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Descriptions of Research Sites in the Integrated Forest Study on Effects of Atmospheric Deposition

E. A. Bondietti

Environmental Sciences Division
Publication No. 3279

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ENVIRONMENTAL SCIENCES DIVISION

DESCRIPTIONS OF RESEARCH SITES IN THE INTEGRATED FOREST STUDY ON EFFECTS OF ATMOSPHERIC DEPOSITION

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Note added in proof: E. A. Bondietti was killed in an automobile accident on February 16, 1990, while returning from a scientific conference at which he presented some of his own research on the Integrated Forest Study. His early contributions to the organization and management of the IFS are recognized and appreciated by those associated with the study.

S. E. Lindberg, Project Manager
Oak Ridge, Tennessee
February 21, 1990

ABSTRACT

E. A. Bondietti (editor). 1990. Descriptions of research sites in the integrated forest study on effects of atmospheric deposition. ORNL/TM-11149. Oak Ridge National Laboratory, Oak Ridge, Tennessee. 140 pp.

The Integrated Forest Study on Effects of Atmospheric Deposition (IFS) was a multisite, multiyear research project designed to study the effects of atmospheric deposition on forest nutrient status. This report discusses the field sites that were studied and was prepared from reports submitted by the investigators. In many cases the reposit represents information available at the beginning of the study and therefore it should not be considered as a final representation of all site characteristics. A separate report, ORNL/TM-11148, describes the objectives, participants, and measurement design of the IFS. Other reports in this series describe the sampling and analysis protocols used in the IFS (ORNL/TM-11214), preliminary data from year 1 of the study (ORNL/TM-11052) and the annual report of 2 years data collection (ORNL/TM-11121).

I. INTRODUCTION

This site descriptions report documents the site characteristics and site-specific measurement approaches of participating sites in the Integrated Forest Study on Effects of Atmospheric Deposition (IFS), a multiyear integrated research effort designed to improve our understanding of how chemicals which are deposited from the atmosphere influence the mineral nutrient cycles in forests. The research has been performed at a series of forested sites in the U. S., Canada, and Norway (Fig. 1 and Table 1). A full description of the study and the detailed measurement protocols are presented in a companion document (ORNL/TM-11214). Other reports in this series describe the preliminary data from year 1 of the study (ORNL/TM-11052) and the annual report of 2 years data collection (ORNL/TM-11121).

The IFS was proposed to the Electric Power Research Institute by ORNL in 1983, was initiated in 1985, and was completed in 1990. Oak Ridge National Laboratory coordinated the research effort (Fig. 2) and provided the basic measurement protocols. Investigators at each site were responsible for site-specific implementation of these protocols. Several of the sites described in this report represent cooperative efforts which were administratively distinct from Oak Ridge National Laboratory. The information presented in this report was meant to assist readers in understanding the characteristics of each site. More detailed information should be obtained from each principal investigator.

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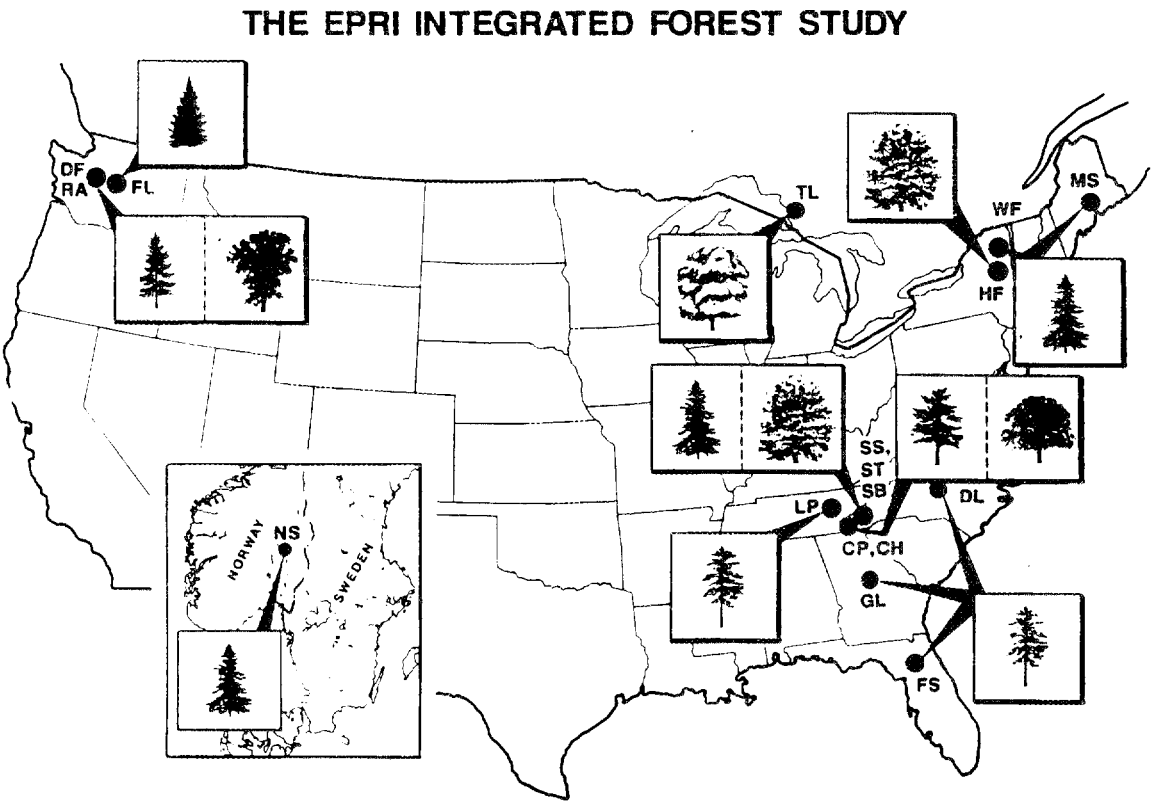

Fig. 1. Sites in the Integrated Forest Study.

Table 1. Sites in the EPRI Integrated Forest Study (arranged from West to East, See Fig. 1 for site codes and locations).

INTENSIVE DEPOSITION MEASUREMENT SITES:

SITE CODE	FOREST TYPE (-Elevation)	SITE LOCATION	PRINCIPAL INVESTIGATOR
DF	Douglas Fir (220 m)	Thompson Forest, WA	D. Cole, H. Van Miegroet
RA	Red Alder (220 m)	Thompson Forest, WA	D. Cole, H. Van Miegroet
LP	Loblolly Pine (300 m)	Oak Ridge, TN	S. Lindberg, D. Johnson
ST	Red Spruce (1740 m)	Smoky Mountains, NC	S. Lindberg, D. Johnson
CP	White Pine (720-1100 m)	Coweeta Hyd., Lab., NC	W. Swank
GL	Loblolly Pine (175 m)	BF Grant Forest, GA	L. Ragsdale, J. Dowd
FS	Slash Pine (100 m)	Gainesville, FL	H. Gholz
DL	Loblolly Pine (215 m)	Duke Forest, NC	K. Knoerr, D. Binkley
TL	N. Hardwoods (350 m)	Turkey Lakes, Ontario	N. Forest
HF	N. Hardwoods (530 m)	Huntington Forest, NY	M. Mitchell
WF	Red Spruce, Balsam Fir (1000 m)	White Mt., NY	A. Friedland
MS	Red Spruce (60 m)	Howland, ME	I. Fernandez
NS	Norway Spruce (200 m)	Nordmoen, Norway	A. Stuanes

BULK DEPOSITION ONLY SITES:

FL	Fir, Hemlock (1100 m)	Findley Lake, WA	D. Cole
SS	Red Spruce (1800 m)	Smoky Mountains, NC	D. Johnson

Table 1. (continued)

INTENSIVE DEPOSITION MEASUREMENT SITES:

SITE CODE	FOREST TYPE (-Elevation)	SITE LOCATION	PRINCIPAL INVESTIGATOR
SB	American Beech (1600 m)	Smoky Mountains, NC	D. Johnson
CH	S. Hardwoods (700-1000 m)	Coweeta Hyd. Lab., NC	W. Swank

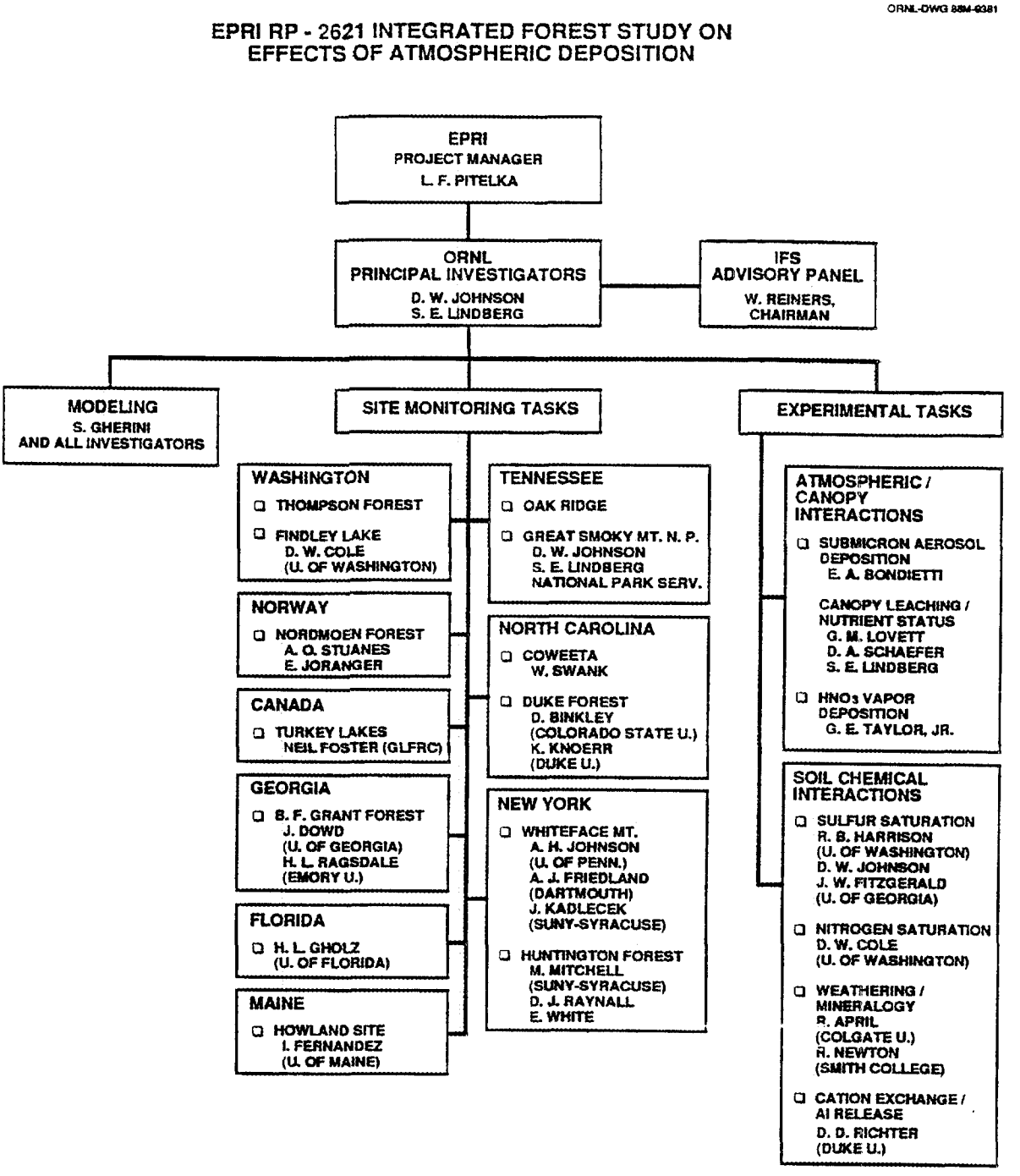

Fig. 2. Organization of the Integrated Forest Study.

II. FIELD SITES

GREAT SMOKY MOUNTAINS SITE

(Beech, Red Spruce)

PARTICIPATING INSTITUTIONS AND INVESTIGATORS - D. W. Johnson, S. E. Lindberg, H. Van Miegroet, D. E. Todd, D. A. Schaefer, K. C. Dearstone, R. B. Harrison, and J. Owens, Oak Ridge National Laboratory; J. Peine and D. Silsbee, National Park Service, Uplands Research Laboratory; G. M. Lovett, Cary Arboretum, Millbrook, New York.

SITE DESCRIPTION AND LOCATION

All three of the Smoky Mountain sites (beech, Becking site - red spruce and Tower site red spruce) are located near Clingmans Dome at elevations 1650-1770 m in the Great Smoky Mountains National Park near 35° 34′ N and 83° 28′ W.

Climate

The climate is characterized by cool summers and cold (but not severe) winters. Stephens (1969) reported average temperatures of -1.8°C for February and 14°C in July for the 1524 m elevation in the park. The distribution of precipitation is fairly uniform, averaging about 19 cm/month or 228 cm/year at the 1524 m elevation (Stephens, 1969 as cited by Becking and Olson, 1976). Snow cover varies considerably within a winter and from year to year; a snowpack lasting through the winter seldom forms, although snow cover typically occurs for approximately 50 days per year (Stephens, 1969). The average occurrence of the first frost is October 4 and last frost is May 9 at the 1524 m elevation (Stephens, 1969 and cited by Becking and Olson, 1976).

Geology

Most of the bedrock in the Great Smoky Mountains is of the Ocoee series and ranges from conglomerates and poorly sorted, coarse-grained sandstones to shales, slates, and phyllites (Wolfe, 1967). The two dominant bedrock types in the study area are the Anakeesta formation, a very dark gray to black slate and phyllite interbedded with sandstone

and conglomerate, and Thunderhead sandstone, a thick-bedded feldspathic sandstone quartzite and conglomerate interbedded with gray slate and phyllite (USDA, 1984).

IFS NUTRIENT CYCLING SITES

Beech Site

The beech site is located on a southerly 30° slope at an elevation of approximately 1600 m 1 km west of Newfound Gap on the road to Clingmans Dome in the Great Smoky Mountains National Park. Soils are classified tentatively as Umbric Dystrochrepts derived from the Anakeesta formation. The soil profile consists of a thin, patchy litter layer (Oi = 1 cm, Oa $\leq$1 cm), a 10-cm-thick A horizon of dark reddish brown loam, a 12-cm-thick BA horizon of brown loam, a 23-cm-thick Bw horizon of strong brown clay loam, a 15-cm-thick CB horizon of brown shaly sand loam, and a C horizon of undetermined thickness (but at least 30 cm) of brown very shaly sandy loam. Roots are most abundant in the surface 25 cm, but are found up to depths of 70 cm.

Overstory vegetation consists primarily of beech (*Fagus grandifolia*) with occasional buckeye (*Aesculus octandra*) and red spruce (*Picea rubens*). Understory is dominated by carex (*Carex eastivalis*), angelica (*Angelica triquinata*), stinging nettle (*Urtica* spp), white snake root (*Eupatorium rugosum*), blackberry (*Rubus canadensis*), goldenrod (*Solidago caesia*), and various ferns.

Becking Spruce Site

The Becking spruce site was so named because it was located on one of the vegetation inventory plots established by Rudolf Becking in 1976 (Becking and Olson, 1976). It is located at an elevation of 1800 m on a southwest slope on a spruce ridge west of Nolan Divide near Clingmans Dome.

The soils are classified tentatively as Umbric Dystrochrepts derived from Thunderhead sandstone. The landscape is characterized by frequent large sandstone boulders on top of and within the soil profile (SCS Class 5). The profile consists of a 3-cm-thick Oe + Oi horizon of leaves and needles in various stages of decay, a 6-cm-thick Oa horizon

of mucky humus, a 15-cm-thick A horizon of dark brown bouldery mucky silt loam, a 22-cm-thick Bw horizon of yellowish brown, bouldery loam, a 15-cm-thick BC horizon of yellowish brown, very bouldery loam, and a 16-cm-thick C horizon of pale brown, extremely bouldery sandy loam overlying sandstone bedrock. Roots are abundant in the A horizon, diminishing rapidly in abundance with depth and virtually absent in the C horizon.

Overstory vegetation consists primarily of old-growth (200 to 300 years old) red spruce with occasional Fraser fir (Abies fraseri), many of which are suffering from infestations of the balsam wooly adelgid. The understory is dominated by patches of Fraser fir regeneration ranging from 4-12 cm in diameter and undergoing significant mortality. Other understory species of note are blackberry, vaccinium (Vaccinium erythrocarpum), witch hobble (Viburnum alnifolium), sorbus (Sorbus americana), oxalis (Oxalis acetosella), various ferns, and abundant mosses.

Tower Spruce Site

The tower spruce site is located at an elevation of approximately 1740 m on a southerly slope (15°) on Nolan Divide near a spur road branching off the main road to Clingmans Dome (Fig. 3). The site was so named because a meteorological tower for detailed atmospheric deposition measurements is located there. The soils are classified tentatively as Umbric Dystrochrepts derived from Thunderhead sandstone. The profile consists of 4-cm-thick Oi + Oe horizon of needles and leaves in various stages of decay, a 4-cm thick Oa horizon of mucky hums, an 8-cm-thick dark, reddish brown mucky loam A horizon, a 27-cm-thick dark brown sandy loam Bw horizon, a 35-cm-thick dark yellowish-brown loamy and CB horizon, and an olive-brown loamy sand C horizon at least 20 cm thick overlying sandstone bedrock.

Overstory vegetation is dominated by vigorous, old-growth (200-300 years old) red spruce with an occasional yellow birch (Betula alleghanensis). Understory consists of patches of Fraser fir and

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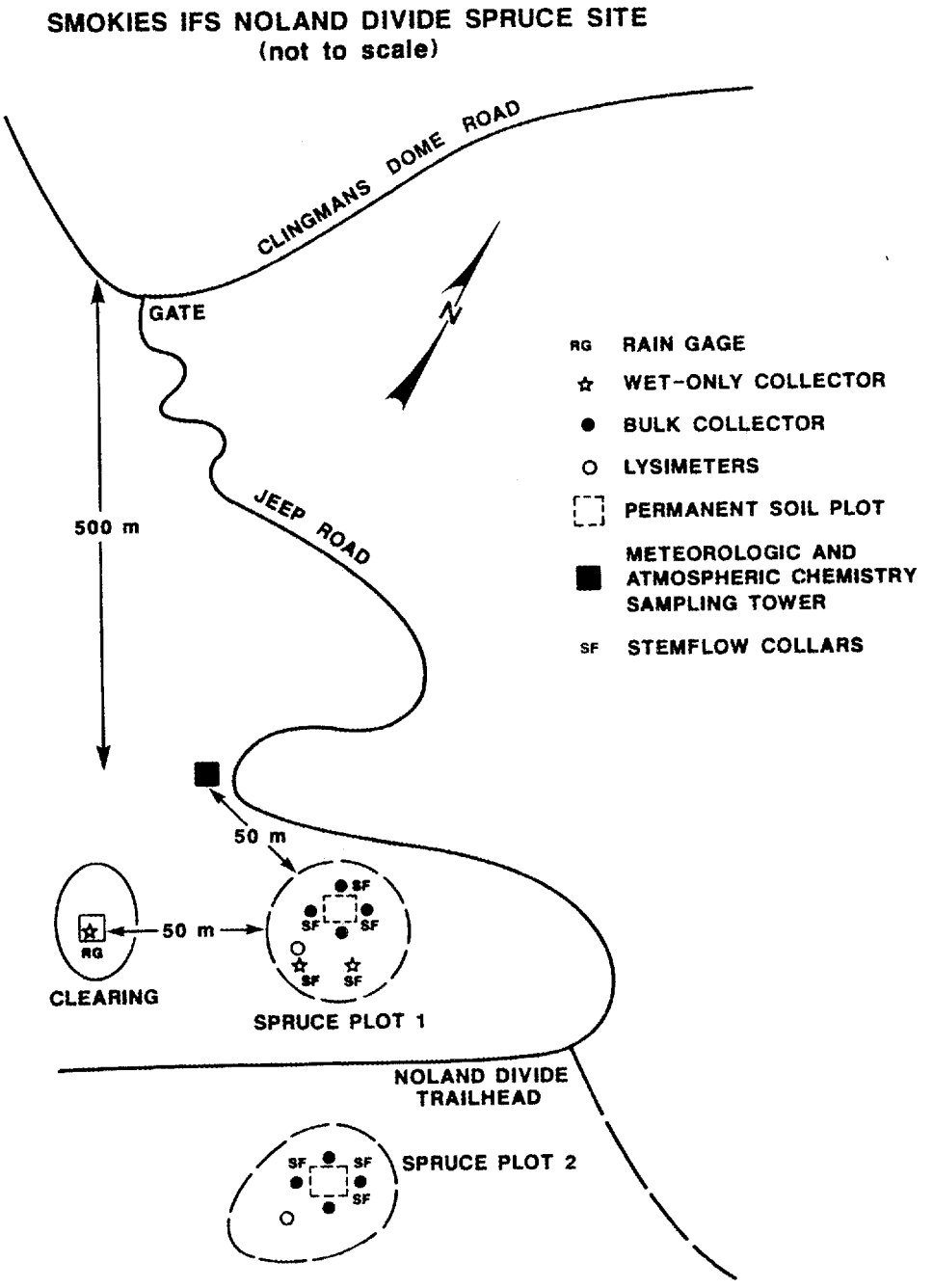

Fig. 3. Map of location of the ST IFS site at Noland Divide on Clingmans Dome, Great Smoky Mountains National Park.

occasional red spruce regeneration, blackberry, witch hobble, vaccinium, sorbus, and various ferns.

Site Installation and Sampling

Two circular nested 0.08-ha plots were established at the beech and Spruce Tower sites, and the existing set of ten adjacent 10- by 10-m plots (for a total plot size of 20 by 50 m) was used at the Becking site. Overstory trees were tallied and tagged (tagging having been already done in 1976 in the Becking plots). Biomass was estimated from equations provided by Weaver (1972) for species in this area.

One of the two circular plots (Plot 1) in the beech and Spruce Tower sites was designated an intensive study site, within which both horizontal and vertical variability in fluxes are monitored, and one plot (Plot 2) was designated an input/output budget site where samples are bulked by level (throughfall, stemflow, soil horizon) and only the solutions from C horizons in soils are monitored (rooting zone output). This design allowed a replication of plots in terms of major system fluxes (throughfall, litterfall, stemflow, leaching output) with a minimum of extra routine analysis (by bulking samples at each level). We felt that the extra time and effort necessary to establish two plots per site were worthwhile given the benefits of replicating plots at minimal extra long-term cost.

All routine monitoring equipment has been in place since July or August of 1985. Bulk precipitation is collected in summer and autumn by funnels placed (by climbing) above tree tops, with Tygon tubing running to a collection bottle (painted black, to inhibit algal growth) on the ground.

In winter, snow collectors (open-bucket type, 15 cm diam by 35 cm high) are placed in nearby ($\leq$1-km) clearings. Use of these clearings is only feasible when the Clingmans Dome road is closed to the public in winter.

Throughfall is collected in summer and autumn with screened plastic funnels (15 cm diam) fitted to plastic bottles (painted black) four per plot. In winter, these are replaced with snowmelt collectors (four reps per plot). The snowmelt collector consists of a bucket 15 cm diam by

35 cm high set upon the litter surface and plastic fitted with a screen at the bottom and a drain which empties into a 16-L bottle placed in a small hole in the ground (to allow drainage from the collector).

Stemflow collars (three trees per plot) were constructed of 2.5-cm-diam Tygon tubing wrapped in a spiral around the tree, nailed at both ends, and sealed to the trunk with elastic. Slits approximately 2 by 10 mm were cut at approximately 20-cm intervals in the tubing to allow stemflow to enter and flow within the tubing to a 120-L collection vessel.

Lysimeters (fritted glass, 2-4 μ pore size, made from modified Buchner funnels) were installed beneath litter (Oa), A horizon (8-15 cm) and within the C horizon (50-70 cm) in the intensive plots (Plot 1 at each site, four reps per plot) and in the C horizon only in Plot 2 of each site (four reps). Tension of 10 kPa was applied to each plate-bottle collection system by independent hanging water column modified from Riekerk and Morris (1983).

Biomass Estimates

Comparisons between the 1976 and 1985 inventory for the Becking plot showed a net loss in live biomass of both red spruce and Fraser fir from 1976 to 1985 (Table 2). The mortality of Fraser fir, most of which was in the form of mortality in the <15-cm-diam class, was most striking on a percentage basis (97%), although the death of a few large spruce trees contributed significantly to the loss in biomass. In any event, this stand had a net negative biomass increment due to mortality (as is often the case in old growth stands). This points out the problems in estimating biomass and nutrient increment in biomass from tree cores only, which cannot give estimates of mortality. Mortality estimates were also obtained from periodic remeasurements of the plots at Spruce Tower and the beech sites.

