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AIR POLLUTION AND ITS BIOLOGICAL EFFECTS IN ÅRDAL, NORWAY, PART I.

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POSTBOKS 130, 2001 LILLESTRØM
NORGE

ISBN 82-7247-425-5

SUMMARY

This report summarizes data concerning air pollution and its biological effects gathered in the region surrounding the aluminium factory at Årdal. In some cases data spans 30 years.

Årdal has a rough topography, with high mountains that fall straight to sea level. These "canyons" have little sun in the winter and are excellent traps for air pollution. The climate ranges from mild coastal to high mountain. The region includes parts of the Jotunheimen National Park with its spectacular waterfalls and very old forests.

The community of Årdal has had a population of circa 6000 since 1970, as compared to ca. 2000 in 1946. Currently 53% of Årdal's working population works for the aluminum factory, A/S Årdal og Sunndal Verk.

The history surrounding the growth and development of the Årdal factory is traced from 1940 to the present. A/S Årdal og Sunndal Verk operates two facilities at Årdal: 1) the aluminum smelter at Øvre Årdal, and 2) the harbor, warehouse and electrode paste production plant at Årdalstangen. Emissions, air pollution control equipment and production facilities are all described. Production has increased from around 10 000 metric tons in 1949 to a high of 180 000 metric tons per year in 1979. Emissions have gone down from 50-60 kg/h fluoride in the 40's and 50's to 30-35 kg/h in the 80's.

The monitoring program for air pollution initiated in 1967 by the Norwegian Smoke Control Council measures yearly, the fluoride content of conifer needles, fruit tree leaves, pasture grass and hay, and animal bones are sampled and analyzed.

The actual measured fluoride levels in all plant and animal species show a general decline in levels as can be expected

from the known decline in emissions. There is however, no observable direct correlation between emissions and fluoride content of leaves and needles. The fluoride content in different plant species do not necessarily correlate with each other. Fluoride accumulation in plants is influenced by other factors as well.

What effects air pollution can be expected to have and why, followed by what has been actually observed in the area is described. Injury, especially in fruit trees, has not always correlated with the measured fluoride content in leaves. This may be indicative of interaction of other factors, possibly other pollutants. However, fluoride levels in bones of farm animals has correlated fairly well with measured fluoride levels in grass and hay.

Air pollution, in addition to its effect on farming and forestry, has affected the environment and man. A full description is given of what is known or measured of the factory's impact on: 1) the local flora and fauna, 2) the Vettismorki area, 3) garden plants, 4) water resources, 5) man's health, 6) sociological factors, 7) man's feeling of well-being. Injury to the natural environment has in some cases (especially the Vettismorki area) been demonstrated.

Finally, interesting topics for future research are suggested and modifications to the monitoring program are offered.

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AIR POLLUTION AND ITS BIOLOGICAL EFFECTS IN ÅRDAL, NORWAY PART I

1. INTRODUCTION

The aluminum industry has been an important part of the Norwegian economy for many years. In the early 1930's, however, came the first report of fluorosis in farm animals around an aluminum factory (Slagsvold, 1934). But it was not until the great expansion of the 1950's that the full extent of the problem was realized. Following preliminary investigations by professor F. Ender and others, the Norwegian government, in 1967, began a monitoring program that regularly measures fluoride in vegetation and farm animals around all the aluminum factories.

Therefore the State Pollution Control Authority (Statens forurensingstilsyn - SFT) asked the Norwegian Institute for Air Research (NILU) to review and summarize all the available information on emissions, pollution and biological effects of emissions surrounding the factories. The tremendous amount of information made it necessary to first focus on one factory - Årdal. This aluminum smelter has been in operation since 1948 and has undergone several stages of expansion and reconstruction. The main aluminum production facilities are at Øvre Årdal, whereas storage and anode production are situated at Årdalstangen.

Data collected for this project originate from two main sources: 1) before 1967 by Professors F. Ender and J.L. Flatla, and 2) after 1967 by Professors H. Robak, J.L. Flatla, Dr. R. Horntvedt and Professor M. Aas Hansen.

In order to increase the readability and usefulness of this work, the report has been divided into two parts. Part I is a generalized overview. Part II contains detailed text, tables and figures in the form of Appendices. It is hoped that this report will allow further decisions concerning emission levels to be based on a comprehensive knowledge of measured effects.

2. ÅRDAL'S NATURAL SETTING

2.1 Topography

Årdal is a municipal division within the county of Sogn og Fjordane. The district lies at the end of the Årdalsfjord in the innermost section of the Sognefjord (Figure 1). To the northeast of the fjord stretches a long valley, with the long slender lake, Årdalsvatn at its bottom. Mountains line both sides of the fjord and valley, reaching heights of 1200 to 1600 meters above sea level. Parts of the mountain formation, Jotunheimen, lies in the northeastern corner of the municipal division. The tall mountain Store Skagestølstind, over 2400 m high, lies to the north.

The name Årdal means, in fact, river valley. It is a region that is extremely rich in water resources. 198 lakes and ponds lie within the boundaries of the municipal division. The rivers and streams of the watershed ultimately collect in the largest lake in the area, Årdalsvatn. The lake lies at 5 m above sea level and is 13 km^2 (9 km long, 186 m deep).

Årdalstangen, with ca. 2000 inhabitants, lies 1 km to the southwest of the lake. To the northeast lies Øvre Årdal with ca. 4000 inhabitants.

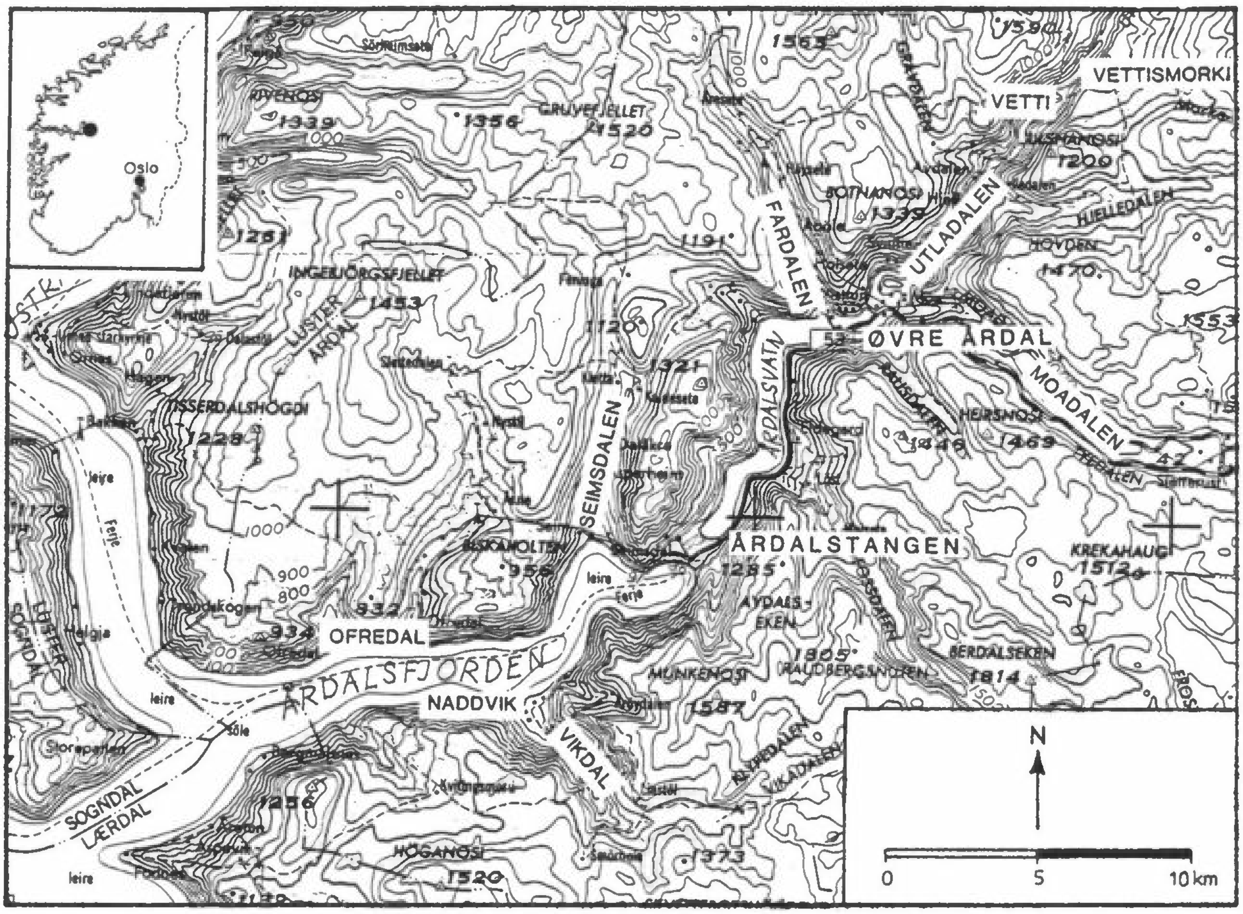


Figure 1: A topographical map showing the region surrounding A/S ÅSV, Årdal Verk.

North and east of Øvre Årdal, the main valley splits into three: Fardalen towards the northwest, Utladalen to the northeast, and Moadalen to the east. Far up the Utladalen valley lies Vetti. It is here, more specifically in Vettismorki that one of the oldest forests in Norway can be found. Some trees are thought to be over 800 years old. It is also here that Vettisfossen, one of Norway's most beautiful waterfalls, cascades 370 m down (of which 275 m are in free fall).

Two narrow valleys cross to the north of the Årdalfjord, inner and outer Ofredal. The conditions for forestry and farming are good here. Likewise to the south of the fjord crosses another farm-rich valley, Vikadalen, where the community of Naddvik lies (around 100 inhabitants). As one approaches Årdalstangen yet another valley cuts to the north, Seimsdalen. Seimsdalen is richer in sunlight than many other areas in the region and its 300 inhabitants are primarily farmers (including fruit tree farmers). The innermost part of the valley is a popular public area both in summer and in winter.

2.2 Meteorology

Årdal's climate ranges from mild coastal to cold high mountain in type. It is characterized by mild, short winters. With increasing altitude, temperatures fall, rain is replaced by snow and the winter season is considerably longer.

Despite its wealth of water resources it is not a region especially high in precipitation relative to the rest of Sogn and Fjordane. Not unexpectedly, however, precipitation increases at higher altitudes so that Vetti has 30 to 50% more precipitation than Øvre Årdal (Figure 2). Between 1967 and 1982 the driest years (precipitation during the growing season) were in 1968 and 1972. The wettest year was 1979.

Part of the winter, due to the high mountains, the valley bottom is without sun at all. On the western side of the region direct sunlight is lacking for 20 weeks of the year. Årdalstangen is without sun 16 weeks of the year. Øvre Årdal even lacks afternoon and evening sun during the longest days of the year.

The main wind direction is along the fjord's axis. The winds are primarily from the southwest during the days, in summer, and from the northeast during nights in summer and during the winter (Figure 3).

Appendix A-I gives a more detailed description of measured meteorological conditions in the Årdal region.

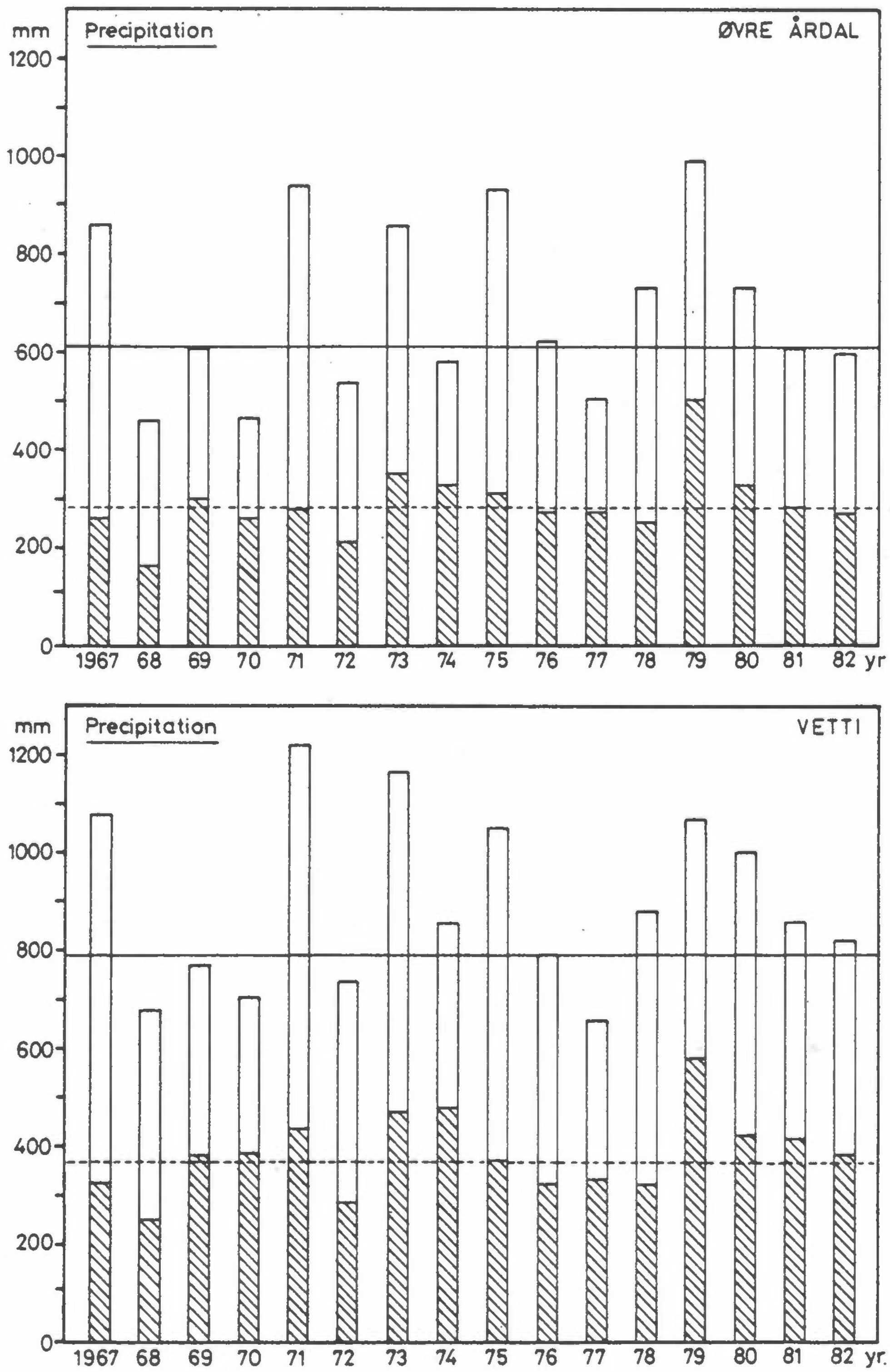


Figure 2: Precipitation in Øvre Årdal and Vetti (in Årdal). That portion of the precipitation falling during the growing season (from April 1 to September 30) is shaded. Average precipitation from 1967 to 1982 is indicated (solid line for total precipitation and dotted line for precipitation during growing season). Source: Norwegian Meteorological Institute.

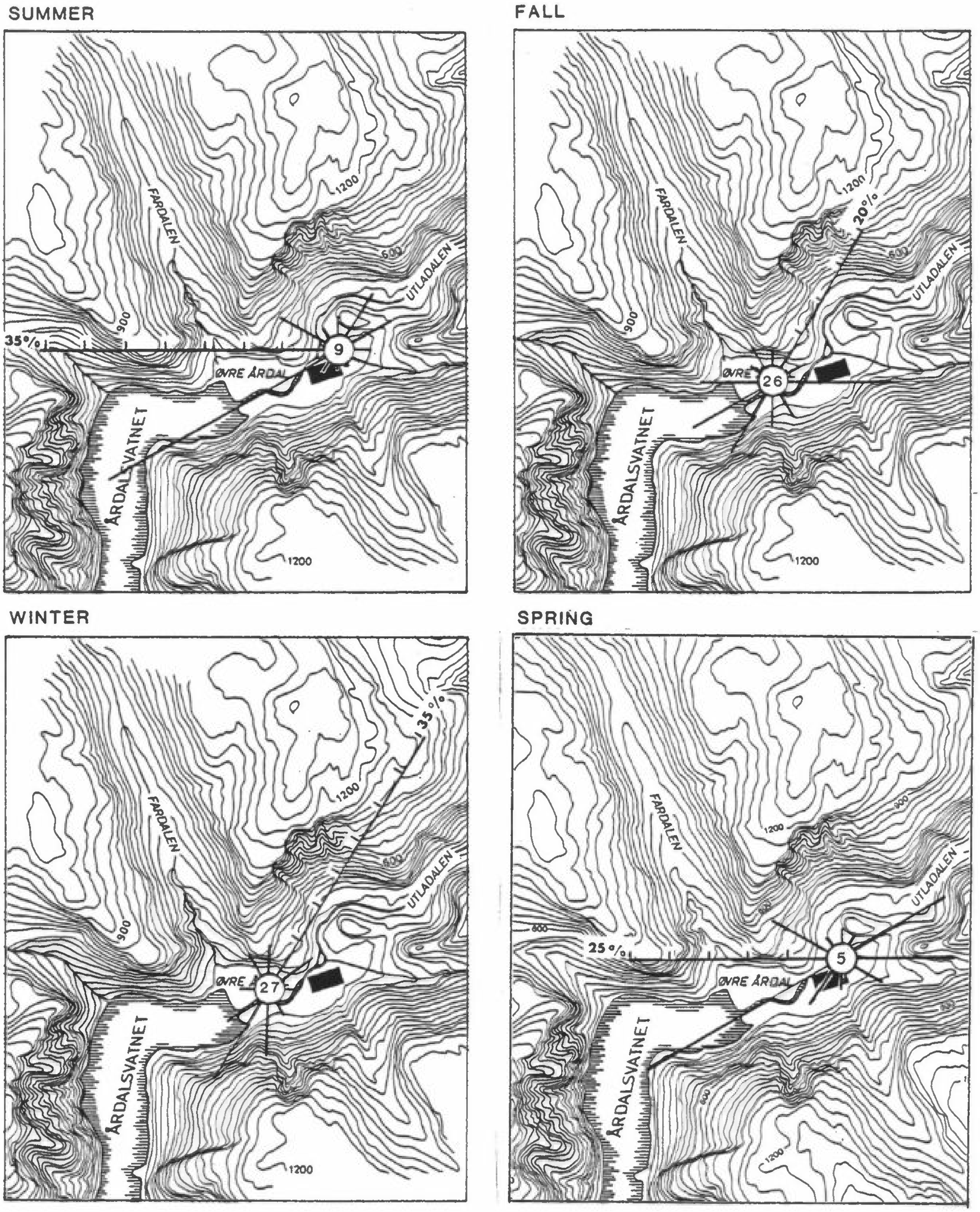


Figure 3: Windroses during the four seasons at Øvre Årdal during 1972-1973. The frequency of calm weather (%) is given in the circles. In the summer winds are primarily from the southwest and in the winter from the northeast. Source: Semb et al., 1975.

2.3 Flora and fauna

The flora and fauna of Årdal is fairly representative for inner western Norway. A partial listing of flora and fauna in Årdal can be found in Appendix A-II.

The flora is mainly determined by the slowly decreasing temperatures with increasing altitudes, and by the gravelly soil that is poor in humus. Such soil easily leads to dehydration.

The main conifer species is Scots pine (Pinus sylvestris). Deciduous forests consist mainly of birch (Betula pubescens, B. pendula) with trembling aspen (Populus tremula) and mountain ash (Sorbus aucaparia) as minor species. Increasing areas of deciduous and pine forests are afforested with Norway spruce (Picea abies). Because conifers are of much greater economic importance for the owners, and because they are more sensitive to fluoride than deciduous trees, they are the only group that are regularly controlled for fluoride levels. Figure 4 shows the location of the major forest types in the region.

Red deer, fox, mice and lemming can be regularly found in Årdal. Other mammals are occasional visitors, such as roe deer, domestic reindeer and moose. The birds of Årdal include: ptarmigan, capercaillies, black grouse, duck, black-throated diver, raven, buzzard, and owl.

3. ÅRDAL'S POPULATION

Prior to the factory, the people of Årdal have lived by farming, fishing and hunting. In 1860 the community separated into a separate municipality whose population totalled 1700 people. This number sank during the 1870's due to massive (outward) emigration.

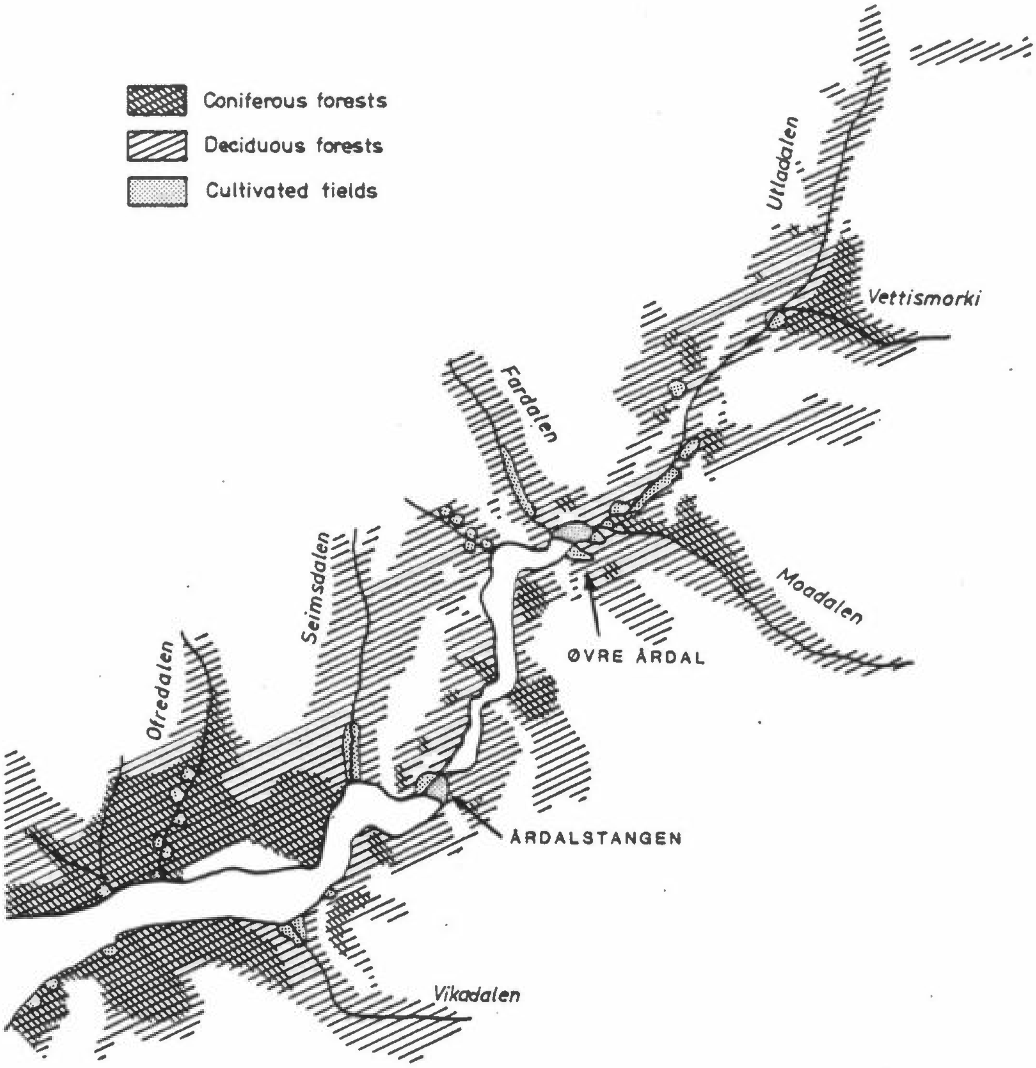


Figure 4: Location of major vegetation types around Årdal.
Source: Ve, 1971.

