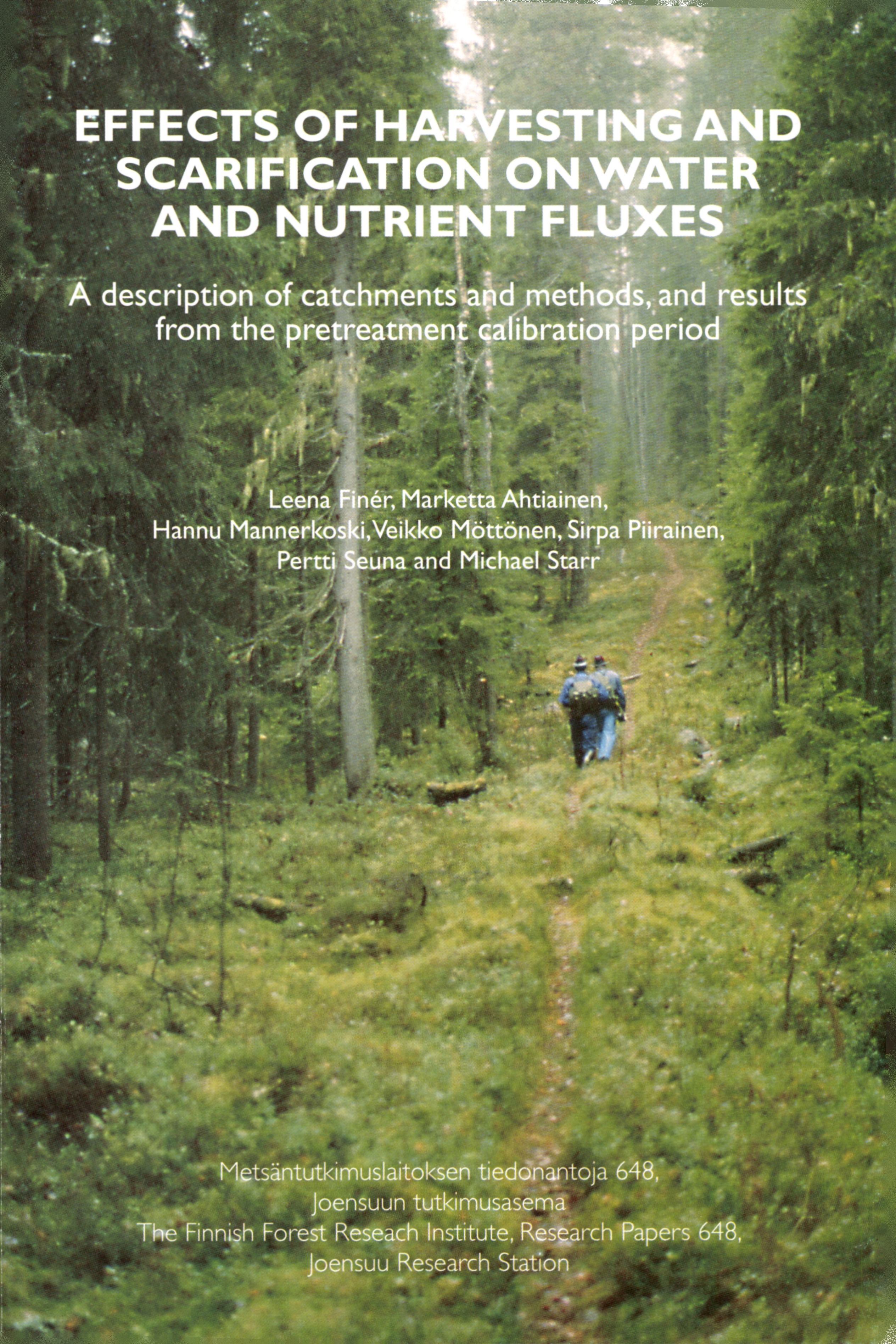

EFFECTS OF HARVESTING AND SCARIFICATION ON WATER AND NUTRIENT FLUXES

A description of catchments and methods, and results from the pretreatment calibration period

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FOREWORD

The economy of eastern Finland is mainly based on forestry. A greater part of the annual forest growth is utilised than in any other part of the country and large areas are annually harvested. However, the people in the region are also concerned about the environmental effects of intensive forestry practices. The Nurmes study, conducted by the North Karelia Regional Environment Centre, carried out pioneer work in studying the effects of various forestry practices in watercourses. This study, "Catchment Studies on the Effects of Forest Harvesting and Soil Scarification on Water and Nutrient Fluxes" and referred to as the VALU project, follows on from the traditions of the Nurmes study. It started in 1990 on the initiative of the North Karelia Regional Environment Centre, the Finnish Forest Research Institute and the University of Joensuu as a part of the METVE project (Joint Research Project on the Adverse Effects of Forest Management on the Aquatic Environment and their Abatement – Saukkonen & Kenttämies 1995). Only the calibration of the catchments could be accomplished during the course of METVE project, which ended in 1995. Early on it was realised that for the study to be successful a multidisciplinary approach was needed, and the group of researchers from different organisations has grown to ten, representing a range of expertise. This long term study has been financed by the Finnish Forest Research Institute, the North Karelia Regional Environment Centre, the Finnish Environment Institute, the University of Joensuu, and the Ministry of Agriculture and Forestry. The catchments are located on land owned by the Finnish Forest and Park Service. In this report we describe the catchments in terms of climatic, soil and tree stand characteristics, and the stream water and nutrient discharge during the 6-year-calibration period (1991-1996) of the study. During 1996-1997 winter, harvesting was carried out on the treatment catchments.