Other features of note in the biomass figures are the estimates of root biomass (from lysimeter pit samples), which show considerable variability, and the very low foliage biomass estimates in the beech

Table 2. Biomass estimates from Smoky Mountains sites

	Becking Site		Tower Site		Beech Site	
	1976	1985	Plot 1	Plot 2	Plot 1	Plot 2
	$kg \cdot ha^{-1}$					
Live Biomass						
Total						
Foliage	24,800	20,300	18,600	16,700	2,000	1,000
Branch	33,800	24,900	28,500	34,700	20,200	15,400
Bole	260,800	201,600	239,200	224,600	106,700	81,300
ΣAG[a]	319,400	246,800	286,400	276,000	128,900	97,700
Roots[b]		19,000	6,300	25,800	12,600	4,700
Fir (ΣAG[a])	46,500	1,300	0	2,800	0	0
Spruce (ΣAG[a])	293,800	245,500	283,250	232,300	5,950	0
Standing Dead						
Total (ΣAG)	17,800	19,400	33,500	9,400	5,700	0
Fir (ΣAG)	20,200	46,100	14,100	9,400	0	0
Spruce (ΣAG)			19,400	0	0	0

[a]Total Aboveground.
[b]Samples taken from 130 cm dia lysimeter pits. Excludes stump and large lateral roots near stump.

stands (Table 1). Clearly, it is desirable to get more data to confirm the root biomass estimates. The low foliage biomass estimates are thought to be an artifact of the regression equations.

IFS ATMOSPHERIC DEPOSITION MONITORING

Tower

A free-standing tower was erected at the Nolan Divide spruce stand in 1985, following extensive site preparation. The base of the tower is fenced for security where a small instrument shed exits. Because of its remoteness, this site is operated on a combination of battery and solar power, with a thermoelectric generator for backup. The tower is located approximately 50 m upslope from soil/throughfall plot #1 described above (Fig. 3). The tower is 33 m high and extends 10 m above the height of the adjacent down- and across-slope tree canopy (Fig. 4). Because of the 30° slope characterizing the site, the tower is below several upslope trees. However, the angle to the tops of those trees within 30 m of the tower is <10° in each case. Beyond this point the majority of the trees are below the tower because of a decrease in the slope and a generally shorter canopy. Prevailing winds are from the southwest and the aspect of the site is south-southwest. The upwind fetch is dominated by spruce and mixed hardwood forest on mountainous terrain for tens of kilometers.

Meteorological and Ozone Equipment

The meteorological package is described in the deposition protocols. Sensors are mounted on booms extending from the tower, with the exception of the temperature/humidity sensors, which are mounted on one upright section of the tower itself.

The following data are collected routinely at the tower top: mean temperature, solar radiation, relative humidity, wind direction, and wind speed; standard deviation of wind direction and speed; and precipitation amount. In addition, we are using a new sensor at canopy level to monitor foliar wetness duration due to rain, fog, or dew. This parameter is important in controlling dry deposition of vapors and possibly fine particles. We are also using a wet sensor modified with

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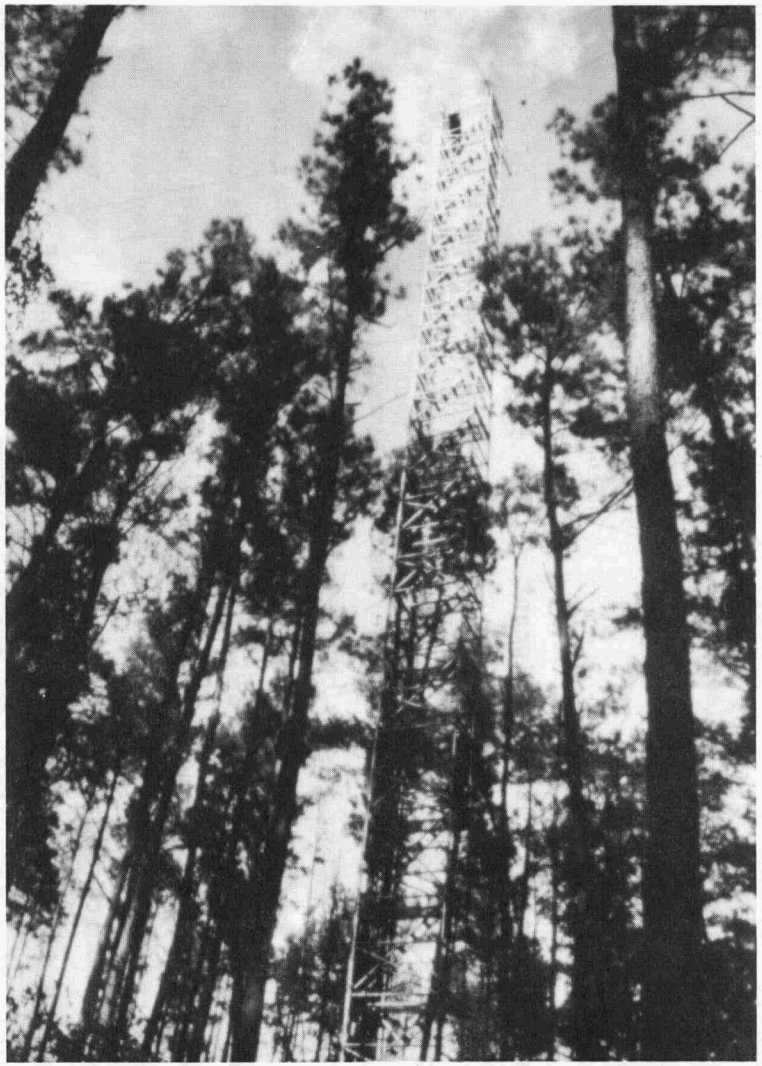

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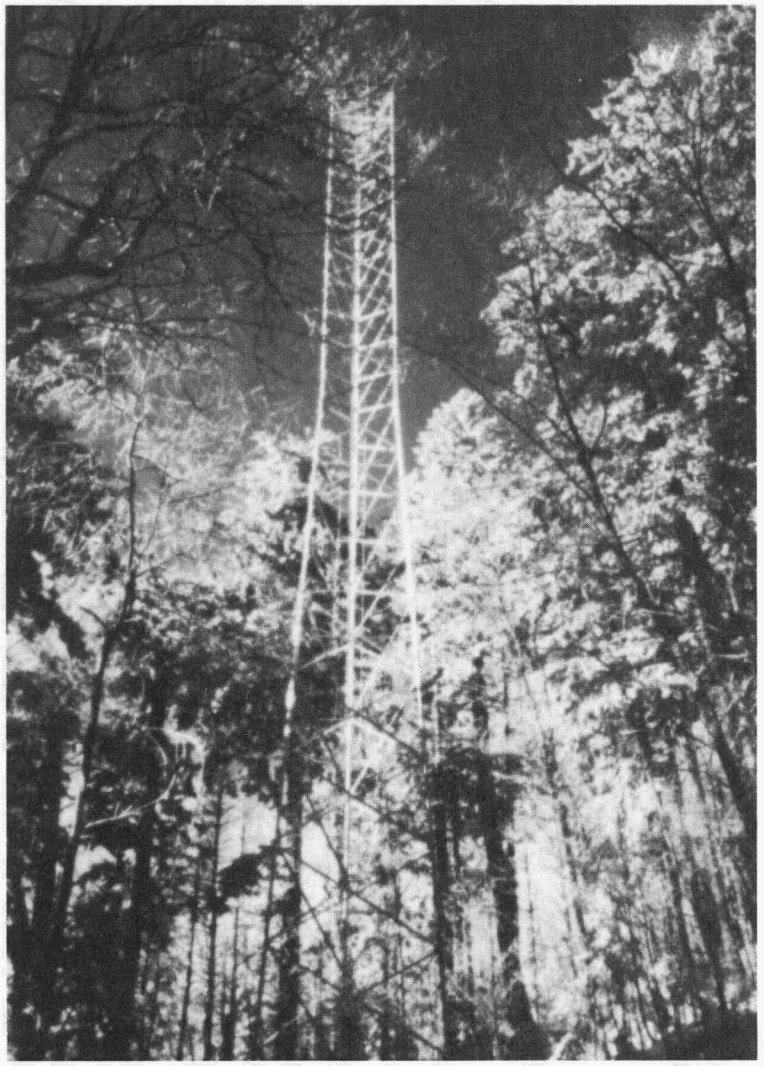

Fig. 4. Meteorological and atmospheric sampling towers installed at the Integrated Forest Study sites in Oak Ridge, Tennessee (LP site, left) and at the Great Smoky National Park (ST site, right).

an overhanging nylon line grid to collect impacting cloud droplets. This sensor provides data for estimating cloud immersion time at this site. Ozone data will be obtained from a nearby National Park Service Station.

Dry Deposition, Atmospheric Chemistry, Fog, and Precipitation Collectors

Automatic dry deposition collectors for coarse particles and aerosol and vapor sampling equipment are installed on the tower. Both of these systems are operated on battery systems using a combination of solar and thermoelectric sources for recharge to prevent the need to transport batteries back to the field laboratory (~50 km away).

An active fog sampler has also been installed on the tower. This unit draws fog-laden air through a mesh onto which fog droplets impact. The collected droplets are then funnelled into a collection bottle for analysis. An additional passive, wind-driven collector is also employed.

The site for intensive collection of throughfall/stemflow on an event basis was established in Soil Plot No. 1. This site includes the bulk throughfall/stemflow and soil water collectors described earlier. The event collectors consist of two commercially available wet-only rain samplers. All collectors are located randomly throughout the plot. Wedge-type standard rain gauges are located adjacent to each sampler and at 10 other randomly picked locations for analysis of throughfall amount on an event basis. In addition, we have installed stemflow collars of the same design used in the soil plots on all of the dominant trees at two of the throughfall sites. Event sampling of stemflow requires manual cleaning of these collars prior to each event.

The site for incident precipitation sampling is located 50 m from the soil plot in the clearing used for ozone monitoring, using NADP protocols. At this site are one wet-only precipitation collector and one standard weighing bucket rain gauge, as well as bulk deposition collectors.

OTHER RESEARCH ACTIVITIES AT THE SITE

The spruce tower site is adjacent to one of the long-term vegetation and soil sampling sites set up as part of the SARRMC (Southern Appalachian Regional Research Management Cooperative) study. This study is designed to evaluate the possible cause of decline in the Appalachian spruce-fir ecosystems and implement approaches for testing various hypotheses (cohort senescence, air pollution, heavy metal deposition) concerning the causes of the decline.

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OAK RIDGE SITE

(Loblolly pine)

PARTICIPATING INSTITUTION AND INVESTIGATORS - D. W. Johnson, S. E. Lindberg, D. E. Todd, D. A. Schaefer, K. C. Dearstone, R. B. Harrison, and J. Owens, Oak Ridge National Laboratory.

SITE DESCRIPTION AND LOCATION

The loblolly pine site is located on the Department of Energy Reservation, National Environmental Research Park, near Oak Ridge, Tennessee at 35° 54′ N and 84° 20′ W. The climate is of the humid mesothermal type with moderate summer and winter temperatures. Mean annual temperature is 14.3°C, and mean annual precipitation is 136 cm as measured at or near Walker Branch Watershed.

Geology, Soil

The site is located on an alluvial soil derived from shale on one of the upper terraces of the Clinch River. Parent material is alluvium consisting mainly of shale with some sandstone and siltstone from the Rome and Conasauga formations. The soil is tentatively identified as Fluventic Dystrochrept and is characterized by a thin (1-2 cm) Oi + Oe horizon with dense grass cover, a 15-cm-thick dark yellowish-brown (10 YR 4/3) Ap horizon of gravelly silty clay loam, a 15-cm-thick yellowish-brown (10 YR 5/4) B/A horizon of gravelly silty clay loam, a 15-cm-thick dark yellowish-brown (10 YR 4/4) Bw horizon of gravelly silty clay loam, and a dark yellowish-brown (10 YR 4/4) BC horizon of gravelly silty clay of undetermined thickness.

Vegetation

Overstory vegetation is loblolly pine (*Pinus taeda*). Understory consists of very occasional red maple (*Acer rubrum*), yellow-poplar (*Liriodendron tulipifera*), black cherry (*Prunus serotina*), and dogwood (*Cornus florida*) in the understory. Ground cover consists of extensive grass (*Eulalia viminea*) with patches of blackberry (*Rubus* spp.) and honeysuckle (*Lonicera japonica*), and occasional onion (*Allium* spp),

various forbs of the Aster family, poison ivy (Toxicodendron radiocans), broom sedge (Andropogon virgininicus), grape (Vitis spp.), and sedge (Carex spp.).

IFS NUTRIENT CYCLING SITE

The loblolly pine installation is identical to the Smoky Mountain installations with the following exceptions: (1) due to the indistinct nature of the litter layer and problems of frequent lysimeter plant wetting and drying, we have used tension-free rather than tension lysimeters in the litter (Oe horizon), and (2) due to previous experiments with heterogeneity in throughfall we have used troughs 320 cm long by 11 cm wide (four per plot), rather than bottles and funnels, in an attempt to integrate some of the variation in throughfall.

As of December 1985, all monitoring equipment was in place on two separate plots (Plot 1 and Plot 2). The late start occurred because of the necessity of moving lysimeter installations (previously installed in February 1985) from downslope sites after winter high water tables were noted.

The biomass inventory is now complete, showing good comparability between plots (Table 3). The 10- by 10-m permanent soil sampling plots were used for soil and vegetation sampling.

IFS ATMOSPHERIC DEPOSITION MONITORING

Tower

A guyed walk-up tower is located in the center of the loblolly pine stand. The tower is located approximately 50 m from and equidistant between the two soil/throughfall plots described above. The tower is 38 m high and extends 9 m above the mean height of the surrounding canopy and is at least 7 m above the tallest trees within a 10 m radius (Fig. 4). The upwind fetch (prevailing winds are from the southwest) is loblolly pine forest on uniform terrain for 500 m, then a mixture of forest and open fields in hilly terrain for several kilometers.

Table 3. Biomass at ORNL Loblolly pine site

	Plot 1	Plot 2
	$kg \cdot ha^{-1}$	
	Overstory (loblolly pine)	
Foliage	3,000	3,000
Branch	16,000	15,500
Bole	103,500	103,800
Σ Aboveground	122,500	122,300
	Understory	
Foliage	130	300
Branch	870	2,400
Bole	3,220	9,400
Σ Aboveground	4,220	12,100

Meteorological and Ozone Equipment

The meteorological package described in the Deposition Protocols is in use. All sensors are mounted on booms extending from the tower, with the exception of the temperature/humidity sensors mounted on one upright section of the tower itself. The following data are collected routinely at the tower top: mean temperature, solar radiation, relative humidity, wind direction, and wind speed; standard deviation of wind direction and speed; and precipitation amount. In addition we are using a new sensor at canopy level to monitor foliar wetness duration due to rain, fog, or dew. This parameter is important in controlling dry deposition of vapors and possibly fine particles.

A Dasibi ozone sensor and its own data logger are installed in a trailer located in an open field approximately 200 m from the tower. The sampling inlet extends 1 m above the trailer.

Dry Deposition, Atmospheric Chemistry, Fog, and Precipitation Collectors

Automatic dry deposition collectors for coarse particles are installed on the tower top facing into the prevailing wind. A filter pack for aerosol and vapor sampling is mounted at the tower top and connected a mass-flow-controlled air pump mounted in the trailer at the tower base. Sampling flow rate is continuously recorded by the data logger discussed above. An active fog sampler is located on the tower. It draws fog-laden air through a mesh onto which fog droplets impact. The collected droplets are then funnelled into a collection bottle for analysis. Our approach to sampling has been to use a timer to run the collector from midnight to 8 am during nights on which fog occurs.

The site for intensive collection of throughfall/stemflow on an event basis was established in Soil Plot No. 1. This site includes the bulk throughfall/stemflow and soil water collectors described earlier. The event collectors consist of six commercially available wet-only rain samplers. All collectors are located randomly throughout the plot. Two wedge-type standard rain gauges are located adjacent to each sampler for analysis of throughfall amount on an event basis. In addition, we have installed stemflow collars of the same design used in the soil plots on all of the dominant trees at two of the throughfall sites.

The site for incident precipitation sampling is located 200 m from the nutrient cycling plot in a clearing. At this site are one wet-only precipitation collector and one standard weighing bucket rain gauge, as well as bulk deposition collectors.

OTHER RESEARCH ACTIVITIES AT THE SITE

Additional research at this site includes DOE-funded research on development of methods for estimating particle dry deposition by foliar extraction, surrogate surface, and throughfall analysis; DOE research on trace metal deposition; DOE research on spatial distribution of deposited material within forest canopies.

WHITEFACE MOUNTAIN SITE

(Spruce-Fir)

PARTICIPATING INSTITUTIONS AND INVESTIGATORS - A. H. Johnson, A. J. Friedland, Dartmouth College; E. K. Miller and A. H. Johnson, University of Pennsylvania; J. A. Panek, J. Kadlecek, State University of New York-Albany (Atmospheric Sciences Research Center).

SITE DESCRIPTION AND LOCATION

Whiteface Mountain (summit elevation 1483 m) is located in Wilmington, New York, in the northeast section of the Adirondack Mountains (44° N, 73° W). The study area is a narrow west-northwest trending drainage basin on the flank of Esther Mountain (summit elevation 1292 m), the eastern peak of the Whiteface massif. A restricted access road to the summit of Whiteface cuts northeast-southwest across the basin at an elevation of approximately 960 m. The IFS nutrient-cycling activities take place between 970- and 1100-m elevation on a north-facing slope of the drainage basin. Air flow at the site is dominated by westerly and northwesterly, upslope winds.

Climate

Mean annual temperatures range between 4.8°C at the base meteorological station (600 m) and 0°C at the Whiteface summit station. The growing season is approximately 90 days (Holway and Scott, 1969). Annual precipitation averages 100 cm at the base and increases substantially with elevation. Approximately 30% of the precipitation occurs as snow. A seasonal snow cover normally persists at the study site from November through April, with peak accumulation of about 30-cm water equivalent (150-cm depth) in February or March. Soil frost to the depth of the forest floor has been observed in the first two years of the study and may be common. Continuing observations suggest the summit of Whiteface can be immersed in cloud up to 30% of the year, and the

study area may be cloud covered up to 18% of the year (Ted Arons, ASRC, personal communication), making cloudwater a potentially significant addition to precipitation.

Vegetation

A number of vegetation zones exist on Esther Mountain including the northern hardwood forest at the base, hardwood-fir-spruce transition, fir-spruce, and fir krummholz towards the summit (Holway and Scott, 1969). Balsam fir [Abies balsamea (L.) Mill.], red spruce (Picea rubens Sarg.), and white birch [Betula papyrifera var. cordifolia (Reg.) Fernald] dominate the study area. Mountain ash (Sorbus americana Marsh) is also present. The species composition represents a typical forest at 1000-m elevation in the Adirondacks; the study area has not been disturbed by fire or logging in recent history (J. Scott and J. Battles, personal communication) and can be considered, in general, mature and overmature forest.

Geology

The bedrock on Esther Mountain is primarily a Precambrian anorthosite. The shallow pockets of till that occur on the site were probably deposited toward the end of the Wisconsin glaciation (10,000 to 12,000 y.b.p.) (Alling, 1918 as cited by Witty, 1968). Soils are Typic Cryohumods or Typic Cryothods developed on anorthosite colluvium and basal till of local origin. The average depth to bedrock is approximately 40 cm. Areas of well developed spodosols up to 1-m deep and organic mats with little or no mineral soil development overlying anorthosite boulders are equally common. The organic mats on boulders increase in importance at the higher elevation plots. The deepest profiles often contain buried and physically mixed horizons due to frequent windthrows. The eluviated (E) horizon is often thin or absent. The soils are acidic (pH in water of forest floor = 3.4, B = 4.2) and have a low base status and a high cation exchange capacity.

IFS NUTRIENT CYCLING SITE (UNIVERSITY OF PENNSYLVANIA)

Solution Monitoring

We have been monitoring precipitation, throughfall, stemflow, soil water solutions and stream water since October 1985. Below, we will describe the instruments, sampling design, and site-specific protocols that are currently employed at Whiteface. We have deviated from the Oak Ridge protocol when the extreme climate and terrain of Whiteface necessitated the development of sampling strategies more compatible with our environment. Further, the logistics of the monitoring effort at Whiteface are complicated by strict limitations on physical and visual alteration of the landscape imposed by the New York Department of Environmental Conservation (NYDEC) and the Adirondack Park Agency (APA).

Four 0.1-ha permanent vegetation plots are located at 1020-, 1060-, 1070-, and 1090-m elevation in the fir-spruce zone (Fig. 5). All solution monitoring and destructive sampling occurs in plots contiguous to the permanent vegetation plots (Fig. 6). We have been careful not to sample or use instruments within our permanent vegetation plots to avoid compaction and disturbance of the fragile organic surface soils.

Incident precipitation (nonwinter). Precipitation volume is measured by tipping bucket rain gauges in three locations: the meteorological tower top, a partial clearing at 970-m elevation, and a partial clearing at 1100 m. The partial clearings do not conform to NADP precipitation site specifications (NADP, 1984). Precipitation chemistry is monitored at the tower top and at the partial clearing near plot C (elevation 1100 m). The 970-m clearing is along the controlled access road and is subject to contamination from auto emissions and blowing soil particles. Therefore, the road site is not suitable for a chemical sampling station during the summer months. The precipitation collector is a polyethylene bucket (NADP issue; NADP, 1984).

Incident precipitation (winter). A bulk snow sampler (0.5-m diam) is located 1 m above the ground in the partial clearing at 970-m elevation. This collector is serviced on an event basis. A periodic sampling traverse of the study area allows tracking of water storage and chemical development of the snow pack. Two sampling methods are used.

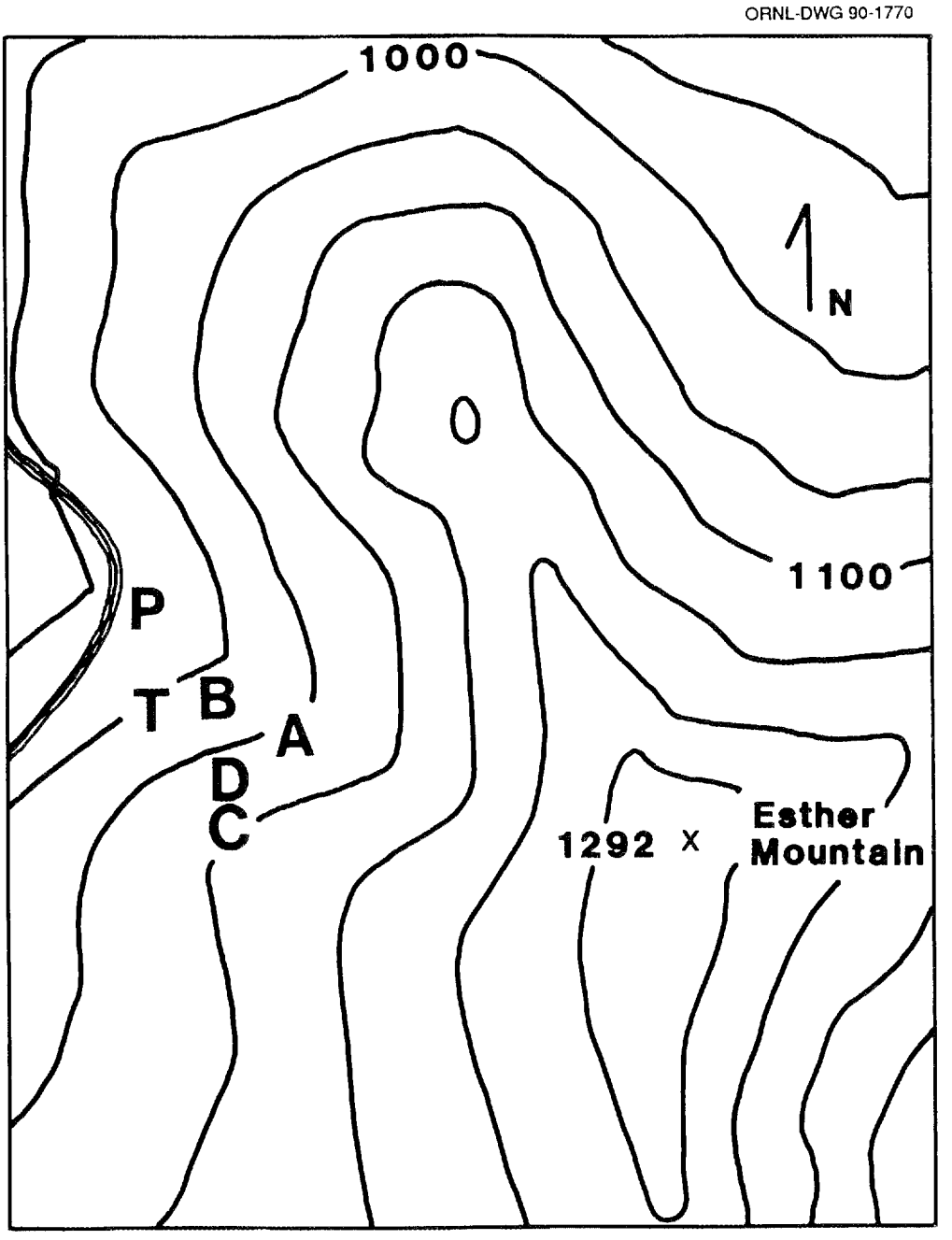

Fig. 5. Location of permanent vegetation plots (A,B,C,D), meteorological tower (T), and precipitation monitoring equipment (P) on Whiteface Mountain.