However, Årdal was very well situated for the development of hydroelectric power. Lake Tyin is situated at an elevation of 1100 m. the combination of large amounts of water and sizeable elevation drops laid the ground work for industrial development in Årdal.

Building and development of the hydroelectric power station began in the river Tya in 1910. The Norwegian Company Norsk Hydro took over in 1911. As building did not proceed too rapidly, labor needs were for the most part covered by the inhabitants themselves in the form of extra work. Some farmland was bought up and many local farmers did only part-time farming in this period. Some labor and engineers were brought into the region. In 1934 summer time road connections were opened up.

When the second world war broke out, the power station was nearly completed. The Germans concentrated on using the power for aluminum production. Labor was brought in from the whole country together with German prisoners from other countries.

In 1946 the parliament decided to pursue the plans for aluminum production and workers were hired. This decision led to an import of labor from other areas of the country and to an increased use of farm land for industrial purposes, as well as housing, shops, schools and other services necessary in an industrial society.

During the span of 100 years the community changed from a society of 1700 people, 100% employed in farming or fishing, to one of 6600 people, 1890 of whom worked for the aluminum factory ÅSV (Figure 5). Whereas before people lived on the farms, they now for most part live in Årdalstangen (around 2000) and Øvre Årdal (around 4000 inhabitants). (Figure 6).

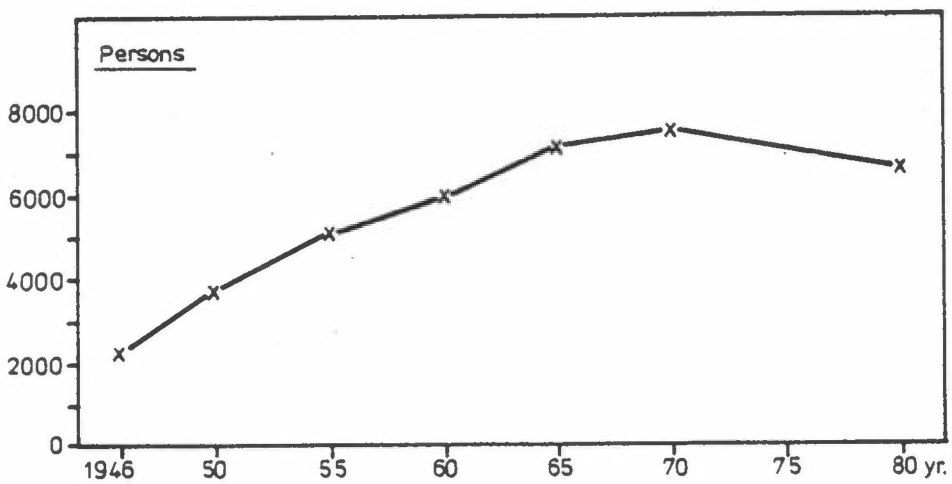


Figure 5: Changes in population size in Årdal since 1946.
Source: Årdalsprosjektet, No. 3, 1973.

In 1970, a large multi-institutional study was undertaken on living conditions in Årdal. This study, called the Årdalsprosjektet (1975) was divided into several parts covering various facets of living conditions in Årdal. Much information can be found in this report concerning population immigration, emigration and structure, (see Appendix G-III-b).

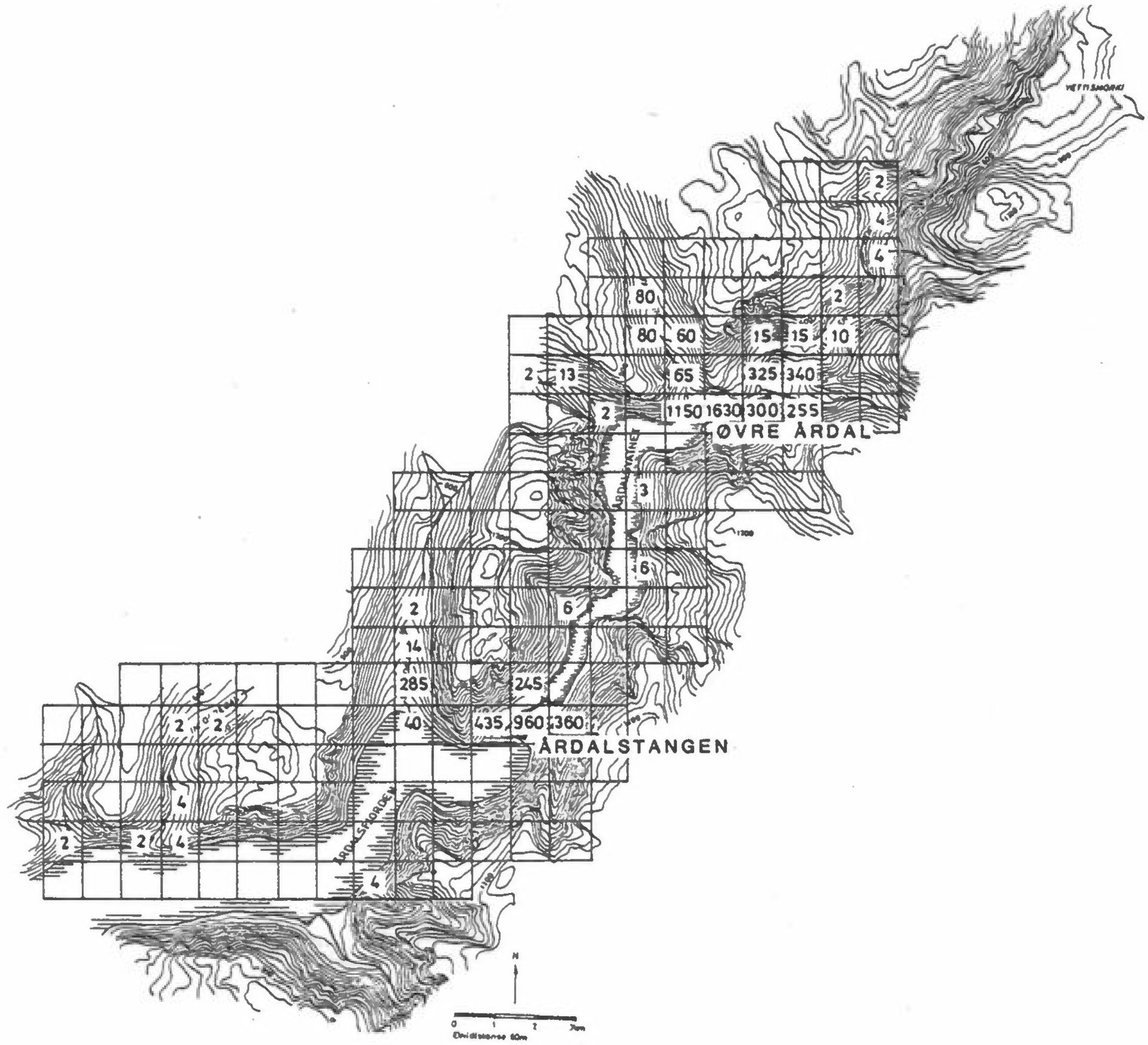


Figure 6: Estimated numbers of persons living in the Årdal region.
Source: Kommunehefta, Folke- og Bustadtelling, 1980.

4. THE ÅRDAL FACTORY

4.1 History and development

It was not until the second world war that the aluminum industry's importance grew, both in Norway and world-wide. The German occupation forces who arrived in 1940 had big plans for aluminum production in this country. Norway's large resources of hydro-electric power were particularly well-suited for this type of industry. They created two large share companies - Nordisk Lettmetall and Nordag. It was the latter that later formed the basis for Årdal Verk and finally A/S Årdal og Sunndal Verk (the company as it stands today). German plans called for building an aluminum oxide plant for 300 000 metric tons/year and smelters producing 170 000 metric tons aluminum per year spread over 11 regions in Norway. Actual building became confined to just a few areas, most importantly Årdal and Saudasjøen. By 1945 nearly 1 billion Norwegian crowns had been invested into the project. The building of the power station at Heirsnosi was nearly finished. Of the two electrolyses halls, planned for a yearly production of 24 000 metric tons, Hall A with its side building was nearly completed and the steel frame for Hall B was up.

The wharf at Årdalstangen was also nearly finished, but the construction of the storage facilities just begun. The road connecting Årdalstangen and Øvre Årdal had been completed during the war, and an electric power plant was already useable. With liberation A/S Nordag became property of the Norwegian State. The government decided in 1946 to pursue aluminum production at Årdal. Årdal I, hall A began manufacturing January 1948 with the first aluminum tapped in February 1948. 7 795 tons raw aluminum were produced during its first year. This increased to 9 890 tons in 1949. Figure 7 graphically presents Årdal's gradual development between 1948 and 1981. Årdal I, Hall B, began in 1950, increasing yearly production to 19 438 tons. Gradually as more and more ovens came into production manufacture increased to 28 625 tons by 1958. Årdal II began in 1959 causing production to make yet another major jump to 45 740 tons and to 63 000 tons in 1961. Årdal III began November 1961 and full capacity was reached in 1964 (109 000 tons per year). Thus, only 16 years after beginning operations, production had increased 14 times.

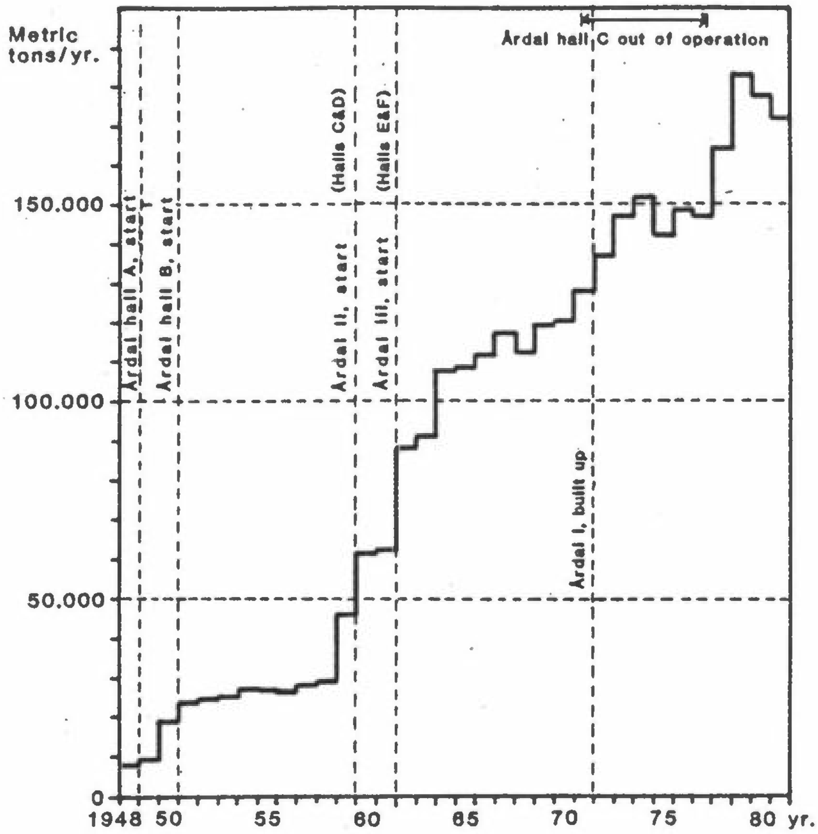


Figure 7: Yearly production of aluminum at ÅSV in Årdal since 1948. Values in metric tons per year.
Source: Yearly reports from Årdal og Sunndal Verk, 1972-1982, Årdal og Sunndal Verk, 1972.

The next big jump occurred in the 1970's. It was decided in 1967 to expand and modernize Årdal I, so that capacity was increased from 33 000 to 85 000 tons per year. Expansion took place in four steps and was completed in 1971. However, Årdal II, Hall C, was put out of operation at the same time reducing output relative to what it could have been during the early 1970's. When Hall C came back into production in 1977, production increased again, hitting a maximum in 1979 with 183 000 tons per year. In the two following years production decreased to 171 500 tons per year (ÅSV 1972-1982).

Figures 8 and 9 show aerial views of Øvre Årdal before and after the building of the aluminum smelter.

Årdal I, halls A and B, began in 1948,using Søderberg anodes. It was rebuilt in 1972 to use preprebaked anodes and closed electrolysis ovens. Årdal II, Hall C, began in 1959 with prebaked anodes (Verftwerk type), and open ovens. When it reopened in 1979 (it had been out of operation for 8 years) it used ordinary prebaked anodes with closed ovens. Hall D uses Søderberg anodes, but it is planned to shift them to prebaked anodes. Årdal III has used Søderberg anodes throughout. The ovens range from 128 000 to 150 000 A (Ampere).

Gases escaping from the ovens are trapped and purified by various kinds of air pollution control equipment. A certain amount of gas escapes into the halls and is emitted. Different gas purification systems have been used. The aluminum oxide dry absorption method is now favored. More detailed information can be found in Appendix C-I.

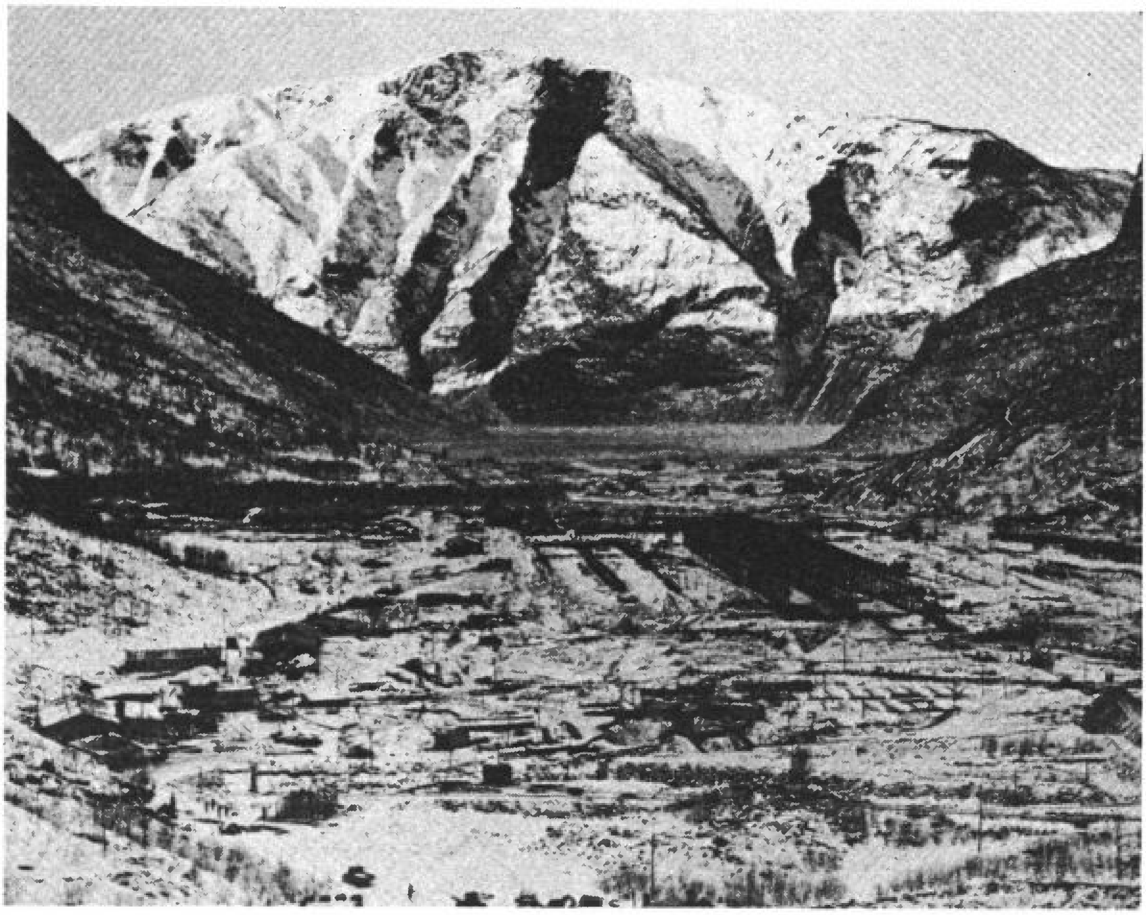


Figure 8: An aerial view of Øvre Årdal before the factory was completed.

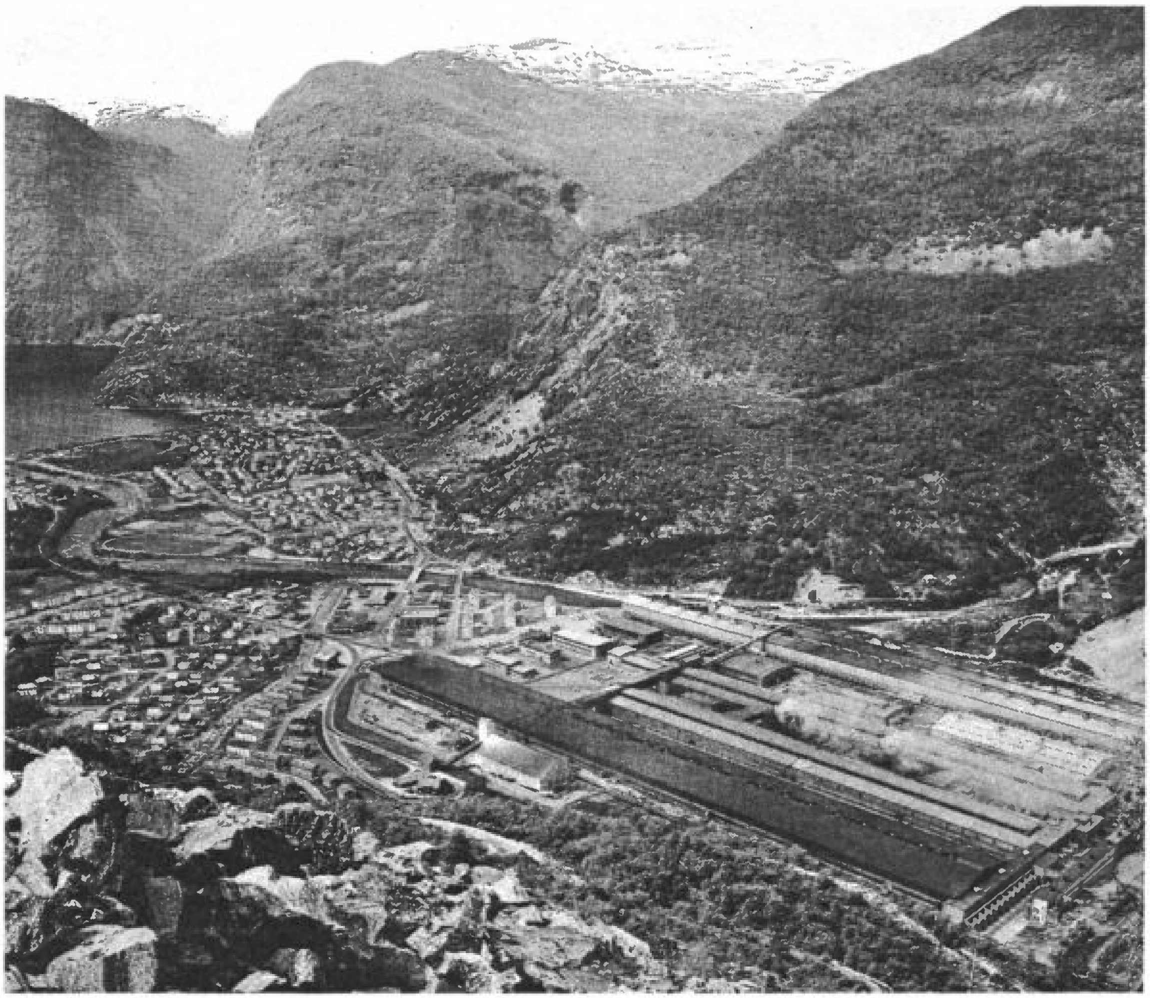


Figure 9: Aerial view of Årdal, I, II and III.

4.2 Air quality

The most important emissions resulting from the production of aluminum are:

- fluoride (both in gaseous and particulate form)
- sulphur compounds
- dust
- polycyclic organic material (POM)

Because of the impact of gaseous fluoride on plants and animals, fluoride compounds have, until recently, been considered of most concern.

There are two ways to view the impact of a major pollution source on air quality. One is to look directly at emissions, and the other is to measure ambient air for selected components. Figure 10 shows emissions at Øvre Årdal from 1964 to 1982 (earlier data considered too uncertain). However, based on observed injury, known production figures and estimated effectiveness of air pollution control equipment one can estimate earlier emissions to be: 50 to 60 kg F/h, yearly average for the 1950's and 45 to 60 kg F/h yearly average for the 60's. In the 1970's emissions have gone steadily down until 1975 and thereafter climbed until 1980.

The pollution control authorities requested in their license of December 1970 that emissions be reduced to 50 kg/h by the beginning of 1972 and to 40 kg/h by January 1981. Current emissions seem to be under these limits.

The chemical form of fluoride emissions (gaseous or particulate) is as important as quantity. In addition, it is necessary to consider the time of year during which the highest amounts are emitted. Figure 11 shows that although Årdal is not the only factory to have high emissions of hydrogen fluoride in Norway, it does emit the highest amount of fluoride in the gaseous phase, the form which causes the most injury to plants and animals. It can also be seen in this figure that more fluoride is emitted during the growing season than is indicated by the yearly average.

Fluoride emissions at Årdalstangen in 1981 were 0.3% those coming from Øvre Årdal (SFT, personal communication 1983) and are due to recycling of anode mass. In a recent study at Årdalstangen (Thrane, 1983) a site was placed to the north of the storage and production facilities. Northeasterly winds are coming from Øvre Årdal and southwesterly winds from the Årdalstangen facility. The results indicate that winds blowing from the northeast contain four times as much fluoride as do winds from the southwest.