Key words: discharge, forest ecosystem, leaching, nutrient cycling, soil water, watershed

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1. INTRODUCTION

Some 86 % of Finland's land area (304 600 km^2) is forest. Two thirds of the forests grow on upland soils and one third on peat soils. Depending on the state of the economy, some 150 000 hectares of forest are cut annually and soil scarification subsequently carried out on about 100 000 ha prior to regeneration (Aarne 1995). Harvesting and soil scarification may lead to an increase in the leaching and runoff of nutrients from the harvesting site to adjacent watercourses (e.g. Bosch & Hewlett 1982, Ahtiainen 1990, 1992, Reynolds et al. 1995).

Harvesting results in more precipitation reaching the ground but at the same time dry deposition may be reduced (Nihlgård 1970, Adamson et al. 1987). Infiltration into the soil depends on surface roughness and porosity, which are strongly altered by harvesting and scarification (Ritari & Lähde 1978, Ross & Malcolm 1982). The logging residues left after harvesting are subject to mineralisation and the organic matter that is already incorporated into the soil may be subject to increased mineralisation as a result of changes in soil temperature and moisture conditions and the severance of nutrient cycling after harvesting and scarification. The nutrients so released may be taken up and cycled by microbes or by plants; or they may be retained in the soil through exchange and complexing reactions; or they may be leached, along with dissolved organic carbon, from the solum and rooting zone (Cronan et al. 1978, Nilsson & Bergkvist 1983). The response of the ground vegetation and microbial population after felling is therefore important in determining the amount of leaching that takes place (Likens et al. 1970). Few studies have investigated the effect of clear-felling on soil erosion and the transport of soil directly to watercourses (McColl & Grigal 1979, Ahtiainen 1990). Especially fine textured soils on steep slopes, in particular, may be susceptible to erosion.

The major plant nutrients Ca, Mg and K are also "base cations". The potential leaching of these nutrients may therefore be off set through cation exchange reactions, but aluminium and acidity can be expected to be released to the soil water in response (Nykvist & Rosén 1985). The effect of clear-felling on the nitrogen cycle, particularly nitrification, appears to be particularly important (Vitousek 1981). Clear-felling has been shown to increase nitrification, resulting not only in the leaching of nitrate but also in that of accompanying cations (Foster et al. 1989, Pardo et al. 1995). However, plant growth on upland sites in northern latitudes is generally limited by the availability of nitrogen, and nitrate is likely to be rapidly taken up (Rosswall 1976, Dahlgren & Driscoll 1994).

The intensity, extent and duration of the effects of harvesting and soil preparation depend upon a number of site factors, including: climate, topography, soil, and treatment factors (e.g. the amount and composition of harvested biomass, the type of harvesting and scarification methods used, the extent of the harvested area, and proximity to watercourses). Because of the different possible combinations of factors involved, studies have reported varying and even contrasting results. Increased leaching from the soil and increased nutrient concentrations in stream water induced by clear-felling has been demonstrated in several studies (e.g. Likens et al. 1970, Bosch & Hewlett 1982, Ahtiainen 1990, 1992, Reynolds et al. 1995). In contrast, nutrient leaching losses from the soil induced by clear-felling have been found to be negligible in other studies however (e.g. Martin & Harr 1989).

In Finland, the effects of forestry practices on watercourses have been studied in the Nurmes study (Ahtiainen 1988, Ahtiainen *et al.* 1988, Seuna 1988, Huttunen *et al.* 1988). In the Nurmes study, which started in 1978, the paired catchment method (calibration of adjacent catchments followed by treatment of one and retention of the other as a reference area) was used for the first time in Finland to study the effects of different forestry practices on the quantity and quality of stream water. The greatest changes in discharge and in the leaching of solids, N, PO_4 and total P were observed during the first years after treatment, but had still not levelled down to the reference levels after ten years on the catchment were no buffer zone was left between the stream and the clear-cut area (Huttunen *et al.* 1988, Ahtiainen 1990, 1992, Ahtiainen & Huttunen 1995, Holopainen & Huttunen 1992). The results thus emphasise the need for long-term monitoring when studying the effects of forestry operations on watercourses.

