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1. Introduction

Tundra is a fragile ecosystem and is very susceptible to disturbance and damage caused by human activity (Billings 1973, Bliss et al. 1973, Dunbar 1973, Dahl 1975a, West 1976, Norderhaug 1979, Sage 1981). Tundra is particularly vulnerable due to its low rate of production (Wilson 1957, Dunbar 1969, Dahl 1975b, Rosswall, Heal 1975), slow turnover (Wielgolaski et al. 1975), low species diversity (Allee et al. 1958, Naumov 1961, Baird 1967), and unique climatic and ground conditions reflected by the presence of permafrost (Ives 1970). For example, lichens which have been damaged by mechanical destruction or from air pollution, recover only after 50 years (West 1976). The destruction of the plant cover in polar conditions may have further consequences, since thermokarsts may develop in areas where the vegetation has been lost (Bliss 1971, Bliss, Wein 1972, Billings 1973, Bliss et al. 1973, Richard, Brown 1974, Eckstein et al. 1979). Oil spills are especially damaging to the surface ground layer (Barber 1970, Bliss 1970, West 1976, Wein, Bliss 1978, Norderhaug 1979). At low temperatures the biodegradation of petroleum-derived fuel is slow because of the low quantity of microorganisms able to decompose oil (Atlas, Busdosh 1976, Gibbs 1976, Malins 1977, Pinholt, Struwe, Hjoller 1979, Engelhardt 1985).

There are only a few papers presenting a comprehensive estimate of the affect of human activities on the tundra ecosystem (Vik 1972, Smith 1977). Most reports in the literature describe particular tundra degrading factors, such as: mechanical damage to the tundra surface, contamination of the soil and water by petroleum-derived compounds around human settlements. One method to estimate the total impact of polar stations on the surrounding tundra is to balance the supplied and consumed materials, as well as to determine the extent of pollution due to the activity of the station. Such investigation have been carried out in the Polish Polar Station, Hornsund, SW Spitsbergen (Krzyszowska 1986). Chemical and mechanical effects were found to be of the greatest importance in altering the environment in the immediate surrounding of the station (Krzyszowska 1985a). Similar investigations were made during the summer 1986 at the Norwegian Station located in Ny-Ålesund (SW Spitsbergen). The work was aimed at determining the quantities of solid, liquid and gaseous wastes penetrating into the environment and at determining the extent of various contaminants in the Ny-Ålesund vicinity.

2. Characteristics of the Ny-Ålesund surroundings

2.1. Geographic position, geology, geomorphology

Ny-Ålesund is located on the island of Spitsbergen, situated on the Broggerhalvoya peninsula on the southern coast of Kongsfjord (78°55' N, 11°56' E). It lies at the altitude of 10 m a.s.l., within a plain delimited on the south by Zeppelinfjellet (584 m) and on the west by Sherdahlfjellet (808 m), and by glaciers (Broggebreane and Lovenbreane) (Fig. 1). The bedrock here consists of: Cyathophyllum limestone, Spirifer Mosquensis (450m thick) belonging to the Middle and Upper Carboniferous and passing into Permian deposits: chert, chert limestone and green glauconite sandstone (250 m thick) (Orwin 1934). There are outcrops of coal-bearing Tertiary deposits, 195 m thick, built of green sandstone (Challinor 1967). The total amount of coal on the Ny-Alesund region has been estimated at 16.2 million tons, of which 40% can be mined (Orwin 1934). The mountain slopes are generally covered with landslip and rubble. A strandflat reaching Kolhamna Bay extends along these slopes. The lowland is partly covered with pelagic deposits transformed during the interglacial period (Forman, Miller 1984). A system of terraces within the lowland is connected with the uplift of Spitsbergen during the Holocene (Jahn 1959, Birkenmajer 1960, Szupryczynski 1968, Boulton et al. 1982). Ny-Ålesund lies within the limits of such uplifted sea-terraces (Repp 1979). The age of soils covering those terraces is 9000 to 12000 years BP (Mann, Sletten, Ugolini 1986). The soils are in the initial stage of development and are characteristic of the polar desert soil zone (Baranowski 1963, Szerszen 1965, Tedrow 1973, Zabawski, Zurawska 1975, Plichta 1977). The dominate soil processes are: frost thrusting of the ground, translocation of silt and precipitation of carbonates (Forman, Miller 1984). The soils are poor in nutrients (Orwin 1934, Rønning 1967).

2.2. Past and present activities in Ny-Ålesund

Ny-Ålesund is a former mining settlement now used for research purposes. The town and surrounding terrain is presently managed by Kings Bay Kull Comp. A/S (KBKC) despite the fact that all coal mining activities have ceased. During the period coal was mined here the output reached ca 300 t in 1916 (Berg, Wahl 1982) and usually about 200 people worked here. In 1963 the coal mine was closed, after 21 miners were killed in an accident on November 5th, 1962 (Hisdal 1985). From 1963 to 1974, ESPRO (European Space Research Organization) set up a satellite monitoring station (Berg, Wahl 1982), these facilities are no longer used but the buildings which contained the radar and equipment remain. In 1968 a scientific station was organized by the Norwegian Polar Institute. It is a basis for observation, laboratory and field investigation in meteorology, glaciology, oceanography, seismology and magnetism (Norsk Polarinstitutts Forksningsstasjon i Ny-Ålesund, 1982). In winter an average of 10 people work in Ny-Ålesund, in summer the number may grow to 100 persons. The settlement comprises 39 building complexes, of which 8 are not used presently (Fig.20). Some of the buildings (No. 3, 4, 15, 17, 23, 25, Fig. 2) are used only in summer, mainly by expeditions. In the NPI research building (No. 29, Fig. 2), there is 330m² of floor area which is utilized as laboratories, offices, a library, a meeting room, storage, and a platform balcony with measuring devices is located on the roof (Norsk Polarinstitutts Forksningsstasjon i Ny-Ålesund, 1982). In the power station (No. 6, Fig. 2) 3 diesel oil engines work alternately. Electric power (95-110 kWh) is used primarily for lighting and to heat water which is used to heat the buildings. Fuel oil is stored in two tanks of 11,000 m³ capacity each (Fig. 2).

Water for Ny-Ålesund is pumped from Lake Tvillingvatnet (photo 1) located 1.3 km from the first buildings and it is distributed through a 2 km utilador system which also contains heating and sewage pipes. Liquid sewage is drained off immediately into the sea, (photo 2) solid wastes are gathered in "honey-bags" and carried away to refuse dumps to be burned periodically (photo 3).

At Ny-Ålesund, there is a harbor for motor-boats and fishing-boats (No. 39, Fig. 2); tourist ships may call when there is no sea-ice (June to November/December). The research station has its own motor-boat which is equipped with scientific apparatus.

Air transport from Longyearbyen (the locations of Svalbard's Governor), 120 km away, goes on by means of helicopters and small aircraft which are able to land at the small airfield at Ny-Ålesund (No. 40, 41, Fig. 2). Light lorries, tractors, stripper-and loader-machines are used in Ny-Ålesund; in summer people ride bicycles and in winter use snow-scooters.

2.3. Flora and fauna of the tundra

The Svalbard tundra is classified into plant zones according to different nomenclature schemes: the high Arctic zone (Polunin 1946, Olsen 1982); the Cassiope zone (Summerhayes, Elton 1923); the northern Arctic tundra zone with zonal syntax, Luzulion arcticae (Elvebakk 1985). Vegetation in the Ny-Ålesund region is not as rich as in other areas of the Spitsbergen (Polunin 1946). Different plants dominate the upper sea-terraces, according to the character of the bedrock: lime-demanding moderate snowbed (Luzulion arcticae) (Elvebakk 1985) with Saxifraga oppositifolia, Cetraria delisei (Brattbakk 1981); and acidophilous moderate snowbed (Luzulion arcuatae) (Elvebakk 1985) with Luzula confusa and lichen (Brattbakk 1981). In humid areas Deschampsia alpina prevails and carpets of moss appear. The vegetation has been disturbed by human activity in the area of the buildings of Ny-Ålesund ; changes were noticed as early as in the forties of this century (Polunin 1964).

A predominating role in biological processes is played by the transient bird population. The Arctic tern (Sterna paradissea) occurs in greatest number and has colonies west of Manevatnet and Solvatnet pond; also Eider (Somateria mollissimma) and Barnacle geese (Branta leucopsis) are present in large numbers. There also occur Snow buntings (Plecrophenax nivalis), Purple sandpipers (Calidris maritima), Turnstones (Arenaria interpres), Red-throated Divers (Gavia stellata). All of these birds come for the breeding season beginning in the middle of June and leave by September. The polar fox (Alopex lagopus) feeds on nestlings and eggs of the bird colonies during the breeding season.

Reindeer (Rangifer tarandus platyrhynchus) can be seen frequently, but the polar bear (Thalarctos maritimus Phipps) is only rarely observed. In Kongsjord the most frequently observed seals are: the Small ringed seal (Phoca chispida), Bearded seal (Evignatus barbatus) and Phoca vitulina. The walrus (Odobenus rosmarus) is very rare.

2.4. Climatic and hydrologic conditions

Ny-Ålesund lies in the polar climate zone, but the temperatures are warmer than usual at this latitude due to the warming effect of the North Atlantic Current (continuation of the Gulf Stream) or rather a branch, the Norwegian Current flowing along the western coast of the

Spitsbergen (Hisdal 1985). The intensity of the total radiation is one of the lowest values on the Earth (Vinje 1977, 1980). An additional factor reducing the radiation is the frequent cloudiness occurring both in summer and in winter. From April 18th to August 24th the sun is continually above the horizon, and the polar night lasts from October 10th to February 17th (Steffensen 1982). The mean yearly temperature in 1971-1980 was -5.8° C (Tab. 1) and the monthly means in May, June, July 1986 were -2.3°, 2.4°, 5.8° C respectively (Tab. 2), this is comparable with the means of 1971-1980 (Tab.1). During the coldest months (January-March) the mean of 1971-1980 was -13.3° C (Steffensen 1982). Considerable and sudden changes of air temperature occur frequently due to eruption of warm and moist air masses from the Atlantic Ocean (Pereyma 1983). The average total of yearly precipitation of 1971-1980 was 385 mm/year with the majority occurring in autumn. In the vicinity of Ny-Ålesund, SE winds prevail in May, June and July with a mean velocity was 2.0 m/s (Tab.2). Along the coasts of the fiord, the permafrost is half as deep in vegetated areas compared to barren areas (Corbet 1972). The snow disappears in the end of June and accumulation usually begins in the end of September (Gjessing, Ovstedal 1975).

At the end of June in 1986, surface waters began flowing under the snow. Ny-Ålesund is situated on an eminence of a terrace from where waters flow in the three directions. Surface water from the vicinity of the laboratory, the mess and the dwelling-house flow into the Manevatnet pond (No. 3, Fig. 3) which subsequently drains into the sea at a flow rate of over 100 dm^3/min. Water from the western part of Ny-

Alesund flows directly to the sea, or into the pond number 4 (Fig. 1),this pond drains with average flow rate 1 m^3/min into the sea. Waters flowing from beneath the oil tanks first accumulate in pond number 1 (Fig. 3), then flow under the road in two main streams into Solvatnet pond (No. 3, Fig. 3). The ponds are very shallow and dry up when not supplied with snow-melt water.

3. Environmental regulations for Svalbard

Since the beginning of the 17th century the islands of the Svalbard Archipelago were wastefully exploited. The fat of walrus and whales was the main product exported from the island by the Dutch, the Danes and the English. This led to the extermination of the Greenland whale, and partly of the walrus. The population of the polar bear was also threatened. Other wildlife such as the seal and the polar fox have suffered less. This led to the necessity of introducing regulations of nature preservation on Spitsbergen and to settlement of the sovereignty treaty of Spitsbergen. On February 9th, 1920 the treaty was signed in Paris, to which Poland acceded on September 2nd, 1931. Article 2 of the treaty states that: " It will be Norway's duty, to keep, undertake and issue adequate regulations for the protection, preservation and, if necessary, the restitution of the fauna and flora that region ...". Norwegian authorities have issued a number of decrees strictly regulating hunting and fishing (Environmental Regulation for Svalbard, 1974). On June 1st, 1973, according to Norwegian Royal Decree, 3 national parks, 2 sanctuaries and 15 reservations for bird breeding were created in the territory of Svalbard. In the national parks and in the sanctuaries (except areas containing mining claims) all human activity that might disturb the natural environment, such as building, mining or littering, is forbidden. Hunting, gathering plants or fossils are not allowed except by special permission given to scientific expeditions by the Governor of Svalbard.

The region of Ny-Ålesund is not situated in a national park but everyone here should comply with the principles of behavior published in the Environmental Regulations for Svalbard (1981) and should acquaint themselves the with rules concerning hunting and fishing. In the vicinity of Ny-Ålesund and Kongsfjord, there is a bird sanctuary on the islands of Mietheholmen, Prins Henrichoya, Loenoyane, Eskjeret. The regulations here are the same as in the national parks, and access to the islands is forbidden from May 15th to August 15th. Now, as prospective boring for oil has begun, rules have been issued in the "Provisional regulations concerning the control of exploitation of the natural environment on Svalbard and Jan Mayen issued by the royal decree of May 28th, 1971" (Environmental Regulation for Svalbard, 1981).

4. Methods

4.1. Balance of waste and sewage

The quantities of waste from kitchen and dwelling houses were determined gravimetrically four times in June and July 1986. The quantities of sewage were determined by measuring them three times during a 24-hour cycle. The quantities of fuel used and the amount spilled were estimated according to information obtained from the manager of Ny-Ålesund and from the chief mechanic.

4.2. Determination petroleum-derived fuel contamination

Contamination due to fuel was determined by measuring the content of oil in water, in soil and in dustfall around the power station. The content of oil in water was determined at 30 sites. At each site, three samples were collected and the oil concentration was determined as the average amount in 1 dm^3 of water. The samples were kept in dark bottles under refrigeration, then taken to Oslo where analyses were made in the NIVA laboratory (Norwegian Institute for Water Research). The water samples were extracted twice in a funnel with n-hexane, 50 cm^3 per 1 dm^3 of sample. The concentration of oil in the extract was measured using a spectrofluorometer, with excitation at 265 nm, emission 326 nm (slit width 5 nm). A standard curve was plotted from sample No. M, from which oil had been determined gravimetrically. In samples No. A, K, and M, the oil was first determined using the gravimetric method and any remaining oil was extracted and measured on the spectrofluorometer. The content of petroleum-derived fuel in the soil was determined in 25 surface samples (to a depth of 5 cm) and in 18 soil profiles. Samples were collected by means of a hand-operated drill from depths of 2, 5, 10, 18, 20, 35, 40 to 60 cm according to lithologic conditions. The content of petroleum-derived substances in the soil was determined by semimicroextraction with n-hexane (Hermanowicz et al.

1976). This method determines the total amount of fats and mineral oils. In order to eliminate the natural group of compounds subject to extraction with n-hexane the amount extracted was reduced by the mean quantity of extracted material from three samples which were not contaminated with petroleum-derived substances (profile No. XVIII). The same method of n-hexane extraction was used to determine the content of petroleum-derived compounds in contaminated, detrital plant material. Soil moisture was determined (Bialousz, Sklodowski 1979) by drying at 105 °C until the weight was constant.

The dustfall was measured by exposing glass traps 2-3 m above the ground during 49 days (photo 4). The dustfall was determined by weighing the dry remainder and is expressed as kg /100m² per month. The quantities of gaseous components coming out of the power station chimneys were measured five times by means of a small hand pump and Draeger indicator tubes for sulphur dioxide, carbon dioxide, nitric oxides and carbon monoxide.

4.3. Determination of chemical composition of water, sewage and soil

In 33 samples of surface water (collected June 17th and 24th), in 10 samples of sewage (collected June 30th) and 3 samples of sewage (collected July 8th), the following parameters were determined: temperature, flow rate, pH, conductivity, ammonia nitrogen, nitrate nitrogen, nitrite nitrogen, phosphate, alkalinity, total hardness, calcium, magnesium, sulfate, chloride (Golterman 1978, Markowicz, Pulina 1979). In 10 soil samples, pH and conductivity were determined in a water extract. Soil moisture was also determined by drying in 105 °C to a constant weight. The conductivity was determined with a Yellow Spring Instruments Co., Model 33, series 128.2; pH was measured with a PH80 pH meter (Radiometer, Copenhagen). To measure nutrients a Zeiss Spectrophotometer Model 10 was utilized. The chemical composition of surface seawater was determined in samples collected at several distances from the outlet of sewer ditch, 6 samples were collected on June 30th and 24 samples on July 8th. In the seawater samples, determination of the temperature, pH, conductivity, salinity, nitrate nitrogen, nitrite nitrogen, ammonia nitrogen, phosphate, alkalinity were performed (Golterman 1978). Salinity was measured with the Yellow Springs Instruments Co. conductivity meter. The above analyses were also done on seawater samples collected with a Nansen cylinder from the depths of 1.3 m at 15 m distance from the shore and from the depth of 2.5 m at 50 m distance from the shore. Microbiological investigations of the sewage and in shore waters were done at 6 sites; 5 and 10 m away from the sewer outlet, on the 3rd, the 11th and 17th of July. At each site two water samples were collected and the total amount of coliform bacteria in 1 cm^3 of water was determined twice for each sample. The bacteria were cultured on nutrient agar at the temperature of 37^o C, the amount of bacteria was estimated after 48 hours.