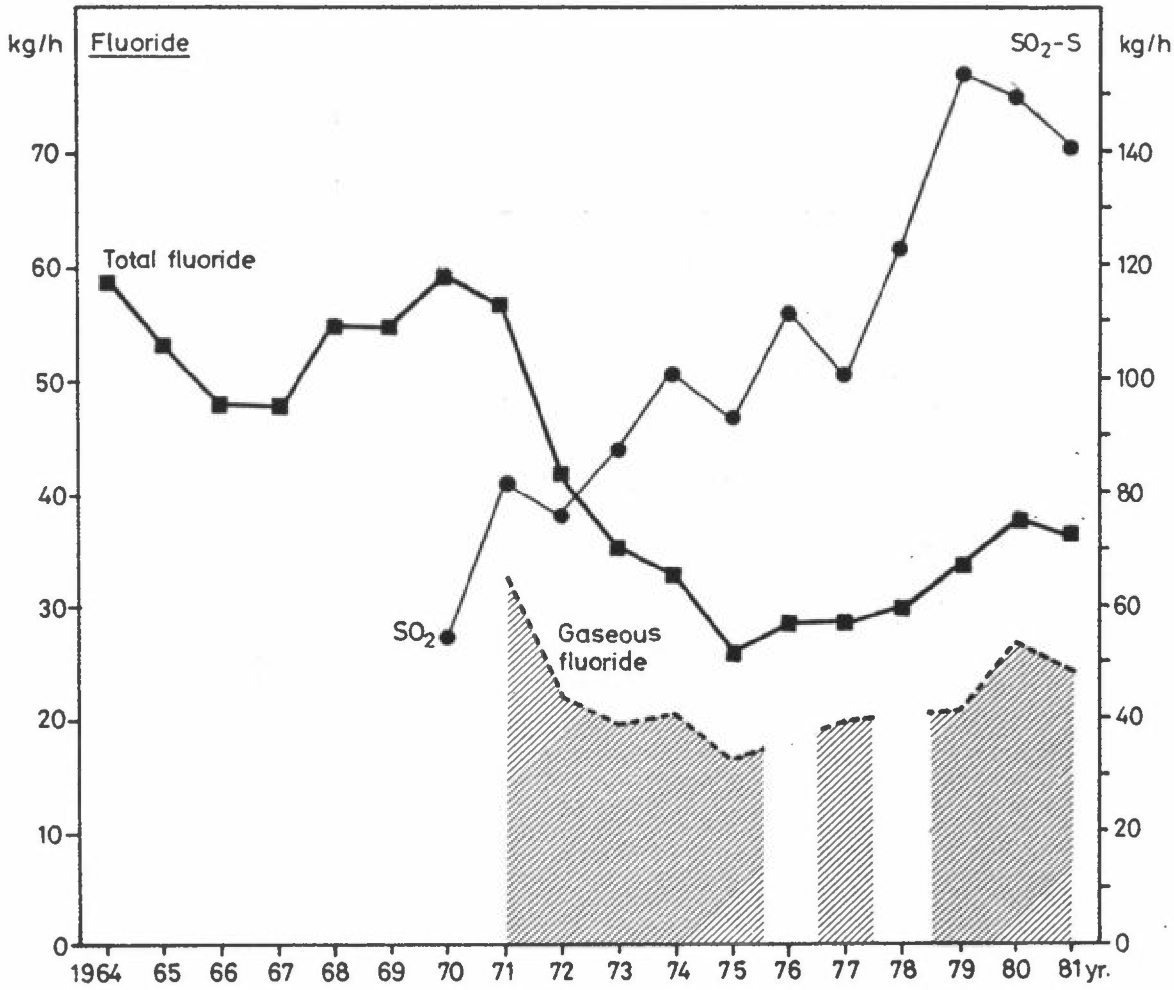


Figure 10: Fluoride and sulphur emissions (kg/h) from Øvre Årdal between 1964 and 1981. The part of total fluoride that escapes as gaseous hydrogen fluoride is shaded where data is available. Source: Yearly reports by Kontrollutvalget for aluminiumverkene, 1964 to 1981.

Regular measurements of fluoride, SO_2, and black smoke have been made in Øvre Årdal and Årdalstangen since 1973 (Hagen, 1972 to 1983). The results are summarized in Figure 12. Fluoride concentrations are higher in the winter than in the summer. Øvre Årdal has higher values than Årdalstangen.

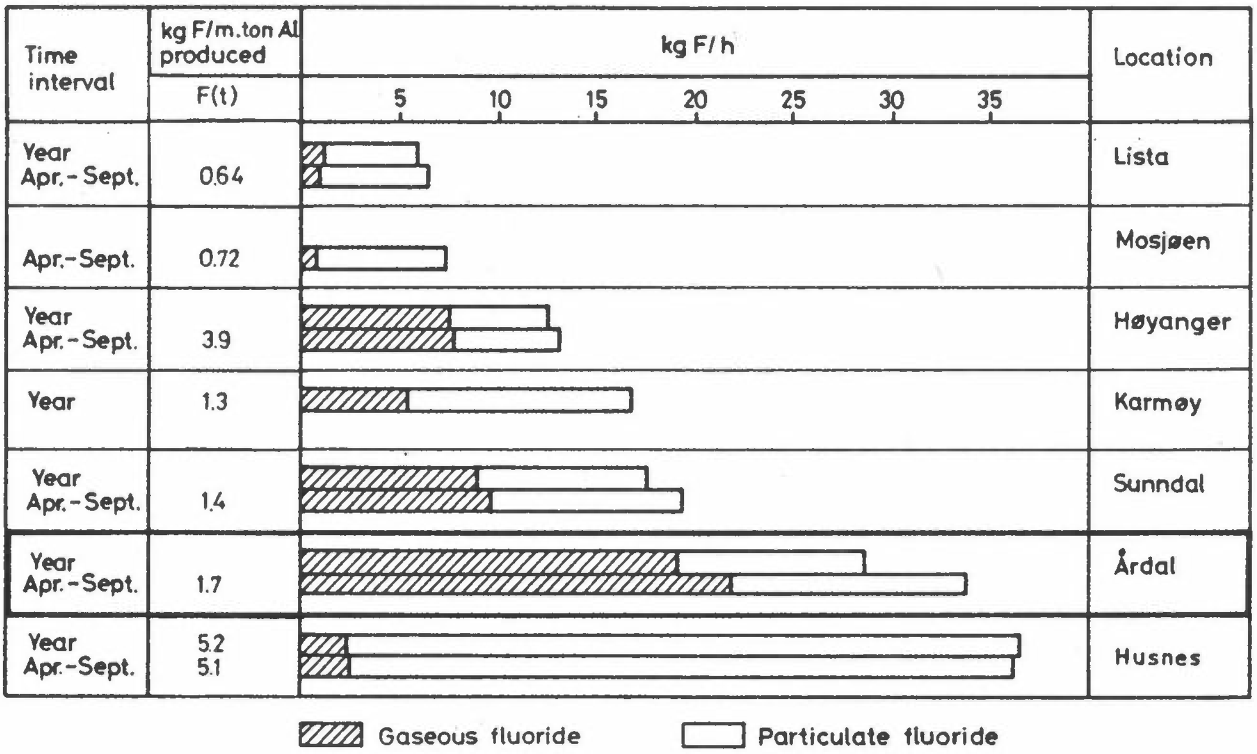


Figure 11: Hourly fluoride emission levels in 1977 at several aluminum factories. For each factory levels are shown as averages for the whole year and during the summer season.
Source: Yearly reports by Kontrollutvalget for aluminiumverkene.

Emission data from Årdal Verk show that SO_2 emissions have tripled between 1970 and 1980 going from 55 kg S/h to 150 kg S/h (Figure 10). Measured ambient sulphur (Figure 12) levels are higher in Øvre Årdal than Årdalstangen, and in winter than in summer.

Emissions of particulate matter from the electrolysis halls have been reduced. From 1970 to 1973 they sank from 280 kg/h to 120 kg/h. After 1973 they sank more slowly to under 100 kg/h. The bulk of these emissions comes from the roof ventilation system.

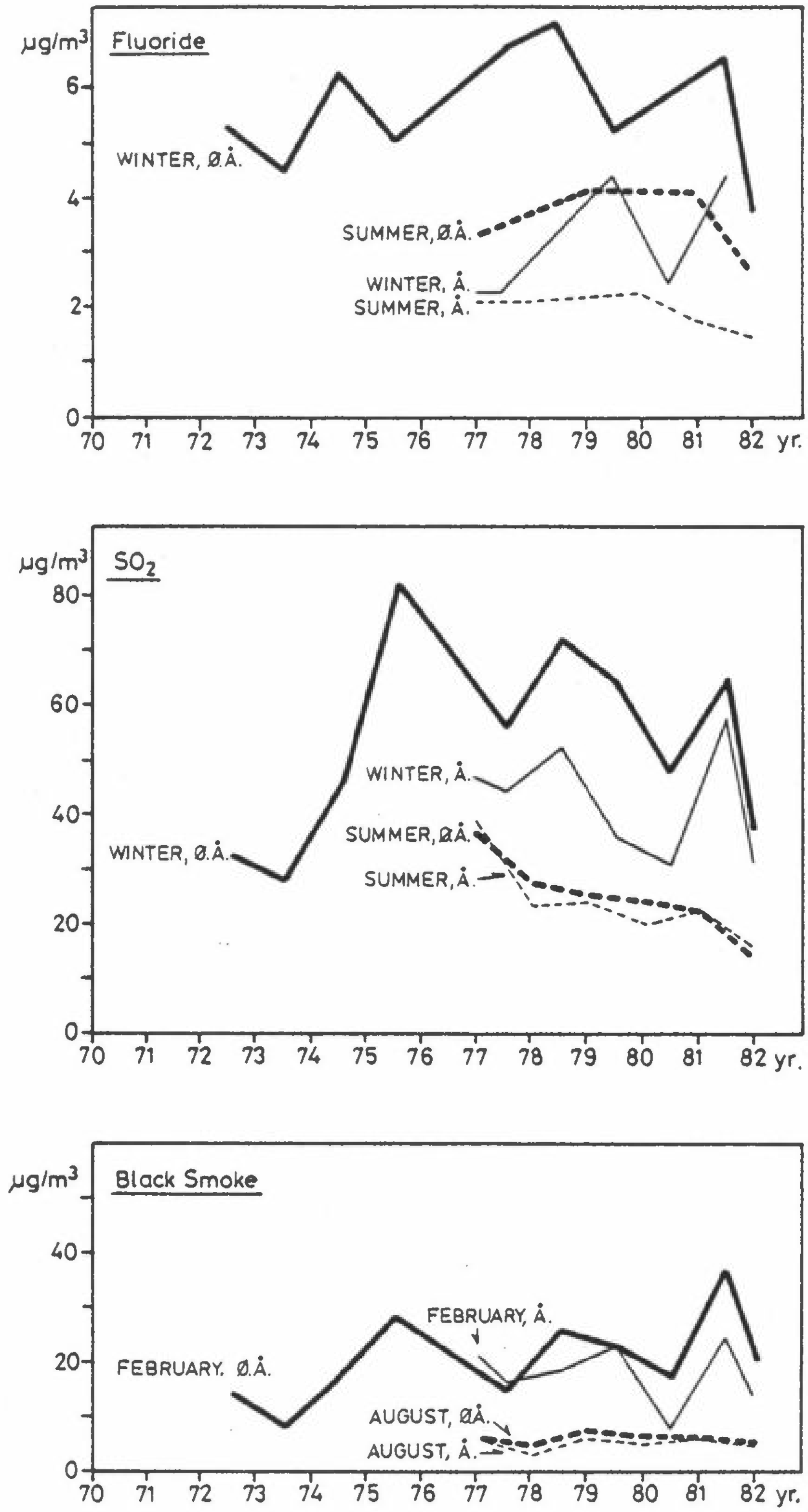


Figure 12: Measured pollution levels at Øvre Årdal and Årdalstangen between 1972 and 1981.
Source: Hagen, 1972 to 1983, Semb et al., 1975.

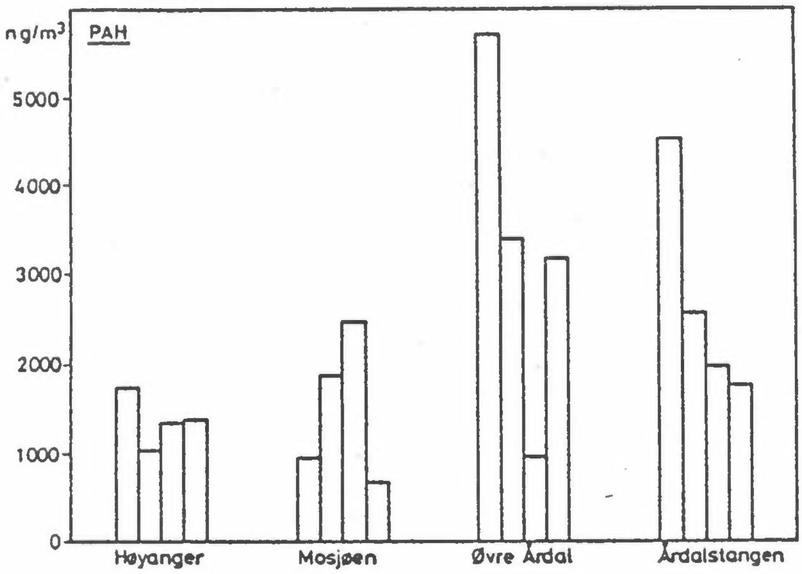


Figure 13: Average concentrations of total polyaromatic hydrocarbons for each season around four Norwegian factories. Results in the order: winter, spring, summer and fall.
Source: Thrane, 1983.

Emissions of particulate matter are an important problem at Årdalstangen where they are released during handling, transport and anode paste production. An earlier study (Hagen, 1972 - 1982) indicates that black smoke levels are fairly similar at both Årdalstangen and Øvre Årdal and higher in winter than in summer. A recent study, (Thrane, 1983), has shown that winds blowing over Årdalstangen from the northeast (thus Øvre Årdal) contain three times as much suspended particulates as wind from the southwest.

Polycyclic organic material (POM) (often referred to as polyaromatic hydrocarbons - PAH) have been measured both at Øvre Årdal and Årdalstangen. Measured values although fairly similar at the two sites are higher in Øvre Årdal. Levels in Øvre Årdal and Årdalstangen were higher than in Mosjøen or Høyanger (Figure 13). Levels are quite high, more than double the immissions resulting from traffic in a street canyon in Oslo (Thrane, 1983a and b, and Larssen, 1982).

More detailed information can be found in Appendix C-II and C-III.

5. THE MONITORING PROGRAM

5.1 General description

During the early years of operation, heavy air pollution, especially black smoke, lead to many complaints in Årdal as well as other towns with aluminum factories. The Norwegian Smoke Control Committee, created in 1956, was responsible for finding means to prevent damage to humans, plants, animals and materials. Following a recommendation to the Royal Norwegian Ministry of Industries and Handicrafts in May 1958, the Norwegian Smoke Control Council was appointed in 1961. It was decided in December 1965 to initiate a Monitoring Program that began operating in 1967. The program measured fluoride levels in: conifer needles, forage grass, bones of farm animals as well as deer.

Between the years of 1950 to 1965 the Chief Veterinary Office of the Ministry of Agriculture requested that the Department of Biochemistry of the Veterinary College of Norway (Oslo), regularly monitor fodder and animal health around three of the factories, one being Årdal. A yearly report was submitted and methods used documented. Animal health and fluoride exposure were monitored in various ways, but grass was systematically sampled and measured.

5.2 Methodology

5.2.1 Fluoride measurements

Between 1950 and 1965, fluoride levels were measured by the Department of Biochemistry of the Veterinary College of Norway using a distillation method.

In 1967, SINTEF (the foundation of scientific and industrial research of the Norwegian Institute of Technology, Trondheim) began doing the fluoride analyses. From 1967 to 1971 SINTEF used the Willard and Winter's method. In 1971, they switched to the SINTEF method, which uses the ion selective electrode. The details of these methods are discussed in Appendix D-I.

5.2.2 Sample collection

The following sections give a brief description of the methods used to gather samples prior to 1967 and in the monitoring program. A more detailed description of all these methods can be found in Appendix D-II.

Pasture grass and hay

Grass and hay are the two forage crops monitored. Fluoride content in forage has been used to estimate effect on farm animals. This has proven necessary since direct measurements on the animals themselves has been more difficult to do systematically. However, some caution is needed in interpreting grass and hay fluoride levels. Hay is a good indicator of winter feed as is grass when used for silo feed. Cows are not sent out much to graze in the fall so that it is doubtful how much they graze at the levels measured in September and October. Most animal husbandry is now restricted to sheep and goats. They are set free to graze in the mountains from July to September which limits their fluoride exposure.

Animal forage has changed very much in the last 30 years. Between 1956 and 1970, over all of Norway the use of:1) hay went from ~25% of total forage to ~10%, 2) pasture grass from ~35% to ~25%, 3) prepared feed from ~20% to ~40% and 4) silo grass from ~5% to ~20% (Hansen, 1972).

From 1950 to 1965, 10 kg grass samples were collected in paper bags, properly marked, from 28 sample sites on 12 farms. The same sampling sites were regularly used although samples were not collected from each site each year. Grass was to be sampled 3 times during the growing season from around the 25th of May to the 20th of October.

From 1967, the methodology for sampling collection was that drawn up by the Smoke Control Council. Briefly it consists of the following:

At least 0.3 kg hay is sampled after the hay has been brought into the barn. The hay is taken from several places in the store-room.

Pasture grass is sampled along a Z shaped line whose parallel lines are 30 meters wide and transverse connecting line 50 m long. Each sample consists of at least 1.0 kg. Sampling should not occur shortly after rain. Samples are taken at least 3 times during the summer once in May or June, once in July or August and a third time in September or October. The sites where samples are currently gathered are marked on Figure 14.

Both the hay and grass samples are stored in clearly labelled plastic bags (so that they need not be opened for identification) with sample species, station number and name, and date of collection.

Hay and grass are dried in a fluoride free drying chamber near, but not over 105^{0}C, for 18 hours. The dried samples are well mixed. 100 grams of each sample is sent to SINTEF in Trondheim, the rest of the sample is sent to the chemical laboratory at Årdal Verk. The samples are analyzed unwashed so as to be reflective of actual animal intake.

<u>Domestic farm animals</u>

Farming in the Årdal area consisted principally of dairy, sheep and goat farming prior to the arrival of the aluminum factory. Shortly after ÅSV began operations in 1948, local farmers began to complain of a host of health problems in

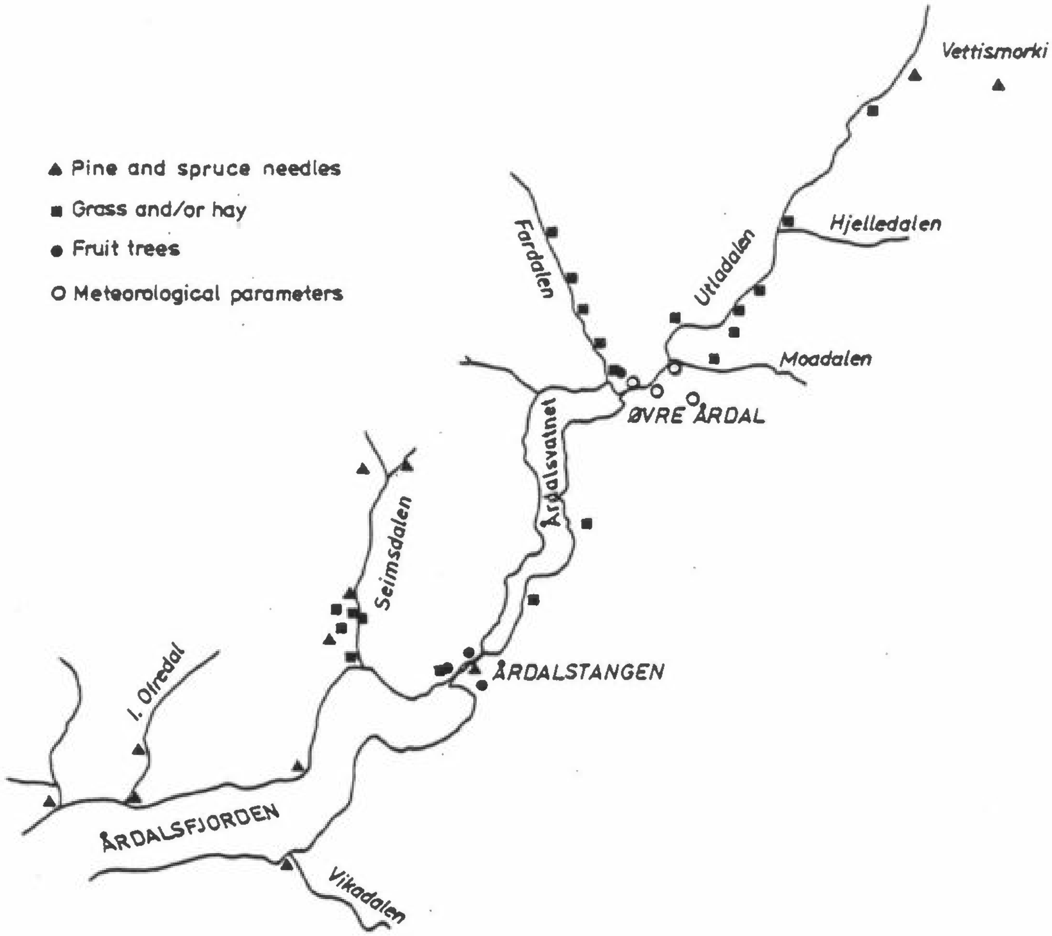


Figure 14: Sites where coniferous needles, grass and hay, fruit tree leaves and meteorological data were collected.

their animals. This initiated a series of measurements of hay and feed in 1950. By 1952 ÅSV claimed to have cleaned the air so well that farmers could begin to buy animals again and generally it was true. But by 1959, the factory had expanded and fluoride emission levels would never again be as low as in the years between 1952 and 1956. Currently dairy farming in Årdal is over. A few sheep and goat farms still function in some of the inner valleys (Figure 15).

During the 50's and 60's some biological sampling and analyzing for fluoride was undertaken although not on a systematic basis. Sporadically, animal deaths were totalled, extensive veterinary examinations were undertaken and bone, teeth, urine, blood and wool samples were analyzed for fluoride.

The monitoring program begun in 1967, proposed a regular measurement program. The ensuing yearly report should include a veterinarian's report and analyses of fluoride content in ribs and mandibles of farm animals.

Conifers

The visible damage to the trees and forests in the Årdal region, in addition to the economic importance of the conifer, led to its inclusion in the regular monitoring program.

In each of the 12 study sites (Figure 14) needles are sampled twice a year.

Those needles that emerge in the spring are measured in the fall and are called current year needles. Fluoride content in these needles are representataive of summer uptake. The following spring this group of needles are measured and are called previous year needles. They are around 1 year old. The following fall the previous years needles are measured again and are about 1 1/2 years old. Each sample consists of at least 200 grams. These are collected as whole branches and later sorted and dried. Half of the sample is sent in sealed, clearly marked plastic bags to SINTEF in Trondheim and half to the chemical laboratory at Årdal Verk. The sample should contain a mixture of needles from 4 to 10 trees each coming from both old and young stands. The same trees are not sampled each time to help preserve the health of the tree. Spruce is sampled at Vassbugen, Dalen, Kletta and Kalset and pine at all the other stations (Figure 14).

Fruit trees

From 1974 on, fruit trees were included in the sampling program. Fluoride content was measured between 1974 and 1981 in the leaves of Victoria plum, Grev Moltke pear and Gravenstein apple. The same tree was used for measurements each year. Leaf samples were sent to SINTEF in Trondheim for analysis.