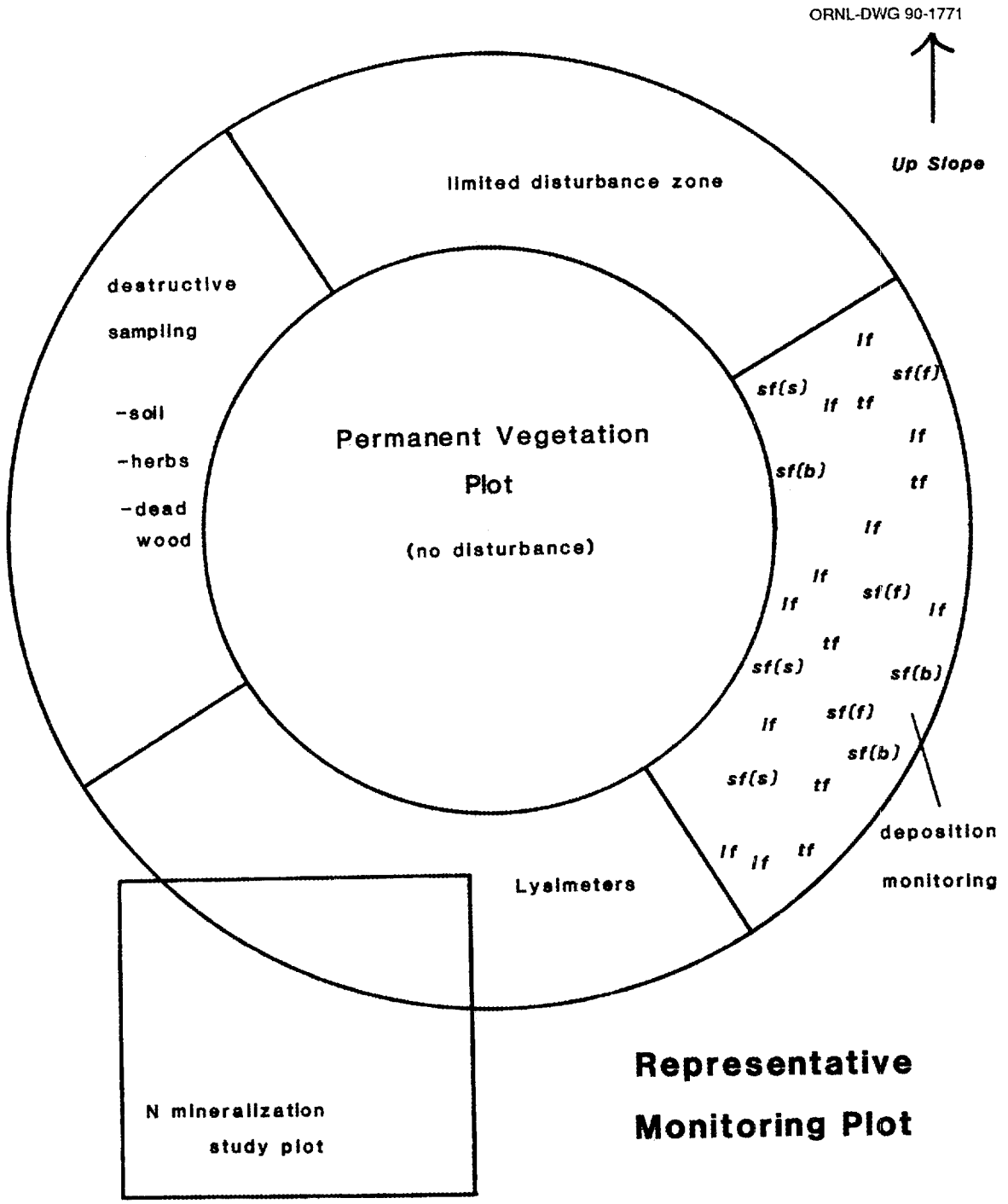

Fig. 6. Representative monitoring plot showing permanent vegetation, monitoring, and sampling layouts.

First, the pack is sampled by volumetric sampling of stratigraphic units. Organic debris is removed before these samples are melted for analysis. Second, the pack is characterized by bulk cores from which no attempt is made to remove organic debris. The snowpack sampling will help to estimate the spatial variability of water and ion storage just prior to their delivery to the forest floor during melt periods.

Through canopy precipitation (nonwinter). Five precipitation samplers (described above) are randomly located in the instrument area adjacent to each permanent plot (Fig. 6).

Through Canopy Precipitation (winter). Two strategies for estimating the water and aqueous ion input to the forest floor are employed. The snow sampling traverse described above actually samples winter throughfall. Net loss of water equivalent from the snowpack which is not due to evaporation is considered flux to the forest floor. The change in snowpack chemical content after correcting for the concentrating effect of evaporation is the ion flux. Snow lysimeters located near the 1070- and 1020-m plots are also employed to estimate the timing and amount of water and ion delivery to the forest floor.

Stemflow. Spiral collars formed from half-inch polyethylene tubing and secured with 3 to 5 epoxy coated nails are fixed on 3 randomly located individuals of spruce, fir, and birch for each monitoring plot. The junction between collar and tree is sealed with silicone caulk. The sample is retained in a polyethylene bottle which is covered to keep the sample cool and to exclude sunlight. Stemflow is not monitored during freezing conditions.

Soil solution. Soil solution is sampled with 60-mm diameter fritted glass tension lysimeters at a suction of approximately 0.1 atm. The lysimeters are downslope from their associated permanent vegetation plot and a disturbance-free zone (Fig. 6). Three replicates in three horizons (one below the O horizon, two depths in the B horizon) are located approximately 0.5 to 1 m apart. The vacuum for this system is generated by a falling column of dilute methyl alcohol. Each lysimeter has its own column. One additional replicate per horizon is provided by zero-tension lysimeters (sand-filled polyethylene funnels). The samples are retained in polyethylene bottles which are stored below ground at

ambient soil temperature and are removed from sunlight. Sample bottles and falling columns are protected from animals and weather by insulated shelters constructed of polyethylene-weatherproofed half-inch plywood. During the winter season two of the lysimeter installations (1020 m and 1070 m) are heated with incandescent light bulbs.

Stream water. Summer stream water chemistry is determined from water samples taken at 970-m elevation from the stream draining the study site watershed. Samples are taken at the same time that all other water samples are removed from the field. Winter stream water is sampled at the time bulk snow is collected or at least weekly.

Solution Collection, Preservation, Pooling, and Analysis

Summer. Precipitation and throughfall collectors are serviced and samples analyzed on an event basis. Lysimeters are serviced on a weekly basis (or more frequently if the water flux requires). Sample volumes are recorded. When the volume collected permits, subsample bottles (which are stored filled with deionized-distilled water) are rinsed with sample twice before filling. Subsamples are drawn and refrigerated within 5 h of collection. When adequate volume of sample is present, pH and specific conductance are measured on water from each collector (total 110 samples). After collections are completed, samples are composited to monthly representative samples using a combination scheme determined by the weekly volumes for each collector. Conductance and pH are measured on the composites and 250 L are frozen and shipped by overnight courier in an insulated container to Oak Ridge National Laboratory (ORNL) for analysis.

Winter. Winter collection protocol is described above in the section pertaining to winter monitoring equipment and sampling strategy. Frozen samples are brought to the lab, melted at room temperature, and then processed according to the non-winter protocol.

Litterfall

Five 0.5-m^2-litterfall traps constructed with 1-mm mesh polyolefin screen are located randomly in the instrument area adjacent to each vegetation plot (Fig. 6). Five additional litter traps are located in

the instrument area of plot D, which is a fir regeneration area. Litterfall is removed twice yearly (November and June) and processed as described above for other vegetation.

Soil Sampling and Analysis

Two 0.7- by 0.7-m pits were quantitatively excavated in the locations that are now the lysimeter pits. Soil layers were removed in logical groupings of horizons, and the volume of each layer was measured. The soil was sieved to separate rocks >2.5 cm. Both fractions were weighed and the small size fraction was homogenized and subsampled. Face samples of distinct horizons were taken from the same pits. Four forest floor (O horizon) samples per plot were removed quantitatively using 15- by 15-cm templates. Soil samples were air dried and sieved to separate the <2-mm fraction for analysis.

Composites were formed from the <2-mm fraction of both face and quantitative samples to represent the soil horizons sampled by each level of lysimeters. These composites were analyzed for total organic matter, N, P, S, SO_4-S, Ca, K, Mg, C, exchangeable Al, Ca, K, Mg, Na, acidity, soluble and adsorbed SO_4-S, and extractable P. All extractions were conducted at the University of Pennsylvania; digestions and elemental determinations were done at ORNL.

In recognition of the highly variable nature of the forest soils on the site, additional characterization of total and exchangeable nutrient content will be made in either the 1987 or 1988 field season.

Vegetation Sampling and Analysis

The density and basal area of overstory species were determined by inventory and measurement of the four 0.1-ha permanent vegetation plots (Tables 4 and 5). Except in plot D, all stems >2-cm dbh were identified and tagged, and their dbh, species, and state of health were recorded. In plot D, a balsam fir regeneration stand, all stems >5-cm dbh were measured and tagged and the 2- to 5-cm size class was characterized in two 5- by 5-m subplots.

We verified by repeated measurements of each plot that we could remeasure the trees in each plot accurately enough to distinguish

Table 4. Overstory species density in stems per hectare for the four intensive monitoring plots (stems per hectare)

Species	Plot A	Plot B	Plot C	Plot D	Mean
Spruce					
Live	50	30	160	90	83
Dead	40	100	100	30	68
Fir					
Live	1520	2410	2090	4090	2528
Dead	660	560	330	320	468
Birch					
Live	50	90	80	50	68
Dead	0	10	0	10	5
Mountain ash					
Live	30	10	70	0	28
Dead	0	0	0	0	0

Table 5. Overstory species basal area in meters squared per hectare for the four intensive monitoring plots (m^2/ha)

Species	Plot A	Plot B	Plot C	Plot D	Mean
Spruce					
Live	5.079	4.185	9.396	11.271	7.48
Dead	3.758	10.185	13.781	5.108	8.21
Fir					
Live	17.393	21.667	10.471	15.348	16.22
Dead	7.190	7.971	5.230	5.348	6.43
Birch					
Live	5.080	2.671	4.215	4.309	4.07
Dead	0	0.638	0	0.860	0.37
Mountain ash					
Live	0.409	0.097	0.684	0	0.30
Dead	0	0	0	0	0

2 years' growth. Height-diameter regressions were determined from measurements of trees on all four plots. Standing biomass was estimated from allometric equations (Table 6) available for New England using our height-diameter relationships (Whittaker et al., 1974; Siccama, unpublished). We are not able to develop site-specific equations due to restrictions on tree harvesting imposed by the NYDEC and the APA.

We have drawn an idealized diagram of the major tree species vegetation pattern for each plot (Fig. 7). The vegetation dynamics were determined by visual observations and by examining the density and basal area data for each plot (Tables 4, 5). Although the species composition and percent live and dead is different, plots A and B are similar in that they are both mature, closed-canopy forests. Plots C and D are more different from each other, but they are both open- or broken-canopy forests. In future analyses of throughfall and soil water variations between plots, we intend to consider canopy cover as one potential influencing factor.

Five components (roots, bark, bole wood, twigs, and foliage) of overstory tree species were sampled for mineral content. Five randomly located individuals of red spruce, balsam fir, and paper birch were sampled near each plot. One mountain ash was sampled at plot D. The sampling was done at the end of the growing season (September 1985) except for birch foliage, which was sampled in July 1986.

Root material was taken from <2-cm diameter roots whenever possible. Bark was obtained by slicing to approximately the depth of the cambium and peeling with a stainless steel knife. Bole wood was removed in three or more cores (taken parallel to the slope at breast height) using a 5-mm increment borer. Twigs and foliage were clipped from the south side and upper two-thirds of the crown. Bark, bole wood, and twigs were transported from the field in paper bags and placed in an oven the same day. Foliage was washed to remove surface contamination by rinsing for 30 seconds in deionized-distilled water. Roots were washed of soil by immersion in an ultrasonic agitator with deionized-distilled water for 30 seconds. All samples were oven dried at 45°C and ground in a Wiley mill, 2-mm mesh.

Table 6. Estimated biomass by tree part and species for the four intensive monitoring plots (10^3kg/ha)

	Bole	Bark	Branch	Dead branch	Leaf	Root	Sum
Balsam fir	32.6	4.9	8.1	4.0	3.1	18.9	71.6
Red spruce	16.6	2.0	5.3	2.0	1.2	8.9	36.0
White birch	10.8	1.1	6.2	0.8	0.4	3.8	23.1
Mountain ash	5.3	0.5	2.9	0.3	0.2	1.9	11.1
							141.8

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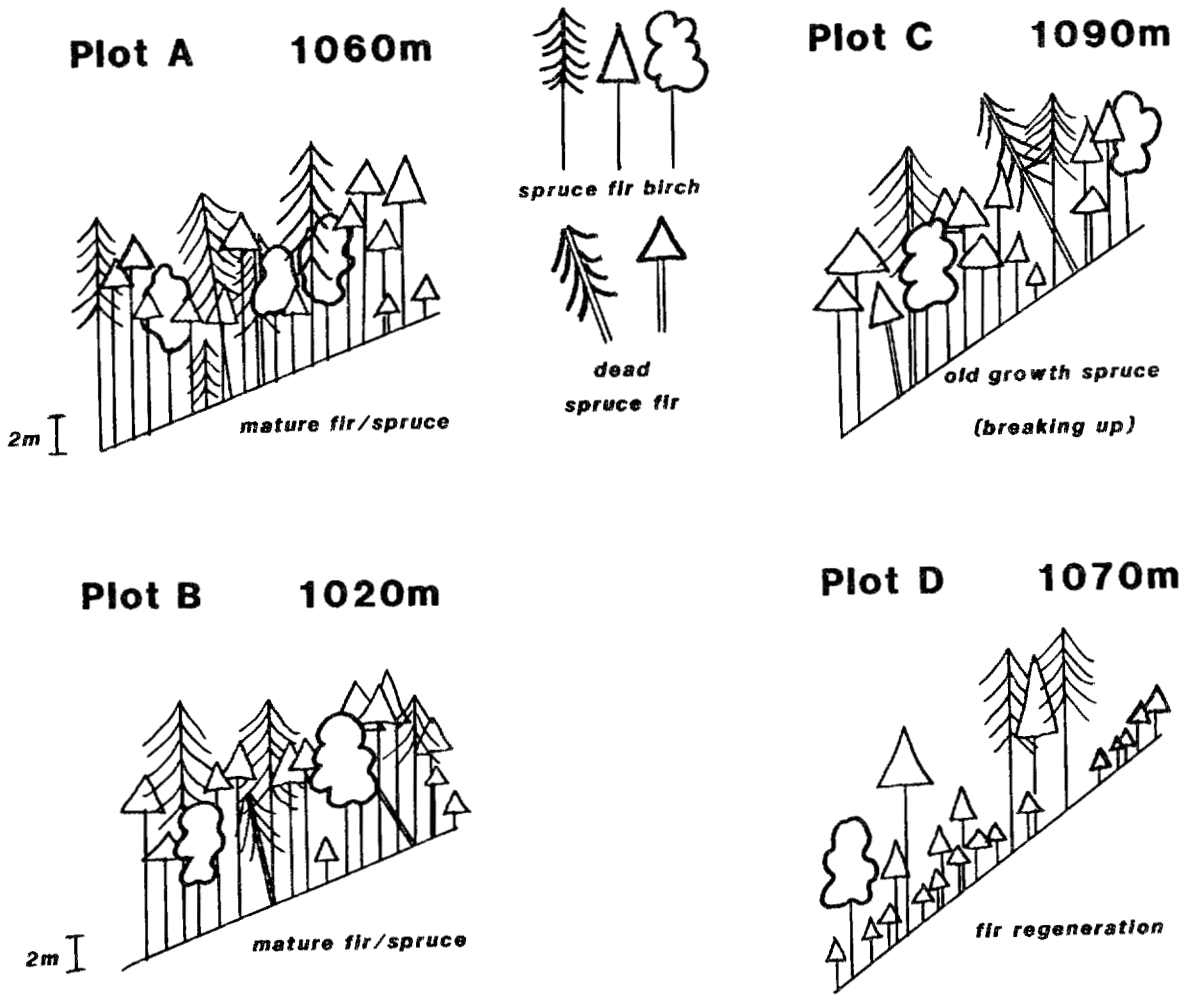

Fig. 7. Vegetation patterns at the four IFS plots located on Whiteface Mountain.

Herb layer species were sampled by complete removal from ten 1- by 1-m plots adjacent to each permanent vegetation plot. This sampling occurred on July 20, 21, and 22. Herbs were oven dried at 45°C and ground in a Wiley mill, 2-mm mesh.

Biomass

A 1986 survey of vegetation on the entire Whiteface Mountain massif (including the area adjacent to the IFS plots) provided us with a large database for comparison with the four IFS plots. The proportion of live and dead trees by species on the IFS plots (Tables 1, 2) is very similar to that determined for the part of Esther Mountain with similar elevation and aspect. The basal area of red spruce on the IFS plots is greater than the average for Esther Mountain because we selected plots that had a slightly higher representation of red spruce. Basal area of white birch is less than the average for Esther Mountain, presumably because the IFS plots are in the relatively small area of the mountain that did not burn in this century (white birch commonly invades recently burned areas of forest).

IFS ATMOSPHERIC DEPOSITION (SUNY-ALBANY, Atmospheric Sciences Research Center)

Meteorological Tower

The site for the meteorological tower (T in Fig. 4) is located at 1009-m elevation, 75 m upslope from the limited access road. The site was chosen because (1) it is far enough away from the road for the effects of automobile traffic not to interfere with the monitors on the tower, but (2) it is close enough to the power source at the road so that a cable can supply instrumentation needs, and (3) the site has a mixture of the forest species found in the permanent plots at this elevation.

The scaffold tower is 17.4 m tall, guyed at two levels to the base of trees. The terrain on which the tower stands is steeply sloping and the canopy around it highly variable in height. For this reason, the "mean canopy height," is an inadequate description of the canopy. In an attempt to better portray the canopy in the immediate vicinity of the

tower, the heights of all canopy trees within a 31-m radius were measured relative to the tower [i.e., their absolute heights were not measured, but rather their height in relation to the tower top (Fig. 8). This takes into account differences caused by slope]. In this context, from 238 trees measured, mean canopy height is 5.7 m lower than the tower, the standard deviation of the mean is 5.4 m, and the highest tree is 15.8 m taller than the tower.

The tower has been lightning protected with a system recommended by the Lightning Protection Institute (Independent Protection Co, Inc., personal communication) and has survived several nearby hits. A safety system utilizing climbing harnesses has been designed that can be used in all seasons and in all weather to climb the tower.

Meteorological and Air Chemistry Measurements

The following instruments were installed on the tower top for the growing season 1986. Meteorological measurements began June 1. Similar measurements are made at the base and summit of the mountain as well (Fig. 9).

Aerochem wet-only collector
ORNL dry deposition collector
Filter pack on 1-m arm
Cloudwater collector on 20-m track
  (extends 2.5 m above tower top)
Ozone monitor
Meteorological instruments:
- Pyronometer
- Tipping bucket rain gauge
- Wind speed and direction
- Relative humidity and temp. on 1-m arm
- Psychrometer
- 5 thermocouples measuring temp profile from forest floor to tower top, mounted on 1-m arms.

<u>Ozone monitor</u>. ASRC uses a Thermal Electron Corporation (TECO) ozone monitor. During the first non-growing season it operated in a heated shed by the access road at 956-m elevation. A heated shed was built at the base of the tower for the second growing season to house all gas-phase monitors. This ozone monitor is one of three on the

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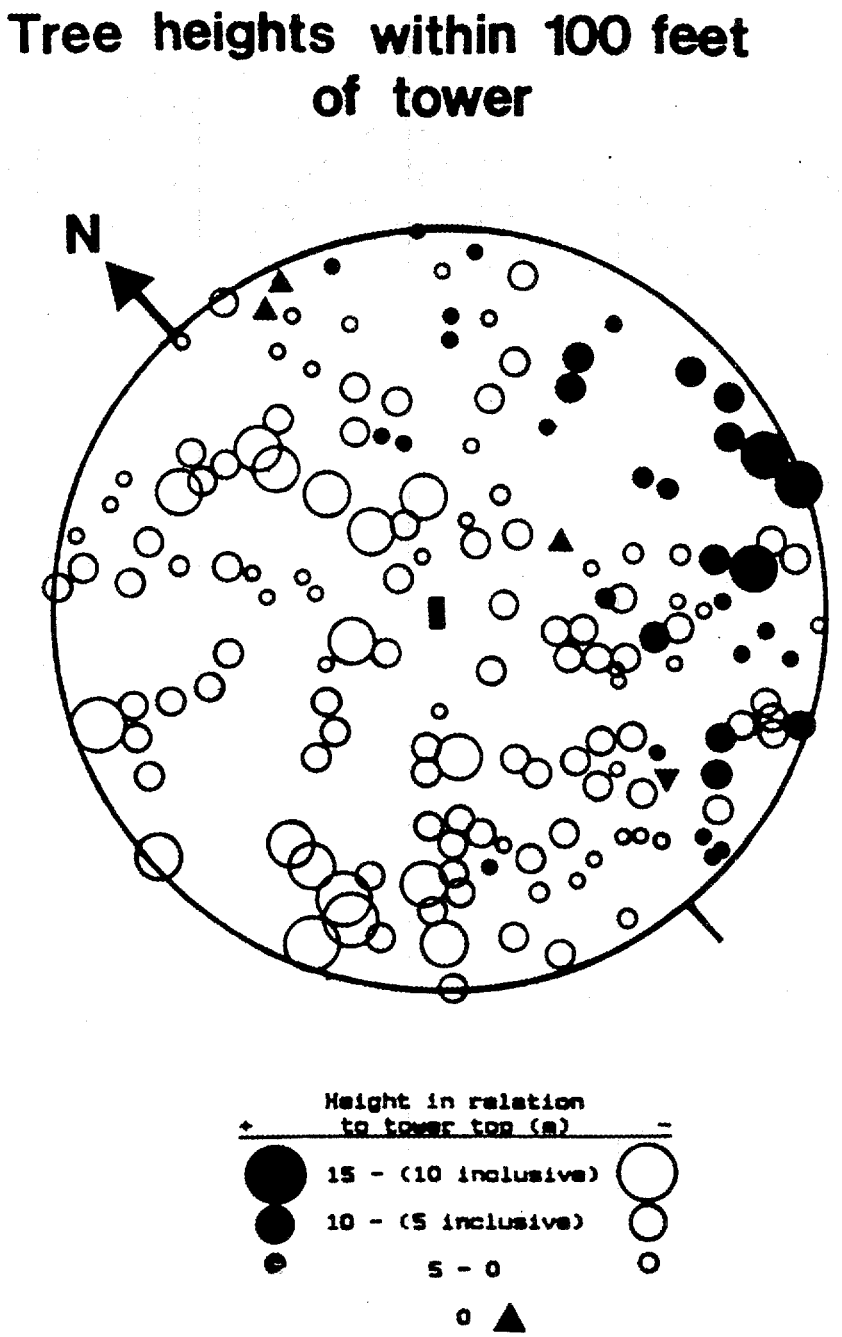

Fig. 8. Location and relative height of trees in the vicinity of the meteorological tower at the WF site. Heights are indicated in meters above (+) or below (-) the tower top.

ORNL-DWG 90-7181

Base (600m)	Tower (1000m)	Summit (1483m)
Ozone	Ozone	Ozone
Meteorological	Meteorological	Meteorological
wind speed	wind speed	wind speed
wind direction	wind direction	wind direction
temperature	temperature	temperature
solar radiation	solar radiation	
relative humidity	relative humidity	
barometricpressure		barometric pressure
Filter (tripack)	Filter (tripack)	Filter (high-volume)
aerosols	aerosols	aerosols
nitric acid	nitric acid	nitric acid
sulfur dioxide	sulfur dioxide	sulfur dioxide
		Gaseous
		sulfur dioxide
		nitrous oxides
Dry deposition (NOAA/ADIL)	Dry deposition	
Precipitation as:	Precipitation as:	Precipitation as:
wet-only (MAPS3S,NADP)	wet-only	
	cloudwater	cloudwater
	rime ice	rime ice
	throughfall	
	stemflow	
Condensation nuclei (summer)		Condensation nuclei (summer)
		Hydrogen Peroxide

Fig. 9. Meteorological and atmospheric chemistry measurements made on Whiteface Mountain at the base, IFS tower, and summit sites.

mountain at different elevations - the summit (1483 m), the project site (956 m and 1009 m) and the base (600 m) and will therefore be a crucial element making possible an elevational study of ozone concentration differences on Whiteface.

