifer
2320	6004	1652	80	Gl. fl. mix.	11	"	LT	W	1971	" "
2321	6004	1652	80	Litt. sand	3	"	LT	W	1971	" "
2322	6005	1653	84	Gl. fl. mix.	15	"	L	W	1971	Upper aquifer
2323	6007	1655	68	Granite	46	Drill	L	W	1971	Lower aquifer
2324	6006	1653	81	"	66	"	L	W	1971	Continuous recording
2325	6006	1653	81	Gl. fl. mix.	28	Tube	L	W	1971	" "
2326	6009	1655	62	Litt. sand	—	Spring	C	W	1971	" "
2327	6008	1655	67	" "	10	Tube	L	W	1971	Upper aquifer
2328	6006	1654	59	" "	—	Spring	C	A	1972	Lower aquifer
F 4	6008	1653	79	Gl. fl. grav.	—	Frost	F	—	1969	" "
F 5	6008	1653	69	Litt. sand	—	"	F	—	1969	Covered by peat
F 6	6008	1653	67	" "	—	"	F	—	1969	
F 7	6008	1653	67	Ma. la. silt	—	"	F	—	1969	

3.23.5. Comments on the diagram

In the diagram (Fig. 56) all observed parameters are shown from the selected stations.

Groundwater

A distinct difference in the variation of quality and quantity of groundwater is found between the main aquifer in the esker and the other aquifers of the area. This is reflected well in the diagram, in which stations nos. 2304 and 2308 represent the main aquifer, and

stations nos. 2306 and 2307 represent the till aquifer, and station no. 2323 represents the bedrock aquifer.

(1) The main aquifer (the esker)

Due to the fact that the main aquifer consists of a coarse and highly permeable material and is overlain by an unsaturated zone of spatially very varying thickness (0—40 m), the seasonal variations of groundwater quality and quantity are very indistinct. The high permeability of the aquifer causes an equalization in space of the groundwater variations, whereas the spatially varying thickness

of the unsaturated zone causes a corresponding repression of variations in time.

The seasonal fluctuations of the chemical composition of the groundwater in the main aquifer (station no. 2308) are not discernible. The groundwater from this spring is dominated by the presence of calcium and bicarbo-

nate. The ion content is relatively low, which indicates a short residence time of the groundwater and/or a low chemical affinity of the aquifer material. The high tritium content (200–250 TU) of the groundwater is an indication of a rather short residence time.

The variation of the groundwater level in the esker

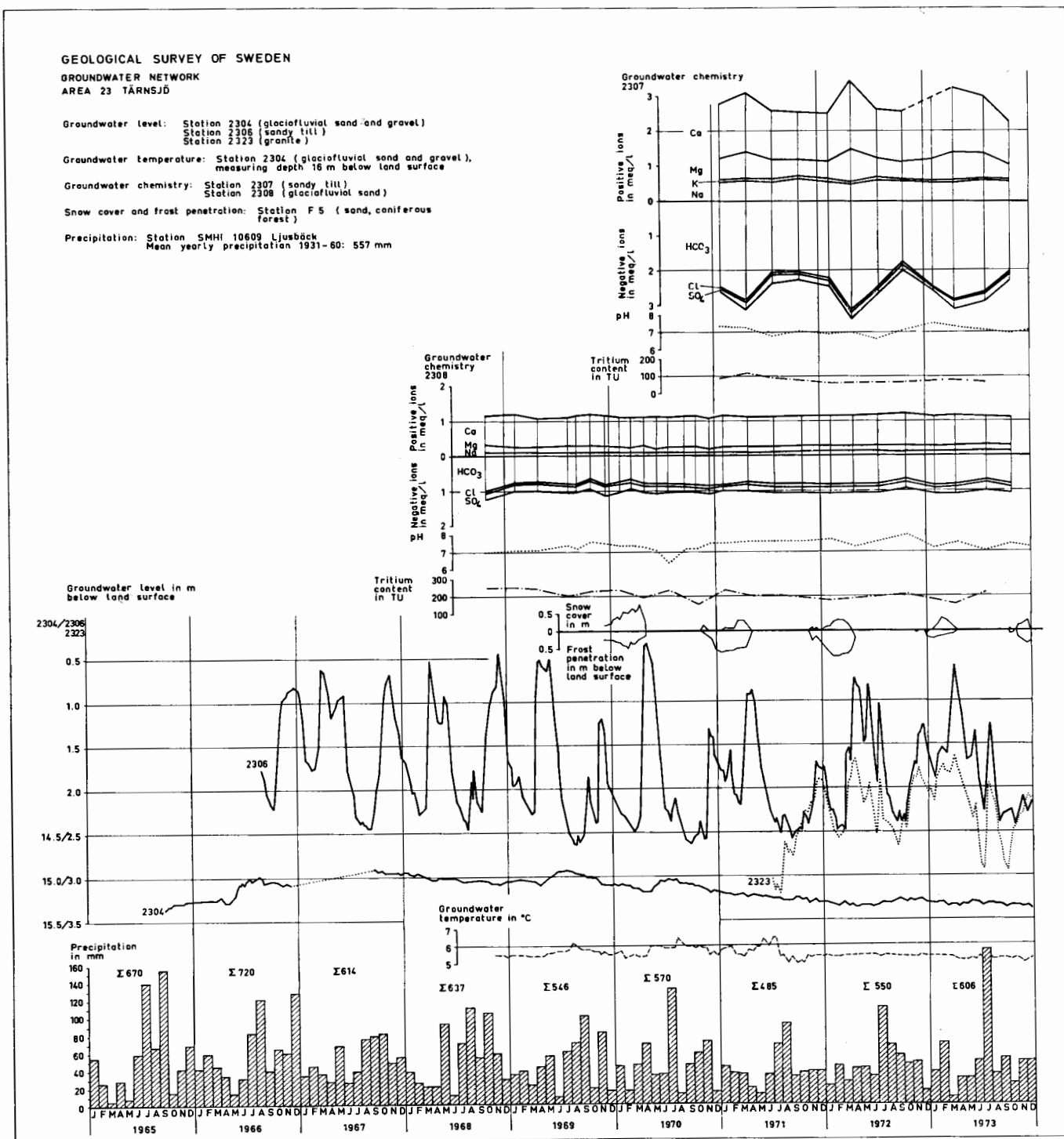


Fig. 56. Diagram from observation area 23 Tärsjö.

is shown from station no. 2304. A weak pattern of seasonal fluctuations is discernible in certain years (1966, 1969, 1970). Highest levels are attained in the summer in these years. The annual amplitude is only 0.1–0.3 m which in part reflects a high effective porosity of the aquifer. A clear multiannual trend of the groundwater level is found and shows a general rise in 1965–1967 and a fall in 1967–1973. The decline from the peak level, observed in 1967, to the bottom level, in 1973, is 0.46 m. A corresponding decline in the yearly mean levels is also present.

By and large the trend agrees fairly well with the different yearly sums of precipitation during the period of observation. Temperature readings of the groundwater at a depth of approx. 15 m below the ground surface have been done since 1968. Due to an unsatisfactory measuring technique and other regrettable circumstances, no attention should be paid to the details of the presented diagram. The yearly amplitude is less than 1°C with a mean value of approx. 5.5°C.

(2) The till aquifers

The variation of the chemical composition of groundwater in the till is shown from station no. 2307. The seasonal fluctuations are distinct, with a high ion content in the spring and a low ion content in the summer and autumn. The scarcity of observations does not allow for any detailed analysis of the variation pattern or of the co-variation of chemical composition and groundwater level. The water of this aquifer has a considerably higher concentration of ions than that of the main aquifer. This is especially true for the contents of bicarbonate, calcium, sodium, magnesium and iron. The high salt concentration is assumed to be the result of a long residence time, which is also reflected by low tritium contents in the water. The existence of fine particles with a high degree of affinity in the till contributes to the relatively high salt concentration of the groundwater.

The variation of the groundwater level in the till is shown from station no. 2306. The pattern of seasonal fluctuations is very distinct. Generally, the recharge takes place during two major periods: in the spring in connection with the melting of the snow and in the autumn in connection with heavy precipitation. The peak level is reached in April–May, or, less commonly, in November. During the summer there is a general decline of the groundwater level. In certain years (e. g., 1972), the decline is interrupted by rises caused by large amounts of rainfall. The lowest levels are found in Au-

gust–September and a secondary minimum is present in March. The yearly amplitude is approx. 1.5–2.0 m, which is an expression of a relatively low effective porosity.

Contrary to the response in the main aquifer, the observable groundwater response to precipitation is very fast in the till.

(3) The bedrock aquifers

The chemical composition of the groundwater in the bedrock has been studied at stations nos. 2323 and 2324. Only sporadic sampling has been done yet, and therefore no information on the seasonal fluctuations is available. The groundwater in the granite below the esker (station no. 2324) resembles the water in the main aquifer. The salt content is somewhat higher in the granite, which is assumed to be caused by a longer residence time in the bedrock than in the esker.

The groundwater at station no. 2323, which is situated in the moraine terraine, resembles that of the till aquifers in respect of the chemical composition.

The variation of the groundwater level in the granite is shown from station no. 2323. As can be seen, there is a very good agreement in the pattern of seasonal fluctuations between the till and bedrock aquifers. They are almost identical in most details.

The yearly amplitude, though, is somewhat smaller in the granite than in the till. Station no. 2323, which is situated in a bedrock outcrop surrounded by till, is equipped with a recorder. From the recorder graphs the response to precipitation has been found to be approx. one day or less. A rhythmical, tidal influence on the groundwater in the bedrock aquifer has also been noted at this station.

At another drilled well (station no. 2324), where the granite is covered by approx. 30 m of sand and gravel, the pattern of fluctuations is identical to that of the main aquifer (the esker). This indicates a good hydraulic communication between the esker and the underlying bedrock.

(4) The upper aquifer of redeposited sediments

Some of the stations of the observation area are established in sand and gravel redeposited from the primary esker.

The chemical composition of water from the upper aquifer (stations nos. 2311, 2312) is characterized by a considerably lower salt content and a larger amplitude of variation than that of the main aquifer.

The pattern of fluctuations of the groundwater levels in these sediments (e. g., station no. 2321) resembles

the pattern of the main aquifer of the esker, although with a considerably larger amplitude. The yearly amplitude at station no. 2321 is approx. 0.40 m.

The penetration of frost and the thickness of the snow cover

Measurements of the penetration of frost and of the thickness of the snow cover are performed at four stations. The recordings from the station no. F5 are shown in the diagram. The station is located in redeposited sand in a coniferous forest. The period during which the ground is frozen is generally 5—6 months long, i. e. November—April. The snow cover has a somewhat shorter duration. The observed maximum depth of frost at this station is 0.8 m.

At station no. F4, which is located in coarse glaciofluvial material close to the crest of the esker, the cor-

responding depth is 1.0 m. The other two stations, nos. F6 and F7, are situated in fine sand and silt, respectively, and maximum recorded depth of frost penetration is 0.5 and 0.3 m, respectively. At the latter two stations, the groundwater level is found close to the ground surface, 0.5—2.0 m, which partly causes the small depth of frozen ground.

The snow cover has been found to reach a maximum thickness of 0.75 m. The variation of thickness is considerable in space and time.

The period of thawing and snow-melting is reflected by a noticeable rise in the groundwater levels in most aquifers. This correlation is demonstrated well in the diagram from stations nos. 2306 (till) and 2323 (granite). The rise of groundwater level starts while there is still some frost left in the ground, which indicates that infiltration and percolation can take place through a partially frozen ground.

3.24. Rengsjö

3.24.1. Geographical location

The observation area Rengsjö is situated in the province of Hälsingland in east central Sweden, between the towns of Söderhamn and Bollnäs. The altitude of the area ranges from approx. 75 to 140 m a.s.l. (see map, Fig. 57).

3.24.2. Geology and geomorphology

The observation area is made up of part of the so-called Ljusnan esker which runs continuously from river Ljusnan generally southwestwards to the coast of the Bothnian Sea. The esker can also be traced, with interruptions, for a long distance northwest of the river Ljusnan. Within the observation area the esker is very high-crested in the Höle region, whereas the esker in the Glössbo region is concealed under redeposited, sandy sediments. Several small ice-hollow lakes and bogs are found in the area, set apart from the surrounding accumulations by steep slopes. The difference in height between hollow and crest approaches 25 m in localized parts of the area.

Gravel pits in the northwestern part of the observation area show the glaciofluvial core material to be coarse (sand, gravel, stones). In the southeastern part of the area no core material has been encountered. The dominating fraction is sand. After the glaciation, the area was inundated by lakes and seas and lacustrine and marine sediments, ranging from sand to clay, were accumulated on top of the glaciofluvial deposits. Due

to wave-washing at times of transgression and regression much of the deposited material was abraded and redeposited. At observation stations nos. 2402, 2404 and 2406 the loose deposits have a vertical extension of 57, 49 and more than 35 m, respectively.

On both sides of the esker a regular moraine and bedrock terrain is present. The main type of till is sandy, holding an intermediate boulder frequency. The bedrock, outcropping at several places, is dominated by Precambrian granites and gneisses, the latter commonly containing veins of quartz and feldspar.

3.24.3. Hydrological and hydrogeological features

The northwestern border of the observation area coincides with the small river Våxboån, which cuts through the esker from north to south. This river and a tributary running along the southern flank of the esker collect most of the surface water from the northwestern part of the area. The southeastern part is drained to the lake Östersjön and the brook Östersjöån. The river Ljusnan, having its mouth south of Söderhamn, receives the waters from both parts of the observation area. East of the esker, the lake Hölesjön receives minor quantities of water that are drained to the river Lötån which reaches the sea just north of Söderhamn. Due to the sandy surface layers of the esker, the infiltration capacity is high and no watercourses are generally found there. The minor lakes or tarns, occupying ice-hollows, are found

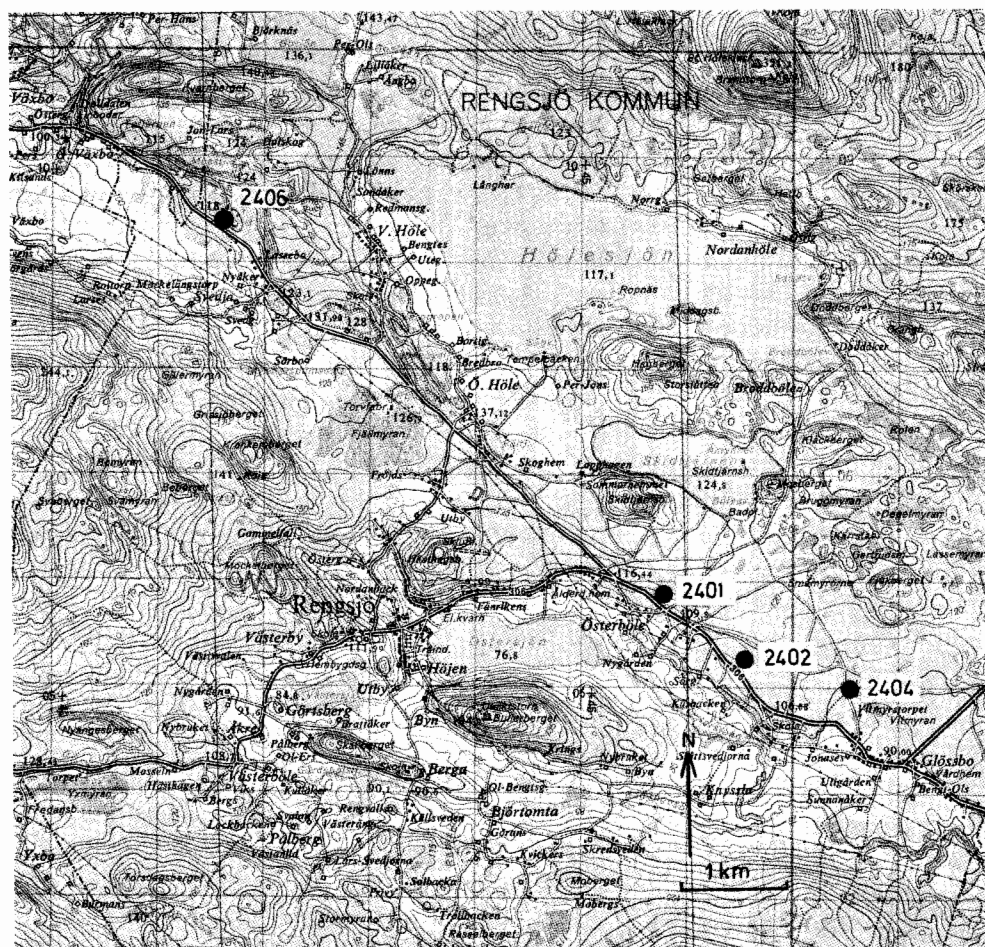


Fig. 57. Map of observation area 24 Rengsjö. (Top. map 15 G SO.)

on different levels, although very close to each other. This suggests that the lakes or tarns are isolated from the glaciofluvial material by fine-grained sediments (or, possibly, till) and organic deposits.

Due to the wave-washing and redeposition of sediments, layers of fine fractions separate different parts of the accumulation from each other. These layers act as aquicludes that cause the formation of more or less temporary, perched aquifers. The relationship between the aquifers is not investigated sufficiently, although the existence of several aquifers is well known within the area. In the central part of the observation area, an upper groundwater reservoir is encountered at a depth of only 2—3 m. At the same place the deep main aquifer has its groundwater level 25—30 m below land surface. The upper groundwater is assumed to be of local character, sensitive to droughts and heavy rainfalls. No general flow direction of the upper groundwater has been affirmed.

All observation stations represent the deep aquifer. The main flow is directed from northwest toward south-

east. There is a rather steep gradient (0.4 per cent) between stations nos. 2406 and 2401; this fact may imply that there is some sort of barrier between the two stations. A local groundwater divide could also be present in this part of the area. The gradient between stations nos. 2401 and 2404 is 0.1 per cent. A few springs yielding a total of 10—15 l/s are found at the southern foot of the esker close to station no. 2406. Minor springs have also been found at Glössbo. At present, the discharge is utilized for water supply purposes at a new water works in Glössbo.

A test pumping was performed by Allmänna Ingenjörbyrå AB (AIB) at the well site in Glössbo in late 1971 and early 1972. A safe yield of 9.5 l/s was obtained. According to calculations by AIB, the consumption of water will be considerably less than 9.5 l/s for the foreseeable future.

Another small community well yielding approx. 0.5 l/s is found in Glössbo. Besides the two wells in Glössbo, only one other well penetrating into the lower glaciofluvial aquifer has been reported from the area. It

is located in the central part of the area and supplies one home with water. Several wells for separate households though, are dug in the upper, shallow aquifer. The total withdrawal from these wells is insignificant. Most of the wells will be taken out of use as the new water works in Glössbo will furnish water to homes in the main part of the area. None of the observation stations are assumed to be directly influenced by pumping from any of the wells.

Besides the aforementioned investigation by AIB, a report on the groundwater conditions has been compiled by Norrländska Konstruktionsbyrån AB (NKB, 1968), in which the several upper groundwater levels have been described.

3.24.4. Observation stations

The main features of the observation stations are presented in the table below.

The locations of the groundwater stations are shown on the map, Fig. 57. Stations nos. 2401, 2402, 2404 and 2406 were all established by the township of Rengsjö in 1968 in search for a suitable well site. None of the stations were judged as suitable for a production well. The stations for frost penetration were erected by SGU in 1969.

3.24.5. Comments on the diagram

In the diagram (Fig. 58), the variation of groundwater levels is shown from three stations. Also, groundwater temperature, frost penetration and snow cover, and precipitation are presented. No clear seasonal patterns of fluctuation are seen in the curves for the groundwater levels. This is probably due to the fact that the deep groundwater is found 13—25 m below land surface. Several semi-pervious layers between the deep groundwater and the surface may contribute to the repression and blending of recharge periods.

A trend of falling groundwater levels is distinctly

observable at the three stations. From 1969 to the end of 1973, the level has decreased by approx. 0.6 m at station no. 2406, 2.0 m at no. 2401, and 2.4 m at station no. 2404. The comparatively small decrease at station no. 2406 may be attributed to an assumed bedrock barrier between stations nos. 2406 and 2401. Such a barrier may separate the two parts of the esker within the area effectively from each other. The two parts may have completely different characteristics as to recharge/discharge conditions. The falling trend cannot be correlated to a simultaneous corresponding trend in precipitation. The high levels in 1969, however, may be caused by large sums of precipitation in 1965—1969. The yearly sums are 594, 696, 543 and 604 mm, respectively, i. e. considerably above average (= 467 mm). In 1962—1964, the yearly precipitation was well below average (460, 396 and 389 mm, respectively). This fact implies that the groundwater levels should approach average values in 1973, provided that there is a correlation between yearly precipitation and groundwater levels.

The groundwater temperature at a depth of 20 m below land surface at station no. 2404 shows no clear seasonal pattern of fluctuation. The jagged curve preceding June, 1971, is caused by an unsatisfactory measuring technique. The average temperature for the period of June, 1971 to December, 1973, is 4.6°C.

The penetration of frost and the snow cover are recorded for four winters. Both parameters have been found to vary quite noticeably from year to year. The thick snow cover of March—April, 1970, is accompanied by a very slight depth of frost penetration. The snow cover has acted as an effectively insulating blanket. The greatest depth of frost penetration, 0.8—0.9 m, was recorded in March—April, 1971 and 1972. The ground is frozen for 5 to 7 months. There is no direct, observable response between thawing of the frost, as well as the snow melting and the groundwater level of the deep aquifer.

Station no.	Lat.	Long.	Land surface m a.s.l.	Geology	Depth of well m	Type of station	Obs. program	Aq.	Start of obs.	Remarks
2401	6122	1639	111	Gl. fl. sand	46	Tube	L	W	1969	Continuous recording 1969—1971
2402	6121	1640	102	„ „ „	56	„	L	W	1969	
2404	6121	1641	101	„ „ „	52	„	LT	W	1969	
2406	6124	1634	121	„ „ „	39	„	L	W	1969	
F 1	6121	1641	101	Litt. sand	—	Frost	F	—	1969	
F 3	6124	1634	121	„ „	—	„	F	—	1969	
F 8	6122	1639	111	„ „	—	„	F	—	1969	

LARS NORDBERG AND GÖSTA PERSSON

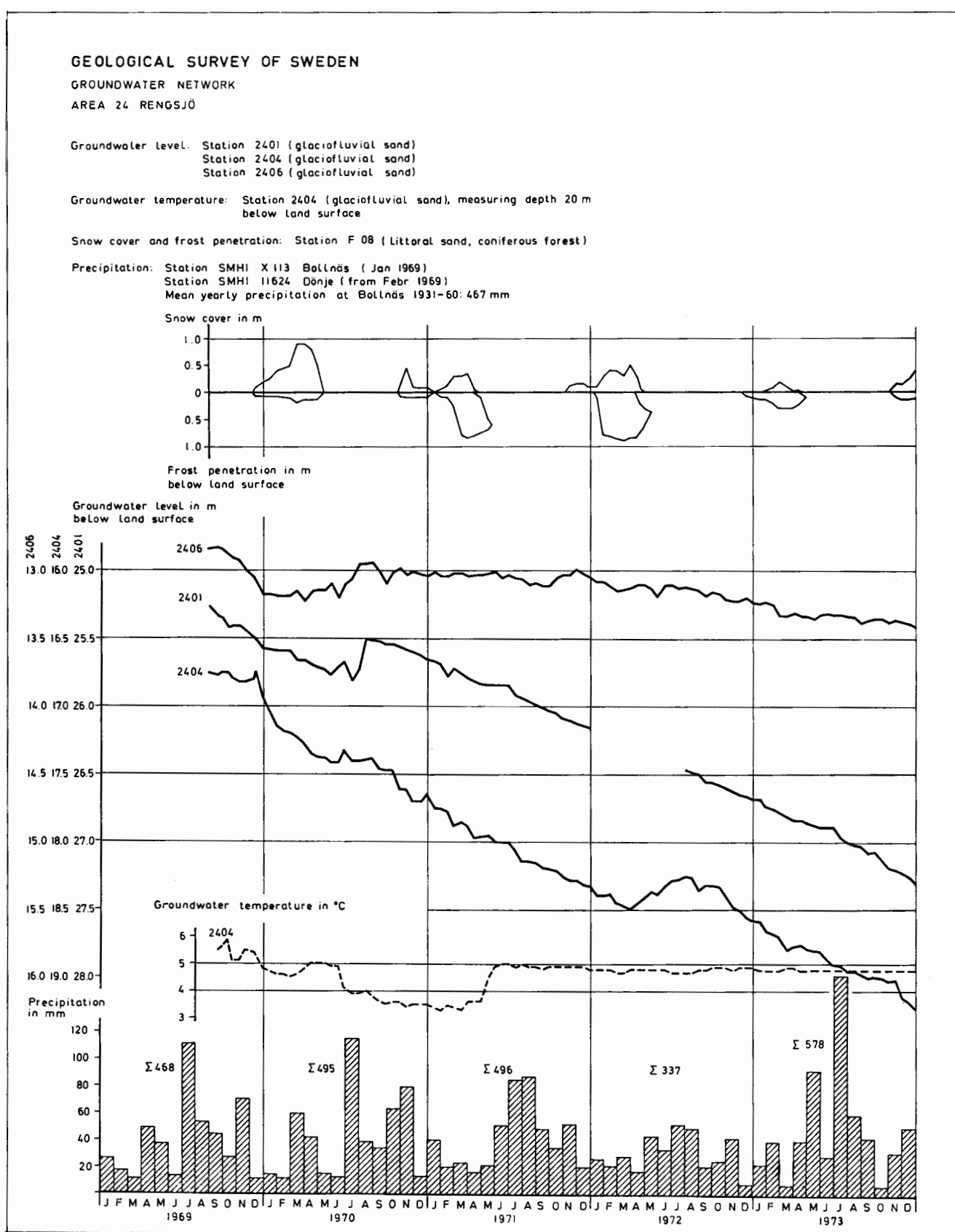


Fig. 58. Diagram from observation area 24 Rengsjö.

3.25. Tunaby

3.25.1. Geographical location

The observation area Tunaby is situated in east central Sweden, approx. 10 km southwest of the town of Sundsvall, on the northern shore of river Ljungan. The elevation of the area ranges from the level of the river, i. e., 10 m a.s.l., to approx. 50 m a.s.l. (see map, Fig. 59).

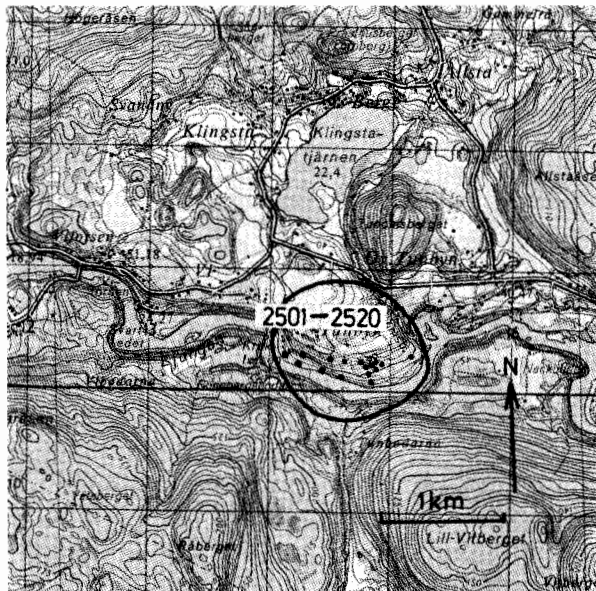


Fig. 59. Map of observation area 25 Tunaby. (Top. map 17 H SV.)

3.25.2. Geology and geomorphology

The area is made up of a part of a glaciofluvial deposit situated in the river Ljungan valley. The deposit can be traced discontinuously on both sides of the river for approx. 100 km from the coast. After the glaciation, fluvial sediments were added to the accumulation. Investigations by Vattenbyggnadsbyrån (VBB, 1953) have revealed a maximum thickness of 60 m of loose deposits. Sand and gravel dominate the sequence. Most of the test borings are reported to terminate against the underlying Precambrian bedrock, but also till has been reported to exist below the glaciofluvial deposits. Neither till nor bedrock is exposed within the area.

The glaciofluvial deposit has a rather steep slope facing the river (10–30 per cent), whereas the north-facing slope is gentle and hardly distinguishable from the surrounding terrain. The morphology of the riverside of the deposit is strongly influenced by processes of fluvial erosion and accumulation.

3.25.3. Hydrological and hydrogeological features

The area is characterized by its juxtaposition with the river Ljungan, having a mean annual discharge of 132 m³/s. No surface runoff is found within the area due to the highly permeable ground. To the east, the area is

Station no.	Lat.	Long.	Land surface m a.s.l.	Geology	Depth of well m	Type of station	Obs. program	Aq.	Start of obs.	Remarks
2501	6218	1712	17	Gl. fl. sand	11	Tube	L	W	1953	
2502	6218	1712	19	" " "	14	"	L	W	1953	
2503	6218	1712	23	" " "	30	"	L	W	1953	
2504	6218	1712	33	" " "	31	"	L	W	1953	
2505	6218	1712	16	" " "	7	"	L	W	1953	
2507	6218	1712	17	" " "	10	"	L	W	1953	
2509	6218	1712	24	" " "	16	"	L	W	1953	
2510	6218	1712	29	" " "	22	"	L	W	1953	
2511	6218	1712	12	" " "	4	"	L	W	1953	
2512	6218	1712	13	" " "	5	"	L	W	1953	
2513	6218	1712	17	" " "	9	"	L	W	1953	
2514	6218	1712	30	" " "	58	"	L	W	1953	
2515	6218	1712	23	" " grav.	45	"	L	W	1953	
2516	6218	1712	26	" " sand	50	"	L	W	1953	
2517	6218	1712	29	" " "	48	"	L	W	1953	
2519	6218	1712	29	" " grav.	44	"	L	W	1953	
2520	6218	1712	29	" " "	47	"	L	W	1953	
KP1	6218	1712	—		—	RSG	L	—	1965	River stage
KP2	6218	1712	—		—	"	L	—	1953	" "

bordered by a deep gully carrying a small brook, the Tunomsbäcken.

The area Tunaby is unique in the SGU network in as much as it is extensively exploited by pumping. The natural groundwater flow toward the river has been reverted completely by the extraction of water from six community wells situated 150–200 m from the shore. The total withdrawal for the town of Sundsvall during the observation period has increased from 50 l/s in 1953 to 250 l/s in 1972. A safe yield of 185 l/s was calculated in the investigation of 1953. The present state implies that the safe yield is passed, but that as yet, no serious overdraft of the aquifer takes place. Due to a good hydraulic communication between the wells and the river, a considerable replenishment of the groundwater takes place through the bottom beds of the river. At a withdrawal of 200–250 l/s a mean gradient of 0.7 per cent is present from the river surface to the groundwater level in the wells. A map of equipotential lines for the groundwater suggests that there is a highly permeable core of coarse glaciofluvial material (in which the wells are placed) parallel to the river, but at a distance of approx. 200 m from the river and separated from it by fine-grained sediments. This is shown by the fact that the groundwater gradient from the river is of the same magnitude throughout the area and directed perpendicularly from all places toward the river.

The hydraulic conditions at the site allow a considerable increase in pumping for consumption provided that the quality of the water remains satisfactory.

3.25.4. Observation stations

The main features of the observation stations are shown in the table on page 91.

All stations were established by Vattenbyggnadsbyrån as a part of investigations made in 1950–1953, which led to the present community water supply wells. The groundwater levels at all stations are controlled both by the pumping and by the river.

3.25.5. Comments on the diagram

The relation between river stage and groundwater level is shown in the diagram (Fig. 60). The pattern of the groundwater variation is influenced strongly by the changes of level in the adjacent river, and, to a minor degree, by pumping. Due to the pumping the groundwater level is generally found 0–100 cm below the surface of the river. The seasonal pattern of variations has a climatological origin. The highest levels are recorded in the summer when the snow in the mountains has melted and furnished large volumes of water to the Ljungan river system. Correspondingly, the lowest

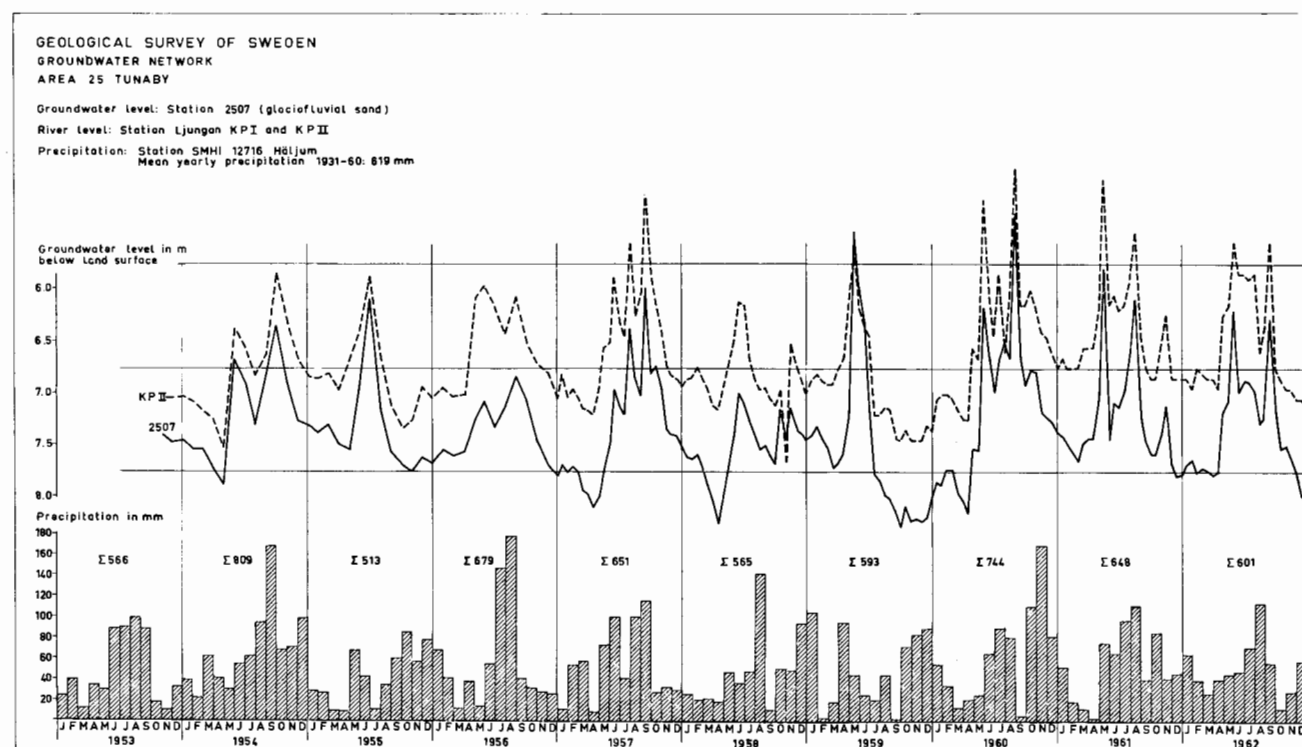


Fig. 60. Diagram from observation area 25 Tunaby.

levels are found in the winter. The annual amplitude is 1–2 m.

The river Ljungan is utilized for hydroelectric power plants and regulated accordingly. The observation area is influenced by seasonal regulations which are in force to diminish the flow variations during the year. Short-term regulations have no influence on the river within the observation area.

The strict agreement between groundwater level and

river stage proves that the groundwater in the glaciofluvial deposits in the area is strongly controlled by the river. This means that the groundwater level is more influenced by the precipitation in the upper part of the Ljungan catchment than by local precipitation.

No distinct, long-term trends can be seen, except for certain small groups of years, e. g. falling trends in 1960–1963 and 1970–1973.

3.26. Kassjöån

3.26.1. Geographical location

The observation area Kassjöån is situated in the border district between the provinces of Jämtland and Medelpad in central Sweden, approx. 60 km from the coast of the Bothnian Sea. The altitude of the area ranges from 225 to 530 m a.s.l. (see map, Fig. 61).

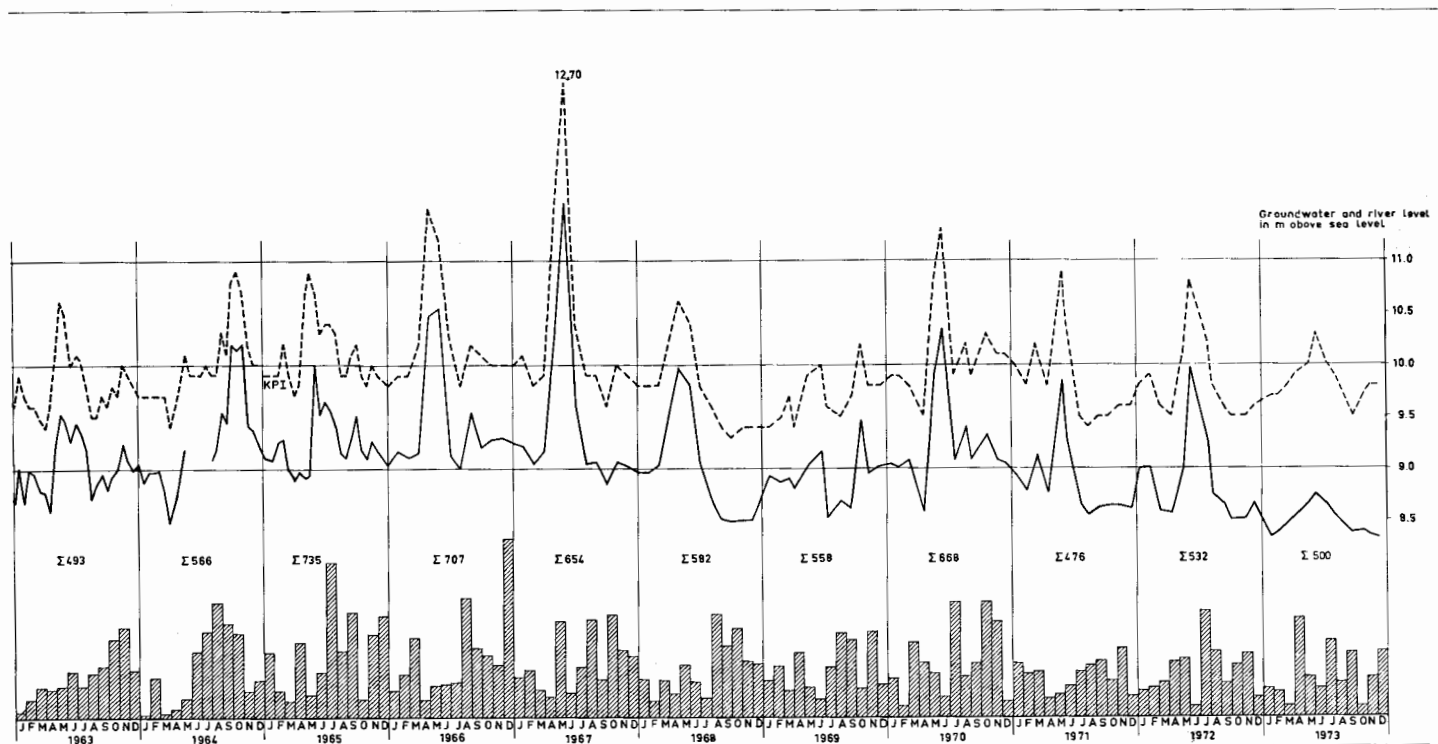
3.26.2. Geology and geomorphology

Precambrian granites and gneisses dominate the bedrock. Dolerite is found sporadically. The basement is exposed at relatively few places and particularly along lines of tectonically dislocated bedrock.