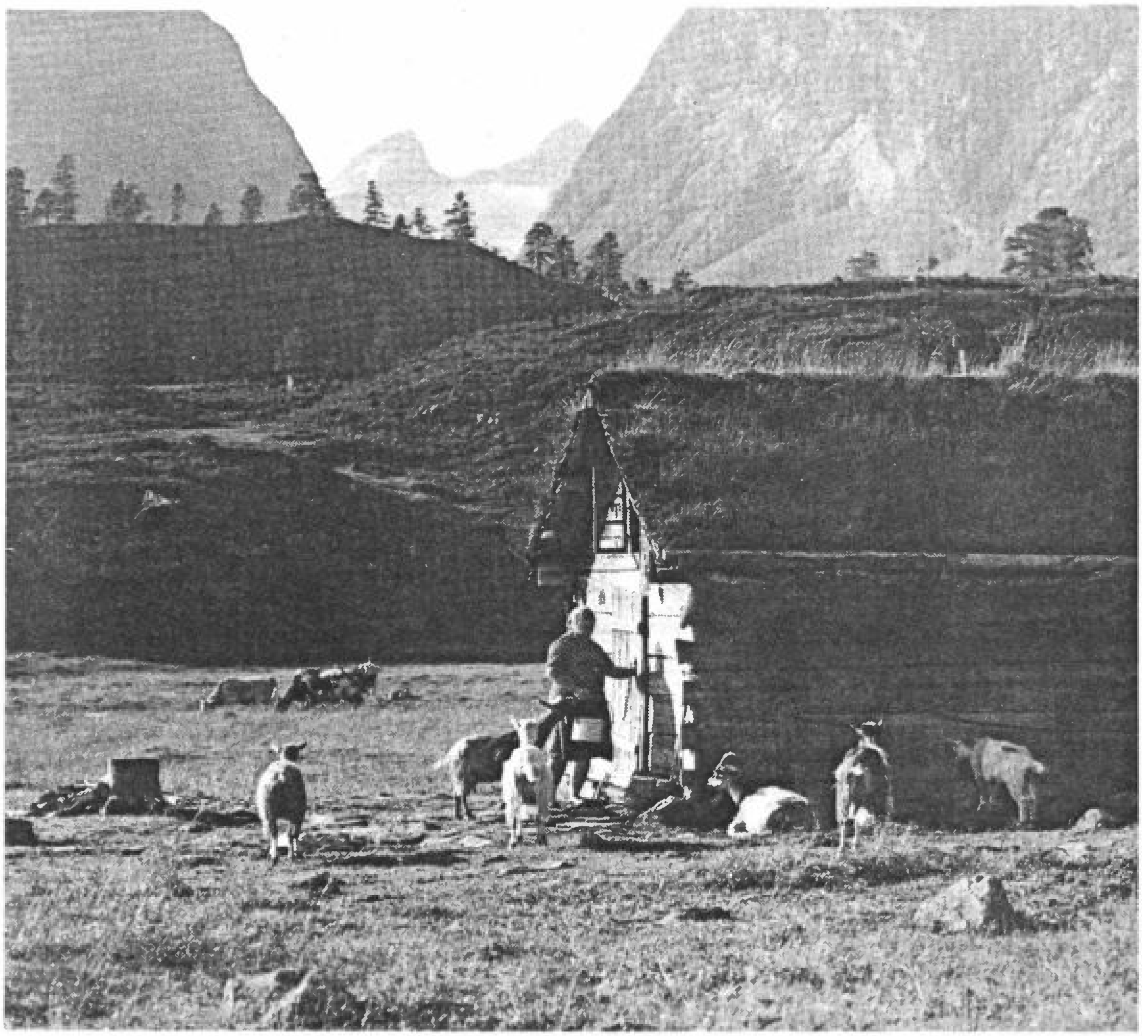


Figure 15: Vetti farm in the Utladalen valley.

Four sites have been continually used throughout the measuring period: P. Øvstetun's farm in Øvre Årdal, G. Hæreid's farm, E. Hæreid's farm and T. Berge's farm at Årdalstangen. In 1977 the Victoria plum at G. Hæreid's farm was removed due to illness. Two other sites have been measured during part of this time. Jens Seim's farm in Seimsdal was used from 1974 to 1976 since in 1977 he removed all his fruit trees. Hans Skogli's farm was selected as a replacement for Seimsdal but unfortunately only had Gravenstein apples.

Sites where fruit tree samples were gathered continuously from 1974 to 1981 are indicated in Figure 14.

6. FLUORIDE LEVELS IN FORESTRY AND FARMING

6.1 Fluoride levels in coniferous trees

Samples of conifer needles have been collected ever since 1968. Both spatial and temporal trends can be observed in fluoride content of the needles.

Figure 16 shows yearly values of current year needles sampled in the fall for each measured site. Several patterns are evident. Values in Vettismorki I in the Utladalen valley to the northeast of the factory are higher (although non-significantly) than those in Vassbugen, at Årdalstangen. Resnes even further southeast is just as high as Vassbugen. Values at sites lying in side valleys - such as those in Ofredal and Seimsdal and Vettismorki II - are significantly lower than those along the main axis. Meteorological conditions, especially wind direction, play an extremely important role. Figure 16 seems to indicate a fairly even distribution of southwesterly and northeasterly winds during the period the needles are sensitive to fluoride absorption. Moadalen (Figure 14), more to the east than Utladalen, is even more heavily exposed. However, all the trees in the valley died many years ago so there are none to sample.

Figure 17 shows another striking feature of the spatial distribution of fluoride levels. This figure distinguishes between winter and summer uptake as calculated from measured fluoride levels in previous and current year needles. Summer uptake calculated in this fashion covers a shorter time period than summer uptake as seen in current year needles.

Vettismorki I and II have predominantly summer uptake whereas the sites to the southeast have either more winter uptake or an equal amount summer and winter. This would suggest that during the summer, winds are primarily from the southwest and during the winter from the northeast, a fact we already know

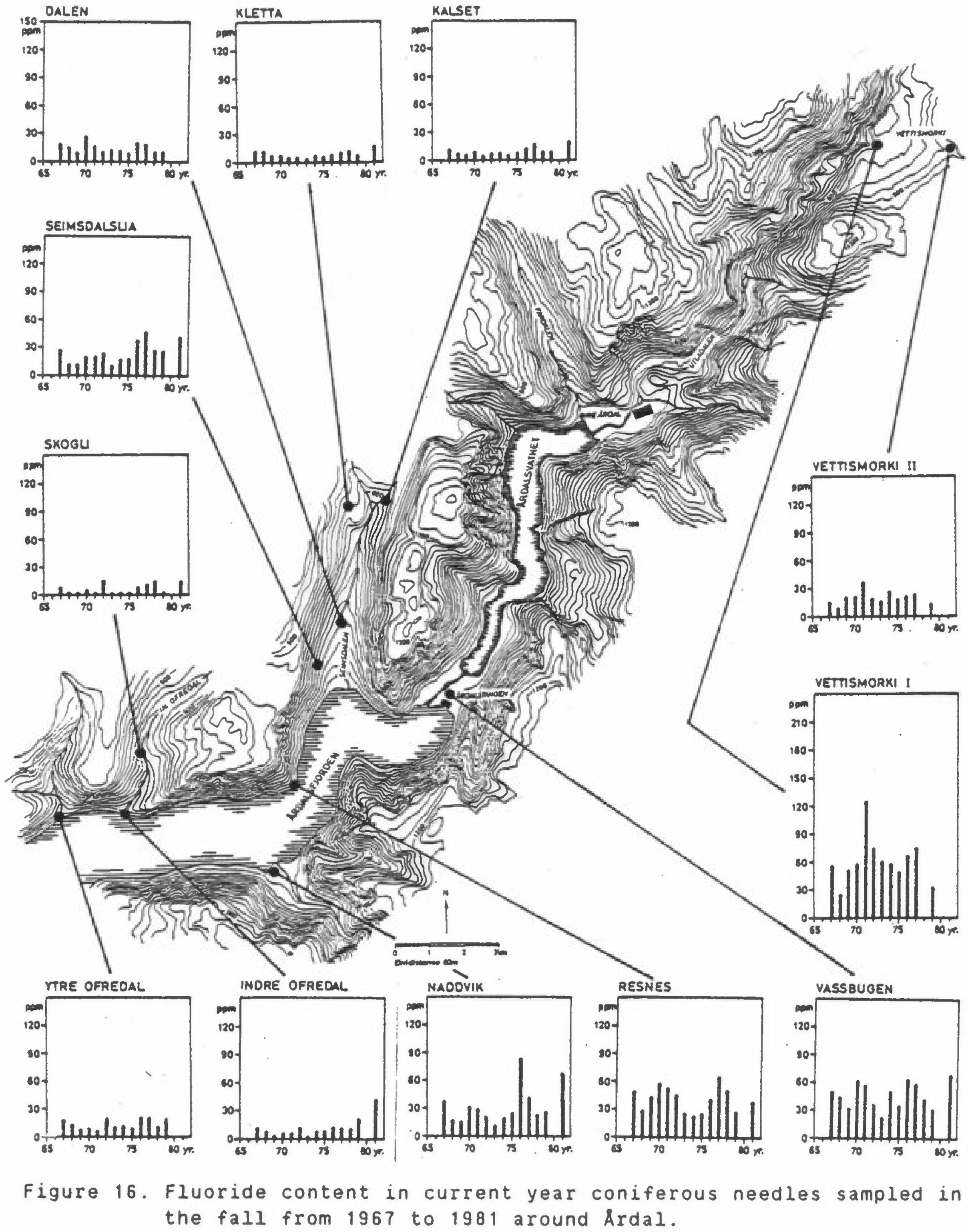


Figure 16. Fluoride content in current year coniferous needles sampled in the fall from 1967 to 1981 around Årdal.
Source: Yearly reports of Kontrollutvalget for aluminiumverkene, 1967 to 1982.

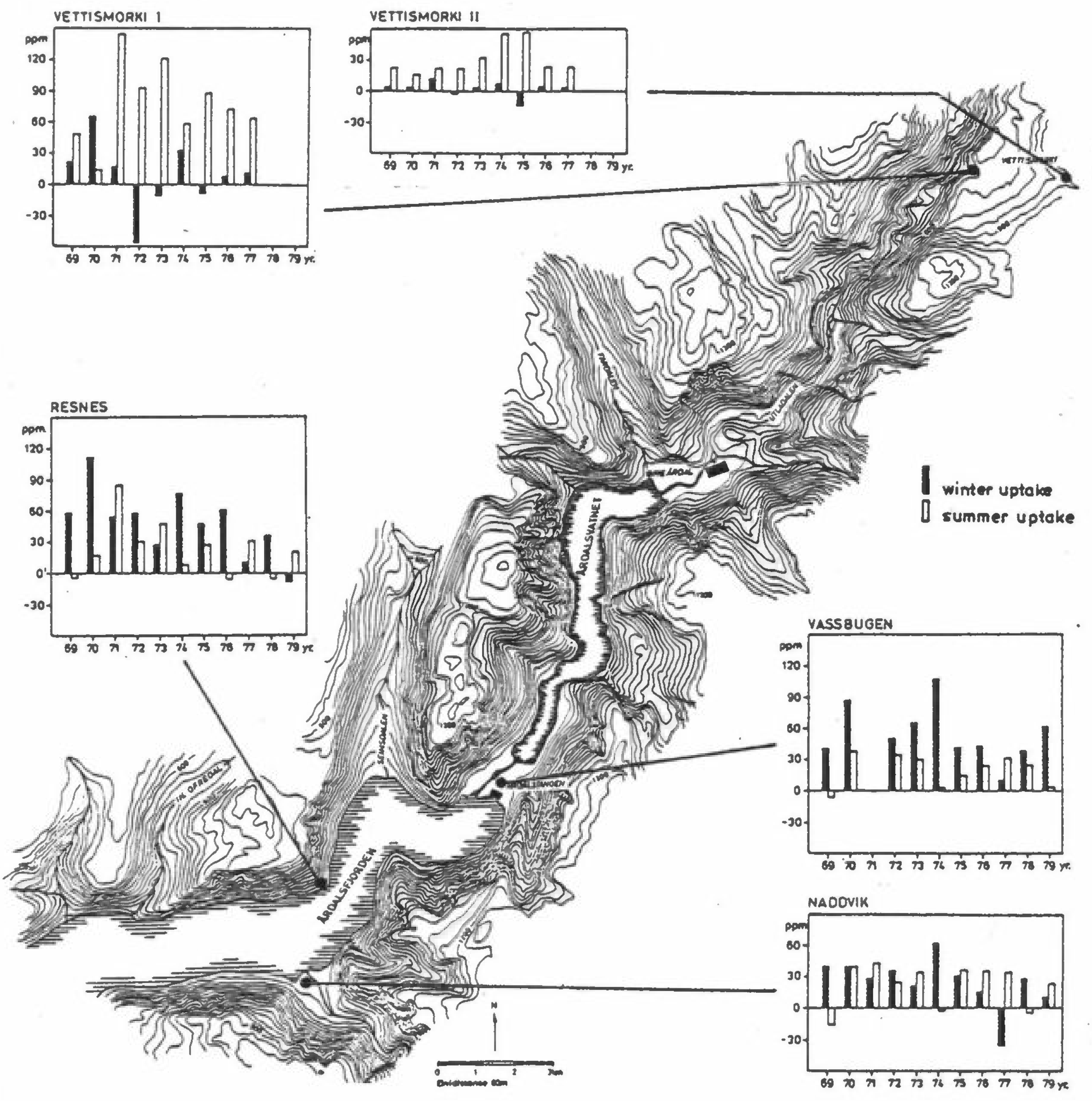


Figure 17: Winter and summer fluoride uptake by coniferous needles sampled from 1969 to 1979 around Årdal. The values aer calculated as follows (the values -1, 0 and +1 are treated equally and given a slight positive value just to indicate a measurement was taken):

Winter uptake = previous year's needles measured in the current spring (circa 1 yr old).
- current year's needles measured in the previous fall (circa 1/2 yr old).

Summer uptake = previous year's needles measured in the current fall (circa 1 1/2 yrs old).
- previous year's needles measured in the current spring (circa 1 yr old).

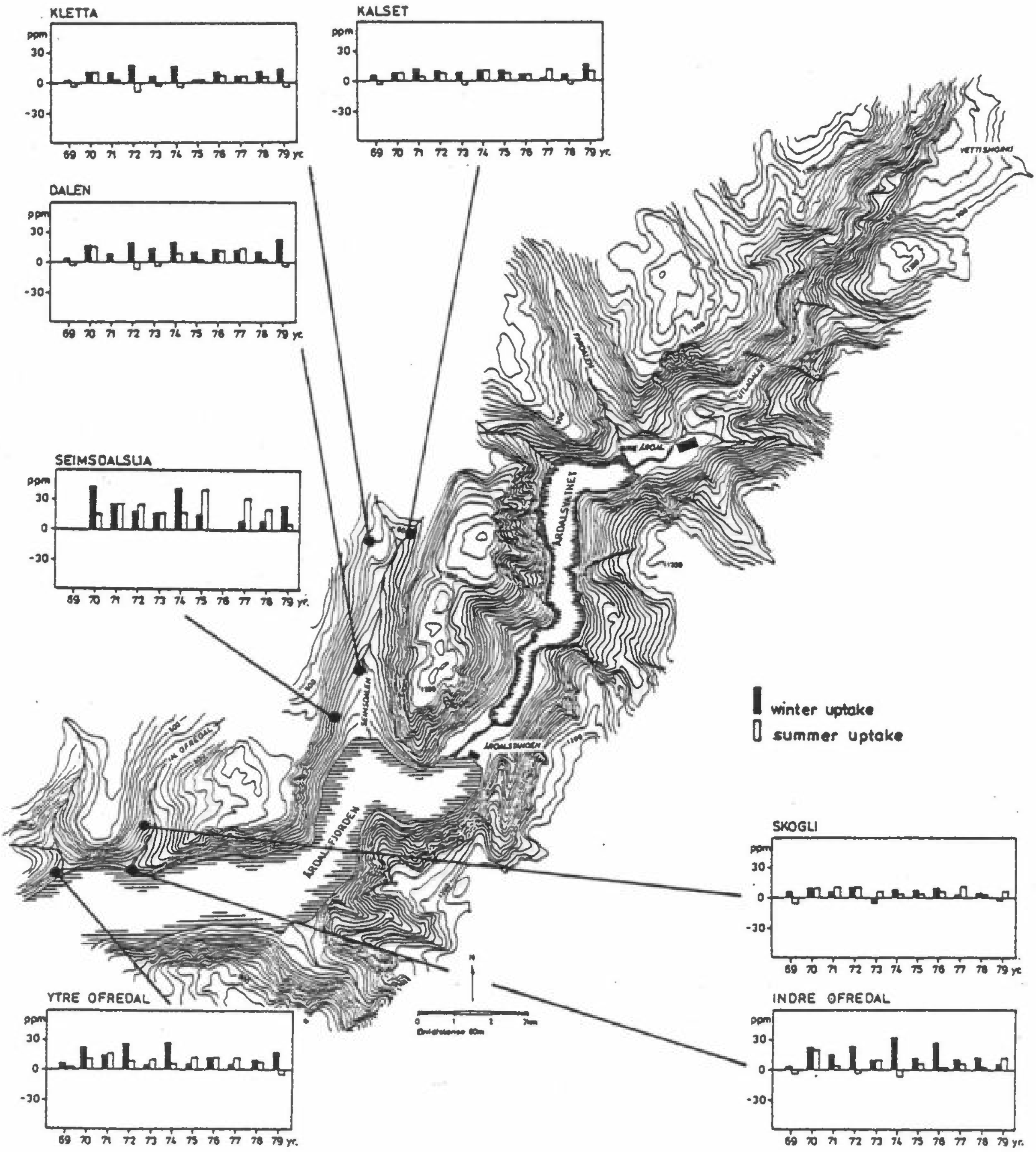


Figure 17 cont.

to be true. This also indicates that at lower altitudes with milder winters, winter uptake of fluoride by conifers is not negligable.

In Figures 18 and 19 are plotted average fluoride levels in current year needles measured in the fall, previous year's needles measured in the fall and calculated winter and summer uptake. Interpretation of winter uptake can be misleading, which is possibly the case here. Several factors can intervene. First the cold harsh conditions seen in winter can cause weaker needles, i.e. those with high fluoride content drop off. Thus in spring only those needles remain that had low fluoride values to begin with. Second, since needles are measured unwashed, changes in precipitation between years can lead to the washing off of fluoride rich dust artificially lowering measured values.

What is evident is that the pattern of fluoride levels in conifer needles over time was not exactly similar to that observed in total emissions. Previous year's needles do show a marked decline but not on the same time scale as emissions. There are two possible explanations. One is that at the same time that fluoride emissions have gone down, sulphur dioxide emissions have tripled between 1970 and 1978. It is possible that SO_2 causes damage to the stomata that leads to higher fluoride uptake. Second it is possible that fluoride levels in needles depends on how and when these emissions are emitted. They do not necessarily escape evenly and continuously throughout the year. Short, high bursts may lead to an accumulation in the needles that does not disappear, even though the total 12 month average emission level is low.

More detailed information on fluoride levels in coniferous needles can be found in Appendix E-I.

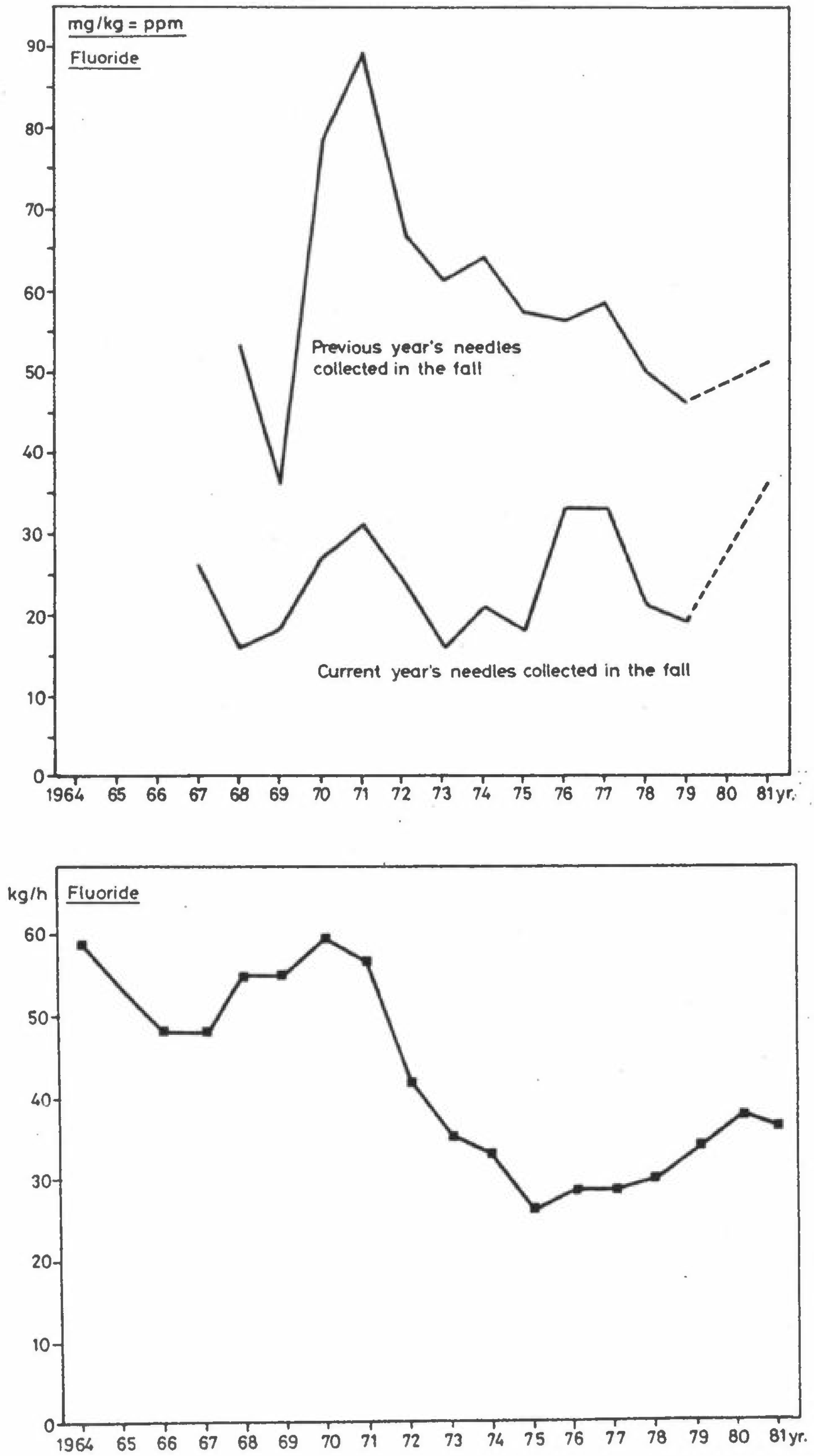
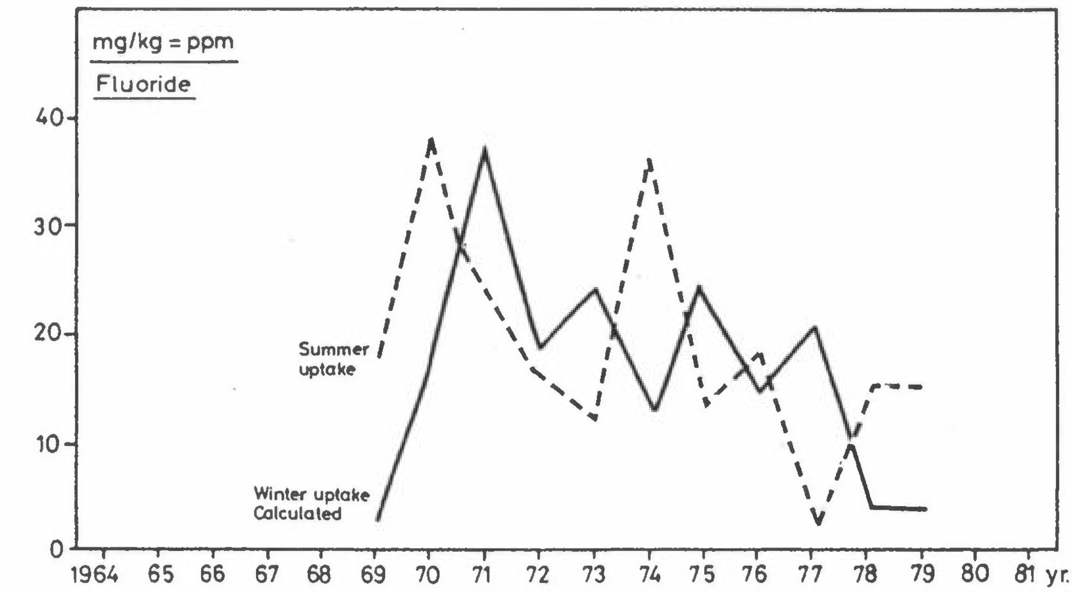


Figure 18: Mean levels of fluoride over all sites both in previous year's (thus around 1 1/2 yrs old) and current year's (around 1/2 yr old) needles collected in the fall, from 1967 to 1981 around Årdal. Fluoride emission levels are given for comparison.