Dry deposition. The project protocol advises the use of the filterpack to collect three species of dry deposition - SO_2, nitric acid, and aerosol during a dry period prior to a wet event. However, due to the harmful effects on the ion chromatagraph column of the SO_2 filter extract, and the difficulty of interpreting chromatograms from such extracts, we measured SO_2 with a TECO pulsed fluorescence continuous monitor. We now have a record of 5-minute average SO_2 values at all times, both during dry periods and during rain and cloud events.

Cloud collection (nonwinter). A passive cloud collector similar to that used at ASRC since 1980 operated through the growing season. A track system was installed for the collector extending 2.5 m above the tower top to clear other instrumentation and to be well above the canopy. The system allows the collector to be raised and lowered from the ground by hand winch; therefore all maintenance, repairs, and cleaning can be done safely on the ground, and the collector can be protected between cloud events at the tower base. Cloudwater samples are collected at 0.5- to 1-hour intervals throughout every event occurring at the tower. For the 1988 growing season a cloud-collection site was added at the 1100 m level.

Rime ice collection (winter). The track system accommodates a rime ice collector of ASRC design as well. Supercooled cloud droplets impact on stainless-steel wires and immediately freeze. When enough sample has impacted to analyze, the collector is lowered to the ground, the rime is scraped from the wires with a specialized polyethylene device, and the sample is stored frozen until analysis. All cloudwater is analyzed for pH, Cl, NO_3, SO_4, Na, NH_4, K, and H_2O_2.

There is no standard meteorological clearing at the project site. As mentioned previously, the laws of the forest preserve in which Whiteface Mountain is located preclude the cutting of trees and therefore the creation of clearings. There are three open "clearings" available in the watershed: the bank above the access road, the tower

top, and a partial clearing - a blowdown - at 1100 m. There are problems with all. The sharp drop-off on the downhill side of the road and the steep slope of the bank above make it susceptible to strong wind shear. Also it does not conform to NADP/NTN network standards in other ways: there is not a 30 degree clearance of all vegetation in all directions, nor is there surrounding ground cover (NADP, 1984). In the summer, when the road opens to tourist traffic, there is the added problem of contamination from auto exhaust, blown dust, or vandalism. All of these make the quality of the samples unreliable. The tower, while free of these problems, experiences turbulent winds above the canopy, as does the blowdown site. Therefore, we collect precipitation using wet-only collectors at all three sites. A years' data has been shown no significant differences between chemistry and amount of precipitation at the road versus the other two sites, so it appears there is no road effect ($P < 0.05$, Wilcoxan Rank Sum Test).

Throughfall and stemflow. Throughfall was measured during the growing season underneath both a predominantly fir and predominantly spruce canopy using wet-only collectors. The experiment described below demonstrated that two collectors were inadequated to estimate throughfall deposition to this site. Therefore, after October 1986, each of the 5 bulk throughfall collectors at the four nutrient-cycling plots were used to collect every event, for a total of 20 collectors each event. Stemflow was terminated after October 1986 due to its small relative contribution to the nutrient budget.

In order to test for proper placement of throughfall collectors, and to establish the necessary collection area to properly describe both volume and chemical composition of throughfall, we established a 25-collector experiment on the same site. Four additional collectors were placed in the open by the road as controls prior to tower construction. The grid was used to monitor throughfall volume, pH, and concentrations of SO_4, NO_3, Cl, K, Na, and NH_4 for every rain event in July and August, 1985, and select events in September and October of the same year. The collectors were set 5 m from each other without regard to the nature of the canopy or the understory. Because the size of the grid and the number of collectors are relatively large, the set of throughfall

samples represents deposition through the varied surfaces that precipitation naturally encounters enroute to the forest floor. The 1985 data set consists of 6 summer events and 3 fall events. We addressed the following important questions relevant to IFS: what is the minimum number of collectors necessary to accurately describe throughfall in this fall? Is collector placement important? What is the nature of variation in throughfall deposition of both water and ions? In 1987, the experiment was continued with 36 bucket collector to measure spatial variability, and 10 troughs sampled periodically through individual events to assess temporal variability.

Sample Analyses

ASRC analyzes all its wet event and cloudwater samples, dry deposition plate extracts, and filters for H, conductivity, Cl, SO_4, NO_3, Na, NH_4, and K, and cloud samples for H_2O_2 (Lazrus et al., 1985), with facilities available at Whiteface Mountain.

OTHER RESEARCH ACTIVITIES AT THE SITE

Atmospheric Sciences Research Center

The Atmospheric Sciences Research Center (ASRC) has been operating atmospheric monitoring facilities on Whiteface Mountain for 25 years. ASRC brings to the atmospheric monitoring task of the Integrated Forest Study a long-term meteorological record and an expanding deposition research program with which to compare results from this project. Since 1963 Whiteface has been an official air quality measurement site for the New York Department of Environmental Conservation. In 1977 the Department of Energy designated Whiteface the rural precipitation chemistry center for the MAP3S network. Since 1984 it has been a National Trend Network site and is presently an NOAA/ATDL and EPA dry deposition research site. At the summit of Whiteface, cloudwater has been routinely collected and analyzed for its chemical composition throughout the year since 1979. The summit station continuously measures sulfur dioxide, nitrous oxides, and ozone. The Mountain Cloud Chemistry Project, which began field operation on Whiteface in the

summer of 1986, is monitoring summit cloudwater chemistry and amount, summit meteorological data, and summit ozone during the growing season.

Data from the EPRI-IFS study will enhance a comprehensive study of the elevation-dependent mechanisms of atmospheric deposition.

University of Pennsylvania

A study of forest-floor nitrification rates, funded by the General Motors Corporation, is underway at the Esther Mountain research site. The main purpose is to determine the relative contribution of atmospherically deposited nitrate and forest floor nitrification to nitrate present in soil water and stream water. Both the temporal and spatial variability in this ratio are being investigated. The significance of forest-floor nitrification to nitric acid pulses in a poorly buffered headwater stream will be tested.

Plots for the nitrification study were chosen to represent the vegetation present in the EPRI-IFS vegetation and instrument plots. Forest-floor nitrification is being assessed in the same monthly time intervals that bulk inputs and soil water fluxes are being measured. We plan to analyze a subset of the samples obtained in this study to estimate net sulfur mineralization rates.

A field study is being conducted on the entire Whiteface Mountain massif, including Esther Mountain, as part of the Spruce-Fir Research Cooperative of the U.S. Forest Service under the Forest Response Research Program of the U.S. Environmental Protection Agency/National Atmospheric Precipitation Assessment Program. The main purpose of this project is to characterize a number of forest characteristics around Whiteface Mountain, including the deterioration of red spruce. Plot surveys, foliar and soil analyses, and a determination of forest pathogens are underway.

A field manipulation study is being planned for the 1987 growing season in an area adjacent to the IFS study plots with the same sponsorship as the study in the preceding paragraph. The main purpose of this project is to determine the effect of varying precipitation chemistry on soil solution chemistry and plant physiological processes.

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DUKE FOREST SITE

(Loblolly Pine)

PARTICIPATING INSTITUTION AND INVESTIGATORS - K. Knoerr, School of Forestry and Environmental Studies, Duke University; D. Binkley, Colorado State University.

SITE DESCRIPTION, LOCATION

The Dailey Tract of the Duke Forest is about 60 km west of Durham, North Carolina, (about 10 km north of Mebane, North Carolina) in Alamance County at 36° 12′ N and 79° 17′ W. The property was acquired by Duke in the 1960s. Prior to Duke's acquisition, the land was used for the farming of various crops, with no records kept of soil treatments.

Climate

The climate is mild. Average temperature for the coldest month (January) is 4°C, and for the warmest month (July) is 25°C. Precipitation averages about 112 cm annually, with each month averaging at least 7 cm.* The frost free growing season is about 197 days. The average dates for the last frost in spring and the first frost in fall are April 10th and October 25th, respectively (Carney, 1955). Summer is not usually droughty, but year-to-year variation is fairly high and some summers have significant dry periods. Most precipitation falls as rain. Annual snowfall is usually less than 20 cm and melts within a few days. Fog is uncommon, probably averaging less than 10-20 days annually.

Vegetation

One-year-old loblolly pine seedlings were planted by machine in rows in 1966-67 on an old field. Furrows are clear but gentle, with

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*Average monthly temperature and precipitation data are 30-year normal values (1941-1970) from the nearest National Weather Service climatic stations. The temperature values are those for Burlington (FS), NC. The precipitation values are averages of Burlington (FS), and Graham 2, NC.

about 5 cm of relief between ridge and trough. Planting density was about 1200 stems ha^{-1}. The stand was thinned by rows (1 row removed from each 4 rows, plus selected stems in other rows) in early 1984. Four growing seasons have elapsed since thinning, and the canopy is at maximum biomass. Site index is 17.7 m at 25 yr, generally a very good site for the Piedmont. Understory vegetation is negligible.

Geology

The Piedmont region is characterized by old, highly weathered landscapes, and land use over the past few centuries has strongly affected the topsoil in most areas. Soil series and associations vary on a small scale (from 1 to 100 ha), due primarily to a patchwork of parent materials. The Durham soil series at the Dailey Tract formed in residual parent material of highly weathered felsic igneous rocks; other common parent materials in the region include mafic igneous rocks and mixtures of felsic and mafic rocks.

IFS NUTRIENT CYCLING SITE

Plot Layout

A 0.1-ha circular plot was established within a fenced enclosure (2.2-m high chain-link fence with barbed wire). Lysimeter pits were dug at 4 locations evenly spaced along the perimeter of the plot. Soils were described, sampled by horizon, and fritted-glass lysimeters placed: (1) beneath the forest floor; (2) beneath the Ap horizon (about 15-20 cm), beneath the E horizon (about 30 cm), and at about 60 cm in the Bt horizon. Near the center of the plot, we established a 10- by 20-m permanent grid for repeated soil sampling. The 10- by 10-m grid recommended in the protocols was expanded to provide walkways between rows to minimize soil disturbance.

Biomass Estimates

Tree biomass was calculated with equations developed for a 22-year-old stand 50 km away (Table 7); samples are being analyzed for site-specific biomass determination.

Table 7. Current stand description (18 yr from planting)

Variable		Value	
Density		760 trees/ha (=100% stocking for commercial forest)	
Average diameter		20.6 cm at 1.4 m height	
Average height		14.1 m	
Basal area		32.4 m^2/ha (140 ft^2/acre)	
Biomass:	Foliage	5.0 kg/tree;	3,800 kg/ha
	Branches	15.3 kg/tree;	11,630 kg/ha
	Boles	88.7 kg/tree;	67,410 kg/ha
	Roots	31.6 kg/tree;	24,000 kg/ha
	Forest floor		63,300 kg/ha

Soil, Physical Description

The Durham series is clayey, kaolinitic, thermic Typic Hapludult. The Ap horizon is fairly sandy, with massive, clayey B and C horizons (Table 8).

IFS ATMOSPHERIC DEPOSITION MONITORING

Instrumentation for the atmospheric deposition measurements were installed during the spring of 1986. Regular collection of continuous weather data, bulk deposition, and dry/wet events were initiated in July 1986. About 75 percent of the dry/wet events have been sampled since the initiation of data collection.

Tower and Meteorological Instrumentation

A twenty-five meter tall walkup scaffold tower with a 1.5- by 2.1-m base (WACO Corp.) has been erected to support the meteorological and other instrumentation. The air temperature and humidity sensors, anemometer, and wind vane are located on the top of the tower and held by instrument supports extending from its westerly face. This orientation for these sensors minimizes any influence of the tower on the measurements for the predominating wind directions at the site (winds from the SE, S, SW, W, and NW sectors). The pyronometer is located on the SE corner above the tower where no solar shadows will affect its readings. The tipping bucket precipitation gauge is located in the center of a small opening near the tower (see Wet Deposition below).

Dry Deposition and Air Quality Measurements

The support for the dry deposition sampling device was initially located approximately 2 m above the canopy at the 19.8-m level of the tower based on the original sampling protocols. In April 1987, it was moved to the top of the tower to minimize any turbulent recycling of particles from the forest canopy. It extends from the SW corner, positioned so that there are no other instruments directly above, minimizing the potential for any dryfall contamination. The wet sensor

Table 8. Soil profile

Horizon	Depth (cm)	Extr. Ca mmol(+)/kg	Color	Text.	Consistency Moist	Consistency Wet	Boundary
Oi	10-5						
Oe	5-0						
A	0-10	0.51	10YR5/3	ls	V. fri.		Non-sticky, Clear, wavy non-plastic
Ap	10-25	0.65	10YR6/3	ls	V. fri.		Non-sticky, Abrupt, wavy non-plastic
E	25-60	0.81	10YR6/4 mottles 10YR6/8	ls	V. fri.		Non-sticky, Grad. irreg. non-plastic
Bt	60-100	6.0	10YR6/6 mottles 10YR6/8	sl	Friable		Slight stck., Grad. irreg. non-plastic
CB	100-140	11	10YR6/6 mottles 10YR6/4	sl,sc	Friable		Slight stck., Grad. irreg. non-plastic
C	140-175+	17	Mottled 10YR6/8 7.5YR5/8	cl	Friable		Sticky, Grad., irreg. plastic

for actuating the sliding cover for the dryfall sampler is located on the top of the tower.

The filter pack for monitoring the atmospheric particulates, HNO_3, and SO_2 is also attached to the dry deposition sampler support. It is oriented in a vertical position with a plastic funnel above it to serve as a rain shield. This location for the filter pack will provide the maximum correlation of its data with that from the dry deposition plates. A Metrex Instrument Ltd. Model AS-2 air sampler was chosen to use with the filter pack. It provides constant air flow in the range of 1 to 8 L per minute controlled by a Tylan mass control valve. We are using it at the protocol-specified 3 to 3.5 L/min.

The ozone sampler is located near the center of the opening used for the bulk precipitation and wet fall measurements. Its intake, protected by an inverted funnel, is located about 1 m above the top of a small building used to house the ozone analyzer. For three months in the fall of 1987 the ozone monitor was moved to the main tower for sampling about within the canopy.

Because of the estimated low frequency of fog events at the research site, a fog sampler was not included in our initial installation.

Wetfall Measurements

Wetfall event samplers are positioned at five locations beneath the canopy to measure the throughfall chemistry during precipitation events. The location of these samplers was determined randomly, tempered by some adjustments to ensure collection of samples for a range of overhead canopy cover conditions (i.e., near the tree bole, center of crown, edge of crown, between crowns). The funnel collectors for measuring bulk throughfall were also located near the event throughfall collectors.

Stemflow during precipitation periods is being measured with stemflow collectors on five trees. Preliminary sampling from these collectors indicates considerable variation in stemflow between individual trees. We have noted some correlation between stemflow amount and crown diameter, indicating the need to consider this as an

additional weighting factor for these measurements. We also decided to use the same stemflow collectors for the event and the bulk samples. The stemflow collector is washed before each selected wet event period. This wash water was collected and analyzed for its chemical composition for several months and found to be insignificant compound to total fluxes. The total monthly bulk stemflow amount and chemical composition are calculated from the sum of the selected wet event samples, the bulk samples between the selected wet events, and the mass of individual chemicals from the wash water.

Because of wind effects on precipitation collectors, the instruments for measuring the chemistry and amount of incident precipitation were located in a small opening about 91.5 m from the meteorological tower. The instruments, including the wetfall collector, the bulk collector, and 2 tipping bucket rain gauges, are located near the center of the opening. The forest surrounding the opening provides a wide shelter of approximately 45 degrees above the horizon for these instruments.

THOMPSON, FOREST, WASHINGTON, SITES

(Douglas-fir and Red Alder)

PARTICIPANT INSTITUTIONS AND INVESTIGATORS - D. W. Cole, R. L. Edmonds, R. Gonyea, P. Homann, College of Forest Resources, University of Washington; H. Van Miegroet, Oak Ridge National Laboratory.

SITE DESCRIPTION AND LOCATION

The intensive monitoring site is conducted at the Thompson Research Center, which is located in the Cedar River Watershed 56 km SE from Seattle near 47° 23′ N latitude. It lies at 220 m elevation on the west side of the Cascade Mountains (Fig. 10). The climate in that area is maritime with cool, dry summers and wet, moderate winters. The recorded mean annual temperature for the area is 9.8°C, with average monthly temperatures of 2.8°C and 16.8°C in January and July, respectively. Mean annual precipitation is approximately 130 cm, most of which falls as rain between October and March.

Vegetation

Douglas-fir and red alder control plots are located in close proximity to each other (Fig. 11). The Douglas-fir stand was planted in 1931 after a series of wild fires, following logging of the original old-growth forest between 1910 and 1920. The stand contains approximately 1100 stems per hectare and has a basal area of 50 m^2 ha^{-1}. It is classified as a low site III (King, 1966) with a site index of 106 for Douglas-fir at age 50. The understory vegetation mainly consists of salal (*Gaultheria shallon* Pursh.), Oregon grape [*Berberis nervosa* (Pursh.) Nutt.], and bracken fern (*Pteridium aquilinum* Kuhn var. *pubescens* Underw.). There are also several species of mosses, predominantly *Hylocomium* spp. and *Eurynchium oreganum* (Sull.) Jaeg.

The adjacent red alder forest established naturally in the burnt area a few years later. Stand density is generally lower than in the Douglas-fir stand, with only 800 stems per hectare, and a basal area of

ORNL-DWG 90-1773

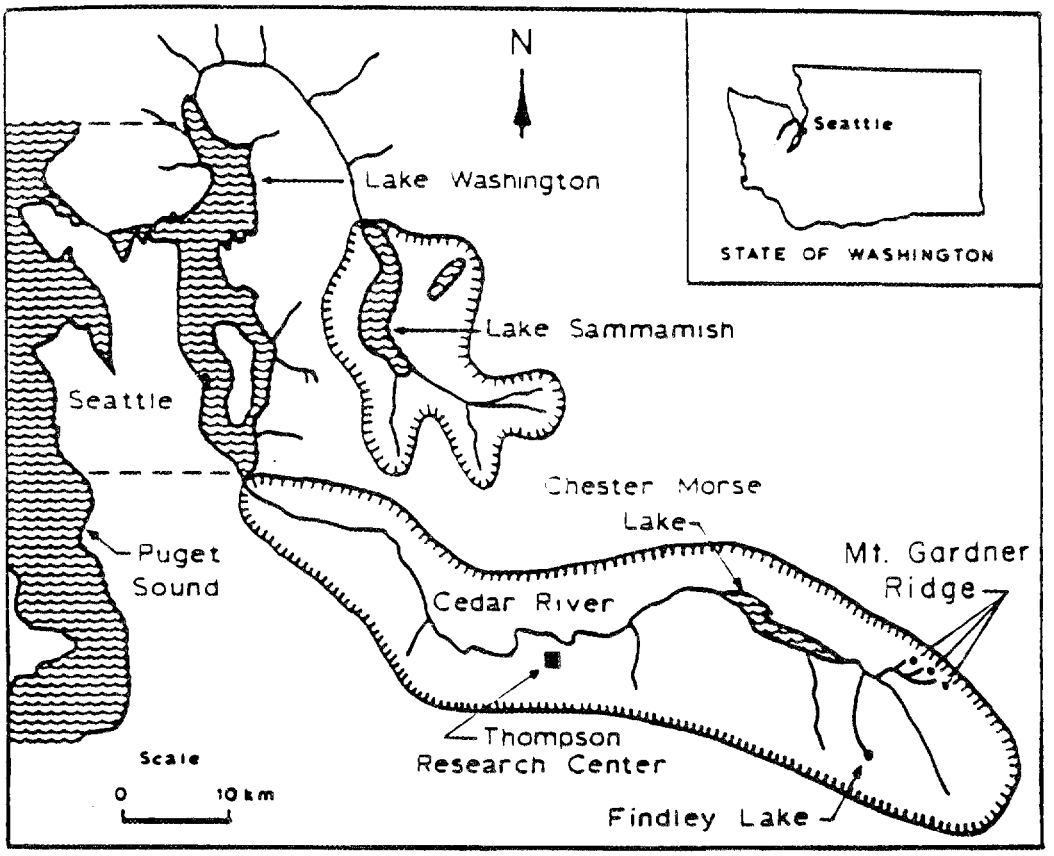

Fig. 10. Location of the Thompson Research Center and Findley Lake within the Cedar River Watershed.

ORNL-DWG 90-1774

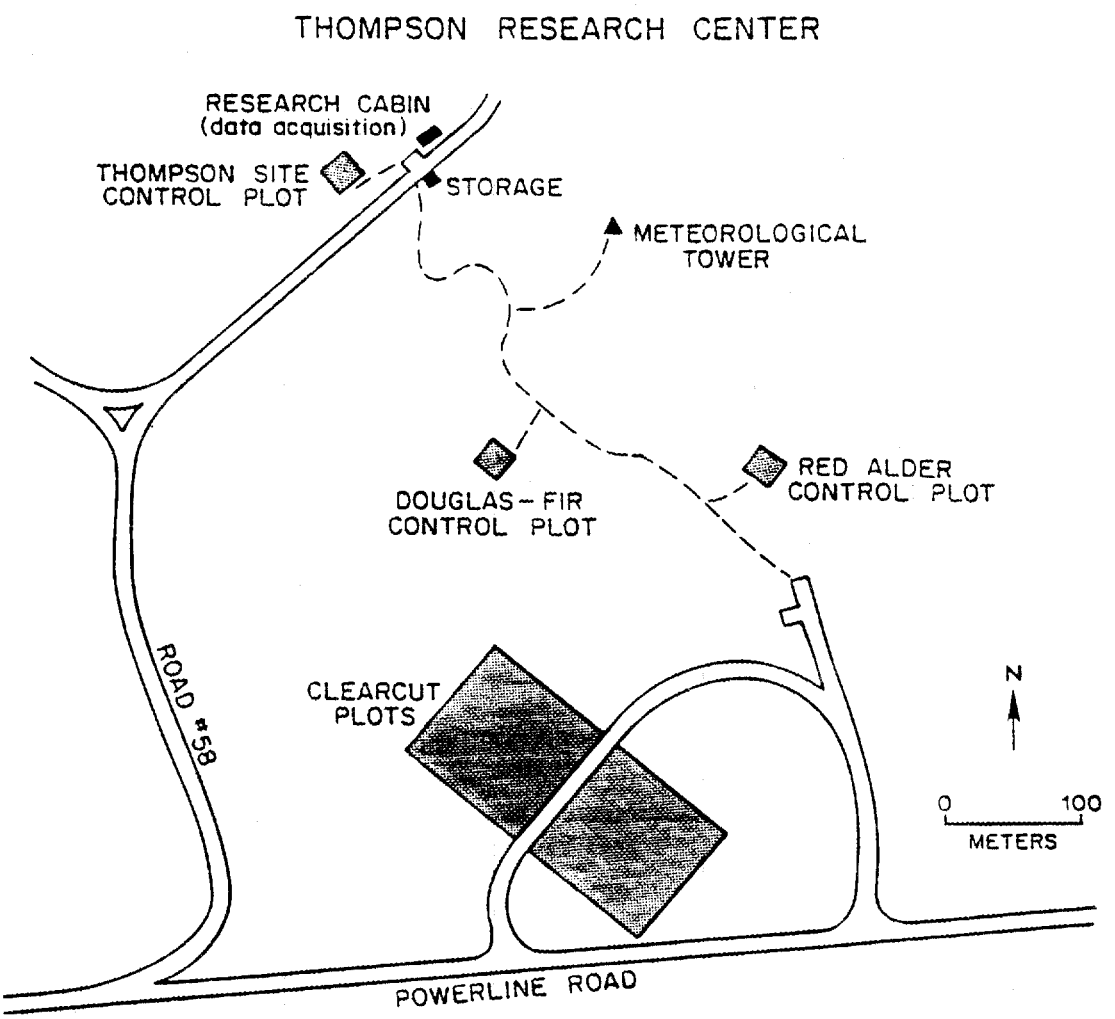

Fig. 11. Location of control, leachate, and clearcut plots, meteorological tower, and data acquisition station at the Thompson Research Center.

36 m^2 ha^{-1}. At age 50 this pioneer species is approaching the end of its rotation, and as a consequence the canopy is rapidly opening up. The understory is more prominent and consists mainly of a dense growth of sword fern [Polystichum munitum (Kaulf.) Presl.] and bracken fern intermixed with some Oregon grape.

Soil

The soil underlying both study sites belongs to the Alderwood series (Dystric Entic Durochrept). It is of glacial origin, developed from ablation till overlying compacted basal till and has a gravelly, sandy loam texture (Cole and Gessel, 1968). Due to the presence of the basal till layer, drainage is restricted in the lower parts of the soil profile, and a shallow watertable is not uncommon during the winter months. A soil profile description is given in Table 9.