In order to get a preliminary evaluation of the extent of sewage dissemination along the inshore waters, fluoresceine tracer was poured into the sewage and its dispersal over a finite time period was observed at the outlet ditch. This was repaeated 5 times on July 6th and 8th, at different wind velocity and direction .

4.4. Measurement of changes of ground physical properties due to trampling and transport

Changes in the tundra environment due to mechanical destruction were observed in 7 cross-sections through roads and paths. In each cross-section the width of the road and the depth of the track was measured, and soil samples were collected from the road and from adjacent undisturbed ground to analyze granulometric composition (mesh analysis, areometric analysis). The thaw depth was measured with a pointed steel rod at 50-70 cm intervals depending on the road type. At four sites at each cross-section (two on the road, two adjacent to the road), the bulk density of the ground was determined using the cylinder sampling method (Falkiewicz, Kowalski 1957) and the soil moisture was measured to a depth of 10 cm, by drying at 105 °C to a constant weight. The water infiltration was determined in cross-sections IV and V with a cylinder infiltrometer. Phytosociological records were obtained for cross-sections I, II, III. Dr.Arve Elvebakk of Tromso University assisted with botanical work. Nomenclature of vascular plants were taken from Rønning (1979), of mosses after Nyholm (1975-1979) and of lichens after Nowak (1965).

5. Results

5.1. Balance of waste in of Ny-Ålesund

The main factor causing changes in the environment was spills of petroleum-derived fuel from damaged of pipelines and oil tanks. Other sources of contamination were sewage and solid waste dumps of household garbage (Fig. 4).

5.1.1. Quantities of solid waste and sewage

From October to the end of April 1986, 10 persons of the technical staff stayed at Ny-Ålesund. The number increased from May to September due to the presence of scientists and technicians During two weeks in July, 25 persons were enrolled in a class given at Ny-Ålesund. The greatest number of people staying at Ny-Ålesund in 1986 was 93 persons in July, the average was 77 people (Fig. 5). In addition, some expeditions sojourned temporarily at Ny-Ålesund, such as a group of scientists from Cambridge who utilize one house (No. 25, Fig. 2).

The amount of food products delivered to Ny-Ålesund from August 1985 to August 1986 was equivalent to an average of 624.4 kg (net weight) per person per year. The food articles produced trash in the form of metal, glass, plastic, paper, cardboard wrapping, food scraps, etc. This trash and garbage from dwelling houses, as well as waste from expeditions, was gathered and taken to the dump to be burned (Fig. 4). Measurements of the waste quantities indicate an average of 17.2 to 36.8 kg of waste per person per month. It may be calculated that 5 to 11 t of household waste were produced in a year at Ny-Ålesund, most of which is burned at the refuse dump. The average quantity of household sewage reaching the sea was 209 dm^3 per person per 24 hours.

5.1.2. Petroleum-derived fuel leaks

Due to oil spills, the environment around Ny-Ålesund was contaminated in 1986 with approximately 110,000 dm^3 of petroleum-derived fuel. Fuel was supplied to Ny-Ålesund by ships and was pumped from the dock through a pipeline to storage tanks (Fig. 4). The main part of the fuel is utilized by ships and fishing boats.

The power station at Ny-Ålesund used ca 6,500,000 dm^3 of fuel from August 1985 to August 1986. Fuel consumption was here greatest in winter and averaged 51,600 dm^3 per month, while 30,000 dm^3 per month was used in summer. Spills from the storage tanks and pipelines are the largest potential source of the environmental contamination (Fig. 4). Several oil spills have occurred and the greatest catastrophe occurred on November, 1986, when ca 88,000 dm^3 of oil flowed out into the sea from a damaged pipeline 50 m distance from the oil tanks and ca 10 m from the edge of the escarpment (oil spill No. I, Fig. 4). This oil spill had not been entirely stopped, and it is estimated that from January to July an additional 1000-3000 dm^3 of oil penetrated the surroundings. During the spring of 1986, probably in May, ca 10,000-15,000 dm^3 of oil leaked out of the tanks (oil spill No. II, Fig. 4). A smaller quantity of fuel, some 1000 dm^3, penetrated into the environment due to cleaning of the oil tanks (oil spill No. III, Fig. 4). In the surroundings of the power station , oil spills occurred due to cleaning, refueling and repairs of motor vehicles (oil spill No IV, Fig. 4). It is difficult to estimate these quantities and it is probable that oil and petrol penetrate into the environment every year from this source. Similar repeated outflows of oil and petrol occurred in the harbor, where motor boats, fishing boats and ships moored (oil spill No. V, Fig. 4).

During the spring thaw, action was taken to reduce the spread of oil contamination. After the 20th of June, 1986, oil traps were installed, including plastic rolls stopping the oil surface layer at the outlet of the pond below the oil tanks, in both streams reaching the pond Solvatnet and its banks (photo 5), and at the outlet of pond No. 4 below the power station. The ground surface most contaminated, on the slope beneath the oil tanks and around oil spill No. III (Fig. 3), was strewn with sawdust (photo 6) which was later removed and disposed of in an inactive mine.

5.2. Contamination of Ny-Ålesund surrounding due to oil spills

5.2.1. Contamination of water with petroleum-derived fuel

The greatest oil contamination of inland surface waters was found to be beneath the oil tanks on the southern slope of the escarpment. The oil spill (No. II, Fig. 4) spread down the slope 50 m long and 15 m wide, and along the escarpment; one branch flowed in a polluted band, 100 m long, toward the power station; and another branch flowed into a local pond (No. 1, Fig. 3). The highest concentration of oil in the pond measured was 60,390 ppm on June 18th, 1986. Within three weeks after cleanup action had begun the oil contamination was reduced by 30% (Tab. 3). Beneath the tank, a stream running across the base of the bank parallel to the road, accumulated the most oil, measured at 308,200 ppm on June 18th, 1986. It decreased quickly after the installation of oil traps and pumping out of contaminated water, so that on June 26th, the oil concentration, 15 m away from the stream origin equaled 3.06 ppm, and on July 7th only 0.07 ppm (No.L, and S, Tab.3). Similarly the concentration of oil in the stream flowing into Solvatnet pond, located below the trap, decreased from 620,800 ppm on June 26th to 6.07 ppm on July 7th (Fig. 6). Solvatnet pond also acted as an oil trap; the oil concentration in the outflowing stream was only 0.08 ppm on June 26th (Tab. 3). Water flowing from under the power station did not contain as high oil concentration as the surface waters around the oil tanks. At the beginning of the main stream below the power station and the road, the oil concentration in the water equaled 6.41 ppm on July 7th (No. Z ,Tab. 3). Rainbow colors characteristic of oil contamination could be seen on the water along the whole stream which disappeared among moss vegetation and emerged again after 100 m to form a pond at the base of the road bank (No. 4, Fig. 3). On July 7th, the oil concentration here was 0.07 ppm. The stream flowed under the road, and after 200 m, reached the sea; no oil was found at its outflow (Fig. 6); this was the only stream in the vicinity of Ny-Alesund reaching the sea without oil contamination.

The main source of contamination in the coastal zone was from the oil spill No. I (Fig. 4). It was most visible when the fast ice along the shore was thawing, when on June 26th, the concentration in the breaker zone was 1340 ppm (No. F, Tab. 3). After the thawing of snow and after the major polluted wave had flowed down the escarpment, the oil concentration decreased and on July 7th it amounted to only 1.19 ppm (No. Z, Tab. 3).

In the harbor where boats moored, the oil concentration amounted to 2.67 ppm on July 7th. The far extent of oil contamination in seawater is evident by oil stains observed July 4th in the coastal zone opposite Brandalpynten, 3 km away from the main oil spill.

5.2.2. Contamination of soil with petroleum-derived fuel

The greatest contamination of soil, followed a similar pattern to the surface water, and was connected with the oil spill from the damaged pipeline near the fuel tanks (oil spill No. II, Fig. 4). The ground surface area polluted by that outflow was 8000 m^2 (Fig. 7). On the southern escarpment slope, in profiles I, IV and particularly in profile V which lies in a depression, a high concentration of oil was extracted with n-hexane (Tab. 4, Fig. 7). In soil profiles, at the depth of 37-50 cm, the concentration of oil was 1150-2020 mg/100 g of soil dry mass (profile I, IV, Tab. 4). Below the escarpment along the main direction of water flow, in spite of a high content of oil in water, the oil contamination of soil penetrated less than 30 cm depth (profile XII, Tab. 4) or was present in very low quantities (profile XIV, Tab. 4). However, contamination increased as more oil was carried along with the water and stopped by traps. Before the outflow of Solvatnet pond, a concentration of 88.33 - 128.63 mg per 1 g of plant dry matter was measured in a moss layer (Tab. 5). The contamination from the largest oil spill (oil spill No. I, Fig. 4) was less severe on the landscape in total, than from oil spill I, but covered a larger area, 15,000 m². The highest soil contamination here was high and amounted to 50.000-11,200 mg/100 g of soil dry weight (Tab. 4, 6). In profile VII which is 3 m from the shore line, contamination occurred to a depth of 27 cm at the water-level, although the gravelly and sandy surface layer had lower concentrations due to washing action of the tides (Tab. 4).

The oil spills from the area of the power station caused contamination of the plant layer over a surface area of 6000 m². It was limited to the surface only, since no n-hexane extracts were found below 5 cm of depth in profiles X, XVII (Tab. 4, Fig. 7).

The contamination due to oil spills during the cleaning of fuel tanks had a local range and was detected along 10 m on the northern side of the escarpment (profile II, Fig. 7). Depending on the slope of the terrain, the contamination was concentrated in the ditch near along 50 m of the road (profile III, Fig. 7); the amount extracted at 9 cm of depth equaled 1190 mg/100 g of soil dry matter (Tab. 4). The surface which was contaminated covered 1200 m².

It was observed that the content of petroleum-derived fuel usually decreased with depth in the soil profiles. The decrease was greatest where there was plant cover and absorbed an average of 87% of the petroleum-derived fuel (Tab. 5, 6). For example, the decrease of content of the n-hexane extractable oil with depth was clearly visible in profile IV, where at 7 cm of depth the content decreased by 31.8% compared to at 2 cm depth; at the depth of 18 cm by 26.5%; at 35 to 50 cm by 21% (Tab. 4).

5.2.3. Dustfall and toxic gases from fuel combustion

Contamination also occured from the the combustion of oil in the power station. Combustion gases contain many products of incomplete oxidation, such as: carbon monoxide, nitric oxides, hydrocarbons and aldehydes. The average amounts of substances escaping from the chimneys of the power station was: 0.01 - 0.6 g/m^3 of sulphur dioxide; 10 - 75 g/m^3 of carbon dioxide; 0.3 - 1.0g/m^3 of nitric oxide; 0.01 - 0.05 g/m^3 of carbon monoxide. In addition to the toxic components, particulates were emitted into the atmosphere. The maximum dustfall was found in the immediate vicinity of the power station and it amounted to 0.47 - 0.59 $kg/100m^2$ per month (Tab. 7). Within an area 250 m west and 500 m east of the power station the dustfall equaled 0.05-0.21 $kg/100m^2$ per month (Tab. 7) which is similar to the mean value of natural dustfall from sea water in coastal zones reported by other authors (Manecki 1978). The method used to measure the dustfall did not allow to elimination natural sources such as seawater or loess.

5.3. Chemical composition of potable and surface water

The potable water from lake Tvillingvatnet (Fig. 2) is of artesian origin and its chemical composition depends on the character of the Zeppelinfjellet bedrock, Cyathophyllum limestone, Spirifer Mosqenses layers belonging to the Permian-Carboniferous and the Upper and Middle Carboniferous (Orwin 1934). The chemical composition of the potable water are within Norwegian standards of potable waters. They are soft, neutral waters containing small quantity of sulfates (10.56–27.84 mg/cm^3) and chlorides (5.96- 11.93 mg/dm^3). They contain more mineral compounds than waters flowing into Ny-Ålesund from thawing snow (Tab. 8). Waters within the buildings area also contain higher quantities of ions then waters flowing into Ny-Ålesund (Tab. 6, 8, Fig. 3). Waters in the surroundings of the refuse dump indicated a continuous source of contamination. These waters have a slow flow rate, they are nearly stagnant, calcium-chloride waters with a high content of ammonia nitrogen, nitrate nitrogen and with sulfates reaching 196.00 mg/dm^3 (Tab. 8). Such a composition of water results, among other things, from the decomposition and oxidation of organic waste from vegetal and animal origin, and from washed out mineral salts. In waters contaminated with oil, ponds or streams where the flow rate reaches 100 dm^3/s, no increased content of the ions measured ~~were~~ was noted, except at site No. 9 which had a high content of nitrate nitrogen (Fig. 3).

Streams flowing to the sea had a high concentrations of phosphates (up to 0.55 mg/dm^3), as well as of nitrate nitrogen (up to 5.4 mg/dm^3) (Tab. 8). This is a result not only of anthropogenic input into waters flowing through Ny-Ålesund, but also due to the bird colonies, mostly Eider and Barnacle geese.

5.4. Environmental contamination due to sewage

The sewage from Ny-Ålesund contain household sewage and wastewater. In the sewage the total hardness reached 7 mval/dm^3, nitrate nitrogen reached 2.00 mg/dm^3, nitrite nitrogen reached 0.25 mg/dm^3, while the content of phosphates was as high as 28.00 mg/dm^3 (Tab. 9). It was determined that high concentrations of ammonia nitrogen (over 30 mg/dm^3) and sulfates (over 300 mg/dm^3) often exceeded Norwegian standards for industrial sewage before treatment (Tab. 9). The greatest concentration of ammonia nitrogen was observed in morning hours, while water hardness, phosphates and sulfates was highest in the early afternoon and evening hours, which was probably due to the intensive use of laundering and cleaning products. The sewer outfall ends at a distance of 7-14 m (depending on tides) from the shoreline (Fig. 4). It was found that the temperature of the seawater at a distance of 5 m around the sewer outfall was not raised (Tab. 10).

In the sea, 1m from the shoreline, the sewage had been diluted several fold as noted by a 4 fold decrease in the concentration of ammonia nitrogen and a 2.5 times lower concentration of phosphate on July 8th, 1986 (Fig. 8). The spread of sewage in the coastal sea water depends on the direction and velocity of the wind. It was observed, for instance, that when the wind was light (1 m/s) the range of the spreading sewage was wider (it reached 70 m after 90 min.) than during strong winds when exchange was more intensive (Fig. 9). The elevated levels of the nutrients, ammonia nitrogen and phosphate from the sewage, extended 200 m along the shoreline (the sewer outfall being the center) and 50 m deep into the bay (Fig. 8). The same range was also observed in the salinity of coastal waters (Fig. 8). In contrast, the concentration of nitrate nitrogen increased at further distances from the sewer outfall (Fig. 8), which probably results from the fact that nitrate nitrogen is the final product of the biochemical decomposition of organic compounds containing nitrogen and is released after time. Those values were higher by an average of 50% as compared with control samples which were taken from the central part of Kongsfjord. Based on the distribution of nutrients, it was calculated that the contamination of the surface layer of seawater around the outlet of the sewer spread over 0.5 ha (Fig.8). Water samples collected at the bottom, at 1.3 m of depth and 15 m of distance (No. 18) and at 2.5 m of depth and 50 m of distance (No. 24) from the sewage outflow did not have increased concentrations of nutrients (Fig. 8).

The presence of bacteria Escherichia coli was used as an indicator of water contamination with feces. Microbiological investigation have showed that the amount of the bacteria E. coli in the sewage, before reaching the sea, ranged between 2.6×10^5 and 3.7×10^6 per 1 cm^3 after 48 hours of incubation at 37 °C on nutrient agar (Tab. 11). The water contained less than 100 E. coli per 1 cm^3 at a distance of 10 m eastwards and 15 m away from the sewer outlet (Tab. 11).

5.5. Changes in soil properties near sources of contamination

In order to determine changes of soil properties around contaminated sources, for example near the sewer outlet and the refuse dump, soil samples were collected. Soil moisture, pH and electrolytic conductivity were determined and compared with samples of non-polluted soil (No. 1, 6, 10, Tab. 12, Fig. 4). The soil around the sewer outfall had a weekly acidic reaction and the highest electrolytic conductivity (250-1150 µs/cm). This indicated the highest concentration of mineral salts dissolved in the soil water solution; it exceeded ten times the levels control sample. Alkaline soils around the refuse dump also revealed a high electrolytc conductivity (Tab. 12).