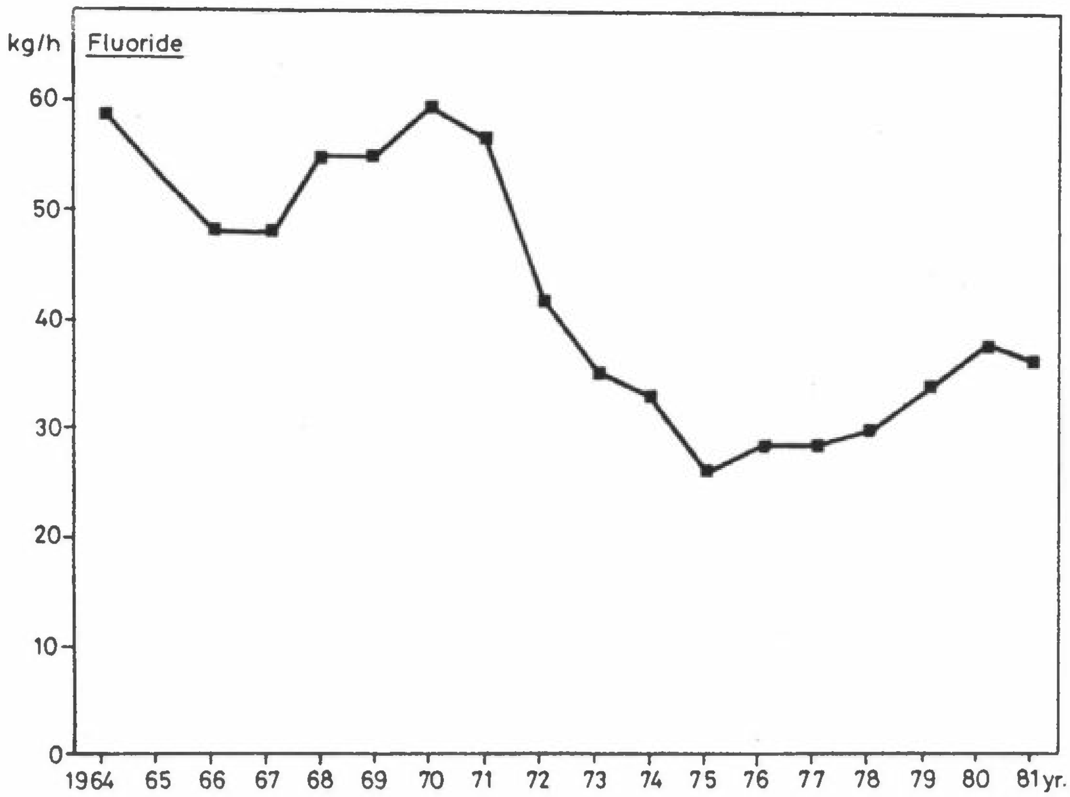


Figure 19: Mean levels of calculated winter and summer uptake over all sites from 1969 to 1981 around Årdal. See caption, Figure 16, for method of calculation. Fluoride emisson levels are given for comparison.

6.2 Fluoride levels in fruits and vegetables

The growing of fruit, especially plums, apples, pears and cherries have represented an important part of the economy of Sogn og Fjordane through the years. As early as 1958 severe concern was expressed for the health of the trees and the edibility of the fruit. In 1962, came a second wave of complaining of the effects of factory emissions on fruit growing. By 1974 concern for injury to crops of local fruit growers from fluoride emissions, led to inclusion of regular measurements to the monitoring program. The problem seemed particularly severe at Årdalstangen.

As can be seen in Figure 20, the spatial distribution of fluoride levels in fruit tree leaves was rather unusual. The two farms to the northwest of the factory have approximately the same fluoride values. The farm to the southeast of Årdalstangen has values as high and even higher than at Øvre Årdal.

There are three possible explanations. The first is that fluoride has been emitted at Årdalstangen. This explanation seems very unlikely since preliminary results from a recent investigation (Thrane, 1983) show that 80% of fluoride measured at Årdalstangen is blown in from northeast of the installation, thus from Øvre Årdal. The second is that the wind coming from Øvre Årdal is directed more to the south bypassing the two farms to the northwest of the wharf. The third and most likely is that the site at Øvre Årdal in fact lies fairly sheltered in Fardalen, thus not truly reflective of values close to the factory.

An overall decrease in fluoride levels in leaves of fruit trees is seen from 1976 to 1979 (Figure 21) followed by a surge upward. Fluoride emission levels indicate a steady increasing trend from 1976 through 1980. However, total precipitation (Figure 2) shows a roughly mirror image, thus fluoride levels are high in years of low precipitation, and low in years of high precipitation.

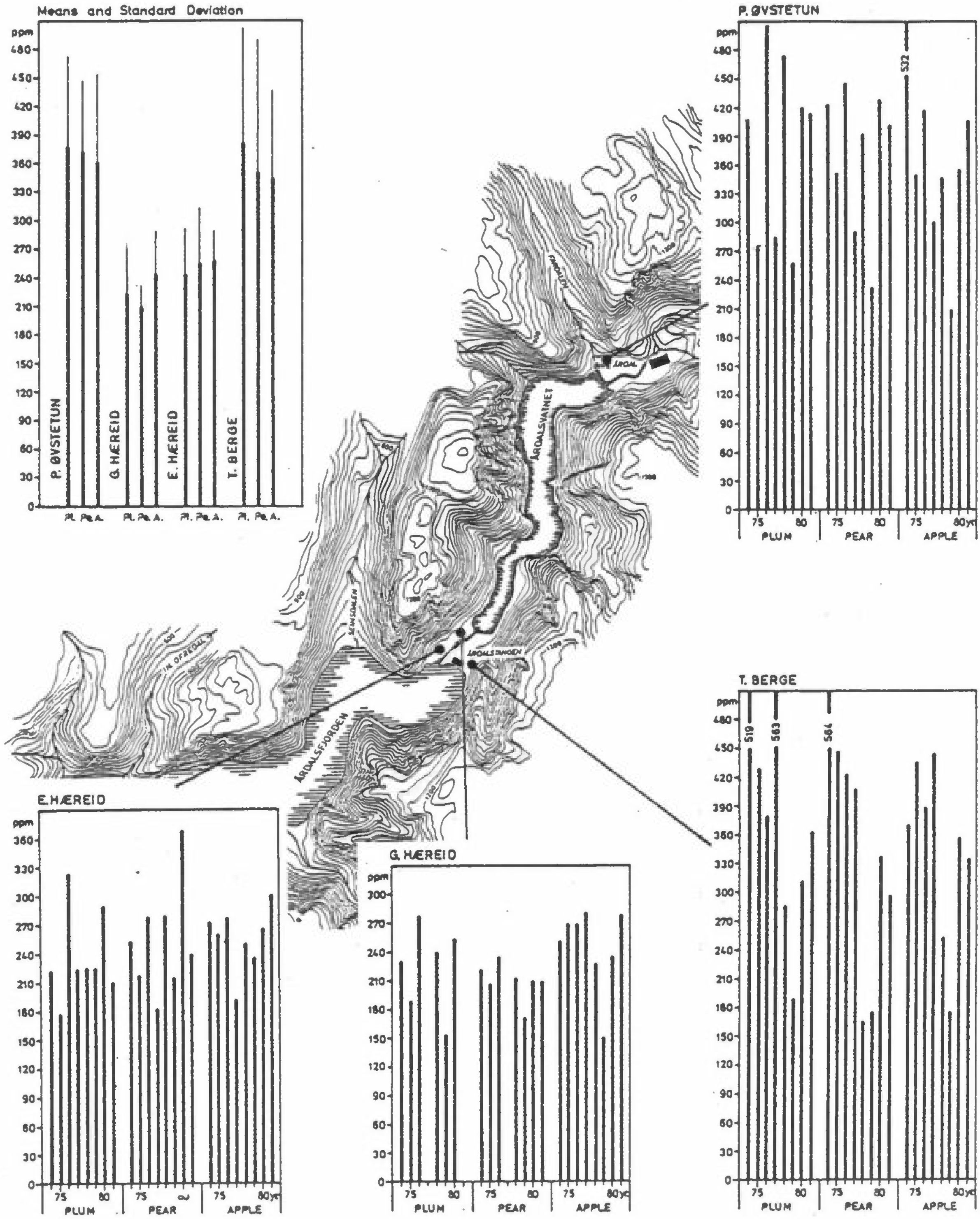


Figure 20: Fluoride levels in the leaves of plum, pear and apple trees from 1974 to 1981 around Årdal.
Source: Yearly reports for the Kontrollutvalget for aluminiumverkene, 1974 to 1981.

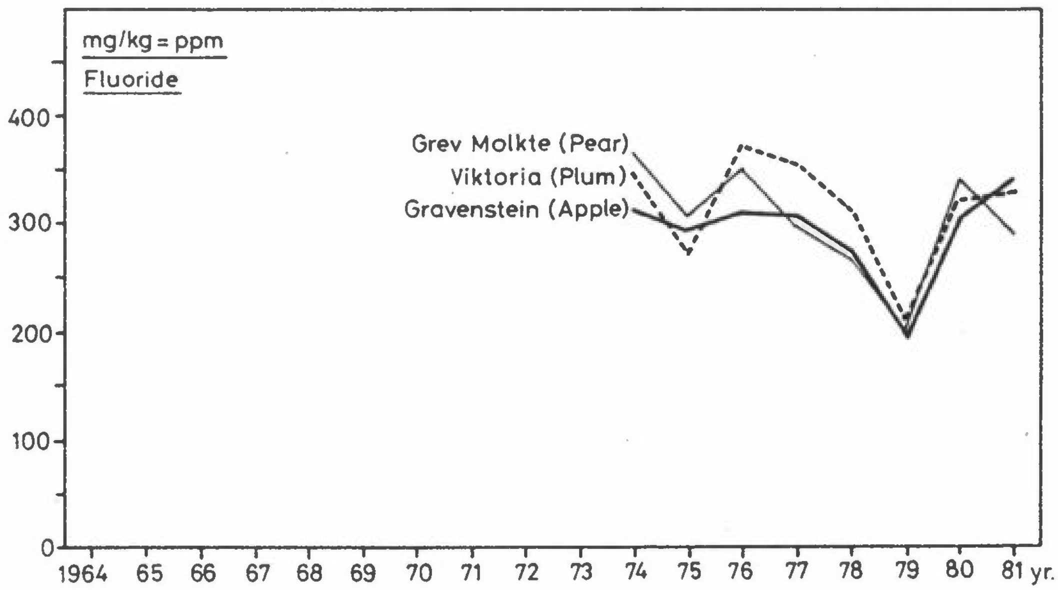


Figure 21: Mean fluoride levels over all sites, in the leaves of pear, plum and apple trees from 1974 to 1981 around Årdal. Emission levels given for comparison.

In the late 1950's concern over danger to human health led to one study of the fluoride content of fruit. The results of this investigation (Appendix E-II) showed expectedly higher levels of fluoride in fruit from Årdal than from a non-fluoride exposed area. The fluoride found, however, was concentrated in the peel.

Other studies done in the same period indicated similar findings in vegetables. Where vegetables ripen above ground the fluoride is concentrated in the peel. Root vegetables have nearly no fluoride levels whatsoever. Grain show the greatest difference in fluoride levels between exposed and non-exposed areas (Appendix E-II).

6.3 Fluoride levels in hay and grass

Measuring fluoride in hay and grass (the principal forage products) is the easiest method of estimating animal exposure. Because animal husbandry is so important to the economy of Årdal, fluoride has been measured in hay dating nearly from the opening of the factory. The data is collected in such a way that three kinds of information are available: 1) spatial trends, i.e. where are fluoride levels highest or lowest, 2) temporal trends, i.e. how do fluoride levels change over the years, and 3) seasonal trends, i.e. how do fluoride concentrations change from spring, to summer, to fall.

Figure 22 shows 20 year means and standard deviations for samples collected at different sites in spring, summer and fall. The highest levels are found at the mouth of the Moadalen valley, second highest in Utladalen. Fluoride levels decrease with increasing distance from the factory, and increase from spring to fall.

In Figure 23, data are collected from 1950 through 1981 from selected sites to give an overall impression of temporal trends in hay and grass. However, it should be kept in mind that up through 1966, fluoride was measured by one laboratory and from 1967 on, by another laboratory. Values after 1960 never again fell to those concentrations found in the mid 50's. It is doubtful that differences in measuring methods can fully account for these observations although this explanation cannot be ruled out (see Appendix D-II for description of fluoride measuring techniques).

In Figure 24, this information is summed up over all sites from 1967 to 1981 (where data are most complete and comparable). Both hay and pasture grass measured in the spring show two peaks: 1) the peak in 1969-1970 is quite high, 2) the one in 1977 only two thirds as high. Fluoride emissions fall very substantially from 1970 to 1974, at which point they slowly begin to rise. Between 1970 and 1974 there is very good correlation between pasture grass and fluoride emission levels. However, between 1974 and 1981 correlation is poor and fluoride uptake by plants is obviously not simply related to air concentrations. The peak in 1977 is particularly interesting. In fruit trees, levels were also high in both 1976 and 1977. Although both fluoride emissions and measured ambient fluoride levels were not particularly high in 1977, precipitation was quite low.

More detailed information on fluoride levels in forage can be found in Appendix E-III.

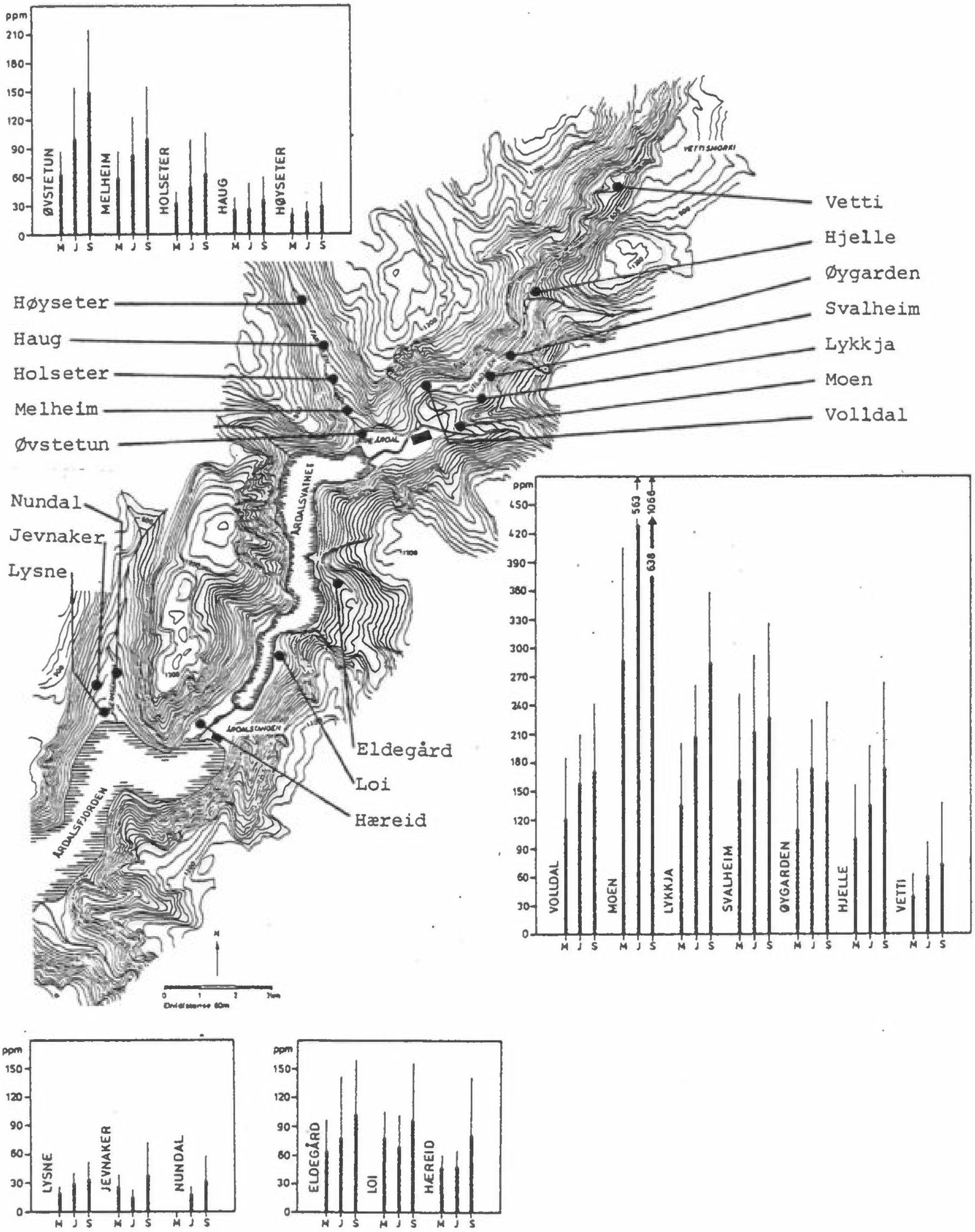


Figure 22: Means and standard deviations of fluoride levels in pasture grass collected in the spring (M), summer (J) and fall (S) from 1961 to 1981 at different sites around Årdal.

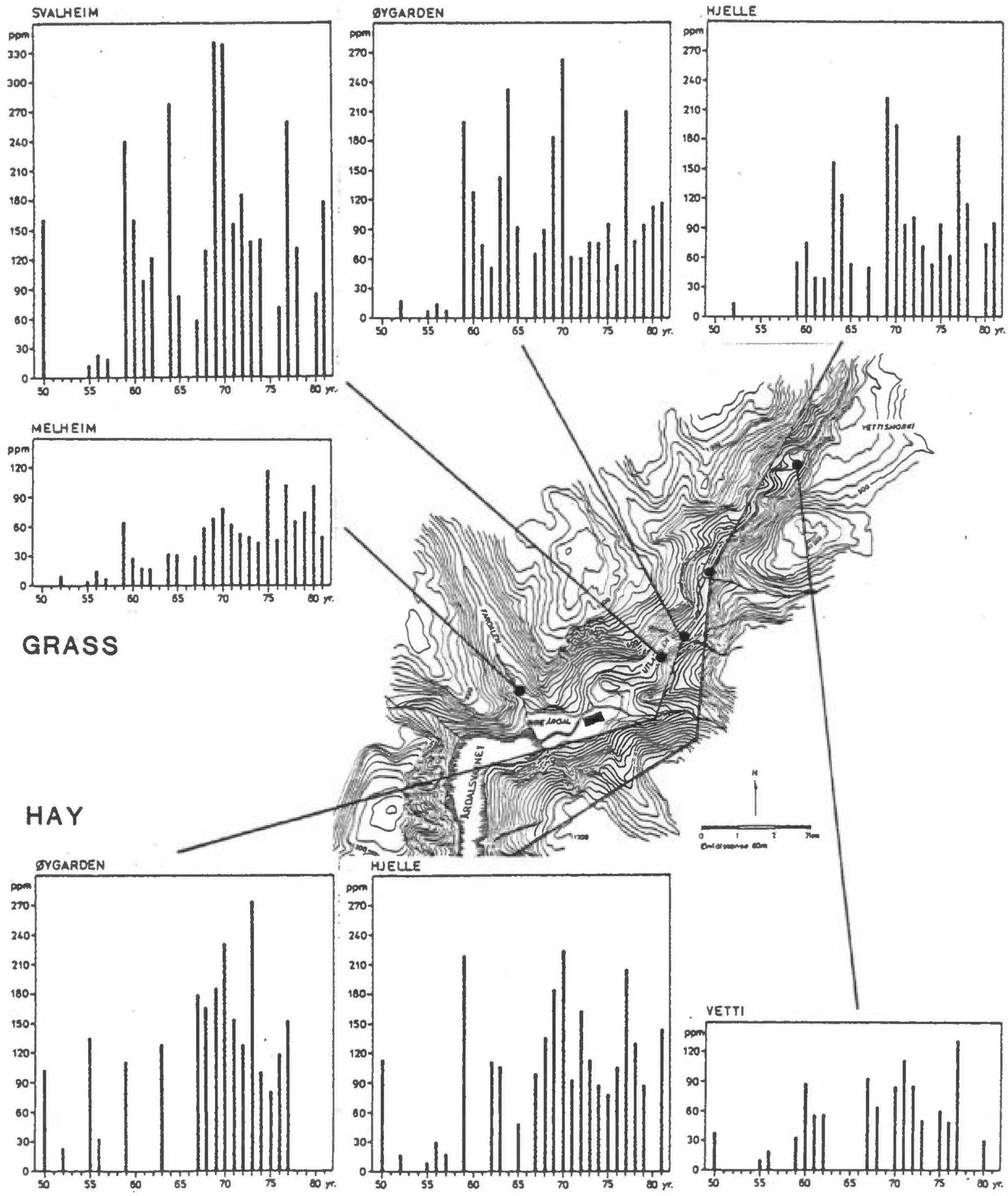


Figure 23: Fluoride concentrations in pasture grass (upper set) and hay (lower set) from 1950 through 1981.
Source: Yearly reports to the Smoke Control Council from the Dept. of Biochemistry of the Veterinary College, and Yearly reports of the Kontrollutvalget for aluminiumverkene.