Experimental Plots for Task B3

In addition to the mature Douglas-fir and red alder forests, the low elevation site also includes a set of red alder and Douglas-fir plantations which have been established on areas previously occupied by these species. The location of these plots with respect to the control plots and other field installations at the Thompson Research Center is given in Fig. 11. Two 50 x 100 m planting units were established in each of adjacent Douglas-fir and red alder stands. They were further subdivided in eight 15m x 15m plots for intensive pre- and post-harvesting sampling as indicated in Fig. 12.

The planting units were clearcut in September 1984. Trees were carefully removed by lifting and maneuvering with a cable system in order to prevent disruption of mineral soil which commonly occurs during tree removal by conventional methods. Units were planted with red alder or Douglas-fir seedlings yielding four distinct treatments:

Table 9. Profile description for the Alderwood series soil under Douglas fir, Thompson Research Center

Horizon	Depth (cm)	Description
Oi	3- 2	Partially decomposed litter
Oa	2- 0	Unrecognizably decomposed litter and humus
A	0-15	Brown (10 yr 4/3) sandy loam; moderate medium granular structure; friable; scattered concretions; clear, wavy boundary; many roots
B	15-30	Pale brown (10 yr 6/3) sandy loam; weak medium subangular blocky structure; friable; scattered concretions; clear, wavy boundary; many roots
B	30-60	Light yellowish-brown (10 yr 6/4) gravelly sandy loam; weak medium subangular blocky structure; friable; clear, wavy boundary; occasional roots
B	60-85	Very pale brown (10 yr 7/3) gravelly, sandy loam; weak medium subangular blocky structure; friable; clear, wavy boundary; occasional roots
C	85+	Dark gray (10 yr 4/1) gravelly, sandy loam; strong medium platy structure to massive; roots rare

Source: Cole and Gessel, 1968

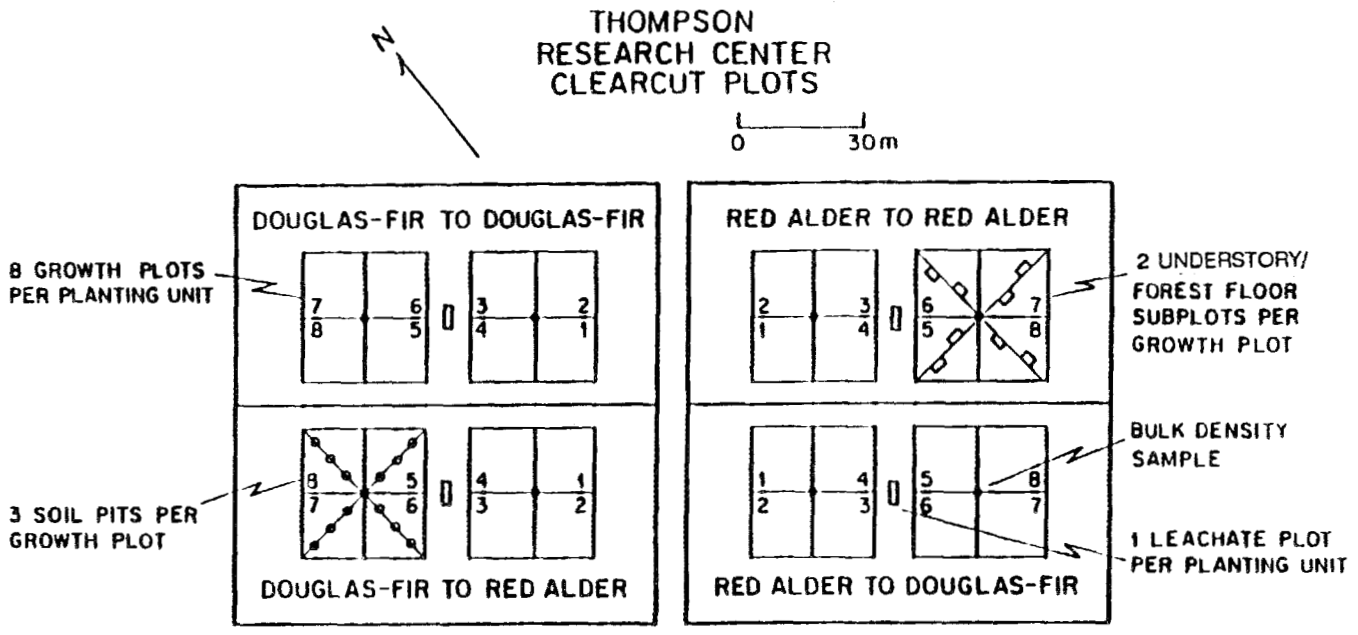

Fig. 12. Plot layout and sampling protocol for clearcut plots, Thompson Research Center.

Original	Replanted	Code
Red alder	Red alder	A x A
Red alder	Douglas-fir	A x F
Douglas-fir	Red alder	F x A
Douglas-fir	Douglas-fir	F x F

These experimental plots are designed to investigate (1) changes in soil and solution chemistry caused by prolonged (natural nitric) acid input and (2) the extent and recovery of soil and solution properties, once strong acid inputs are stopped.

IFS NUTRIENT CYCLING SITE

Sampling and Analysis - Control Plots

The current investigation extends and intensifies the continuous monitoring of the red alder and Douglas-fir control plots which began in 1979 using sampling protocols described in Johnson et al., 1981 and Van Miegroet, 1986. Nutrient flux monitoring installations have been updated to conform to the protocols of IFS. In the red alder control plots where solution pH values occasionally drop below pH 4.5, two fritted glass lysimeters have been installed at each collection depth, in addition to the three replicate ceramic plates currently in use. This will enable a comparison of the chemical composition (particularly aluminum concentration) of solutions collected with either lysimeter type.

Initial characterization of soil properties and quantification of the major nutrient pools in the Douglas-fir and red alder forest ecosystems are completed. Biomass and nutrient distribution estimates are summarized in Table 10.

Future efforts will extend to the sampling and analysis of root biomass and quantification of this below ground nutrient pool in the Douglas-fir and red alder ecosystem.

Table 10. Biomass and nutrient distribution in Douglas-fir and red alder control plots, Thompson Research Center.

Ecosystem Component	Biomass	N	S	P	Ca	Mg	K	Na
	kg ha^{-1}							
				DOUGLAS FIR				
Overstory								
Foliage	6,180	92	9	19	38	7	38	0.2
Branchwood	22,900	68	5	10	86	8	39	1.0
Bole	242,300	150	11	10	99	8	23	5.3
Total	271,400	309	25	38	223	23	100	6.5
Understory	3,050	30	4.5	4	25	6	29	0.5
Forest floor								
Humus and litter	23,500	295	29	24	182	23	27	12
Woody debris	13,200	84	9	7	45	7	9	6
Logs	107,200	131	7	13	73	13	48	4
Mineral soil (0-45 cm)		5,080	658	3,700	1,090 (Exchangeable Cations)	100	263	117
				RED ALDER				
Overstory								
Foliage	3,500	116	7	10	23	6	43	0.2
Branchwood	29,400	167	10	15	96	11	91	0.7
Bole	193,400	545	27	21	403	40	190	8.9
Total	226,300	830	44	46	522	57	323	9.8
Understory	6,010	87	9	8	24	11	109	1.0
Forest floor								
Humus and litter	79,600	1,527	140	80	666	86	112	38
Woody debris	18,900	101	8	5	165	11	8	2
Mineral soil (0-60 cm)		7,050	666	1,860	904 (Exchangeable cations)	73	144	50

The cycling pattern of the base cations, N, P, and S in a mature red alder and Douglas-fir forest has been calculated based on aboveground biomass, litterfall and solution data from both control plots as part of current and previously EPRI-funded research.

Sampling and Analysis - Plantations

Initial (pretreatment) characterization of the four planting units has been completed. Prior to forest removal and site conversion, several understory forest floor and soil samples were taken according to the sampling protocol illustrated in Fig. 12. Chemical analysis of the soil samples has been completed.

IFS ATMOSPHERIC DEPOSITION

Tower

A 36-m tower extending several meters above the Douglas-fir canopy contains the sensors for monitoring atmospheric inputs to the ecosystem. The tower is situated on a 0-5° slope with a western aspect, at an elevation of 228 m. Prevailing winds are from the southwest. Equipment was installed to make following measurements:

wind speed & direction (R. M. Young Model 5103, 5602), air temperature (Minco platinum resistor), dew point temperature (Heated Li-Cl hygrometer), solar radiation (Science Assoc. Solar radiatometer #632-2), precipitation volume (Texas Ele. Raingauge #525), incident precipitation, wet only (Aerochem Matrics wet/dry collector), vegetation wet or dry (Wong labs dew sensor), ozone (Dasibi #1008-Ah UI.V. photometric ozone analyzer), coarse particulates (ORNL automatic dry deposition collector with polycarbonate petri plates), and fine particulates and nitric/sulfuric acid vapors (filter pack with Zeflour, Nylasorb and S&S Fastflow #2 filters).

Duplicate sensors exist for windspeed, wind direction, solar radiation, air temperature, dew-point temperature and precipitation volume. In addition, during the months of June, July, and August a second ozone monitor on loan was used to measure ozone concentrations at the tower base.

The sensors are interfaced via a Remote Measurement Systems 16-channel A/D converter to a Commodore 64 computer which is located in the research cabin 100 m from the tower. Readings are taken every minute and 1-h averages, and their corresponding Julian date and times are recorded in a newly created file on a 5" floppy disk in a Commodore disk drive. Each floppy can hold up to 60 days of such data. The disk is periodically taken to the University of Washington where it is transferred via a hardwire link to an IBM PC for data processing.

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FINDLEY LAKE SITE

(Subalpine Fir)

PARTICIPATING INSTITUTIONS AND INVESTIGATORS - D. W. Cole, R. L. Edmonds, R. Gonyea and P. S. Homann, University of Washington; H. Van Miegroet, Oak Ridge National Laboratory.

SITE DESCRIPTION AND LOCATION

The Findley Lake site lies within the Cedar River Watershed, approximately 65 km SE of Seattle, Washington. It is located on the west slopes of the Cascade Mountains at an elevation of 1130 m. Mean annual temperature is 5.4°C. Mean annual precipitation is 273 cm with a snowpack from 2 to 7 m.

The area lies within the Abies amabilis vegetation zone (Franklin and Dyrness, 1973). The stand is dominated by approximately 180-year-old Abies amabilis. Associated species are Tsuga mertensiana (Bong.) Carr. and Tsuga heterophylla (Raf.) Sarg. Major shrubs include Vaccinium membranaceum Dougl. ex Hook., V. ovalifolium Smith, V. alaskaense How., Sorbus sitchensis Roemer, and Alnus sinuata (Reg.) Rydb. Low shrubs and herbs include Cornus canadensis L., Xerophyllum tenax (Pursh.) Nutt., Clintonia uniflora (Shult.) Kunth, Achlys triphylla (Smith) D.C., Rubus pedatus J. E. Smith, and Viola sempervirens Greene.

Study area parent material is primarily fractured andesite overlain with andesite moraines 1 to 3 m thick. Ash layers 5 to 25+ cm thick overlay these materials. Ash deposits are primarily St. Helen W and Y (from Meier, 1981).

The soil in this mature Pacific silver fir forest is a Spodosol, which has tentatively been classified as a Typic Cryohumod (Chickamin Series) by the SCS National Cooperative Soil Survey (from Dahlgren, 1984). A soil profile description is given in Table 11.

Table 11. Profile description of the podzolized Cryandept at Findley Lake

Horizon	Depth (cm)	Description
Oi	6- 5	Partially decomposed litter
Oa	5- 0	Unrecognizable decomposed litter and humus
E	0-18	Abrupt, irregular boundary; dark reddish-grey (5 yr 4/2); 10-18 cm thick; coarse loamy sand; weak fine to medium subangular blocky structure
Bhs	18-23	Abrupt, irregular boundary; very dark brown (10 yr 2/2); 0-5 cm thick; clay loam; broken, discontinuous, moderate fine to medium sub angular blocky structure
Bs	18-43	Abrupt, wavy boundary; dark brown (7.5 yr 3/4); 20-28 cm thick; gravelly fine sandy loam; moderate, medium subangular blocky, breaking to fine subangular blocky structure; mottled with Bhs
BC	43-80	Clear wavy boundary; dark yellowish brown (10 yr 4/4); gravelly fine sandy loam; moderate to coarse subangular blocky structure; breaking to fine subangular blocky structure
C	80+	

IFS NUTRIENT CYCLING SITE

Four replicate throughfall, stemflow and litterfall collectors have been installed in a 25- by 25 m control plot. Ceramic lysimeter plates were installed in a nearby leachate plot (Fig. 13) at each of three levels: underneath the forest floor, E horizon and at the boundary between the B and BC horizon. Two fritted glass lysimeters have been added at each depth for comparison of soil solution chemistry. The field installation are fully operational and solutions have been collected since January 1986. During winter snow cores are taken periodically in an open area adjacent to the plots (lake) to characterize atmospheric nutrient inputs.

Sampling and Analysis

Initial sampling for site characterization was performed in September 1985 and included the following:

- Tagging and dbh measurement of all trees within the 25- by 25-m control plot.
- Sampling of foliage, branchwood, bark and stemwood from 10 trees chosen in proportion to the stand diameter frequency distribution
- Removal of eight 1 m^2 understory and 0.25 m^2 forest floor samples
- Soil sampling by horizon from 5 pits within the plot.

Chemical analyses of these samples are now completed. Biomass and nutrient distribution estimates are summarized in Table 12.

ORNL-DWG 90-1776

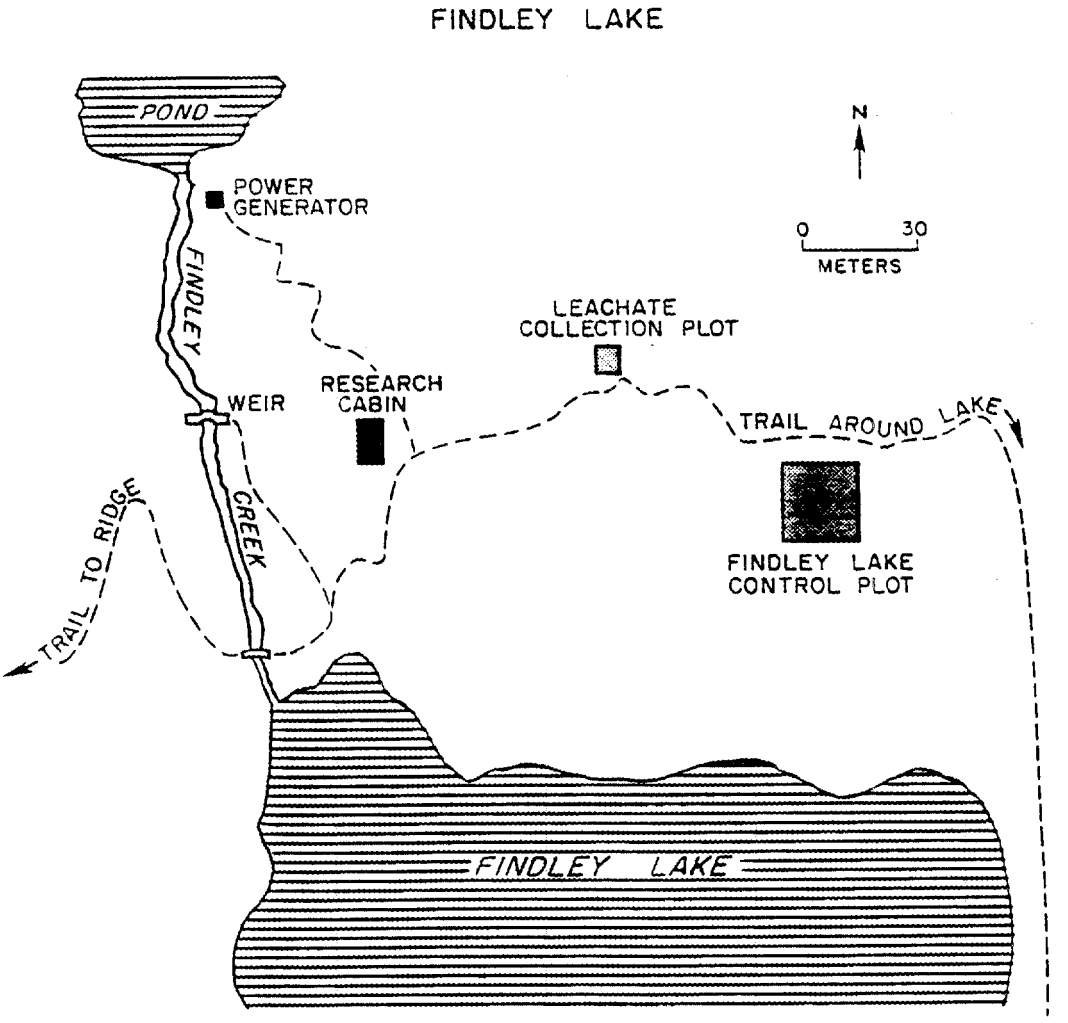

Fig. 13. Plot layout of the Findley Lake site.

Table 12. Biomass and nutrient distribution in Findley Lake control plot, Cascade Mountains, Washington, September 1985

Ecosystem component	Biomass	N	S	P	Ca	Mg	K	Na
	kg/ha							
Overstory								
Foliage	24,400	271	26	38	134	22	157	1.3
Bark	85,900	221	22	26	661	20	59	5.3
Branchwood	75,700	156	10	25	268	25	108	4.6
Wood	378,000	189	15	21	231	43	271	18.3
Total	564,000	837	73	109	1290	109	591	28.8
Understory	660	8	0.7	1.2	2.5	0.9	6.0	0.2
Forest Floor	54,800	575	62	60	159	47	84	80

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HUNTINGTON FOREST SITE

(Mixed Hardwoods)

PARTICIPATING INSTITUTION AND INVESTIGATORS - Myron J. Mitchell, Dudley J. Raynal, Edwin H. White, Russell Briggs, James Shepard, Tommy Scott, Marianne Burke, Todd Lotter, Ann Moore, and Yi-Min Zhang, State University of New York, College of Environmental Science and Forestry.

SITE DESCRIPTION AND LOCATION

The Huntington Forest is a 6,066-ha property of State University of New York, College of Environmental Science and Forestry (S.U.N.Y. C.E.S.F.) located in western Essex County and eastern Hamilton County within the Adirondack State Park of New York. The latitude and longitude of the Huntington Forest are approximately 43° 59′ North and 74° 14′ West, respectively. Elevation ranges from 466 to 806 m.

Climate

Since 1940, basic meteorological data have been collected on a systematic basis at the Huntington Forest. The regional climate is cool, moist, and continental. The mean annual temperature is 5.4°C with a January mean of -8.7°C and a July mean of 18.8°C. Total annual precipitation averages 106 cm with an annual snowfall of 284 cm. Generally the average maximum depth of the snowpack occurs in early March and measures 58 cm (Raynal et al., 1983).

Geology

The underlying bedrock of the Huntington Forest, like most of the Adirondacks, is characterized by Precambrian rocks mostly of the hornblende-granitic gneiss type and occasionally smaller amounts of metamorphosed sediments from the Grenville Formation including impure marbles, quartzites, amphibolites, and schists (Black, 1942). The surficial geology is directly related to Wisconsin deglaciation which occurred about 10,000 years ago (Van Diver, 1985). Mountains are generally covered with a layer of glacial till and the valleys with

stratified drift and lake-deposited material (Heimburger, 1934). Within the Huntington Forest 46 soil taxa have been described which are included within the Histosol, Inceptisol, and Spodosol orders with the latter being most common (Chandler, 1939; Sommers, 1986).

Hardwood Site

The mixed northern hardwood site is located at an elevation of 530 m and is about 200 m southeast of an access road to the Arbutus Lake Complex. This area is typical of much of the Adirondack region since it was heavily cut 75 years ago and has regenerated into a northern deciduous forest dominated by Fagus grandifolia Ehrh. (American beech) and Acer saccharum Marsh. (sugar maple). Other major tree species include Acer rubrum L. (red maple), Betula lutea Michx. F. (yellow birch), Prunus serotina Ehrh. (black cherry) and Picea rubens Sarg. (red spruce). The herbaceous layer is dominated by Dryopteris austriaca (Jacq.) Woynar (shield fern) while Lycopodium annotinum L. (stiff clubmoss) and Dennstaedtia punctilobula (Michx.) Moore (hay-scented fern) are also common. In the spring Erythronium americanum Ker. (dog tooth violet) and Claytonia caroliniana Michx. (spring beauty) are abundant.

The soil is a Becket, bouldery, fine, sandy loam, a Typic Haplorthod. Similar soils are found throughout the Adirondack Region and other areas of the Northeast United States (Sommers, 1986). The soil overlies a bedrock of gneiss, is shallow (<1 m depth) and contains a hardpan derived from the parent material of glacial till. There are considerable coarse fragments and high organic concentrations in the mineral horizons (David and Mitchell, 1987). This site has been the location of other studies on the effects of acidic deposition (David et al., 1984; Mollitor and Raynal, 1982; 1983, Raynal et al. 1980, 1985) sulfur dynamics (David et al. 1982, 1983; David and Mitchell, 1987; Schindler et al., 1986; Schindler and Mitchell, 1987), and aluminum relationships (David and Driscoll, 1984) in this forest ecosystem.

IFS NUTRIENT CYCLING SITE

Monitoring Equipment

Bulk collectors for snow using buckets were installed in November 1985 and are monitored at least monthly during the winter months. In the spring, the collectors were replaced by funnel collectors. Also two snow lysimeters (Rasher et al., 1987) were installed by Dr. Charles Driscoll (Syracuse University) in a complementary project.

Fritted glass lysimeters were installed in November 1984 in the E and Bs2 horizons with two replicates per horizon for comparison with ceramic plate lysimeters which were already installed at the site in two previously utilized lysimeter pits. These latter lysimeters have been monitored from May to September 1979 (Mollitor and Raynal, 1982, 1983) and April 1982 (David et al., 1984; David and Driscoll, 1984) to March 1985. A comparison of solutions collected at 10 kPa from the glass and ceramic plate lysimeters in May and June of 1985 did not detect any major differences based on lysimeter type in cations, silica, or aluminum. It was thus decided to install additional fritted glass lysimeters in the site.

Three additional soil pits have been established at the site and at each pit two replicate fritted glass lysimeters have been installed in the Oa, E, and Bs3 horizons. In addition to these lysimeters a companion set of zero-tension lysimeters were installed in each of the three pits in association with the project under the direction of Dr. Charles Driscoll. Also a vacuum system that maintains the lysimeters at 10 kPa tension was installed in the instrument building adjacent to the site. Both the new (fritted glass and zero-tension) as well as the old lysimeter systems (fritted glass installed in November 1984 and ceramic plates) have been monitored since April 1986. Monitoring all these lysimeter systems helped ensure that past solution data sets from this site could be linked to the present study.

Separate sets of stemflow collectors were used for events and for continual monitoring. For event monitoring five trees were outfitted with stemflow collectors. The collectors consisted of 1.75-cm-o.d. Tygon tubing sealed in a spiral around each tree with silicone rubber caulk. A slit ca. 90° of arc was cut in each tube to form a trough.

The trees are associated with the two wet/dry collectors in the site. The trees selected were those in which the canopy was directly above the wet/dry collectors. Three trees are American beech and two are sugar maple. Stemflow from these trees was collected with the wet-only event samples from the wet/dry collectors.

Plots were established for monitoring stemflow on a continuous basis. Four fixed area plots (100 m^2) were selected randomly but in a manner such that the basal area of the trees selected in the plots as a whole was representative of the distribution of basal area among the four major tree species (sugar maple, American beech, yellow birch, and red maple). The four plots included 19 trees of which there are 6 sugar maple, 11 American beech, and one each of yellow birch and red maple. They were sampled at the same time intervals as that for soil solution and throughfall.

Vegetation

All trees on a 0.1-ha circular plot were numbered and diameter outside bark at breast height (dbh) was measured to the nearest 0.1 cm. In addition, harvesting and subsampling for estimating biomass was completed for American beech and red maple, while for the other major tree species literature information was utilized in conjunction with size distribution data collected at the site. Five dbh classes (9, 17, 25, 32 and 40 cm) were chosen to cover the dbh range of American beech. Forty sample points were systematically located approximately 20.1 m (one chain) from the perimeter of the intensive monitoring area. Prior to visiting each sample point in the field, a dbh class was randomly assigned to each sample point. The beech tree nearest the point which fell into the preassigned dbh class was designated as the sample tree. Dbh was measured to the nearest 0.1 cm using a steel tape. After felling, total height, height to a 10-cm top, and height to the first live branch were measured. Each tree was felled and branches with their leaves attached were cut from the bole. Branches were defined as all woody material less than 10 cm in diameter. All of the foliage was picked from the branches and taken to the laboratory. Branch fresh mass was determined in the field. Ten branch subsamples, each of which

included three approximately 20-cm lengths removed from the base, middle, and end of the sample branches, were collected for estimation of moisture content. The bole of each sample tree was divided into three sections of equal length. Three sample discs were randomly located in each section for estimation of moisture content and percent bark. After cutting each bole section into pieces and weighing on a hanging scale, sample discs were removed and fresh mass determined. Using a procedure similar to that employed for American beech, 16 red maple trees were destructively sampled for the development of biomass equations.