The Precambrian bedrock is generally concealed by

Quaternary deposits of varying thickness. Till from the latest glaciation dominates in the area. The till is sandy; the clay content very sporadically amounts to 5–10 per cent by weight. It has been found that the clayey type is almost wholly restricted to high-lying parts of the area.

The morphology of the moraine terrain is gently rolling on the high-lying, flat bedrock surfaces. The thickness of the till cover is assumed to be relatively small in this type of terrain. The underlying bedrock is exposed at several small outcrops. In the valleys a more pronounced moraine topography is found. Steep-sided moraine hills and ridges, 5–10 m high, are frequently found and indicate that dead-ice conditions existed at



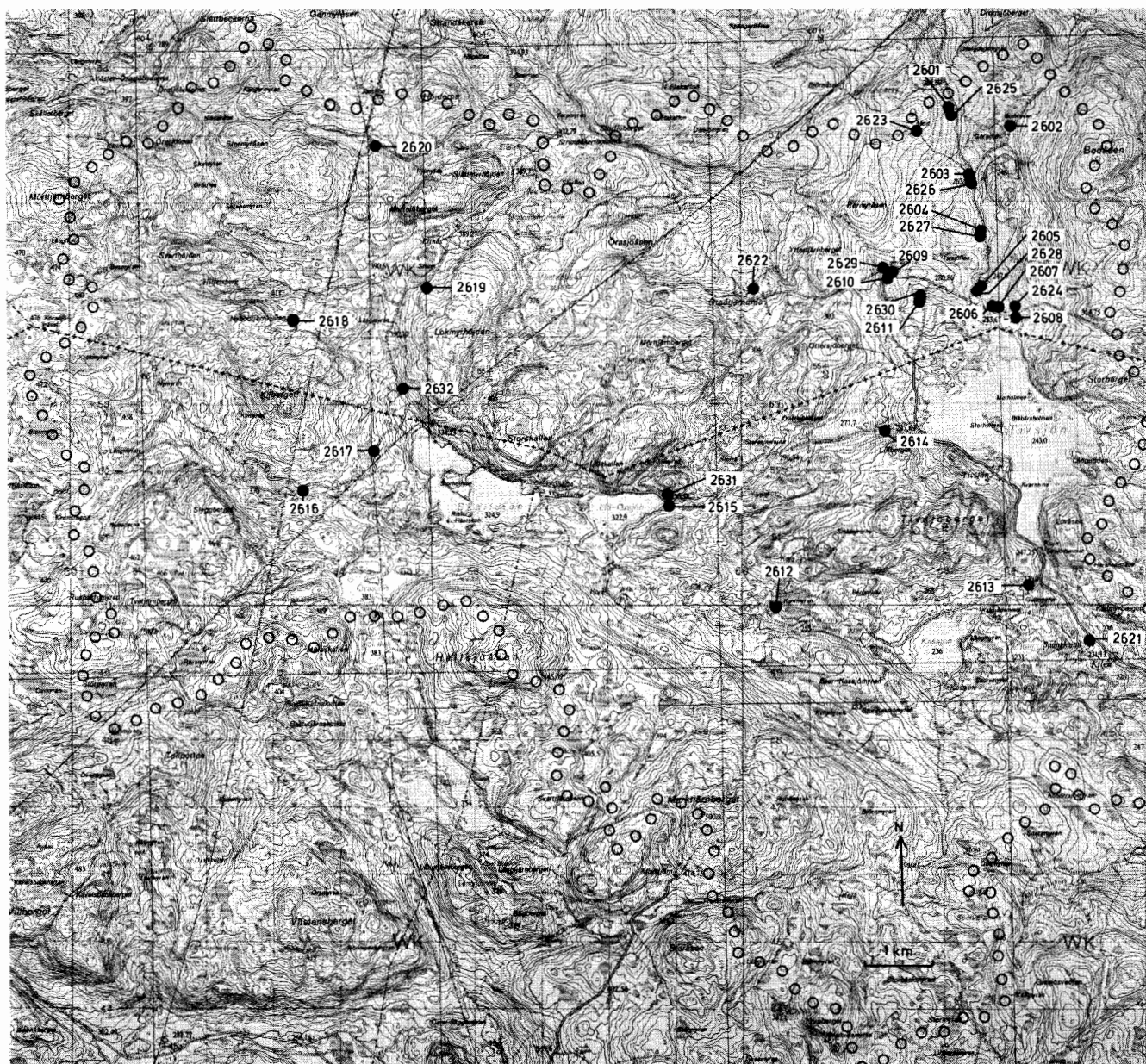


Fig. 61. Map of observation area 26 Kassjöån. Water divide of basin roughly indicated by line of circles. (Top. map 17 G NV, 17 H SV.)

the time of their formation. The hills and ridges generally are characterized by a high frequency of large boulders at the surface.

After the deglaciation the sea in the area reached a maximum level of 255–260 m above the present sea level; i. e., the eastern lowlands around the lakes Kassjöån and Stora Tivsjön were inundated. Due to the rapid land upheaval the area was under water for a relatively short period of time. Abrasion of the moraine terrain took place mainly during the regression of the sea, resulting in a partial removal of the fine fractions from

the top layer of the till. These fractions, i. e., fine sand, silt and clay, were redeposited on the sea-bottom and, nowadays, are exposed in some rather small patches along the shores of the lake Stora Tivsjön, the river Kassjöån and the lake Leringen. These sediments cover only a very small part of the total area. The wave-washed till does not differ significantly from the till above the highest shore line.

Glaciofluvial deposits are few and poorly developed. Some small eskers have been reported (Linnman, 1966), as have also deltas. The latter ones are found at the level

of the highest shore line, mainly around the lake Stora Tivsjön. The glaciofluvial material is sandy and gravelly. The topography of the glaciofluvial deposits is not particularly noticeable in the landscape. Some minor glacial lake deltas, which consist of sand, formed above the maximum level of the sea, are also observed.

The distinction between stratified and non-stratified drift is not easily seen everywhere in the area. The sorting of the glaciofluvial material, particularly that which is above the highest shore line, is incomplete. Therefore, zones of transitional material are reported from localized parts of the area.

A large portion of the area is covered by peat. The largest peatlands are found in the low valleys and on the flat, high-lying plateaux in the moraine terrain. Most of the lakes in the area are partially surrounded by expanding peatlands.

3.26.3. Hydrological and hydrogeological features

The area, which is a representative IHD basin with a size of 165 km², consists of a well-defined watershed. It is drained through the river Kassjöån to the river Gimån, a tributary to the river Ljungan which discharges into the Bothnian Sea. The river Kassjöån collects the water from the catchment via a large number of brooks and other small watercourses.

The groundwater conditions in the area follow the general pattern of a moraine landscape. Almost the whole catchment is a recharge area, divided into a number of small sub-areas with local recharge — transition — discharge characteristics. The general groundwater flow is in accordance with the moraine topography, which implies the existence of a multitude of local aquifers and flow systems. The final groundwater discharge within the area takes place through seepage into the brooks and rivers.

A number of springs have been reported by Linnman (1966). They are all very small, yielding less than 1 l/s. In periods of drought some of them are dry.

In the moraine terrain the groundwater is generally found at a depth of 0—3 m below land surface. Artesian conditions exist locally where the till is covered by fine-grained sediments. There the piezometric head may be temporarily above land surface.

Being sparsely populated, the area has only very few wells for withdrawal of water. As a matter of fact, Linnman has reported a total of 16 wells in the whole area, ranging in depth from 3.25 to 7.80 m. The extraction from the wells has no significant influence on the groundwater conditions of the basin.

3.26.4. Observation stations

The main features of the observation stations are presented in the table on page 97.

Stations nos. 2601—2624 were established by the Swedish Meteorological and Hydrological Institute (SMHI) in connection with the establishment of the representative IHD basin Kassjöån. SMHI is in charge of several other hydrometeorological observation programs within the basin. The rest of the groundwater stations (nos. 2625—2632) were established by SGU in collaboration with SMHI in order to improve the network. All stations are also used by SMHI for water balance studies of the basin.

3.26.5. Comments on the diagram

In the diagram (Fig. 62) the fluctuations of level at three different groundwater stations are shown in relation to monthly precipitation. The fluctuations of groundwater temperature at one station are also presented.

A distinct pattern of seasonal fluctuations of the groundwater level is seen at all three stations. Two periods of groundwater replenishment and two of depletion are found each year. The main period of net replenishment is April—May when water from the melting snow and thawing ground percolates to the groundwater. The resulting rise of groundwater level is approx. 1.0—1.5 m. During the period of intensive plant growth in the summer the groundwater level is falling, occasionally interrupted by minor rises due to heavy rainfalls. The secondary period of recharge is in the autumn (September—November), when only a very small part of the precipitation is lost by evapotranspiration. In some years the autumn recharge is very little, or even absent. During the winter the groundwater reservoir is depleted steadily because the ground is frozen and the precipitation is in the form of snow. The annual amplitude is described fairly well by the spring rise, i. e., 1.0—1.5 m. It is remarkable that not only the pattern of fluctuation but also the size of the annual amplitude is very similar for the three stations, representing three different aquifers. This fact suggests that the till and the granite bedrock have about the same effective porosity and that the two aquifers are hydraulically well connected. It also suggests that the glaciofluvial sand has a very limited extension and that the composition is characterized by poor sorting. The small size of the sand aquifer may imply that the surrounding till controls the groundwater level in the sand. A good hydraulic communication between the till and the sand is assumed to exist.

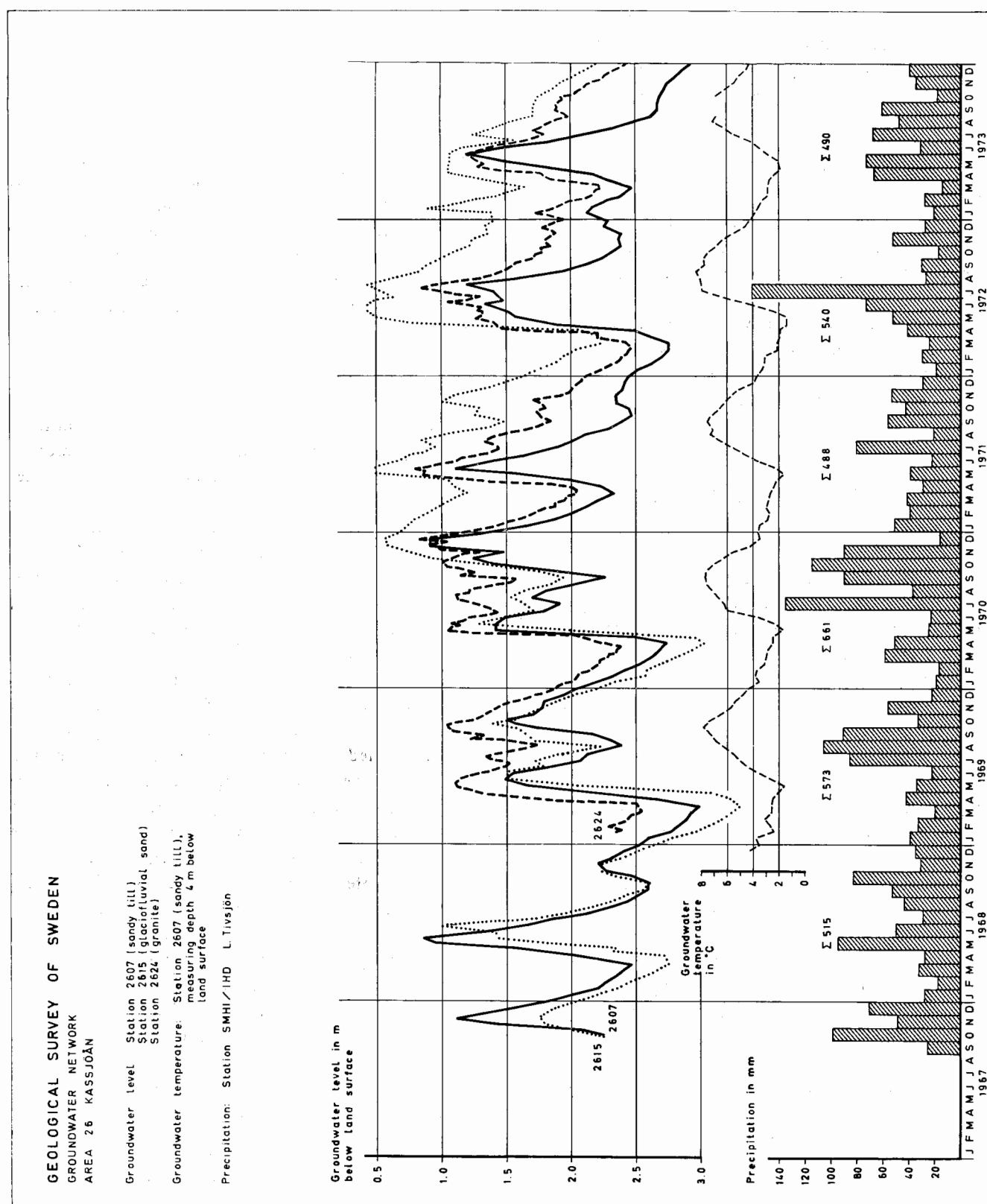


Fig. 62. Diagram from observation area 26 Kassjöän.

THE NATIONAL GROUNDWATER NETWORK OF SWEDEN

Station no.	Lat.	Long.	Land surface m a.s.l.	Geology	Depth of well m	Type of station	Obs. program	Aq.	Start of obs.	Remarks
2601	6244	1614	288	Sandy till	4	Tube	L	W	1967	
2602	6244	1615	258	" "	4	"	L	W	1967	
2603	6243	1614	269	" "	3	"	L	W	1967	
2604	6243	1614	253	" "	4	"	L	W	1967	
2605	6243	1614	257	" "	4	"	L	W	1967	
2606	6242	1615	250	" "	4	"	L	W	1967	
2607	6242	1615	251	" "	4	"	LT	W	1967	Covered by silt
2608	6242	1615	254	" "	3	"	L	W	1967	
2609	6243	1613	284	Litt. sand.	2	"	L	W	1967	Covered by peat
2610	6243	1613	285	" "	4	"	L	W	1967	
2611	6242	1613	263	Sandy till	3	"	L	W	1967	
2612	6240	1610	257	" "	5	"	L	W	1967	
2613	6240	1615	240	" "	4	"	L	W	1967	
2614	6241	1612	277	" "	3	"	L	W	1967	
2615	6241	1609	329	Gl. fl. sand	8	"	L	W	1967	Continuous recording from 1970
2616	6241	1602	371	Sandy till	5	"	L	A	1967	Covered by silt
2617	6241	1604	369	" "	4	"	L	W	1967	
2618	6242	1602	419	" "	2	"	L	W	1967	
2619	6243	1605	406	" "	3	"	L	W	1967	
2620	6244	1602	419	" "	4	"	L	W	1967	
2621	6240	1616	237	" "	6	"	L	W	1967	
2622	6243	1610	342	" "	4	"	L	W	1967	
2623	6244	1613	319	" "	5	"	L	W	1967	
2624	6243	1615	258	Granite	50	Drill	L	W	1969	Continuous recording
2625	6244	1614	280	Sandy till	4	Tube	L	W	1970	
2626	6243	1614	264	" "	4	"	L	W	1970	Continuous recording
2627	6243	1614	251	" "	3	"	L	W	1970	
2628	6243	1614	253	" "	4	"	L	W	1970	
2629	6243	1613	282	" "	3	"	L	W	1970	Covered by coarse sediment
2630	6242	1613	262	" "	6	"	L	W	1970	
2631	6241	1609	329	Gl. fl. grav.	8	"	L	W	1970	
2632	6242	1604	348	Sandy till	6	"	L	W	1970	

The increasing yearly sums of precipitation in 1968—1970 are well reflected by generally rising groundwater levels for the same years. No other multiannual trends are discernible in the variation of the groundwater levels.

The fluctuations of groundwater temperature at a

depth of 4 m show a seasonal pattern with maximum values in September—October and minimum values in May. The yearly amplitude is approx. 3.0°C, and the mean temperature for the whole period of observation is 4.4°C.

3.27. Rundhögen and 3.28. Visjövalen

3.27.1.—3.28.1. Geographical location

These two observation areas are situated close to each other in the Caledonian mountain range in the province of Jämtland in west central Sweden. The areas are situated close to the Norwegian border. The elevation of the area ranges from 650 to about 800 m a.s.l. A map of the area is shown in Fig. 63.

3.27.2.—3.28.2. Geology and geomorphology

The mountains of the Rundhögen—Visjövalen area have relatively gentle slopes and reach only moderate heights (Visjövalen, 700 m; Finnvallklumpen, 773 m a.s.l.). The highest peaks in the surrounding area are Snasahögarna (1 463 m), southeast of the observation areas, and Storkluken (1 108 m), west of the area on the Norwegian

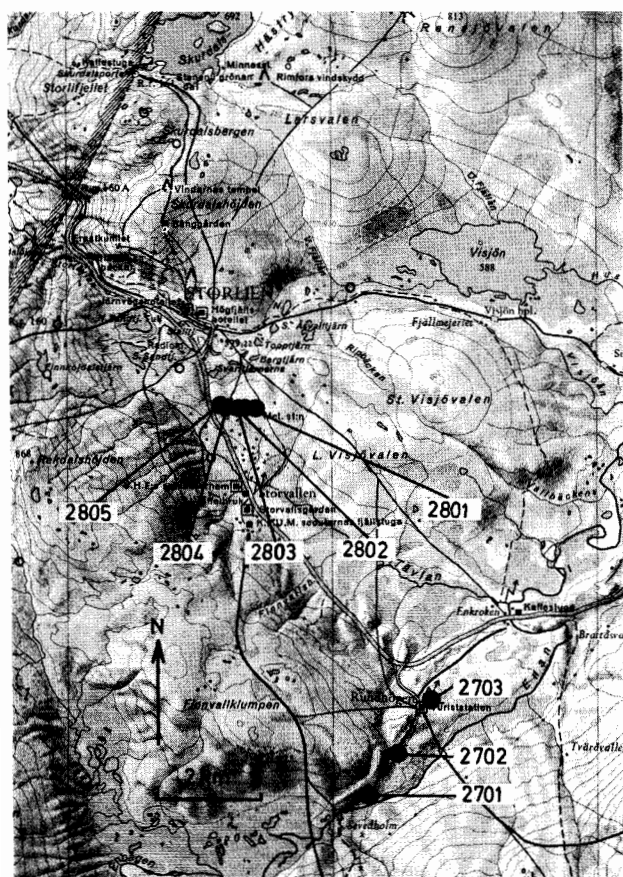


Fig. 63. Map of observation areas 27 Rundhögen and 28 Visjövalen.

border. The bedrock, consisting mainly of schists which have been metamorphosed and folded during the Caledonian orogeny, outcrops frequently in the area.

In most places the bedrock is covered with till from the latest glaciation. The till cover is thin and a thickness of 1—2 m is common. The morphology of the till surface seems, in most cases, to be strongly influenced by the morphology of the bedrock surface. However, some low ridges with the main direction parallel to the assumed icefront have been found in the Rundhögen area. Sandy till dominates, although silty and gravelly till have been found too.

An esker runs through the area in a southwest—northeast direction, following the valley of the river Enan. Within the area the esker is found north of the river at a distance of less than 1 km. In the eastern part of the area the esker is crossing the river, and east of the area the esker is found on the south side of the Enan.

A tributary esker joining the main esker at Rundhögen and extending in NW—SE is found in the valley of river Tävlan at a distance of about 1.5 km southwest of the river. Toward the northwest the Tävlan valley esker be-

comes less distinct and gradually changes into a system of terraces mainly made up of sand deposited in a narrow lake which once was dammed between the slope of Finnvallklumpen and the landice then occupying the Tävlan valley. Through abrasion in the successively lowered glacial lake and through erosional activity of small brooks on the northwestern slope of Finnvallklumpen, parts of the terraces have been removed and the material has been redeposited at lower levels. During the last stages of the Tävlan valley glacial lake, sediments consisting of fine sand and silt were deposited on the floor of the Tävlan valley. Due to later fluvial erosion the sediments now appear as low hills of irregular shape.

Extensive areas are covered by peat, both in the moraine terrain on the slopes of Visjövalen and Finnvallklumpen and in the sediment areas in the valleys. The thickness of the peat only rarely exceeds 1—2 m.

3.27.3.—3.28.3. Hydrological and hydro-geological features

The surface water of the area drains through the river Enan and its tributary, the river Tävlan. The Enan belongs to the river system of the Indalsälven, which discharges its water into the Bothnian Sea.

The flow pattern of the groundwater in the moraine terrain is strongly influenced by the local topography. The main flow directions are towards the rivers of the area.

The flow direction of the groundwater in the eskers and the terraces of glacial lake sediments on the slopes of Finnvallklumpen coincides with the main flow direction of the groundwater in the moraine terrain on the slopes. Hence, the groundwater movement in these deposits is transverse to the directions of the esker ridges and terraces.

A large number of springs have been recorded from the area. Most of them are found in connection with the slopes of the eskers or terraces, which are facing the Enan or Tävlan valleys.

3.27.4.—3.28.4. Observation stations

The main features of the observation stations are presented in the table on page 100.

The locations of the stations are shown on the map in Fig. 63. The springs used as sampling stations yield 2—5 l/s (no. 2701 and no. 2702) and 15—20 l/s (no. 2703). The wells used as observation stations (nos. 2802—2805) were established for the water supply of vacation houses. Only very small quantities of water are extracted from these wells and they are used only spo-

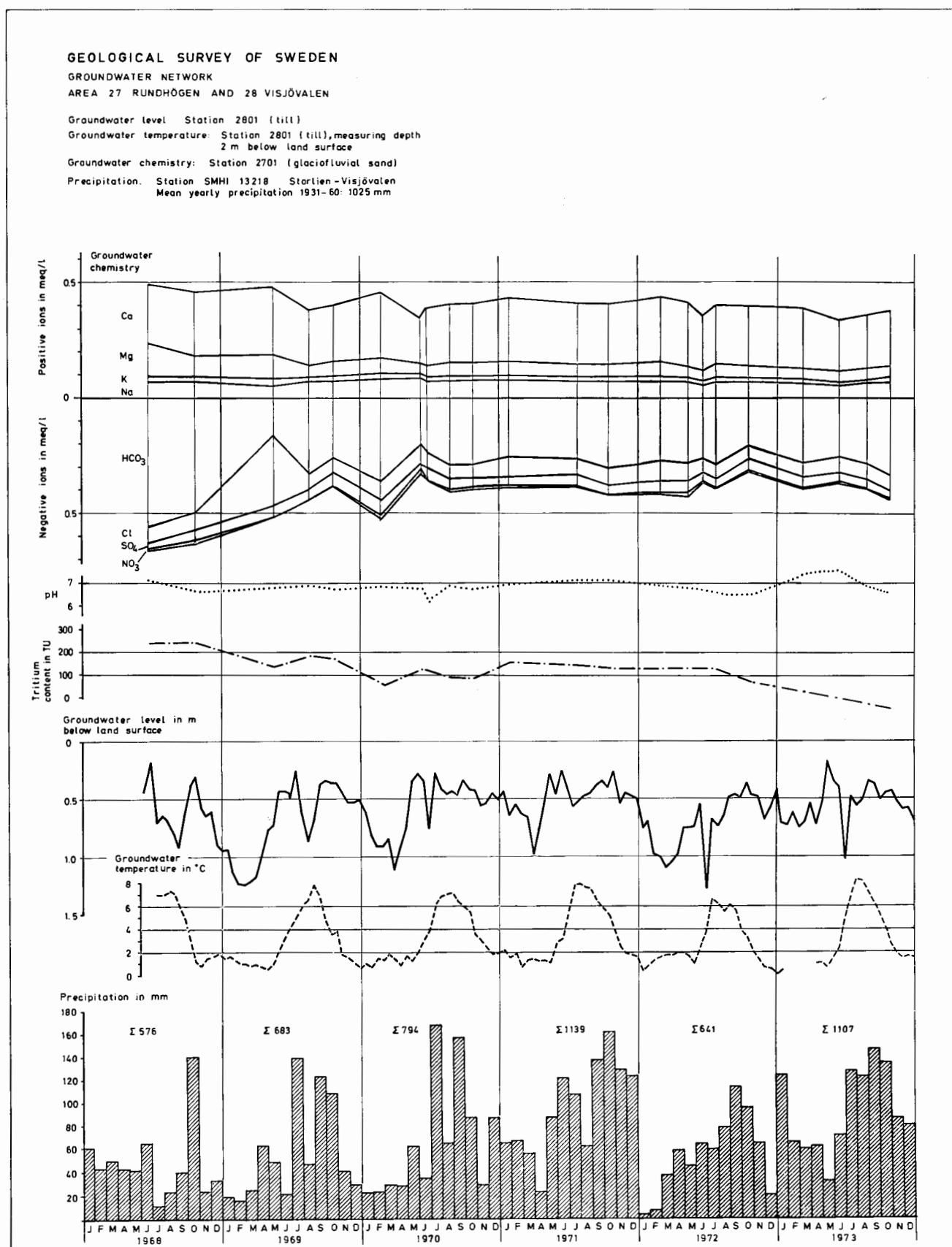


Fig. 64. Diagram from observation areas 27 Rundhögen and 28 Visjövalen.

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Station no.	Lat.	Long.	Land surface m a.s.l.	Geology	Depth of well m	Type of station	Obs. program	Aq.	Start of obs.	Remarks
2701	6314	1210	649	Gl. fl. sand	—	Spring	C	W	1968	Sporadical sampling
2702	6314	1211	655	" " "	—	"	C	A	1970	
2703	6315	1211	620	" " "	—	"	C	W	1972	
2801	6318	1208	636	Sandy till	2	Dug	LT	W	1968	Dug down to the bedrock surface
2802	6318	1208	631	" "	2	"	LT	W	1968	
2803	6318	1208	612	" "	2	"	LT	W	1968	
2804	6318	1208	605	" "	2	"	LT	W	1968	
2805	6318	1208	598	" "	2	"	LT	W	1968	

radically. The observation well no. 2801 is used for the water supply of the meteorological station at Visjövalen. However, only small quantities of water are pumped from this well. The influence from the pumping in these wells on the groundwater level is assumed to be negligible.

3.27.5.—3.28.5. Comments on the diagram

In the diagram (Fig. 64) the variations of groundwater chemistry, level and temperature are shown for selected stations.

The water at station no. 2701 has a very low salt content. Calcium and bicarbonate are the dominating ions. No clearly visible seasonal fluctuations are found in the diagram. However, a trend of decreasing salt content is found during the period of 1968—1970. This long-term variation is probably caused by the great variations in annual precipitation these years.

A decreasing tritium content in the water is also found during the sampling period. This trend reflects the decreasing tritium content in the precipitation.

The pattern of seasonal fluctuations in the groundwater level in the till at station no. 2801 is characterized by low levels during the winter and a rapid rise of the levels when the snow melts (April—June). The groundwater generally has a high level in the summer and the autumn. In some years a small summer minimum is found. The yearly amplitude is 0.7—1.0 m.

The great variations in yearly precipitation found during the observation period do not seem to influence the yearly maximum levels of the groundwater. However, a correlation between precipitation and both duration and intensity of the minimum levels of the groundwater can be seen in the diagram.

The variation of the temperature of groundwater in till at a depth of 2 m below land surface shows a seasonal cyclicity with highest temperatures in July—September and lowest in the winter and early spring (November—May). The yearly amplitude is 6—7°C, and the mean temperature for the whole period of observation is 3.3°C.

3.29. Ytterån

3.29.1. Geographical location

The observation area Ytterån is situated in the province of Jämtland in central Sweden, approx. 30 km northwest of the town of Östersund. The area is bordered by Lake Storsjön at a mean elevation of 292 m a.s.l. (see map, Fig. 65). The highest altitude within the observation area is approx. 310 m a.s.l.

3.29.2. Geology and geomorphology

The bedrock within the area consists of Ordovician shales. They have not been found to outcrop anywhere within the observation area.

The bedrock is covered by glacial drift, mainly till, which has a gently undulating topography. Many of the hollows and low-lying parts of the area have peat at the

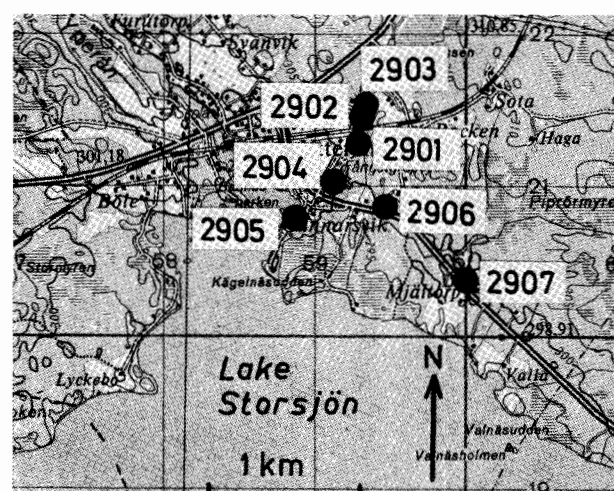


Fig. 65. Map of observation area 29 Ytterån. (Top. map 19 E SV.)

surface. At least three different types of till have been found: sandy till, clayey silty till and clay till. All types are characterized by a great predominance of shale particles which are derived from the local bedrock.

An esker runs through the area in the direction NNE—SSW. It is only 50—100 m wide and, at the most, 10 m high. According to J. Lundqvist (1969), the esker is typical for the area: subglacially formed in crevasses in the ice in a NE—SW direction. A characteristic feature for these types of eskers is their location on south-facing slopes, perpendicular to the contour lines.

The material in the esker is dominated by particles of shale of all grain sizes.

3.29.3. Hydrological and hydrogeological features

The surface water and the groundwater in the moraine terrain flow toward the peat-covered, low-lying parts of the area. In these parts the water is collected by numerous brooks and ditches that discharge into Lake Storsjön. The level of the lake is artificially regulated, and the maximum yearly range is 2.75 m. The groundwater within the esker flows longitudinally at a gradient of approx. 0.7 per cent toward Lake Storsjön. At a few places there is indication of groundwater seepage at the foot of the esker. No distinct spring has been found along the esker, though. The only flowing spring of some importance within the area is situated in peat at the eastern margin of the area, at the mire Piprörsmýren. The discharge of the spring has been estimated to 5—7 l/s.

The producing wells within the area are few and only supply water to separate households. Their influence on the general groundwater situation is insignificant.

Pumping tests have been performed in the esker at observation station no. 2905 (Orrje & Co, 1954). A safe yield of 5 l/s was obtained, but no community water well has been established, mainly due to the presence of phenol in the groundwater. The phenol is assumed to originate from a nearby tar production plant which is not operating any longer.

3.29.4. Observation stations

The main features of the observation stations are presented in the table below.

The locations of the stations are shown on the map, Fig. 65. Stations nos. 2901—2905 are situated in the esker along a line running from the highest part of the esker to the lowest part close to the lake. They were established in 1954 by Orrje & Co in connection with an investigation for a community water well. Stations nos. 2906 and 2907, made by SGU, are situated in silty, sandy till, 500 and 1 200 m from the esker, respectively.

The pumping of water from the relatively few and small wells for separate households within the area do not materially influence the groundwater levels at any observation stations.

3.29.5. Comments on the diagram

The variations of the groundwater levels in sand and till and the groundwater temperature in sand are presented in the diagram (Fig. 66).

There is a distinct, seasonal pattern of fluctuation in the groundwater levels, both in sand and till. The main recharge of groundwater takes place in connection with the period of snow-melting in April. The groundwater reaches its peak level in May. During the summer the levels generally fall although with frequent interruptions of rises due to heavy rainfall. There is also a secondary period of recharge in the autumn. During the winter the groundwater levels fall steadily with few and short interruptions, and the low extremes are reached in March. In the glaciofluvial sand (station no. 2901), the low levels in March are generally accompanied by almost as low levels in the autumn. The annual amplitude in sand is 55—90 cm and in till, 70—140 cm.

The groundwater response to rainfall is evident. Thus, e. g., the heavy rainfall in July, 1970, the period of most intense plant growth, causes a rise of groundwater levels of 50 cm (sand) and 45 cm (till). No clear multiannual trend in the variation of groundwater levels

Station no.	Lat.	Long.	Land surface m a.s.l.	Geology	Depth of well m	Type of station	Obs. program	Aq.	Start of obs.	Remarks
2901	6319	1411	300	Gl. fl. sand	2	Tube	L	W	1968	
2902	6319	1411	303	" " "	8	"	LT	W	1968	Temp. 1968—1969
2903	6319	1411	307	" " "	6	"	L	W	1968	
2904	6318	1411	296	" " "	5	"	LT	W	1968	Temp. from 1969
2905	6318	1411	294	" " "	3	"	L	W	1968	
2906	6318	1411	298	Sandy till	4	"	L	W	1969	
2907	6318	1412	300	" "	3	"	L	W	1969	

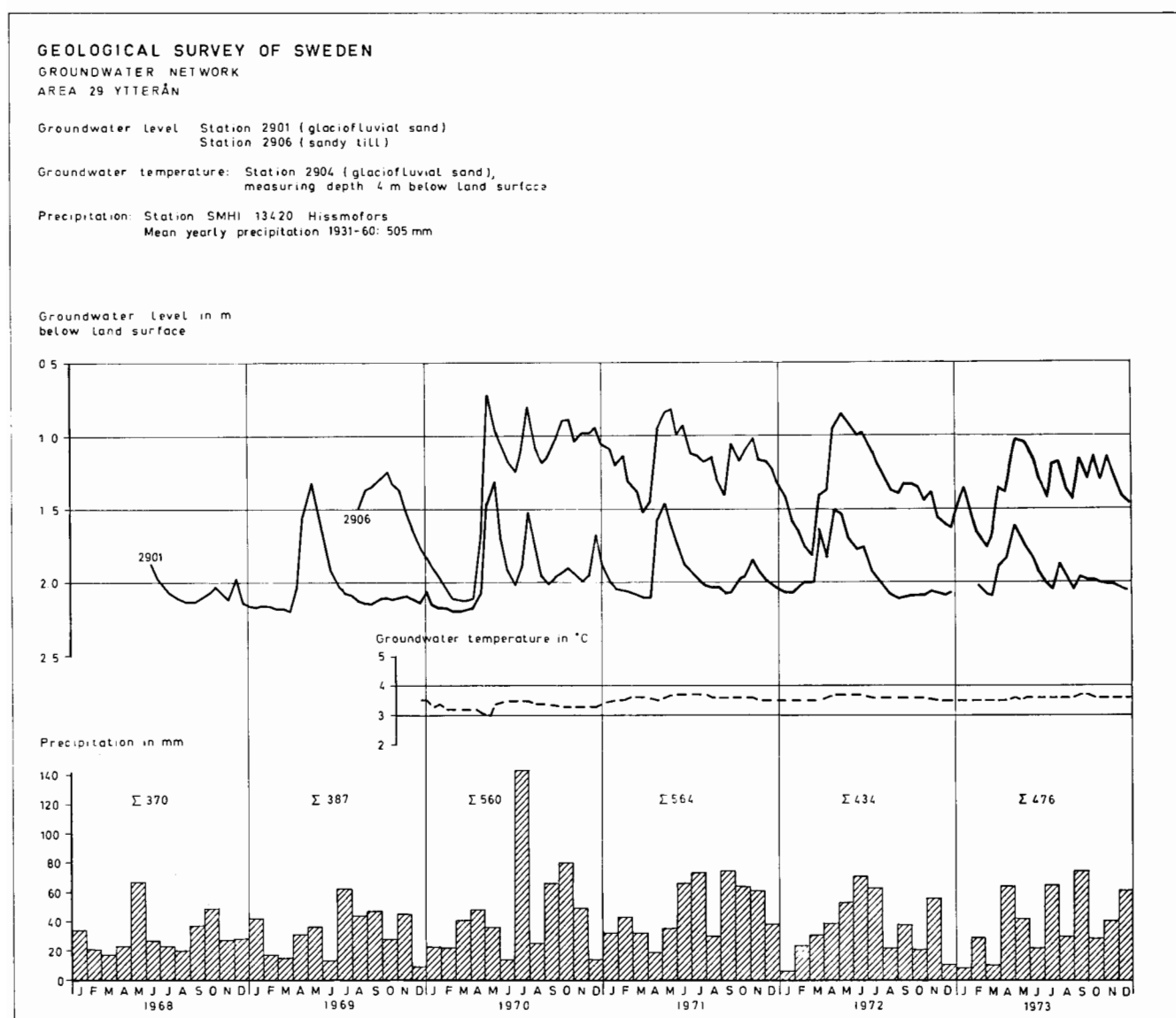


Fig. 66. Diagram from observation area 29 Ytterån.

can be found. In the till, though, a weak, falling trend can be seen from 1970 to 1973. The very small recharge in the autumn of 1972 is explained by low amounts of precipitation during the same season.