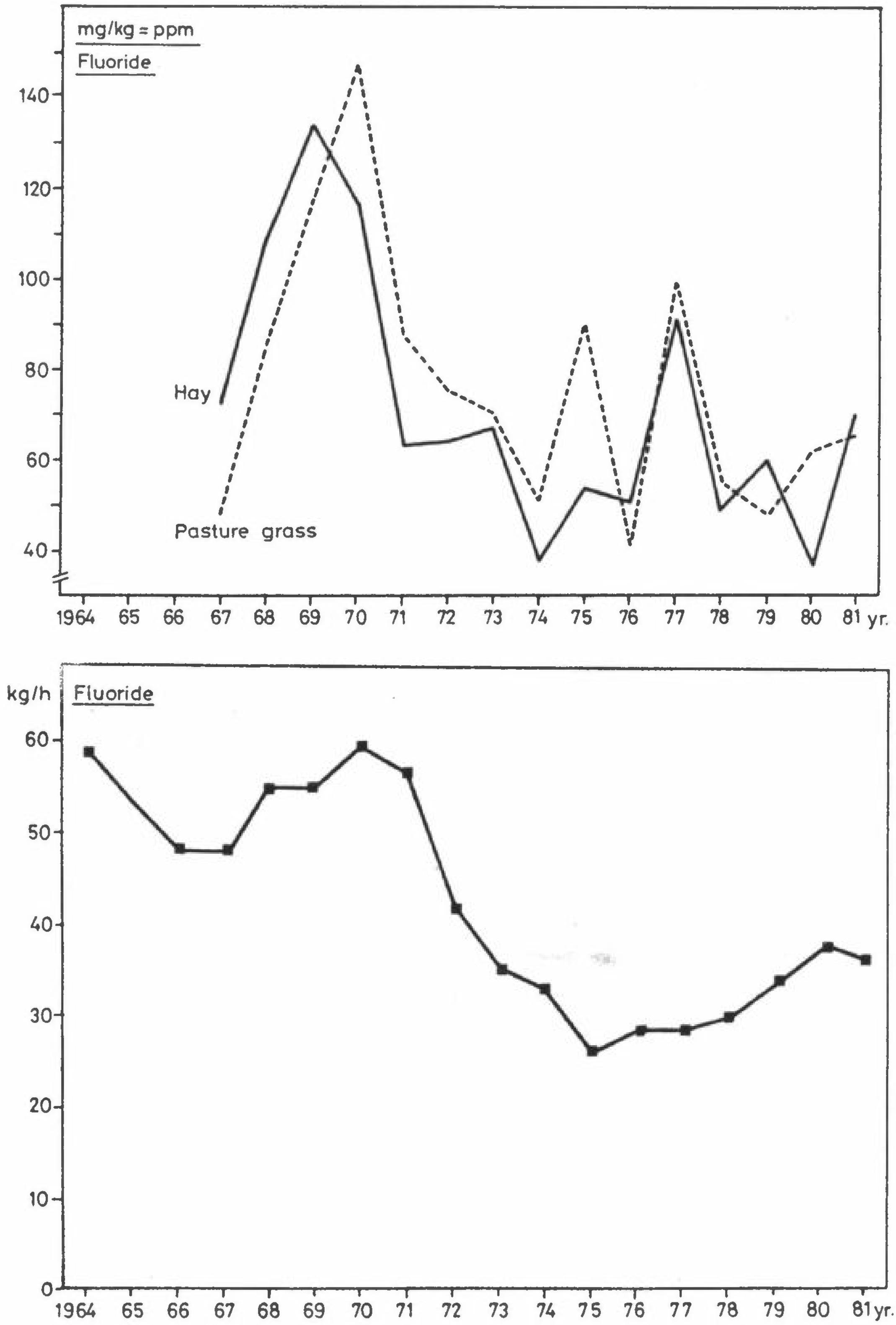


Figure 24: Mean fluoride levels over all sites in hay and pasture grass (spring samples) from 1967 to 1981 around Årdal. Fluoride emission levels are given for comparison.

6.4 Fluoride levels in farm animals

Although the monitoring program calls for regular measurements of fluoride in bones of animals, practical problems have led to relatively little sampling after 1975. To interpret fluoride levels one must take into account the age of the animal. In Figure 25, animals are classified as to anticipated effect (low, medium or high) through their measured bone fluoride levels. These classifications (see Figure 25, caption) take into account the age of the animal, and reflect estimated effect of fluoride. In the lowest category one would not expect to find any measurable effect. In the moderately exposed group one could expect to find teeth changes, such as discoloration, enamel defects and abnormal wear of the cheek teeth (dental fluorosis), but nothing leading to deterioration in health of the animal. In the highest category one might begin to see problems such as lameness, stiffness, extreme teeth changes and unthriftiness (damaging fluorosis). Despite the small number of samples, spatial distribution of fluoride levels generally conforms to those expected from the measured pasture grass and hay fluoride levels. A guideline of 30 ppm (=mg F/kg dry matter) in grass or hay (SFT report No. 38) has been proposed as the upper limit under which ingestion produces no measurable effects on animals. This has been attained only in sites lying in the inner side valleys of Seimsdal and Ofredal. Fluoride in grass has averaged between 30 and 40 ppm. Fluoride levels measured in bones from animals in this region corresponds to an estimated moderate effect.

It is very difficult to associate grass levels with fluoride in bones because importance of other manufactured feed has increased in the later years over the whole country (Hansen, 1972). In addition, during the summer, sheep are released into the high mountains where fluoride levels are unknown.

More information from earlier studies in Årdal on fluoride exposure in farm animals can be found in Appendix E-IV.

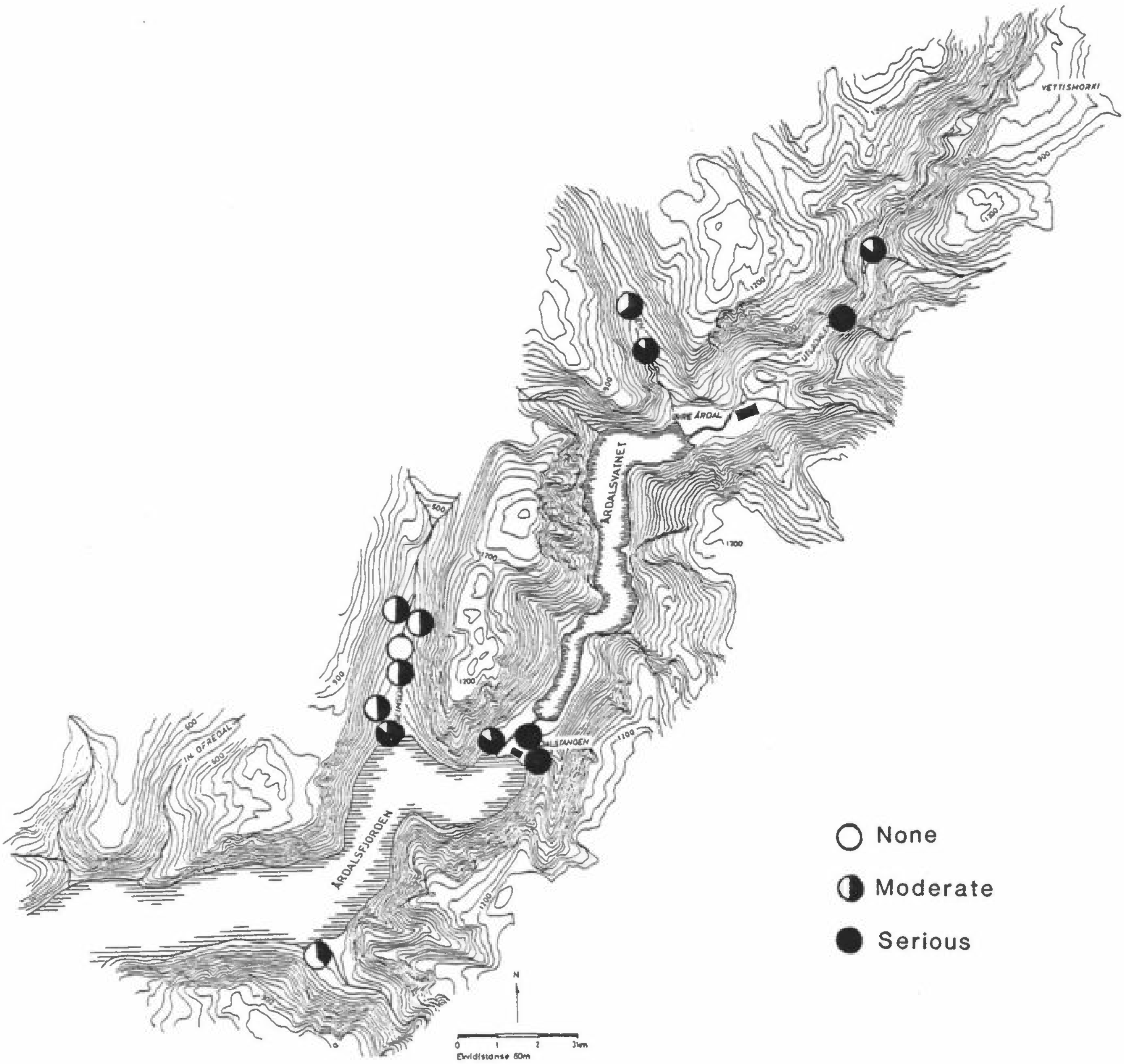


Figure 25: Effect of fluoride on farm animals estimated and categorized from measured fluoride levels in bone. See text for description of categories.
*Fluroride levels (in ppm) used for categorization of damage.

Animals age	None	Moderate	Serious
2 years	<1919	2000-4499	≥4500
2-5 years	<3499	3500-5999	≥6000
≥5 years	<4499	4500-7999	≥8000

Source: Yearly reports of Kontrollutvalget for aluminiumverkene, 1967 to 1981.

7 EFFECTS OF POLLUTION ON FORESTRY AND FARMING

The primary aim of the monitoring program started in 1967, was to measure fluoride levels. Effects or damage due to fluoride or other pollutants was not systematically quantified. Any special damage or effect noted in a particular year are, however, described in the yearly reports to the Kontroll-utvalget for Aluminiumverkene.

7.1 Injury to coniferous trees and forests

Fluoride is absorbed from the air through the stomata (openings in the leaf), then migrates to the margins or apical tips of the leaves. (Very little if any is absorbed through the roots.) In the conifer, this ultimately leads to visible damage through scorching or tip-burn that is unlike that caused by other pollutants. This may begin at levels possibly as low as 10 ppm in current year needles (Horntvedt, personal communication.) As the fluoride concentrations increase, more and more of the needle is burned. Eventually, the needle drops off. Spruce loses needles more readily than pine. If sufficient needles fall, the vitality of the tree diminishes eventually leading to tree death.

However, this is overly simplistic. Many factors affect the amount of injury caused by fluoride emissions. First, external parameters such as the pattern of emission levels themselves can be important. High fluoride levels, over a very short period of time, can injure as much as lower ambient levels over a longer period of time (NAS, 1971). Climatic factors such as temperature, rain and wind can also affect fluoride availability to the needles.

Second, and as important, are internal parameters of the tree. The biological sensitivity of the tree is not the same at all times and under all conditions. The stomata are usually more open during the day than at night, thus more absorption takes place during the day. Temperature, humidity and light intensity affect both stomatal opening and plant metabolism, influencing absorption and resultant injuries (NAS, 1971). High temperature and low humidity cause the stomata to close even if light intensity is high (Robak, 1964). Genetic differences between species and between individuals within a single species leads to differential sensitivity. Nutritional deficiencies can make plants more fluoride sensitive, while water deficiency increases resistance (NAS, 1971). Generally, young but fully developed needles are most sensitive. But injury does not usually become apparent until the fall. The consequences of injury to older trees is greater than to younger trees. It is largely unknown to what degree combination of fluoride with other pollutants can affect both accumulation of and damage done by fluoride. Evidence indicates that HF + SO_2 can act synergistically, increasing injury thus decreasing absorption. The combination of HF + NOx is less harmful than either of these compounds alone (Amundsen et al., 1982). Some evidence indicates that fluoride injury in the form of reduced growth and morphological alterations takes place even before any visible sign of damage (Amundsen, Weinstein, 1980).

In 1951 (Table E-7, Appendix E-I) damage was heavy in Moadalen and Utladalen. However, in 1963 (Roll-Hansen, 1967) injury was said to have spread much further southwest then had been observed before. It now extended to Resnes and 2 km west of Naddvik. Further west there was no injury. As can be seen in Figures 26 and 27, which represent the area of injury as of 1971 (Horntvedt, personal communcation) injury seems to have extended yet further west.

In 1976 burn damage to pine (not spruce) was observed in Naddvik, Seimsdalslia and Resnes, but not in Ofredal. This was especially unfortunate since these areas had been in the process of recovering up through 1975 (yearly report for

Kontrollutvalget for Aluminiumverkene, 1976). To put this damage report in perspective, fluoride values in current year needles went from (in ppm):

	1975	1976
Naddvik	24	81
Seimsdalslia	17	40
Resnes	28	43

Values in previous year needles did not substantially change between 1975 and 1976 at any of these stations (they averaged around 80 to 90 ppm).

7.2 Injury to fruits and vegetables

In 1962, N. Moen in Moadalen, complained about damage to fruit trees. Leaves were collected and measured for fluoride content at the Veterinary College of Norway. The levels were 2450 ppm. To put this in perspective, sweet cherries began to show damage in Hardanger at levels of 80-90 ppm.

Much damage was reported in 1976 (yearly report - 1976) on T. Berge's farm, at Årdalstangen. However, it was noted at that time that the injury was not typical fluoride injury. It was suspected that the injury might be in part due to SO_2.

The comments made concerning damage to fruit trees, however, do not specify what kind of damage. Injury can occur to the tree itself, reducing the vitality of the tree, even causing death of the tree. Injury, limited to the flowering period, can reduce the amount of fruit. However, fluoride exposure while fruit are ripening can lead to conditions such as

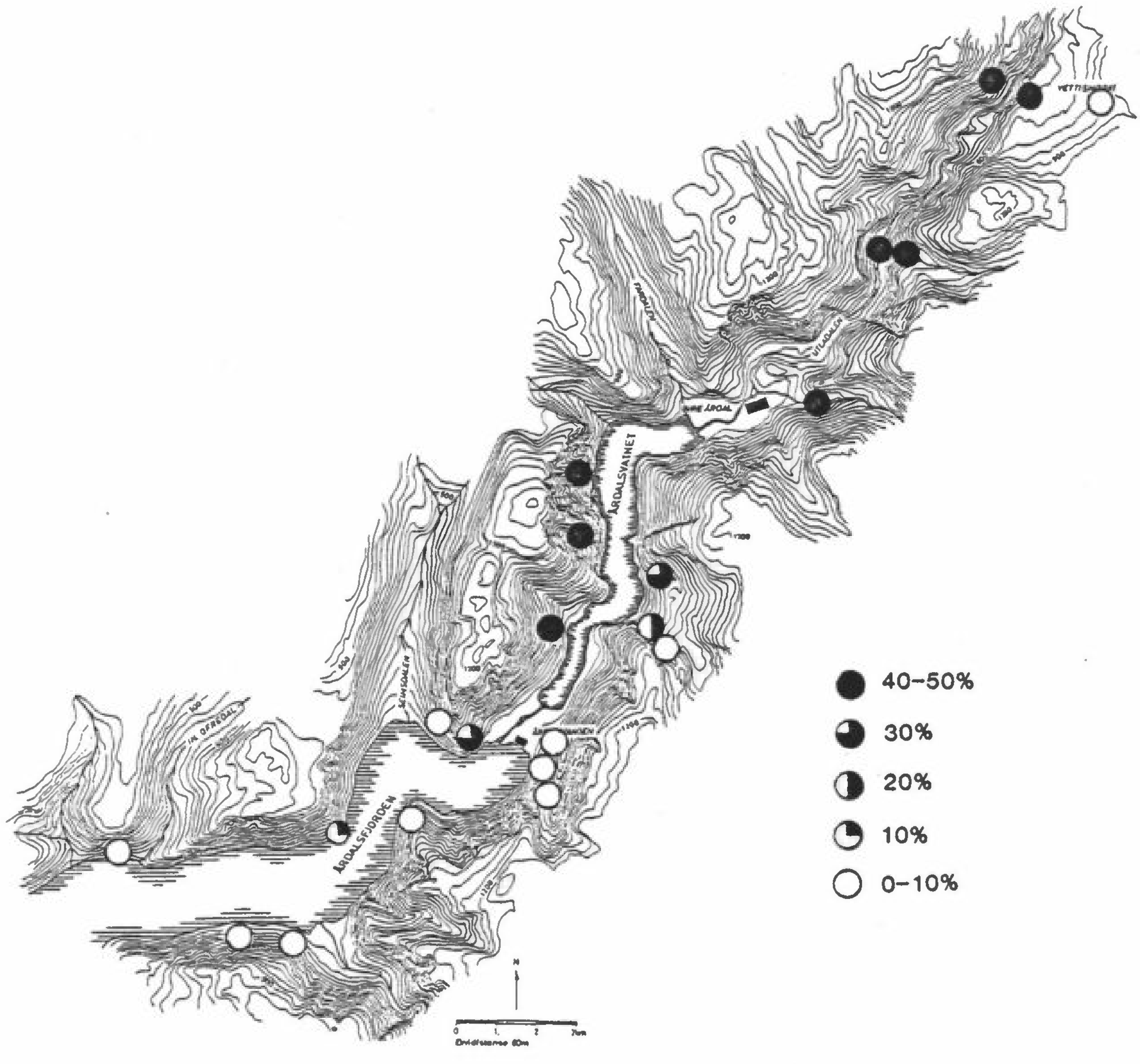


Figure 26: Dead or dying pines around Årdal, based on observations in 1971-1972.
Source: Horntvedt, personal communication.

"suture red spot" or "soft suture" of peaches; depressed lesions at the stylar end of apricots, pears and cherries; and "snub nose" or "shrivel-tip" of sweet cherries (NAS, 1971).

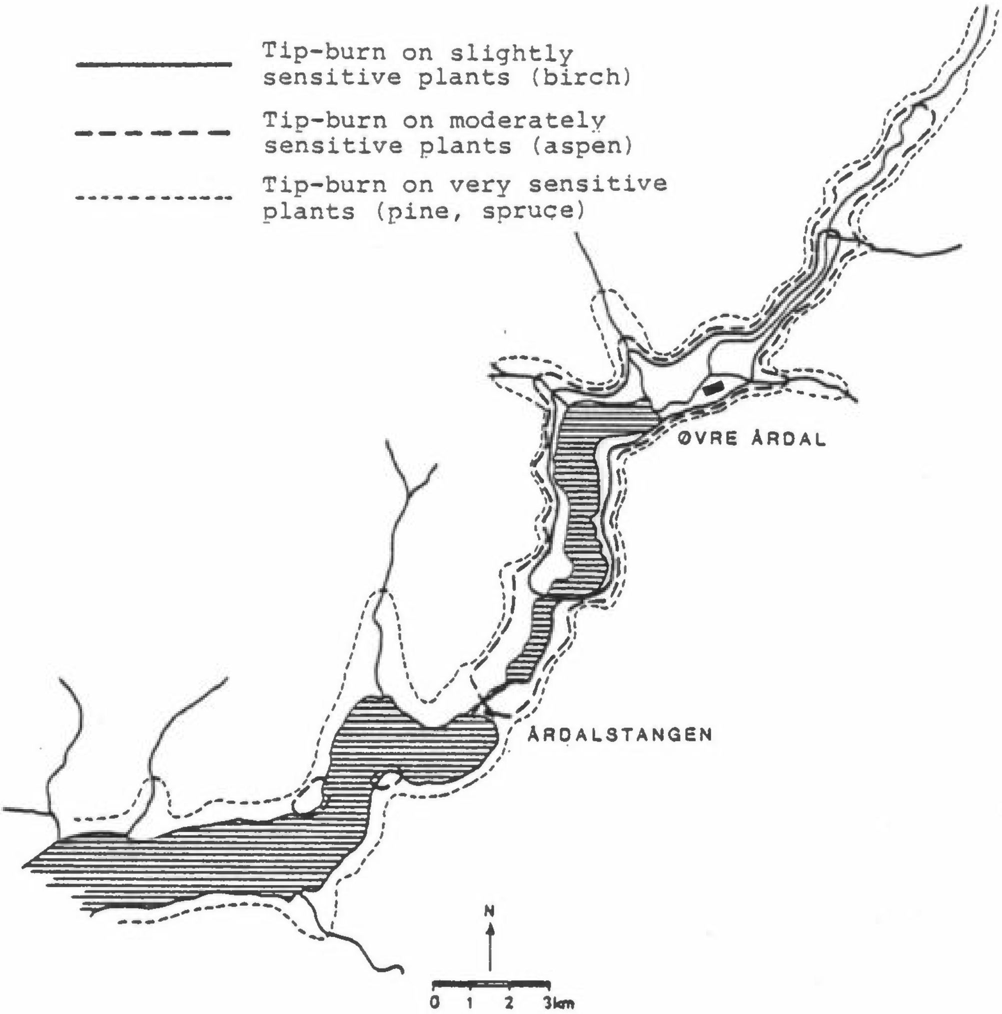


Figure 27: Tip-burn on trees from the Årdal area.
Source: Romøren, 1973.

Although healthy leaves absorb less HF in the dark than in the light (stomata are open in day light), they are more prone to injury during the dark phase (NAS, 1971). In Norway, where daylength is quite different between spring and mid summer, this may be a factor of importance.

One study, done in 1970 (Johnson, 1970) indicated that during the 20 year period 1949 to 1969, pollution reduced fruit crop yield by a total of 54% (see Appendix F-I).

No measures have been taken of reductions in yields of other vegetable crops.

7.3 Effects on farm animals

The injury to animals raised in the proximity of an aluminum factory was recognized as fluorosis as early as 1934 by Slagsvold. The symptoms of fluorosis are: 1) heavy teeth wear, 2) lameness or problems in walking or lifting of the body, 3) exostosis on mandibles and bones of the extremities, 4) poor appetite and emaciation. These symptoms, however, are rarely seen in Norway today, since animal husbandry is no longer practiced in the most highly exposed areas and due to greater dependence on manufactured feed in lesser exposed areas. Animal sensitivity to fluoride varies with 1) species, 2) age, 3) state of nutrition, 4) health and level of stress, 5) amount and duration of ingestion and 6) solubility of fluoride ingested. Fluoride exerts its effects through its ability to incorporate into bone apatite, and its ability to bind to proteins, especially enzymes, altering and interfering with their function.

There has been no systematic measuring in later years of fluoride damage to animals. A veterinary report is issued every year however, that lists what fluoride related health problems have arisen during the year. Some comments follow:

In 1967 G. Hæreid complained that lambs only weighed 1/3 to 1/2 their weight previous years. He also claimed that cows could be only kept 2 years before their teeth deteriorated so that they could no longer eat. In 1969, Årflot reported only a weak fluoride effect in Seimsdalen, although an examination of teeth indicated greater damage in 1969 than the previous years. He found cows more sensitive than sheep.

In 1972 a new veterinarian was hired. He indicated that cows seemed healthy whereas goats and sheep were more injured. The sheep are slaughtered after 4 to 5 years instead of 5 to 7 years. He also found an unwillingness among farmers to try mineral additives. The slaughter house did not report different weights for lambs slaughtered from the Årdal area than for those from other areas. In 1974 fluorosis was found in Fardalen in both cows and goats. Generally health was considered better in larger than in smaller ruminants. In 1982, two cows had to be slaughtered because of clinical fluorosis (lameness) at Vetti, in Årdal (Hansen, personal communication).