Tissue Nutrient Concentrations

Five trees were randomly chosen for each of three species represented on the 0.1-ha plot (sugar maple, yellow birch, and red maple) for estimation of component tissue nutrient concentrations. Sample points were randomly chosen from the 40 sample points located around the perimeter of the intensive monitoring area. The tree of the predetermined species occurring nearest to the sample point was designated as the sample tree. Foliage and branches were obtained from the lower crown and the highest point in the crown accessible using pole pruners and tree ladders. Bark samples were obtained at dbh and at 8 m up the bole. Increment corers were utilized to obtain 5-6 cores of wood through the pith from the locations where bark was removed. Two of the trees felled to facilitate tower installation (a 25-cm-dbh red maple and a 33-cm-dbh sugar maple) were also subsampled for component nutrient concentrations.

Biomass Estimates

Prediction equations relating component dry mass to dbh and total height were applied to the inventory data for the 0.1-ha plot. The equations utilized were from a variety of sources. For American beech and red maple the equations were developed from data collected from the Huntington site. Biomass equations for sugar maple ranging from 10 to 45 cm dbh were obtained from Briggs et al. (1986), developed for trees sampled from the Green Mountain National Forest, Vermont. In order to provide reasonable estimates for trees less than 10 cm dbh, a simple

linear regression of component dry mass on dbh was developed utilizing the data of Briggs et al. (1986) for the 10-cm-dbh class. Since separate dry mass estimates are not available for bolewood and bolebark components of red maple and yellow birch, weighted nutrient concentrations were computed using the ratio of bolewood and bolebark dry mass to total bole mass for sugar maple and American beech.

Ground Vegetation and Forest Floor

Composition of the ground vegetation in the central 1 m^2 of each of the 20 subplots was recorded as percent cover by species. Ground vegetation on the five subplots adjacent to the soil pits was sampled. Forest floor, ground vegetation, and woody litter samples were also obtained. All collected material was transported to the laboratory. Vegetation and forest floor samples were dried at 65°C and dry mass determined.

A 20- by 20-m square plot, located in the center of the 0.1-ha circular plot, was divided into 100 2- by 2-m square subplots. Subplots were numbered from 1 to 100, and 20 were randomly selected. Woody litter greater than five cm in diam and located in the central 1 m^2 of each subplot was marked with cloth tags and its mass was determined.

Fine Roots

In conjunction with the IFS research, a study determined the role of fine roots in the organic matter and nutrient budgets. Toward this end, we estimated (a) belowground production, (b) phenology of fine root growth, and (c) factors that affect fine root chemical composition. Nutrient storage, flux, and availability potential were determined. An additional objective was to investigate a potentially less labor-intensive and more accurate method of estimating fine root production. This method involved a double sampling scheme which compared root elongation increments (from root observation chambers called rhizotrons) and fine root biomass and length increments (from sequential soil coring).

Production. A soil-coring method was developed for root biomass. Cores of soil 10 cm in diam were removed using a diamond bit attached to

a power post-hole digger via a machined adapter. A computerized root length measuring procedure was developed to rapidly and accurately measure fine root length.

Phenology. Fine root growth phenology was studied using six rhizotrons which were installed at the site. These consist of glass observation windows encasing reconstructed soil profiles. Darkness and natural temperature conditions are maintained. Natural thermal gradients were measured using permanently installed temperature probes in each rhizotron and two control sites.

Chemical composition. Chemical composition of roots, was determined using tissue analysis methods.

Soils

Soil pits were constructed using a post-hole digger on five of the subplots where rocks and large boulders did not impede a tile probe from making contact with the basal till. Each of the five soil pits was described according to Soil Conservation Service procedures. Soil samples were collected by horizon from each soil pit and returned to the laboratory for analysis. A description of a typical pit is given in Table 13.

Each of 20 subplots was divided into a central 1 m^2 area with 12 0.5- by 0.5-m subplots surrounding the perimeter. One of the 12 subplots was randomly chosen for sampling the organic horizons. A serrated knife was used to cut around a 0.5- by 0.5-m wooden template placed on the forest floor. The Oi, Oe, and Oa organic horizons were collected separately and air dried.

During the digging of the lysimeter pits, the soils were also sampled by horizon. Bulked samples from each pit have been returned to the laboratory for further homogenization. A portion of these samples will be maintained in field moist condition at 1°C (for some analyses which are sensitive) to soil drying processes (e.g. Al and Fe fractions, S fractions). The remainder of the sample were air dried and analyzed for N, P, K, Ca, Mg, S, and sulfate as well as cation exchange capacity,

Table 13. Soil Description of pit 25 in Hardwood Site at Huntington Forest

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Soil Series: Becket loam

Taxonomic Class: coarse-loamy, mixed, frigid, Typic Halplorthod

Conditions: Soil described under moist conditions

Oi - 5-4 cm; slightly decomposed hardwood leaf litter and debris; approximately 95% fiber, 90% rubbed; clear smooth boundary.

Oe - 4-1 cm; dark reddish-brown (2.5YR 3/4) and (5YR 2.5/2) intermediately decomposed organic matter; approximately 75% fiber, 60% rubbed; common fine roots; extremely acid (pH 3.8); clear smooth boundary.

Oa - 1-0 cm; dark reddish-brown (5YR 2.5/2) highly decomposed organic matter; approximately 35% fiber, 20% rubbed; common fine roots; extremely acid (pH 3.8); clear broken boundary.

A - 0-1 cm; dark reddish-brown (5YR 2.5/2) loam; weak fine granular structure; friable; common fine and few medium roots; 3% fine, medium and coarse gravels; common fine washed sand grains throughout; few fine and medium pieces of charcoal; extremely acid (pH 4.2); clear wavy boundary.

E - 1-3 cm; brown (7.5YR 4/2) coarse sandy loam; many medium distinct, very dark gray (5YR 3/1) organic streaks; weak, fine granular structure; friable; common fine and few medium roots; 3% fine, medium, and coarse gravels; common fine washed sand grains throughout; extremely acid (pH 4.2); clear broken boundary.

Bh - 3-6 cm; very dusky red (2.5YR 2.5/2) and dark reddish brown (2.5YR 3/4) fine sandy loam; weak fine subangular blocky parting to weak fine granular structure; friable; common fine and medium and few coarse roots; 5% fine, medium, and coarse gravels; few fine washed sand grains; few fine pores; extremely acid (pH 4.4); clear wavy boundary.

Bhs - 6-15 cm; dark reddish-brown (5YR 3/3) and (5YR 3/2) fine sandy loam; weak fine and medium subangular block parting to weak fine granular structure; friable; common fine and medium and few coarse roots; 7% fine, medium, and coarse gravels; few fine pores; extremely acid (pH 4.4); clear wavy boundary.

Table 13. (continued)

Bs1 - 15-28 cm; dark reddish-brown (5YR 3/4) fine sandy loam; few fine distinct dark reddish-brown (5YR 3/2) organic streaks on pedon faces; weak fine subangular blocky parting to weak fine granular structure; friable; few fine and medium roots; 10% fine, medium, and coarse gravels, 3% cobbles; few fine pores; very strongly acid (pH 4.6); clear wavy boundary.

Bs2 - 28-53 cm; dark reddish-brown (5YR 3/4) sandy loam; common medium distinct dusky red (2.5YR 3/2) organic streaks and common few distinct yellowish- red (5YR 5/6) decomposing roots; weak fine subangular blocky parting to weak fine granular structure; friable; few fine and medium roots; 10% fine, medium, and coarse gravels, 5% cobbles; few fine pores; very strongly acid (pH 4.6); clear smooth boundary.

BC - 53-76 cm; brown (10YR 4/3) coarse sandy loam; many medium distinct dark reddish-brown (5YR 3/3) mottles; weak fine to medium platy structure; firm; few fine roots; 10% fine, medium, and coarse gravels, 5% cobbles; very strongly acid (pH 4.8); clear smooth boundary.

C - 76-87+ cm; dark grayish-brown (2.5YR 4/2) loamy sand; few fine distinct yellowish-brown (10YR 5/4) and few medium distinct strong brown (7.5YR 5/6) mottles; 40% massive, 60% weak fine and medium platy structure, brittle; very firm; 10% fine, medium, and coarse gravels, 5% cobbles; very strongly acid (pH 4.8)

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exchangeable cations, Al^{3+}, extractable P, and total carbon. A portion of the soil samples were sent to ORNL for quality assurance and further analysis.

Soil Minerals and Weathering

The goals of this phase of the project included (1) the determination of the mineralogical composition of the soils by horizons on the site utilizing X-ray diffraction procedures; (2) the determination of elemental composition of the minerals utilizing X-ray fluorescence; (3) calculation of approximate weathering rates using information on changes in composition and mass of soil minerals with depth. Bulk sample horizons were obtained from pits excavated for the tower construction and lysimeter installation. Samples were air dried, passed through a 2-mm sieve, and prepared for mineralogical analyses. Master strip charts compiled from NBS standards were used in both X-ray diffraction and X-ray fluorescence for qualitative and semi-quantitative analysis.

IFS ATMOSPHERIC DEPOSITION MONITORING

Tower Installation

A 30-m (100 ft) tower was installed on the site. The tower footing and anchor excavations were done by hand to minimize soil disturbance; both the footings and the anchors were placed in reinforced concrete as per tower specifications. Five trees had to be cut since they interfered with the guy wires from the tower; fortunately two of these trees could be utilized in vegetation analysis as described previously. The tower is equipped with a platform, lightning protection package, and safety climb system. The installation of 110 V power at the tower site was completed. A building for aiding in the distribution of power and other equipment at the site was constructed and is located about 60 m northwest of the tower.

Meteorological and Ozone Equipment

The following equipment was installed in May 1986 on the tower at the site: meteorological package (anemometer, wind direction sensor,

radiometer, temperature and relative humidity sensors, and data logger), fog collector, aerosol and vapor filter pack, dry deposition collector, and aerosol vacuum pumps. An ozone monitor and tipping bucket rain gauge were installed at the nearby NADP site in June 1986. We were able to utilize an existing instrument building after some trees in the proximity of the building were removed to minimize any canopy effects on ozone concentration.

Two wet-only precipitation collectors were installed in the hardwood site in June 1986. One was installed under a pure beech canopy and the other under a pure sugar maple canopy. A third wet-only collector was installed in the open at the NADP site.

OTHER RESEARCH ACTIVITIES AT THE SITE

Driscoll, C.T., Principal Investigator. An evaluation of the source of nitric acid inputs to low ionic strength surface waters. National Science Foundation.

Fakundini, R., Principal Investigator. Crystalline rock survey project. Geological Survey of New York.

Flynn, D., Principal Investigator. Environmental, social, and economic effects of acid precipitation on metal. U.S. Bureau of Mines.

Nelson, L., Principal Investigator. Environmental, social, and economic effects of acid precipitation on stone. U.S. National Park Service.

Nyland, R., Principal Investigator. Assessment of growth and yield of individual tress and forest stands in New York. McIntire-Stennis.

O'Brian, J. and M. Birmingham., Principal Investigators. Cooperative survey of red spruce and balsam fir decline and mortality in NH, NY, and Vermont. U.S. Forest Service and New York State Department of Environmental Conservation.

Raynal, D., Principal Investigator. Measurement of precipitation chemistry at the Huntington Forest. New York State Electric and Gas Corp.

Valentine, H., Principal Investigator. Mortality risk functions for American beech and associated species in northern hardwood forests. U.S. Forest Service.

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COWEETA SITE

PARTICIPATING INSTITUTION AND INVESTIGATORS - Wayne T. Swank and Lee Reynolds, Coweeta Hydrologic Laboratory.

SITE DESCRIPTION AND LOCATION

The Coweeta Hydrologic Laboratory is located in the Nantahala Mountain Range of southwestern North Carolina, 35° 03′ N, 83° 27′ W, 22 km south of Franklin, North Carolina. The study sites for this project include a 30-year-old white pine plantation located on Watershed 1 (IFS abbreviation: CP), and an uneven aged, mixed hardwood stand located on Watershed 2 (IFS abbreviation: CH). Plots 0.1 ha in size are located in each stand following recommended project protocols. Both plots are at approximately 720-m elevation with a slope of about 40 to 45% and an aspect of 140°. Within the Coweeta basin, elevations range from about 680 to 1600 m; thus the plots are at low elevations, only slightly above nearby valley floors.

Climate

The climate, characterized by abundant rainfall evenly distributed throughout the year and moderate temperature, is classified as Humid Temperate (or Marine Temperate). Lower elevations at Coweeta, where the plots are located, are characterized as intermediate between the Humid Temperate and the Humid Subtropical climatic zones. Other basic climatic information from Swift et. al. (1984) for a 37-year period are: mean annual precipitation, 177 cm; range of average monthly precipitation: 11.2 cm (October) to 20.3 cm (March); range of average monthly air temperature: 3.3°C (January) to 21.6°C (July); and range of average monthly evaporation: 0.30 cm (December) to 10.8 cm (July).

During the growing season (May 1-October 31), the median antecedent dry period is about 3 days; 31% of storms follow a dry period of less than 1 day, while 14% of storms follow a dry period of more than 10 days (data from Chris Potter, pers. comm.). Snow comprises less than 5% of annual precipitation, and snow cover lasting more than a few days is

unusual in areas at the altitude and aspect of the study plots (Swift et al., 1984).

Vegetation

A 30-yr-old, essentially pure, plantation of white pine (Pinus strobus) was established in 1957 following clearcutting of the original hardwood forest on Watershed 1 (Swank and Miner, 1968). Competing hardwood sprouts have been mostly removed by cutting and spraying. There is a thin, patchy understory of Rhododendron maximum; a few vines of Vitis and Parthenocissus spp. have reached the canopy level.

Watershed 2 is covered by native, mixed mesophytic hardwood forest typical of the region. It has served as a control watershed since 1934, and no man-caused disturbance has occurred there since 1923. The multi-storied, uneven-aged stand is comprised of Quercus spp.(50% of basal area), Oxydendrum arboreum (11%), Rhododendron maximum (11%), Acer rubrum (10%). Carya spp. (6%), Cornus florida (3%), and a variety of other species (9%).

Geology

Coweeta is situated on the deeply dissected eastern flanks of the Nantahala Mountain range, part of the Southern Blue Ridge Province. Both study plots are underlain by bedrock of the Tallulah Falls Formation, metamorphic rocks of upper precambrian age. This formation is composed predominantly of biotite paragneiss and biotite schist, containing quartz, plagioclase, biotite, orthoglase, muscovite, and garnet. Within the formation are interlayers of pelitic schist and metasandstone (Hatcher, 1979). Mineral weathering rates in the Coweeta basin have been the subject of a recent investigation (Velbel, 1985).

IFS NUTRIENT CYCLING SITE

Plot Layout

Monthly, seasonal, and annual water and nutrient fluxes are being measured using the following set of collectors: (1) Bulk precipitation - with the system in place at Coweeta and a supplementary collector atop the tower on WS 1; (2) Throughfall - with six funnels, 26 cm in diam,

connected to polyethylene bottles by tygon tubing, randomly located on each plot; (3) Stemflow - from 11 collared white pines on WS 1 and from 19 collared trees on WS 2. Species and number of trees collared on WS 2 are: Acer rubrum 2, Quercus coccinea 1, Q. alba 1, Q. velutina 1, Oxydendrum arboreum 2, Rhododendron maximum 5, Kalmia latifolia 3, Cornus florida 3, and Fagus grandifolia 1; (4) Soil solutions - at 4 lysimeter pits on each watershed, randomly located. Each pit contains one zero-tension, lysimeter-collecting, forest floor leachate at the soil surface, and three hanging water column lysimeters set to a suction of 0.1 atm. at varying depths in order to sample the A, BA, and upper BC horizons.

Throughfall, stemflow, and soil solution samples have been collected weekly since October 1985. These were been composited on a monthly basis and sent to ORNL for nutrient analysis.

Biomass, Nutrient Pools, and Nutrient Uptake

The 0.1-ha plot on WS 1 (CP) was established and inventoried on March 23, 1985. Stand basal area was 39.6 $m^2 \cdot ha^{-1}$ with a mean tree dbh of 23.1 cm, a stocking of 950 trees ha^{-1}, and a mean height of 25 m for dominant trees.

Productivity and nutrient uptake on this white pine stand have been monitored periodically since its establishment. Twenty randomly located, 0.08-ha plots were established on the watershed in 1967 and inventoried by measuring and marking dbh of each tree. Plots have been reinventoried periodically to the present time. Over the same period of time the population has been sampled to estimate foliage, branch, and stem biomass and surface area; these same tree components have been sampled for nutrient concentrations. The last sampling date was April 1985. Litterfall has also been measured at selected times during the past 20 years, and root biomass was estimated at age 20. Samples of white pine tree components have been obtained. The 0.1-ha plot on the mixed hardwood stand (CH) was established and inventoried on Dec. 3, 1985. Basal area was 40.6 $m^2 \cdot ha^{-1}$. Biomass of the hardwood stand will be estimated using existing allometric equations. Samples for nutrient

analysis were collected in the summer of 1986. These were used with the biomass estimates to obtain estimates of standing nutrient pools for the plot.

Periodic net primary production and associated nutrient uptake will be estimated from dbh inventories and remeasurements on each plot. Within-season growth dynamics will be derived from dendrometer bands. In the white pine stand, dendrometer bands were placed on ten trees (all white pine) in and adjacent to the EPRI plot in June 1985. Five additional trees were banded during December, 1985. Readings were taken every 2 weeks in winter and more frequently during the growing season. In the hardwood stand, bands were placed on 27 trees and shrubs in and adjacent to the EPRI plot during November and December of 1985. Distribution of bands by species is as follows: Quercus coccinea (6), Q. alba (1), Q. velutina (1), Oxydendrum arboreum (6), Rhododendron maximum (8), Acer rubrum (4) and Cornus florida (1). These bands were read on the above schedule.

Radial growth increment in white pines was found to be highly predictable from initial dbh After 1 year of measurements from the dendrometer bands, a regression of radial increment versus initial dbh yielded an r^2 of 0.89 ($n = 15$). Thus, reliable estimates of biomass increases and nutrient uptake can be obtained from the combination of dendrometer band data, periodic (2-3 years) inventories for dbh and nutrient analysis of tree components.

Nutrient return from trees to the forest floor were measured with standard box-type litter traps, 0.50 m^2 in area. The nylon screen covering the bottom of the litter traps was the same as that through which throughfall was filtered at the bottom of the collection funnels, so readily soluble nutrient ions associated with small (<1 mm) litter particles were measured in throughfall. Litterfall has been collected from 4 traps on the white pine stand since June 28, 1985, and from 4 traps in the hardwood stand since August 3, 1985. Litterfall is being collected every week during periods of heavy litterfall to minimize leaching losses and every 2 to 4 weeks during the remainder of the year. Litterfall samples were being composited into two periods (January through August and September through December) and were sorted

into three categories (foliage, wood, and other litter). Samples were then dried, weighed, ground, and composited for nutrient analyses.

Six forest floor samples (0.063 m^2) and 6 woody litter samples (1 m^2) were taken on each plot in December 1985. Three horizons within the forest floor were separable in the white pine stand (Oi, Oe, and Oa); two horizons could be differentiated in the hardwood forest floor (Oi + Oe, Oa). These were analyzed to determine for each horizon the standing crop (weight per unit area), organic matter content, and nutrient pools.

Soil Physical Characteristics

Soil profile descriptions were compiled for each of the lysimeter pits soon after they were excavated during the summer of 1985. Four lysimeter pits were randomly located on each of the two plots. With one exception, lysimeter pit soils are classified as mesic Typic Hapludults of the Fannin soil series. The exception was pit #4 in the hardwood stand, which was classified in the Cashiers soil series (mesic Umbric Dystrocrepts).

Within the Fannin series there are some differences between the plots in horizon depths and other soil characteristics. These are probably due to both microtopographic and historical factors, including the clearcutting, logging, and conversion to white pine on WS 1 and probably earlier impacts such as woodland grazing. Profile descriptions for the two plots (Tables 14 and 15) and bulk density and % gravel (Table 16) are given below.

IFS ATMOSPHERIC DEPOSITION MONITORING

Meteorological Tower

A meteorological tower, 31 m in height, was erected during 1985, and a heated instrument shed was constructed near its base in the white pine stand on WS 1. The tower extends 3-4 m above the nearby canopy; tower height, relative to more distant points in the canopy, is influenced by the ground slope.

Table 14. Profile description for Coweeta white pine (CP)

FANNIN SERIES

Taxonomic Class: Fine-loamy, micaceous, mesic Typic Hapludults

Typical Pedon: Fannin loam, forested. (Colors moist)

Oi - 4-3.5 cm; pine needles.

Oe - 3.5-0.5 cm; decomposing pine needles, fungal hyphae.

Oa - 0.5-0.0 cm; ranges from 0.5 cm to unmeasurable; indistinguishable material; fungal hyphae.

A - 0-9 cm; dark brown (7.5 YR 3/4) loam; moderate fine and medium granular structure; very friable; many fine and common coarse roots; common fine mica flakes; clear smooth boundary.

BA - 9-28 cm; yellowish-red (5 YR 4/6) loam; moderate medium subangular blocky structure; friable; common medium to coarse roots; common fine mica flakes; clear smooth boundary.

Bt -28-62 cm; red (2.5 YR 5/8) clay loam; moderate medium sub-angular blocky structure; friable to firm; common mica flakes; few medium and coarse roots; clay films on peds; gradual wavy boundary.

BC - 62-91 cm; red (2.5 YR 4/8) loam; weak, coarse and medium sub-angular blocky structure; friable; few coarse roots; many fine and medium mica flakes; weathered schist fragments; gradual wavy boundary.

C - 91+ cm; red (2.5 YR 4/8) gravelly loam; massive; friable; few coarse roots; common fine mica flakes; weathered mica schist, mica gneiss, and feldspar fragments.

Table 15. Profile description for Coweeta mixed hardwood site (CH)

FANNIN SERIES

Taxonomic Class: Fine-loamy, micaceous, mesic Typic Hapludults

Typical Pedon: Fannin loam, forested. (Colors moist)

Oi - 4.5-2.5 cm; intact but partially decomposed leaves.

Oe - 2.5-0.5 cm; fragmented leaves with fungal hyphae.

Oa - 0.5-0 cm; 0.5 cm to unmeasurable; indistinguishable material mixed with fine roots.

A - 0-12 cm; dark brown (10 YR 4/3) loam; weak fine and medium granular structure; very friable; common fine and many medium and few coarse roots; common fine mica flakes; acid; clear wavy boundary.

BA - 12-20 cm; dark yellowish brown (10 YR 4/4) fine sandy loam; weak fine subangular blocky structure; friable; many fine medium and coarse roots; common fine mica flakes; acid; clear smooth boundary.

Bt - 20-70 cm; yellowish red (5 YR 5/8) loam; moderate fine and medium subangular blocky structure; friable; many fine medium and coarse roots; many fine mica flakes; acid; clear smooth boundary.

BC - 70-100 cm; yellowish red (5 YR 5/6) stony fine loam; weak fine and medium subangular structure; very friable; few fine and medium roots; many fine mica flakes; acid; clear smooth boundary.

C - 100+ cm; yellowish red (5 YR 4/6) sandy loam; massive; very friable; many fine to large mica flakes; acid.

Table 16. Percent gravel (% >2mm) and bulk density for Coweeta lysimeter pit soils

	White pine (CP)		Mixed hardwood (CH)	
Horizon	Bulk density ($g \cdot cm^{-3}$)	% Gravel	Bulk density ($g \cdot cm^{-3}$)	% Gravel
A	0.79	22	0.93	9
BA	0.94	28	1.29	12
Bt	1.03	38	1.20	38
BC	1.15	37	1.45	37

Meteorological instrumentation has been operating continuously since March 28, 1986, except for the wetness sensor, which became operable on August 14, 1986. The following variables are being recorded on an hourly basis:

(1) Temperature: minimum, maximum, and hourly mean (°C).
(2) Relative humidity: minimum, maximum, and hourly mean (%).
(3) Vapor pressure: minimum, maximum, and hourly mean (MB).
(4) Wind speed: hourly mean ($m \cdot s^{-1}$).
(5) Standard deviation of wind speed ($m \cdot s^{-1}$).
(6) Peak wind speed ($m \cdot s^{-1}$).
(7) Time of peak wind speed (hours, minutes).
(8) Wind direction (degrees).
(9) Standard deviation of wind direction (degrees).
(10) Precipitation ($mm \cdot h^{-1}$).
(11) Moisture (presence/absence).
(12) Solar radiation above canopy ($\mu E/m^2 \cdot s$).
(13) Solar radiation below canopy ($\mu E/m^2 \cdot s$).
(14) Flow rate of mass flow controller ($L \cdot min^{-1}$).

Ozone Monitoring

Ozone concentrations are being monitored at the meteorological tower above the white pine canopy and at ground level in a clearing adjacent to the white pine watershed. This equipment was installed in August of 1986. Hourly maximum, minimum, and mean ozone concentrations are recorded.