Within 7 m to 14 m around the sewer outfall the soil was very fertile and considerable levels of Oligochaeta sp. were present, which is an indicator of eutrophication of the environment. At the sewer outfall, the author found the mushroom, Psilocybe meridaria (identified by Gro Gulden) which had not been recorded on the Spitsbergen before, and is characteristic of soils rich in nutrients.

5.6. Changes of tundra surface due to trampling and transport

Changes in the tundra environment due to the mechanical damage caused by vehicles and humans were investigated for 7 cross-sections through roads and paths in the surroundings of Ny-Ålesund (Fig. 10). The cross-sections differed in the intensity of use, the plant assemblage, the type of ground (Tab. 13). It was found that on surface damaged by vehicles and trampling, the vegetation cover was damaged and changes in moisture and granulometric composition of the ground followed. The bulk density increased and the thaw was greater.

5.6.1. Damage of the plant cover

On roads used with variable intensity, no lichens occurred (cross-section I, II, III) and vascular plants were generally absent compared to adjacent to the road, including: Salix polaris (cross-section II, III), Saxifraga oppositifolia (cross-section I, III), Pedicularis hirsuta, Silene acaulis (cross-section I, II). The moss Aulocomnium turgidum did not occur on roads in spite of its presence on the adjacent ground (cross-section I, II). Instead, plant species were present on the road which were not present adjacent to the road, in particular: Poa alpina, Phippsia algida and; the mosses Potia heimii, Distichium inclinatum and Omphalina (Tab. 14). On roads presently not used , the dominant species were: Deschampsia alpina and Poa alpina which formed characteristic tussocks (Photo 7). All the main roads and paths in the vicinity of Ny-Ålesund have been mapped on a scale of 1:10,000 and classified according to the degree of plant cover (Fig. 10). The major roads without any plant growth have an overall length of 8.8 km, roads covered with 20% vegetation have a length of 1 km; paths with 60% plant cover are 3.3 km long and seldom used paths for 0.4 km.

5.6.2. Changes of the granulometric and physical properties of the ground

The roads and adjacent terrain investigated consisted primarily of sandy-gravel and only in cross-section VI there was silty-sand. Due to mechanical destruction by vehicles and people, the roads material was crushed into finer particles. The sandy fraction increased by 17% on the average and the gravel fraction decreased by 60% (Tab.15). The ground became compacted, surface layer bulk density increased compared with the adjacent terrain. The increase of the bulk density was 13% (cross section VII) to 32% (cross section IV) except cross section VI where the adjacent ground has a high bulk density (Tab. 16). The ground compactness caused a decrease in permeability. The permeability in cross-section IV was 5 times less than the adjacent ground, while the bulk density was 32% higher on the road. On roads with distinct tracks (cross-section I, II, III) which were pathways for water drainage, the soil moisture was increased by 67%; this was also due to the sandy clay texture present in the tracks (Tab. 16). But, if there were no distinct tracks, in sandy-gravel texture, the roads were less moist than the ground next to the roads (cross-section III, IV, V). Where the plant cover had been damaged on the roads, the thaw depth was greater by 0.7 - 5.9 cm (Fig. 11).

6. Discussion

6.1. Specific character of materials and waste management in polar stations

There are few papers investigating the complex effects of polar stations activities on the tundra ecosystem. Most existing studies describe the principles of the operation of polar stations, including, water and sewage management, heating management, sewage treatment technology and solid waste management (Grainge, Shaw 1971, Straughn 1972, Grainge et al. 1973, Heinke, Deans 1973, Schindler et al. 1974). The problem of water and sewage management and of solid waste management in northern regions became particularly relevant in the seventies when large scale oil exploitation started and small settlements were built (Grainge et al. 1973). Protective laws were issued, such as "The Village Safe Water Act" for Alaska (Sargent, Scribner 1976). Technical solutions of some problems were sought, for example: the problem of a potable water supply (Whitmer 1967, Coutts 1976), sewage disposal (Heinke, Deans 1973, Cameron, Christensen, Gamble 1977, Johnson 1977),and solid waste disposal (Rice, Alter 1974, 1975).

The aim of the this paper was to evaluate the material and waste management at Ny-Ålesund. The methods for obtaining potable water are the same at Ny-Ålesund as in many other polar stations (Hofman, Sherwood 1966, Schindler et al. 1974, Smith 1977). Potable water in some polar stations is treated by adding lime or passing through a column with active coal to remove organics (Smith 1977). Treatment of the potable water at Ny-Ålesund does not seem necessary (Tab. 8).

Sewage from settlements and polar stations is often piped directly into the sea (Grainge, Shaw 1971, Rice, Alter 1974, 1975, Cameron, Christensen, Gamble 1977, Smith 1977, Frearson 1983). However, in some cases the sewage is first treated in settling tanks; this method is used at the H. Arctowski, Polish Polar Station on King George Island, Antarctica. In Alaska, the most common is waste lagoon treatment (Grainge et al. 1973, Budrick, Johnson 1977). During the summer of 1987, a sewage treatment plant will be installed at the Polish Polar Station on the Spitsbergen. It is a "Bioblok" type of plant with rotating disks (1.8 x 2.0 x 2.5 m) biological treatment, designed to treat

6.0 m³ of sewage per 24 hours and a maximum of 400m³. The energy required is 5 kWh and the degree of reduction in BOD and suspended matter is as high as 93-95%. This type of plant has been used successfully in winter condition to -30 °C.

Wastes accumulated in most polar stations and settlements are disposed of in a landfill (shredded or unshredded); baled (shredded or unshredded) and then disposed into a landfill or transported to another area for disposal or incineration (Grainge, Shaw 1971, Straughn 1972, Grainge et al. 1973, Smith 1977). In Arctic conditions it is recommended to shred and compact wastes in order to reduce their volume by 10-30% and to use incinerators (Grainge et al. 1973). At Ny-Ålesund an average of 5-11 t of waste was accumulated during one year which is comparable with 8 t of waste from the Polish Polar Station, Hornsund (Krzyszowska 1986). In other terms, these quantities at Ny-Ålesund correspond to 0.5-1.2 kg per person per 24 hours; this is comparable with the waste amounts accumulated in the construction camps in Alaska (Tab. 17). Such large quantities of the waste are characteristic of research stations lying far away from towns and settlements. It is connected with the type of packaging necessary for materials and food transported long distances

6.2. The effect of Ny-Ålesund activities on its immediate surroundings

In order to categorize the character of environmental changes in the vicinity of Ny-Ålesund, mechanical and chemical effects leading to degradation of the environment were distinguished. Vehicular transport and trampling by people, cause damage of the overgrowth and alternations in the granulometric composition and physical properties of the ground (Kaltenborn 1986).

The degree of surface change is a function of time, soil composition, vegetation and type of exploitation (Ives 1970, Rickard, Brown 1974). Mechanical destruction was observed to successively affected lichens, then mosses and finally vascular plants (Fig. 14). These results are similar to the data of Chapin, Shaver (1981) and of Greller, Goldstein, Marcus (1974) who have found that areas covered with mosses suffer faster destruction, while grassy areas are more resistant to degradation. Such plant species as Phippsia algida, Deschampsia alpina and Potia heimii prefer moist, wet environments, and therefore can be found in roads tracks (Tab. 14). In the succeeding stages of destruction, after the damage of the plant cover, comminution of the ground follows (Tab. 15) and compaction occurs, thereby increasing the bulk density (Tab. 16). These factors led to an increase of the depth to frozen ground, i.e. an increase of thickness of the active layer on roads devoid of plant cover (Fig. 11).

Besides mechanical effects on the Ny-Ålesund environment, chemical effects which led to tundra degradation were distinguished. The chemical effects were due to fuel spills onto the ground and into the water, as well as sewage disposed of into the sea, solid waste, and solid and gaseous products of oil combustion (Fig. 4). Oil spills due to catastrophic leaks of pipelines and tanks are most dangerous for the tundra land environment (Barber 1970, Bliss 1979, Mackay et al. 1975, Moore, Philips 1975, West 1976, Getman 1977, Lissauer, Murphy 1978, Westlake, Jobson, Cook 1978). Aside from spills from damaged tanks and pipelines causing contamination of the tundra with tremendous quantities of oil, fuel spills occurring during oil transfer to tanks are also dangerous (Krzyszowska 1981). In the vicinity of Ny-Ålesund the concentration of n-hexane extracted compounds in surface waters ranged from 0.07 ppm to 308200 ppm and in the soil surface layer from 51.54 to 15,100 mg/100 g of soil dry matter. (Tab. 4, 6). The spread of oil in the surroundings of Ny-Ålesund depended, among other things, on the bedrock conditions, surface slope, hydrological conditions (Fig. 3), character and texture of the ground, content of organic substance, and presence of plant cover. For example, where thick-grained permeable deposits were present (profile VII), the concentration of the n-hexane extractable substance was less than in depressions with sandy deposits (profile V, Tab. 4). The greatest contamination with oil, both in the soil and in water was connected with the spill near the oil tanks (No. II, Fig. 4). The contamination here reached as deep as 30 cm. The contamination spread along the water flows, and during intensive snow thawing the content in water of n-hexane extracted substance was nearly 100% (0.6209 g/cm^3), before the installation of traps. For comparison, the density of this pure oil is 0.83 g/cm^3 (Analyserapport Esso Norge). The Solvatnet pond was such an efficient oil trap, that the water flowing out of the pond into the sea had a very small oil content, the same as the soil near the outflow into the sea (Tab. 3, 6). The oil concentration decreases with distance from the contamination source (Fig. 6). The oil is trapped in layers of moss or soil, for instance, in profiles X, XVII (Tab. 5) no n-hexane extracted substance was found under a 5 cm thick plant layer. After petroleum-derived products penetrated into the soil, infiltration and absorption are very low, the natural composition of the microflora undergoes changes, and the biological balance is disturbed (Engelhardt 1985). The plant cover is extensively damaged and does not grow again (Raisbeck, Mohtadi 1974), or after one season, 20-55% regrew, consisting only of vascular plants (Wein, Bliss 1973); the level of regrowth probably depends on the severity of the oil contamination. The temperature is below 0 °C in the polar zone at ground level for 8-9 months and this reduces biological degradation of oil in the soil (Atlas, Busdosh 1976, Doane 1977, Sextone, Atlas 1977). Leaching of oil by water is very slow process because of the low solubility of hydrocarbons and their derivatives (Verstraete et al. 1976). Hydrocarbons were still found in some soils 28 years after an oil spill had occurred (Engelhardt 1985). Slow biodegradation also occurs in the water of streams and lakes which results from a small number of microorganisms and the long period when the water is frozen. It seems that even the greatest outflow of oil into the coastal zone (oil spill No. I, Fig.4), is less dangerous than oil spills in the tundra due to the action of breakers.

Another factor causing degradation in the tundra environment is household sewage. Ny-Ålesund produces, on the average, 209 dm^3 of sewage per person per 24 hours, this is comparable with the sewage quantities in other polar stations (Tab. 18). The chemical properties of this sewage depend primarily upon the chemical composition of laundry and cleaning products, therefore when compared to the sewage of the Polish Polar Station, Hornsund, the content of phosphates is 14 times smaller and the concentration of nitrate nitrogen- 14 times higher (Tab. 9). The high content of nitrate nitrogen in the sewage exceeds even the concentration of strongly contaminated domestic sewage in USA, and the average content of ammonia nitrogen corresponds with the concentration of fairly polluted sewage in the USA (Todd 1970). The influence of sewage in increasing the nutrient concentration in Kolhamna Bay was estimated to occur in 0.5 ha around the sewer outlet (Fig. 8). In untreated sewage from Ny-Ålesund, the concentration of nitrate nitrogen was comparable to that in the water from the drainage basin of Ariekammen (SW Spitsbergen) (Krzyszowska 1985b) which were fertilized with the excretions of little auks. Near the sewer outlet the seawater salinity decreased to 5% , and it increased to 24% at 15 m from the outlet (Fig. 8). These values are compared with control samples from Kolhamna and are characteristic of the salinity of shallow bays fed with fresh water (Urbanski, Neugebauer, Sajcer 1980). Detergents are probably present here in low concentrations since they are subject to a high degree of biodegradation (Zdybiewska, Matyjaszczuk 1970). Coliform bacteria, E. coli, in spite of zero temperatures, have a high survival rate (Smith 1977) and may be a menace to human health where sewage is not treated.

In surface waters around the refuse dump the concentration of nitrate nitrogen was similar to the concentration in the sewage (Tab. 11).

The chemical effect in the environment of Ny-Ålesund surroundings may be also due to solid and gaseous products of fuel combustion. However, the dustfall from burning oil at the power station was minimal and occurred only near the surroundings of the power station (Tab. 7). The quantities of sulphur dioxide escaping from the chimney were 10 times higher than in polluted ice fog in Fairbanks, and the concentration of nitrogen oxides was 20 times higher (Holty 1973), but these are quickly diluted after emmision from the smoke-stack.

6.3. Estimation tundra degradation in the Ny-Ålesund vicinity

Various tundra environments have different susceptibility to human induced stress. The reaction of particular tundra ecosystems to anthropogenic factors depends, among other things, on the physical and chemical properties of the ground, on hydrologic conditions, on the degree the terrain is covered with plants, and on the ground moisture. At Ny-Ålesund, hydrologic conditions were the most important factor causing the spread of oil. Using criteria given by Baab, Bliss (1974) the susceptibility of grounds to anthropogenic factors may be distinguished: areas most subject to destruction belong the lowest sea-terraces with periodic ponds, wet areas with prevalently mossy vegetation; areas of medium susceptibility to destruction belong to higher sea-terraces where vascular plants prevail over mosses, these areas are usually dry with periodic ponds, and in some places rocks outcrops; areas more resistant to destruction belong to the youngest geomorphologic deposits, the youngest shore-ridges, bank moraines of the glacier.

Ny-Ålesund lies within an area of the greatest and medium susceptibility to destruction. In the course of determining the range and degree of impact in the Ny-Ålesund vicinity, a map "Tundra degradation in the surroundings of Ny-Ålesund" was made in a scale of 1:10000 (Fig. 10). The following estimation criteria were utilized: degree of plant cover destruction, changes of granulometric composition of the ground, occurrence of petroleum-derived products in soil and water, and the damage of the tundra surface (cinder piles, excavations) due to mining activities prior to 1963. The surface degraded by present day human activities covers approximately 45 ha and the surface destroyed by previous mining activities covers approximately 33 ha. Within the limits of Ny-Ålesund there are ca 13.5 km of roads (Fig. 10).

7. Conclusions

- Ny-Ålesund accumulates yearly ca 2 t of solid wastes, the average amount of sewage is 200 dm^3 per person per 24 hour.

- Not the quantity of wastes, but rather the quality of the waste remaining in the environment has a decisive effect on the tundra degradation in the vicinity of Ny-Ålesund. Mechanical and chemical effects are the most dangerous.

- Mechanical effects cause the destruction of the plant cover, successively from lichens to mosses to vascular plants; followed by changes in the ground moisture and an increase of the fine grained fraction as well as compaction and greater thaw depth.

- The chemical effect most dangerous for the tundra environment was petroleum-derived fuel spills, because of its spreading through surface waters.

- Sewage contaminates the Kolhamna Bay waters over a surface of 0.5 ha around the sewer outlet and may pose a health hazard due to the presence of coliform bacteria.

- In the surrounding of Ny-Ålesund, the surface degraded by present day human activities covers ca 45 ha and the surface destroyed by previous mining activities covers ca 33 ha.

8. Recommendations concerning waste management at Ny-Ålesund

The factors which can degrade the environment at Ny-Ålesund are: petroleum-derived fuel, sewage, solid waste and mechanical destruction by vehicles and people. That is why there is a necessity to utilize the solid waste, burned and unburned, to have sewage treatment and to controll fuel management.

I. Environment protection against fuel spills

In order to prevent contamination due to oil spills, an alarm system should be installed around the potential sources of contamination such as oil tanks and pipelines. It is suggested that safety embankments be made around the oil tanks to prevent the spread of oil in the event on a spill; these may consist of compacted earth or concretes of suitable resistance and imperviousness. In addition, it is advisable to have supplies available for containment and cleanup in the event of an accident, including fertilizer, sacks of sand or a supply of diatomite to barricade the site of outflow. Traps installed in the summer of 1986 on the main flows formed a partial barrier against further spread of contamination.

II. Water and sewage management

Ny Alesund does not need any treatment of potable water since the water quality conforms to Norwegian Standards of potable water. Treatment of sewage is recommended because of the bacteriological contamination of the Kolhamna Bay. The choice of the type of a treatment plant for a quantity of 200 dm per person per 24 hours should be studied by specialists. The most commonly used in polar regions is the lagoon waster-water treatment. At the Polish Polar Station in Hornsund a container treatment plant will be installed in the summer of 1987 with rotating biological disk treatment, thereby reducing BOD and suspended matter up to 93-95 %. Mechanical treatment of sewage could be performed by a 3 or 4 chamber settling tank with manually removed sediments.