8 POLLUTION EFFECTS ON THE ENVIRONMENT AND MAN

8.1 Pollution's effect on the terrestrial ecosystem

Very little information has been collected on fluoride in the natural environment. However, there have been some measurements of fluoride levels in deciduous trees (primarily birch) and in deer.

8.1.1 Flora

8.1.1.1 Natural flora

Fluoride levels can increase much higher in leaves of deciduous trees than in conifer needles. This is primarily due to a better fluoride tolerance leading to greater accumulation of fluoride before causing leaf drop.

The environmental and biological factors that contribute to fluoride accumulation in deciduous trees are the same as those contributing to accumulation in conifer needles and will not be repeated here.

Deciduous trees, having relatively little commercial value, have not been sampled systematically. However, a certain number of observations have been made. (Observations documented in yearly reports for Kontrollutvalget for Aluminiumverkene).

In 1964 severe scorching of broad-leafed trees was reported in Øvre Årdal around the factory (Roll-Hansen, 1967) with some birches losing all their leaves. In Moadalen, mountain birch willow and mountain ash had been damaged.

In 1968, one farmer (O. Vee in Øvre Årdal, near the factory) indicated that death to the birch forest had spread sufficiently since 1964 to create a threat of landslide. The lower rims of the hardwood forest had been damaged as early as 1964 but had since spread. Figure 27, shows spread of damage as of 1971 in species of trees having different sensitivity to fluoride.

In 1976, deciduous trees showed more damage than had ever been observed before. By 1981 the forest growing on the Heirsnosi cliff south of the factory was reported to be severely scorched, again raising the possibility of earthslides. This latter report stimulated a study undertaken in 1981 that measured both fluoride and sulphur in birch leaves. Fluoride values were measured at 100 m intervals on the cliff, Heirsnosi, south of the aluminum factory. The values were rather irregular but were very high between 300 and 400 m and again at 600 m. The sulphur content in the leaf followed very closely the fluoride content (see appendix G-I-a).

It is evident that fluoride levels and injury should be measured systematically in the hardwood forests surrounding Årdal. Although they may be of limited commercial value, they are the predominant forest type of the area and represent an important esthetic value. Since they are more abundant, a greater number of sites could be selected that would provide better information in the future concerning the spread of emissions from the two Årdal factories. However, in addition to their esthetic value, these trees play an essential role in preventing landslides. This, all by itself, makes it essential to monitor the damage caused by fluorides in the area.

In 1974 (Yearly report for Kontrollutvalget for Aluminiumverkene, 1974) the suggestion was first made to begin planting more fluoride resistant plants, such as lark, sallow or goat willow and other pioneer plants, in an effort to prevent erosion on the cliffs. This is an idea that should be followed up.

Damage to conifers around Årdal seems to be spreading. Studies should be undertaken now in the 1980's to confirm this. Specific information is also needed on the ability of the forests to regenerate themselves including the relative susceptibility of the young seedlings. Finally, no information is available on altered forest ecology. Differential susceptibility of species will lead to a change in the population structure of the forest. Gradual dying of pines will allow a tighter growth of birch to take its place. Such tight growth, however, can then cause lower growth to disappear or change. Appendix A-II lists locally found vegetation. The fluoride susceptibility of these plants is largely unknown.

8.1.1.2 Ornamental gardens

Damage to ornamental plants and shrubs in Årdal have been studied extensively through the work of E. Ellingsen. It is possible to have beautiful and varied gardens despite the fluoride pollution, but the esthetic value is sometimes reduced by tip burns, particularly in Øvre Årdal. A list of plants that are recommended for Årdal is given in Appendix G-I-b.

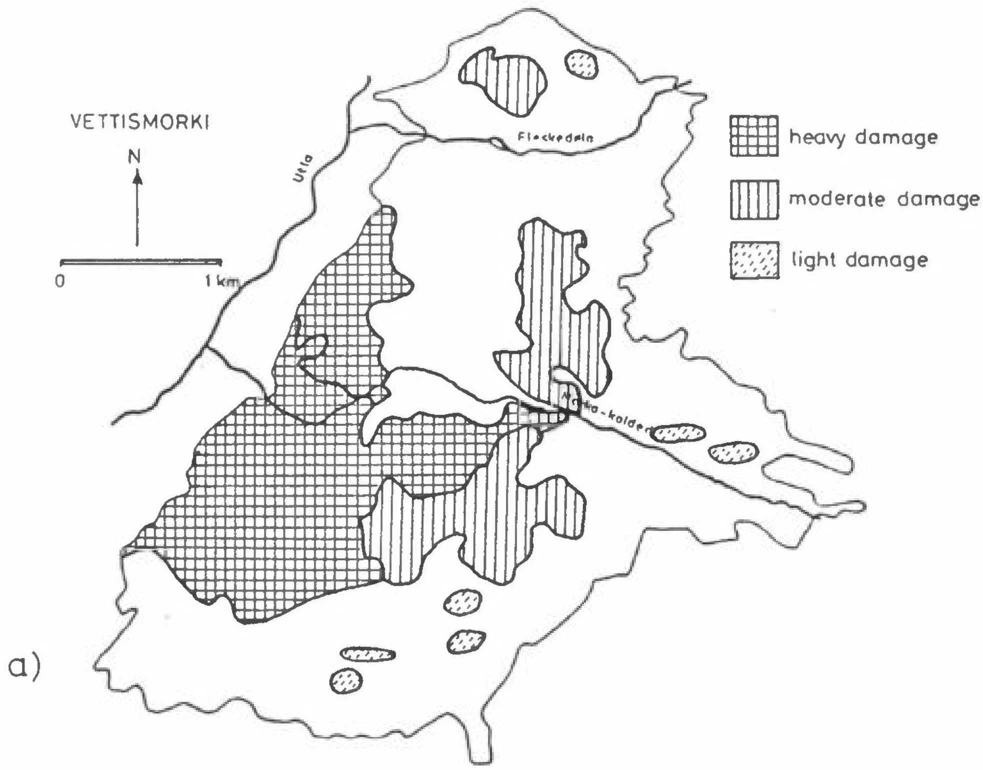
8.1.1.3 Vettismorki

The northeastern boundary of the Årdal municipal district is part of a unique area, Vettismorki, in the Jotunheimen National Park. This area contains one of Norway's oldest forests, with some trees over 800 years old and one of the loveliest and tallest waterfalls. It is Vettismorki that makes the pollution problem around Årdal so different from that of the other aluminum factories. Fluoride damage to Vettismorki has been considerable.

However, man's impact on the pine forests of Vettismorki date back to at least 1700. The trees have been heavily logged up to the second World War. A massive tree death occurred between 1822 and 1865 that was probably due to natural causes such as insects or climate. But it was not long after Årdal began to produce aluminum that injury to coniferous trees was noticed.

Vettismorki has been singled out for more careful study several times in the past 20 years. In 1962 (Skar, 1964) injury was noted along the edge of Utladalen and up in Fleskenoshaugene. In the early summer of 1964 the tops of the trees of the whole area were reported to be brown and many had lost their needles (letter written by Sigmund Huse, of the Veterinary College). He claimed this had not been the case in 1962. In the summer of 1968 Braanaas (1970) did a very thorough investigation of fluoride damage in the Vettismorki area (see Figure 27 and Appendix G-I-c). Of all the sample trees of giant pines, 15% were in serious danger and 85% in less danger. Tree vitality as measured by growth in diameter was lowest (only 49% of that measured in 1938-1940) in the area nearest Utladalen.

In 1970 Horntvedt (1971) undertook another study of fluoride injury to the Vettismorki area (see Figures 28 and 29 and Appendix G-I-c). Injury observed in 1969 needles indicates a spreading of damage since 1968 (by comparing previous to current year needles). Looking at needles as old as 8 years (dating back to 1961 or 62) indicates that in no year was damage as bad as in 1969. However, in the stations to the south of the factory, the situation was reversed with greater damage being done to the 1968 needles than the 1969 needles. Figure 17 shows that in 1969 the areas to the south of the



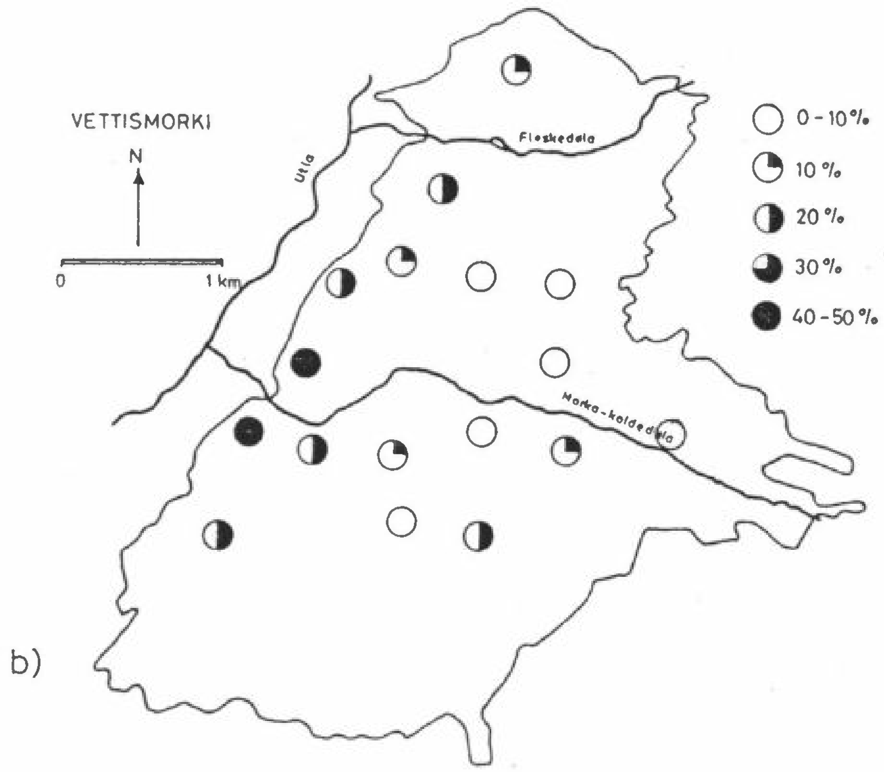


Figure 28: a) Injury to trees in the Vettismorki area in 1968.
Source: Braanaas, 1970.
b) Percentage dead and dyring trees in the Vettismorki area in 1969.
Source: Horntvedt, 1971.

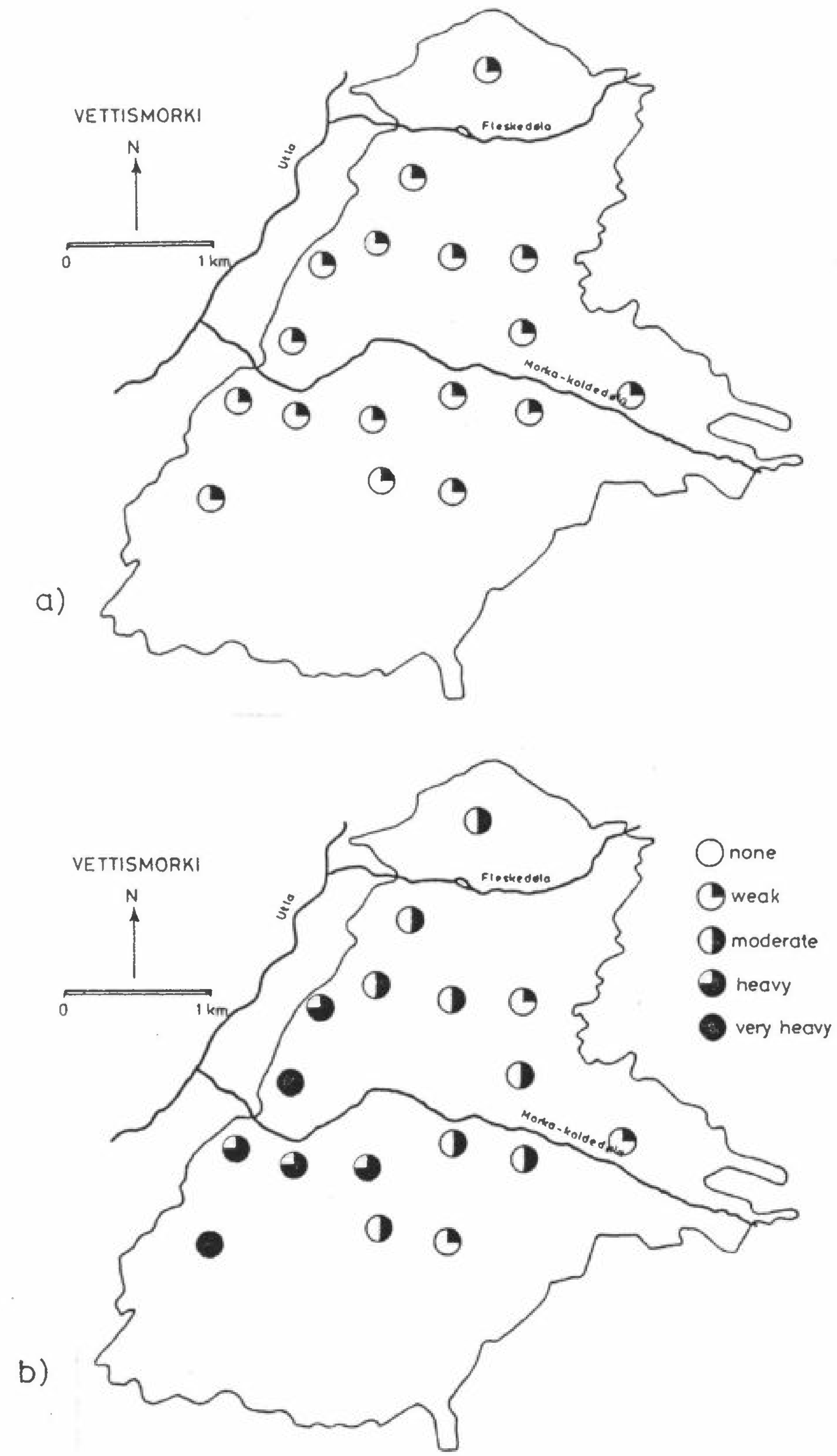


Figure 29: a) Tip-burn in 1968 coniferous needles in Vettismorki.
Source: Horntvedt, 1971.
b) Tip-burn in 1969 coniferous needles in Vettismorki.
Source: Horntvedt, 1971.

factory had mostly winter uptake and little summer uptake indicating possibly predominantly southerly winds during the summer.

Appendix 6-I-c gives more detail on the above-mentioned studies.

8.1.2 Fauna

The amount of information that has been collected on the wild animal population in the Årdal area is extremely small. The only data that are available are fluoride levels in bones from wild deer. These deer were for the most part hunted, although a few were found dead. As seen in Appendix G-I-d, fluoride concentrations vary considerably, yet in some cases can be quite high. Using the same classification system as used for farm animals, one can categorize exposure as none, moderate or serious. Roughly half of the deer were moderately affected, the remainder being distributed between none and serious. Deer wander throughout the entire region (Figure A-10, Appendix A-II) invalidating any attempt to assess the origin of exposure.

Most discussion concerning the effects of fluoride on the wild animal population should focus on what has not, but should be done. There are several food chains that should be followed. The wild deer is a plant eater. Both vegetation and deer are seen to have high concentrations. Next in the food chain are the predators, which in this area would be restricted to predatory birds, the owl, buzzards and ravens. However, since fluoride levels are concentrated in bone and not flesh, this is probably unimportant. Another more important unexplored food chain consists of insects and birds.

It seems quite evident that if deer show such high levels of fluoride, other animals will do so as well. In Appendix A-III is a partial listing of mammals and birds found in the Årdal area. Excluding the occasional visitor, one finds other populations of mammals that are likely to be exposed, e.g. mice, rats, hares and lemmings. The literature has indicated that insects may preferentially feed off of weakened trees. Thus high exposure to fluoride through ingestion can exist in addition to exposure through inhalation. The house wren, an insectivorous bird that eats aphids and dipterians, has been shown to be adversely affected by fluoride emissions around an aluminum factory in Czechoslovakia, (Newman, 1980). The adverse effects included reduced nesting density, colony size and occupancy.

It seems evident that the bird populations in the Årdal area are probably at risk for rather high exposure to fluorides both directly through inhalation and ingestion. A more concerted effort should be made to see what effect this is having on existing populations, especially of rare or endangered species.

The Vettismorki area serves as an important wildlife refuge. It is a desolate, isolated area. As evident in Appendix A-II many birds inhabit the area who are potentially at risk from fluoride emissions. Pollution emissions from Årdal can exert an effect on wildlife through various means: 1) directly, e.g. fluorosis, 2) weakening the health of the animal, increasing it susceptibility to disease or natural stress, 3) changing its ecological habits (e.g. migratory patterns, etc.), 4) changing the balance of species allowing other species to increase in numbers, 5) shifting the age structure of the population, 6) changing vegetation structure thus altering habitats, making them less or more desirable for various species.

Vettismorki's proximity to Jotunheimen as well as its pristine quality increases the necessity for studying in depth the effect of emissions from the aluminum factory on wildlife and the ecology of the region.

8.2 Pollution's effect on the acquatic ecosystem

One cannot discuss the impact of the aluminum factory at Årdal without also considering its impact on water. The largest lake in the area, Årdalsvatn, lies at the foot of steep mountains and separates Årdalstangen from Øvre Årdal. The ground surrounding Årdalsvatn consists of erodable, basic material of volcanic origin. There is much sedimentation where the Utla and Tya rivers join.

The drinking water for Årdalstangen today is extracted from the morraine between the lake and the fjord. Thus, the water from Årdalsvatn passes through several meters of sand which will remove the great majority of pollutants (Baalsrud, personal communications, 1983).

There are several possible man-made impacts on the water supply. Sewage from Øvre Årdal is treated by a biological treatment plant before being relaesed into Årdalsvatn. In addition, precipitation can be contaminated by air pollution in the region. And last, funneling of water in pipes tends to keep water running into the lake, colder than it normally would have been, whereas use by the factory of the water as a cooling agent releases warmer than natural water to the lake. However, despite these possible impacts on water quality, present investigations show that the lake water is very clean with respect to heavy metals and PAH (Baalsrud, personal communication, 1983). In studies doen by NIVA in the late sixties and early seventies (Kristiansen, H., 1971, Hals, B., 1971), the water was also reported to be clean.

The Norwegian Institute for Water Research (NIVA) has done a series of studies in the Årdal area. They are currently (in 1983-1984) doing an investigation of water quality in the Årdal fresh water - salt water system that will be reported to the State Pollution Control Authority. This report will pay particular attention to airborn pollutants and the pH situation.

NIVA has earlier done a series of studies to examine the impact of the factory on the local river fauna (Grande, M., 1971, 1972, 1974). Pollution can affect fish populations in several ways, 1) directly, 2) indirectly via pollutant concentration in the food chain, and 3) indirectly via altered breeding success caused by soot or oil layers on the water. The final report in the series concluded that although injury to fish populations was described earlier in the factory's history, these had been reduced to virtually nothing by 1969. It should be noted however, as seen in Figure 10, that emissions had reached their highest levels by 1970. Fluoride emissions in 1972 (when the last study was done) were only 2/3 those of 1970. SO_2 levels however, have more than doubled between 1970 and 1980.

Greater detail from these reports can be found in Appendix G-II.

8.3 Pollution's effect on man

8.3.1 Effects on human health

After Årdal began production, so much damage was noted to vegetation and farm animals that concern was raised as to the effects of fluoride emissions on human health. Since that time it has been found that aluminum factories also emit large quantities of polyaromatic hydrocarbons (PAH) that are potent mutagens. SO_2 emission levels have been increasing with increased production. Concern over health effects to the inhabitants of the area has increased again in later years.

Due to the composite nature of pollutant emissions, the following are potential areas of investigation of risk to human health: 1) respiratory system; lung function, incidence of respiratory disease, etc., 2) morbidity and mortality, 3) specifically, cancer mortality, 4) dental and musculo-skeletal system; fluoride effects on teeth and bones, and 5) subclinical effects; endocrine system, metabolism, etc. Investigations on health effects should be concerned both with the workers, exposed to the higher concentrations within the factories, and with the inhabitants (including women and children) living in the surrounding region whose exposure are high but not as high. One cannot assume that women and children have the same sensitivity to the effects of air pollution as do adult men. Very little research has been directly done in Årdal itself. Much information concerning occupational exposure can be considered applicable to all factories. However, study on the effects of exposure to ambient levels in the remainder of the population should be done on site.

The concern for the effects of emissions on respiratory function has increased in later years. Evidence indicates that an asthma-like syndrome exists among potroom workers (Bruusgaard, 1960, Glomme et al., 1975). Death due to pneumonia and bronchitis have also been reported to be higher among workers in aluminum factories. No research has specifically addressed this problem in Årdal. A study is about to begin (Nordheim, personal communicaton), however, to examine the incidence and etiology of the asthma-like syndrome at all plants in the Norwegian aluminum industry. No studies have been undertaken concerning the residents (non-workers) around the smelters. Such a study would probably have been of interest.

A great deal of literature exists concerning morbidity and mortality patterns - both among workers and among people living in the vicinity of aluminum plants. No project has concerned itself with Årdal. The literature suggests increased morbidity and mortality due to respiratory diseases and reduced mortality due to cardiovascular diseases (Gibbs, 1979). No study has been done at Årdal on morbidity and mortality, either within the factory or due to ambient pollutant levels (one exception is lung cancer that is discussed in the next paragraph).

Studies in the past have indicated risk of lung cancer and possibly also esophageal cancer among workers in the aluminum industry. One study found increased risk for leukaemia and cancer of the lymphatic system and pancreas, whereas another study found reduced risk. Mutagenicity testing has revealed that the tar components in the air seem to be the most highly mutagenic component of the various compound groups.

In 1981, mutagenicity was tested around four aluminum factories in Norway (Øvre Årdal, Årdalstangen, Høyanger and Mosjøen) at the same time that air quality was measured (Aune et al., 1982; Møller, Hongslo, 1982; Thrane, 1983). Mutagenicity was tested using both T98 and T100 strains of Salmonella typhimurium. Since substances can be mutagenic both directly and indirectly via enzymatic transformation, the tests were repeated with and without the rat liver enzyme activation system S9.

The results indicated:

1) Positive mutagenicity was found at all four sites both with T98 and T100 and both with and without S9. Thus the samples contained both direct and indirect mutagens.

2) Samples from Øvre Årdal were the most mutagenic followed by Årdalstangen, then Mosjøen and last Høyanger. Samples from Øvre Årdal had in some cases 2 to 3 times the mutagenic activity than those from Høyanger.

3) Tests from summer samples in Øvre Årdal were unexpectedly higher than those from winter samples, but unusual meteorological conditions that year may be the explanatory factor.

4) Measured values from Øvre Årdal samples were much higher than those measured in a high traffic street in downtown Oslo (St. Olav's gate).

One study has been done in Norway concerning increased risk of lung cancer in workers of several smelters including Årdal (Andersen et al., 1982; Kreyberg, 1982). This study, although indicative of increased risk, remained inconclusive because of an inability to account for smoking habits in determination of risk.

The dental and musculo-skeletal system has received a great deal of interest over the years because of fluoride's known effect on teeth and bones. One study is currently underway at Årdal by Dr. Willy A. Nielsen, at the Institute for Cariology and Odontology in Bergen that is examining the dental effects of fluoride in children. Preliminary results indicate the possibility of reduced caries in children living in Årdal as opposed to the control area Florø (Nielsen, personal communication). No studies concerning structural changes in bones, or disease of the musculo-skeletal system has been done.