Wet and Dry Deposition

Sampling of dry deposition and wetfall on an event basis began March 19, 1986. Dryfall sampling required a minimum of 3 to 4 rainless days; deposited particles are collected on 2 polycarbonate petri dishes mounted on the meteorological tower above the canopy. Airborne particles, HNO_3 vapor, and SO_2 vapor are collected on filters, and this instrumentation is also located on the meteorological tower. Wetfall samples include stemflow, wet-only precipitation, and wet-only throughfall. Stemflow was collected from the same set of collared white

pines used for the monthly nutrient cycling samples (stemflow collection containers are subsampled and emptied, if necessary, and cleaned prior to event sampling). Throughfall and precipitation are sampled with Aerochem wet/dry collectors.

Fog Collection

An active fog collector has been in operation on the tower periodically since August 1, 1986. During the summer of 1986, fog was seen rarely, due in part to the unusually dry conditions. During September and October (61 days), morning radiation fog was observed on 28 days and the sampler operated on 11 days. At the tower site, fog did not appear until at or shortly after sunrise, at which time fog began to move very slowly upslope, so that the tower was immersed in fog for a period of at most 2 or 3 hours. Fog density during this time was variable. Canopy drip due to fog water collection has not been observed. Volumes of fog water collected are small (1-10 mL) and liquid water content of the air during the 2 to 3 hours of fog immersion is so low (up to 0.06 $g \cdot m^{-3}$) that it does not appear that fog has contributed a significant flux of ions to this particular site during the past season. Nearby areas do experience fogs of longer duration.

During November, no morning radiation fog was observed, although on 9 days, fogs associated with precipitation events occurred. These would be difficult to sample, since much of the fog formed during periods of intermittent, light rain.

OTHER RESEARCH ACTIVITIES AT THE SITE

The Coweeta Hydrologic Laboratory is a site of numerous cooperative studies (50+) involving a variety of terrestrial and aquatic research projects. Extramural studies currently involve more than 100 investigators and technicians. The site participates in the National Atmospheric Deposition Program, Long Term Ecological Research Program (funded by National Science Foundation), and the Direct Delayed Response Project (funded by EPA).

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TURKEY LAKES WATERSHED SITE

(Mixed hardwoods)

PARTICIPATING INSTITUTION AND INVESTIGATORS - N. W. Foster, I. K. Morrison, J. A. Nicolson, Forestry Canada, Ontario Region.

SITE DESCRIPTION AND LOCATION

The overall study area, Turkey Lakes Watershed (latitude 47° 03′ N; longitude 84° 25′ W) is located approximately 60 km north of Sault Ste. Marie, Ontario.

Climate

The climate is modified continental with prevailing winds from the west. The average January temperature is -10°C and the average July temperature is 18°C. The mean annual precipitation is approximately 1200 mm.

Vegetation

Samples were collected from a 1-ha study site, established within an uneven-aged sugar maple (Acer saccharum Marsh.) forest with a lesser component of yellow birch (Betula alleghaniensis Britton). In addition there was scattered red maple (Acer rubrum L.), ironwood [Ostrya virginiana (Mill.) K. Koch], red oak (Quercus rubra L.) and white spruce [Picea glauca (Moench) Voss] in the overstory and understory, and balsam fir [Abies balsamea (L.) Mill.] and eastern white cedar (Thuja occidentalis L.) confined mainly to the understory.

Mean dominant height of the main stand was 22.1 m; mean dbh was 19.6 cm; basal area was 28.6 $m^2 \cdot ha^{-1}$ and gross volume was 238 $m^3 \cdot ha^{-1}$. Measured stump ages ranged from 40 to 152 years. (For inventory purposes, the stand had been assigned an age of 120 years in 1966; i.e., 140 years in 1986).

NUTRIENT CYCLING SITE

For the present investigation we collected and analyzed solutions for the period January 1, 1984, to December 31, 1986. Information on

the phytomass and bioelement content of overstory and overstory vegetation, litter, and soil chemical properties is also available.

Monitoring Equipment

- precipitation (bulk) and throughfall with 20-cm-diam plastic funnel-bottle sets.
- stemflow by 2.5 cm Tygon collars at dbh on three sugar maple trees, representative of the range of diameters in the stand.
- lysimeters - 12 tension-free lysimeters under the F horizon
    - 3 ceramic porous cups lysimeters at 10 cm
    - 3 ceramic porous cups at 50 to 60 cm (effective depth of rooting)
- litter traps - 24 1-m^2 and 24 0.25-m^2 fine mesh trays

Sampling and Analysis

1. Vegetation - Tree weight and bioelement contents were collected in 1981 (Morrison, in press).
2. Litterfall - Litterfall was collected monthly during the growing season and again at the end of the winter, over a four-year period 1981 to 1984 (Morrison, in press).

   Litter and soils - Forest floor bulk and organic weights were determined by quantitatively excavating 80 0.1-m^2 samples (Morrison, in press).

   - Four soil pits were sampled by horizons in 1980 and chemical analyses completed (Foster 1985a,b).

Geology

The study site is located in moderately steep terrain at an elevation of 350 to 400 m. The soil consists of a stony, silty loam ablation till over a compacted basal till at a depth of 0.5 m. Soils (Table 17) are Orthic Humo-Ferric and Ferro-Humic Podzols (Spodosols) derived from basalt and granite.

Plot Layout

All samples were collected from within a 1-ha plot: vegetation from our four 0.1-ha sub-plots, soils from one pit in each sub-plot.

Table 17. Soil physical characteristics at the Turkey Lakes site

Horizon	Depth cm	Description
L	7-5	Hardwood leaves and twigs; pH 5.1; abrupt smooth boundary.
F	5-2	Dark reddish-brown (5YR 3/2) semidecomposed organic material; abundant fine roots; pH 4.7; abrupt smooth boundary.
H	2-0	Black (5YR 2/1) decomposed organic material; abundant fine and medium roots, pH 4.4; abrupt wavy boundary.
Ae	0-4	Dark reddish-gray (5YR 4/2) silt loam; amorphous; common medium and fine roots; pH 4.2; clear wavy boundary; 2 to 10 cm thick; bulk density 0.7 g/cc; 35% coarse fragments.
Bhf_1	4-7	Dark reddish-brown (5YR 3/4) silt loam; amorphous; abundant medium and fine roots; pH 4.4; clear wavy boundary; 2 to 6 cm thick; bulk density to 0.8 g/cc; 35% coarse fragments.
Bhf_2	7-15	Dark reddish-brown (5YR 3/3) silt loam; amorphous; abundant medium and fine roots; pH 4.5; clear smooth boundary; 4 to 20 cm thick; bulk density 0.8 g/cc; 35% coarse fragments.
Bf	15-57	Brown (10YR 4/3) sandy loam; amorphous; abundant medium and fine roots; pH 5.0: clear smooth boundary; 12 to 35 cm thick; bulk density 0.9 g/cc; 35% coarse fragments.
II BC	57-82 cm	Dark yellowish-brown (10YR 4/4) loamy sand; amorphous; few fine roots; pH 5.0; clear smooth boundary; 12 to 32 cm thick; bulk density 1.3 g/cc; 35% coarse fragments.
II C	82 cm+	Grayish-brown (10YR 5/2) loamy sand; amorphous, few fine roots; pH 5.1.

Biomass Estimates

Individual data on tree weight came from two sources, from 19 sugar maple and 25 yellow birch trees from old-growth forests in Algoma District, and from 15 sugar maple and 10 yellow birch trees felled in the study stand. Data sets by components, combinations of components, and whole trees were plotted separately and together, the overlays between the sets being sufficiently complete that the sets were merged to produce one larger set per species. Relationships of the form:

$$Y = b_1 * X^{b_2} + e$$

where Y = additional individual tree biomass in kg, X = dbh, and b_1 and b_2 are parameters of the model to be estimated, were calculated for components and whole trees for each species. These were used in conjunction with stand table data to estimate standing-crop biomass (Table 18) by components for each of the four 0.1-ha plots.

Samples of foliage from all parts of the crown, of live and dead branch material, and of stemwood and stembark were collected from a number of trees in the study stand during August 1981. Data were averaged to give mean foliar, live branch, dead branch, stemwood, root, etc., concentrations for each element, and these were applied to the figures for component weight per are to give N, P, K, Ca, Mg and S contents per hectare.

ATMOSPHERIC DEPOSITION MONITORING

No work is being conducted by the investigators. The Atmospheric Environment Service of Environment Canada has a CAPMON station at the Turkey Lakes Watershed, where air quality and wet deposition are monitored.

OTHER RESEARCH ACTIVITIES AT THE SITE

The larger project of which the present investigation is part was formulated in 1979-1980 as the Turkey Lakes Watershed Study, to examine acid rain effects on forests, water, and fisheries in natural ecosystems of the Precambrian Shield of central northern Ontario. Collection and

Table 18. Biomass inventory of the Turkey Lakes site

Component	Biomass (kg/ha)	Horizon	Organic matter (kg/ha)
Foliage	4,200	L	5,583
Branches, live	48,400		15,412
Branches, dead	2,000	F	
Stem bark	19,500		
Stem wood	135,000	H	12,009
Stumps and roots	35,000		
Total	244,100	Total	33,004

chemical analysis of bulk precipitation, throughfall, stemflow, and forest floor percolate on an event basis, and mineral soil solution weekly, was carried out during 1981 to 1983 (Foster, 1985a, 1985b; Foster and Nicholson, in press; Foster et al., 1986). Some of the foliar chemistry, stand biomass, and bioelement contents have been reported (Morrison, 1985).

The study plot is within a 7-ha basis which has been gauged for stream flow and chemistry from 1981 to the present. Two studies of litter decomposition in relation to various acid and liming treatments were conducted on the study area. A Forestry Canada contract to determine how chemical and microbiological properties of soil are changed under conditions of accelerated loadings of strong acids was completed both in the field and in the laboratory by researchers in the Department of Chemistry, Microbiology, and Geography, Queen's University, Kingston, Ontario.

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NORWAY SITE

(Norway Spruce)

PARTICIPATING INSTITUTIONS AND INVESTIGATORS - Arne O. Stuanes, Ingvald Rosberg, and Magne Huse, Norwegian Forest Research Institute; Einar Joranger, Norwegian Institute for Air Research.

SITE DESCRIPTION AND LOCATION

The Norwegian site is located at Nordmoen Field Station (1106' E.Gr. 60° 16' N) about 60 km north of Oslo at an elevation of 200 m (Fig. 14).

Climate

Monthly and annual standard normals (1931-60) for Gardermoen Meteorological Station run by the Norwegian Meteorological Institute about 10 km south of the site at an elevation of 202 m are given in Table 19.

According to the measurements at Gardermoen meteorological station there were annually 122 days with rain, 80 days with snow, and about 73 days with other forms (occult) of precipitation during the period 1970-1979. The number of days with more than 1 mm of precipitation was 110 and the days with more than 10 mm of precipitation was 22. Snow cover varies considerably within a winter and from year to year; a snowpack usually lasts from late December to late April. There are 171 days with temperatures below 0°C.

Vegetation

All six plots included in the Norway spruce site (NS) study (A-2 circle no. 3, 4, 10 and 11 and A-4 plot 1 and 2) are all located on the same flat plain (Fig. 15). In the area of the NS site the mature vegetation is a mixture of Scots pine (Pinus sylvestris L.) and Norway spruce [Picea abies (L.) Karst.]. On drier soils pine dominates. The height profiles of the stands are shown in Fig. 16.

ORNL-DWG 90-1777

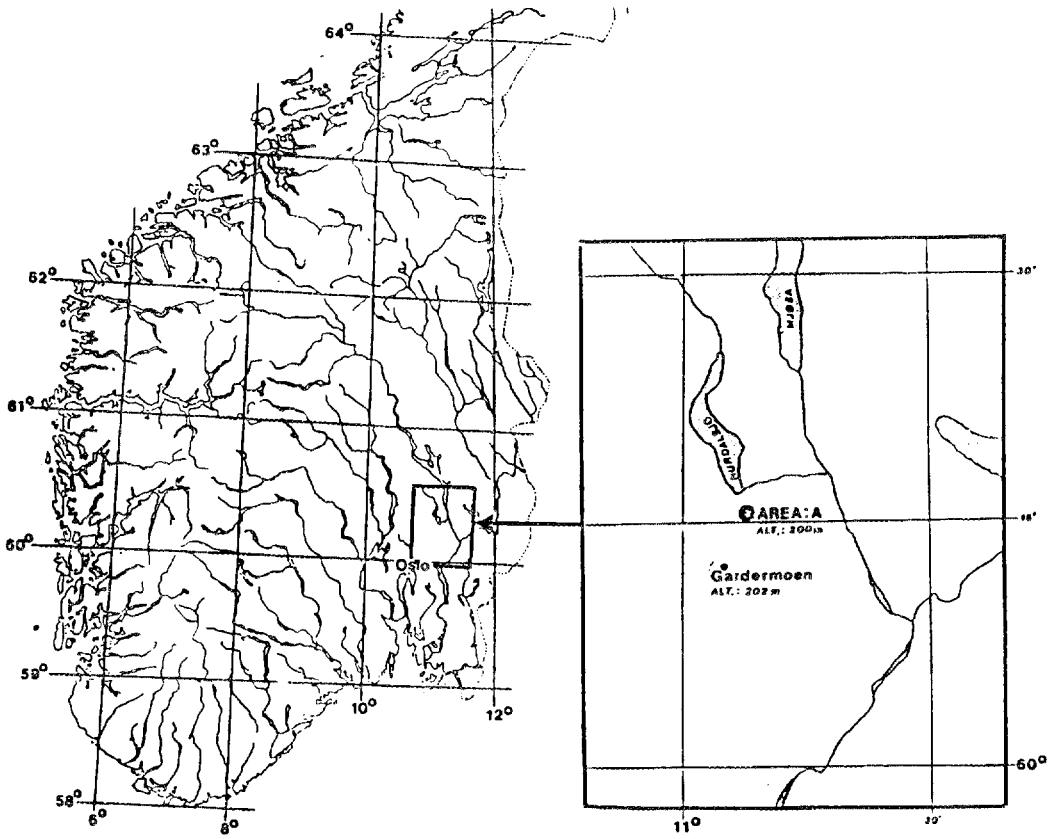

Fig. 14. The location of the Norway Spruce site.

Table 19. Monthly and annual standard normals (1931-60) for Gardermoen Meteorological Station. 171 days with temperature below 0°C

	J	F	M	A	M	J	J	A	S	O	N	D	Year
Temperature (°C)	-6.9	-6.3	-2.3	3.2	9.4	13.6	16.0	14.6	10.0	4.5	-0.6	-3.9	4.3
Precipitation (mm)	59	43	32	48	51	72	94	105	84	86	82	76	832

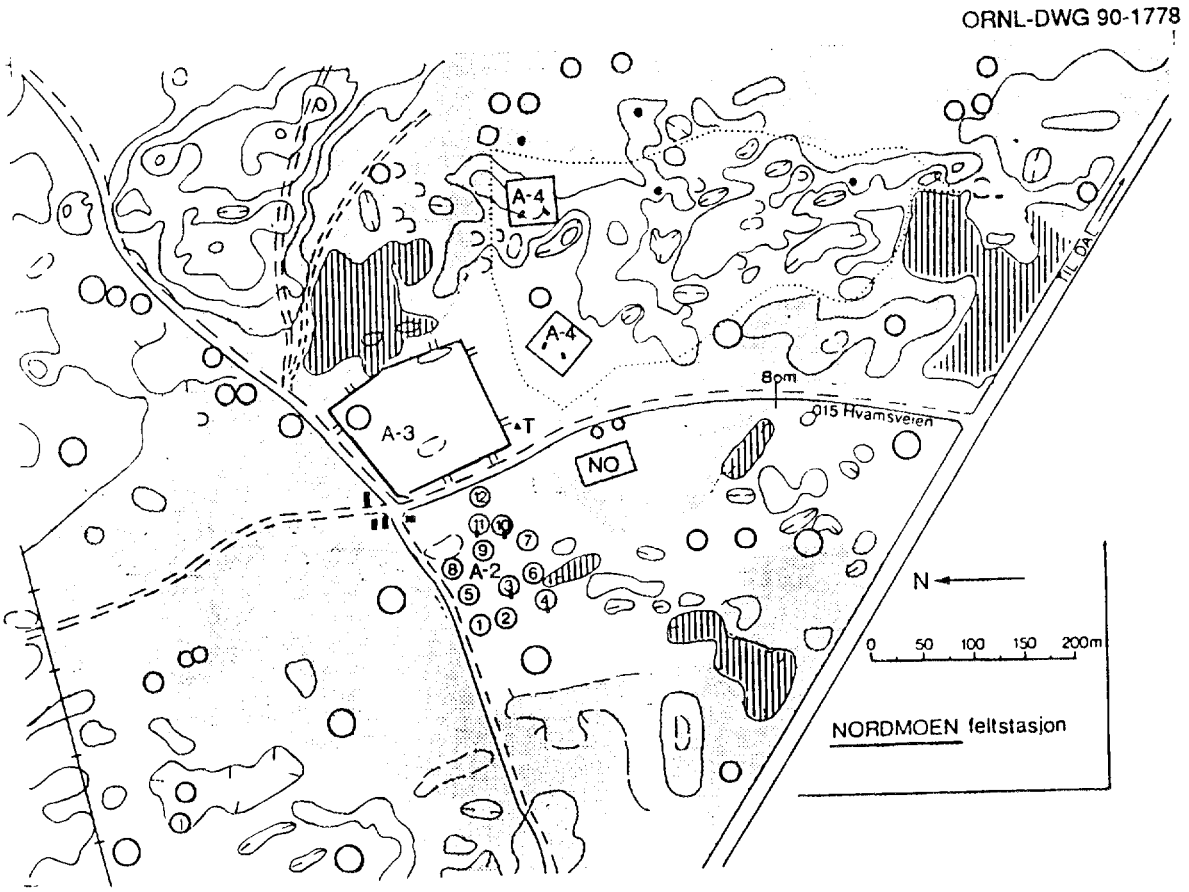

Fig. 15. The location of the different plot at the Norway Spruce site.

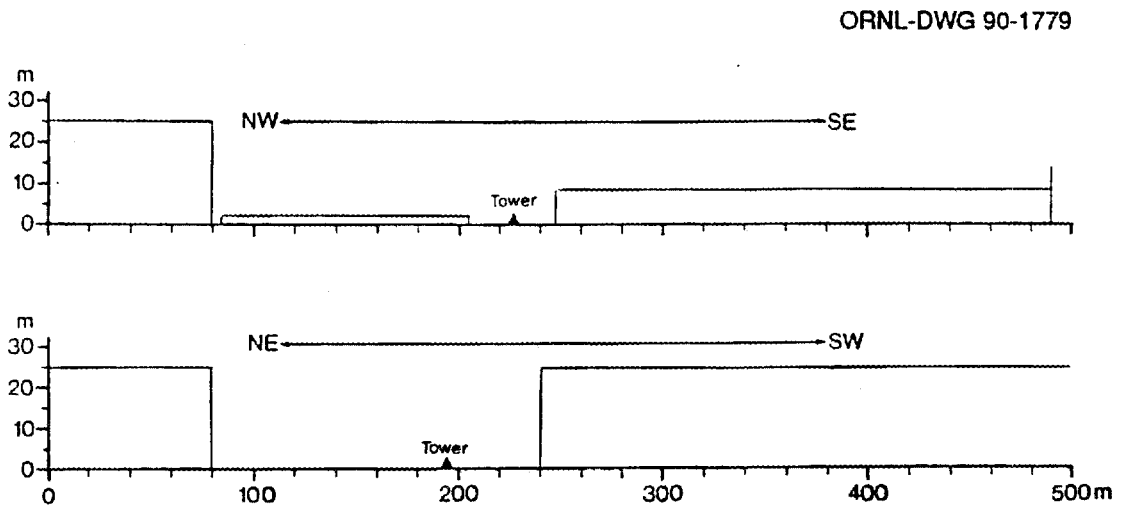

Fig. 16. The height profile of the stands.

The overstory vegetation on all plots is largely Norway spruce with a few scattered pines. The A-2 stand was planted in 1957 and has a mean density of ca. 2400 trees ha^{-1}. The age of the trees at A-4 plot 2 is about 30 years, and the density is 3250 trees ha_{-1}. Tree height is about equal for the A-2 plots and A-4 plot 2, at 8-8.5 m. The tree age at A-4 plot 1 is about 40 years, the tree height is ca. 13.5 m, and the tree density is 2250 trees ha^{-1}.
The understory vegetation is poor in species both in the A-2 and the A-4 stands. The dominating vasculars are Vaccinium myrtillus L. and Deschampsia flexuosa (L.) Trin. (=Aira flexuosa L.). Other vasculars are Calluna vulgaris (L.) Hull, Vaccinium vitis-idaea L., Luzula pilosa (L.) Willd., Diphasium complanatum (L.) Rothm., Lycopodium annotinum L., Maianthemum bifolium (L.) F.W. Schm., Melampyrum pratense L. and Trientalis europaea L. The forest floor layer is dominated by moss species such as Pleurozium schreberi (Brid.) Mitt., Hylocomium splendens (Hedw.) BrEur., Ptilium crista-castrensis (Hedw.) DeNot. and Dicranum (Hedw.) spp. There are a few lichen species at the forest floor, mainly Cladina Nyl. spp., Cladonia G.H. Web. spp., and Cetraria islandica (L.) Ach., but lichens are a minor component of the forest floor compared to mosses. The lichen Hypogymnea physodes (L.) Nyl. is the most important epiphyte in the stands.

The dominating plant community in the area, and also for the stands A-2 and A-4, is Eupiceetum Kl. 62. On drier soils Vaccinio-Pinetum Caj. 21 dominates.

Geology

The Norwegian site is located on a flat plain of glacifluvial deposits partly covered by a sheet of eolian sand. The deposits are about 60 m deep overlying Precambrian and Permian crystalline bedrock.

IFS NUTRIENT CYCLING SITE

Plot Layout

Six plots are included in the study. Of these, four circular 150-m plots have previously been watered with 50 mm•$month^{-1}$ of groundwater of pH 6 (plots no. 4 and 10) and with groundwater adjusted to pH 2.5

(plots no. 3 and 11). The watering of these plots started in July 1973 and ended in September 1978 with a total of 27 irrigations of 50 mm each. These plots are later referred to as A-2 plots. In addition two square 0.1-ha plots were established, later referred to as A-4 plots. In the middle of each of these plots a 10- by 10-m subplot was subdivided into a 1- by 1-m grid for random sampling (see Fig. 2 for location of the plots).

All trees within the six plots have been marked at breast height and tagged with a number (this was done already in 1973 for the A-2 plots). Aerial photographs have been taken to calculate the tree projections.

Solution Sampling

Throughfall and litterfall collectors have been in place at the A-2 plots since 1982. Ten collectors for both throughfall and litterfall were randomly placed on each plot. Samples from all collectors within one plot have been pooled since each treatment has been replicated three times (only two replicates are included in this study). On the two A-4 plots throughfall and litterfall collectors have been in place since the end of June 1986. Twenty throughfall and litterfall collectors were randomly placed on each plot. The samples from each plot are pooled in four groups, five collectors in each group.

The throughfall collectors consist of one plastic bottle with the bottom cut off. This bottle is used as a funnel and is screwed into the sampling bottle with a screen in between. The collection area for the throughfall collectors is 59.45 cm for the A-2 plots and 109.36 cm for the A-4 plots.

For litterfall collection on the A-2 plots, plastic funnels with a collection area of 314 cm were used. As litterfall traps in the A-4 plots, square plastic trays were used. The collection area of the litter trays is 1140 cm.

During winter, snow is collected on 0.5- by 0.5-m snowboards and snow samples are taken by use of a plexiglas cylinder. Snowboards are placed both within the plots and in the open. Also a few snow lysimeters are placed within the plots to collect the meltwater in

the period with snowcover. The snow lysimeters are constructed of cylindric polyethylene containers placed on the ground with outlets to sampling bottles which are placed in holes in the ground, as for the throughfall collectors. A few centimeters above the bottom of the containers, sieves consisting of the upper part of polyethylene Buchner funnels were placed. Sampling can be performed through a tubing from the sampling bottles by use of suction. The collection area of the snow lysimeters is 246.06 cm.

Stemflow collectors are thus far placed on only three trees to check the importance of stemflow in our stands. Our experience shows that we will have some stemflow in late fall. Additional stemflow collectors will therefore be installed. The collectors consist of split tubing nailed to the tree. Polyurethane foam is used between the tubing and the tree.

Lysimeters (fritted glass, 4-5.5-m pore size, made from modified Buchner funnels) were installed beneath the raw humus layer (Oa, 1-4 cm), beneath the E horizon (2-10 cm), beneath the Bs horizon (20-30 cm) and within the upper C horizon (60 cm). There is one lysimeter pit in each of the A-2 circles with three lysimeter replicates in each pit. In the A-4 plots there are two pits in each plot with two lysimeter replicates in each pit. A tension of 10 kPa was supplied to each plate-bottle collection system by a central vacuum pump. The vacuum was adjusted by a vacuum valve in each pit and a mercury manometer was placed in the vacuum line to each lysimeter as a control of the vacuum applied.