III. Utilization of solid wastes

The best disposal of solid waste would require a universal incinerator. Since there is a low likelihood of such an installation, it is advisable to divide waste into burnable, compostable and non-combustible waste (glass, metal) and to dispose of them to places specifically designed for them, for example waste fermentation ditches. A simple incinerator may also be used to burn waste in a contained space, so that ashes and unburned remains would not be spread over the landscape by the wind. It would be advisable to remove (carry away and immerse in the sea) ashes produced by waste incineration.

IV. Behavior rules for persons staying at Ny-Ålesund

Persons staying the Ny-Ålesund for a longer time period should be instructed how to minimize impact on the fragile tundra environment (photo 8). Rules should be given concerning the principles of behavior of persons staying at Ny-Ålesund, e.g. vehicular traffic should go on along already existing roads, gathering of plants and other objects should be limited to indispensable needs only, when possible the effects of working in the field should be minimized (filling up bore holes, removing poles, etc.).

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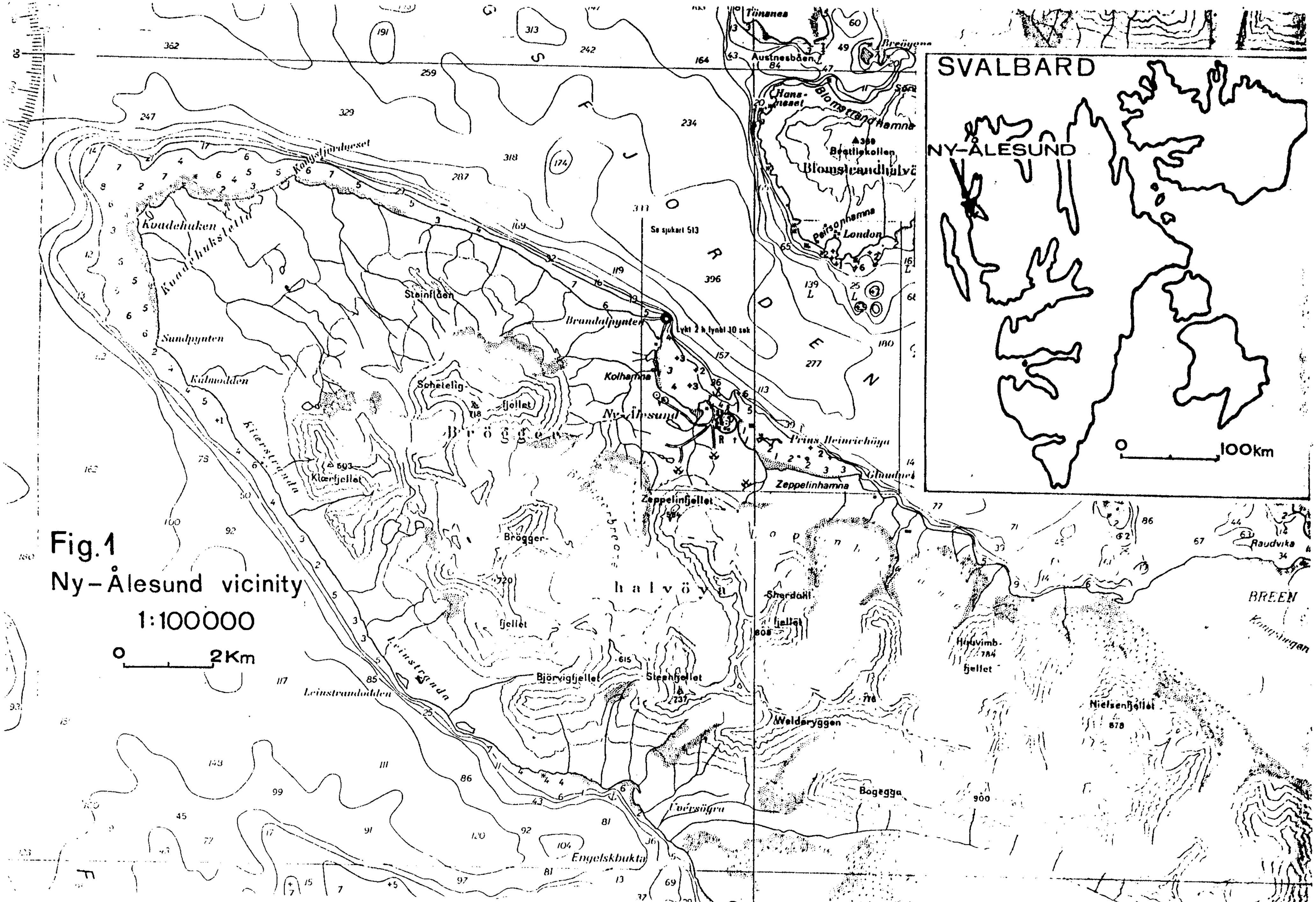


Fig.1
Ny-Ålesund vicinity
1:100000
0 2Km

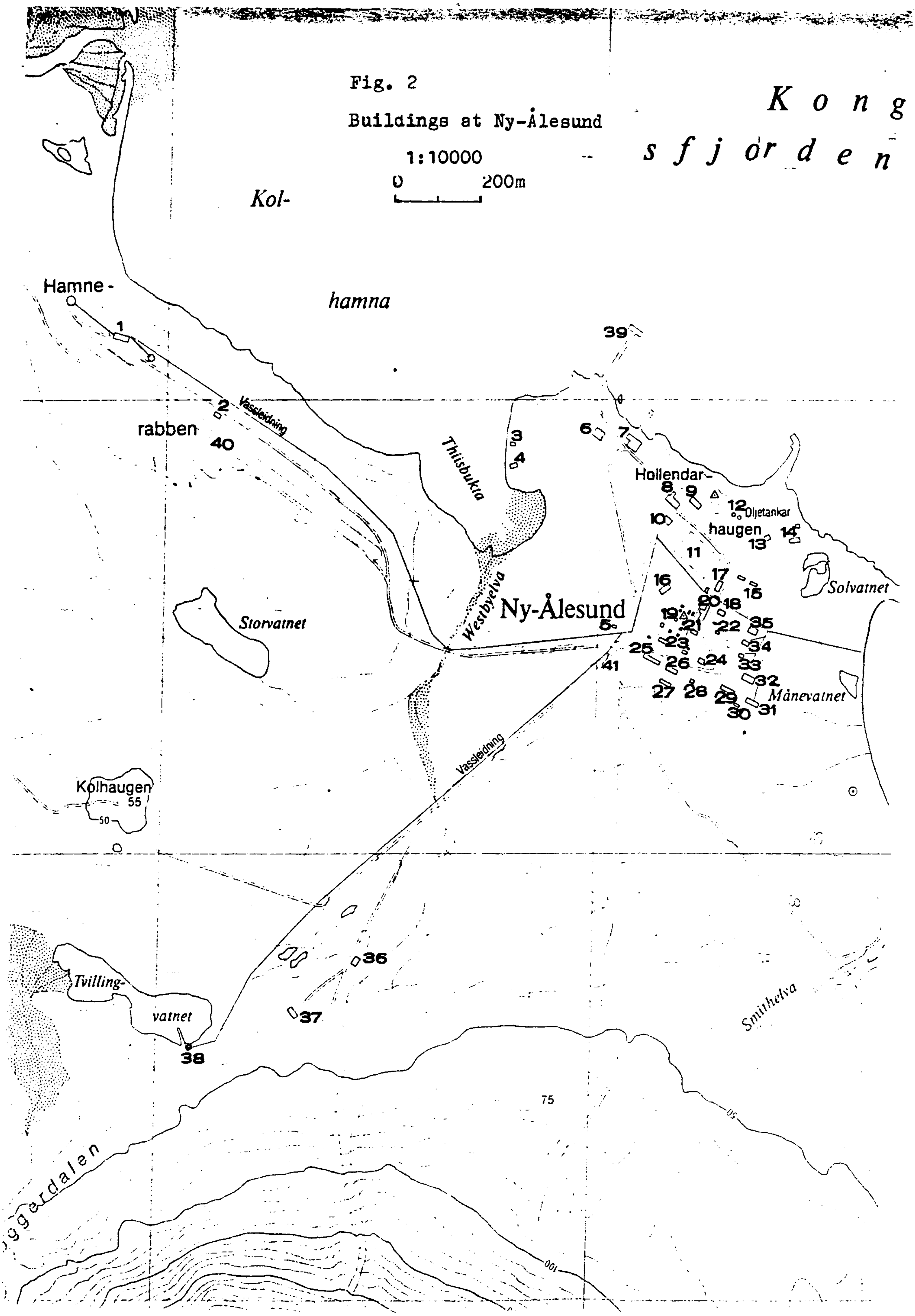


Fig. 2

Buildings at Ny-Ålesund

1:10000

0 200m

Fig. 2 Buildings at Ny-Ålesund, scale 1:10000

1- space photos receiving station, 2- airport building, 3,4- buildings for boats, used periodically, 5- kennel, 6- building formerly serving for cleaning coal, not used, 7- abandoned power station, 8- power station, 9- carpenter's store, 10- store, 11- football stadium, 12- oil tanks, 13,14- store, 15- "London" buildings used periodically, 16- abandoned carpenter's store, 17- tourist shop, 18-school,not used, 19- miners' houses, not used, 20,22,31- dwelling houses, 21- hotel, 23- dwelling house used periodically, 24- post office, 25- building used by Cambridge University, 26- store of Norsk Polarinstitutt, 27,28,30- not used buildings, 29- research station, 32- mess, 33- hospital, 34-telex, telephone, 35- laboratory, 36- building of the Institute of Air Research, 37- seismologic station, store, 38- pumps, 39- harbour, 40- runway, 41- landing field for helicopters.

Fig. 3 Hydrologic conditions /18.06-2[illegible].06.1986/ in the vicinity of Ny-Ålesund.

1 : 5000

- main direction of flowing water
- streams
- streams, ponds contaminated by oil

A-Ø - sites of water sample collection /oil determination/

1-33 - sites of water sample collection / determination of chemical composition/

1-4 - main, periodic ponds

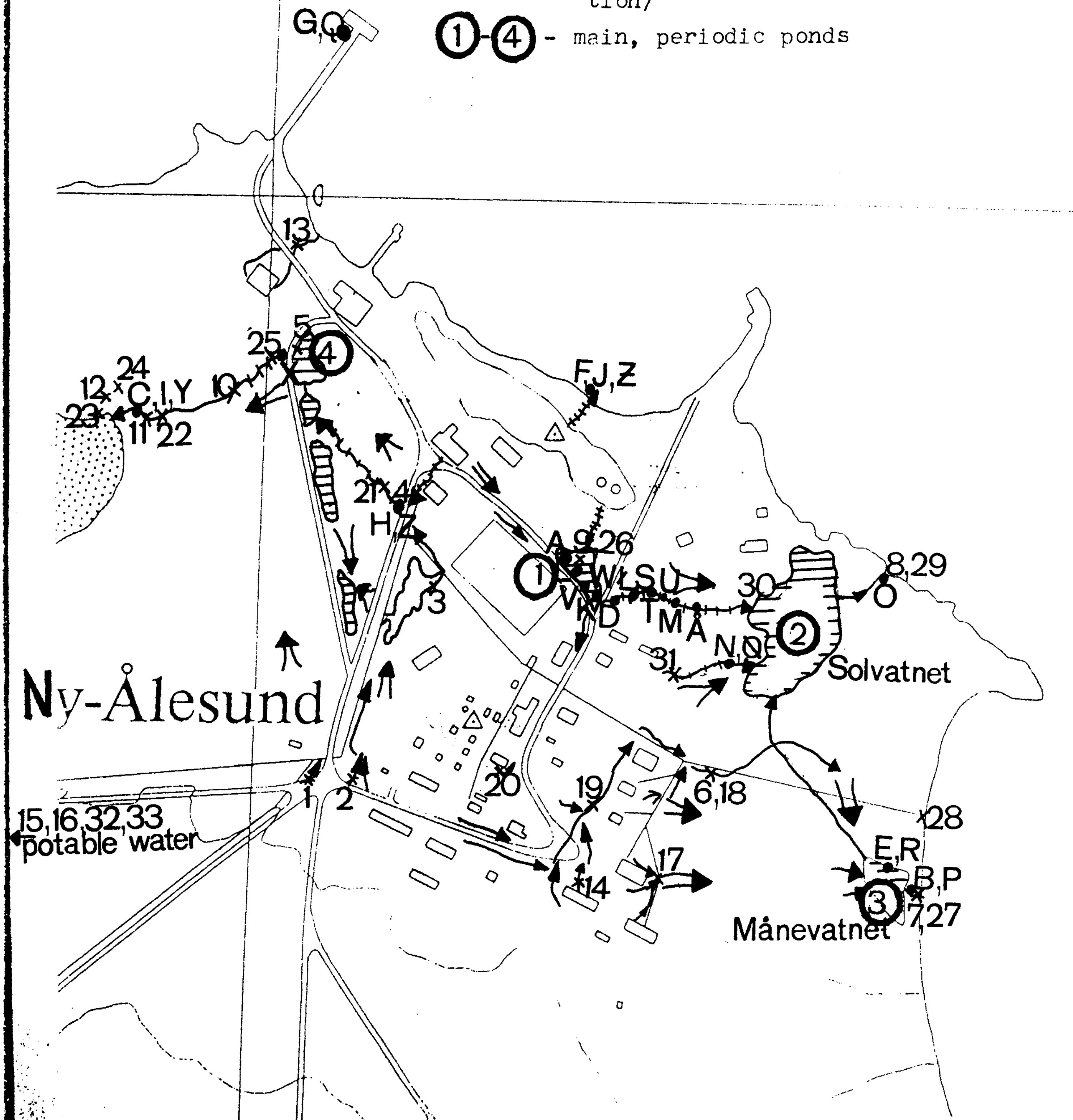


Fig. 4 Sources of environment contamination in the vicinity of Ny-Ålesund.
1:5000

A - oil tanks, oil spills II, III.

B - oil pipe line, oil spills I.

C - power station, oil spills IV

D - harbour, oil spills V

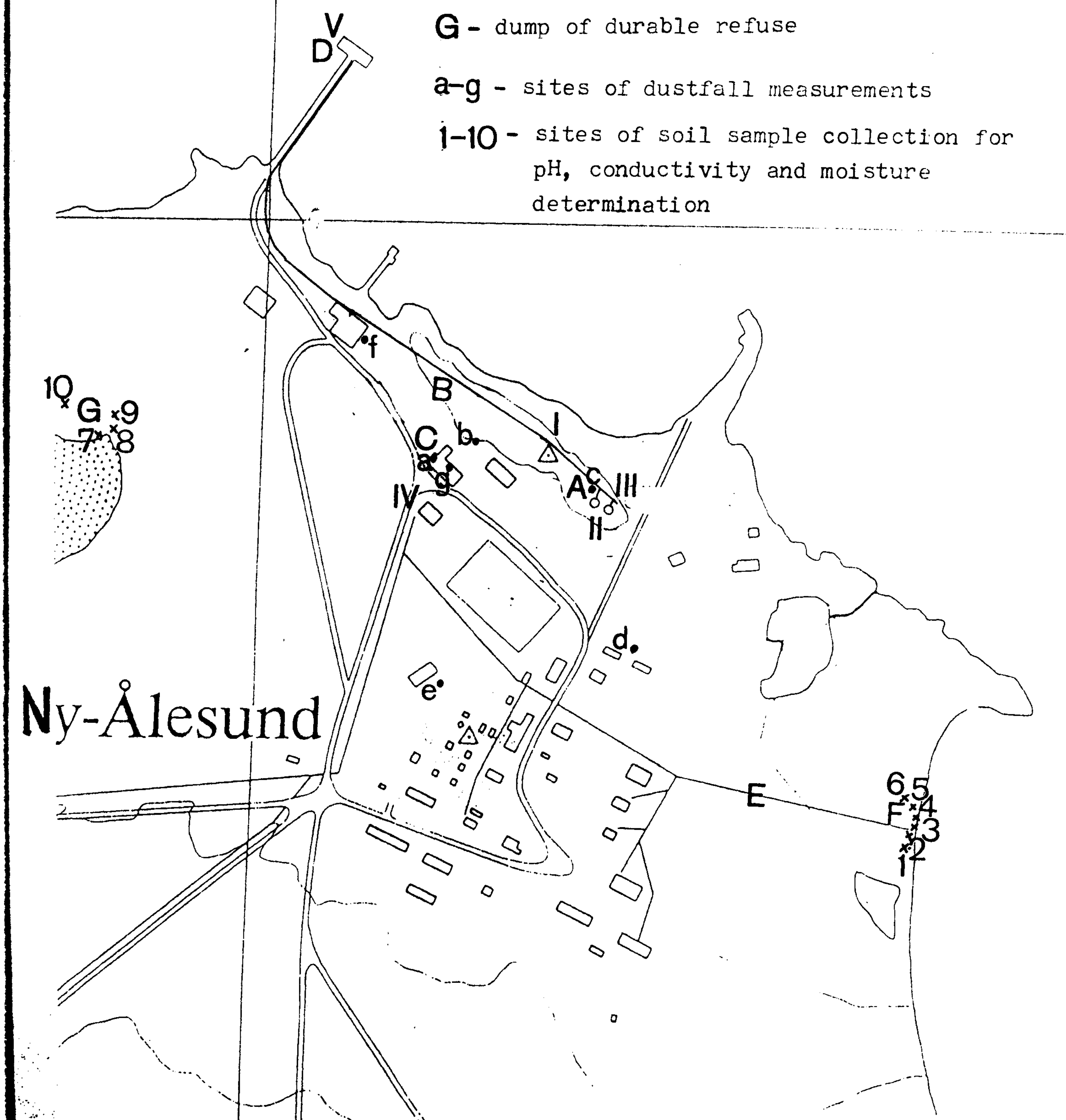
E - communal sewer

F - outlet of sewage

G - dump of durable refuse

a-g - sites of dustfall measurements

1-10 - sites of soil sample collection for pH, conductivity and moisture determination