Fluoride and probably the other pollutants as well alter metabolism, endocrine function and other systems of the body to a certain although sometimes only a small degree. What subclinical effect this will ultimately have on health is unknown and largely unstudied. Again no work has been done or is being planned concerning this area.

By the mid 1980's a certain number of research projects on health and disease in Årdal should be completed allowing for a better overview of the risk to health posed by the pollution emissions of the smelter. Certain research areas, however, are not being studied that could be considered as being of potential interest in the future.

One questionnaire study (Årdalsprosjektet, 1970) compared perception of health in various population groups living in Årdal (see Appendix G-III-a). Unskilled male employees working in the aluminum factory complained more of nervous complaints, stomach ailments, eye, nose and throat irritation than those working elsewhere in Årdal. They did not complain more of headaches, pharyngitis, bronchitis or asthma, or pain in the back, hips or sciatica.

Males working in offices in the factory, complained more of headaches and migraine, and pharyngitis, bronchitis or asthma than office employees for other employers than the aluminum factory in Årdal. However, they have few nervous complaints, stomach ailments, eye, nose and throat irritation and pain in back, hips and sciatica. These findings are interesting and should be looked into in more detail.

8.3.2 Social consequences

Living conditions in Årdal have been the subject of an extensive investigation based on interviews. The study was carried out in the 1970's (Årdalsprosjektet, 1973, see Appendix G-III-b).

As pointed out earlier (section 3), the community of Årdal has changed from a typical farming community to an industrial community with one main employer, the aluminum factory. This employer has led to Årdal having the most stable population (less than 1.1% change in population numbers between 1970 to 1978) in Sogn og Fjordane. Årdal also has a greater percentage of male inhabitants, the least number of people aged over 67, and the highest yearly income. Three quarters of this income comes from industry, less than 1/10 from farming and 1/4 from services. This division of sources of income can be compared to another municipality in the region, Førde, which has roughly 1/3 of income originating from each of the three sources (Statistisk fylkeshefte 1977 and 1980, Statistisk Årbok, 1980).

The adverse impact of the aluminum factory on farming activities has been extensive, and the farms adjacent and near the smelter had to close down. (One farm, Eldegård, had been in the same family for more than 300 years). Other farms further away, in Seimsdalen and Ofredal, have been able to continue, but in a reduced and less intensive mode of operation. Milk production, in particular, was rendered impossible. The early slaughter of sheep (4 to 5 years instead of 5 to 7 year life-span) also lead to reduced production. The reduction in the production of fruit has been documented (section 7.2).

The possible adverse social consequences of a small society dependent on a single source of income is documented in the Årdalsprosjektet report. However, the role of air pollution in preventing a more balanced society with alternative sources of income is not discussed, yet may be a decisive factor for other activities such as farming, tourism, small industry, fish nursuries, etc.

8.3.3 Effects on the feeling of well-being

Factory emissions can also affect the human sense of well-being (health and disease treated in a previous section). Frustrations, fear, as well as reduced health can lead to a lowered feeling of well-being. Some frustrations are: having to dust every day; inability to hang clothes on the line; fear for children's health, inability to have flowers in a garden, damage to paint on cars. Severe complaints of dust by organized groups of local housewives was important in initiating the procedure that finally culminated in a monitoring program. The large study, Årdalstangenprosjektet, examined many of these factors.

Most of the people in Årdal live either in Øvre Årdal or in Årdalstangen, close to the factories. Only 9% of the population indicated that they were not all bothered and 22% said they were very bothered by air pollution (the remaining expressed different degrees of annoyance). Those living at Ve were more bothered than those at Farnes in Øvre Årdal because wind generally blows from the factory in that direction. People at Årdalstangen feel better off than those at Øvre Årdal (Appendix G-III-c).

The most common complaints were that laundry hung out to dry would get dirty and window sills needed to be washed every day. At Ve they also complained of etched window panes due to the reaction between ambient fluoride and glass.

Even those in Seimsdal and Naddvik were bothered by air pollution, though levels are considerably less there than at Årdalstangen or Øvre Årdal. However, income in these valleys is based on activities that might be adversely affected by air pollution so that the inhabitants may be more aware of the problem.

9 CONCLUSIONS

The aluminum industry has played an important role in Norway's history. It is also an industry whose emissions have been known to produce severe injury to forestry and farming. In order to more properly assess the impact of this industry on the surrounding region, one smelter in western Norway (Årdal) was chosen for review.

Several factors are distinctive for the Årdal factory:

1) It is situated in a long, deep and narrow valley, perfect conditions to intensify air pollution problems.

2) It lies adjacent to some of the most pristine areas of the Jotunheimen Natural Park.

3) Årdal is one of the older and larger factories (it began production in 1948) and has the highest emission levels of gaseous fluoride and probably polycyclic organic material (POM) as well, for all the factories in Norway.

The most important emissons resulting from the production of aluminum are: fluoride, sulphur compound, dust and POM.

In an attempt to control the impact of air pollution on the commercial interests of forestry and farming, a yearly monitoring program was established in 1967. This program has been designed to cover factory emissions, fluoride uptake by conifers (especially pine), fruit trees, hay and pasture grass as well as measuring fluoride accumulation in animal bones.

Now after 35 years of existence and 15 years of a regular monitoring program, it seemed necessary to assess the impact of the factory on the region.

9.1 Effect of air pollution on commercial interests

The most studied impact of the smelter has been on the commercial interests. Although the factory itself has improved the economy and stabilized the population of the region, it has also necessitated a complete stop in dairy farming, with substantial reduction in animal husbandry, fruit and vegetable farming and forestry activities.

In order to evaluate the effect of fluoride, it is necessary to have an idea of ambient levels. Fluoride emission levels varied from a high in 1970 of 60 kg/h to a low in 1975 of 25 kg/h. Air levels measured at Øvre Årdal varied between 4 - 7 $\mu g/m^3$ in winter, between 1972 and 1982, and 2 - 4 $\mu g/m^3$ in the summer.

9.1.1 Conifers

Levels of fluorides in the needles of conifers indicate that fluoride pollution has been high and has travelled long distances, both to the northeast and southwest of the factory. Levels in needles were high even as far as 17 to 18 km away in the main valley. When comparing fluoride levels to emission levels over the years, it becomes evident that other factors such as precipitation are also very important in influencing fluoride content of needles.

Based on the assumption that to prevent any injury, fluoride values in current year needles should not exceed 10 ppm (Horntvedt, personal communication) one sees values were so low only 3-4 km into the side valleys of Ofredal and Seimsdal, (roughly 14-17 km away).

Moadalen, to the east of the factory, and Utladalen, to the northeast, were very severely damaged as far back as 1951, and conifers have never grown back in Moadalen. Observations in 1963, 1971 and 1976 indicated that fluoride injury to conifers had spread to Resnes and Naddvik. The 1976 observation was particularly interesting since it indicated that areas that had been in the process of recovering were newly injured.

9.1.2 Fruits and vegetables

The production of apples, plums and pears is an important industry in this part of the country. In 1962, the trees on the Moa farm were lost. In 1976 one of the farms at Årdalstangen reported severe injury. However, it was noted at the time that the damage resembled more SO_2 injury than fluoride. One interesting study of fruit production levels on one farm, indicated that during the 20 year span from 1949 to 1969, pollution reduced fruit crop yield by a total of 54%.

An earlier study on fruits and vegetables indicated that root crops contain very little fluoride, fluoride in fruits is concentrated in the peel and grains contain the most fluoride.

9.1.3 Farm animals

Injury to farm animals was one of the earliest described effects of fluoride. Dairy farming is totally forbidden in areas surrounding aluminum smelters. Following a courtcase in 1956, one time compensation was awarded to many farmers in the area. Many farms ceased to function from that time. Others, further from the factory, continued to operate, relying more on purchased feed. Complaints during the years have included that lambs weighed 1/3 to 1/2 normal weight (never confirmed); lambs have needed to be slaughtered 1 to 2 years earlier than in unpolluted zones, and the necessity of slaughtering sheep and cows because of fluorosis. As late as 1982, two cows from Vetti in Utladalen were slaughtered because of fluorosis.

Accepting that a limit of 30 ppm fluoride in hay and pasture grass is necessary to prevent injury to farm animals (SFT report No. 38), one finds that these values can only be assured in inner Ofredal and Seimsdal valleys.

9.2 Effect on the terrestrial and acquatic ecosystems

During the years isolated injury has been observed on the natural flora and fauna of the area. Fluoride in bones of occasionally found or shot deer have been analyzed. Some animals seem to have died of fluorosis. Otherwise no information has ever been gathered on other animal life such as small herbivorous mammals, birds or insects.

Injury has been observed on the birch forests in the area. Much damage was noted in 1964 in Moadalen. Spreading of damage to birch forests was again noted in 1976, with the Heirsnosi cliff strongly affected in 1981. In both cases, the possible increased risk for earthslides was mentioned. No systematic measurements of fluoride are made of birch leaves.

The impact of air pollution on the terrestrial ecosystem is even less understood. Ecosystems consist of a balance of plant and animal species that offer food and shelter to other species in the ecosystem. Little is known of accumulation of pollutants such as fluoride or POM through such food chains as vegetation-herbivore or insect-carnivore. High fluoride levels in wild deer, levels that may even have been partial cause of death, indicate that such research is necessary. Altering plant species variability and distribution can have repercussions on animal survival through disappearance of habitats necessary for reproduction and survival. Large scale destruction of vegetation increases erosion and the chance for earthslides. Severe damage to birch forests in the area increase the desirability of furthering studies in these fields. It would have been interesting, for example, to study the changes that have occurred in Moadalen.

The importance of documenting the impact of air pollution on the terrestrial ecosystem seems even more appropriate in Årdal because of the proximity of the Vettismorki area of the Jotunheimen National Park, an important wildlife refuge. It is already known that extensive damage to the old pines, some thought to be over 800 years old, has occurred. Systematic measurements are needed to assess if damage is spreading.

Although the impact of the factory on the acquatic ecosystem was fairly extensively studied in the early 1970's, current surveys are necessary. An investigation of the water quality of the Årdal fresh water - salt water system is being carried out in 1983-1984 by The Norwegian Institute for Water Research.

9.3 Effects on man

Pollution can affect both man's health and his feeling of well-being. Some information is known concerning the effects of pollution inside the factories on the health of the workers, although very little work has been done, specifically in Årdal. However, nothing is known about the effect of exposure to those ambient levels found around the factory in the possibly more sensitive populations of women and children. This has become of even greater interest after the discovery of the high levels of polycyclic organic compounds emitted by aluminum smelters. In contrast, more is known about the feeling of well-being expressed by the inhabitants of Årdal. Only 9% of the population indicated that they were not at all bothered by air pollution whereas 22% said they were strongly bothered (the remainder expressed being bothered to varying degrees).

Table 1 chronologically sums up comments or observations made from 1964 through 1982 (primarily from the yearly reports) stemming from pollution problem in the Årdal region. This table gives a good impression of the dimensions of the problem there.

Revisions to the current monitoring program should be considered. These revisions should:

1) Extend measurements of ambient pollutants and meteorological parameters.

2) Extend measurements to include the flora and fauna such as birch, wild birds, insects, etc.

3) Include more systematic measuring of pollution effects or injury caused by pollution.

Table 1: A review of comments and observations made between 1964 and 1982 in the Årdal region.

Year	Comment or observation	Source
From miscellaneous sources		
1964	Many complaints of soot and dust in Årdal Damage to forests in Vettismorki	S. Huse (NLH)
1965	Fluoride levels in pasture grass and hay very high	F. Ender
1967	Complaints of dust from Årdalstangen	Local garden society
	In Årdal from 1950 to 1963, 9 horses, 176 cows, 354 sheep and 267 goats were slaughtered because of fluoride injury	Printed in The Farsund newspaper (21.6.1967) from information from the Veterinary Directorate.
1970	Large investigation of damage trees	R. Horntvedt
From Yearly reports to Kontrollutvalget for aluminiumverkene		
1968	Very high fluoride levels in pasture grass and hay - animal husbandry stopped at Moen, Lykkja, Svalheim and Eldegård farms.	I.L. Flatla
	High values of F in coniferous needles in 1967 at many stations outside the region of damage noted in the 1950's.	H. Robak

Table 1 cont.:

1969	Very high fluoride levels in past. grass and hay. Not unusual to find fluoride damage in animals. Complete stop of animal husbandry on several farms.	I.L. Flatla
	Fluoride damage in farm animals in Årdal The same as previously reported.	Dist.vetr. Heimdal
	Fluoride levels in coniferous needles are persistently too high in the whole of Utladalen and valleys in Årdal.	H. Robak
1970	High F-values in coniferous needles.	
1971	F-levels in past. grass and hay consistently very high in most places. Almost all animal husbandry stopped on most farms in Utladalen. High F-content in bones from Seimsdalen.	I.L. Flatla
	No new cases of fluorosis in farm animals in Årdal.	Dist.vet. Heimdal
	Sharp increase in F-levels in the Vettismorki stations.	
1972	F-level in past. grass and hay still very high. F-content in bones very high, especially in Utladalen. Extremely high F-values in a deer found dead.	I.L. Flatla
	Teeth defects in sheep, especially in Utladalen and Øvre Årdal.	Dist.vet. Østenvig
	F-content in needles, to a great degree the same as the previous year.	H. Robak
1973	F-levels in hay and past. grass, high in most places. Bone analysed indicate substantial to strong F-exposure. Diagnosed fluorosis in sheep from Naddvik (5 km SW of Årdalstangen). Analyses of deer indicate substantial F-exposure. No diagnosed fluorosis in cattle in 1973. Teeth effects registered in sheep.	I.L. Flatla
	F-levels in needles remain quite high, but a little lower than in 1972.	H. Robak
1974	F-levels in hay and past. grass somewhat lower than in 1973, but still high enough to indicate risk for F-effect on animals. Bone analyses indicate high F-concentrations.	M. Hansen

Table 1 cont.:

	F-levels in needles very similar to 1973.	H. Robak
	Suspicion of some cases of fluorosis in farm animals.	Dist.vet. Østenvig
1975	F-level in hay and past. grass somewhat higher than in 1974 - danger for F-injury to animals at many places. Bone analyses (6 animals indicate that all the animals have been exposed to substantial F-levels.	M. Hansen
	Total F-uptake in needle lower than in 1974, but still quite high. Continued quite high levels in fruit tree leaves, especially at Årdalstangen.	H. Robak
1976	F-levels in hay and past. grass higher than in 1975 in most places, with fairly high levels at many stations.Danger for F-injury to farm animals especially in Utladalen, Fardalen and around Årdalstangen. F-effect on teeth in sheep and goats.	M. Hansen
	Higher F-content in pines and spruce needles than has been recorded for several years. More tip-burn observed than in the last few years. Severe tip-burn observed on deciduous trees and horticultural plants at Årdalstangen. Greater F-uptake in fruit tree and tomato leaves than in 1975.	R. Horntvedt
1977	F-content in hay and past. grass higher than in 1976 and risk for F-injury to farm animals. Bone analyses from 1978 indicate that all animals have been clearly exposed to F-effect at Årdalstangen and Seimsdalen. Teeth effects noted in sheep and goats.	M. Hansen
	F-uptake in current year's needles higher than in 1976 at most places. Tip-burn in Vettismorki on current year's needles more severe than on previous year's and earlier needles.	R. Horntvedt
1978	Samples from vegetation indicate a substantial decline in F-values, but still levels are high in many places. Utladalen and portions of Fardalen are most exposed.	M. Hansen

Table 1 cont.:

	Most F-values in trees from Årdalstangen and Seimsdalen are substantially lower in 1978 than in 1977, while values from Øvre Årdal are higher.	R. Horntvedt
1979	A general tendency for lower values than earlier, but a few isolated very high values (that may have been contaminated).	M. Hansen
	Analyses indicate lower F-uptake in vegetation in 1979 than in 1978.	R. Horntvedt
1980	Hay samples are approximately the same as in 1979. Past. grass indicates an increase in F-levels. Diagnosed substantial F-effect on 2 animals (cow and sheep).	M. Hansen
	No samples collected from forest stations. F-levels in fruit trees higher than in 1979.	R. Horntvedt
	F-emissions were higher in 1980 than in the last few years, especially than in gaseous form.	J. Jahr
1981	Increase in F-content in hay and somewhat in past. grass. F-levels in vegetation samples are overall so high that animals are exposed to a F-effect.	M. Hansen
	No samples collected from forest stations in the spring. Current year's needles sampled in the fall had substantially higher F-levels than the average for 1973 to 1979.	R. Horntvedt
	F-emissions in 1981 were as high as 1980, especially in gaseous form.	J. Jahr
1982	2 cows had to be slaughtered at Vetti because of clinical fluorosis (lameness).	M. Hansen

10. FUTURE ACTIVITIES

10.1 General discussion

This report is a review of what in some cases includes almost 30 years of data and 15 years of a regular monitoring program. After reviewing what is known and not known, one can examine the current program and see if it fulfills the needs, and goals for which it was originally established and whether or not it should be expanded.

Therefore suggestions for what should be done in the future can be divided in two: one are suggestions for the monitoring program itself, and two are suggestions for future research.

10.2 Suggestions for the development of the monitoring program.

Two goals can be identified for the monitoring program: 1) to maintain an independent record of air pollution levels and their effect on vegetation, fauna, and human health and well-being, and 2) to provide a basis for remedial actions, e.g. reducing emissions, stop grazing on pasture grass with too high levels of fluoride, etc.

To meet these goals, the monitoring program needs to provide sufficient, reliable information on air quality, and fluoride contamination in vegetation and animals.

Air quality

Information is needed on a regular basis on meteorological conditions. Wind frequencies, average precipitation by month, temperature, and humidity should be included in the yearly report.

Information is also needed on emissions levels. Each yearly report should include monthly fluoride emissions both total and gaseous fluoride, as well as SO_2 and particulates (dust). Due to the recent finding of elevated polycyclic organic material, the inclusions of regular information on POM emissions should be considered.

It would also be beneficial to consider expansion of the measurements of ambient pollutants to include more frequent measuring and possibly more sites.

Vegetation

The trees currently monitored are those having the greatest economic interest, that is conifers and fruit trees (grass will be included in the section on animals).

The number and placement of sites for the measurement of conifers seems adequate. Likewise, fruit trees are sampled where fruit tree production occurs. There is need, however, to assure that samples are regularly collected from all sites every year.

Trees are injured by fluoride content within the needle. The current practice is to measure needles unwashed. Whereas this is a useful practice for grass and hay (being reflective of actual intake) it may be misleading in the case of trees. The possibility of doing samples both washed and unwashed should be explored.

Deciduous trees are the most prevalent type in Årdal and yet never systematically measured. Although not of the highest economic importance, they are of esthetic value and are an important factor in the reduction of threat of avalanches. Sampling sites can be selected so as to provide information as to spread of emissions. It is recommended that they be included in the control program.

Actual injury to forests is not measured systematically. However, the spread and extent of injury to the forest should be documented using standardized methodology that allows comparing damage from one time period to another. It is not necessary that this added aspect of the monitoring program be repeated on a yearly basis. Some parameters could be measured at intervals of, for example, 5 years.

Farm animals

The most consistent measure of animal injury has been through the monitoring of the forage crops grass and hay. Sampling pasture grass and hay should be restricted to areas where cattle and sheep are still kept, and the results used for advising the farmers of remedial action. However, it is possible that a reevaluation of the sites currently being sampled is justified. The possibility should be explored of measuring fewer sites in the smaller valleys. For example, it may be possible to reduce the number of sites in Seimsdalen or Ofredal to one at either end of the valley, estimating values at intermediate sites. It is important, however, that those sites that are chosen, be measured regularly at least three times a year, spring, summer and fall. The possibility should also be explored of adding one or two sites up in the mountains where sheep are likely to graze in the summer.

The collecting of bone samples has been very sporadic in Årdal for a variety of reasons. Methods of increasing the supply of bone samples should be investigated. Solutions may require not sampling every year but rather every 2 or 3 years, but then sampling thoroughly.

A regular survey at, for example 5 year intervals, of animal health and possible fluoride injury would have been beneficial. Incorporating such a step into the monitoring program would allow developing and standarizing a methodology that would allow comparison between time periods.

10.3 Suggestions for future research

In addition to the regular monitoring program, it would be useful to incorporate research into the scope of the monitoring program. There are several needs not covered by the monitoring program that warrant further investigation.

Not enough is known about the relationship between ambient fluoride concentrations and the concentration of fluoride in grass, or the appearance of damage to various plant species. This could be examined by carefully selecting several sites that differ in air quality. Using these sites, measurements could be made at more frequent intervals, coupled with more frequent measuring of ambient air parameters such as fluoride, and SO_2. In addition potted plants could be used to measure fluoride deposition.

More emphasis should be put on the effects on the human population, both exposure (blood or hair sampling) and actual effect both to health and to well-being (as for example smell, excessive soiling etc.).

And finally more effort should be put into measuring both fluoride levels and effect on the natural environments both terrestrial and aquatic. This would include not only effects on the individual species of plants or animal, but also effects on the ecosystem level.

ACKNOWLEDGEMENT

This report is merely the collection of data meticulously collected by many individuals:

- prior to 1967, two names stand out, Professor F. Ender and Professor J.L. Flatla;

- after 1967, Professor H. Robak and J.L. Flatla, subsequently followed Dr. R. Horntvedt and Professor M. Hansen.

During its several revisions, the constructive criticism of many individuals was invaluable: R. Horntvedt (NISK), M. Aas Hansen (NUH) and P.Å. Beck (SFT), in addition to many colleagues at NILU.

At the Norwegian Institute for Air Research, we were many to contribute to the making of this report. First and foremost, O.F. Skogvold, who personally wrote many sections. Ivar Haugsbakk and Kjell Skaug were also very important to its final realization. Finally, this report has required an unusual amount of tables, drawing and graphs and could not have been completed without the patient help of Kirsten Gram and May Aamodt.

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(NORGES TEKNISK-NATURVITENSKAPELIGE FORSKNINGSRÅD)
POSTBOKS 130, 2001 LILLESTRØM
ELVEGT. 52.
TLF. (02) 71 41 70

RAPPORTTYPE OPPDRAGSRAPPORT	RAPPORT NR. OR 56/83	ISBN--82-7247- 425-5
DATO OKTOBER 1983	ANSV.SIGN. O.F. Skogvold	ANT. SIDER 95
TITTEL Air pollution and its biological effects in areas in Norway, Part I		PROSJEKTLEDER O.F. Skogvold NILU PROSJEKT NR. O-8139
FORFATTER(E) Jocelyne Clench-Aas		TILGJENGELIGHET** OPPDRAGSGIVERS REF.
OPPDRAGSGIVER Statens forurensningstilsyn		
3 STIKKORD (á maks. 20 anslag) Fluoride	Biological Effects	Aluminum Industry
REFERAT (maks. 300 anslag, 5-10 linjer)		
TITLE		
ABSTRACT (max. 300 characters, 5-10 lines. This report discusses the impact of an aluminum factory on the surrounding valley in Norway, Information covers: emissions, meteorology, topography, population, fluoride uptake in vegetation and animals, and resultant effects on forestry, farming, terrestrial and acquatic ecosystems, and man. Data covered as much as 30 years.		

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