One tension-free lysimeter is placed close to each tension lysimeter beneath the raw humus layer. A soldered copper-Constantan thermocouple is placed close to each tension lysimeter. The thermocouple wires are led into a switch-box in each pit, and temperature readings are taken by a voltmeter at the time of sampling. The lysimeter installation was finished in the beginning of October 1986.

Sampling intervals are weekly for throughfall, stemflow, and soil solutions and monthly for litterfall. During dry periods the sampling

intervals may be expanded. In some periods samples from following weeks have to be pooled to give enough sample.

Biomass Estimates

The understory vegetation, forest floor, and roots were sampled from a 1- by 1-m area in connection with the digging of the lysimeter pits. In addition, the understory vegetation and the moss layer were sampled from 20 random 0.5- by 0.5-m subplots in each of the A-4 plots. The raw humus layer and the upper 10 cm of the mineral soil were sampled from an area of 0.5 by 0.25 m from the same subplots to give a better estimate of root biomass.

Branches from the 3rd, 6th, 10th, and 15th whorls have been clipped to sample the lower, middle, and upper part of the crown. Eight trees were sampled in each of the A-2 circles. These are the same trees that had been sampled in the previous study. In the A-4 plots 20 trees within the 10- by 10-m subplots were sampled. The height and diameter in breast height (dbh) is measured for all trees within the plots. Boles are sampled by coring trees with a increment corer.

For the A-2 stand, regression equations were established for calculation of biomass. Since the A-4 stand is some years older than the A-2 stand, 16-20 trees outside these plots will be harvested to expand the equations to cover the 4-18 cm dbh range. The standing of biomass and nutrient contents for the A-2 stand in 1983 are given in Table 20.

Soil Physical Characteristics

Soil profiles are described after digging the eight lysimeter pits, one profile description for each of the A-2 plots and two for each of the A-4 plots. As a mean for the 8 pits the depths of the layers were (with the lowest and highest value given within parentheses): litter layer, Oi = 1.7 cm (1.0 - 3.0), Oe + Oa = 2.6 cm (1.0 - 5.0), E (EA) = 1.0 cm (0.5 - 1.6), Bs = 21 cm (15 - 27), BC = 17 cm (12 - 22), and the C layer down to about 60 m. This shows that the eight profiles are very similar. In two of the profiles the upper B was a Bhs about

Table 20. Standing crop of various biomass components and nutrient content for the Norway Spruce site, A-2 plots in 1983 (roots and forest floor are not included)

	Biomass	N	S	P	K	Mg	Ca	Al
	- - - - - - - -	- - -	- - -	-kg ha^{-1}	- - -	- - -	- - -	- - -
Live biomass								
Needles	11700	129.2	10.0	18.7	53.6	10.1	89.4	2.04
Branches	11000	51.1	4.0	7.1	29.9	6.0	39.3	1.34
Cones	500	1.9	0.2	0.3	1.8	0.2	0.1	0.02
Stem bark	3900	21.4	1.5	3.2	13.5	2.8	26.1	0.61
Stem wood	21900	17.6	1.5	2.3	17.6	2.9	16.7	0.01
Total	49000	221.2	17.2	31.6	116.4	22.0	171.6	4.02
Standing dead	2100	13.6	1.3	1.1	2.2	1.0	11.1	0.84
Lichens	1500	14.0	1.5	1.5	5.2	1.0	7.6	0.98

5 cm thick. Complete profile descriptions will be reported as soon as the soil physical and chemical analyses are finished. However, the soil in the nearby experiment A-3 is classified as a Typic Udipsamment (Stuanes and Sveistrup, 1979, profile 1 and 2).
Soil samples were taken from all horizons. There is no gravel or rocks present in the soil. The bulk density was measured by 100-cm steel cylinders. This is possible since the soil is so homogenous. pF-measurements will be carried out on the soil cylinders before bulk density is determined.

In addition to the soil samples taken from the lysimeter pits, 5 random 0.5- by 0.5-m areas within each of the 10- by 10-m subplots in the A-4 plots were sampled. The humus layer and the E horizon were taken from the entire 0.5- by 0.5-m area, but the deeper horizons were sampled by a cylinder auger.

The A-2 plots have been sampled every third year since 1975. Twenty samples taken with a gouge auger from each circle have been pooled by horizon. Some of the results from the sampling in 1984 are given in Table 21.

Solution Chemistry

Throughfall has been measured in the A-2 plots since 1983. The first throughfall from the A-2 plots in 1986 was collected May 14 due to a late snowmelt. Throughfall collection on the A-4 plots started at the end of June, 1986.

ATMOSPHERIC DEPOSITION

Tower

A telescopic tower was erected in an opening of the spruce stand, and a heated instrument house with AC line power was installed near the base. The tower is situated 100 to 150 m from the plots. The tower is 30 m high, extending 5 m above the mean height of the established canopy.

Table 21. Soil pH, total acidity, exchangeable Na^+, K^+, Mg^{2+}, and Ca^{2+} and base saturation at pH 7.0, A-2 plots, Norway spruce site. The figures are means of the two replicates. The sampling was carried out in September 1984

	Soil pH	Total acidity H_2O	NA^+	K^+	Mg^{2+}	Ca^{2+}		Base saturation (%)	
			mmol kg^{-1}						
A-2	pH 2.5	0	3.79	411	0.66	7.91	3.17	10.42	8.0
E			3.80	138	0.23	0.96	0.52	0.45	2.2
BS1*			4.50	91	0.15	0.60	0.13	0.19	1.5
Bs2*			4.63	40	0.10	0.31	0.04	0.13	1.8
A-2	pH 6	0	3.81	423	1.04	9.92	4.16	16.21	10.7
E			3.83	128	0.28	0.88	0.48	1.06	3.2
BS1*			4.55	92	0.17	0.59	0.14	0.37	1.9
BS2*			4.81	40	0.11	0.34	0.05	0.17	2.1

*The depth for BS1 was 8-13 cm and for BS2 23-28 cm.

Meteorological and Ozone Equipment

The set-up of the station is shown in Fig. 17. The installation of the 30-m tower and the field testing of the sensors and the data logger took place in January 1986. The wind speed (Vaisala anemometer WAA), direction (type NILU), and air temperature (platina resistance, Pt 1000)is measured at the 30-m height. The temperature difference (air stability) is measured between the heights 30 m and 6 m. The radiation (Schenk star pyranometer, No. 1293) and the relative humidity (hair hygrometer and transducer) are measured at 6 m above the ground. The hygrometer is calibrated regularly. All different measuring devices are mounted on separate booms.

The Dasibi ozone unit and its data logger are installed in the instrument house, and the sensor has its sampling inlet at 2.5 m above the ground. From January 1987 the sampling will be made 10 m above the ground by means of a telescopic mast.

Dry Deposition, Atmospheric Chemistry, Fog, and Precipitation Collectors

During January 1986, the filter packs for aerosol and gas samplings were mounted, with 2.5 m as the sampling height. The sampled components are SO_2-gas, SO_4^{2-}-aerosols, NO_2-gas, total NH_4^+ NH_3 and total NO_3^- + HNO_3. The samplings are made 3 times a week (two at two-day intervals and one at a three-day interval). Filter blanks are analyzed weekly. Information about the different analyses is presented in Table 22.

Dry deposition may be calculated by multiplying the measured concentrations with empirically determined deposition velocities, which depend on seasonally varying surface conditions (wetness, physical activity of the vegetation) and variation of air stability.

From January 1987, sampling will be done at the height of 10 m by means of a telescopic mast which is connected to mass flow controlled air pumps mounted in the instrument house at the base.

The dry deposition of coarse particles will be sampled in petri dishes from Spring 1987. If coarse particles are of any importance at the site, an automatic sampler (ORNL) will be installed. It is not, as of yet, planned to use active fog samples at the Norway spruce site.

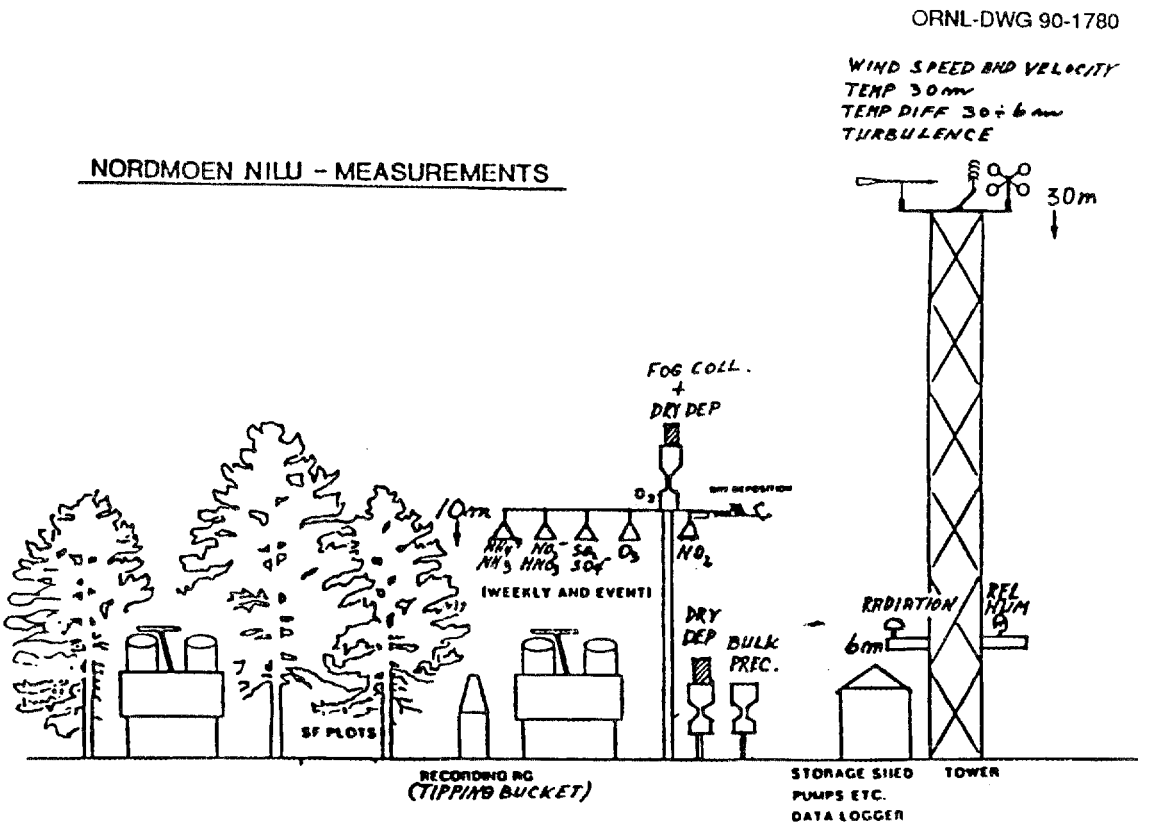

Fig. 17. The atmospheric deposition sampling at the Norway Spruce site.

Table 22. Chemicals and analytical methods for air sampling

Filter level	Impregnation		Analytical method	Detection
SO_2	Whatman 40	KOH (1)	Ion chromatography	0.1 mg S m^3
SO_4^{2-}	Whatman 40		Ion chromatography	0.1 mg S m^3
NO_2	-	-	TGS-ANSA method Norwegian standard 4855	0.3 mg N m^{-3}
$NO^{-3} + HNO_3$	Whatman 40	NaOH (1%)	Ion chromatography	0.01 mg N m^{-3}
$NH^+_4 + NH_3$	Whatman 40	Oxalic acid (3%)	Indophenol method	0.01 mg m^{-3}

ORNL-DWG 90-1781

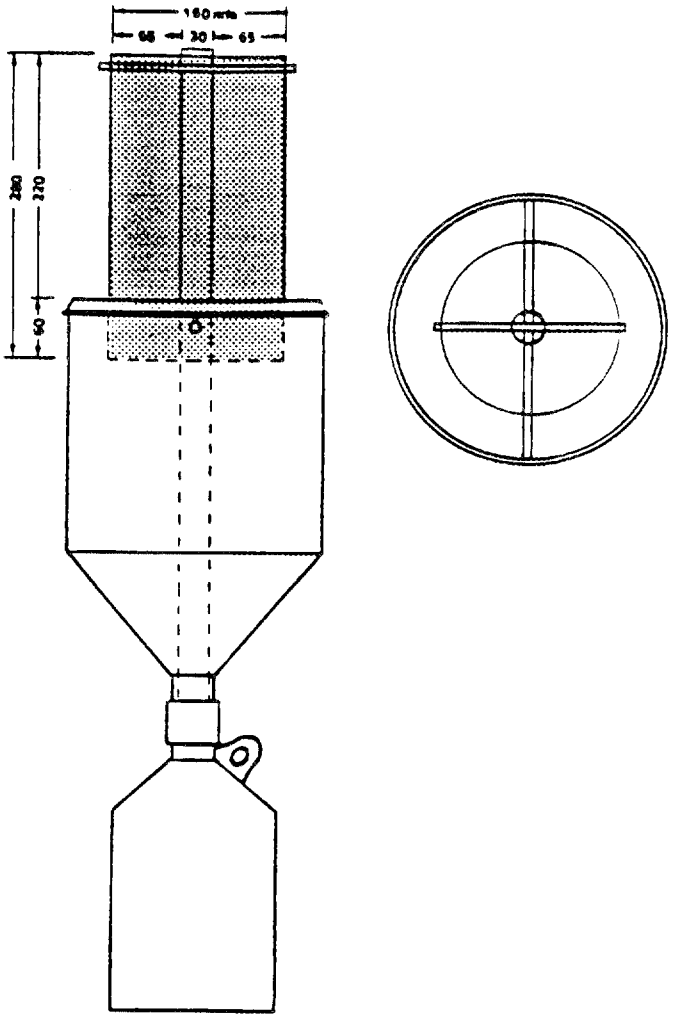

Fig. 18. The combined passive fog and dry deposition sampler (NILU).

A new, combined passive fog and dry deposition sampler has been designed, as shown in Figure 18. The diameter of the polypropylene netting threads is similar to the spruce needles. This sampler will be applied during the summer season, generally as a weekly sampler but also on an event basis. It will be used in combination with a bulk sampler of the same design to obtain a measure of the net deposition to the forest stand. The ratio between the total deposition area of the present netting and the opening of the precipitation gauge corresponds to a "leaf area index" (LAI) of 7.88. A typical forest in southern Norway consists of 25 spruces, 12 pines and 7 birches per decare, with a total needle/leaf area of 4.4 decares (LAI 4.4). The leaf area for the forest stand at Nordmoen will be estimated later. Two samplers of this type were installed at the Norway spruce site in November 1986 near the incident precipitation collectors to test the reproducibility of the sampling. One sampler is exposed at the Norwegian Institute for Air Research.

The collectors for incident precipitation were installed in January 1986 near the 30-m tower. Hitherto, in the atmospheric deposition study, precipitation samples from two bulk samplers have been used for analyses of the main ions H+(pH), SO_4^{2+}, NO_3-, total N, NH_4+, Ca^{2+}, K+, Mg^{2+}, Na+, Al^{3+}, Cl-, ortho-phosphate, and the heavy metals Pb, Cd, and Zn, respectively. The samples are not analyzed for alkalinity because the pH is mainly below 5.0.

Bulk samples are taken weekly and as event samples. A tipping bucket, type Lambrecht 1518H3, is used as a rain recorder.

Three commercial, wet-only rain samplers (Parelco AAPS, Finland) are used. One sampler will be placed in the clearing near the bulk and dry deposition/fog sampler. The other two samplers will be placed in the forest stand. The sampling frequency is weekly, but some event samples will be collected during intensive sampling periods.

OTHER RESEARCH ACTIVITIES AT THE SITE

Three of the field experiments used in the Norwegian SNSF-project are situated close to the Norway Spruce site (Abrahamsen et al., 1976). Part of one of these experiments (A-2) is included in the IFS study.

After the artificial watering stopped in 1978, reversibility of the induced acidification has been studied by soil sampling every third year. Needle samples are taken and the tree heights and dbh are measured yearly. For some results from these experiments see Abrahamsen (in press); Hagvar, 1984; Hagvar and Amundsen, 1981; Tveite, 1980a, 1980b.

In the same stand as the A-4 plots, litter decomposition studies are in process. Influence of both soil flora and fauna on litter decomposition are included. The study started in 1986 and will last until 1990.

Weathering studies are also being carried out at the Nordmoen field station. These studies are funded by the Surface Water Acidification Programme (a joint program between Great Britain, Norway, and Sweden). The objective of the study is to arrive at both historical and present weathering rates for the soil at Nordmoen.

The NO plot in Fig. 2 is one of several plots in the Monitoring Program for Forest Damage. The NO plot was established in 1986 in a 90-year-old stand of Norway spruce. The average height of the stand is about 25 m. Various vitality parameters are measured yearly in the plot. Throughfall and litterfall collectors (10 of each) are randomly placed on the 1500-m plot. Tension lysimeters (alundum plates) are installed in one lysimeter pit.

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B. F. GRANT FOREST SITE

(Loblolly Pine)

PARTICIPATING INSTITUTIONS AND INVESTIGATORS - H. L. Ragsdale, Emory University; J. Dowd and W. Nutter, University of Georgia, Athens.

SITE DESCRIPTION AND LOCATION

The IFS loblolly pine (Pinus taeda) site in Georgia is located in the B. F. Grant Memorial Forest in east-central Georgia near the town of Eatonton near 33° 22′ N and 83° 27′ W. The site is in the middle Piedmont of the southeastern United States approximately 300 km from the Atlantic Ocean. The 2.5-ha pine stand is owned and managed by the School of Forest Resources, The University of Georgia, Athens, Georgia. The B. F. Grant Memorial Headquarters (404-485-8159) may be reached by automobile by taking Route 441 south from I-20 to Eatonton and then following Godfrey Road northwest approximately 15 km.

Climate

The B. F. Grant Forest is representative of the soils, climate, and forest types of the middle Piedmont region. Climate is humid mesothermal with hot summers and mild winters. The mean annual temperature is 14.5°C, and the annual precipitation ranges from 110 to 135 cm. Snowfall or fog occurs infrequently.

Soils

The pine stand is located on an upland site with an elevation of 140-150 m. Soils at the site are primarily Typic Hapladults of the Cecil series. The A horizon of Piedmont soils is generally thin due to erosion from previous agricultural usage. The dominant minerals are biotite and mica gneiss. A typical profile has a sandy loam epidon 10 to 20 cm thick underlain by red clay subsoils. The organic horizon of the forest floor consists of decaying pine needles, some deciduous leaves, pine bark, pine branches, and pine boles of fallen trees. The organic litter layer, excluding branches and boles, is 1 to 5 cm thick.

The A horizon (0-8 cm) is a brown, very friable, sandy loam soil of medium granular structure containing many fine roots. The E horizon (8-16 cm) is a yellowish-red, friable, sandy clay loam of weak medium granular structure containing many fine roots. The BE horizon (16-30 cm) is a red clay loam soil with fine subangular blocky structure and numerous medium roots. The deeper (30-81 cm) B horizons, Bt1 and Bt2, are red clays. The BC horizon (81+ cm) is a red clay loam with yellow mottles.

Vegetation

The stand is an approximately 2.5-ha remnant of a 17-year-old loblolly pine plantation that was decimated by the southern pine bark beetle in 1978. Tree height is 15-17 m (1986) with an average dbh of 14.9 cm and a range of 11-24 cm. Loblolly pines were planted on 6' x 8' spacing and have not been thinned. The present density of living loblolly pine trees is 17,700 stems per hectare. Although the stand was planted, deciduous trees and vines are present throughout, a typical situation in planted pine stands in this region. Overstory vegetation is loblolly pine (*Pinus taeda*) with an occasional large white oak (*Quercus alba*) or red oak (*Quercus rubra*). In the subcanopy and understory, in order of prominence, are red maple (*Quercus rubra*), tulip poplar (*Liriodendron tulipfera*), sweet gum (*Liquidambar styraciflua*), blackcherry (*Prunus serotina*), and dogwood (*Cornus florida*). The most prevalent vines are greenbriar (*Smilax* sp.) and Japanese honeysuckle (*Lonicera japonica*).

HOWLAND, MAINE, SITE

(Spruce-Fir)

PARTICIPATING INSTITUTION AND INVESTIGATORS - I. Fernandez, S. M. Goltz, Department of Plant and Soil Sciences, University of Maine.

SITE DESCRIPTION AND LOCATION

The Howland site is located in eastern central Maine (approximate coordinates are 45° 10′ N, 68° 40′ W) within the 6300-ha International Paper Company Northern Experiment Forest. Topography of this site is relatively flat with an approximate elevation of 60 m. The Atlantic Ocean lies 60 miles to the south. The site is funded by the Forest Response Program (Spruce-Fir Cooperative, U.S. Forest Service.

Climate

Climate at the Howland site is cold, humid, and continental. Occasional maritime storms do occur, however, primarily from the northeast. Annual precipitation is generally between 80 and 100 cm. Winter temperatures frequently fall below -20°C, and the snowpack is continuous from December through March, accumulating to a depth of 1 to 2 m. Summer temperatures are cool, seldom exceeding 30°C.

Forest Type

The major forest type which occurs at the study site is spruce-fir (*Picea rubens* and *Abies balsamea*, respectively), with a strong component of eastern hemlock (*Tsuga canadensis*). Additional species which occur with less frequency include northern white cedar (*Thuja occidentalis*), eastern white pine (*Pinus strobus*) and paper birch (*Betula papyrifera*). This forest type is typical of low elevation, commercial softwood stands which occur over a large region in central Maine.

Forest History

The selected study site at Howland has always existed as forestland. Mixed stand composition has resulted from a history of partial cutting and high grading. The property was acquired by

International Paper in 1965. An uneven age management plan of single-tree selection over a 20-year cutting cycle was implemented prior to 1977, after which the area was dedicated as International Paper Company's Northern Experiment Forest. Management emphasis is now on applied research.

Geology

Bedrock geology is classified in the moderately metamorphosed Waterville and Vassalboro formations. The area was deglaciated between 14,000 and 13,000 years ago, leaving a layer of till which was primarily locally derived. A gravel esker passes within a few kilometers of the site.

Soils

Three soil series, Plaisted, Skerry, and Westburg, have been identified within the vicinity of the selected study areas. The Plaisted series is classified as a coarse-loamy, mixed, frigid, Typic Haplorthod; the Skerry series as a coarse-loamy, mixed, frigid, Aquic Haplorthod; the Westburg series as a coarse-loamy, mixed, non-acid, frigid, Aeric Haplaqueod. These soils are all derived from basal till and range from well drained to poorly drained.

FLORIDA SITE

(Slash Pine)

PARTICIPATING INSTITUTION AND INVESTIGATORS - H. L. Gholz, Dept. of Forestry; E. Allen and D. Lundgren, Dept. of Environmental Engineering; P. Nkedi-Kizza and S. Rao, Dept. of Soil Science, University of Florida, Gainesville.

SITE DESCRIPTION AND LOCATION

This site is on a 60-ha plantation block of 20-yr-old (1986) Pinus elliottii on land under a long-term commercial timber lease to Container Corporation of America, 38 km northeast of Gainesville in Alachua County, Florida (29° 44′ N, 82° 29′ 30" W). The site was established in 1986 under a coordinated project on carbon, water and nutrient interactions (National Science Foundation Grant No. BSR 8516678). IFS work is funded by the Forest Response Program (Southern Commercial Forest Research Cooperative, USDA, Forest Service).

Climate

The area receives an average of 1350 mm of annual precipitation with no snow and little fog. Rainfall is concentrated into the hot and humid summer months, as a result of convectional thunderstorms, and into the winter months as a result of frontal activity due to cold air penetration from the north. The 30-year mean annual air temperature is 21°C.

Topography and Soils

The topography of the area is flat (39.5± 1.8-m S.D.). The predominant soil type is an uletic haplaquod (sandy, silicious, thermic), although the relative development and depths of the subsurface spodic (organic) and argillic (clay) horizons are highly variable over the 60 ha. Soils are derived from marine deposits and are sandy and very low in nutrients; organic matter is concentrated in the forest floor and the spodic horizon. Due to the low relief, sandy texture and underlying clay horizon, a water table is usually present above 150 mm

depth (average depth of 60 cm). There is little downward percolation of soil water and only slow drainage into lower surrounding wetlands. Flooded conditions can occur at any time depending upon rainfall patterns.

Vegetation and Management History

Even-aged slash pine dominate the site. This species is indigenous to these sites (along with *P. palustris*). The understory also consists of indigenous species, with gallberry (*Ilex glabra*), saw palmetto (*Serenoa repens*) and wire grasses the most common. Site preparation after the stem-only harvest of the former plantation stands (the current stands are second rotation) consisted of chopping of the residues, broadcast burning and machine planting of seedlings. After establishment there was no further treatment of the stands. Canopy closure occurred at about 10-12 years.

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