In order to study the groundwater temperature, a stationary thermometer was installed 4 m below land

surface at station no. 2904 in December, 1969. The seasonal fluctuations are remarkably small, in general less than 0.5°C for a year. The highest temperature is reached in May—July while the lowest temperature occurs in the winter. The mean temperature for the period 1970—1973 is 3.5°C.

3.30. Viksmon

3.30.1 Geographical location

The observation area Viksmon is situated in central east Sweden, approx. 20 km southwest of the town of Sollefteå. The area borders on the lakes Hultsjön and Graningesjön at an elevation of 200—203 m a.s.l. (see

map, Fig. 67). The highest parts of the area are approx. 225 m a.s.l.

3.30.2. Geology and geomorphology

The area is characterized by sandy and, in localities, silty deposits of Quaternary age. An isolated glacioflu-

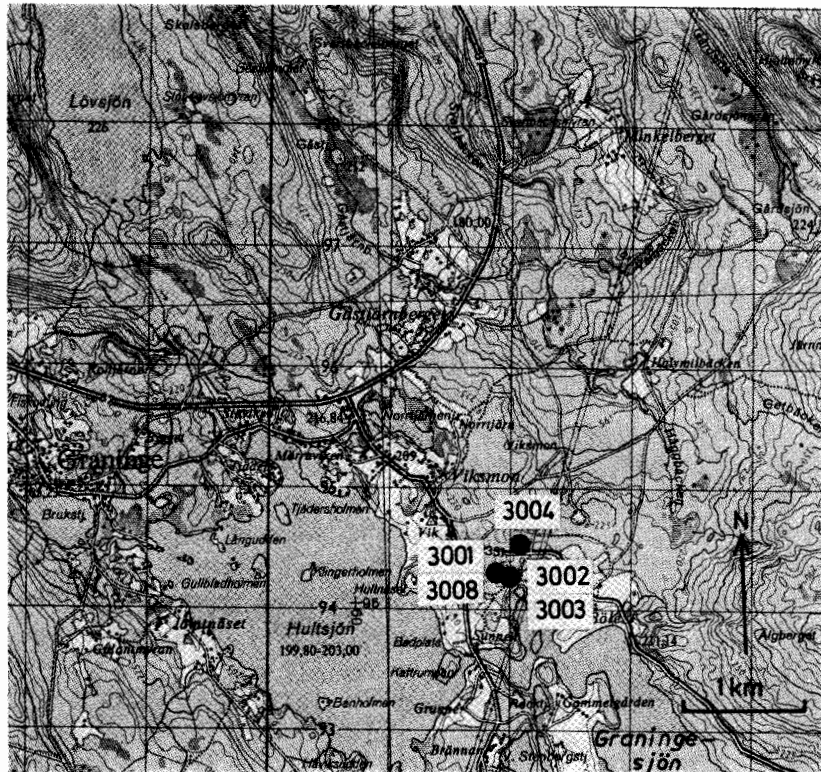


Fig. 67. Map of observation area 30 Viksmon. (Top. map 18 H NV.)

vial deposit is found around the northern tip of the lake Gräningsjön. Sand is the dominating fraction at the surface, whereas coarser material has been found at some depth in a gravel pit. Several deep and steep-sided dead-ice hollows are found in the area. Some of them are floored by peat having a thickness of more than one meter. Borings in two of the hollows have penetrated 14 m of sand and silt without reaching bedrock. The rims of the hollows are situated 15–20 m above their floors. Therefore the total thickness of the loose deposits are likely to exceed 30 m.

After the glaciofluvial deposition the area received large amounts of fine-grained sediments, mainly silt, but even some clay, from the river discharging into the inundated valley of the area. These fluvial sediments concealed much of the glaciofluvial deposits and the surrounding moraine terrain. When, due to the land upheaval, the area became a zone of abrasion, a far-reaching transport and redeposition took place. In this way the sand was moved and came to cover fluvial silt on top of parts of the glaciofluvial deposit. For this reason it is not possible to state definitely the extension of the primary glaciofluvial material. It is very likely, though, that it could be found under the concealing sediments surrounding the central part of the area.

Wave-washed sandy till and exposures of the Pre-

cambrian bedrock are found in localized spots of the area. These outcrops indicate a rather undulating topography of the basement.

3.30.3. Hydrological and hydrogeological features

The observation area is bordered by the lakes Hultsjön and Gräningsjön which are drained northwestwards through the river Bruksån to the river Faxälven. The Faxälven is a tributary to the Ångermanälven river discharging into the Bothnian Sea. No surface watercourses are found within the area because the infiltration capacity of the superficial sediments is good. In the moraine terrain, though, minor brooks are present in the low-lying parts of the terrain.

The general groundwater flow is directed toward the lakes. The lakes are regulated in order to steady the seasonal fluctuations. Therefore the regulation controls the adjacent groundwater level to a certain degree. During periods of rapidly rising lake level (chiefly in May), the groundwater level is lying below the lake level. This is also generally the case during periods of high lake stages in the summer and autumn. The gradient from the lake to the groundwater observation stations is, in such cases, 0.1–0.2 per cent. In May and June the gradient may approach 1 per cent. In the winter the gradient also

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may amount to 1 per cent, but then sloping from the observation stations towards the lakes. These facts suggest that the hydraulic conductivity is not very good, which indicates the presence of silt or clay between the lakes and the observation stations. At observation stations in the dead-ice hollows of the sediment, the groundwater is found 4—6 m below land surface. Borings in the flat-lying sandy area have penetrated 15 m without encountering any water.

A pumping test was performed by an engineering company, K-Konsult-LBF, in 1958, in the central part of the observation area. Pumping was done from tube no. 3008 with a constant withdrawal of 2.5 l/s. No significant cone of depression was recorded at a distance of 50 m from the pumping well. Therefore, a safe yield of more than 2.5 l/s was postulated. The quality of the water was satisfactory. However, no community water supply well was ever founded in the area. Instead, water is extracted from a bedrock well in the northwestern part of the area. The mean withdrawal is only 0.25 l/s. No other wells are pumped in the area.

3.30.4. Observation stations

The observation stations are presented in the table below.

Stations nos. 3001—3003 and 3008 were established by K-Konsult-LBF in 1958 as part of the aforementioned investigation for a suitable water well site. The other stations have been erected by SGU for the national groundwater network.

3.30.5. Comments on the diagram

In the diagram (Fig. 68) the variations of groundwater level, lake level, groundwater temperature, snow cover and frost penetration are shown in relation to monthly precipitation.

The seasonal patterns of variation are very distinct in

the curves of the groundwater level and the lake level. From a late winter minimum, in April—May, the levels are rising steeply to a maximum level in July. By means of regulation the high level is maintained all through the summer, autumn and early winter until a rather rapid decline, in December—January, leads to the minimum level in April—May. Whereas the maximum level is maintained for several months, the minimum level persists for only a few days. The yearly amplitude is 1.5—2.0 m. A time lag of approx. one month can be seen between the variations of the lake level and the groundwater level. Therefore, in periods of rising and high levels the lake level is found above the groundwater level, whereas, during periods of falling and low levels, the reverse situation is present.

A weak multiannual trend of falling levels is found for the period 1969—1973. A simultaneous trend of decreasing yearly amplitudes is also present. The trends reflect the low precipitation during the last few years, not only within and close to the observation area, but also in the entire catchment area of lake Graningesjön.

The variations of the groundwater temperature were recorded at a depth of 5—6 m in 1968—1971. In late 1971 a stationary thermometer was placed 11 m below land surface. Therefore the readings are more reliable from that date to present than those taken earlier. A seasonal pattern of fluctuations is present, with high temperatures in the winter and low in the summer. The yearly amplitude is close to 1.0°C and the mean temperature for the period of observation is 4.3°C.

The graphs for snow cover and frost penetration show that the snow cover has been rather thin for the last four winters (less than 0.5 m). The ground is covered by snow for approx. 6 months. The ground is frozen for almost the same period, i. e., from November—December to April—May. In exceptional cases, the ground is frozen as long as in June. The maximum recorded depth of the frost penetration in snow-covered ground in a

Station no.	Lat.	Long.	Land surface m a.s.l.	Geology	Depth of well m	Type of station	Obs. program	Aq.	Start of obs.	Remarks
3001	6303	1701	207	Gl. fl. sand	13	Tube	LT	W	1968	Continuous recording 1970—71
3002	6303	1701	208	„ „ „	9	„	L	W	1968	
3003	6303	1701	206	„ „ „	8	„	L	W	1968	
3004	6303	1701	208	„ „ „	8	„	L	W	1969	
3008	6303	1701	207	„ „ „	13	„	L	W	1971	Continuous recording
F 11	6303	1701	210	„ „ „	—	Frost	F	—	1970	
F 12	6303	1701	213	„ „ „	—	„	F	—	1970	
F 13	6303	1701	208	„ „ „	—	„	F	—	1970	
F 14	6303	1701	215	„ „ „	—	„	F	—	1970	

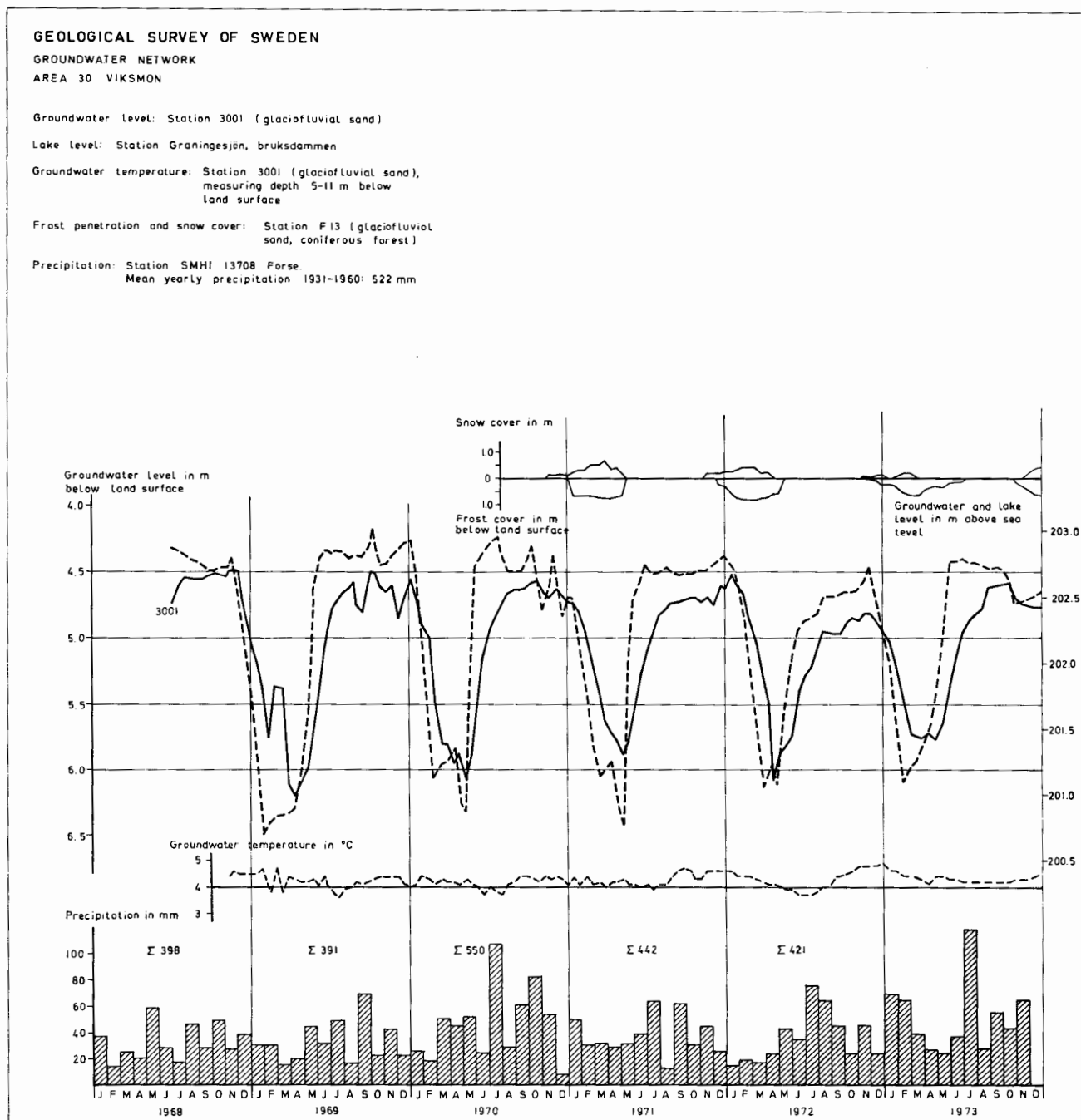


Fig. 68. Diagram from observation area 30 Viksmon.

coniferous forest within the observation area is 0.8 m. It can be noted that the period of snow-melting and frozen ground coincides fairly well with the bottom turning point of lake and groundwater levels. The main

rise of the levels, though, is caused by large contributions of water from the entire catchment area of lake Graningesjön.

3.31. Lo-Frök

3.31.1. Geographical location

The observation area Lo-Frök is situated in east central Sweden, on the northern shore of the river Ångermanälven, approx. 25 km eastsoutheast of the town of Sollefteå (see map, Fig. 69).

3.31.2. Geology and geomorphology

The observation area is made up of Precambrian granite which is partly overlain by various fluvial sediments, mainly fine sand. The observation stations are established where the bedrock surface slopes steeply down to the valley floor which is only 3–10 m a.s.l. The bedrock is exposed frequently at higher levels. At a distance of one kilometer from the margin of the sediment-filled valley the elevation of the land surface is 50–100 m a.s.l. The direction of the valley is assumed to be tectonically controlled.

3.31.3. Hydrological and hydrogeological features

The hydrology of the area is dominated by the proximity to the large river, Ångermanälven. The river is only

approx. 500 m from the observation stations. The surroundings are drained to the river by small streams and ditches, of which Loån is the biggest within the area. The groundwater in the sediments is assumed to be directly controlled by the river. In the moraine and bedrock terrain the groundwater moves in small, local flow systems. These systems form part of a major system discharging into the Ångermanälven river valley. The movement of groundwater in the bedrock is restricted to fissures. At the points of observation the groundwater level is found at a depth of 1–7 m below the ground surface.

3.31.4. Observation stations

The main features of the three stations are presented in the table on page 107.

The locations of the stations are shown on the map, Fig. 69. All three stations were drilled for water supply purposes, but they were used only very sporadically for withdrawal of water. Since the start of observations, no extraction has taken place from these three wells. The small communities of Lo and Frök are supplied with water from a surface water works at Ytterlänns. No

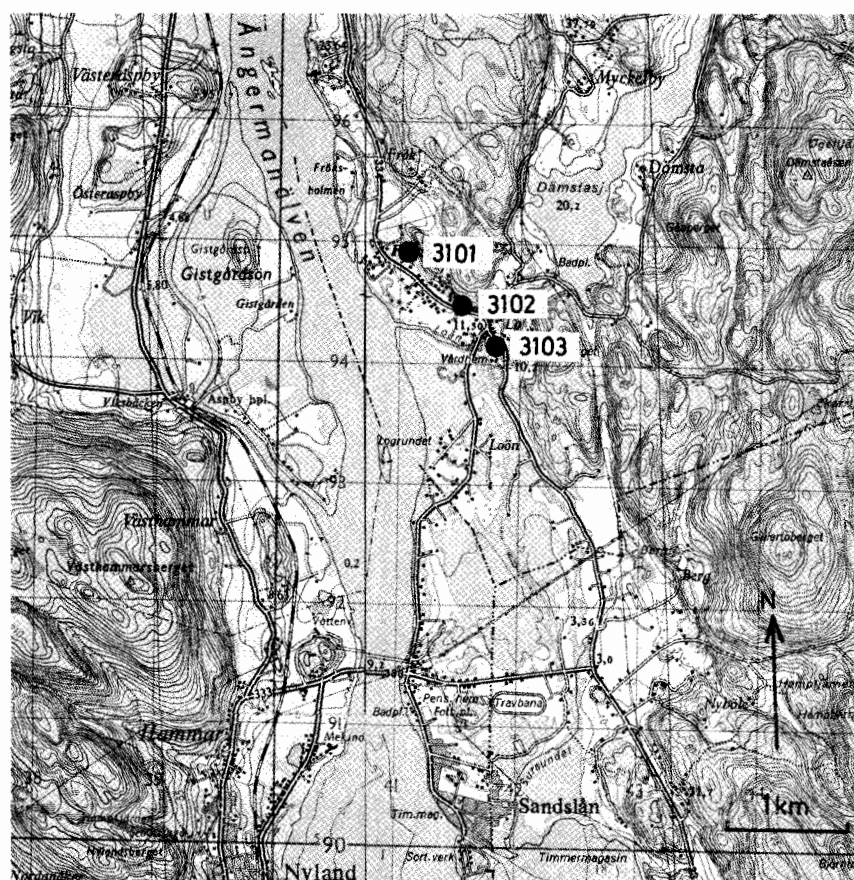


Fig. 69. Map of observation area 31 Lo-Frök. (Top. map 18 H NO, 18 I NV.)

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Station no.	Lat.	Long.	Land surface m a.s.l.	Geology	Depth of well m	Type of station	Obs. program	Aq.	Start of obs.	Remarks
3101	6302	1748	9	Granite	89	Drill	LT	W	1968	Covered by till Temp. 1968—1972 Continuous recording since 1972
3102	6303	1748	9	„	73	„	LT	W	1968	Covered by till Temp. since 1972
3103	6303	1747	7	„	163	„	L	W	1968	

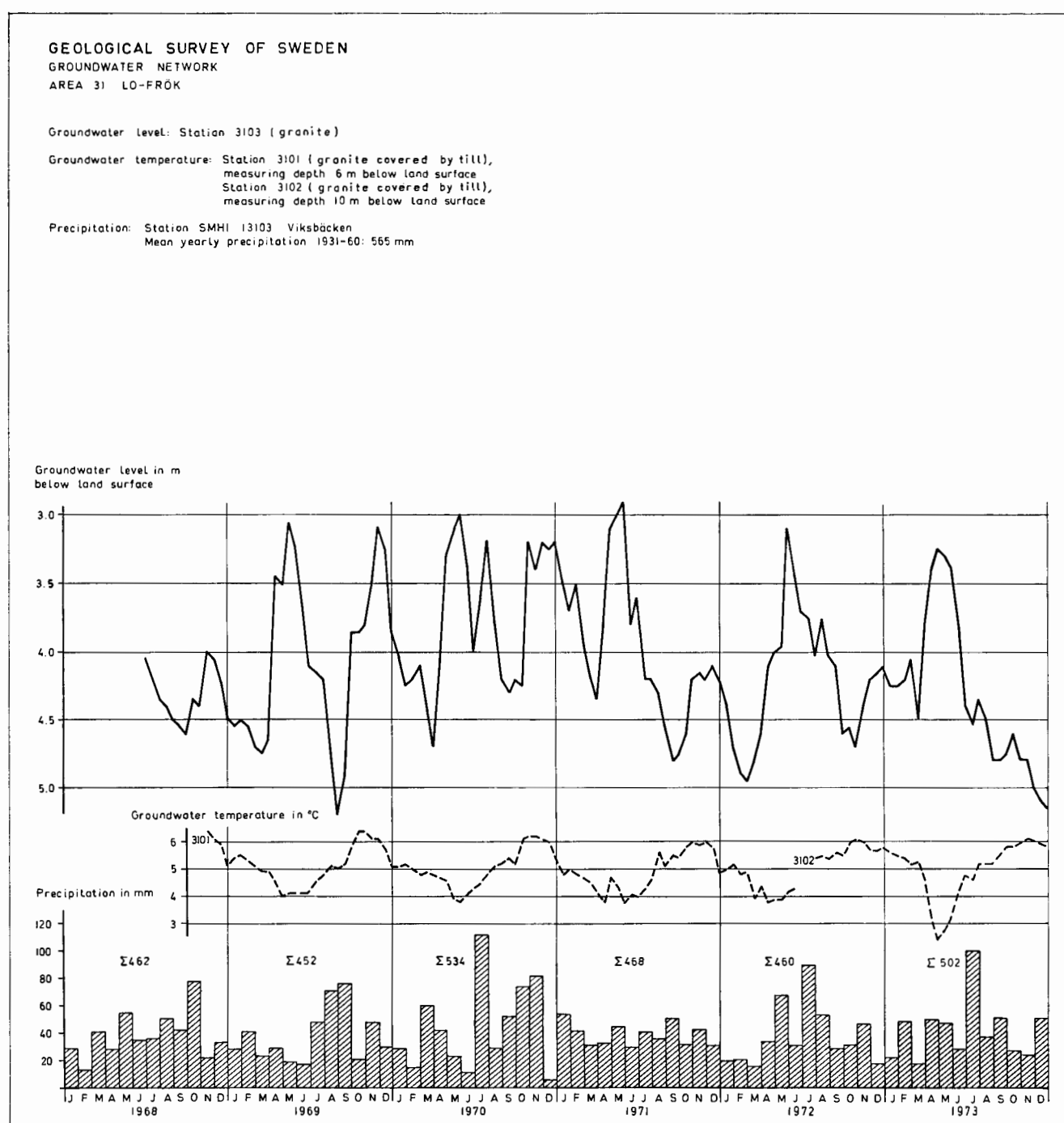


Fig. 70. Diagram from observation area 31 Lo-Frök.

extraction of water takes place within the observation area. Therefore, there is no human influence on the variation of groundwater. In connection with periods of intensive snow-melting stations nos. 3101 and 3102 can be directly influenced by meltwater. This is an indication of good hydraulic conductivity in the upper part of the bedrock and in the overlying loose deposits. Due to the local topography around well no. 3101, a direct flow of meltwater from the surface into the pipe may have occurred at times of extensive snow-melting. Since 1972, this possibility is partly eliminated by the installation of an extension of the pipe.

The bedrock at station no. 3101 is reported to be only moderately fractured and covered by 10 m of loose deposits. At station no. 3102 the corresponding thickness is 2 m. The upper 21 m of the bedrock are heavily fractured at station no. 3102. At station no. 3103 there is no loose overburden, and the bedrock is reported to be without extensive fractures.

3.31.5. Comments on the diagram

In the diagram (Fig. 70) groundwater level, groundwater temperature and precipitation are shown for the period of observation.

A distinct, seasonal pattern of groundwater level fluctuations is present. The peak level is reached in May—June, i. e., just after the period of snow-melting. A secondary peak occurring in late autumn or early winter is caused by heavy rainfalls after the period of plant growth. Sometimes, a quick response to precipitation can be recorded in the groundwater even in the middle of the summer. The yearly amplitude is approx. 2 m.

For the years 1968—1971 a weak trend of rising levels is discernible. This is particularly true for the yearly minimum levels. From 1971 to 1974, the trend has been falling weakly. During the whole period of observation the yearly precipitation has been below average. Therefore the groundwater level, too, is assumed to be below normal.

The fluctuation of the groundwater temperature at a depth of 6 m below the ground surface shows a seasonal cyclicity. The lowest temperature is present in May—June, probably influenced from cold meltwater, whereas highest temperature is reached in October—November. The yearly range is 2.0—2.5°C with a mean temperature of 5.2°C.

3.32. Hälla

3.32.1. Geographical location

The observation area Hälla is situated in north central Sweden, approx. 160 km west of the town of Umeå. The area is a part of the river Ångermanälven valley at an elevation of 292—297 m a.s.l. (see map, Fig. 71).

3.32.2. Geology and geomorphology

The Precambrian bedrock is not exposed anywhere within the area, but it is assumed to consist of porphyritic Revsund granite. The overburden consists of deposits from the latest glaciation and from the period after that. Till, which is the dominating type of soil at some distance from the river valley, is found only very sporadically in the valley. It has been found to be coarsely sandy in composition. Glaciofluvial deposits of esker type occur as patches in the valley. At the village of Hälla in the southern part of the area the glaciofluvial valley train diverges from the present Ångermanälven river valley and follows a former drainage path toward the southeast. The material of the esker is mainly sand.

After the deglaciation the glaciofluvial sedimentation was gradually succeeded by the deposition of fluvial sediments. Thus, large volumes of fine sand and silt were

accumulated in the broad river valley. The present river channel, which is much narrower than its predecessor, has cut into the fluvial sediments. These are partly covered by peat nowadays.

The topography of the observation area is very flat, whereas the river valley itself is set apart from the moraine terrain by a climb of 50—100 m. The slope along the river-course is very gentle.

3.32.3. Hydrological and hydrogeological features

The river Ångermanälven has a width of approx. 300 m where it flows through the observation area. Due to several hydroelectric power plants on the river, the flow is regulated in order to even out the large seasonal variations of discharge. The regulated mean discharge at Hällby, 8 km south of the southern edge of the area, is 159 m³/s. The maximum weekly mean value is 731 m³/s, and the corresponding minimum value is 39 m³/s. By comparison it can be noted that the mean discharge at Sollefteå, close to the mouth of the river, is 471 m³/s.

Minor brooks, which come from the surrounding moraine terrain, discharge into the river within the observation area. The peatlands in the river valley are drained through ditches to the river.

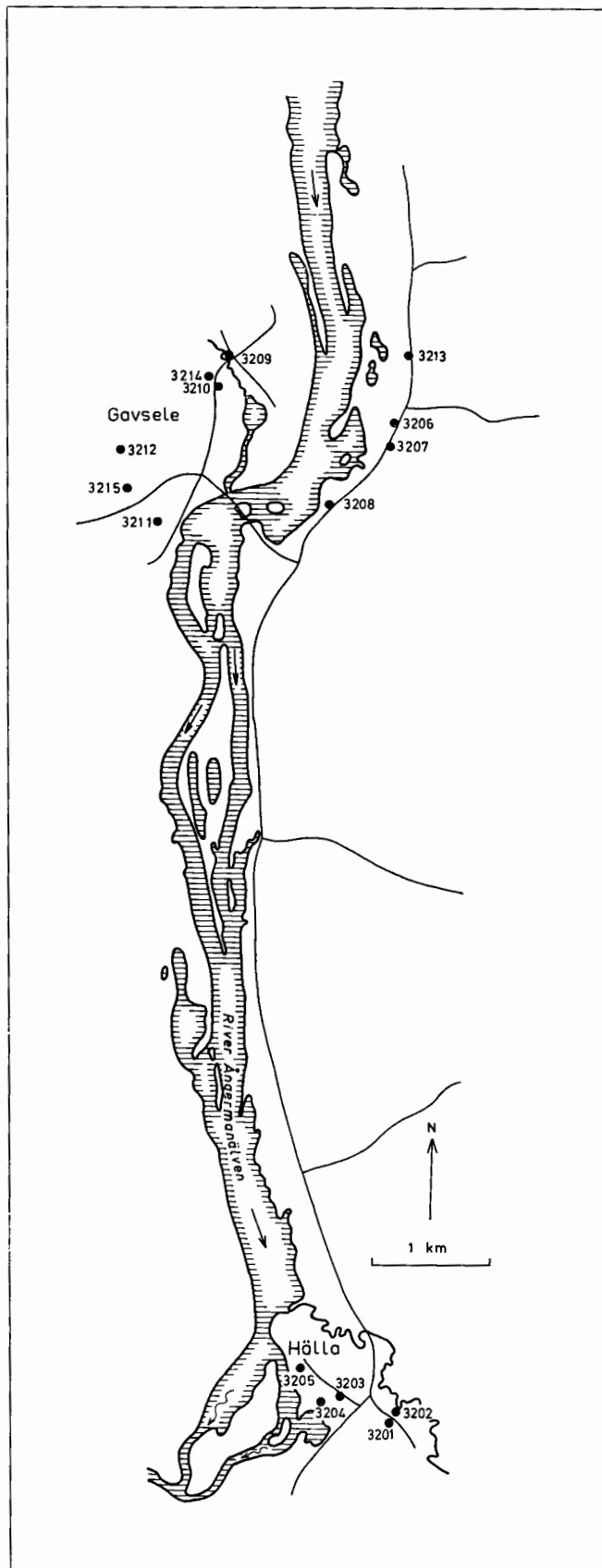


Fig. 71. Map of observation area 32 Hälla.

The groundwater in the valley is controlled by the river. The groundwater level is found 1—3 m below the surface of the valley sediments. Very gentle gradients are found in the groundwater levels, although the existence of silty parts in the sediments may induce local and temporary steep gradients.

The two small communities in the area, Hälla and Gavsele, have municipal dug wells. There are also several dug wells for separate households. In total, a withdrawal of 0.2—0.3 l/s for the two communities, respectively, has been assumed. This low volume of extraction is regarded as having no influence on the general groundwater conditions.

The hydroelectric power plant at Hällby, 8 km southwest of Hälla, started to operate in March—April, 1970. In connection with the start of operation, a reservoir was created upstream above the dam at Hällby. Behind the dam, the water level was raised by a maximum of 19 m. The reservoir is assumed to have no impact on the groundwater conditions in the observation area as this is situated at a higher elevation than the maximum reservoir level.

3.32.4. Observation stations

The main features of the observation stations are presented in the table on page 110.

The stations are selected from a network of observation points established by the power company Gulsele AB as a contribution to the investigations concerning the consequences of the aforementioned power plant and its reservoir.

3.32.5. Comments on the diagram

In the diagram (Fig. 72) the variations of groundwater levels are shown from three stations: in till, in silt and in peat, respectively. Station no. 3204 is situated in the community of Hälla, only 60 m from the bank of the river. Stations nos. 3213 and 3215 are situated in Gavsele, 160 m and 600 m from the river, respectively. All three stations show a general, seasonal cyclicity with highest levels in May—June and lowest in March—April. The yearly amplitude is 0.5—1.0 m. As can be expected, the curves differ in detail as much as they correspondingly differ in geology and in distance to the controlling river.

Unfortunately, the variation of the river level has not been recorded within the observation area. A calculation of the fluctuations of the river stages at Hälla, though, has been made from data on discharge of the

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Station no.	Lat.	Long.	Land surface m a.s.l.	Geology	Depth of well m	Type of station	Obs. program	Aq.	Start of obs.	Remarks
3201	6355	1717	296	Gl. fl. sand	3	Tube	L	W	1958	
3202	6355	1717	295	Fluv. silt	3	"	L	W	1958	
3203	6356	1717	293	Peat	2	"	L	W	1958	
3204	6356	1717	294	Grav. till	2	"	L	W	1958	
3205	6356	1716	295	Fluv. silt	4	"	L	W	1958	
3206	6400	1717	296	" "	2	"	L	W	1958	Tube of tile
3207	6400	1717	296	" "	3	"	L	W	1958	" " "
3208	6400	1717	295	" "	2	"	L	W	1958	
3209	6401	1716	296	" "	4	"	L	W	1958	Tube of tile
3211	6400	1715	293	" "	1	"	L	W	1958	" " "
3212	6400	1715	294	" "	2	"	L	W	1958	" " "
3213	6400	1717	296	" "	3	"	L	W	1958	
3214	6401	1716	296	" "	4	"	L	W	1958	
3215	6401	1716	294	Peat	2	"	L	W	1958	Tube of tile

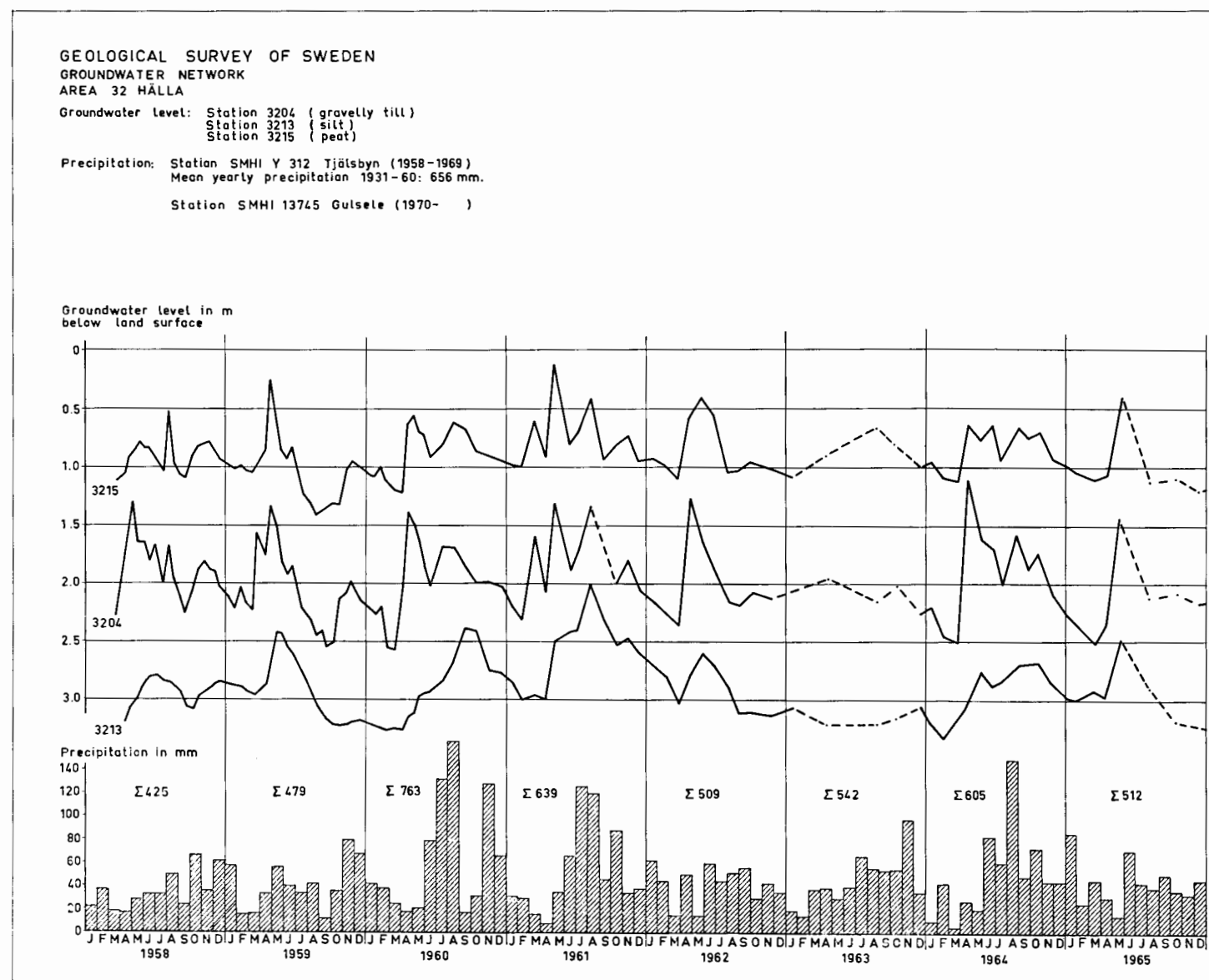
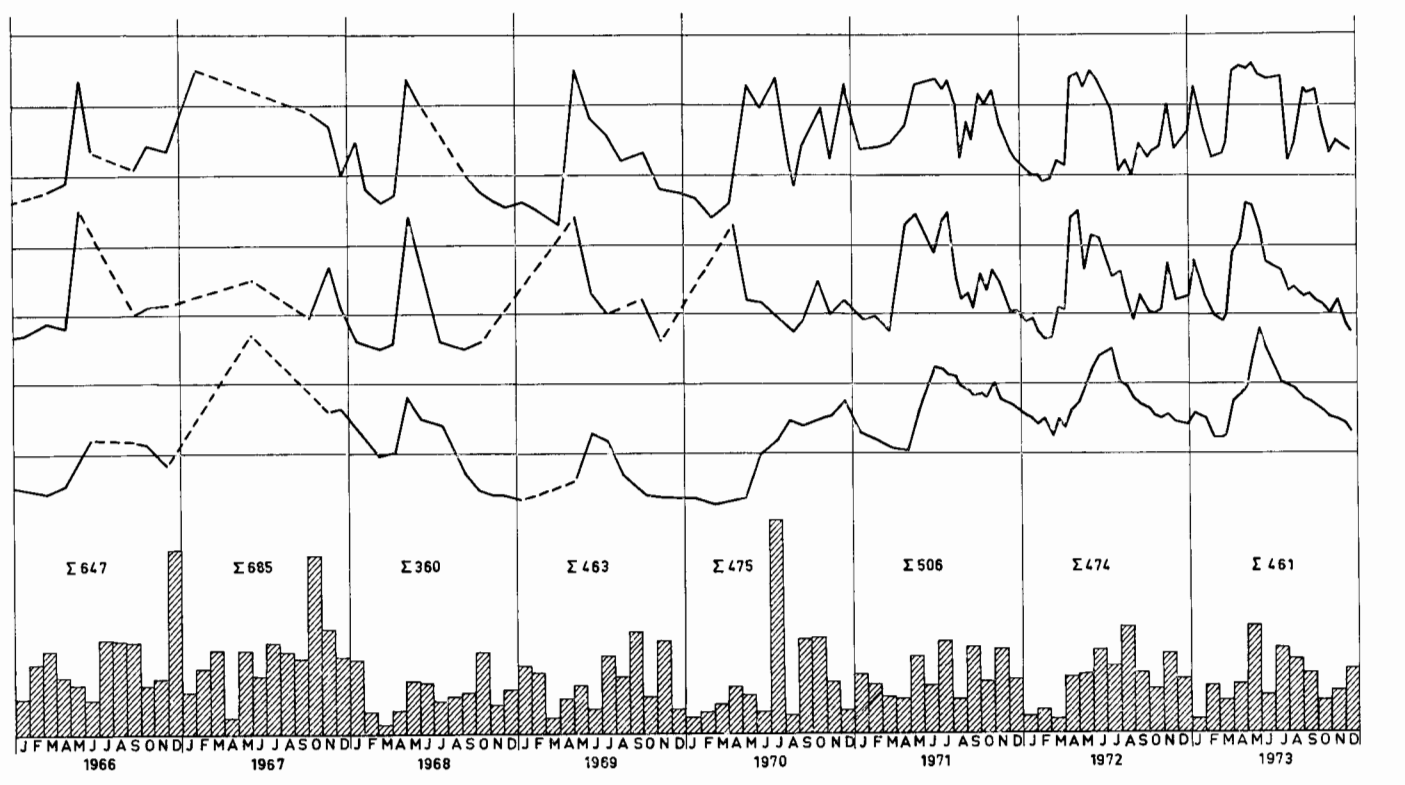


Fig. 72. Diagram from observation area 32 Hälla.

river Ängermanälven at Gulsele, 15 km south of Hälla, and a constructed diagram showing the relation between discharge and level at Hälla. There is a generally good agreement between the fluctuations of the river level and the fluctuations of the groundwater level at adjacent stations. At station no. 3204, situated 60 m from the river, the groundwater is usually found 0.5–1.0 m above the level of the river. In periods of spring flood, the river may temporarily rise above the groundwater level at station no. 3204.