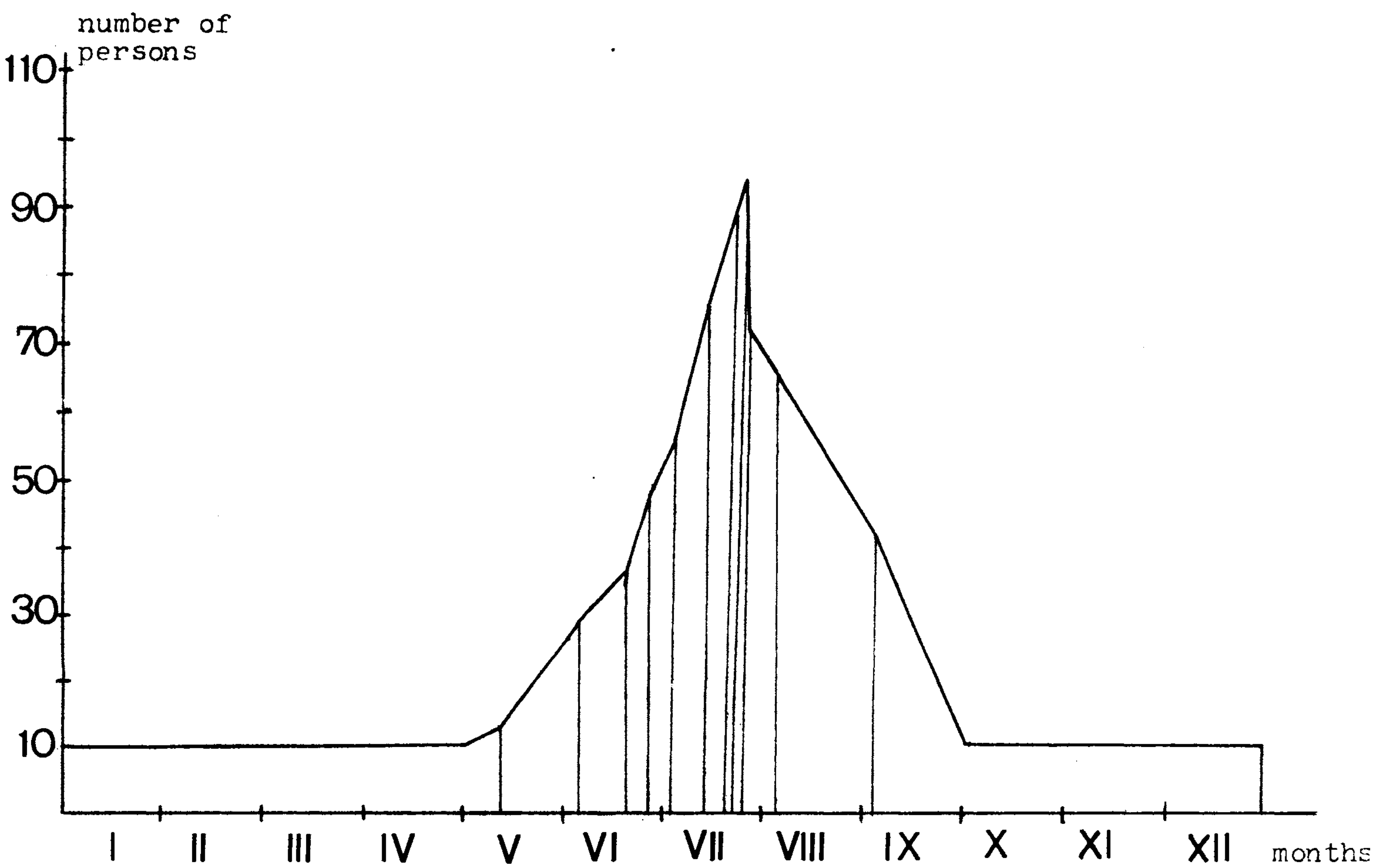
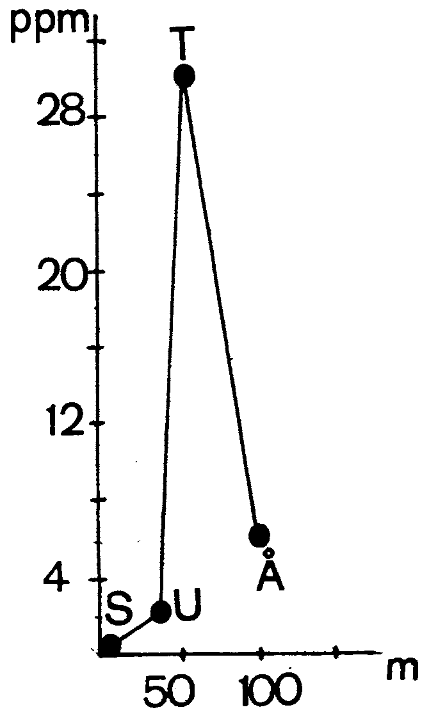


Fig. 5 Number of persons staying at Ny-Ålesund in 1986.



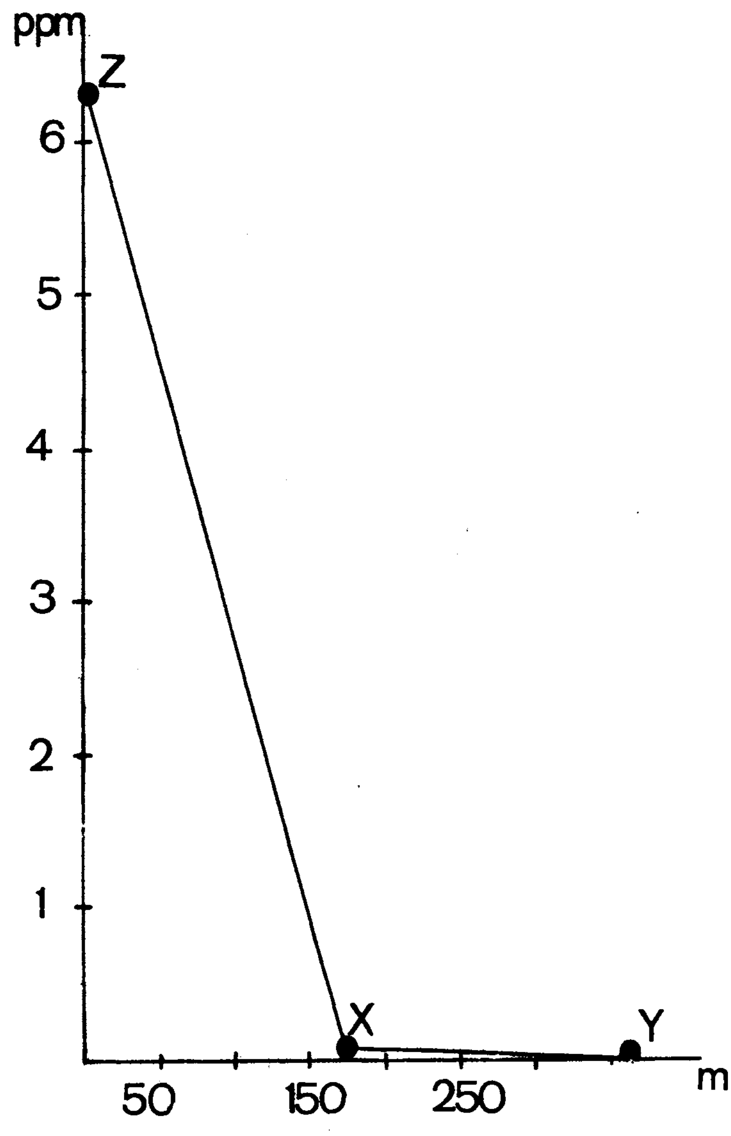


Fig. 6 Oil content /07.07.1986/ along cross-sections: S-U-T-Å, and Z-X-Y /location Fig.3/.

S, Z - beginning of the stream

Fig. 7 Map of soil samples contaminated by petroleum-derived fuel /1986/.

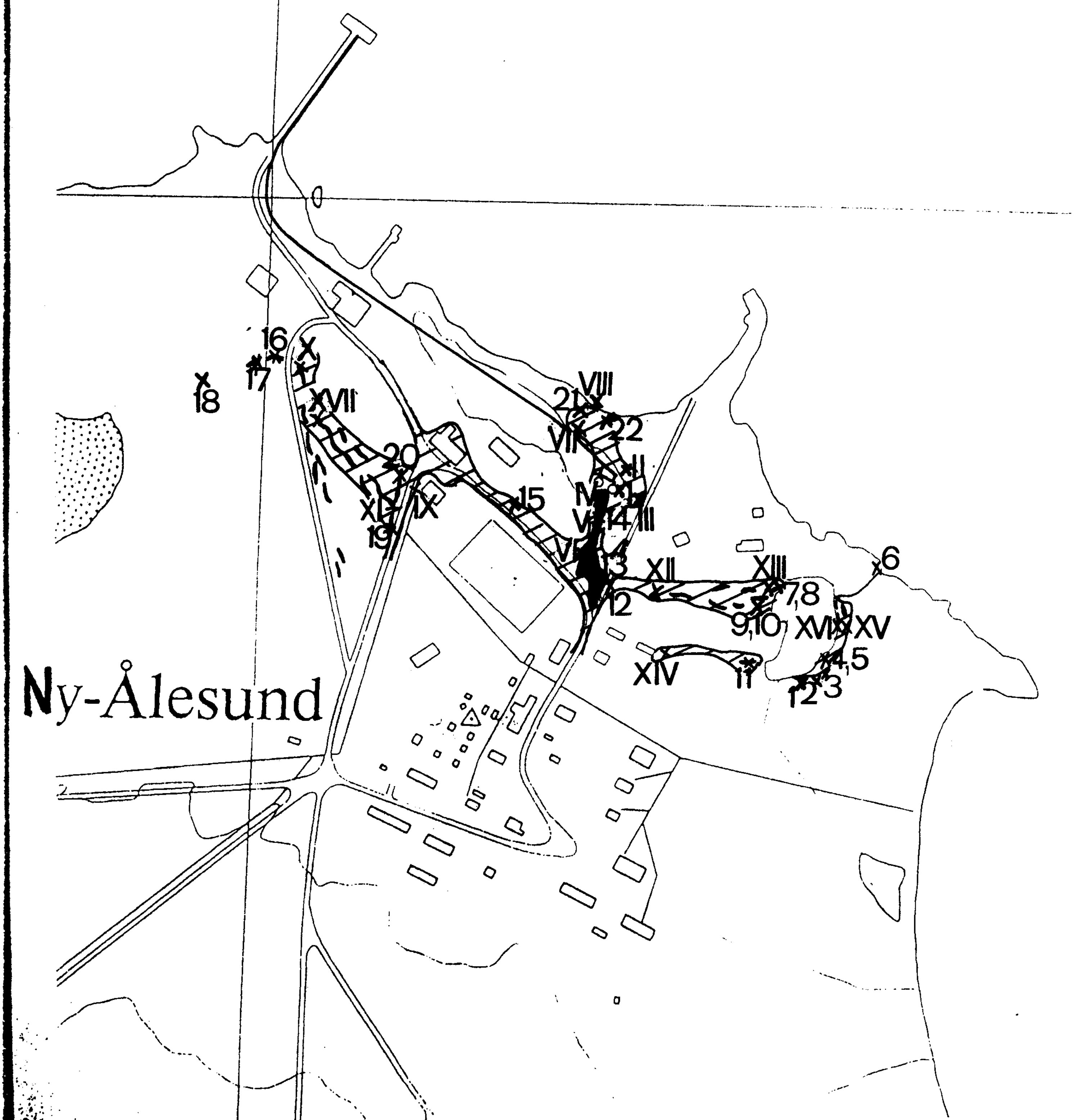
1 : 5000

×1-23- sites of soil and plant sample collection

× I-XVII- profiles of soil sample collection

(hatched symbol) - ground contaminated by fuel

(black symbol) - ground surface contaminated by fuel



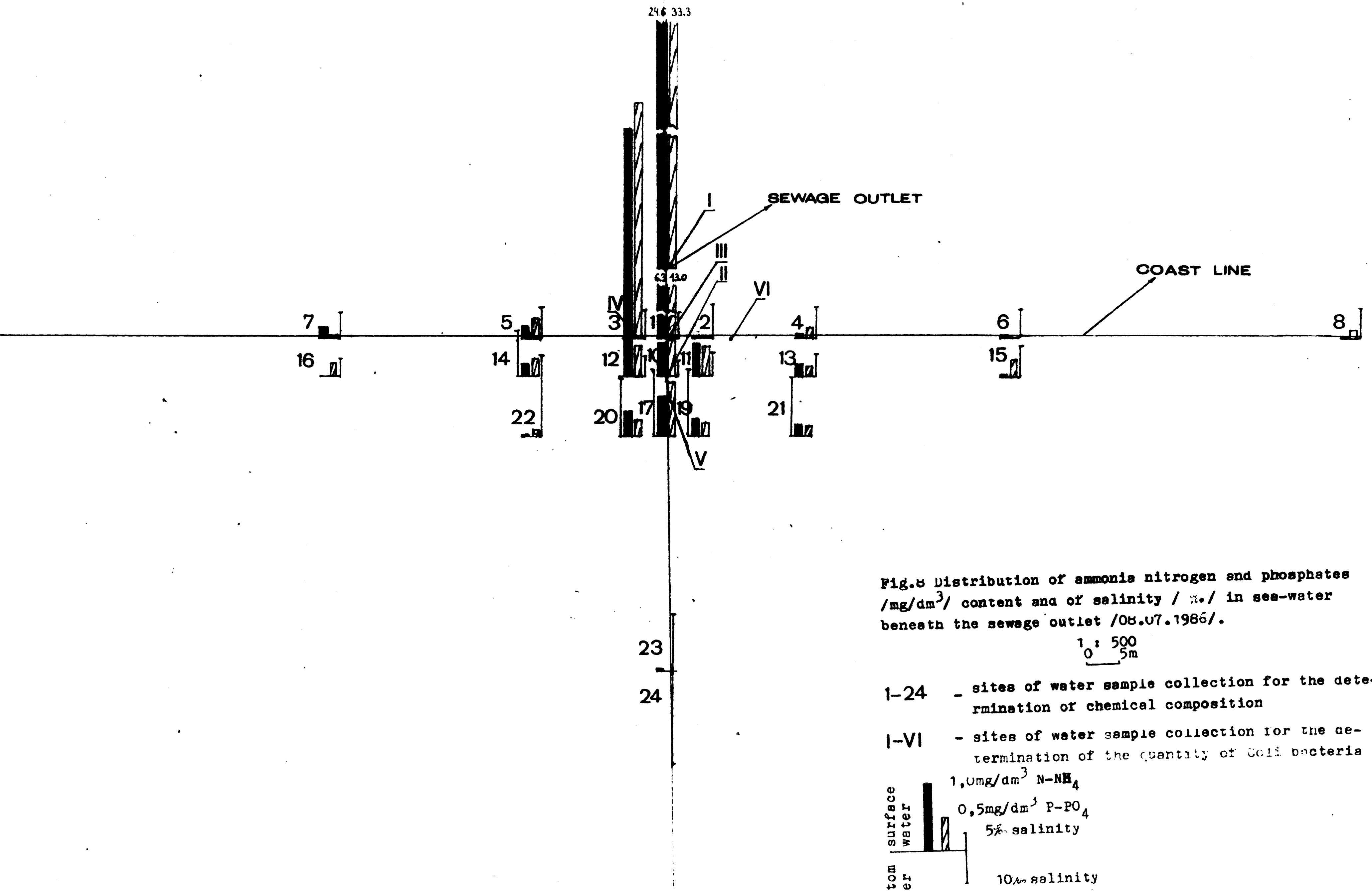


Fig.8 Distribution of ammonia nitrogen and phosphates /mg/dm^3/ content and of salinity / ‰ / in sea-water beneath the sewage outlet /08.07.1986/.