No distinct long-term trends are discernible with the exception of the rising trend since 1970 for station no. 3213 (station no. 3215 shows a similar, although weaker, trend). The reason for this development, and the reason

why station no. 3204 does not show the same trend, are not known. Neither the regulation of the river nor the recorded climatological variations can explain the multiannual trends since 1970 at station no. 3213. It is also apparent that station no. 3213 shows a smoother curve of variation than the other two stations. A possible explanation is the presence of coarse glaciofluvial (or fluvial) sediments under the silt at station no. 3213. Thus, the assumed, good hydraulic communication within the large glaciofluvial aquifer facilitates the repression of fluctuations and excludes much of the local and rapid fluctuations. In such a case, station no. 3213 can be expected to be representative of a fairly large area and suitable for studies of long-term variations.



3.33. Sävarheden

3.33.1. Geographical location

The observation area Sävarheden is situated in the coastal district of the province of Västerbotten, approx. 25 km northnortheast of the town of Umeå. The elevation of the area ranges from 55 to 70 m a.s.l. The area is shown on the map, Fig. 73.

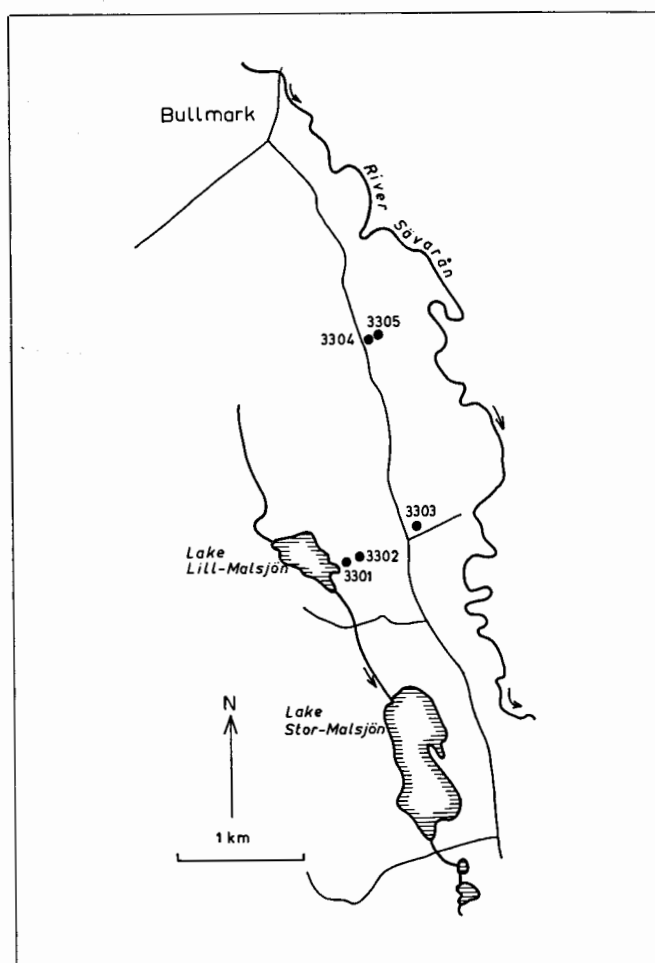


Fig. 73. Map of observation area 33 Sävarheden.

3.33.2. Geology and geomorphology

The main part of the observation area is comprised of glaciofluvial deposits belonging to an esker trending NNW—SSE. The esker was accumulated in the valley of the river Sävarån and can be traced without interruptions for approx. 30 km. Farther up in the valley the esker appears as discontinuous ridges separated by fields of silt and sand. Within the observation area the surface of the esker is thoroughly wave-washed. Therefore, there is no well-defined crest of the esker. Its surface is smooth with gentle slopes. The central part of

the esker consists of coarse sand and gravel, according to borings within the area and gravel pits outside the area. Redeposited sand covers the flanks of the esker. Fine sediments are found commonly at the margins of the esker, particularly around the river Sävarån, east of the esker, where silt dominates at the surface. Extensive areas of peat are found on both sides of the esker.

In the moraine terrain west of the esker, sandy till plays an important role. The terrain lies somewhat higher than the esker.

The Precambrian basement crops out in the moraine terrain and in the redeposited sediments particularly west of the esker. The bedrock consists of gneisses.

3.33.3. Hydrological and hydrogeological features

No surface water is found on the esker due to its high infiltration capacity.

West of the esker the water from the peat and moraine terrain collects into brooks and ditches that drain into the lakes Lill-Malsjön and Stor-Malsjön. The lakes discharge into a brook that joins the river Sävarån south of the observation area. On the eastern side of the esker the water flows into Sävarån through minor ditches. The river Sävarån discharges into the Bothnian Sea 15 km east of Umeå.

The groundwater in the esker within the observation area flows northwards from an assumed transversal groundwater divide in the southern part of the area, in the vicinity of the lake Lill-Malsjön. The groundwater divide is situated in an area where several outcrops of bedrock are found. These outcrops may indicate the presence of a high-lying bedrock surface, beneath the esker, which acts as a barrier for the groundwater flow. A small branch of the esker is found between the lake Lill-Malsjön and the main esker. Groundwater levels in the branch are 3–4 m higher than those in the main esker, 500–700 m away. These circumstances imply that the hydraulic conductivity between the branch and the main esker, and within the branch itself, is rather poor. Complete or partial bedrock barriers under the loose deposits may cause this situation.

Seepage of groundwater from the esker branch into the lake Lill-Malsjön is very probable.

A longitudinal gradient of approx. 1.4 per mille has been calculated over a distance of 900 m south of the groundwater divide. A corresponding gradient of the same magnitude, north of the divide, has been assumed.

A groundwater flow from the esker eastwards into the river Sävarån is indicated by the presence of peat-

land at the eastern foot of the esker. The peat is assumed to be partially fed by groundwater from the esker. Small springs are found close to the river just north of the observation area.

Peatlands are also found west of the esker. The hydraulic relationships between the water in these peatlands and the water in the esker are not investigated. Height conditions indicate that the esker, in certain areas, may receive water from the peatlands. It is also possible that the hydraulic conductivity between the peat and the esker is very poor and allows no major exchange of water.

Sävarheden and the southern extension of the esker have been dealt with by VAB (1968) in connection with an investigation of the geology and hydrogeology of the esker. The investigation proposes five areas suitable for future extraction of groundwater. All five areas are situated south of the aforementioned groundwater divide. At the northern margin of the observation area, in the town of Bullmark, the establishment of another well was proposed by VAB (1965). In 1971 2–5 l/s were withdrawn from that well. No other community well is present within, or in the vicinity of, the observation area. In Sävar, approx. 12 km southeast of the observation area, a new well was constructed in 1969. A pumping test indicated a capacity of 18 l/s. The present extraction of water is approx. 5 l/s.

By a decision in 1971, the entire length of the esker from Sävar to Bullmark was declared a protected area for water supply. There are no further plans for the exploitation of water within the area.

3.33.4. Observation stations

The main features of the observation stations are presented in the table below.

The locations of the groundwater stations are shown on

the map, Fig. 73. The groundwater stations are selected by SGU from a profile network of stations erected by VAB in 1967. The stations for frost penetration were established by SGU. None of the stations are influenced by pumping or other human activities.

3.33.5. Comments on the diagram

In the diagram (Fig. 74) the variation of groundwater level and temperature is shown in relation to precipitation. The thickness of the snow cover and the penetration of frost are also shown.

There is a very clear seasonal pattern of fluctuation of the groundwater level. A major spring rise starts while there is still some snow left on the ground and while the ground is frozen. The highest levels are reached in late June, i. e., 1–2 months after the snow has vanished. From the peak level the groundwater is falling all through the summer, autumn and winter. A minor autumn recharge took place in 1970, and a similar period of recharge was present in the winter of 1972–1973. The lowest levels occur in April, prior to the melting of the snow and the thawing of the frozen ground. The yearly amplitude is 0.6–1.0 m.

A weak trend of a falling groundwater level is discernible from 1968 to 1973. The spring recharge in 1973, though, has almost restored the high levels from 1968.

The variation of the groundwater temperature, in silt at a depth of approx. 9 m below ground surface, shows a seasonal cyclicity which has the highest temperatures in the winter and the lowest in the summer. This fact indicates a time lag between the temperature of the air and of the groundwater of approx. half a year. The yearly amplitude is in the order of 0.5°C, and the mean temperature for the whole period of observation is 3.8°C.

The jagged curves for 1969 and 1970 are caused by an unsatisfactory measuring technique, which was re-

Station no.	Lat.	Long.	Land surface m a.s.l.	Geology	Depth of well m	Type of station	Obs. program	Aq.	Start of obs.	Remarks
3301	6400	2030	65	Gl. fl. grav	9	Tube	L	W	1968	
3302	6400	2030	68	„ „ „	9	„	L	W	1968	
3303	6400	2030	63	„ „ sand	9	„	L	W	1968	Continuous recording since 1972
3304	6400	2029	67	Ma. la. silt	8	„	L	W	1968	Covered by coarse sediment
3305	6400	2029	67	„ „ „	8	„	LT	W	1968	Covered by coarse sediment
F 36	6400	2030	63	Gl. fl. sand	—	Frost	F	—	1970	
F 37	6400	2029	70	Ma. la. silt	—	„	F	—	1970	
F 38	6400	2030	59	„ „ „	—	„	F	—	1970	

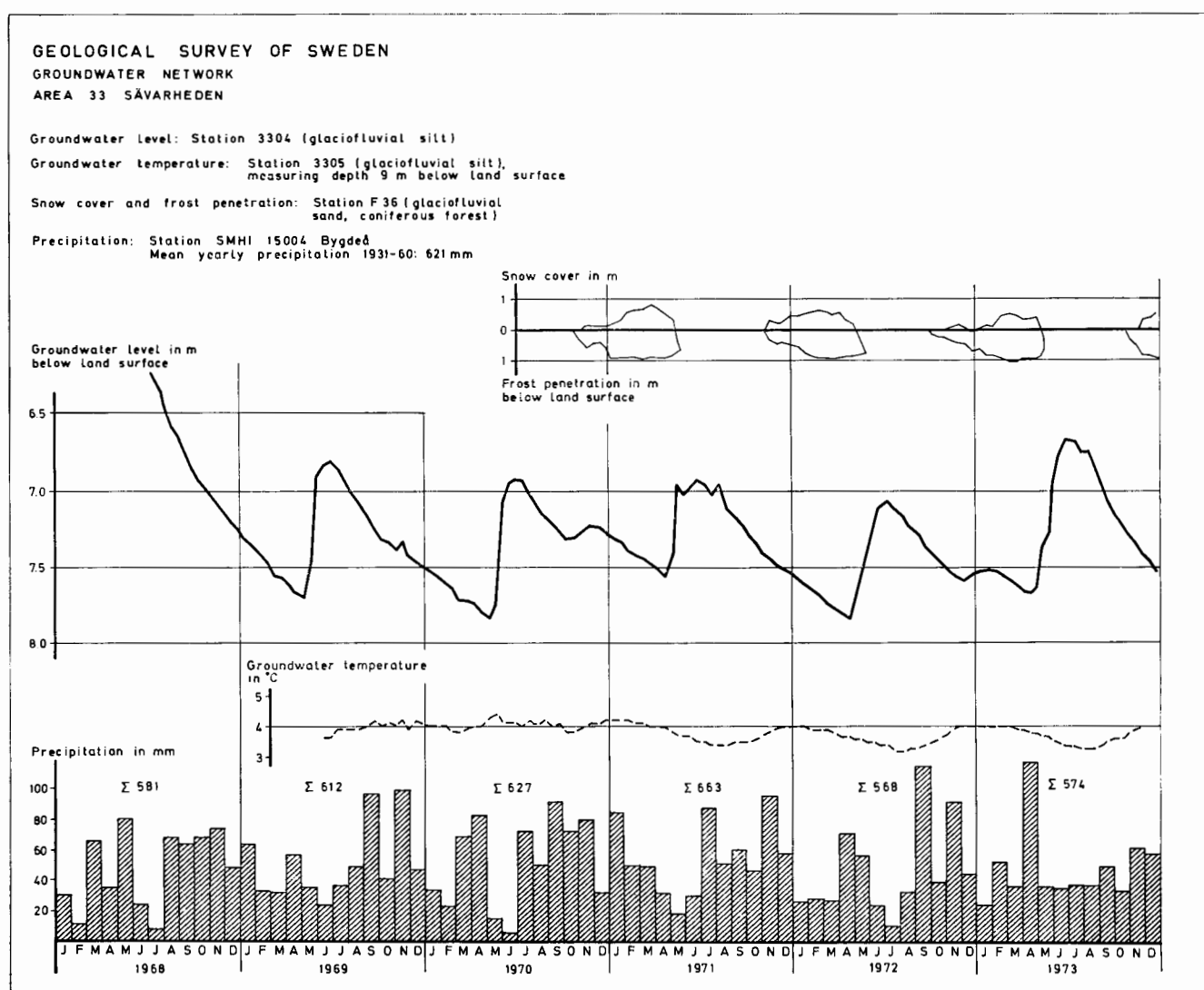


Fig. 74. Diagram from observation area 33 SÄVARHEDEN.

placed by a more reliable method in the beginning of 1971.

The diagram for snow cover and frost penetration shows that the ground is frozen from October—Novem-

ber to May—June. The greatest depth of frost penetration is close to one meter, and the snow cover may reach 0.7—0.8 m.

3.34. Drängsmark

3.34.1. Geographical location

The observation area Drängsmark is situated approx. 20 km north of the town of Skellefteå in the coastal part of Norrland, approx. 5—10 km from the coast of the Gulf of Bothnia. The altitude of the observation area ranges from 30 to 70 m a.s.l. The area is shown on the map, Fig. 75.

3.34.2. Geology and geomorphology

The area is made up of a part of an esker which can be traced continuously for 50 km from the coast north of Skellefteå toward the northwest. This esker was formed subaqueously. The esker is generally 500 m wide and stands 10—15 m above surrounding terrain. The surface of the esker is smoothed by wave action. Dead-ice hol-

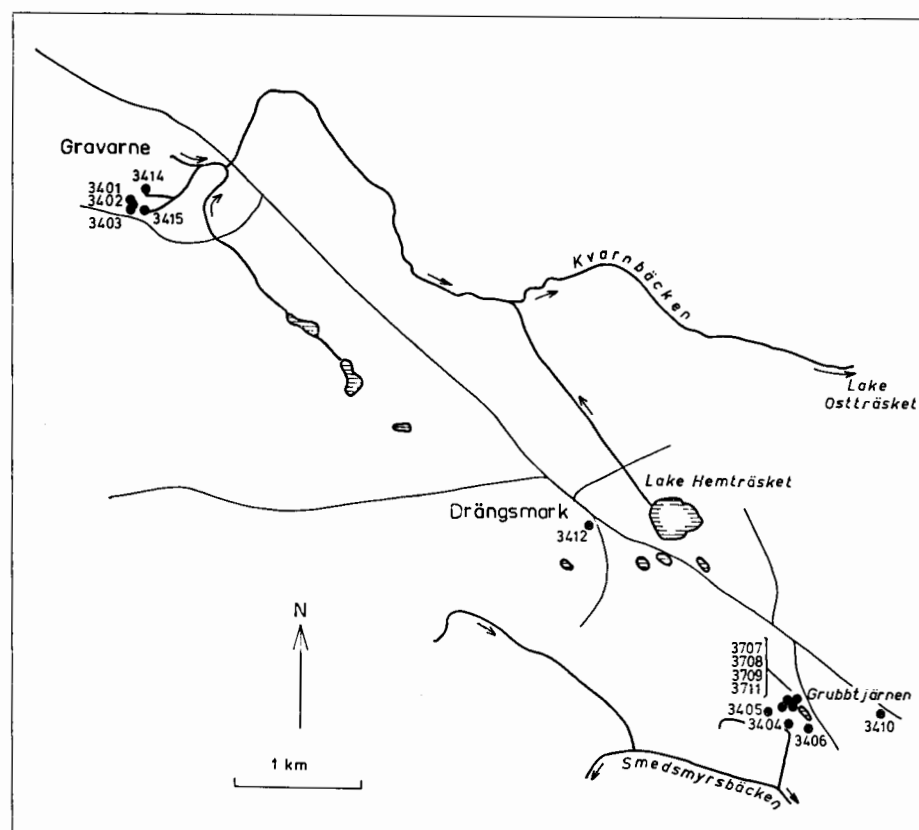


Fig. 75. Map of observation area 34 Drängsmark.

lows are rather common, and some of these are filled by lakes. In general, the lake bottoms are impermeable and the water level of the lakes does not have any hydraulic connection with the groundwater. Sand appears to be the most common fraction at the surface. However, gravel pits show that the central part of the esker consists of a coarser material. The esker is surrounded by sandy and silty sediments redeposited from the esker through wave action in the sea. Extensive peatlands are found in the lower parts of the surrounding terrain. The formation of peat is supposed to be caused partly by groundwater leakage from the esker.

The bedrock (porphyritic Revsund granite) is exposed very sparsely in contact with the esker, whereas outcrops are more common in the surrounding moraine terrain.

3.34.3. Hydrological and hydrogeological features

The main direction of groundwater flow is toward the southeast, but groundwater barriers (high-lying bedrock) can divert the flow in some parts of the area. In the northwestern part of the area several large natural springs appear. A discharge of 70 l/s has been recorded

(Orrje & Co, 1964) from the springs in this part of the area.

The surface water from the area mainly is drained by two small rivulets: the Kvarnbäcken discharging into the lake Ostträsket and the Smedsmyrbäcken discharging into the sea.

3.34.4. Observation stations

The main features of the stations are presented in the table on page 117.

The locations of the groundwater stations are presented on the map, Fig. 75. Stations nos. 3401—3403 and 3414—3415 are situated close to each other in a discharge area in the northwest at Gravarne. Stations nos. 3404—3409, 3411 and F 26—F 28 are situated in the southeast, close to a little tarn, the Grubbtjärnen, which occupies a dead-ice hollow.

Station no. 3410 is situated approx. 800 m east of the Grubbtjärnen, and nos. 3412 and F 29 are situated in the village of Drängsmark, half-way between Gravarne and the Grubbtjärnen.

Most of the stations were established in 1964 in connection with an investigation for a groundwater supply

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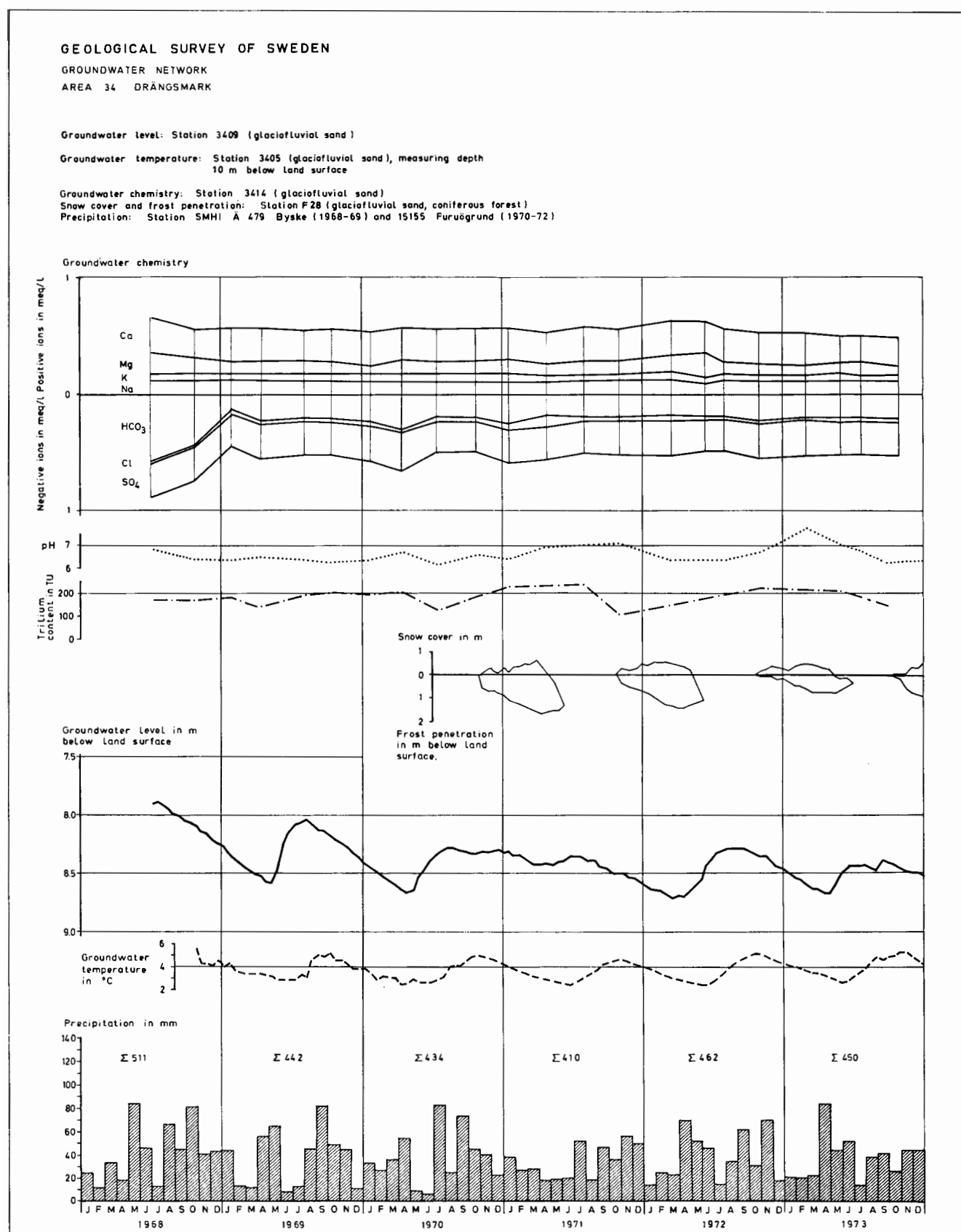


Fig. 76. Diagram from observation area 34 Drängsmark.

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Station no.	Lat.	Long.	Land surface m a.s.l.	Geology	Depth of well m	Type of station	Obs. program	Aq.	Start of obs.	Remarks
3401	6456	2053	62	Gl. fl. sand	3	Tube	L	W	1968	Gauging four times a year
3402	6456	2053	61	" " "	8	"	L	W	1968	
3403	6456	2053	62	" " "	14	"	L	W	1968	
3404	6454	2059	34	" " "	12	"	L	W	1968	
3405	6454	2059	35	" " "	11	"	LT	W	1968	
3406	6454	2059	33	" " "	13	"	L	W	1968	Gauging four times a year
3407	6454	2059	35	" " "	12	"	L	W	1968	
3408	6454	2059	36	" " "	16	"	L	W	1968	
3409	6454	2059	36	" " "	17	"	L	W	1968	
3410	6454	2100	31	" " "	12	"	L	W	1968	
3411	6454	2059	36	" " "	9	"	L	W	1968	Gauging four times a year
3412	6455	2056	47	" " "	7	"	L	W	1969	Sporadic sampling
3414	6456	2053	62	" " "	—	Spring	C	W	1968	
3415	6456	2053	62	" " "	—	"	C	W	1968	
F 26	6454	2059	34	" " "	—	Frost	F	—	1970	
F 27	6454	2059	35	" " "	—	"	F	—	1970	
F 28	6454	2059	36	" " "	—	"	F	—	1970	
F 29	6455	2056	47	" " "	—	"	F	—	1970	

project. The investigation was carried out by Orrje & Co (1964 and 1965 a and b). A pumping test was performed in 1965 close to the Grubbtjärnen, and a safe yield of at least 50 l/s was recorded. However, no extraction of groundwater has been done to date (1974). The small, community water supply well for Drängsmark is situated close to station no. 3412. The extraction from the well is approx. 0.5 l/s. A number of small wells for separate households are found in Drängsmark. No influence from these wells on the groundwater levels at the stations has been observed.

3.34.5. Comments on the diagram

All observed parameters are shown from the selected stations in the diagram (Fig. 76).

The low salt concentration and the relatively high tritium content indicate a short residence time for the groundwater in the northwestern part of the area. The time series is too short to allow any conclusions concerning seasonal variations and multiannual trends in the chemical composition of the groundwater to be drawn.

The selected station for frost penetration is situated in a relatively flat area in a coniferous forest. The dia-

gram shows that the ground was frozen from the end of October to the beginning of June. The deepest level of frost penetration was reached in the beginning of April and was approx. 1.5 m below ground surface. The thawing of the frost and the melting of the snow start in April.

A considerable groundwater recharge — seen in rising groundwater levels — takes place in May and June. The groundwater starts to rise even while the ground is still partly frozen and snow-covered. The highest groundwater levels are recorded generally in July—August. From this maximum, the level falls until the minimum is reached in March—May. The annual amplitude is 0.3—0.5 m. A multiannual trend of falling groundwater levels, for the period 1968—1973, is clearly visible in the diagram. This trend is probably connected with the low sums of precipitation in 1969—1971

During the observation period, the temperature of the groundwater ten meters below ground surface ranges from 2.5 to 5.5°C with a mean of 3.7°C. The annual amplitude is 2.0—2.5°C with the minimum temperature in June and the maximum temperature in October. Due to an unsatisfactory measuring technique (see page 10) in 1968—1970, the curve for this period is somewhat rough.

3.35. Kallaxheden

3.35.1. Geographical location

The observation area Kallaxheden is situated a few kilometers south of the town of Luleå in north Sweden (see map, Fig. 77). The elevation of the area ranges from 0 to 30 m a.s.l.

3.35.2. Geology and geomorphology

The Kallaxheden area consists of extensive glaciofluvial deposits which form a peninsula in the Gulf of Bothnia. Outcrops of Precambrian bedrock are very rare within the area. Most outcrops are found near the northern shore of the peninsula. In connection with the rock outcrops, small patches of sandy, wave-washed till are

found. In the morain terrain west of the Kallaxheden area the bedrock frequently outcrops. The till in this area has, in most places, been exposed to intense wave-action during Postglacial time. Relatively large areas with redeposited material (sand and gravel) are found.

The glaciofluvial deposits of Kallaxheden form a part of an esker system trending in a NW—SE direction in the valley of the river Luleälv. The esker can be followed for about 25 km toward SE from Kallaxheden as a series of small islands built up by sand and gravel. An exposure of fine sand in a sand pit is shown in the photo, Fig. 78.

The glaciofluvial deposits of Kallaxheden have a length of about 8 km and a width of 3—4 km. The direction

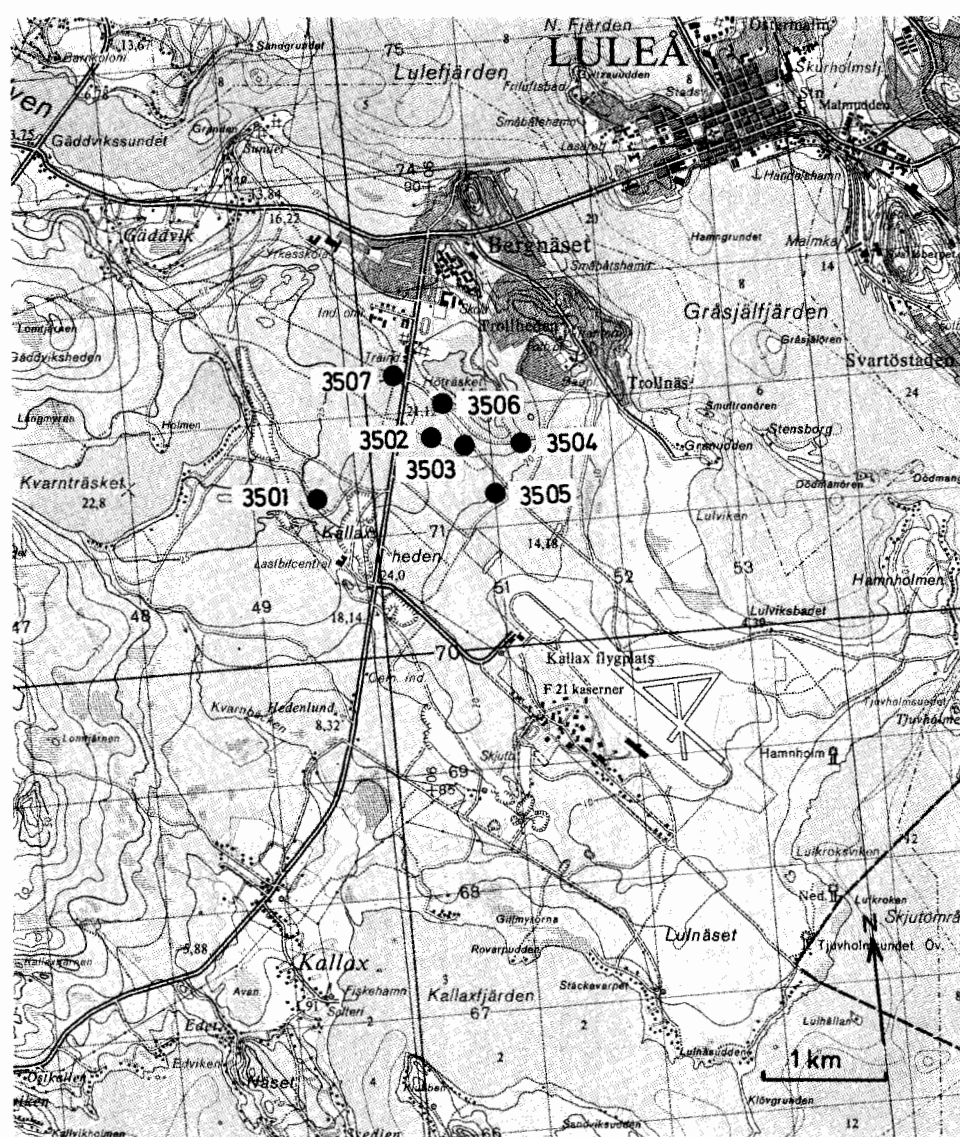


Fig. 77. Map of observation area 35 Kallaxheden. (Top. map 24 L. NO.)



Fig. 78. Excavation in glaciofluvial sand 300 m SW of station no. 3501. Note a lens of coarse material in the center of the picture. Photo L. Nordberg 1973.

of the length axis is NW—SE. In the northwest and the southwest the glaciofluvial deposits continue below the water surface. Toward the southwest and the northeast the glaciofluvial deposits are bordering on moraine terrain. The contacts are concealed by redeposited material (mainly sand), abraded from the glaciofluvial deposits by intense wave action during the Postglacial time. The wave-activity of the sea has changed the morphology of the glaciofluvial deposits very much. The original surface of the deposit probably had a more distinct esker ridge form. Perhaps the formation is made up of several parallel ridges. Geoelectrical investigations (Orrje 1965 c) indicate the presence of two zones with coarser material in the northwestern part of the formation, which may indicate two concealed esker ridges. Through the Postglacial wave activity the surface of the deposit has been transformed into a sand plain with very low relief. A low, indistinct ridge trending NE—SW, however, can be found in the central part of the deposit.

The surface morphology of Kallaxheden has also

been changed by eolian activities. Low dune ridges consisting of sand are commonly found in parts of the area.

3.35.3. Hydrological and hydrogeological features

Most of the surface water of the moraine terrain immediately west of Kallaxheden flows to lake Kvarnträsket and its outlet, Kvarnbäcken, which discharges into the sea south of Kallaxheden. As the infiltration conditions on the sand plain of Kallaxheden are very good, the surface water plays an unimportant role within the area. Almost all precipitation water not removed by evapotranspiration forms groundwater. One lake, the Höträsket, is found in this area. Lake Höträsket has no visible inlets or outlets. The level of the water surface seems to coincide with the groundwater level in the surrounding terrain. The groundwater in the area flows in two main directions, toward NW and SE. The watershed between these two groundwater flow systems is situated near the observation stations nos. 3502 and 3506 (see map, Fig. 77).

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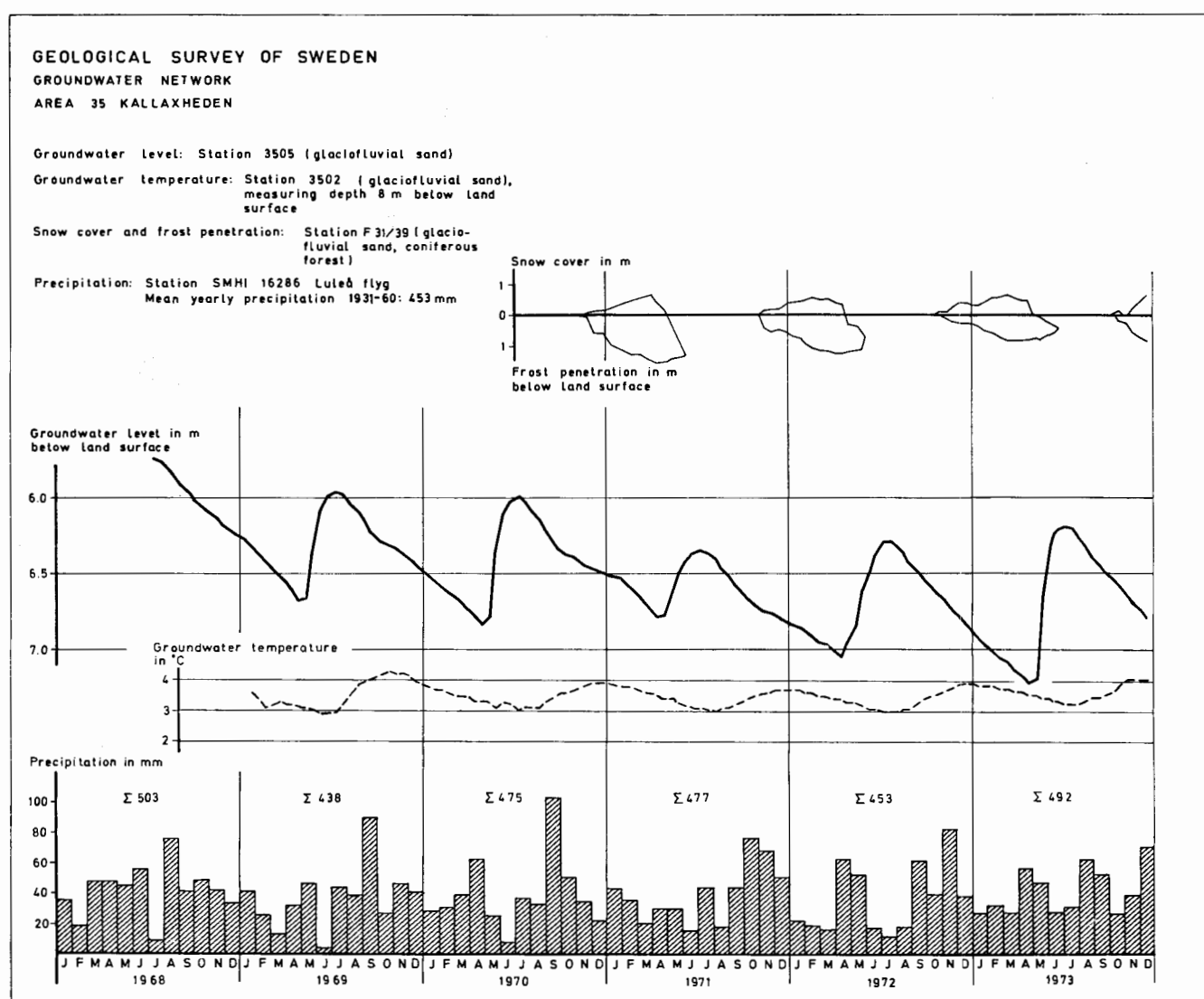


Fig. 79. Diagram from observation area 35 Kallaxheden.

Station no.	Lat.	Long.	Land surface m a.s.l.	Geology	Depth of well m	Type of station	Obs. program	Aq.	Start of obs.	Remarks
3501	6533	2204	22	Gl. fl. sand	17	Tube	L	W	1968	
3502	6533	2205	20	" " "	9	"	LT	W	1968	
3503	6533	2206	20	" " "	12	"	L	W	1968	
3504	6533	2206	21	" " "	12	"	L	W	1968	
3505	6533	2206	20	" " "	9	"	L	W	1968	
3506	6533	2206	20	" " "	10	"	L	W	1968	
3507	6534	2205	20	" " "	6	"	L	W	1968	
F31/39	6533	2206	20	" " "	—	Frost	F	—	1970	
F32	6533	2206	20	" " "	—	"	F	—	1970	Ended 1971
F33	6533	2205	20	" " "	—	"	F	—	1970	Ended 1971
F34/40	6533	2205	20	" " "	—	"	F	—	1970	

The village of Bergnäset, situated in the northern part of the Kallaxheden area, is supplied with water from three wells at Gäddvik, west of the village. In 1972, 669 000 m³ (= 21 l/s) and in 1973, 605 000 m³ (= 19 l/s) of water were extracted from these wells. At Gäddvik the glaciofluvial deposits are covered with clay and redeposited sand. Prior to the establishing of the wells, artesian conditions with a groundwater pressure level above land surface existed in this area.

No other producing wells with a water extraction comparable with that of the Gäddvik wells are found in the Kallaxheden area.

3.35.4. Observation stations

The main features of the observation stations are presented in the table on page 120.

The locations of the groundwater stations are presented on the map, Fig. 77. All the stations are situated within a distance of 1 km from the main groundwater divide. None of them seem to be influenced by any producing well of the area.

3.35.5. Comments on the diagram

The variations of groundwater level and temperature at station no. 3502 and the snow cover and frost penetration at station no. F 31/39 are shown in the diagram (Fig. 79).

A very clear, seasonal pattern of fluctuation of the groundwater levels can be seen in the diagram. The highest levels are reached in June or July, and the lowest levels in April. The rapid spring rise starts when there still is some snow left and the ground is still frozen. The maximum level is reached 2—3 months after the snow has vanished. The groundwater level falls all through the summer, autumn and winter. The yearly amplitude is 0.5—1.0 m.

A trend of falling groundwater level is discernible from 1968 to 1973. Both the yearly maximum and minimum levels are about 0.5 m lower in 1973 than in 1968—1969.

The groundwater temperature at a depth of 8 m below ground surface shows a seasonal pattern of fluctuation with highest temperatures in the winter and lowest in the summer. Hence, the time lag between the temperature of the air and that of the groundwater is found to be approx. half a year. The yearly amplitude is about 1°C, and the mean temperature for the observation period is 3.5°C.

The diagram for snow cover and frost penetration shows that the ground is frozen from October—November to June. The greatest depth of frost penetration, 154 cm, was recorded at station no. F 33 in April, 1971. The snow cover generally reaches a maximum thickness of 0.6—0.8 m.

3.36. Mårdudden

3.36.1. Geographical location

The observation area Mårdudden is situated in the province of Lappland in north Sweden, approx. 50 km northnorthwest of the town of Boden. The altitude of the area is about 180—185 m a.s.l.

3.36.2. Geology and geomorphology

The area is situated at the foot of the south slope of a hill consisting of Precambrian bedrock covered with sandy till from the latest glaciation. The surface of the till is wave-washed. The highest shore line after the latest glaciation is found at an altitude of about 195 m a.s.l. In the lower parts of the terrain the till is covered by peat.

3.36.3. Hydrological and hydrogeological features

The surface water and the groundwater of the area flow toward the peat-covered low-lying parts of the area.

A small brook, the Svartmyrbäcken, flows through the peatland and discharges into the river Råneälv.

Several small springs discharging groundwater from the till are found at the foot of the hill. Probably the peat formation in the lower parts of the terrain is partly caused by this groundwater seepage.

One of the springs has been selected as an observation station.

3.36.4. Observation station

The main features of the observation station are presented in the following table:

Station no.	Lat.	Long.	Land surface m a.s.l.	Geology	Type of station	Obs. program	Start of obs.
3601	6618	2118	182	Sandy till	Spring	C W	1968

The discharge from the spring ranges from 2 to 3 l/s in the summer and less than 0.1 l/s in late winter. Some

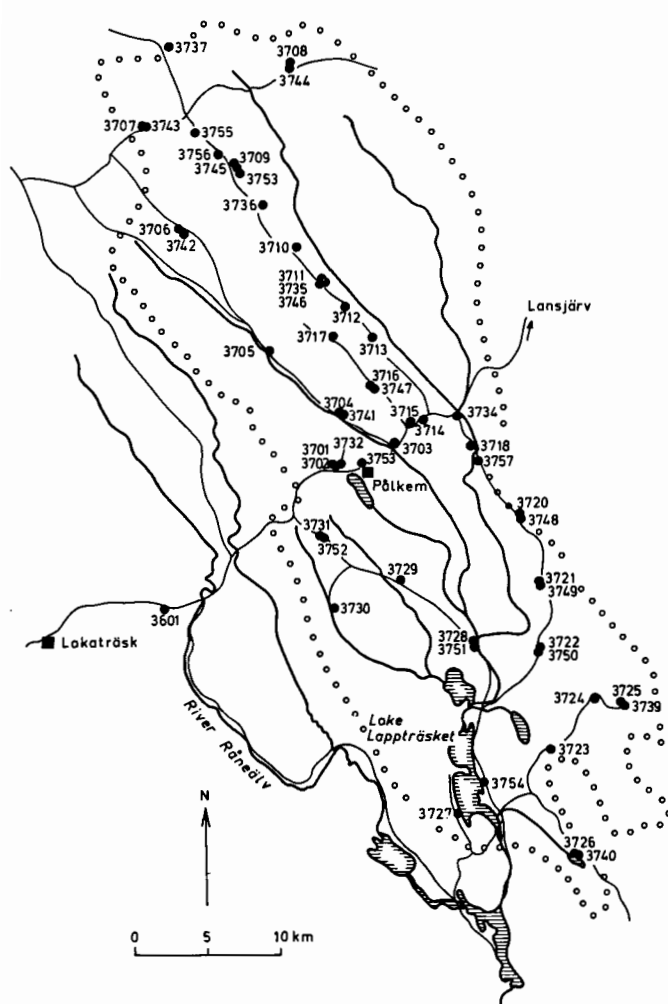


Fig. 80. Map of observation areas 36 Mårdudden and 37 Lappträsket. Water divide of basin roughly indicated by line of circles.

years, the spring becomes completely dry in the winter. The location of the station is shown on the map, Fig. 80.

3.36.5. Comments on the diagram

In the diagram (Fig. 81) the chemical composition and tritium content of the groundwater from station no. 3601 are shown. Most analysed samples have a relatively low salt content; certain samples (May, 1970 and 1972), however, have a very high content of calcium and chloride. Whether these changes are parts of natural, seasonal fluctuations in the composition of the water, or indicate contamination of the water, cannot be stated yet as the number of samples collected each year has been too small. A possible source of contamination is a road running only about 10 m from the spring.

The tritium curve shows a high content of tritium (200–400 TU), which indicates a short residence time of the water in the till. The curve shows a decreasing trend, reflecting the decreasing tritium concentration in the precipitation water.

3.37. Lappträsket

3.37.1. Geographical location

The observation area Lappträsket is situated approx. 100 km northnorthwest of the town of Luleå, in the provinces of Norrbotten and Lappland in north Sweden. The entire area is 1 004 km² and one fifth of it is north of the Arctic Circle. The altitude of the area ranges from 50 to 485 m a.s.l. A map of the area is shown in Fig. 80.

3.37.2. Geology and geomorphology

The bedrock of the area consists of Precambrian granites — mainly in the northern part of the area — and porphyrite and migmatized diorites — mainly in the southern part of the area. Minor occurrences of other types of rocks are also found. The bedrock is outcropp-

ing at a number of localities in high-lying terrain, some of them with steep precipices surrounded by talus slopes.

The structure of the bedrock controls the general topographic pattern of the area, giving rise to a valley-ridge landscape with a long-axis orientation of NW—SE. The relative relief between the valleys and ridges amounts to 100–200 m.

During the latest glaciation till was deposited on the bedrock surface. Due to alternating ice movement directions, at least two different till beds are identified in the area: an upper, brown, sandy variant with a loose composition; and a lower, gray, sandy-silty type with portions of stratified sediments. This type of stratigraphy has been described by Modig and Nordberg (1971) from the central part of the area and by Fromm (1965) from a locality just east of the area. The thickness of the till

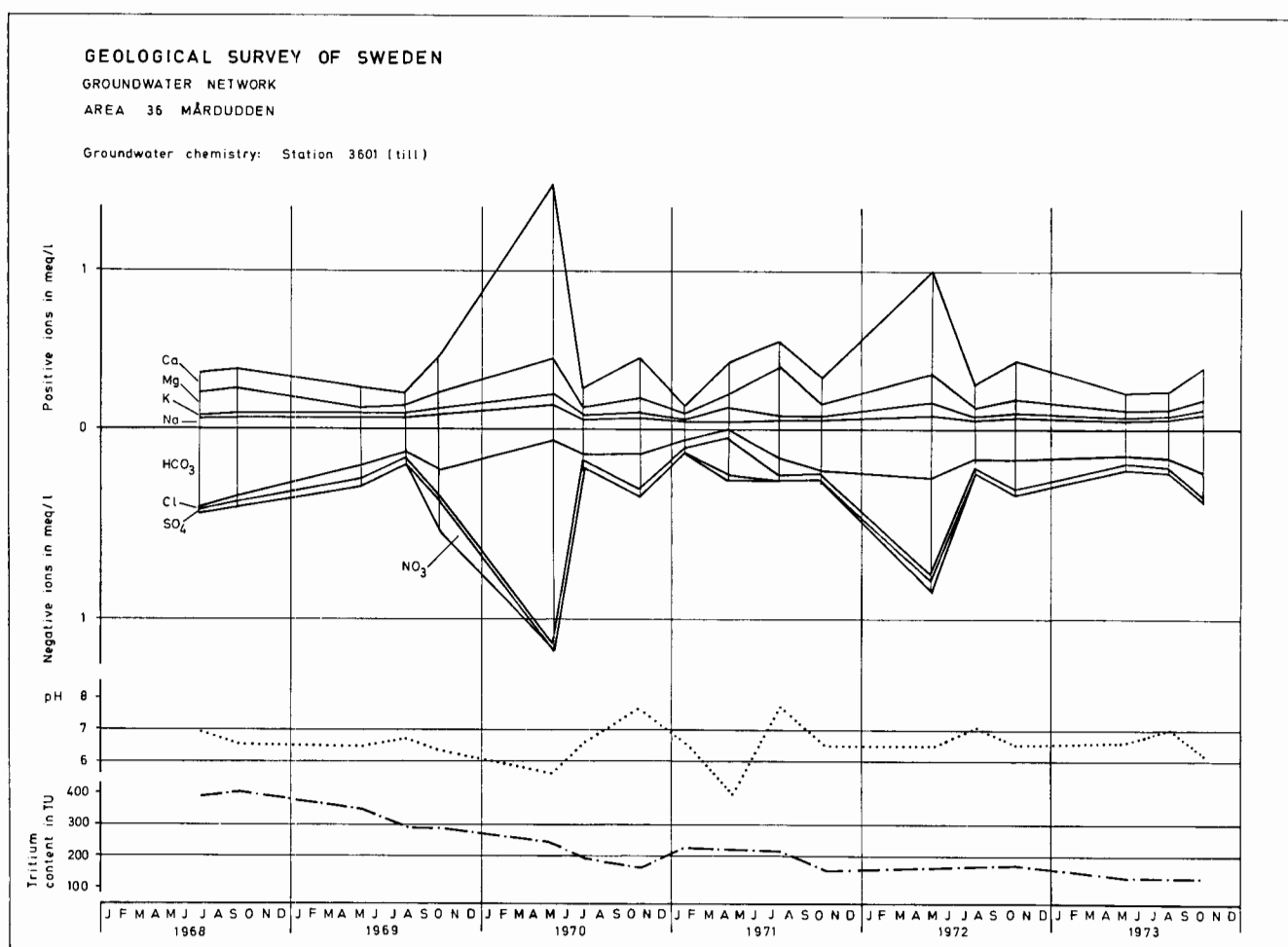


Fig. 81. Diagram from observation area 36 Mårdudden.

is not investigated sufficiently but it is assumed to range from 0 to 10 m. This assumption does not exclude the existence of occasionally greater thicknesses.

Generally, lacking a distinct morphology of its own, the till cover has a levelling effect on the topography. Pronounced moraine ridges and hills are found only in certain spots of the area.

Stratified drift is present in the form of glaciofluvial eskers within the area. With the maximum Late-glacial sea level at approx. 195 m above the present sea level, the eskers in the northern half of the area were deposited subaerially, whereas they were subaqueously formed in the southern half of the area. This fact suggests a distinction in composition and shape of the two esker types. The typical subaerial esker is narrow, steep-sided and winding. The material in it is not very well sorted. The subaqueous esker, on the other hand, is generally larger, flattened by abrasion. Its material is well sorted. This distinction is recognized at large within the area. With respect to area, the glaciofluvial deposits

play a minor role, except for a large outwash plain in the south central part of the area. This plain is a delta of sand and gravel, deposited just below the maximum Late-glacial sea level. During the regression of the sea, the delta was abraded and large amounts of sand and gravel were redeposited south of the delta. Similar formations of smaller size are also found elsewhere within the southern half of the area.

The observation area is situated in a region where peatlands are common, and is covered by peat to 29 per cent. The main feature of the peat landscape is the NW—SE pattern of the elongated mires. They cover the till in many of the valleys and on the gentle slopes. The thickness of the peat in the central part of the mires in the southern half of the area is reported by Fromm (1965) to be 2—3 m. The mires are more abundant in the northern part of the area than in the southern part, and, also, they are assumed to be of greater thickness.

The loose deposits of the area have been mapped by Melander (1972), mainly as an air-photo interpretation.

3.37.3. Hydrological and hydrogeological features

The area constitutes a representative IHD basin. The catchment area is fairly well-defined as to surface water and groundwater divides. The main watercourses of the area, all having a NW—SE general direction, lead the water to the lakes Grundträsket and Lappträsket, discharging into the river Rörån which is a tributary to the river Råneälv. The latter one reaches the Gulf of Bothnia 35 km north of Luleå. The total discharge from the catchment area is measured at the southern tip of the lake Lappträsket, where a discharge station has been in operation since 1923. The mean annual discharge at this station is 11.9 m³/s. During peak floods in May—June the momentary discharge may exceed 150 m³/s, whereas the lowest discharge in late winter approaches 2 m³/s. The pattern of discharge variations reflects the climatological situation with a major peak in connection with snow-melting and a minor peak caused by heavy autumn rainfalls. The great seasonal amplitude in discharge causes the existence of a multitude of temporary brooks. They flow, in particular, in periods of snow-melting. During this period a wide-spread surface runoff, without any defined watercourses, may take place down many slopes, particularly if the ground is still partially frozen.

The large peatlands of the area play an important role for the water budget as the mires hold considerable volumes of water. It is generally assumed that the peatlands repress and equalize the amplitude of the variations of quantities of water passing through an area. Special investigations in the Lappträsket basin, though, have indicated a contrary behavior of mires. A mire, when saturated, cannot incorporate further volumes of water, but will act merely as a conduit for water. This situation is common in periods of snow-melting.

The groundwater in the loose deposits of the area flows in accordance with the local topography. Thus, in the moraine terrain, a great number of small, more or less independent, flow systems exist. Therefore, several sub-areas of recharge and of discharge are found. The order of the flow systems ranges from very local to regional. The ultimate groundwater discharge within the area takes place through seepage into the brooks and rivers.

Several natural springs are found in the area, particularly along brooks and rivers. The maximum yield of the separate springs in moraine terrain has been estimated to 2—5 l/s. Springs discharging from glaciofluvial deposits have been estimated to have a maximum yield of 5—10 l/s. During periods of high groundwater level, temporary springs may be found in localized places.

The groundwater in the moraine terrain is found at a general depth of 0—4 m below land surface. A large amount of precipitates of iron compounds at a depth of 0.5—1.0 m may locally introduce temporary, artesian or semi-artesian conditions.

Within the area, the number of wells for withdrawal of water is very small as the area is sparsely populated. The wells supply water only to separate households. Therefore, the extraction of groundwater has no significant influence on the hydrological conditions of the area.

3.37.4. Observation stations

The main features of the observation stations are presented in the table on page 125.

Stations nos. 3701—3732 were established by the Swedish Meteorological and Hydrological Institute (SMHI) in connection with the creation of the representative IHD basin Lappträsket. Stations nos. 3733—3740 and 3757 are dug wells in which SMHI has started observations. Stations nos. 3741—3752 were established by SGU in collaboration with SMHI in order to improve the network. Four natural springs, stations nos. 3753—3756, have been selected for sampling by SGU. SMHI is in charge of several other hydrometeorological observation programs within the basin with the objective of studying water balance and hydrological processes.

3.37.5. Comments on the diagram

In the diagram (Fig. 82) the variation of groundwater level is shown from four different stations, the variation of groundwater temperature and chemistry from two other stations, respectively. The precipitation at a centrally located station is also shown.

All four stations show a distinct pattern of seasonal fluctuations. Generally, there are two periods of net recharge; the major one in May—June in connection with the snow-melting, and a minor one in September—October induced by heavy autumn rainfalls and low evapotranspiration. The short summer lasting from June to August is characterized by falling groundwater levels as is the winter October—April. The absolute minimum level is reached just prior to the spring rise in April. Stations nos. 3701 and 3712 are located in till and have a yearly amplitude of approx. 2 m. Station no. 3732 is a drilled well in gneiss. Its yearly amplitude is 1.0—1.5 m. The fourth station, no. 3745, is situated in sand and the amplitude is 0.5—1.0 m. The various amplitudes are a rough reflexion of the varying effective porosity of the three different aquifer materials. No clear multiannual trends can be seen in the diagram.

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The fluctuations of groundwater temperature show a seasonal cyclicity which has the highest values in October—November and the lowest in June. The yearly

amplitude is approx. 2.0°C; the mean temperature for the period of observation is 3.3°C.

The groundwater at station no. 3756 has a very low

Station no.	Lat.	Long.	Land surface m a.s.l.	Geology	Depth of well m	Type of station	Obs. program	Aq.	Start of obs.	Remarks
3701	6623	2135	255	Sandy till	3	Tube	L	W	1968	
3702	6623	2135	255	" "	3	"	L	W	1968	
3703	6624	2140	191	Gl. fl. grav.	3	"	L	W	1968	
3704	6625	2135	224	" " "	3	"	L	W	1968	
3705	6627	2128	273	Sandy till	3	"	L	W	1968	
3705	6632	2120	326	" "	3	"	L	W	1968	
3707	6636	2117	366	" "	3	"	L	W	1968	
3708	6638	2131	382	" "	3	"	L	W	1969	
3709	6634	2125	323	Gl. fl. sand	3	"	L	W	1968	
3710	6631	2130	345	Sandy till	3	"	L	W	1968	
3711	6630	2133	307	" "	3	"	L	W	1969	
3712	6629	2136	288	" "	3	"	L	W	1968	
3713	6628	2138	276	" "	3	"	L	W	1969	
3714	6625	2142	194	" "	3	"	L	W	1968	
3715	6624	2141	192	Gl. fl. sand	3	"	L	W	1968	
3716	6626	2138	230	Sandy till	2	"	L	W	1968	
3717	6628	2133	275	" "	3	"	L	W	1968	
3718	6624	2147	191	" "	3	"	L	W	1968	
3720	6621	2151	207	" "	3	"	L	W	1968	
3721	6619	2153	165	" "	2	"	L	W	1968	
3723	6612	2154	111	" "	3	"	L	W	1968	
3724	6614	2158	154	" "	2	"	L	W	1968	
3727	6610	2145	66	" "	2	"	L	W	1969	
3728	6616	2147	105	" "	3	"	L	W	1969	
3729	6619	2140	178	Gl. fl. sand	3	"	L	W	1969	
3730	6618	2134	169	" " grav.	3	"	L	W	1968	
3731	6620	2133	291	Sandy till	3	"	L	W	1968	
3732	6623	2135	255	Gneiss	49	Drill	L	W	1968	Continuous recording
3733	6623	2137	273	Sandy till	8	Dug	LT	W	1968	" "
3734	6623	2145	201	" "	5	"	LT	W	1969	" "
3735	6630	2133	307	" "	5	"	LT	W	1969	
3736	6633	2128	365	" "	10	"	LT	W	1969	
3738	6616	2152	143	Litt. sand	2	"	LT	W	1968	
3739	6614	2200	206	Sandy till	5	"	LT	W	1968	
3741	6625	2135	227	Gl. fl. grav.	4	Tube	L	W	1970	
3742	6632	2120	326	Sandy till	4	"	L	W	1970	
3743	6636	2117	366	" "	5	"	L	W	1970	
3744	6638	2131	381	" "	5	"	L	W	1970	
3745	6634	2125	320	Gl. fl. sand	5	"	L	W	1970	
3746	6630	2133	307	Sandy till	4	"	L	W	1970	
3747	6626	2138	229	" "	3	"	L	W	1970	
3748	6621	2151	207	" "	4	"	L	W	1970	
3749	6619	2153	166	" "	5	"	L	W	1970	
3750	6616	2152	144	Litt. sand	3	"	L	W	1970	
3751	6616	2147	104	Sandy till	4	"	L	W	1970	
3752	6620	2133	290	" "	4	"	L	W	1970	
3753	6634	2125	318	Gl. fl. sand	—	Spring	C	W	1970	
3754	6612	2146	51	Litt. sand	—	"	C	W	1970	Sporadical sampling
3755	6635	2121	334	Gl. fl. sand	—	"	C	W	1970	" "
3756	6634	2125	320	" " "	—	"	C	A	1971	Covered by peat
3757	6623	2148	199	Sandy till	4	Dug	L	W	1972	Continuous recording

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salt content and a relatively high tritium content, which reflects a short residence time of the groundwater in the small esker in which the station is situated. A seasonal

cyclicality in the fluctuation of both salt content and pH-value is discernible. The highest pH-values and ion concentrations are found in late spring.

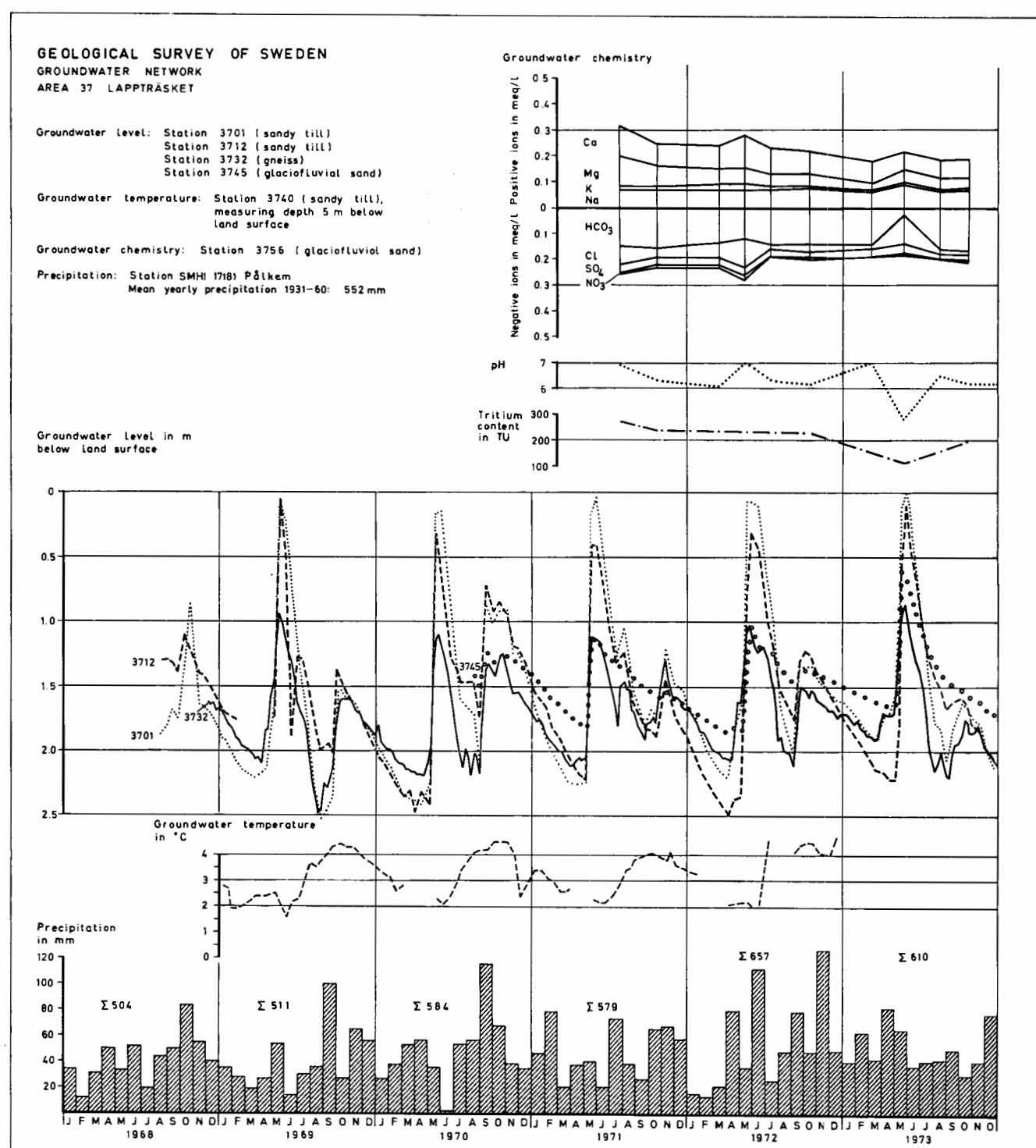


Fig. 82. Diagram from observation area 37 Lappträsket.

3.38. Svappavaara

3.38.1. Geographical location

The observation area Svappavaara is situated 6—7 km northwest of the town of Svappavaara in the province of Lapland (see map, Fig. 83). The altitude of the area ranges from 310 to 370 m a.s.l.

3.38.2. Geology and geomorphology

The Svappavaara region is a moraine landscape characterized by low hills consisting of till from the latest glaciation. In the low parts of the terrain the till is covered by peat. The altitude of the moraine terrain is 300—400 m a.s.l. in this area. Single mountains reaching levels of 100—200 m above the moraine terrain are found. The bedrock of the region, consisting of Precambrian intrusives and metamorphosed sediments, frequently outcrops in the mountains. Several ore de-

posits are found in this part of Lapland. The Leveäniemi iron ore mine is situated only 7 km south of the observation area. The observation area is situated in the moraine terrain south of Mount Bergsmannivaara (see map, Fig. 83) between the stream Liukattijoki and its tributary Pruukinjoki. Along Liukattijoki, deposits of sand and gravel are found. South of the observation area these deposits appear as ridges and hills. Within the area the deposits have a flat surface. The sand and gravel, south of the observation area, were deposited in a glaciofluvial stream. The morphology of the original deposit has been changed by erosion by meltwater streams from the landice. The eroded material was transported northwards by these streams and redeposited within the present observation area as an accumulation with a flat surface gently sloping toward NE. In the central part of the observation area, the sand and gravel completely cover the till. In the northern part

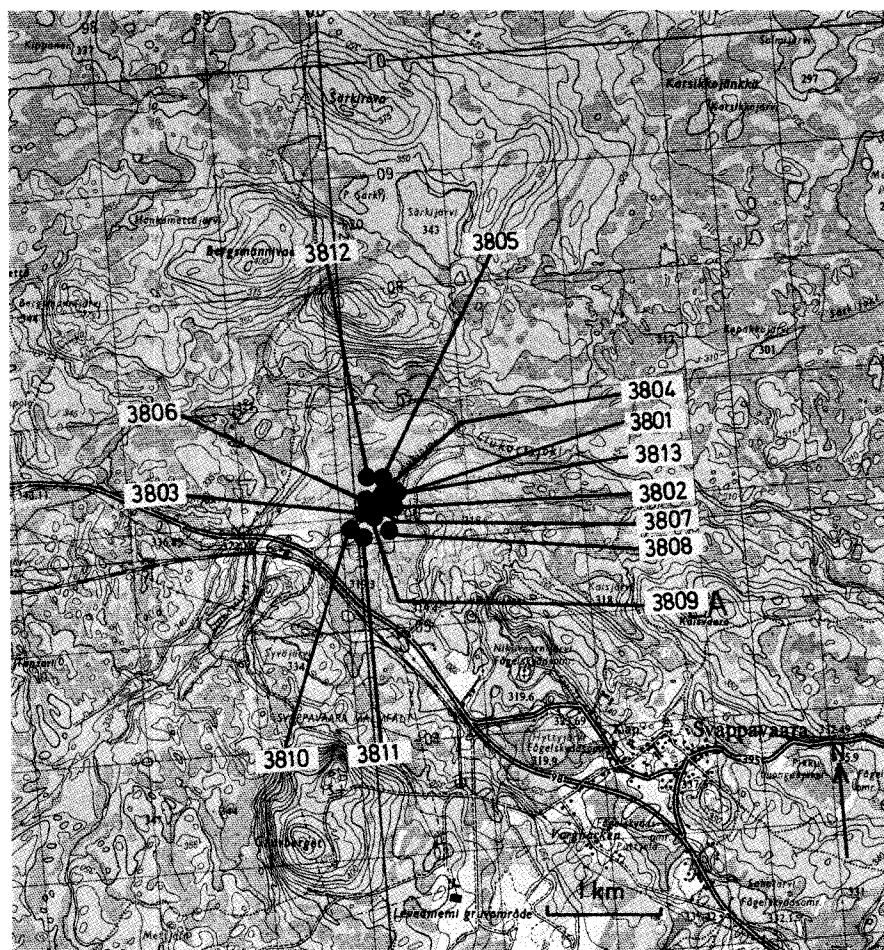


Fig. 83. Map of observation area 38 Svappavaara. (Top. map 29 K SV.)



Fig. 84. A shallow excavation in gravel close to station no. 3805. Note groundwater seepage at bottom of excavation. Photo L. Nordberg 1973.

of the area, single moraine hills surrounded by sand and gravel are found. The greatest recorded thickness of the sand and gravel deposits in the observation area is 8 m and was found in the south part of the area. An exposure in the sand and gravel is shown in Fig. 84.

3.38.3. Hydrological and hydrogeological features

The surface water of the area is drained through the river Liukattijoki and its tributary Pruukinjoki to the river Torne älv, which discharges into the Gulf of Bothnia on the border between Sweden and Finland.

The groundwater of the observation area has a main flow direction, SW—NE. Along the river Pruukinjoki a diffuse groundwater seepage, as well as a few small springs, is found. At some places the seepage causes peat formation.

The groundwater conditions of the observation area were investigated by AIB (1962). A number of observation tubes were established to obtain information on

groundwater levels in the sand and gravel deposits. Two test pumpings were performed during 1961. A safe yield of about 20 l/s was obtained. During the test pumping the groundwater seepage along the river Pruukinjoki ceased and was replaced by infiltration of water from Pruukinjoki along the shore. The test pumpings were made in order to investigate possible future well sites for the water supply of the town of Svappavaara. No wells have, however, been established within the area.

3.38.4. Observation stations

The observation stations are presented in the table on page 130.

The location of the stations is shown on the map, Fig. 83. Stations nos. 3801—3810 were established by AIB in connection with the aforementioned investigation. Stations nos. 3811 and 3812 were established by SGU. Station no. 3813 is a natural spring yielding less than 0.1 l/s.

None of the stations are influenced by pumping.

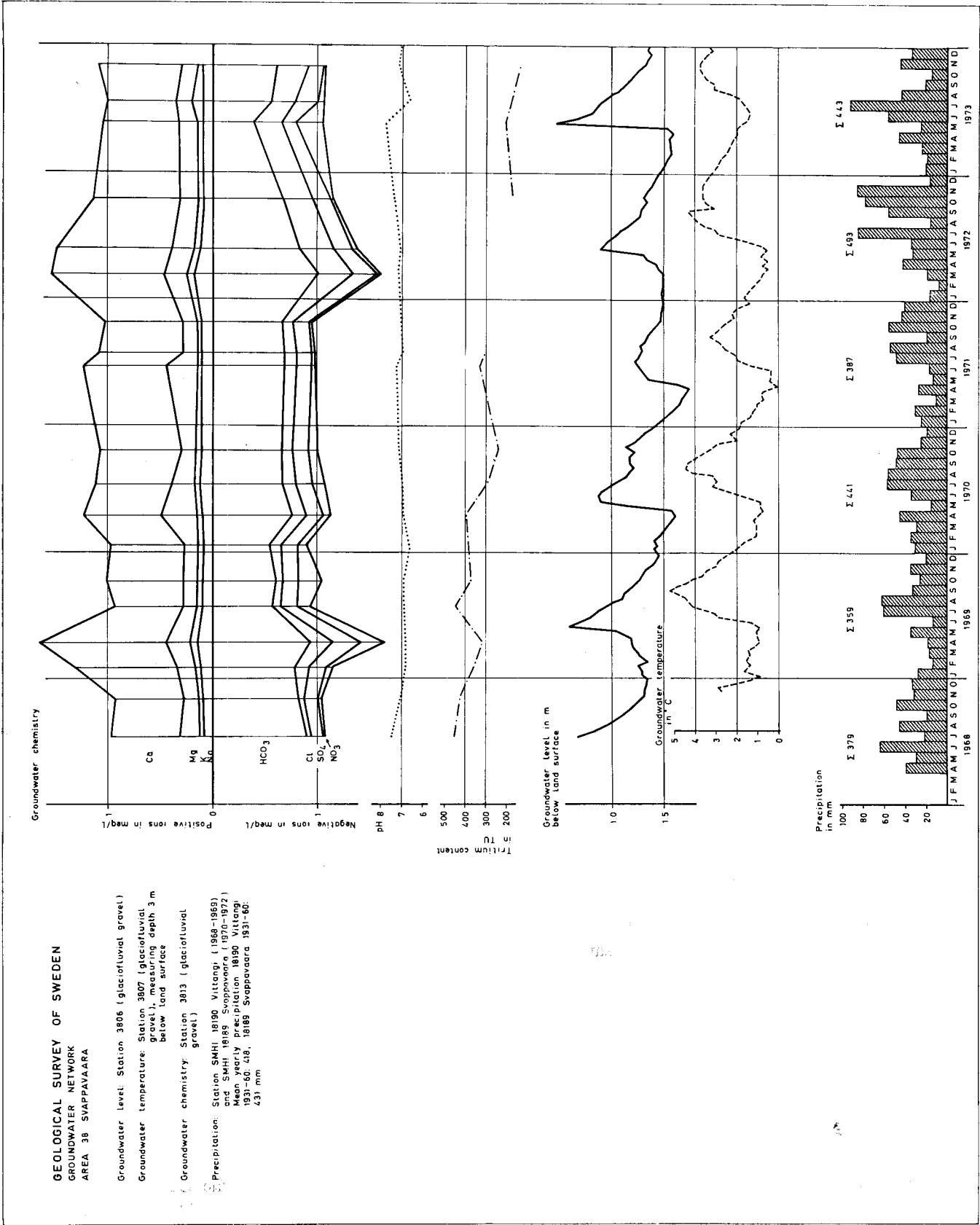


Fig. 85. Diagram from observation area 38 Svappavaara.

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Station no.	Lat.	Long.	Land surface m a.s.l.	Geology	Depth of well m	Type of station	Obs. program	Aq.	Start of obs.	Remarks
3801	6740	2101	318	Gl. fl. grav	6	Tube	L	W	1968	
3802	6740	2101	318	„ „ „	5	„	L	W	1968	
3803	6740	2100	319	„ „ „	3	„	L	W	1968	
3804	6740	2101	318	„ „ „	5	„	L	W	1968	
3805	6740	2101	318	„ „ „	3	„	L	W	1968	
3806	6740	2100	318	„ „ „	4	„	L	W	1968	
3807	6740	2100	319	„ „ „	6	„	LT	W	1968	
3808	6740	2101	319	„ „ „	4	„	L	W	1968	
3809	6740	2100	318	„ „ „	5	„	L	W	1968	Continuous recording from 1969
3810	6740	2100	320	„ „ „	3	„	L	W	1968	
3811	6740	2100	320	Sandy till	6	„	L	W	1970	
3812	6740	2100	320	„ „	5	„	L	W	1970	
3813	6740	2101	316	Gl. fl. grav	—	Spring	C	W	1968	

3.38.5. Comments on the diagram

In the diagram (Fig. 85) the variation of groundwater level, chemistry and temperature is shown in relation to precipitation.

One major period of groundwater recharge is found each year. The recharge is caused by the melting of the snow in April and May. Due to a high permeability of the aquifer material (gravel and sand), a rapid percolation of meltwater down to the groundwater takes place. The maximum groundwater level is generally reached in May or June. During the summer, autumn and winter the groundwater level generally falls. Due to high evapotranspiration in the summer, recharge takes place only in connection with periods of heavy rainfall. During the winter the precipitation is accumulated as snow and the ground is frozen. These conditions minimize the recharge.

The salt content in the groundwater also reflects the recharge conditions. A relatively high salt concentration is, in most years, found in late winter when the groundwater level is low and when a very small recharge has taken place during the period prior to the sampling. In 1971, no sampling could be performed in the winter as the spring had ceased to flow. The lowest groundwater level during the observation period was recorded this winter.

During the summer after the great, spring recharge a lower salt concentration in the water is found. These variations are probably due to the different residence times of the water in the ground.

The total salt concentration in the water is low. Calcium and bicarbonate are the dominating ions. The low salt concentration, as well as the high tritium content, indicate a short residence time of the water in the ground.

A multiannual, decreasing trend can be found in the tritium concentrations, reflecting the decreasing tritium content in the precipitation.

A falling trend in the groundwater levels can also be seen during the years 1969—1971. This trend is probably caused by the precipitation conditions during these years. Due to a rising trend in the groundwater levels in 1972 and 1973, the high level from 1968 has been restored.

The groundwater temperature at a depth of 3 m below land surface shows a distinct, seasonal variation with maximum values in September and minimum values in April—May. The annual amplitude is approx. 4°C. The mean temperature for the observation period is 2.4°C.

3.39. Abisko

3.39.1. Geographical location

The observation area Abisko is situated on the southern shore of Lake Torne träsk in the northernmost part of Lappland, 200 km north of the Arctic Circle (see map, Fig. 86). The altitude of the area is approx. 375—390 m a.s.l.

3.39.2. Geology and geomorphology

The bedrock of the area consists of schists belonging to the large western nappes of the Caledonian mountain range. A good vertical exposure of the upper part of the bedrock is found in the canyon of the river Abiskojokk, two kilometers west of the observation area. Elsewhere,

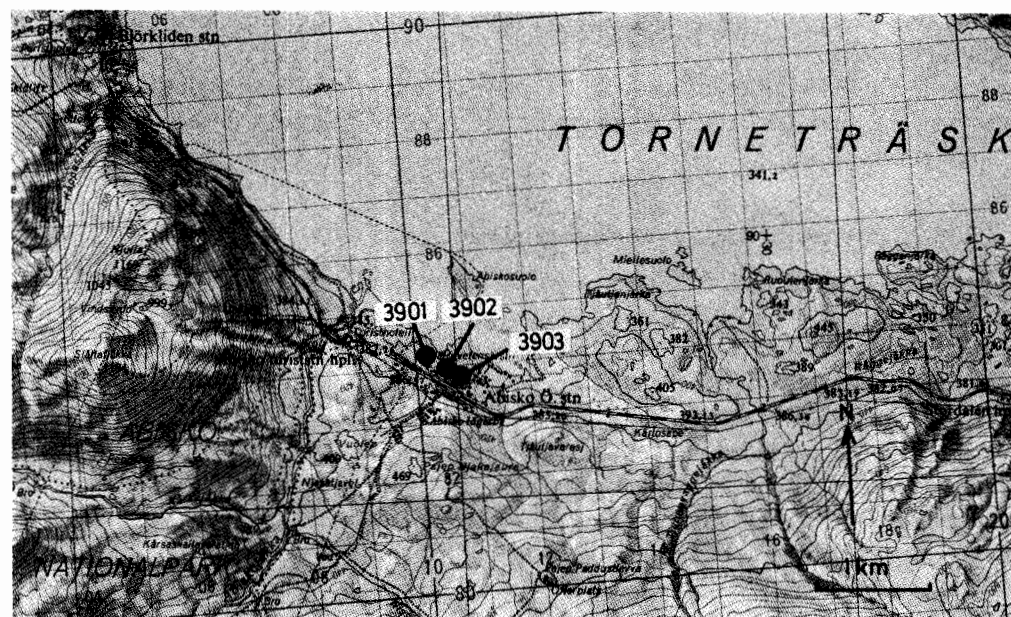


Fig. 86. Map of observation area 39 Abisko. (Top. map 30 I.)

the bedrock is generally concealed under glacial deposits from the latest glaciation.