1 : 500
0 5m

1–24 - sites of water sample collection for the determination of chemical composition

I–VI - sites of water sample collection for the determination of the quantity of Coli bacteria

surface water
bottom water

1,0mg/dm^3 N-NH_4

0,5mg/dm^3 P-PO_4

5‰ salinity

10‰ salinity

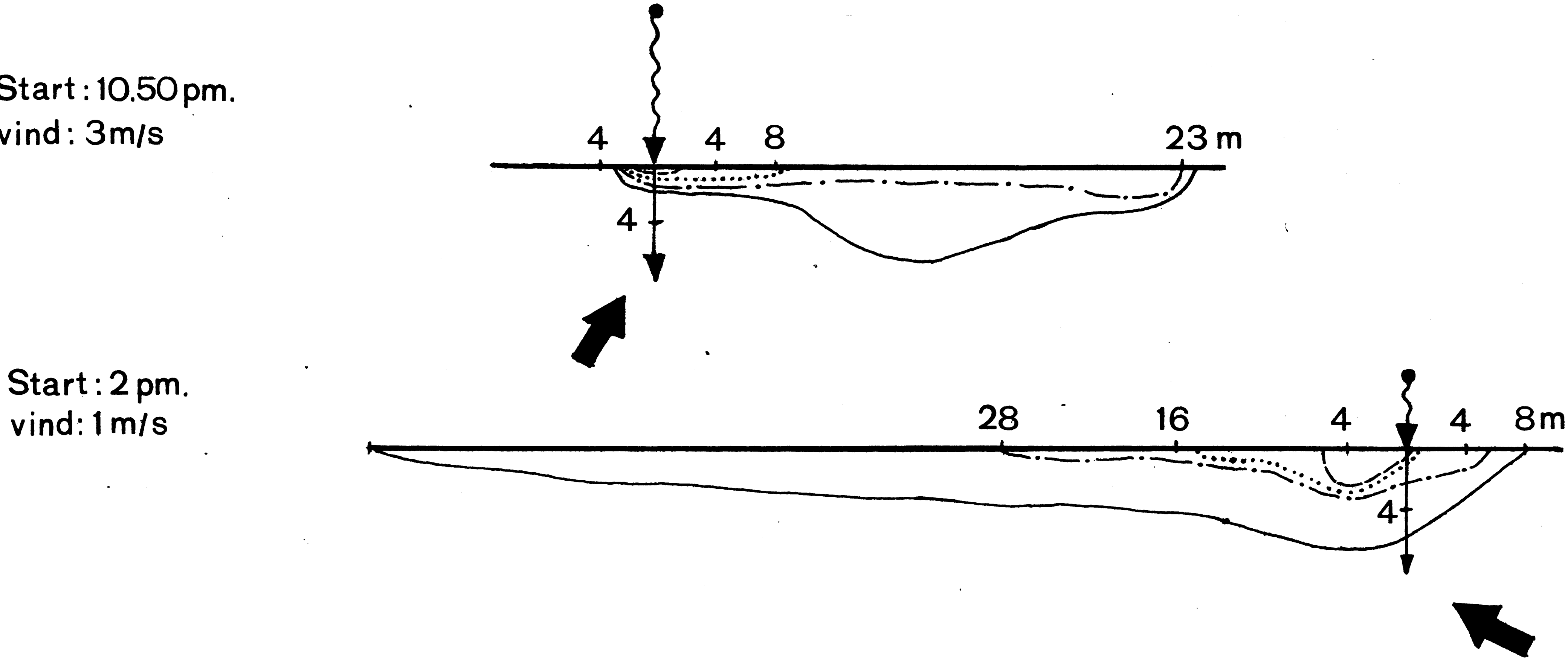


Fig. 9 Sewage distribution along coast line estimated by fluoresceine traser /06.07.1986/

wind direction

front of sewage wave on pouring fluoresceine after:

- - - - 3min.
.... 10 min.
-.-.- 40 min.
——— 90 min.

sewage outlet

coast line

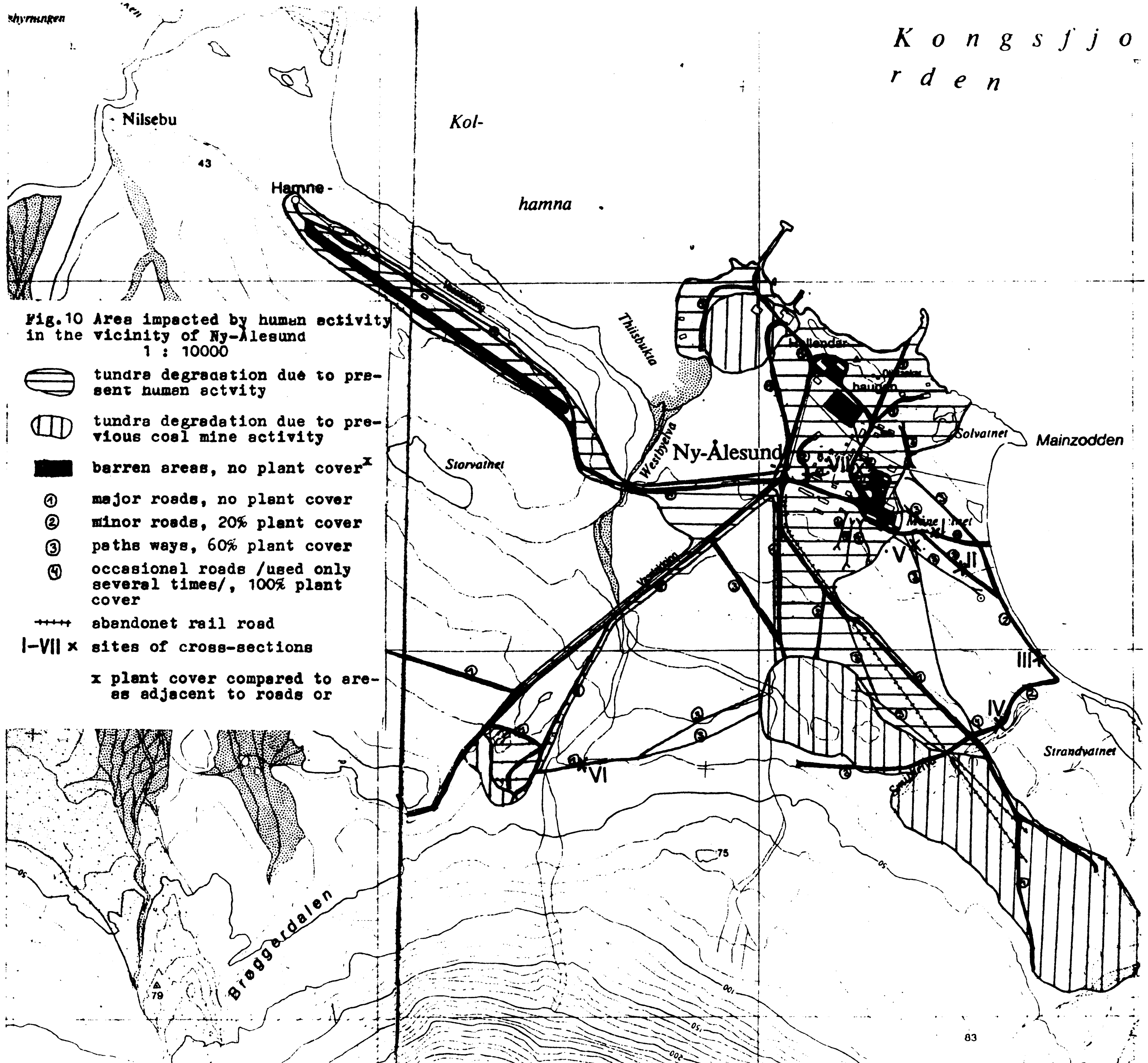


Fig.10 Area impacted by human activity in the vicinity of Ny-Ålesund 1 : 10000

Fig. 11 Thaw depth along cross-sections /location Fig.10/

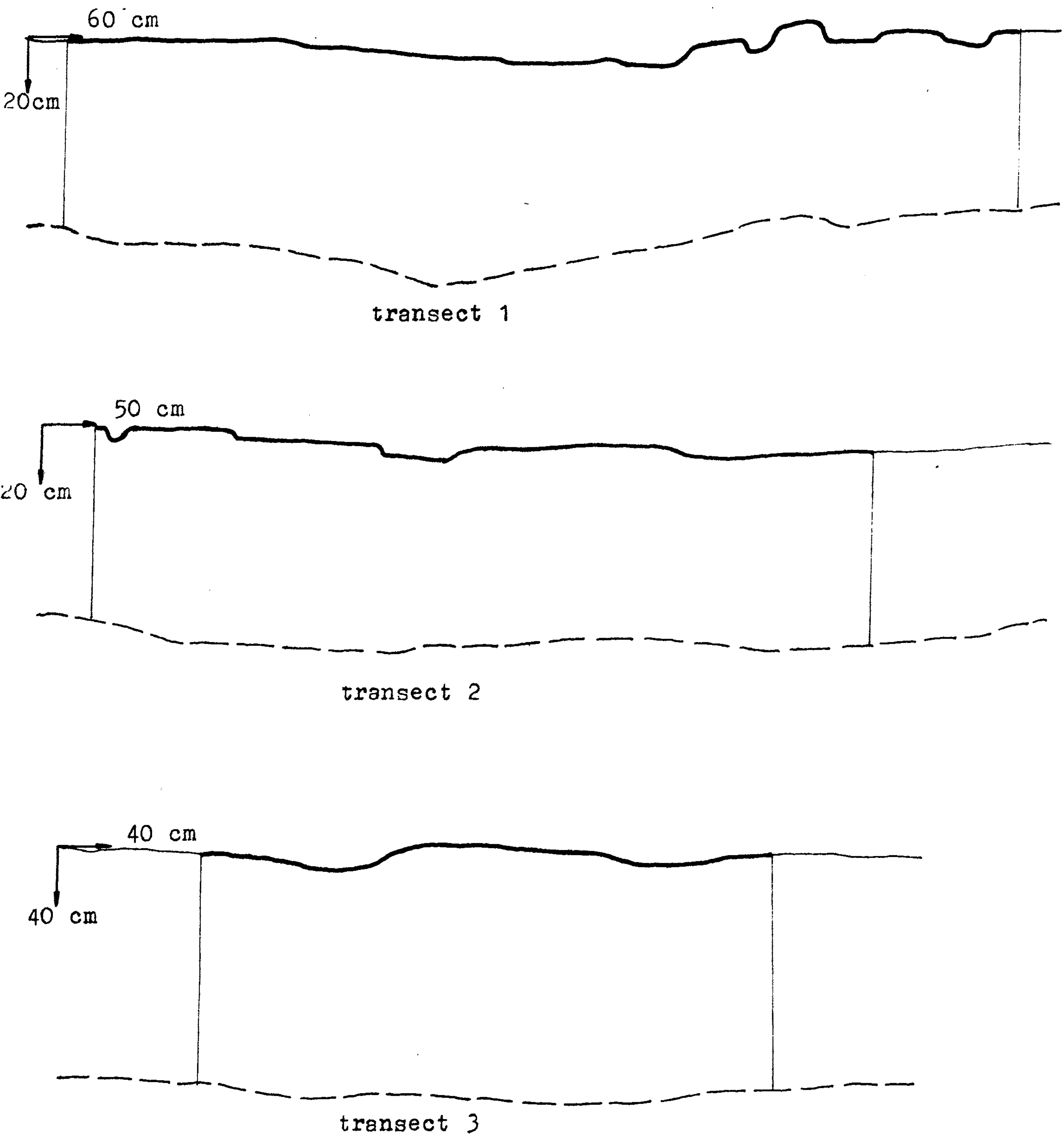
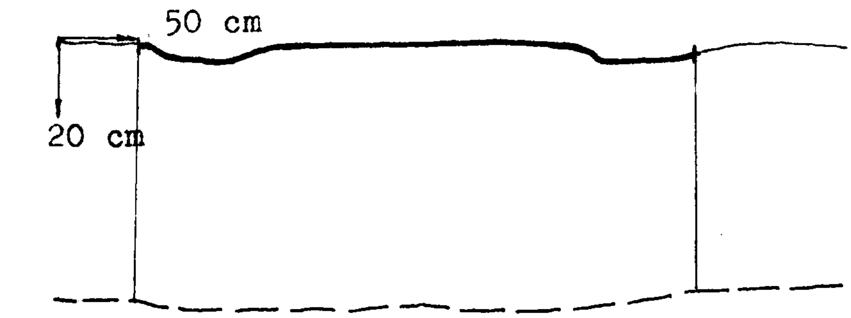
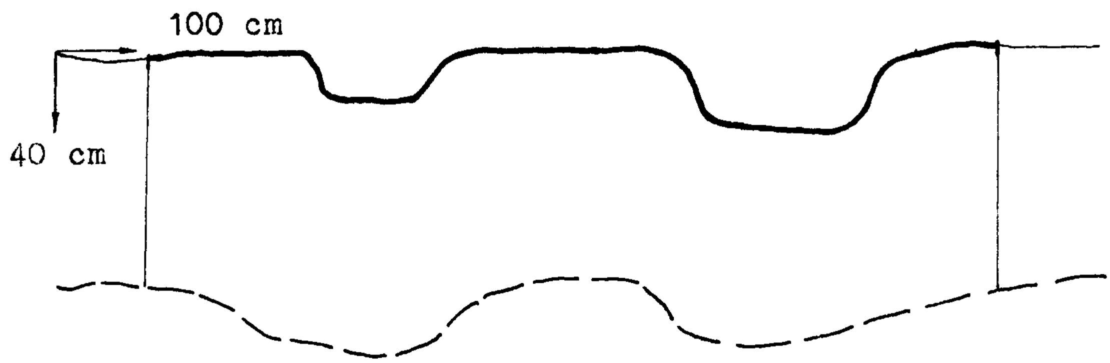


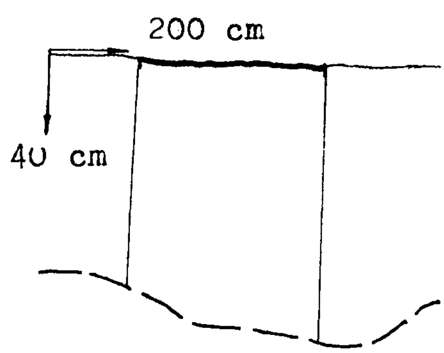
Fig. 11 continued



transect 5



transect 6



transect 7


road
roadside
permafrost begining

Photo 1. Lake Tvillingvatnet with potable water

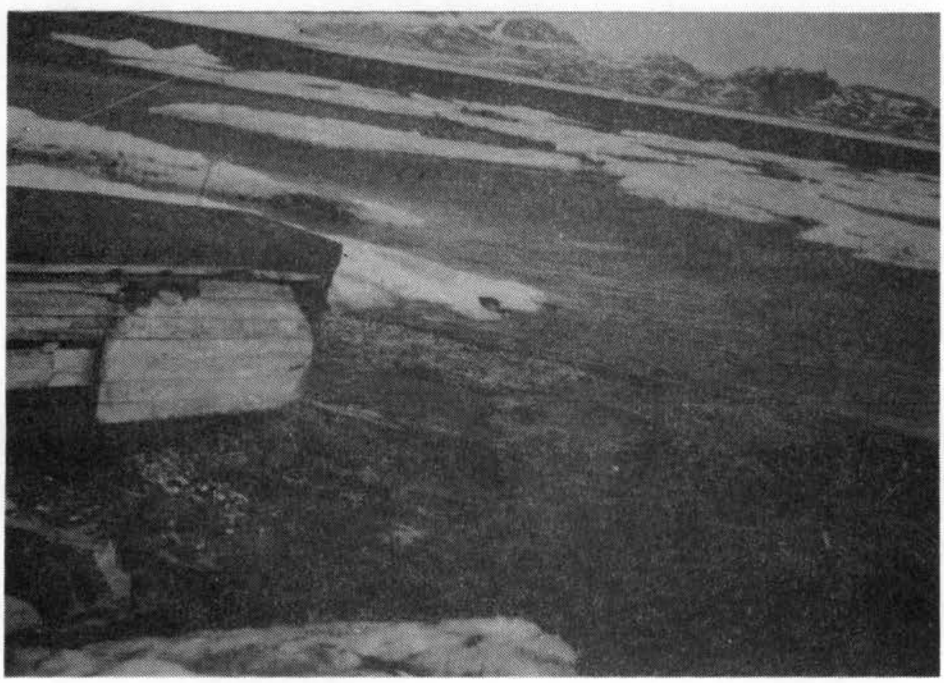


Photo 2. Outlet of sewer ditch.

Photo 3. Solid waste dump.

Photo 4. Site of dustfall measurement, fuel tanks in the background.