The dominating Quaternary deposit of the area is till. It is composed of — in decreasing order — gravel, sand, silt and clay. The clay content (< 0.002 mm) is approx. 4 per cent in two samples (see Fig. 87). The boulder frequency is generally high.

The moraine topography is hummocky, indicating

dead-ice conditions at the time of deposition. Located approx. 40 m above the level of Lake Torne träsk, the observation area is on the lower slope between the mountains (Njulla, Kieron, Tjåmuhas, Pallentjåkko, Nissuntjärro) ranging 1 000—1 700 m a.s.l. and the lake.

Adjacent to the observation area, particularly along the river Abiskojokk, sandy stratified sediments are found. They range in age from glacial (glacial lake de-

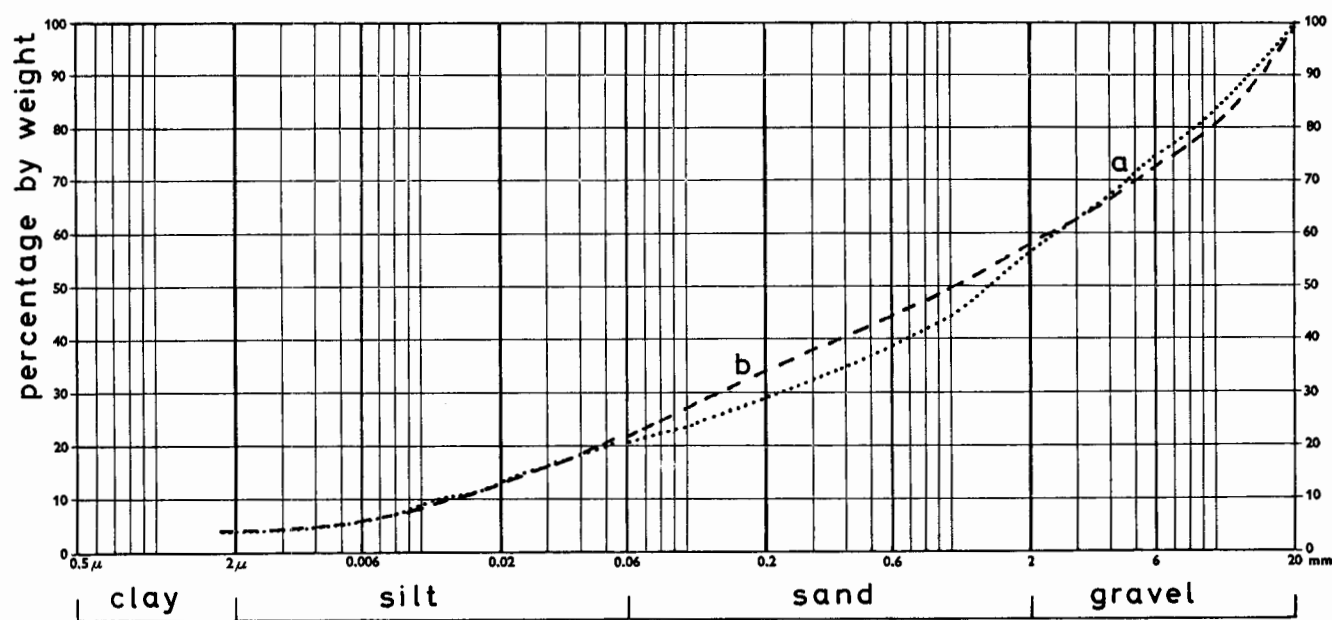


Fig. 87. Grain size distribution of till. Sampling close to station no. 3901. Curve a 1 m below ground surface, curve b 2 m below ground surface.

posits) to present (delta deposits at the mouth of Abisko-jokk) deposits.

Considerable deposits of peat are found in many places in the area, not only in topographic hollows, but also on gentle slopes.

3.39.3. Hydrological and hydrogeological features

The area is drained to Lake Torne träsk by a number of small brooks. Some of them carry water only at the period of snow-melting or major rainfall. Large volumes of water are temporarily stored in the peat.

The groundwater in the till is drained in the direction of the slopes, i. e., generally toward the Lake Torne träsk. Due to the hummocky moraine topography there are several small, local flow systems. Temporary discharge of groundwater can be found at the foot of hummocks, whereas the hummocks themselves act as recharge areas. In the latter ones the groundwater is encountered at a depth of 1—7 m below land surface. At other places the groundwater can be found very close to the surface.

There is no major withdrawal of groundwater within the observation area as the town of Abisko is satisfactorily supplied with water from a small lake.

3.39.4. Observation stations

The main features of the observation stations are presented in the table below.

The locations of the groundwater stations are shown in Fig. 86. Stations nos. 3901 and 3902 were originally established for water supply purposes. Well no. 3901 belongs to the Abisko Natural Science Research Station. The research station has organized continuous recording of the fluctuations of the groundwater level at station no. 3901 since 1955. No extraction of water from the well has been performed since that year. The former head of the research station, Dr. Gustaf Sandberg, has kindly put the results of measurements at our disposal. Station no. 3901 is now incorporated in the national groundwater network.

Station no. 3902 is, too, a dug well, 500 m SE of sta-

tion no. 3901. To increase the depth of the well, a plastic tube has been inserted at the bottom of it.

In collaboration with the National Swedish Road and Traffic Research Institute, stations nos. 3903, F 1 and F 2 were established in 1972.

3.39.5. Comments on the diagram

In the diagram (Fig. 88) the variation of the groundwater level at station no. 3901 and the monthly sums of precipitation from the same place are shown. The variation of groundwater temperature at station no. 3902 is also shown, as well as snow cover and penetration of frost at station F 1.

The seasonal pattern of groundwater fluctuations is well developed. Throughout the winter, the groundwater level regularly falls to a minimum in May—June. The main recharge takes place in connection with the snow-melting in early summer. A deeply frozen ground may delay and decrease the recharge. The maximum level is reached in late summer or early autumn (July—October). During the winter no percolation of water to the groundwater reservoir can take place due to the frost. In some years, though, the winter is interrupted by periods with mild atlantic air. In such periods the frozen ground is partly thawed, and some recharge can take place, as was the case in 1960 and 1964. The yearly amplitude is 2—4 m. The height of the amplitude is mainly controlled by the amount of snow stored prior to the snow-melting and the condition of the ground (frozen/not frozen) at the time of the snow-melting.

Some multiannual trends can be seen in the diagram. The zone of variation ranged from approx. 4 to 6 m below land surface in 1955—1959. The two years, 1960 and 1961, show extreme situations and were a transition to lower groundwater levels. From 1962 to 1973, the yearly range has been from approx. 5 to 7 m below land surface. Thus, there is a general trend of falling groundwater during the period of observation. During the last few years, a weak, rising trend is discernible, though.

The correlation between the amount of yearly precipitation and the groundwater level is not quite distinct. The generally low amount of precipitation should be

Station no.	Lat.	Long.	Land surface m a.s.l.	Geology	Depth of well m	Type of station	Obs. program	Aq.	Start of obs.	Remarks
3901	6820	1849	384	Grav. till	10	Dug	L	W	1955	Continuous recording
3902	6820	1849	382	" "	6	"	LT	W	1968	Tube in bottom of well
3903	6820	1849	380	" "	3	Tube	L	W	1972	
F 1	6820	1849	380	" "	—	Frost	F	—	1972	
F 2	6820	1849	380	" "	—	"	F	—	1972	

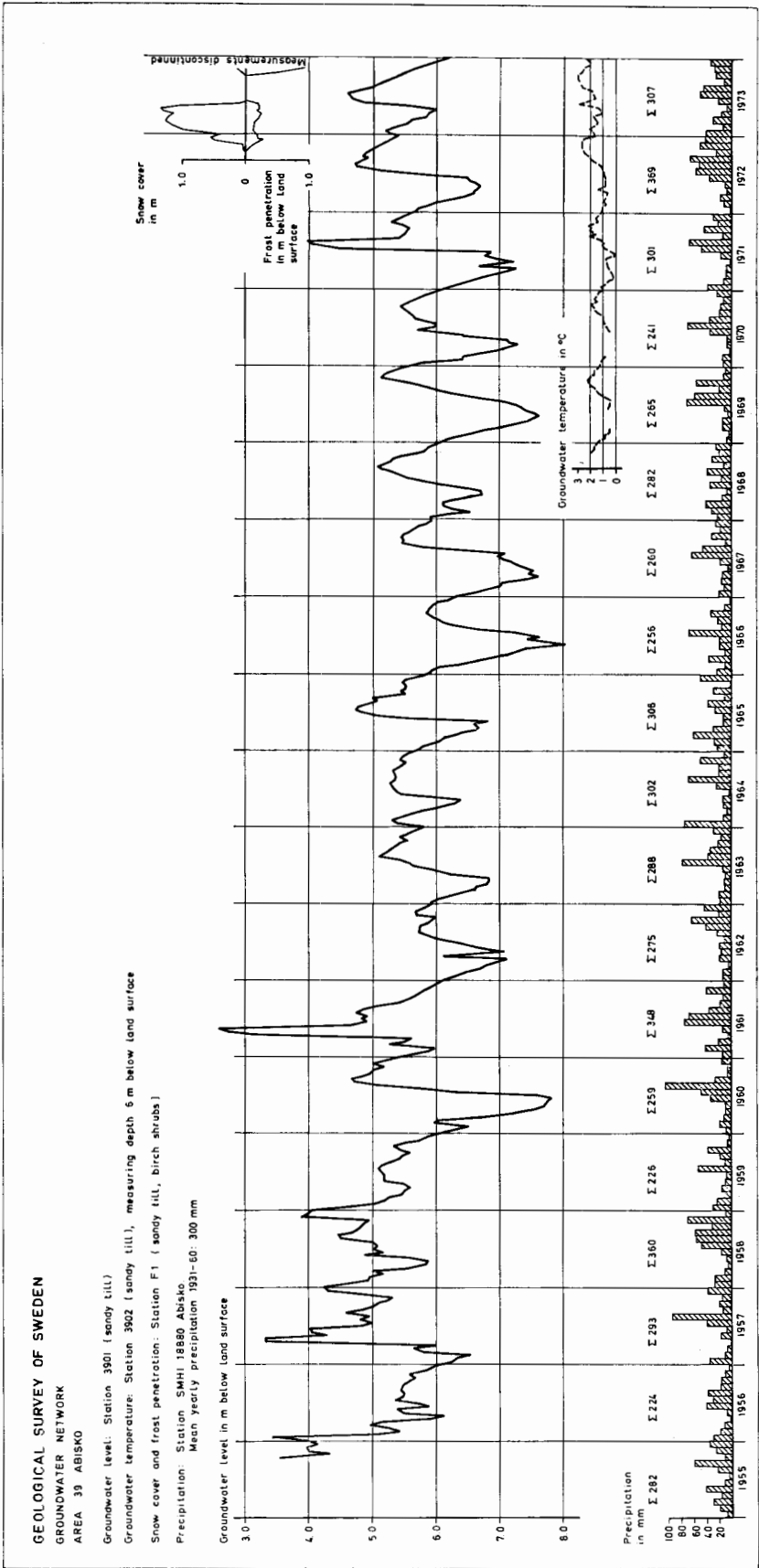


Fig. 88. Diagram from observation area 39 Abisko. Maximum peak level in 1961 is probably caused by leakage from a nearby water conduit.

noted. It is due to the effect of the lee-side situation of the area, on the eastern slope of the Caledonian mountain range. In an area with subarctic climate, like Abisko, the seasonal distribution of precipitation plays an important role in the evaluation of the water available for recharge of the groundwater reservoir. A deeply frozen ground may eliminate infiltration and percolation, and in such a case, precipitation is directed to surface runoff. Therefore, the monthly temperatures control much of the infiltration rate. A study of the relationship between temperature, precipitation and groundwater level has been made by Gottschalk et al. (1974).

The fluctuations of the groundwater temperature have been observed at station no. 3902 since 1968. The lowest temperatures are recorded in the spring (March—May) and the highest ones in the autumn (October—November). The yearly amplitude is approx. 2°C. The relatively

large amplitude, not anticipated to be found at a depth of 6 m below land surface, is assumed to be caused by the fact that the station is a well with a diameter of 90 cm, which allows air to be in free contact with the groundwater surface. No measurements could be performed in the late winters of 1969 and 1970 due to lack of water in the well. The mean temperature for the whole observation period is 1.5°C.

The penetration of frost and the thickness of the snow cover were measured in the winter of 1972—1973. Due to moderate temperatures and a thick, insulating cover of snow, the frost penetration was very limited. The observed maximum snow cover was 135 cm, and the deepest frost penetration approx. 25 cm. Due to the only slightly frozen ground, the melting of the snow caused a considerable and rapid rise of the groundwater level in late May, 1973.

3.40. Skanör-Falsterbo

3.40.1. Geographical location

The observation area Skanör-Falsterbo is situated on the Falsterbo peninsula in the province of Skåne, in the extreme southwest corner of Sweden (see map, Fig. 89). The elevation of this coastal area is only 1—2 m a.s.l.

3.40.2. Geology and geomorphology

The Falsterbo peninsula is a sandy littoral deposit located at the turning point between the Baltic Sea and the Sound between Sweden and Denmark. The coasts of the peninsula are constantly reworked by the sea waves, and considerable abrasion, transport and redeposition take place. On the westward coast, typical shore features are found, e. g., bars, spits and lagoons. Eolian activity has influenced the top layers in certain parts of the area; thus, sand dunes are found locally. According to Gustafsson (1972), the thickness of the sand is 5—15 m. It is underlain by 10—20 m of clay till. The underlying rock consists of Cretaceous (Danian) limestone with flint.

3.40.3. Hydrological and hydrogeological features

The area is characterized by its coastal location. The surrounding sea controls the groundwater level in the sand aquifer directly. As the sand has a high permeability the gradients of the groundwater level are slight. At high water stages some parts of the area become soggy. The limestone aquifer is also influenced by the proximity of the sea.

The extraction of water from wells on the peninsula plays a minor role for the groundwater conditions at large. Pumping is assumed to have had no influence on the groundwater levels during the period of observation.

The quality of the groundwater in the sand is characterized by contamination from organic material. The

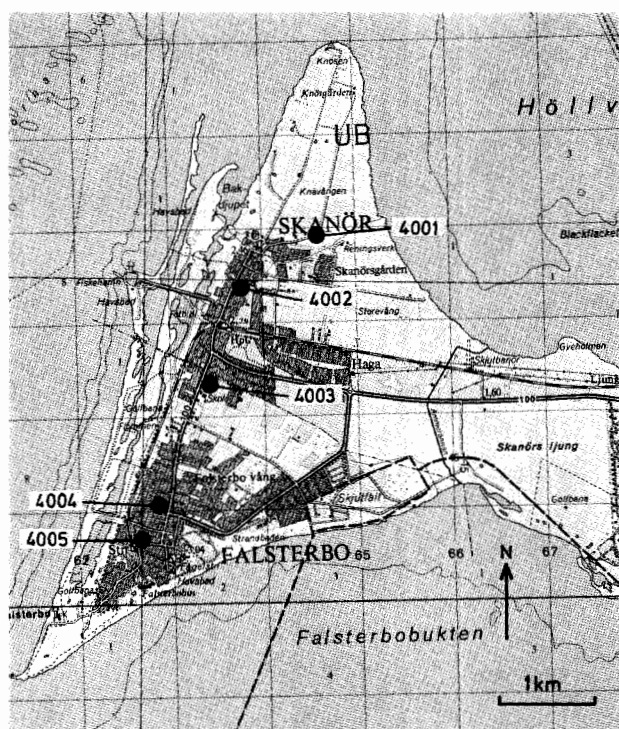


Fig. 89. Map of observation area 40 Skanör-Falsterbo. (Top. map 1 C NV.)

groundwater in the limestone is, in certain wells, salty, having a salt content exceeding 300 mg Cl/l.

Except for ditches no surface water drainage is present on the peninsula.

3.40.4. Observation stations

The main features of the observation stations are shown in the table below.

All stations, except no. 4003, are dug wells which were used for the water supply of separate households before the communities of Skanör and Falsterbo received municipal water distribution from the limestone wells east of the peninsula. Station no. 4003 is a tube installed by SGU. The observations were terminated in August, 1970.

3.40.5. Comments on the diagram

The diagram (Fig. 90) shows a very distinct pattern of seasonal fluctuations of the groundwater level. The highest levels are present in late winter and spring, whereas the summer is characterized by falling groundwater levels. The minimum is reached in early autumn. The yearly amplitude is close to one meter. No multiannual trends independent of the sea can be expected in the groundwater variations. The sea level and the very small, unsaturated zone above the groundwater surface control the range of the groundwater variations. Eustatic and isostatic changes of the sea level, though, influence the long-term behavior of the groundwater level in the sand on the Falsterbo peninsula.

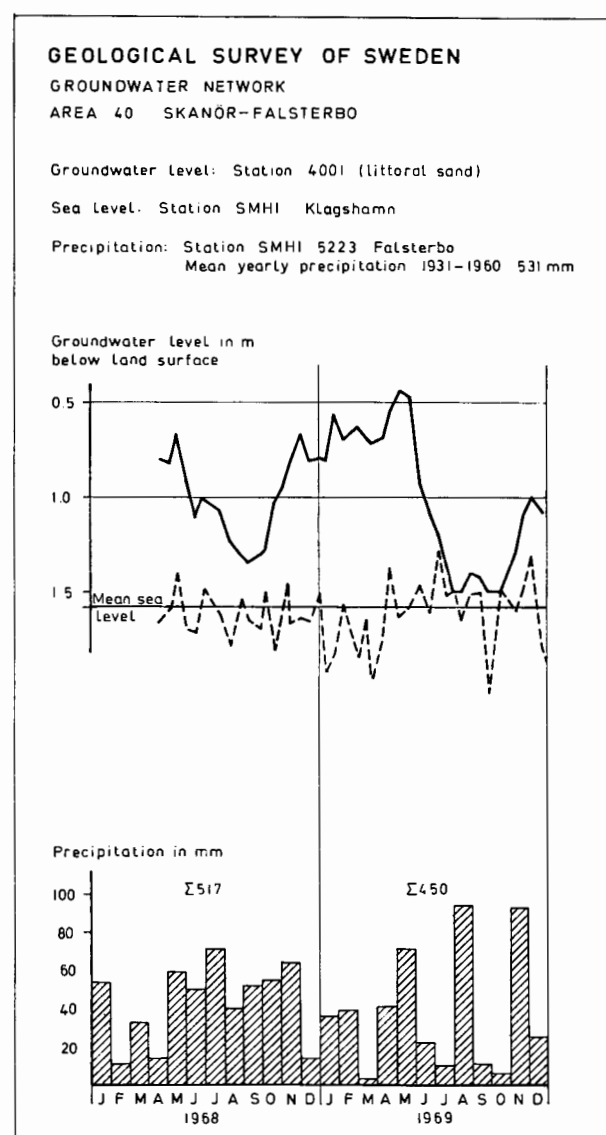


Fig. 90. Diagram from observation area 40 Skanör-Falsterbo.

Station no.	Lat.	Long.	Land surface m a.s.l.	Geology	Depth of well m	Type of station	Obs. program	Aq.	Start of obs.	Remarks
4001	5525	1251	2	Litt. sand	3	Dug	LT	W	1968	Ended 1970
4002	5524	1250	2	" "	3	"	L	W	1968	" "
4003	5524	1250	2	" "	2	Tube	L	W	1968	" "
4004	5523	1250	1	" "	3	Dug	L	W	1968	Continuous recording Ended 1970
4005	5523	1250	1	" "	2	"	L	W	1968	Ended 1970

3.41. Sandhammaren

3.41.1. Geographical location

The observation area Sandhammaren is situated in the southeastern part of the province of Skåne, approx. 20 km east of the town of Ystad. The elevation of the area ranges from 0 to 30 m a.s.l. (see map, Fig. 91).

3.41.2. Geology and geomorphology

The bedrock of the area consists of Cambro-Silurian and Mesozoic rocks. A few minor outcrops consisting of Silurian shales are found north of the observation area. In the rest of the area the bedrock is completely covered by Quaternary deposits.

The bedrock of the area is covered with clay till from the latest glaciation. These deposits form a relatively flat plain gently sloping toward SE. In the northwestern

part of the area the till is exposed; in the southeastern part it is covered by littoral and eolian sand. The Kåseberga esker is the dominating, geomorphologic feature in the southwestern part of the area. This esker rises 20–30 m above the surrounding terrain. The esker is 0.5–1 km wide and has a relatively flat surface. The esker is trending in a W–E direction and can be followed westwards from the observation area for about 10 km along the shore of the Baltic Sea. Within the area the esker ends abruptly, but it probably has a connection with a series of very low hills, consisting of sand and gravel, trending in a SW–NE direction. Northeast of the area the hills continue as a low esker ridge. The Kåseberga esker is a very complex formation consisting mainly of stratified sand, but layers consisting of sedimentary clay, as well as clay till, have been found within



Fig. 91. Map of observation area 41 Sandhammaren. (Top. map 1 D NO.)

and on top of the esker. The formation probably was built up in a major crevasse in the landice. The material was transported by glaciofluvial meltwater streams to the crevasse where the material was deposited in more or less stagnant water. The low hills northeast of the Kåseberga esker formation are probably parts of a feeding esker of the formation.

The slopes of the Kåseberga esker are rather steep and indicate former ice-contacts. The south slope of the formation has been changed by intense wave action during the Postglacial time.

East of the Kåseberga esker, a series of shore bars trending in a SW—NE direction are found. These bars, consisting of sand, were formed during the Littorina time, when the transgressing sea reached 5—6 m above present sea level in this area. Northwest of the bars, a small lagoon existed during the Littorina time. The lagoon was eventually filled up with organic material, (gyttja and peat) and was transformed to a peat bog.

Eolian sand plays an important role in the area. In a zone approx. 5 km wide along the shore, eolian sand forms a dune landscape. The dunes have been active during the last millenium. Today, only few active dunes remain. Most of the area is covered by pine forest. Thin layers of eolian sand covering littoral sand or till are found in many places in the area.

3.41.3. Hydrological and hydrogeological features

The superficial drainage pattern of the area has been changed through agricultural activities. Only a few open ditches and brooks remain. Most of the surface water of the area is drained to the sea through one small brook, Tygeå, which flows from the northeast through the area and discharges into the Baltic Sea in the southwest part of the area.

The general flow direction of the groundwater is toward the sea. Following the topography, local deviations from the general flow pattern are found. Due to the complex stratigraphy of the Kåseberga esker, several

perched aquifers may exist. The depth to the groundwater level of the main aquifer in the esker is about 5—15 m.

A large number of producing wells are found in the area. Most of them supply water to individual households or farms. Their influence on the general groundwater situation is insignificant.

3.41.4. Observation stations

The main features of the observation stations are presented in the table below.

The locations of the stations are shown on the map, Fig. 91. All stations were established by SGU as observation stations. None of the stations seem to be influenced by pumping of water from the wells in the area.

3.41.5. Comments on the diagram

The variations of groundwater levels, temperature and chemistry at selected stations are shown in the diagram (Fig. 92).

The water at station no. 4101 (eolian sand) has a very low salt content. Sodium, chloride and sulphate are dominating ions and the pH-value is low (5—6). Due to a low chemical affinity of the aquifer material, the composition of the precipitation water is changed to a very slight degree during the percolation down to the groundwater. The tritium content of the water (100—200 TU) indicates a relatively short residence time. The analysed series of samples is too short to give information about any annual or multiannual variations.

The variations of groundwater level in two different aquifers are shown in the diagram. Station no. 4107 represents the main aquifer of the Kåseberga esker. The seasonal fluctuation of the groundwater level at station no. 4107 is very indistinct and irregular. This pattern of fluctuation is probably caused by the inhomogeneities and the spatially varying thickness of the unsaturated zone.

Station no.	Lat.	Long.	Land surface m a.s.l.	Geology	Depth of well m	Type of station	Obs. program	Aq.	Start of obs.	Remarks
4101	5523	1411	3	Eol. sand	5	Tube	LC	W	1970	
4102	5523	1411	4	Litt. sand	8	„	LT	W	1970	
4103	5523	1411	5	„ „	7	„	L	W	1970	
4104	5524	1410	16	Gl. fl. sand	11	„	L	W	1970	
4105	5525	1409	22	Clay till	6	„	L	A	1970	
4106	5525	1408	24	„ „	2	„	L	W	1970	
4107	5523	1408	10	Gl. fl. sand	12	„	L	W	1970	
4108	5523	1408	11	„ „ „	12	„	L	W	1970	

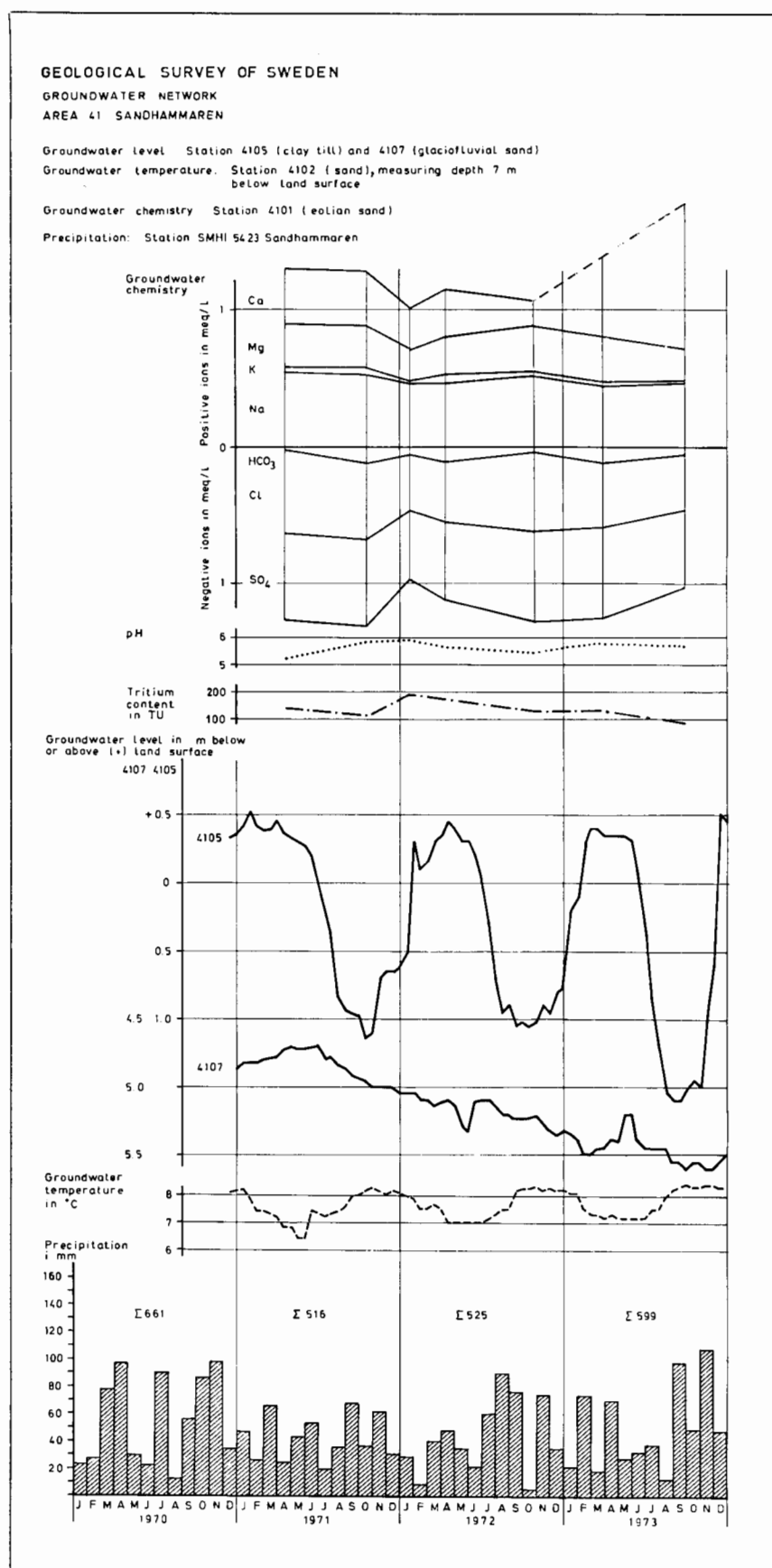


Fig. 92. Diagram from observation area 41 Sandhammaren.

At station no. 4105, representing the clay till area, the seasonal pattern of variations of the groundwater levels is quite different. A very distinct, annual cyclicity, with maximum levels in late winter or early spring and minimum levels in the autumn, is found. The annual amplitude is 1.5–2.0 m. At station no. 4105, artesian conditions are found. The recorded levels refer to the groundwater head in sandy layers in the lower parts of the clay till. Hydraulic connection evidently exists between the sand layers in the clay till at station no. 4105 and areas at a higher altitude in the northern part of the observation area.

A distinct, falling trend in the groundwater level is discernible at both stations, nos. 4105 and 4107, during the observation period. This trend probably is caused by low precipitation in 1971–1973.

The groundwater temperature at a depth of 7 m at station no. 4102 shows an annual cyclicity with an amplitude of about 1.5–2.0°C. Maxima are found in October–November and minima in May. The mean temperature during the observation period is 7.7°C.

3.42. Arjeplog

3.42.1. Geographical location

The observation area Arjeplog is situated in the central part of the province of Lapland in north Sweden, 60 km south of the Arctic Circle. The altitude of the area ranges from 440 to 470 m a.s.l. A map of the area is shown in Fig. 93.

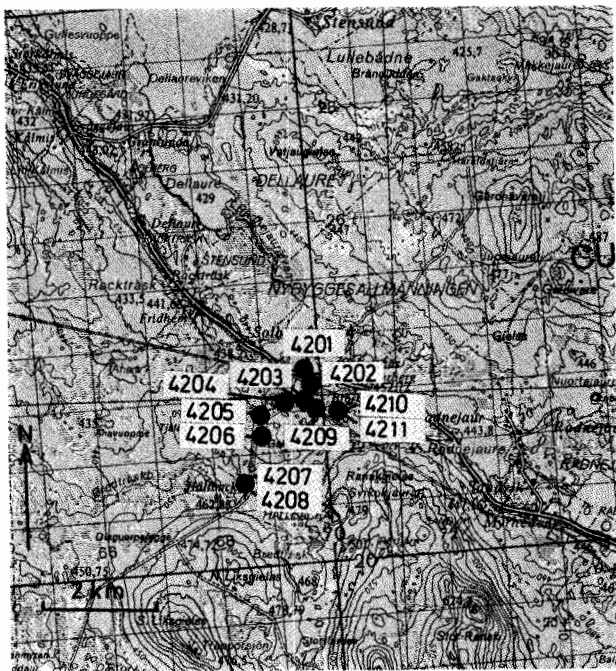


Fig. 93. Map of observation area 42 Arjeplog. (Top. map 25 I.)

3.42.2. Geology and geomorphology

The main part of the observation area is comprised of glaciofluvial deposits belonging to an esker system extending in NW–SE. Between the town of Arjeplog and the observation area, 15 km southeast of the town, the glaciofluvial deposits consist of a net of anastomosing ridges separated by deep and narrow trenches. At the

observation area, the deposits have a more flat appearance. There are a few deep depressions, though, indicating the presence of bodies of dead-ice at the time of deposition. Some of the depressions are occupied by small lakes. The material at the surface is sand and fine sand which have been redeposited by colian activities. Silt is found in the western part of the area. A few gravel pits indicate that coarser material (gravel and cobbles) is to be found at some depth.

The underlying and surrounding till is sandy, and, in localized areas, rich in boulders. The petrographic composition of the till shows a great predominance of particles of Precambrian origin. The low parts of the area are occupied by peatlands. Diagrams of the grain size distribution are shown in Fig. 94.

The bedrock does not outcrop anywhere within the observation area. It is assumed to be composed of Precambrian granites.

3.42.3. Hydrological and hydrogeological features

The sandy glaciofluvial deposits have a high infiltration capacity. Therefore, no surface runoff is ever found in these deposits.

In the moraine and peat terrain small brooks collect the water. They discharge into the lakes Kakel, Hornavan and Uddjaur all of which belong to the Skellefte river system.

The groundwater of the area flows toward the low peat-covered lands and from there, into the brooks. The moraine terrain north of the esker system receives groundwater from the sandy deposits, whereas south of the esker system, the conditions are reversed. The groundwater gradient in the glaciofluvial deposits is fairly level.

There is no extraction of water within the area except for one private well in the southern, till-covered part.

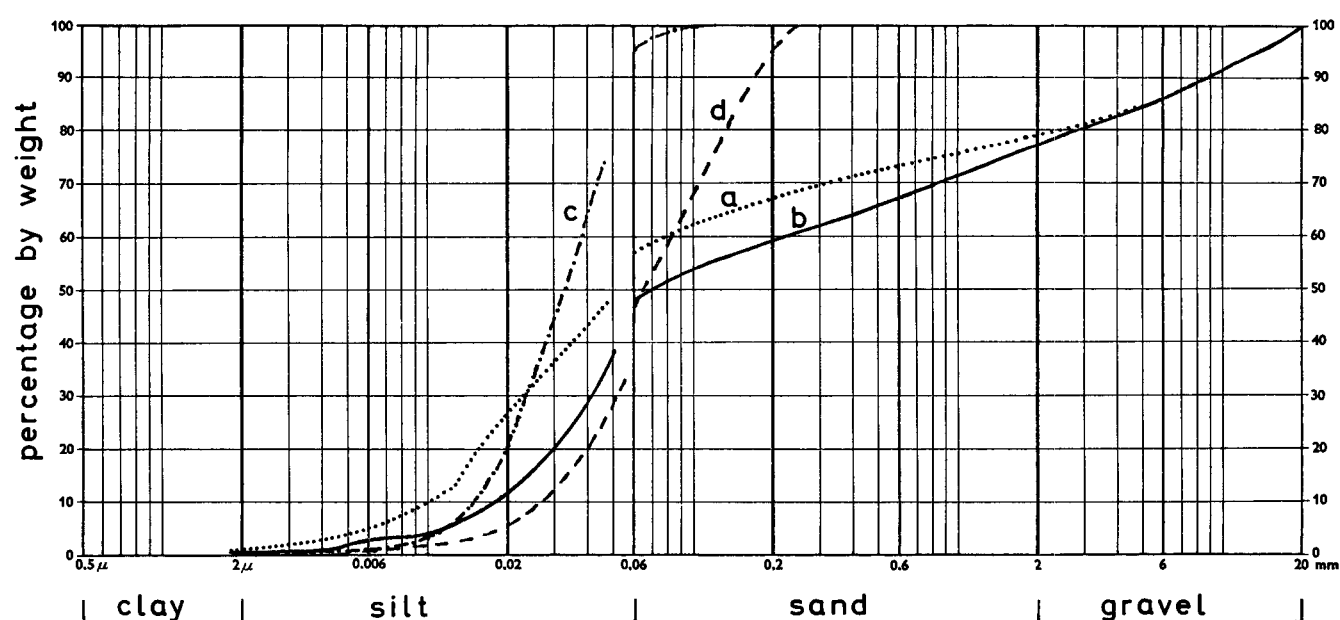


Fig. 94. Grain size distribution of till and sediments. Curve a 500 m W of station no. 4201, curve b 800 m S of station no. 4210, curves c and d 100 m SW of station no. 4205. Sampling 0.5 m below ground surface.

3.42.4. Observation stations

The main features of the observation stations are presented in the table below.

The locations of the groundwater stations are shown on the map, Fig. 93. All stations were established by SGU, in 1971, exclusively for the national groundwater network.

3.42.5. Comments on the diagram

The fluctuations of the groundwater levels in till and sand, also precipitation, snow cover and the penetration

of frost, are shown in the diagram (Fig. 95). Regular observations started in July, 1971; therefore the observation period is relatively short.

The groundwater levels fluctuate in a distinct, seasonal pattern. The main recharge to the groundwater reservoir takes place in connection with the snow-melting in the spring. The groundwater level starts to rise in April—May. The reaction starts somewhat earlier in the till than in the sand, and the peak level is reached very rapidly in the till, i. e., in June—July. In the sand, the maximum level is reached in September—October. From its highest le-

Station no.	Lat.	Long.	Land surface m a.s.l.	Geology	Depth of well m	Type of station	Obs. program	Aq.	Start of obs.	Remarks
4201	6559	1808	444	Sandy till	4	Tube	L	W	1971	
4202	6559	1808	445	" "	4	"	L	W	1971	Covered by sand
4203	6559	1808	445	Gl. fl. sand	3	"	L	W	1971	
4204	6559	1808	448	" " "	9	"	LT	W	1971	
4205	6559	1807	448	" " "	8	"	L	W	1971	
4206	6559	1806	448	Sandy till	5	"	L	W	1971	
4207	6558	1806	461	" "	4	"	L	W	1971	
4208	6558	1806	461	" "	5	"	L	W	1971	Continuous recording 1971—72
4209	6559	1808	451	Gl. fl. sand	11	"	L	W	1971	
4210	6559	1809	450	" " "	10	"	L	W	1971	Continuous recording
4211	6559	1809	450	" " "	10	"	L	W	1971	
F 19	6558	1806	461	Sandy till	—	Frost	F	—	1971	
F 20	6559	1806	448	" "	—	"	F	—	1971	
F 21	6559	1808	451	Gl. fl. sand	—	"	F	—	1971	
F 22	6559	1809	450	" " "	—	"	F	—	1971	

GEOLOGICAL SURVEY OF SWEDEN

GROUNDWATER NETWORK

AREA 42 ARJEPLOG

Groundwater level: Station 4205 (glaciofluvial sand) and 4206 (sandy till)

Groundwater temperature: Station 4204 (glaciofluvial sand),
measuring depth 9 m below land surface

Snow cover and frost penetration: Station F 21 (glaciofluvial sand, coniferous forest)

Precipitation: Station SMHI 16771 Arjeplog. Mean yearly precipitation 1931-60: 508 mm

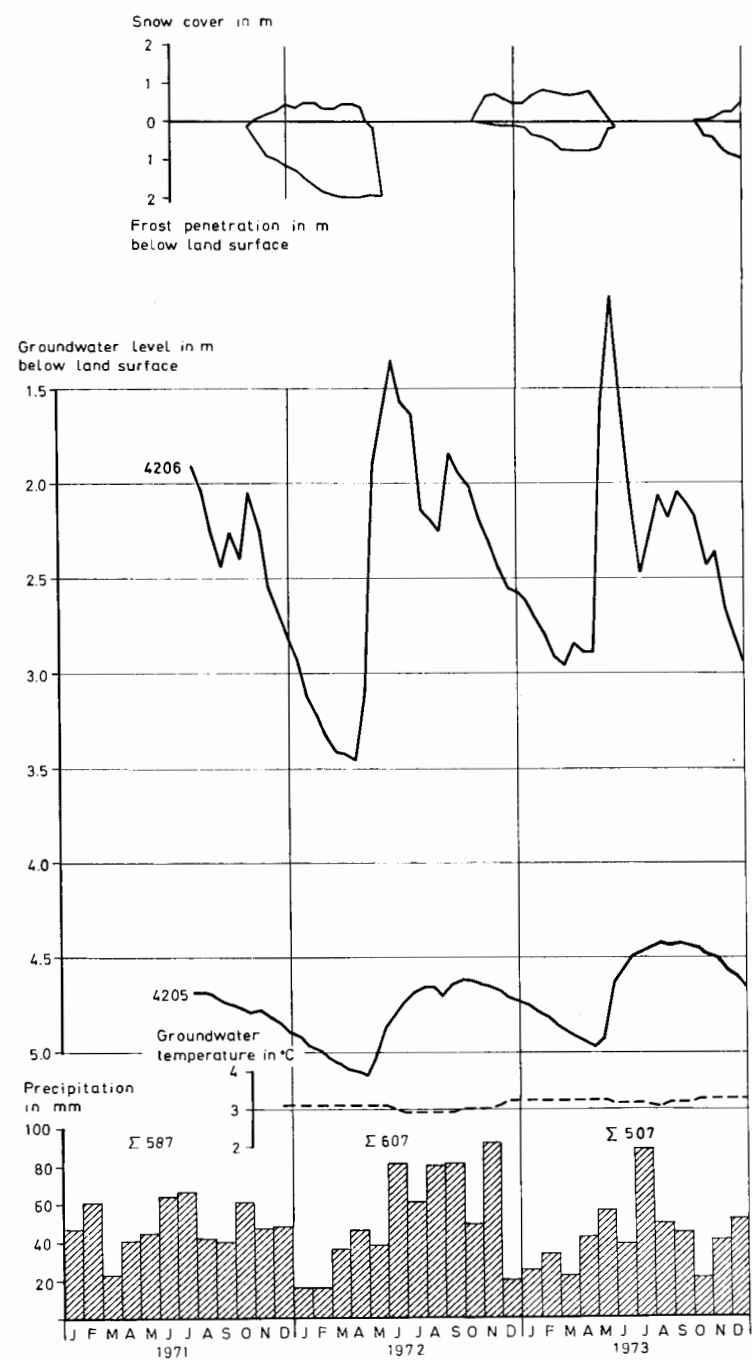


Fig. 95. Diagram from observation area 42 Arjeplog.

vels the groundwater falls all autumn and winter long to its lowest levels in late winter. Due to heavy rainfall, minor recharge can take place in the autumn also. The yearly amplitudes are approx. 2 m in till, and 0.5 m in sand.

In 1971—1972 there was a snow cover from the start of November, 1971, to the middle of May, 1972. The next year the duration of the snow cover was somewhat longer. The frost penetrated to a maximum depth of 2 m in April—May, 1972, and approx. 1 m in May, 1973. The remarkable differences in depth between the two years can be partly explained by the thick snow cover in 1972—1973 which functioned as an insulating cover against low air temperature. It should be pointed out that the rise of the groundwater starts approx. one month before the complete disappearance of frost in the ground. This indicates that the frozen ground does not act like a

sealing roof in the spring. From November to April, however, it eliminates infiltration; and, hence, there is no percolation of water to the groundwater zone during this period.

The temperature of the groundwater at a depth of 9 m below land surface is steadily close to 3.0°C. A minimum of 2.9°C is reached in July—September while a maximum of 3.1°C—3.2°C is prevalent during the most part of the rest of the year. Thus the yearly amplitude is only 0.3°C. The time lag between the seasonal fluctuation in air temperature and groundwater temperature seems to be approx. half a year.

Due to the short period of observation no long-term trends can be seen. It is obvious, though, that the minimum groundwater levels in 1973 were considerably higher than those in 1972.

3.43. Stensele

3.43.1. Geographical location

The observation area Stensele is situated close to the river Ume älv in south central Lappland. The location is approx. 200 km west of the Bothnian coast and 20 km east of the eastern marginal zone of the Caledonian mountain range. The elevation of the area ranges from 316 m a.s.l., which is the level of the river Ume älv, to 424 m a.s.l. which is the altitude of the lake Skarvsjön at the southern edge of the area (see map, Fig. 96).

3.43.2. Geology and geomorphology

The bedrock is exposed at a few places within the area. It consists of porphyritic Revsund granite. The surface of the bedrock slopes gently toward the river Ume älv at the northern margin of the area. The bedrock is generally concealed under loose deposits, mainly till.

The till is essentially sandy and has an intermediate boulder frequency at the surface. In the northern and southern parts of the area, though, the boulder frequency is higher. A silty variety of the till has been found locally in the central part of the area. The thickness of the till is generally 3—4 m.

Peat is found frequently as patches in the moraine terrain, particularly in the southern half of the area. It occupies the depressions between moraine ridges and hills. The thickness of the peat is not known, but it can be assumed to be approx. 1—3 m.

Two esker systems are found within the area, one at the bottom of the Ume älv valley, and one in the high-lying moraine terrain in the southern part of the area.

The northern glaciofluvial deposit belongs to a system of eskers and outwash plains along the river Ume älv. The part of the deposits that is found within the area consists of a flat-lying accumulation of sand and gravel. Large boulders are found on the surface. The maximum thickness of the sand and gravel exceeds ten meters.

The southern glaciofluvial deposit is a topographically well-defined esker that can be followed across the lake Skarvsjön as disconnected hills and ridges. North of the lake, the crest of the ridge is only 2—5 m above surrounding terrain. The esker has a general direction of NW—SE. In the northwestern portion of the esker, in the vicinity of the river Storbäcken, it attains a height of about 15 m above the surrounding ground. The central part of the esker is dominated by coarse sand, gravel and stones, whereas, fine sand dominates in the peripheral parts.

3.43.3. Hydrological and hydrogeological features

The surface water and groundwater of the area flow in accordance with the local topography. The peat-covered lowlands receive water from surrounding hills. The water is directed to the lake Skarvsjön, the river Storbäcken and minor brooks, and, eventually, to the river Ume älv that discharges its water into the Bothnian Sea.

The extraction of water by pumping from the area is very slight; only a few wells for separate households are in operation. The small village of Skarvsjö is supplied with water from the nearby lake. The towns of Stensele and Storuman, north of the observation area,

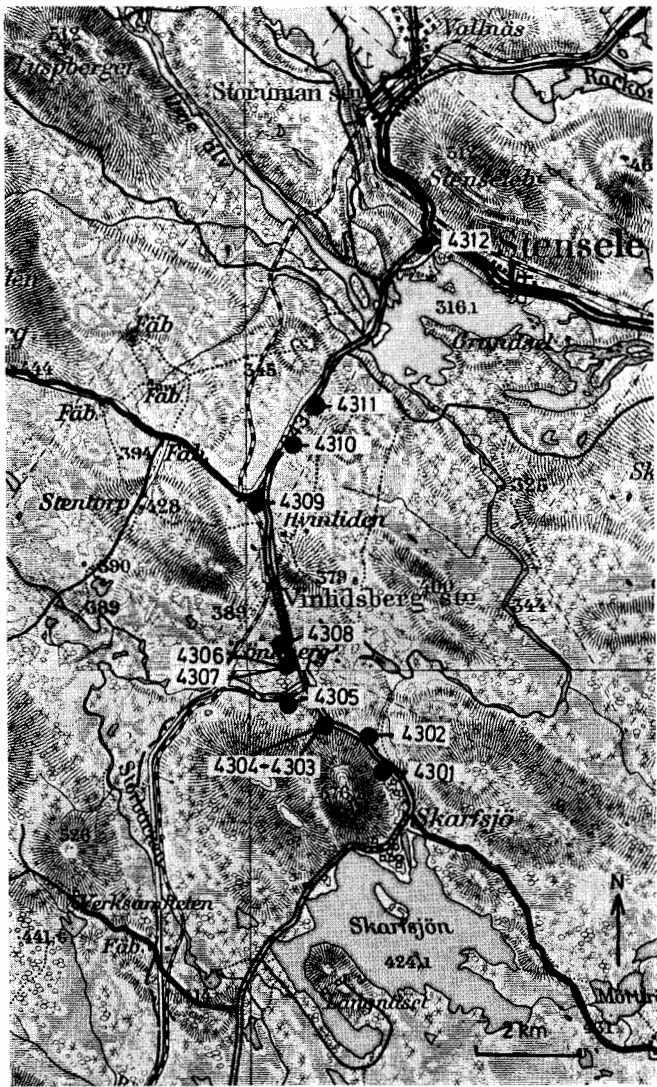


Fig. 96. Map of observation area 43 Stensele.

extract water from glaciofluvial deposits in the lake Storuman where there is a good hydraulic connection between the lake water and the groundwater.

3.43.4. Observation stations

The main features of the observation stations are presented in the table below.

The locations of the groundwater stations are shown on the map, Fig. 96. All stations were established by SGU exclusively for the groundwater network.

3.43.5. Comments on the diagram

In the diagram (Fig. 97) the variations of groundwater levels in till and sand are shown in relation to precipitation, groundwater temperature, frost penetration and snow cover.

Station no. 4305 refers to observations of groundwater levels in glaciofluvial sand. There is a distinct pattern of seasonal fluctuations. The lowest levels are present in April—May, just prior to the period of snow-melting and frost-thawing. During this period the major recharge of groundwater takes place, and the highest levels are reached in June—July. The groundwater levels fall all through the autumn and winter, with occasional interruptions in the autumn, caused by heavy rainfalls. The yearly amplitude is 0.5—0.6 m. Due to the short period of observation, no trends can be seen.

Station no. 4309 is situated in sandy till. The pattern of seasonal fluctuations is similar to that of station no. 4305, but with considerably larger extreme values. Thus the yearly amplitude in the till is approx. 1.5 m, i. e., three times as large as in sand. This is a reflection of the

Station no.	Lat.	Long.	Land surface m a.s.l.	Geology	Depth of well m	Type of station	Obs. program	Aq.	Start of obs.	Remarks
4301	6459	1707	396	Gl. fl. sand	9	Tube	LT	W	1971	
4302	6459	1707	384	" " "	3	"	L	W	1971	
4303	6459	1706	380	" " grav.	4	"	L	W	1971	
4304	6459	1706	380	" " "	4	"	L	W	1971	Continuous recording
4305	6459	1704	378	" " sand	3	"	L	W	1971	In sand pit
4306	6500	1704	380	Sandy till	4	"	L	W	1971	Continuous recording
4307	6500	1704	380	" " "	4	"	L	W	1971	
4308	6500	1704	385	" " "	4	"	L	W	1971	
4309	6501	1703	372	" " "	4	"	L	W	1971	
4310	6502	1704	356	Silty till	5	"	L	W	1971	
4311	6502	1705	348	" " "	3	"	L	W	1971	
4312	6504	1708	319	Gl. fl. grav.	3	"	L	W	1971	In gravel pit
F 15	6459	1707	396	" " sand	—	Frost	F	—	1971	
F 16	6459	1706	380	" " "	—	"	F	—	1971	
F 17	6500	1704	380	Sandy till	—	"	F	—	1971	
F 18	6501	1703	372	" " "	—	"	F	—	1971	

GEOLOGICAL SURVEY OF SWEDEN

GROUNDWATER NETWORK

AREA 43 STENSELE

Groundwater level: Station 4305 (glaciofluvial sand) and
Station 4309 (sandy till)

Groundwater temperature: Station 4301 (glaciofluvial sand),
measuring depth 8 m below land surface

Snow cover and frost penetration: Station F 15 (glaciofluvial sand, meadow)
and F 16 (glaciofluvial sand, coniferous forest)

Precipitation: Station SMHI 15772 Stensele
Mean yearly precipitation 1931-60: 494 mm

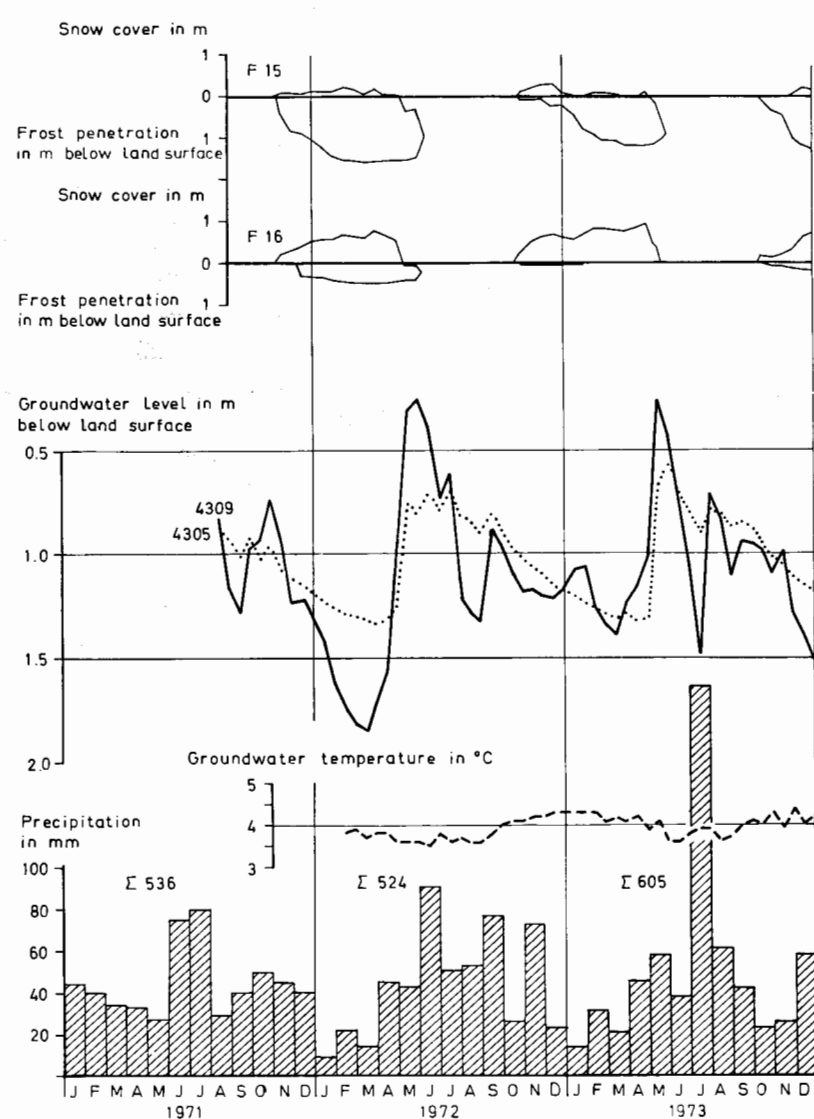


Fig. 97. Diagram from observation area 43 Stensele.

tration are presented from two stations in sand, one in an open meadow, and one in a pine forest. The meadow station (no. F 15) commonly has a very slight snow cover due to drifting, while the forest station (no. F 16) may be covered by almost one meter of snow. Due to the insulating effect of the snow, the ground is frozen to a maximum depth of only 0.4 m in the forest. In the meadow, more or less blown clean from snow, the frost penetrates to a maximum depth of 1.6 m. The duration of the frost is 6—7 months. It is noticeable that the groundwater starts to rise in the spring, well in advance of the complete vanishing of the frost. It should be pointed out that at both groundwater stations the unsaturated zone is only 1—2 m deep.

The thickness of the snow cover and the frost pene-

in NW—SE across south-

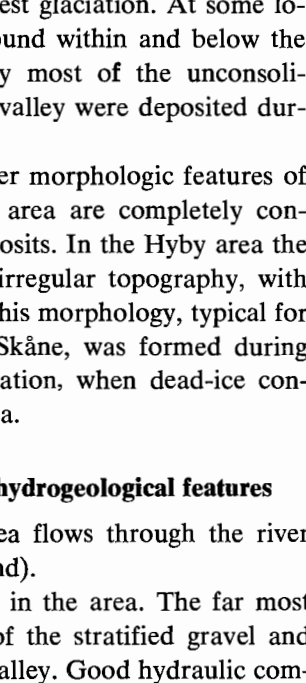
The Alnarp valley is filled completely with Quaternary deposits, consisting of stratified gravel, sand, silt and clay. The sequence is covered in most places by till from the last stages of the latest glaciation. At some localities till beds have been found within and below the stratified sediments. Probably most of the unconsolidated deposits in the Alnarp valley were deposited during the latest glaciation.

er morphologic features of the area are completely consistent. In the Hyby area the irregular topography, with this morphology, typical for Skåne, was formed during deglaciation, when dead-ice con-

hydrogeological features

Several aquifers are found in the area. The far most important of these consists of the stratified gravel and sand deposits in the Alnarp valley. Good hydraulic communication seems to exist between the gravel and sand aquifer and the limestone aquifer. Several less important aquifers, separated from each other by till or clay layers may be found in the upper parts of the unconsolidated deposits.

groundwater in the main
main water divide is found



between the gravel and sand
if a gravel layer is present.

parts of the unconsolidated

groundwater in the main
main water divide is found

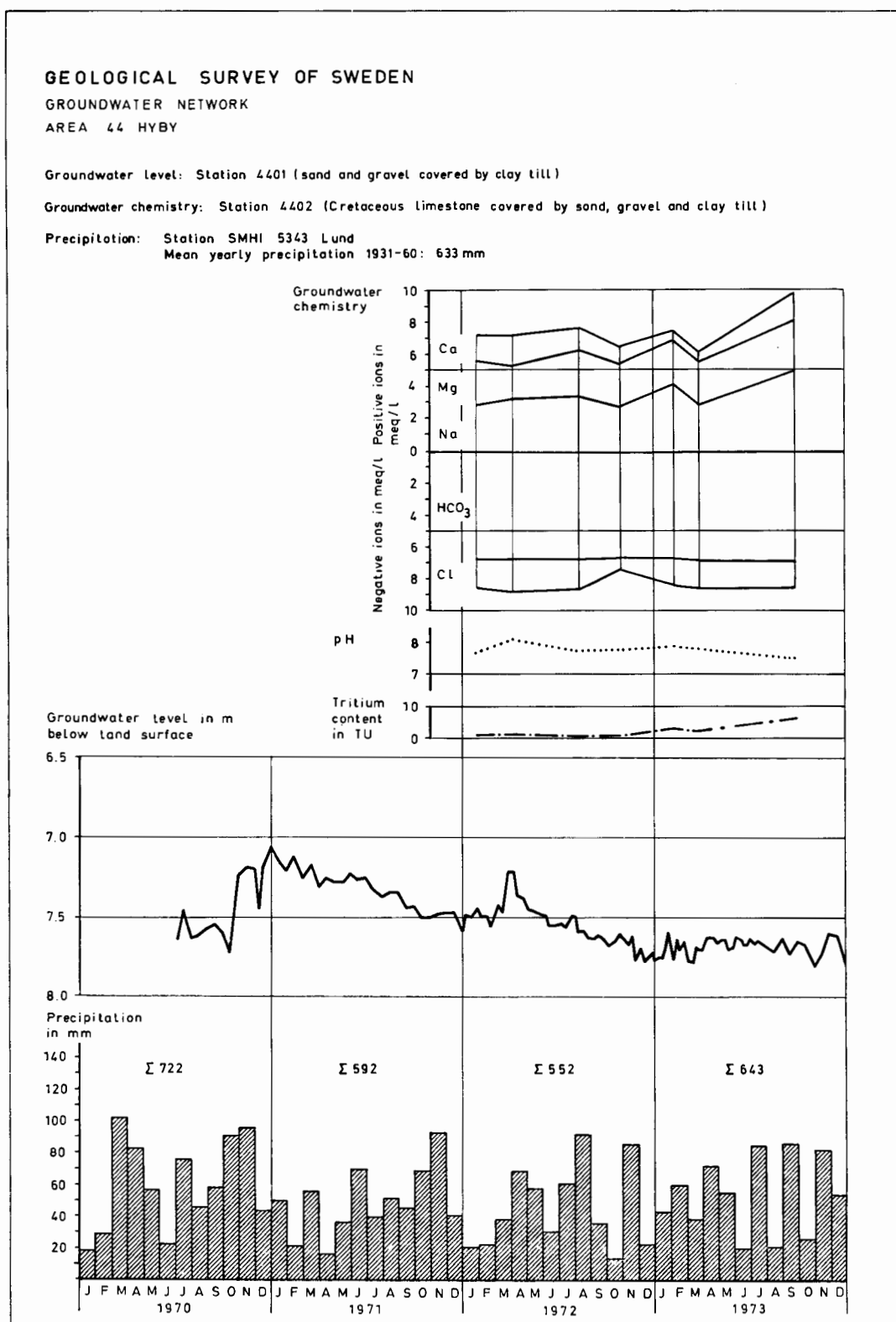


Fig. 99. Diagram from observation area 44 Hyby.

about 10 km southeast of Hyby in this aquifer. Southeast of this divide, the main flow is directed toward SE.

A large number of wells for water supply purposes have been established in the Alnarp valley sediments. The most important pumping of groundwater from the main aquifer is performed about 5 km northwest of the Hyby area where several wells which contribute to the water supply of the town of Malmö are situated. The withdrawal of water at these wells in 1968 was about 9 000 000 m³/yr (= 300 l/s). The total amount of water pumped from the aquifer in 1968 was about 16 000 000 m³/yr (= 500 l/s), according to Brinck and Leander (1970).

This withdrawal of water from the main aquifer of the Alnarp valley has lowered the piezometric level of the aquifer in the northwestern parts of the valley. Prior to the start of the pumping at the end of the 19th century, flowing wells were found in many places in this area.

However, the pumping does not seem to have any great influence on the groundwater conditions in the Hyby area.

Several investigations concerning the geology and hydrogeology of the Alnarp valley have been made, e. g., by Brinck and Leander (1970) and Nilsson and Gustafsson (1967).

3.44.4. Observation stations

The main features of the stations are presented in the following table:

Station no.	Lat.	Long.	Land surface m a.s.l.	Geology	Depth of well m	Type of station	Obs. program	Aq.	Start of obs.	Remarks
4401	5534	1315	35	Sand	97	Drill	L	A	1970	Continuous recording 1970—1973
4402	5534	1315	44	„	132	„	C	A	1972	

Station no. 4401 is drilled 2 m and no. 4402, 22 m in the limestone below the Alnarp valley sediments. Station no. 4401 was established 1965 by "Samarbetskommittén för Alnarpsströmmen" for aquifer investigation purposes. Station no. 4402 was established in 1969 for the water supply of a small workshop.

3.44.5. Comments on the diagram

Fig. 99 shows the variations in groundwater composition and level at the two observation stations in the area.

The groundwater has a relatively high ion content; the dominating ions are sodium and bicarbonate. The period of sampling is too short to permit any conclusions about trends or patterns of fluctuations to be drawn.

The tritium content is very low (1—6 TU), which indicates a very long residence time of the water in the aquifer.

No distinct, annual cyclicity is discernible in the curve showing the groundwater level fluctuations. However, a multiannual trend is clearly visible in the diagram. During 1971 and 1972, the groundwater level was successively sinking by a total amount of about 0.7 m. During the autumn of 1970, a fast rise of the groundwater level of about the same amount took place. These variations seem to reflect the different sums of annual precipitation these years. The precipitation in 1970 was above average, whereas, in 1971 and 1972, it was below average.

3.45.—3.49. Ströms Vattudal, Flåsjön, Tåsjön, Ormsjön and Malgomaj

These five areas are treated as one area of observation as they were established in their location for one special reason. The large rivers in the area are regulated for hydroelectric power plants further downstream. The replenishment of the reservoirs in the winter is almost entirely dependant upon the supply from groundwater, as the precipitation is in the form of snow and no melting takes place. The ground is frozen for 6—7 months. For this reason it has been declared that a better knowledge of the groundwater conditions in the catchment may facilitate the issuing of predictions of winter recharge

of the surface water reservoirs. The project is performed in co-operation with the Swedish Meteorological and Hydrological Institute (SMHI) and the Ångermanälven Regulation Authorities.

The collected data on groundwater are integrated into the national groundwater network of SGU.

3.45.1.—3.49.1. Geographical location

The five areas nos. 45—49 (see map, Fig. 100) make up the upper part of the catchment of the river Ångerman-

älven and its tributaries, the Fjällsjöälven and the Faxälven. The areas are situated between the Swedish—Norwegian border, and the lakes, which have given their names to the observation areas. The areas cover the northernmost part of the province of Jämtland and southwestern Lappland — a total of approx. 10 000 km². The 53 observation stations are found within a range of elevation from 224 m a.s.l. to 642 m a.s.l. The highest peaks within the area are 1 400 m a.s.l.; they are found on the international border in the west.

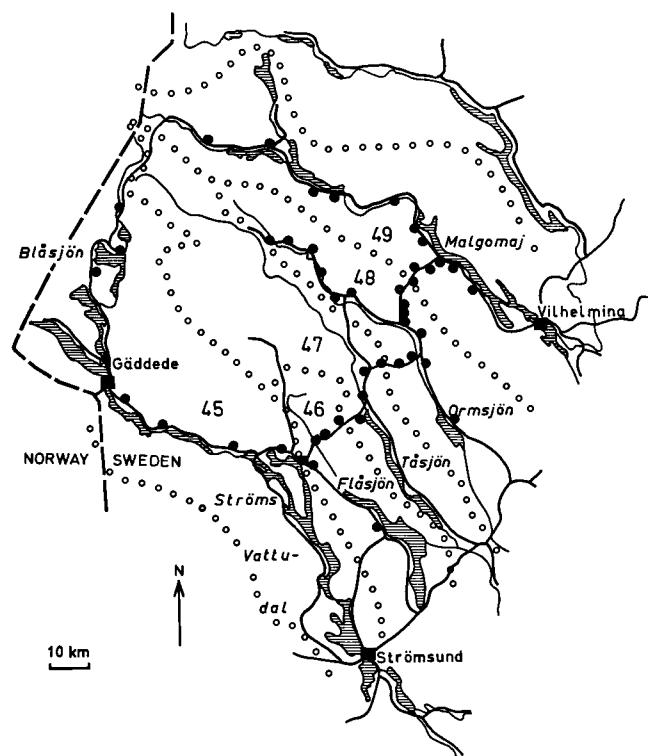


Fig. 100. Map of observation areas 45 Ströms Vattudal, 46 Flåsjön, 47 Tåsjön, 48 Ormsjön, 49 Malgomaj. Water divides between areas roughly indicated by lines of circles.

3.45.2.—3.49.2. Geology and geomorphology

The vast area makes up a representative part of the northern Swedish inland. In the west, the Caledonian mountain range runs in a NNE—SSW direction. It is composed of rocks of the large western nappes, mainly phyllites, schists and quartzites, but also magmatic rocks like amphibolites and peridotites. East of the nappes, sparagmites, Ordovician shales and Variegian quartzites are the most common rock types in the marginal mountain region. In the easternmost part of the area, the autochthonous Precambrian granites and gneisses form the basement.

The highest mountains reach above the timberline.

There the loose deposits are thin or absent; the main soil type is colluvium, i. e., weathering residue. Fluvial sand and gravel may occur along the river courses. Till is found locally.

Below the timberline, the wooded areas are characterized by till. This is the dominating type of Quaternary deposit. The thickness of the till varies considerably with topography. On high hills and along steep slopes the thickness approaches zero, whereas low-lying, flat areas may have 2—5 m of till. Locally a thickness of 10 m or more can be assumed. The table of observation stations (see page 149) presents the depth of the stations; as most measuring tubes stand on bedrock (or boulders) the depth is an indication of minimum soil thickness. The composition of the till is determined by the local bedrock. Therefore, several types of till are found: silty, sandy and gravelly. A bimodal distribution of fractions has been found in several places; the most common distribution of this type is the silty gravelly till. Clayey silty till is found west of the lake Blåsjön in the western part of the area. In general, the sandy (fine sand dominating) till is the most common type in the area of observation.

Glaciofluvial deposits occur only very sporadically within the area. They are small and disconnected.

Some of the high valleys of the area were inundated by local ice-lakes at the end of the deglaciation. In these valleys sandy and silty sediments are found. With respects to area they play an inferior role.

Much of the moraine terrain is characterized by peatlands. They are most common in the southeastern part of the area. Due to the relative humidity in this part of the country, they are assumed to be growing and expanding. The oblique land upheaval (increasing south-eastwards toward the Bothnian coast) may also contribute to the growth of the peatlands.

The general geomorphology of the area is characterized by the five major river valleys: the lake Malgomaj—Ångermanälven, the Långseleån—Ormsjön, the Saxälven—Tåsjön—Fjällsjöälven, the Flåsjön and the Ströms Vattudal—Faxälven. The relative relief along a line crossing the valleys is several hundred meters.

3.45.3.—3.49.3. Hydrological and hydro-geological features

The general surface hydrology of the area is characterized by the major drainage from the mountainous region in the west, southeastwards through the forested foothills to the undulating inland between the mountains and the coast of the Bothnian Sea. The area is equivalent to the

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Station no.	Lat.	Long.	Land surface m a.s.l.	Geology	Depth of well m	Type of station	Obs. program	Aq.	Start of obs.	Remarks
4514	6420	1506	382	Sandy till	3	Tube	L	W	1972	Covered by peat
4515	6421	1449	305	Grav. till	3	"	L	W	1972	
4516	6423	1428	318	Sandy till	4	"	L	W	1972	
4517	6428	1414	332	" "	3	"	L	W	1972	Covered by fine sand
4518	6433	1408	368	" "	5	"	L	W	1972	Continuous recording
4519	6433	1408	368	" "	4	"	L	W	1972	
4520	6445	1403	493	" "	2	"	L	W	1972	Covered by peat
4521	6449	1412	478	" "	3	"	L	W	1972	
4522	6454	1412	464	Grav. till	8	"	L	W	1972	
4601	6418	1518	224	Sandy till	3	"	L	W	1972	
4602	6421	1521	385	" "	5	"	L	W	1972	
4603	6422	1523	436	" "	4	"	L	W	1972	Continuous recording
4604	6423	1527	504	" "	4	"	L	W	1972	Covered by fine sand
4605	6423	1527	504	" "	4	"	L	W	1972	Covered by fine sand
4612	6411	1538	279	" "	3	"	L	W	1972	"
4613	6417	1521	335	" "	4	"	L	W	1972	
4652	6422	1523	436	" "	3	"	L	W	1972	Covered by fine sand
4701	6432	1540	415	Grav. till	—	Spring	C	W	1973	
4706	6425	1532	306	" "	4	Tube	L	W	1972	
4707	6427	1535	300	Sandy till	5	"	L	W	1972	
4708	6430	1535	343	" "	3	"	L	W	1972	
4709	6432	1540	415	Grav. till	3	"	L	W	1972	
4732	6449	1503	570	Sandy till	2	"	L	W	1972	
4810	6432	1546	426	" "	6	"	L	W	1972	
4811	6434	1551	329	Grav. till	8	"	L	W	1972	
4823	6424	1603	278	" "	6	"	L	W	1972	Continuous recording
4824	6424	1603	278	" "	7	"	L	W	1972	
4825	6432	1553	310	" "	2	"	L	W	1972	Covered by peat
4826	6436	1552	309	Sandy till	4	"	L	W	1972	
4827	6442	1531	373	" "	6	"	L	W	1972	
4828	6442	1527	490	" "	3	"	L	W	1972	
4829	6445	1520	469	" "	6	"	L	W	1972	Covered by silt
4830	6449	1514	498	" "	5	"	L	W	1972	Continuous recording
4831	6450	1507	525	" "	5	"	L	W	1972	
4833	6439	1545	335	" "	5	"	L	W	1972	
4834	6440	1546	407	Grav. till	7	"	L	W	1972	
4835	6442	1546	444	Sandy till	2	"	L	W	1972	Covered by peat
4836	6444	1547	533	" "	5	"	L	W	1972	
4837	6444	1547	533	" "	5	"	L	W	1972	Continuous recording
4938	6445	1551	642	" "	5	"	L	W	1972	Covered by peat
4939	6446	1554	588	" "	1	"	L	W	1971	" " "
4940	6446	1557	519	" "	3	"	L	W	1971	Covered by sand
4941	6448	1600	354	" "	6	"	L	W	1971	
4942	6442	1615	360	" "	3	"	L	W	1972	
4943	6446	1608	388	" "	2	"	L	W	1972	
4944	6451	1554	387	" "	6	"	L	W	1972	
4945	6454	1552	369	Grav. till	3	"	L	W	1972	Clayey-silty variety
4946	6456	1542	471	Sandy till	4	"	L	W	1972	
4947	6457	1526	554	Grav. till	2	"	L	W	1972	Covered by peat
4948	6459	1517	558	" "	6	"	L	W	1972	
4949	6504	1503	613	Sandy till	3	"	L	W	1972	
4950	6503	1444	566	" "	2	"	L	W	1972	
4951	6503	1444	566	" "	2	"	L	W	1972	Continuous recording

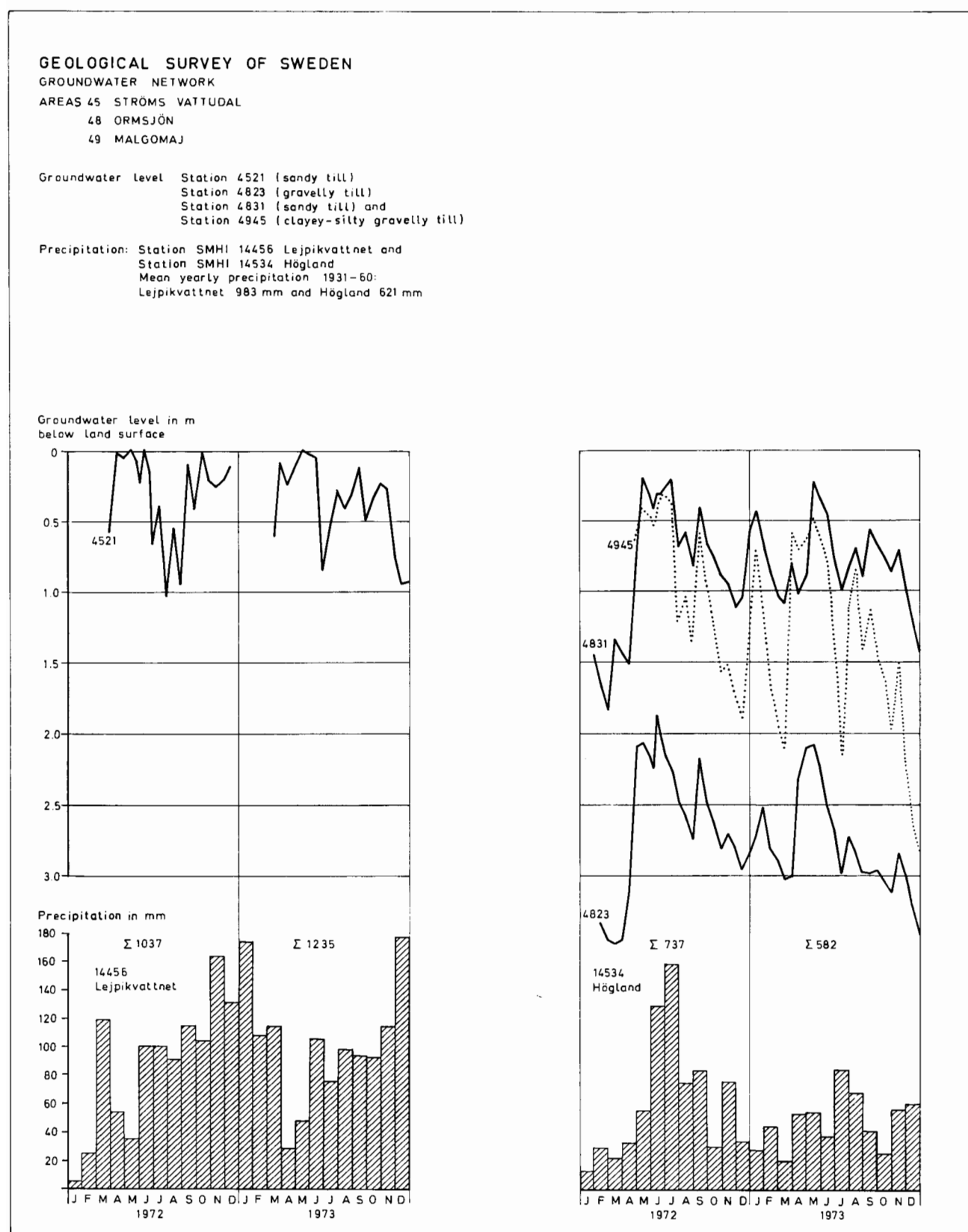


Fig. 101. Diagram from observation areas nos. 45 Ströms Vattudal, 48 Ormsjön and 49 Malgomaj, representing the group of areas nos. 45-49.

upper part of the catchment of the Ångermanälven river system. The mean yearly discharge of the river, having a total drainage area of 30 640 km², close to its mouth at Sollefteå, is 471 m³/s. In spite of extensive regulation of several lakes in the river system, the seasonal variations are considerable; a range in daily values from less than 100 m³/s to approx. 2 000 m³/s has been recorded during the last few years. The lake percentage of the catchment is 7.5.