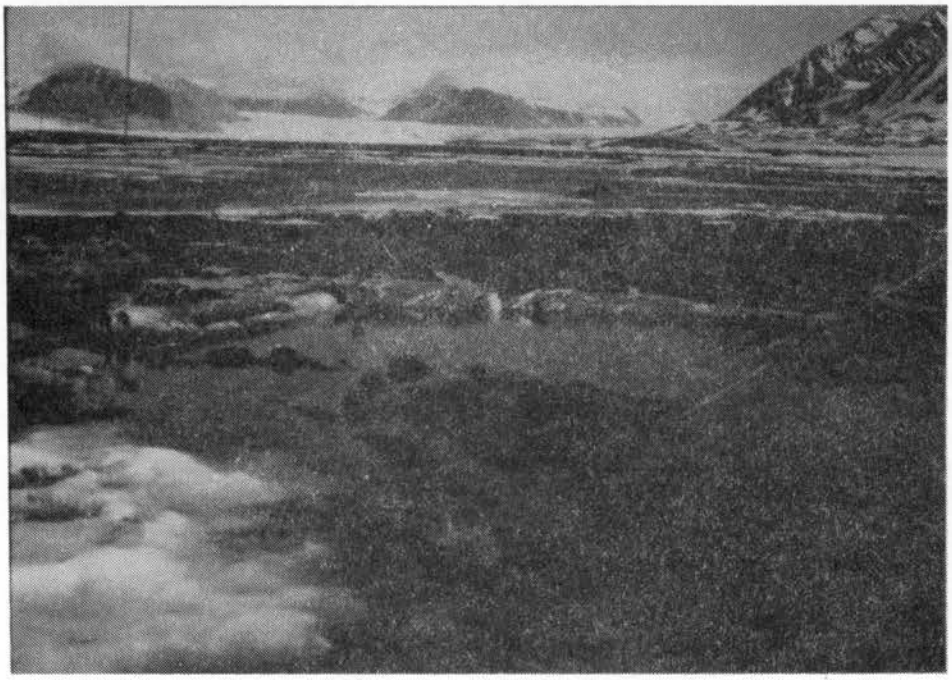


Photo 5. Oil trap on stream flowing into the Solvatnet pond.

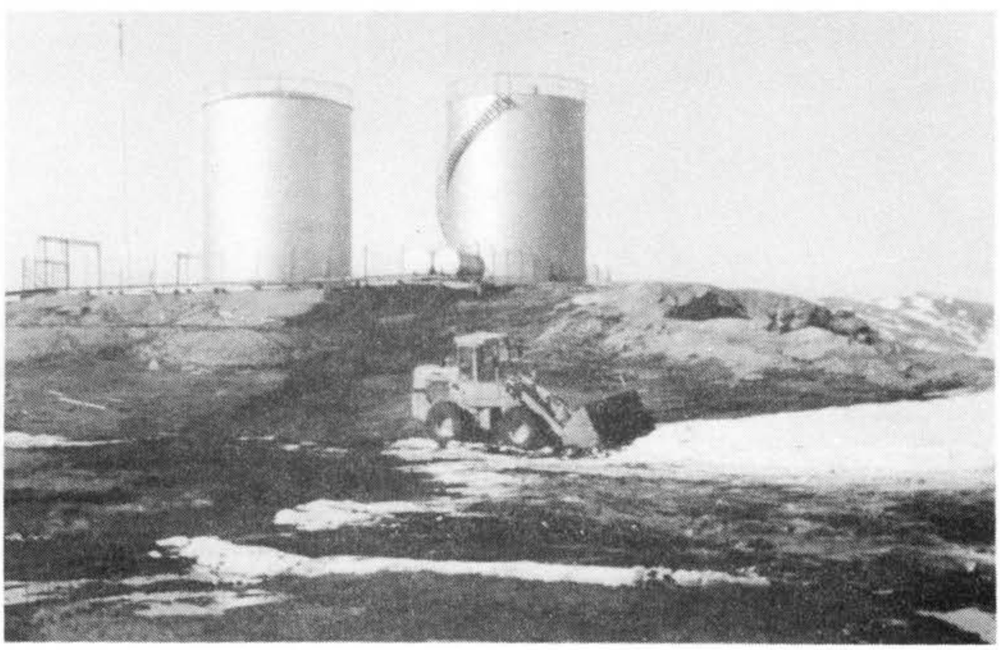


Photo 6. Removing contaminated soil beneath oil tanks.

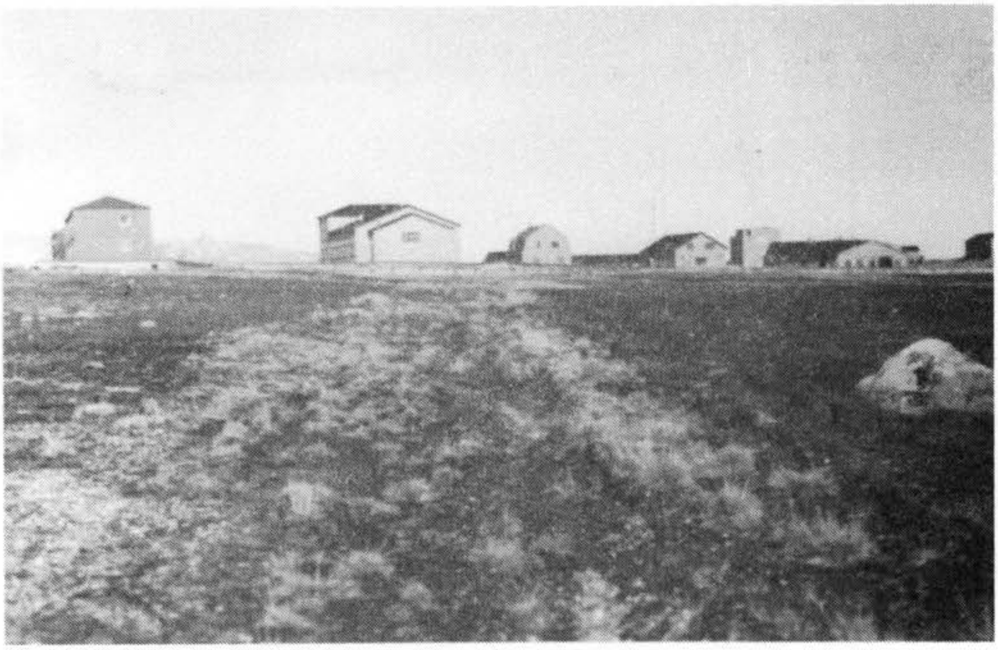


Photo 7. Road with tussocks of Deshampsia alpina at cross-section no.1

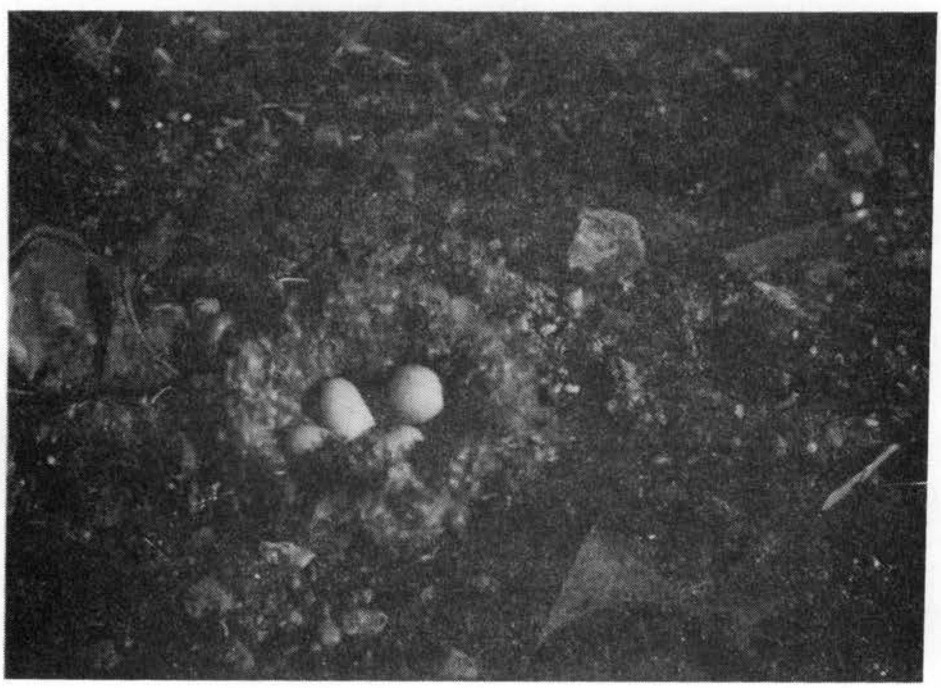


Photo 8. Has Man been here?

Table 1. Some climatic data (monthly means) in the period 1971-1980 at Ny-Ålesund (Steffens 1982)

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Atmospheric pressure hPa average sea level	1007.4	06.9	09.2	13.8	16.6	13.4	10.9	10.5	07.4	09.9	07.5	00.9	1009.6
Air temperature °C average	-12.8	-13.9	-13.1	-11.1	-3.8	2.1	5.2	4.1	0.1	-5.5	-9.7	-11.7	-5.8
extreme values highest	- 4.2	-10.6	- 6.3	- 8.4	-2.2	3.2	6.2	5.3	2.2	-2.3	- 5.0	- 7.1	-3.7
lowest	-20.0	-19.3	-20.5	-16.6	-6.9	-0.5	4.4	2.5	-1.8	-7.9	-16.9	-18.3	-7.1
Relative humidity (%) average	77	79	79	78	81	85	87	87	85	71	68	69	79
Precipitation average monthly fall mm	31	34	39	19	22	13	33	42	39	47	35	31	385
Clouds and visibility average, octas	4.8	4.9	4.9	4.3	5.4	5.9	6.2	6.5	6.3	6.0	4.5	4.7	5.4
No of clear days	6.1	6.1	4.9	7.2	4.6	2.2	2.0	0.9	1.4	2.4	7.1	7.1	52.0
No of overcast days	12.6	12.6	12.4	9.5	15.4	16.1	19.0	18.7	18.0	17.9	11.0	12.1	175.3
Global radiation cal/cm 1975-79	-	57	17661	7439	13734	14217	10785	5986	2296	-	-	-	56527
Wind force, Beaufort scale Percentage frequence of													
0	27.9	29.3	37.6	49.3	38.1	29.8	14.8	21.0	24.2	20.8	17.8	23.2	27.8
1-2	37.8	36.2	31.8	27.2	33.3	45.4	60.0	57.0	44.9	43.7	37.1	37.3	41.0
3-5	30.0	32.3	27.2	22.0	28.0	23.0	25.0	21.8	30.7	32.5	39.8	38.2	29.2
6-8	4.3	2.2	3.4	1.5	0.6	1.8	0.2	0.2	0.2	3.0	5.3	1.3	2.0
9 or more	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 2. Some climatic data (decade and monthly means) in the months of May, June, July 1986 at Ny-Ålesund

Month	Decade	Atmospheric pressure at		Temperature			Wind velocity	Humi-dity	Total precipi-tation
		station level	sea level	mean	min.	max.			
		hPa	hPa	°C	°C	°C	m/s	%	mm
	1	1024.8	1025.8	-6.5	-10.7	-4.9	2.0	62	0.1
	2	1006.5	1007.6	-0.4	- 1.2	0.8	3.0	78	2.5
May	3	1014.9	1016.1	-0.2	- 2.1	1.0	1.5	70	0.0
	mean	1015.4	1016.5	-2.3	- 4.6	3.1	2.0	70	2.6
	1	1011.2	1012.0	2.4	0.9	3.8	2.5	80	3.2
	2	1007.7	1008.8	2.4	1.5	3.4	1.5	82	5.0
June	3	1007.2	1007.7	2.4	1.7	3.7	3.0	77	6.5
	mean	1008.6	1009.5	2.4	1.3	3.6	2.3	80	14.7
	1	1009.8	1012.1	5.7	4.8	6.7	1.5	75	1.7
	2	1012.7	1013.8	6.1	5.1	7.4	3.0	74	2.8
July	3	1011.6	1013.3	5.6	4.8	6.9	2.0	81	36.2
	mean	1011.3	1013.0	5.8	4.9	7.0	2.0	76	40.7

Frequency of occurence of wind directions (%)

directions	N	NE	E	SE	S	SW	W	NW	calm
May	2.3	1.1	4.6	29.9	10.3	2.3	8.0	12.6	28.7
June	8.4	0	12.0	15.7	7.2	0	18.1	21.7	16.9
July	9.6	3.6	36.1	18.1	3.6	1.2	4.8	7.2	15.7

Table 3. Oil content (ppm) in waters surrounding Ny-Ålesund

Sample No.	Location (Fig. 3)	Flow rate dm^3/min	Date	Content of oil hydrocarbon in water samples ug/ml (ppm)
A	pond (No 1) beneath oil tanks		18.06	60.330
K			26.06	53.700
W			7.07	17.700
L	pools above pond (No 1)		26.06	7.76
V			7.07	225
D	beneath pond (No 1) beginning of stream	120	18.06	308.200
L	15 m from the stream beginning	60	26.06	3.06
S		180	7.07	0.07
U	stream bend, stagnant water		7.07	2.67
T	stream reaching oil trap	60	7.07	30.0
M	oil trap		26.06	620.800
Å	stream reaching the Solvatnet pond (No 2)	30	7.07	6.07
N	stream	5	26.06	0.08
Ø		0.5	7.07	1.19
O	outflow from the Solvatnet pond	115	26.06	0.08
E	Månevatnet pond (No 3)		21.06	0.07
R			7.07	0.07
B	outflow from pond Månevatnet into the sea	180	18.06	0.08
P		300	26.06	0.39
F	sea water within the zone of		21.06	1340.
J	breakers at the maximum tide		26.06	19.7
			7.07	1.19
G	sea water in the harbour		21.06	0.17
O			7.07	2.67
H	stream	5	26.06	0.26
Z		30	7.07	-6.41
X	stream	17.5	7.07	0.09
C	outflow into the sea	1000	18.06	0.19
I		1500	26.06	0.11
Y				not detected

Table 4. Content of n-hexane extract (mg/100 g of dry soil mass) in soil profiles in in the vicinity of Ny-Ålesund (location Fig. 7)

No of profile	No of sample	Depth of sample collection (cm)	Content of n-hexane extract (mg/100 g soil D.M.)	Moisture %
I	1	5	9790	25.0
	2	20	1880	17.4
	3	37	1150	13.3
II	2	5	429	12.7
	3	18	223	12.0
III	2	9	1190	11.7
IV	1	2	5230	7.7
	2	7	3570	14.3
	3	18	2620	7.7
	4	35	2070	5.7
	5	50	2020	9.5
V	1	2	55400	73.4
	2	5	52400	70.8
	3	18	1970	31.5
	4	36	852	32.6
	5	40	1200	28.7
VI	2	5	735	7.7
	3	12	351	51.2
	4	28	97	10.8
VII	1	2	5000	12.4
	2	5	1330	25.2
	3	10	202	12.1
	4	20	541	9.1
VIII	1	2	129	5.4
	2	5	402	6.4
	3	15	382	9.9
	4	27	290	7.2
IX	1	2	21900	35.4
	2	5	14400	31.1
X	2	10	n.d	26.7
	3	38	n.d	20.5
	4	60	n.d	19.2
XI	2	5	916	74.4
	3	13	36.6	15.7
XII	2	5	1630	21.0
	3	7	129	19.3
	4	27	152	14.9
	5	32	n.d	10.5
	6	52	n.d	18.3

XIII	2	9	1330	88.8
	3	39	3500	74.0
	4	47	157	41.7
XIV	1	2	3130	27.0
	2	6	49.3	8.8
	3	30	161	13.1
XV	2	15	102	92.6
	3	28	n.d	85.4
XVI	2	15	1390	86.5
	3	24	1810	87.7
XVII	2	21	n.d	16.8
	3	50	n.d	16.9
	4	60	n.d	15.6
XVIII	2	15	n.d	57.2
	3	30	n.d	23.7
	4	45	n.d	14.5
	5	60	n.d	16.3

n.d. - not detected

Table 5. Content of n-hexane extract (mg/1 g of dry plant mass) in the plant layer of surface samples and soil profiles (location Fig. 7)

No of profile / No of sample	Depth of sample collection (cm)	Content of n-hexane extract (mg/1·g of plant dry mass)	Moisture %
4	5	116.74	86.62
7	5	128.63	81.08
9	5	88.33	80.29
II/1	2	158.54	70.65
III/1	2	13.32	20.78
VI/1	2	22.36	74.21
X/1	5	554.08	83.87
XI/1	2	14.47	54.26
XII/1	2	161.55	77.22
XIII/1	6	465.22	67.55
XV/1	7	600.63	83.06
XVI/1	5	36.05	90.66
XVII/1	5	824.58	87.64
XVIII/1	5	10.59	79.95

Table 6. Content of n-hexane extract (mg/100g of dry soil mass) in the surface soil layer, at a 5 cm depth (location Fig. 7)

No. of samples	Content of n-hexane extract (mg/100 g of soil D.M.)	Moisture %
1	3475	71.48
2	n.d	30.66
3	n.d	82.98
5	n.d	34.60
6	n.d	5.77
8	n.d	23.64
10	n.d	32.02
11	n.d	76.90
12	3116	19.27
13	8820	78.03
14	15100	65.64
15	6230	56.97
16	n.d	26.67
17	51.54	24.06
18	n.d	21.92
19	255	60.48
20	521	56.25
21	11200	38.50
22	8670	59.50

n.d. - not detected

Table 7. Dustfall in the vicinity of Ny-Ålesund (June-July 1986) (location Fig. 4)

No of sites of dustfall measurement	Total dustfall kg/100 m month
a	0.47
b	0.16
c	0.05
d	0.14
e	0.21
f	0.21
g	0.59

Table 8. Chemical composition of surface freshwater in the vicinity of Ny-Ålesund (mean value ± SE range)

Elements compared	Water flowing up to Ny-Ålesund	Water in the surroundings of buildings and of sewer pipes	Water near the soild waste dump	Water polluted with oil	Water reaching the sea	Potable water	Norwegian standards for potable water
1	2	3	4	5	6	7	8
pH	eg)7.8±0.4 eg)7.3-8.7	7.6±0.1 7.2-7.9	7.8±0.3 7.2-8.2	7.4±0.1 7.0-7.6	7.3±0.1 6.8-7.6	7.3±0.1 7.1-7.5	9.0±8.5 -
electrolytic conductivity ../cm	34.00+4.90 24.48-40.80	67.30+11.41 28.56-107.75	- 77.88-1034.40	99.80+16.38 41.80-172.40	88.59+11.93 57.12-120.68	115.19+2.46 112.06-122.40	
ammonia nitrogen mg/dm^3	0.00 -	- 0.00-0.50	0.07+0.01 0.04-0.08	0.01+0.00 0.00-0.01	- 0.00-0.04	0.00 -	0.08
nitrite nitrogen mg/dm^3	0.00	0.00	0.00	0.00	0.00		
nitrate nitrogen mg/dm^3	0.00	- 0.00-1.80	0.60+0.23 0.00-1.20	- 0.00-6.00	- 0.00-5.40	0.22+0.13 0.00-0.50	2.5
phosphate mg/dm^3	- 0.00-0.03	0.04-0.02 0.00-0.12	0.04-0.01 0.02-0.06	0.19+0.02 0.00-0.20	0.11+0.07 0.00-0.55	0.00 -	-
alkalinity $mval/dm^3$	0.33+0.08 0.25-0.50	0.54+0.08 0.50-2.25	1.52+0.34 0.50-2.25	1.01+0.2 0.35-2.10	0.88+0.07 0.50-1.20	0.99+0.07 0.90-1.10	-

total hardness $mval/dm^3$	0.47+0.03 0.42-0.50	0.76+0.11 0.56-1.40	9.33+3.37 0.70-20.00	1.30+0.21 0.66-2.40	1.68-0.79 0.46-6.00	1.11+0.15 1.08-1.64	-
calcium mg/dm^3	5.73±1.18 4.00-8.00	9.31±1.88 6.00-20.00	134.13±47.04 7.20-256.00	16.36±3.13 4.80-33.60	12.06+3.06 0.80-25.20	17.30+2.52 12.00-22.00	-
magnesium mg/dm^3	3.73+0.87 2.00-4.80	6.00-0.70 2.80-8.40	- 6.40-144.00	9.64+1.63 2.40-17.20	- 4.40-94.80	9.70-0.73 9.00-11.60	10
sulphate mg/dm^3	18.29+5.33 9.60-28.00	21.53+4.57 6.72-44.16	- 5.96-196.00	21.71+2.78 12.48-35.52	34.72+10.38 7.68-81.60	16.75+3.82 10.52-27.84	100
chloride mg/dm^3	5.72+0.24 5.96-5.25	4.99+0.57 4.16-8.02	18.96+1.95 12.99-21.80	5.72+0.31 3.91-6.96	11.98+5.21 4.19-37.63	8.70+1.41 5.96-11.93	100
number of samples	3	7	3	9	7	4	
no. of samples location Fig. 3	1, 2, 3	6, 13, 14, 17, 18, 19, 20	12, 23, 24	4, 5, 9, 10, 21, 25, 26, 30, 31	7, 8, 11, 22, 27, 28, 29	15, 16, 32, 33	

Table 9. Chemical composition of sewage (mean value±SE, range) and of surface water beneath the outlet of sewer ditch (30.06.1986)

Elements compared	sewage	Sites of sea-water sample collection at various distance from coast line: 1 m, distance from sewer outlet:				3 m	10 m	"zero samples" from Kolhamna	concentration range in domestic sewage in USA (Todd 1970)	sewage of the Polish Polar Station (Krzyszowska 1985)	Norwegian standard for industrial (Retningslinjer 1983)
		along the direction of sewer outlet	15 m to the East	15 m to the West	60 m to the East	along the direction of sewer outlet					
1	2	3	4	5	6	7	8	9	10	11	12
pH	6.9-8.4 7.7±0.2	7.5	7.7	7.7	7.8	7.7	7.9	8.2	-	5.4-9.1 7.2±0.5	6.5-10.0
electrolitic conductivity µs/cm	350.88-672.36 561.81±34.17	11016.00	8976.00	9720.00	6120.00	8568.68	10200.00	-	-	-	-
ammonia nitrogen mg/dm^3	2.24-59.02 28.09±5.48	3.85	0.02	0.87	0.01	2.75	0.04	0.01	15.0-50.0	-	30.0
nitrite nitrogen mg/dm^3	0.00-0.25	0.07	0.01	0.01	0.00	0.03	0.00	0.00	0.0-0.10	-	10.0
nitrate nitrogen mg/dm^3	0.00-2.00 0.76±0.18	0.52	0.05	0.05	0.05	0.25	0.00	0.50	0.10-0.40	0.01-14.80 1.61±0.50	100.0
phosphate mg/dm^3	0.50-28.00 14.14±2.49	1.24	0.11	0.46	0.00	1.09	0.02	0.00	-	0.07-1.20 0.10±0.05	-
alkalinity mval/dm^3	2.80-6.50 4.48±0.41	2.87	1.50	1.80	2.00	1.60	1.50	1.45	-	-	-
chloride mg/dm^3	10.15-20.02 16.64±1.10	-	-	-	-	-	-	-	15.0-175.0	0.38-1.98 1.30±0.08	2500.0
salinity ‰	-	11.2	8.0	9.0	5.5	7.0	9.0	25.0	-	-	-
sulphate mg/dm^3	76.80-528.00 242.09±48.32	-	-	-	-	-	-	-	-	-	300.0
total hardness mval/dm^3	2.00-7.00 4.06±0.42	-	-	-	-	-	-	-	-	-	-
calcium mg/dm^3	4.00-68.00 27.60±5.13	-	-	-	-	-	-	-	-	-	-
magnesium mg/dm^3	2.40-72.00 32.16±5.70	-	-	-	-	-	-	-	-	-	

Table 10. Temperature of sewage and surface of sea water (07.11.1986) beneath the outlet of sewer ditch

Time (hours)	Temperature °C				Wind	
	Sewage	Sea water, 0.5 m from coast line			direction	velocity m/s
		along the outlet	5 m to the West from the outlet	5 m to the East from the outlet		
4:30 pm	17.2	6.8	6.5	6.8	N-S	3.5
5:00 pm	20.2	6.8	6.5	6.6	N-S	3.5
5:30 pm	27.0	7.0	6.0	6.0	N-S	3.5
6:00 pm	26.8	6.4	5.6	5.6	N-S	2.5
6:30 pm	22.4	5.9	5.8	5.6	N-S	2.0
7:00 pm	22.2	7.4	6.2	6.2	N-S	1.0
7:30 pm	23.0	6.2	6.6	6.1	N-S	1.0
8:00 pm	21.4	6.2	6.2	6.2	N-S	1.0
8:30 pm	21.0	5.6	5.6	5.8	NW-SE	1.0
9:30 pm	18.0	6.0	6.0	4.8	W-E	1.0
10:00 pm	20.8	12.0	5.8	6.0	W-E	1.0

Table 11. Quantity of **Coli** bacteria in sewage and in surface of sea water beneath the outlet of sewer ditch

No of samples (location Fig. 8)	Date hours	Wind velocity direction	Quantity of Coli bacteria in 1 ml of surface water, sewage after 48 h incubation at 37°C
I	3.07. 11:00 am	1 m/s NE-WS	$3.7 \cdot 10^{6}$
II	3.07. 11:05 am	1 m/s NE-WS	$2.1 \cdot 10^{3}$
III	11.07. 2:30 pm	1 m/s N-S	$2.6 \cdot 10^{5}$
IV	11.07. 2:40 pm	1 m/s N-S	$2.4 \cdot 10^{4}$
V	17.07. 6:30 pm	4 m/s N-S	$3.5 \cdot 10^{1}$
VI	17.07. 6:40 pm	4 m/s N-S	$4.0 \cdot 10^{1}$

Table 12. Some properties of soil samples (location Fig. 4)

No of sample	Moisture %	pH	electrolitic conductivity µs / cm
1	15.4	8.4	110
2	85.6	6.7	1150
3	91.2	6.8	350
4	90.9	6.3	600
5	88.8	6.5	850
6	17.7	8.5	134
7	22.5	8.6	300
8	16.3	8.1	889
9	11.9	8.1	430
10	40.2	8.0	85

Table 13. Cross-section through roads, paths in the vicinity of Ny-Ålesund (location Fig. 10)

No of section	1	2	3	4	5	6	7
landform	sea terrace 4 m a.s.l	sea terrace 3 m a.s.l.	coastal embankment 1 m a.s.l.	sea terrace 18 m a.s.l.	sea terrace 6 m a.s.l.	sea terrace with landship 40 m a.s.l.	sea terrace 7 m a.s.l.
lithological characterization of soils	coarse sand, sharpedged gravel	sand, sharpedged gravel	fine sand with metamorphic stones	coarse sand, sharpedged gravel	coarse sand, sharpedged gravel	clayey sand	gravel, sand
vegetation community	luzulion arcticae (Elvebakk 1985) (Saxifraga oppositifolia, Cetraria delisei)		luzulion arcuatae with lichens (Elvebakk 1985)		Deschampsia alpina with mosses	Deschampsia alpina (Brattbakk 1981)	Deschampsia alpina (Brattbakk 1981)
intensity of use	trampling, permanent used by vehicles	trampling only	trampling, used by vehicles (sometimes)		trampling only	trampling, permanent used by vehicles	
width of disturbed area total (cm)	830	550	300	450	265	810	350
depth of track maximum (cm)	8	6	10	5	4	30	1

Table 14. Plant species occuring on roads, foot paths and adjacent to them (location Fig. 10)
(+ present, - absent, D - dominant)

	Cross-section I		Cross-section II		Cross-section III	
	Road	Adjacent to road	Road	Adjacent to road	Road	Adjacent to road
Total cover of plants %	5	80	50	90	3	90
1	2	3	4	5	6	7
Equiestum arvense	-	-	D	-	-	+
Salix polaris	+	-	-	+	-	D
Oxyria digyna	+	+	-	-	-	-
Polygonum viviparum	+	-	-	+	-	-
Sagina intermedia	+	+	+	-	+	+
Stellaria crassipes	-	-	-	+	-	-
Cerastium regeli	+	+	+	-	-	-
Cerastium arcticum	-	-	-	-	-	+
Silene acaulis	-	+	-	+	-	-
Cardamine bellidifolia	-	+	-	-	-	-
Cochlearia officinalis	+	+	-	-	-	-
Draba lactea	+	+	+	+	-	-
Saxifraga oppositifolia	-	+	+	D	-	D
Saxifraga cernua	+	+	+	+	-	-
Saxifraga hyperborea	-	-	-	-	+	+
Saxifraga cespitosa	-	+	+	+	+	D
Saxifraga hieracifolia	-	-	-	-	-	+
Pedicularis hirsuta	-	+	-	+	-	-
Juncus biglumis	-	-	D	+	-	-
Luzula confusa	-	-	-	-	-	+
Luzula arctica	D	D	-	D	-	-
Phippsia algida	+	-	-	-	D	D
Deshampsia alpina	-	-	D	+	-	-
Poa alpina	+	-	+	-	-	+
Colpodium vahlianum	-	-	-	+	-	-
Festuca rubra	-	+	+	-	-	-
Anthelia juratzkana	-	-	-	-	-	+
Aneura pinguis	+	+	+	+	-	-
Aongstroemia longipes	-	-	+	-	-	-
Aulocomnium turgidum	-	D	-	D	-	-
Blepharostoma trichophyllum	-	-	+	-	-	-
Bryum sp.	D	+	+	+	+	+
Catoscopium nigritum	+	-	+	+	-	-
Distichium inclinatum	+	-	D	+	+	-
Drepanocladus badius	-	-	-	+	-	-
Drepanocladus revolvens	D	+	+	+	-	-
Drepanocladus uncinatus	D	+	-	+	-	D
Jungermannia sp.	-	-	+	-	-	-
Kiaeria sp.	-	-	-	-	-	+
Omphalina sp.	-	-	-	-	+	-
Oncophorus wahlenbergii	+	D	-	-	-	-
Oncophorus virens	-	+	-	-	-	-
Orthothecium strictum	+	+	-	+	-	-
Philonotis tomentella	+	+	-	+	-	-
Plagiomnium ellicticum	-	-	-	-	-	+
Pohlia cruda	+	-	-	-	-	+
Pohlia nutans	-	-	-	-	-	+
Polytrichum alpinum	+	-	-	+	-	+
Pottia heimii	-	-	-	-	D	-
Ptilidium ciliare	-	-	-	+	-	-
Scorpidium turgescens	-	-	+	-	-	+
Tayloria lingulata	-	+	+	+	-	-
Timmia austraica	+	+	+	-	-	-
Cetraria delisei	-	+	-	D	-	+
Cladonia macroceras	-	+	-	+	-	-
Cladonia pocillum	-	-	-	+	-	-
Lecidea ramulosa	-	-	-	+	-	-
Ochlorechia frygida	-	-	-	+	-	+
Stereocaulon alpinum	-	-	-	-	+	+
Nostoc commune	-	-	+	+	-	-

Table 15. Granulometric composition of soil in cross-sections through paths and roads of Ny-Ålesund vicinity (location Fig. 10)

Soil sample collected	No of cross-section	Kind of ground	Percentage of fractions				
			Stone >25mm	Gravel 25-2mm	Sand 2-0.05mm	Dust 0.05-0.002mm	Clay <0.002mm
	I	sand, gravel aggregate	3	40	54	3	0
on	II	"	3	50	44	3	0
	III	"	12	39	47	0	0
road	IV	"	12	51	37	0	0
	V	"	7	44	35	10	4
	VI	sand dust	0	0	60	33	7
	VII	sand gravel aggregate	0	51	44	5	0
mean value			5	39	46	8	2
	I	sand gravel aggregate	4	66	30	0	0
adjacent	II	"	1	42	51	6	0
to	III	"	43	43	28	29	0
road	IV	"	24	40	36	0	0
	V	"	11	68	20	1	0
	VI	sand dust	0	0	49	43	8
	VII	sand gravel aggregate	3	43	50	4	0
mean value			12	43	38	12	1

Table 16. Mean moisture, bulk denisty, premeability of ground, thaw depth of frozen ground along cross-section through paths, roads (location Fig. 10)

No of cross-section	I		II		III		IV		V		VI		VII	
	road	road-side	road	road-side	road	road-side	road	road-side	road	road-side	road	road-side	road	road-side
plant cover %	to 5	80-100	40-60	80-100	to 3	80-100	to 50	to 80	to 5	80-100	to 10	to 80	0	to 80
moisture %	34.5	17.3	28.0	16.0	27.7	29.8	4.6	22.5	16.0	25.0	25.3	16.9	17.4	24.9
bulk density G/cm^3	1.81	1.39	1.81	1.55	1.49	1.25	1.67	1.27	1.66	1.37	1.84	1.89	1.67	1.48
thaw depth cm	97.4	91.5	96.0	95.3	121.3	115.6	–	–	92.2	90.3	88.3	83.0	99.0	92.3
permeability $cm/s \cdot 10^{-3}$	–	–	–	–	–	–	1.4	6.9	5.7	7.1	–	–	–	–

Table 17. Quantities of solid waste in some Arctic Stations

Stations	Waste quantity kg/head . 24 h	References
Polish Polar Station Hornsund, Svalbard	0.12	Krzyszowska 1986
construction camp at Alaska	2.3 - 3.6	Smith 1977
construction camp at Alaska	0.3 - 2.6	Grainge 1973
Norwegian Polar Station, Ny-Alesund Svalbard	0.5 - 1.2	

Table 18. Quantities of sewage in some Arctic Stations

Stations	Sewage quantity dm^3/head . 24 h	References
Polish Polar Station Hornsund, Svalbard	42	Krzyszowska 1985 a
Construction camp at Alaska	178 - 318	Smith 1977
Artificial Islands (Mackenzie Bog)	108	Smith 1977
Station at Prudhoe Bay	132 - 204	Smith 1977
Norwegian Polar Station, Ny-Alesund, Svalbard	209