As the area is situated in moraine terrain with humid climate a rather dense network of brooks and small rivers is found between the major river valleys. Many of the small watercourses flow only after heavy rainfall or snow-melting. Much water is stored in the peatlands in the moraine terrain.

The groundwater in the moraine terrain is found close to the surface except in places where the till has a higher porosity and permeability than usual, i. e., it is usually encountered at 1—3 m below land surface. The flow of the groundwater is determined by the local topography. It can be stated that the whole region is an area of recharge. Discharge takes place mainly along the watercourses and around the peatlands. Natural springs and zones of groundwater seepage are found in several places in the low-lying moraine terrain.

The population of the area is small. No urban districts are found. Only minor towns and scattered individual houses exist. They are preferably situated in the valleys. The extraction of groundwater is therefore completely negligible.

3.45.4.—3.49.4. Observation stations

The main features of the observation stations are presented in the table on page 149.

The locations of the stations are shown on the map, Fig. 100. The stations were established by the River Regulation Authorities in co-operation with SGU.

3.45.5.—3.49.5. Comments on the diagrams

Four stations are selected in the diagrams (Fig. 101):

no. 4521 is situated close to the lake Blåsjön in the west, no. 4831 is situated in the central part of the area, and stations nos. 4823 and 4945 are found near the lake Ormsjön and the lake Malgomaj, respectively, in the east. It is approx. 100 km between the western and eastern stations.

The groundwater curves are very jagged, indicating a fast response between precipitation and rise of groundwater level. A general, seasonal pattern of fluctuations is discernible, showing maximum levels in May. The peak levels are reached in connection with the vanishing of the snow and frozen ground. During the summer, autumn and winter, there is a general fall in the groundwater levels, interrupted by temporary rises caused by heavy rainfall or the snow-melting. The minimum level is reached in March—April.

The short period of observation does not allow for any generalizations of the pattern. The winter of 1972—1973 was exceptional with respects to a major period of thawing in December—January. The thawing caused a considerable recharge of the groundwater reservoir, which, probably, is not the case regularly in the winter. The yearly amplitude of the groundwater variations is 1.5—2.0 m at the four stations. Station no. 4945, which is located in clayey-silty gravelly till, shows especially rapid and large fluctuations. This is assumed to be caused by a low effective porosity in this type of till due to the high contents of clay and silt particles. In the sandy and gravelly till the fluctuations are somewhat less pronounced. The period of observation is still too short to allow for any far-reaching analysis of the relation between fluctuations and soil composition.

The great difference in mean yearly precipitation between the two shown precipitation stations should be pointed out. In an area of this size and relief it can be expected that there is a very wide range of mean values of precipitation between the stations. The local range of daily and monthly precipitation is even larger. This fact will be reflected in the corresponding groundwater conditions.

3.50. Siljansfors

3.50.1. Geographical location

The observation area Siljansfors is situated in the province of Dalarna in central Sweden, approx. 10 km west of Lake Siljan (see map, Fig. 102). The altitude of the area ranges from 241 m a.s.l., which is the level of the lake Jugen, to 456 m a.s.l.

3.50.2. Geology and geomorphology

The area is underlain by Sub-Jotnian volcanics, mainly Dala porphyry. They are outcropping in the high parts of the area, particularly as steep precipices. The pronounced bedrock topography is reflected in the corresponding, general topography of the area. During the

Figure 1 is a semi-logarithmic graph showing the percentage by weight of soil particles versus particle size in microns. The x-axis is logarithmic, ranging from 0.5 microns to 20 mm. The y-axis is linear, ranging from 0 to 100 percent by weight. Two curves are plotted: curve 'a' (dashed line) and curve 'b' (solid line). Curve 'a' represents a finer soil, while curve 'b' represents a coarser soil. The soil is divided into four regions: clay (below 0.006 microns), silt (0.006 to 0.06 microns), sand (0.06 to 2 mm), and gravel (above 2 mm).

Particle Size (microns)	Curve 'a' (%)	Curve 'b' (%)
0.5	8	0
2	12	2
0.006	15	5
0.02	25	10
0.06	40	20
0.2	60	50
0.6	75	65
2	85	75
6	95	85
20	100	100

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latest glaciation, till was deposited over the area. The composition of the till is characterized by the local bedrock, i. e., there is a high degree of porphyritic material in the till. The proximity to Silurian sandstone and shale north of the area, however, has influenced the composition of the till locally. Thus, till with a high degree of fine fractions is found in some places of the area. Particles of Jotnian sandstone and Dala granite also play an important part in the composition of the till. In places where the sandstone is prevalent, the till is coarse and has a high frequency of boulders. The grain size distribution from different till samples is shown in Fig. 103. A vertical differentiation of various types of till can be expected to exist in certain places.

The moraine terrain is mainly gently rolling without any strong topographic features of its own. The till cover is assumed to exceed 5 m only sporadically, particularly where the till has a hilly topography, indicating dead-ice conditions at the time of deglaciation. Such topography is found locally within the area.

At the western margin of the observation area an esker runs in a NW—SE direction. It forms part of the shore of the lake Jugen. Being deposited subaerially, the esker is steep-sided and sharp-crested. Locally it consists of two narrow ridges separated by a deep trench. The maximum relative relief is 15—20 m. The dominating fractions of the esker material are sand and gravel, mainly derived from sandstone, porphyry and granite. A boring made on the floor of a trench has penetrated 7 m of sand, gravel and stones. The bottom of the boring reached finer material which could be interpreted as till.

Minor areas are covered by peat, and they particularly occupy low stretches of the moraine terrain.

3.50.3. Hydrological and hydrogeological features

The area is drained through minor brooks to the lake Jugen, and the rivers Jugån and Ryssån, the former river a tributary to the latter. Ryssån flows to the lake Siljan which is drained through the river Dalälven to the Bothnian Sea.

The groundwater in the moraine terrain flows in general agreement with the surface topography. Therefore several minor flow systems lacking interconnection exist. Discharge takes place along brooks and in other low parts within the area. Some springs, yielding a maximum of 1 l/s each, have been found. Considerable groundwater seepage into the small tarns of the area has also been reported.

The esker in the western part of the area is assumed to contribute groundwater to the lake Jugen, partly collected from the adjacent moraine terrain.

No significant withdrawal of groundwater takes place in the area as it is populated only to a very low degree. There are only a few dwellings in the valley of the river Jugån.

3.50.4. Observation stations

The main features of the observation stations are presented in the table below.

The main part of the area coincides with the Siljansfors Forest Park which is administered by the Royal College of Forestry, Stockholm.

The stations were established in 1972 and 1973 as a contribution to the Swedish Coniferous Forest Project. The research program is mainly financed by the Swedish Natural Science Research Council and aims at an investigation of the total ecological system in the area. Stations nos. 5001—5004 and 5011—5013 are plastic

Station no.	Lat.	Long.	Land surface m a.s.l.	Geology	Depth of well m	Type of stn.	Obs. program	Aq.	Start of obs.	Remarks
5001	6054	1422	303	Sandy till	2	Tube	L	W	1972	
5002	6054	1422	292	" "	1	"	L	W	1972	
5003	6054	1422	279	" "	6	"	L	W	1972	
5004	6054	1422	276	" "	3	"	L	W	1972	Covered by peat
5005	6052	1420	255	Gl. fl. mix.	7	"	L	W	1973	
5006	6052	1420	255	" " "	7	"	L	W	1973	
5007	6053	1422	230	Sandy till	3	"	L	W	1973	
5008	6053	1423	240	" "	3	"	L	W	1973	Clayey variety
5009	6054	1422	225	" "	6	"	L	W	1973	
5010	6054	1422	225	" "	6	"	L	W	1973	
5011	6053	1421	167	" "	5	"	L	W	1973	
5012	6053	1421	259	" "	4	"	L	W	1973	
5013	6053	1421	274	" "	2	"	L	W	1973	

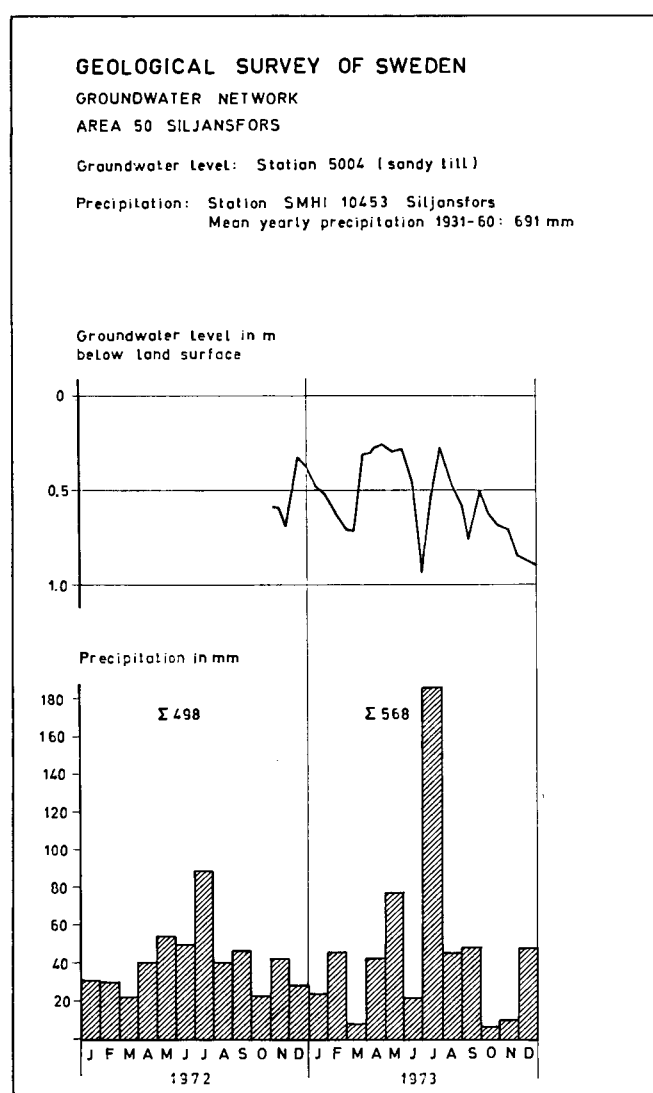


Fig. 104. Diagram from observation area 50 Siljansfors.

tubes allowing collection of uncontaminated water samples for chemical analysis. The main sampling and analysis program will be formulated by the Forest Project Authorities. At the same time as the stations are utilized for special purposes within the Forest Project, they supply data to the routine activities of the national groundwater network. The observation routines will be subject to necessary alterations in the future in accordance with information collected by the Forest Project and SGU.

3.50.5. Comments on the diagram

Due to the short period of observation the diagram (Fig. 104) presents a correspondingly short curve of groundwater variation.

Station no. 5004 is situated in till overlain by 20 cm of peat. The seasonal pattern of variation for the first year of observation shows a successive decline of levels in the winter, from the middle of December to the middle of March. In connection with the snow-melting in late March, the level rises to a maximum value which is maintained until June when a summer decline takes place. A second peak is reached in late July due to heavy rainfall, after which the decline continues. Recharge also takes place in late autumn. The annual amplitude is 0.7 m; the relatively low value is assumed to be caused by a limited groundwater rise due to a considerable lateral drainage in the surface layers. At other places within the area the amplitude is twice as large.

3.51. Näsbyholm

3.51.1. Geographical location

The observation area Näsbyholm is situated in the south part of the province of Skåne, about 3 km southwest of the town of Skurup (see map, Fig. 105). The altitude of the area ranges from 45 to 55 m a.s.l.

3.51.2. Geology and geomorphology

The area is characterized by a dead-ice morphology with gentle hills and depressions. The dominating Quaternary deposit in the area is clay till deposited at the end of the latest glaciation by the "Baltic Ice" moving west to northwestwards across the area. On some of the hills the clay till is covered by thin layers of sediments, generally consisting of clay, but at some localities, silty

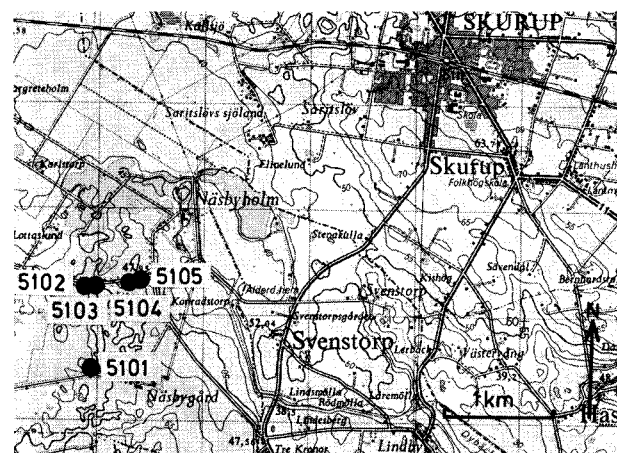


Fig. 105. Map of observation area 51 Näsbyholm. (Top. map 1 D NV, 2 D SV.)

and sandy sediments are found, too. These sediments were deposited in small glacial lakes dammed by dead-ice which occupied the depressions in the moraine terrain during part of the Late-glacial time. Today peat and gyttja are generally found in the depressions.

3.51.3. Hydrological and hydrogeological features

The area is completely cultivated and ditched. Before the ditching the depressions generally had no outlets, and at the times of the year when the groundwater level was high and in connection with periods of heavy rainfall, small lakes were found in the depressions. Nowadays, the ditching has lowered the groundwater level in the depressions and the rainwater is carried away by the ditches. Probably the ditching has diminished the groundwater recharge in, as well as the evaporation from, the area.

A water divide is found in the north part of the area

and the groundwater level in the superficial deposits slopes southwards.

The clay till of the area has a low permeability and the main water movement in the till is restricted to very thin layers of silt and sand.

3.51.4. Observation stations

The main features of the observation stations are presented in the table below.

The stations were established by SGU in connection with a research project concerning the effects of the use of fertilizer on the quality of groundwater and surface water. The investigations are carried out in co-operation with Lantbrukshögskolan (The Agricultural College of Sweden) and Naturvårdsverket (The National Swedish Environment Protection Board).

The observations in the area started in March, 1973. Hence, very few data are available yet.

Station no.	Lat.	Long.	Land surface m a.s.l.	Geology	Depth of well m	Type of station	Obs. program	Aq.	Start of obs.	Remarks
5101	5527	1327	48	Clay till	7	Tube	LC	W	1973	Plastic tube
5102	5527	1327	53	Sand	3	„	LC	A	1973	„ „
5103	5527	1327	53	Silt	2	„	LC	W	1973	„ „
5104	5527	1327	50	Clay till	7	„	LC	W	1973	„ „
5105	5527	1327	50	„ „	4	„	LC	W	1973	„ „

4. THE EVALUATION OF REGIONAL GROUNDWATER FEATURES

With data from a systematic, groundwater observation network covering the whole country, a differentiation of regional regularities can be executed. Such regularities are generally attributed to large scale climatological influences, i. e., to patterns of atmospheric circulation. Variations in the pattern may cause corresponding variations in the groundwater conditions in most aquifers. In order to obtain reliable information on regional groundwater regimes, the observation network must be comprised of stations of a certain spacing. Data on groundwater have to be available for a long period of observation and must be taken with regular measuring intervals. An observation period of less than ten years is too short for allowing any definite conclusions as to long-term trends and mean values to be made. It is true that the longer the period of observation, the better the possibilities of drawing correct conclusions concerning the long-term behavior of the groundwater.

In the U.S.S.R., Semenov and Konoplyantsev (1969) and Konoplyantsev (1970) have compiled maps of the relative water level position over a series of years by use of the coefficient of the relative groundwater level position. It is determined from the equation

$$\lambda = \frac{H_i - H_{\min}}{H_{\max} - H_{\min}}$$

where

H_i = the mean water level for a given year
 $H_{\max}$ and $H_{\min}$ = the maximum and minimum water level position for the whole period of observation

When $\lambda = 0$, i. e., when $H_i = H_{\min}$, there is an indication that the water level position for a given year is a minimum value in a perennial aspect, and when $\lambda = 1$ ($H_i = H_{\max}$), it is a maximum value. With this technique it is possible to compare areas of different geological character with each other, minimizing local and accidental factors. However, all effects of geology, depth of unsaturated zone, measuring intervals, etc. are not eliminated, but the principal regional regularities are sufficiently well differentiated. In the European part of the U.S.S.R., where long (50—80 years) observation periods are present, informative maps of the relative moisture balance are compiled for each year. They give a quite clear picture of the regional distribution of the relative groundwater storage of a large territory and its temporal variation.

Unfortunately the groundwater network of Sweden was established very late, in the late 1960's. Therefore a reliable calculation of the coefficient of relative ground-

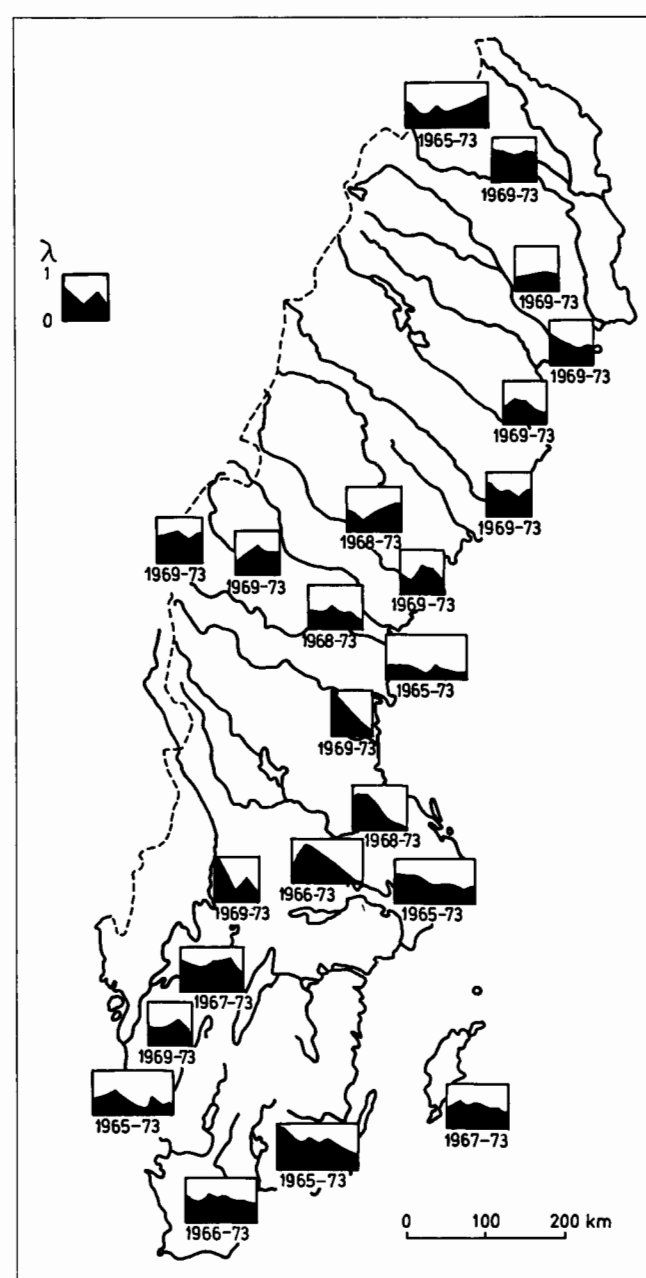


Fig. 106. Map of Sweden with λ -values from selected stations, showing the temporal variations of relative groundwater level position. Note that the calculated values derive from observation series of different length. All series are too short for allowing any general analysis of long-term trends to be made. For explanation of λ , see text.

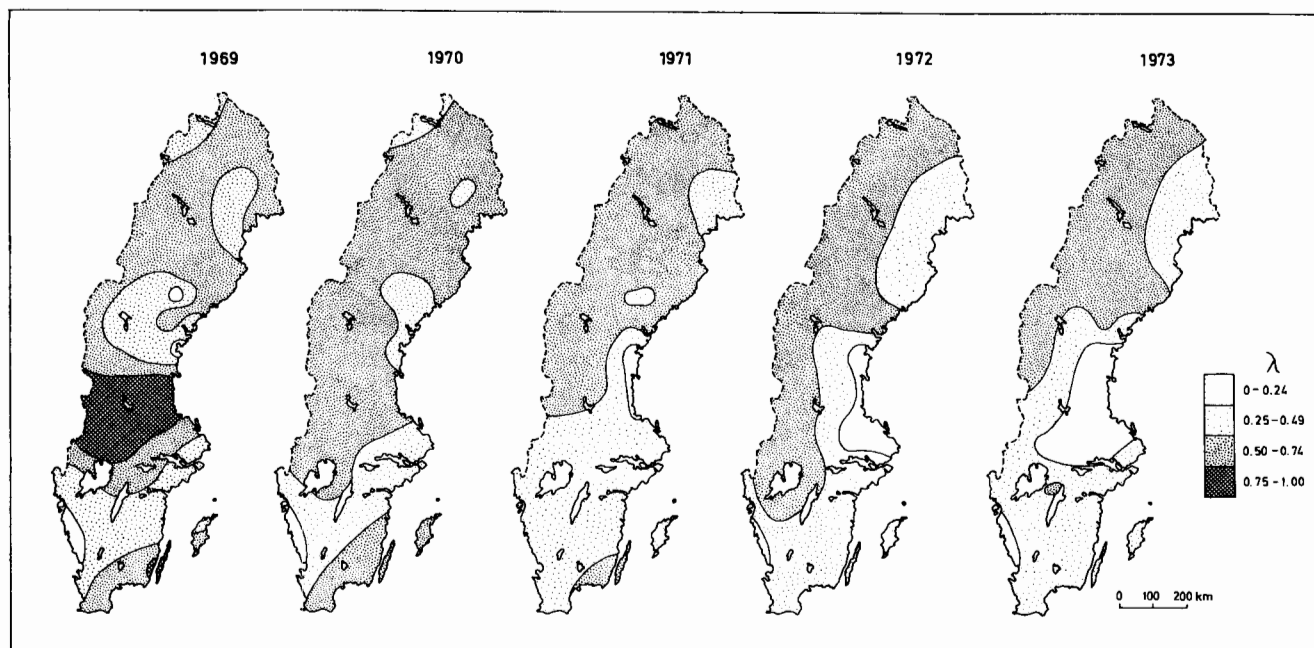


Fig. 107. Maps of Sweden, tentatively showing a zonation according to λ -values from selected stations for the years 1969—1973. Values are grouped in four classes, with increasing λ -values indicating increasing, relative groundwater level. Due to the small number of stations and the short period of observation the maps must be regarded as rough attempts. For explanation of λ , see text.

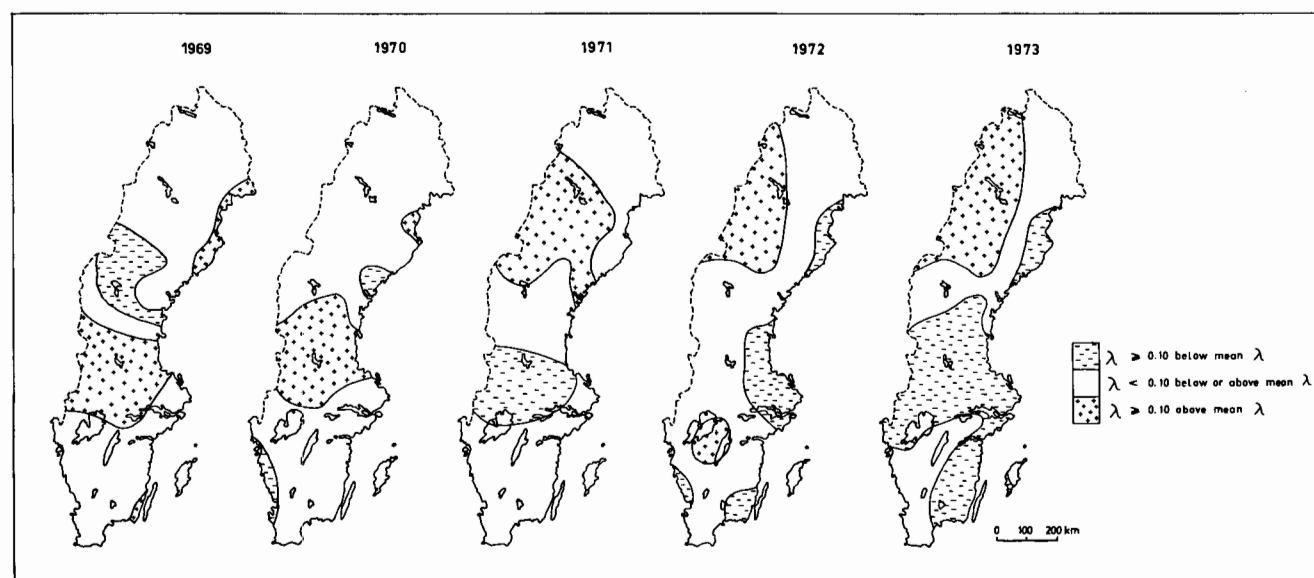


Fig. 108. Maps of Sweden showing the regional deviation from mean λ -values for selected stations for the years 1969—1973. Values are grouped in three classes, indicating normal, below normal and above normal situations. The maps are rough attempts. For explanation of λ , see text.

water level position, according to Semenov and Kono-
plyantsev, cannot be made. Moreover, the central west-
ern and northwestern parts of the country came under
observation only in the 1970's. In spite of this, some
tentative calculations have been made for selected sta-
tions. The maximum period of observation used in this
calculation is 1965—1973, i. e., nine years. It has to
be noted, though, that besides the too short observation
periods, the difference in observation length be-
tween areas impairs any comparative studies. Ne-
vertheless, in Fig. 106, a map is shown on which
the coefficient λ is presented for a number of selected
stations. The small diagrams give a rough picture of the
relative groundwater situation for the last few years.
Some regional regularities appear from the data. They
are demonstrated in Fig. 107 where calculations for the

years 1969—1973 are included. Even without paying
any attention to details in the maps, it is evident that the
eastern part of Sweden is characterized by subsiding
groundwater levels during the period of 1969—1973.
The decrease in levels can be attributed to a correspond-
ing decrease in yearly precipitation. The mean coeffi-
cient for the period of observation at the selected sta-
tions has been calculated, and the yearly mean deviation
from that value is presented in Fig. 108. It has to be
clearly stated that the calculations were made solely for
testing the method. As the number of stations is too
small and the period of observation too short for allow-
ing the drawing of any generally true conclusions, the
results must be regarded as uncertain. In the future,
though, this method will be used with increasing con-
fidence.

5. AVAILABILITY OF DATA

A regular inter-nordic publication of selected data col-
lected within the IHD is made in *Hydrological Data —
Norden*. At present three volumes have appeared: *In-
troduutory volume*, *Basic Data 1965—1969*, and *Basic
Data 1970—1971* (Goffeng 1971a, 1971b, 1973).

Data on groundwater level, groundwater temperature,
composition of groundwater, penetration of frost and

thickness of snow cover from all stations will be pub-
lished annually by SGU. The first volume, appearing in
1975, contains data from the start of observations up
to December 31, 1973.

Information about the current groundwater situations
in the observation areas is available from the ground-
water network office of the Geological Survey of Sweden.

6. REFERENCES

- GFF = Geologiska Föreningens i Stockholm Förhandlingar
 SGU = Sveriges geologiska undersökning, Stockholm
 SMHI = Sveriges Meteorologiska och Hydrologiska Institut, Stockholm
- BRINCK, S. and LEANDER, B., 1970: Alnarpsströmmen, utredningar 1965—1969. — Nordisk Hydrologisk Konferens, Stockholm 27—29 aug. 1970. Vol. 1. Lund.
- VON BRÖMSEN, U., 1968: Grundvattenbildning i geologiskt olika terrängavschnitt. — Metod — Teknik — Analys. Stockholm.
- FAGERLIND, T. and NORDBERG, L., 1973: Variation of groundwater levels and a calculation of the effective fissure porosity at File Hajdar, Gotland. — GFF, Vol. 95. Stockholm.
- FROMM, E., 1965: Jordartskarta över Norrbottens län nedanför lappmarksgränsen jämte beskrivning. — SGU Ca 39. Stockholm.
- GANDHAHL, R., 1957: Bestämning av tjälgräns i mark med enkel typ av tjälgränsmätare. — Grundförbättring, årg. 10, nr 1. Uppsala.
- GOFFENG, G. (ed.), 1971 a: Hydrological Data — Norden, IHD Stations, Introductory Volume. — Ås, Norway.
- 1971 b: Hydrological Data — Norden, IHD Stations, Basic Data 1965—1969. — Ås, Norway.
- 1973: Hydrological Data — Norden, IHD Stations, Basic Data 1970—1971. — Ås, Norway.
- GUSTAFSSON, O., 1972: Beskrivning till hydrogeologiska kartbladet Trelleborg NV och Malmö SV. — SGU Ag 4. Stockholm.
- HÖRNER, N. G., 1927: Brattforsheden — ett värmländska randdeltakomplex och dess dyner. — SGU C 342. Stockholm.
- LUNDQVIST, G., 1961: Karta över landisens avsmältning och högsta kustlinjen i Sverige. — SGU Ba 18. Stockholm.
- LUNDQVIST, J., 1969: Jordartskarta över Jämtlands län jämte beskrivning. — SGU Ca 45 Stockholm.
- KONOPLYANTSEV, A. A., 1970: Evaluation of the ground water balance of large territories. — Symposium of world water balance, Reading, England. IASH-Unesco. Paris.
- KNUTSSON, G., 1971: Studies of Ground-Water Flow in Till Soils. — GFF, Vol. 93. Stockholm.
- MUNTHE, H., HEDE, E. and POST, L. VON, 1925: Gotlands geologi — en översikt. — SGU C 331. Stockholm.
- NILSSON, K., 1966: Geological Data from the Kristianstad Plain, Southern Sweden. — SGU C 605. Stockholm.
- NORDBERG, L. and PERSSON, G., 1970: Sveriges geologiska undersöknings riksnät för observation av grundvatten. — Nordisk Hydrologisk Konferens. Stockholm 27—29 aug. 1970. Vol. 2. Lund.
- NORDBERG, L. and MODIG, S., 1974: Investigation of effective porosity of till by means of a combined soil moisture/density gauge. — Symposium on Isotope Techniques in Ground-Water Hydrology. International Atomic Energy Agency, IAEA-SM-182/47. Vienna.
- PERSSON, G., 1974: Tritium Data from Groundwater in the Kristianstad Plain, Southern Sweden. — Symposium on Isotope Techniques in Ground-Water Hydrology. International Atomic Energy Agency, IAEA-SM-182/3. Vienna.
- SEMEV, S. M. and KONOPLYANTSEV, A. A., 1969: Karty informacii i regima podzemnyh vod, Razvedka i Ohrana nedr. — Moscow (in Russian).
- Arbetsgruppen för Östbo och Västbo häraders vattenförsörjning, 1967: Den framtida vattenförsörjningen för större tätorter inom Östbo och Västbo härad. — Forsheda.
- ENGQVIST, P., 1966: Geologisk kartering och brunnsinventering m. m. inom representativa området Velen. — SGU. Stockholm.
- GOTTSCALK, L., LINDBERG, M., and NORDBERG, L., 1974: Linear analysis of groundwater level response on climatic input for different geological environments. — International Hydrological Decade Sweden. Report No. 40. Stockholm.
- Kjessler & Mannerstråle, 1970: Österbo—Dalkarlsåsen. Seismiska mätningar. — Kjessler & Mannerstråle AB 140171. Stockholm.
- 1973: Gävleåsen, Råsbo. Rapport över seismiska mätningar. — Kjessler & Mannerstråle AB 141028. Stockholm.
- KNUTSSON, G., 1966 a: Geohydrologisk och kvartärgeologisk undersökning av Bödaåsen. Ölands vattentäktförbund. — Sydsvenska Ingenjörbyrå AB. Malmö.
- 1966 b: Huvuddragen av Nybroåsens geologi. Principförslag till Kalmar—Nybro-regionens och Ölands framtida vattenförsörjning. — Sydsvenska Ingenjörbyrå AB. Malmö.
- K-Konsult, 1958: Rapport över VA-anläggning för Graninge bruk, Långsele kommun. — Kommunernas Konsultbyrå (K-Konsult) — LBF 5 YL a 181. Härnösand.
- 1968: Utredning angående grundvattentillgången inom Kumla—Hallsberg-regionen. — Vattenbyggnadsbyrå and Kommunernas Konsultbyrå (K-Konsult) — LBF. Örebro.
- LINNMAN, G., 1966: Geologisk kartering och brunnsinventering i representativa området Kassjöän. — SGU. Stockholm.
- LUNDAHL, G. and PERZON, J., 1971: Geologisk-morfologisk undersökning av partiet Masteråsen av Enköpingsåsen, Västmanlands län. — Academic thesis, Chalmers Tekniska Högskola, Geologiska Institutionen. Göteborg.
- MELANDER, O., 1972: Jordartskarta över Lapträskets representativa område jämte beskrivning. — SMHI. Stockholm.
- MODIG, S. and NORDBERG, L., 1971: Hydrogeologiska studier i morän. Projektredogörelse vid IHD:s sammanträde den 11.1.1971. — SGU. Stockholm.
- NILSSON, K. and GUSTAFSSON, O., 1967: Borrprofiler och sektioner inom Alnarpsströmmens grundvattenområde. — SGU. Stockholm.
- NORDBERG, L. and MODIG, S., 1973: Försök till bestämning av effektiv porositet i morän. — International Hydrological Decade Sweden. Report No. 30. Stockholm.
- NKB, 1968: Redogörelse över utförda grundvattenundersökningar inom Rengsjö, Regnsjö (sic) kommun, Gävleborgs län. — Norrländska Konstruktionsbyrå (NKB) AB X 1401—090. Sundsvall.
- Orrje, 1954: Redogörelse över verkställd grundvattenundersökning inom Ytterån, Rödöns kommun, Jämtlands län. — Orrje & Co. Östersund.
- 1964: Redogörelse för översiktlig utredning angående vattenförsörjning för Kåge samhälle samt byarna Ersmark och Kusmark, Skellefteå landskommun. — Orrje & Co 52.641. Stockholm.
- 1965 a: Preliminärt yttrande angående pågående provpumpning i Smedsmyran för gemensam vattentäkt för delar av Skellefteå och Byske landskommuner. — Orrje & Co 52.0444-02. Stockholm.
- 1965 b: Redogörelse för provpumpning av grundvattentillgång vid Smedsmyran avseende gemensam vattenförsörjning för delar av Skellefteå och Byske kommuner. — Orrje & Co 52.0444-02. Stockholm.
- 1965 c: Yttrande angående grundvattentillgången vid befintligt vattenverk i Gäddvik, Bergnäsens vattenförsörjning, Nederluleå kommun. — Orrje & Co 52.0568-07. Stockholm.

Mimeographed and similar reports

- AIB, 1962: Redogörelse för grundvattenundersökningar år 1961—1962 i Svappavaara. — Allmänna Ingenjörbyrå AB (AIB) BD 842601. Kiruna.
- 1972: Redogörelse den 6.3.1972 över grundvattenundersökning och provpumpning inom Glössbo, Rengsjö kommun, Gävleborgs län. — Allmänna Ingenjörbyrå AB (AIB) 8315. Sundsvall.

LARS NORDBERG AND GÖSTA PERSSON

- 1966 : Redogörelse över för Stenbrohults kommun utförda grundvattenundersökningar jämte ekonomisk jämförelse mellan olika förslag till framtida vattenförsörjning för Diö—Liatorpsområdet. — Orrje & Co 52.0789-02. Växjö.
- SIB, 1963 : Vattenbyggnadsteknisk utredning avseende den framtida vattenförsörjningen för Varbergs stad. — Sydsvenska Ingenjörbyrå AB (SIB). Malmö.
- 1967 : Principförslag till Östbo och Västbo häraders vattenförsörjning. — Sydsvenska Ingenjörbyrå AB (SIB). Malmö.
- UNESCO, 1963 : Report from preparatory meeting on the long-term programme of research in scientific hydrology. — UNESCO/NS/181. Paris.
- 1965 : Report of the (ad hoc) working group of the Unesco co-ordinating council for IHD on network planning and design. — WMO/IASH Symposium on design of hydrometeorological networks. Quebec.
- 1967 : Report of the Panel of Experts on Network Planning and Design. — UNESCO CS/SC/75/67. Paris.
- VAB, 1965 : Principförslag till VA-anläggningar. Redogörelse för utförda grundvattentäktundersökningar för Bullmark inom Sävar kommun, Västerbottens län. — Västerbottenskommunernas arkitekt- och byggnadskontor (VAB). Umeå.
- 1968 : Redogörelse för inventering av grusåsen mellan Sävar samhälle och byn Bullmark, Sävar kommun, Västerbottens län. — Västerbottenskommunernas arkitekt- och byggnadskontor (VAB). Umeå.
- WEIJMAN-HANE, G. and HÖRBERG, I., 1969 : Slutrapport, Samarbetskommittén för Kristianstadslättens Hydrologi. — Kristianstad.
- Viak, 1957 : Yttrande över grundvattenundersökningar för vattenförsörjningen inom Herrljunga köping. — Viak 5032. Vänersborg.
- Viak, 1963 : Redogörelse över grundvattenundersökningar vid Bärmö för Sigtuna stads vattenförsörjning. — Viak 12.2066. Stockholm.
- Viak, 1970 : Kristianstads stad, Redogörelse för grundvattenundersökningar på Kristianstadslätten, oktober 1967—december 1969. — Viak 12.2274. Malmö.
- 1973 : Kristianstads kommun, Geohydrologisk utredning rörande Kristianstads nuvarande och framtida grundvattenuttag. — Viak 88.1035. Malmö.
- VBB, 1953 : Redogörelse för grundvattenundersökningarna vid Grönsta för en vattentäkt för Sundsvalls stad. — Vattenbyggnadsbyrå (VBB). Stockholm.