The catchments in the Nurmes study contained a high proportion of peat soils and most of the forestry operations were carried out on the peatlands or paludified upland areas. Peatlands have a considerable capacity to buffer runoff yield and quality (Laine et al. 1995). In only two of the catchments was harvesting carried out on upland soils. Many changes have been made in the practice of forest harvesting since the Nurmes study. Among these changes are the decrease in the extent of single clear-felled areas, the decrease in the intensity of soil preparation, and the technical development of the harvesting methods and machines to minimise the damage to vegetation and soil. Buffer strips along the shores of lakes and streams in which the forest is left standing are also used and some standing living and dead trees are left on the harvested site itself.

The aim of our VALU study is to determine the water and nutrient fluxes at five catchments and the subsequent effects of harvesting and soil preparation. The paired catchment method has been used. The catchments are considered to be closed hydro-geomorphological units, thus allowing complete water and nutrient budgets to be made. We have also taken an integrated ecosystem approach.

In this report we describe the catchments and the methods and sampling procedures that have been used during the 6-year-calibration period (1991-1996) of the study. The results of climate/weather, deposition, soil water fluxes, soil and tree stand characteristics, and the stream water and nutrient discharge collected during the calibration period are summarized. In the winter of 1996-1997, harvesting was carried out on two of the catchments and three were left as reference controls. The harvesting operations were only carried out on those forest compartments classified as ”mature for final cutting” which covered a combined area of 10 and 30 % in each of the two treated catchments, and in accordance with the current normal practices of the Forest and Park Service (Korhonen 1994). Soil preparation and regeneration treatments are still being decided upon, but they are intended to be carried out within 2-3 years.

2. MATERIAL AND METHODS

2.1. The catchments

The five first-order catchments included in the study are called: Kangasvaara, Kangaslampi, Iso-Kauhea, Korsukorpi and Porkkavaara. They are on state owned land in the communities of Sotkamo and Kuhmo in eastern Finland, and all within 30 km of each other (Table 1, Figs. 1 and 2). They vary in area from 29 to 176 ha. In terms of geobotanical zonation (Ahti *et al.* 1968), the catchments are located in the middle boreal zone, and, in terms of forest vegetation zonation (Kalela 1961), they are located at the southern limit of Ostrobothnia-Kainuu zone. The mires in the catchments are classified as aapa mires (Ruuhijärvi 1983).

In terms of land use, virtually all of the land in the catchments is classified as forestry land (Table 1). The Iso-Kauhea and Korsukorpi catchments contain small lakes, which constitute 3-4 % of the total catchment area. At least half of the area of Iso-Kauhea and Korsukorpi is covered by peatland. The area of peatland in Kangasvaara and Kangaslampi catchments is less than 10 %. For comparison, the proportion of forestry land covered by peatlands in South Finland is 28 % and in North Finland, 40 % (Aarne 1995).

Table 1. The location, area and land use of the VALU catchments.

	Iso-Kauhea	Korsukorpi	Porkkavaara	Kangasvaara	Kangaslampi
Latitude	63°53'	63°53'	63°52'	63°51'	63°52'
Longitude	28°37'	28°40'	29°10'	28°58'	28°57'
Elevation of dam, m a.s.l	200	198	182	187	184
Elevation of highest point, m a.s.l.	231	221	226	238	238
Area, ha	176	69	72	56	29
Peatlands, %	50	56	16	8	9
Forestry land, % x)	97	96	100	100	100
forest land, % xx)	74	46	89	97	100
scrub land, % xx)	15	28	11	2	
waste land, % xx)	11	26		1	
Other land, %	1				
Watercourses, %	3	4			

x) For definitions for forestry land, forest land, scrub land and waste land see Aarne (1995).
xx) % of forestry land.

The main soil types in all of the catchments are somewhat thin, weakly developed iron podzols, peaty podzols, and shallow fibric histosols (*Sphagnum* peat). The soils have developed on shallow (often < 2 m on slopes), stony to very stony till material. The riparian zone along side the perennial and intermittent streams in the catchments are peat or paludified. The underlying bedrock at all catchments is formed of gneiss granite and granodiorite.

The forests and soils at the catchments have been inventoried once. Weather, tree stand characteristics, soil properties, deposition, throughfall and stemflow, soil water, ground water and discharge are, depending on catchment, continuously monitored (Table 2).

2.2. Catchment-scale studies

2.2.1. Weather

Precipitation is recorded in an open area close to the catchment boundary. Kangasvaara and Kangaslampi have a common automatic weather station (Campbell Scientific Ltd.) located approximately 100 m east from the outlet of the Kangasvaara catchment (Fig. 2). Precipitation is collected at this station with a tipping-bucket rain gauge.Precipitation is also recorded inside the Kangaslampi catchment using a siphon gauge with a clock-driven drum recorder (pluviograph). Iso-Kauhea and Korsukorpi also have a common automatic weather station. This is located on a clear-cut area between the outflow streams

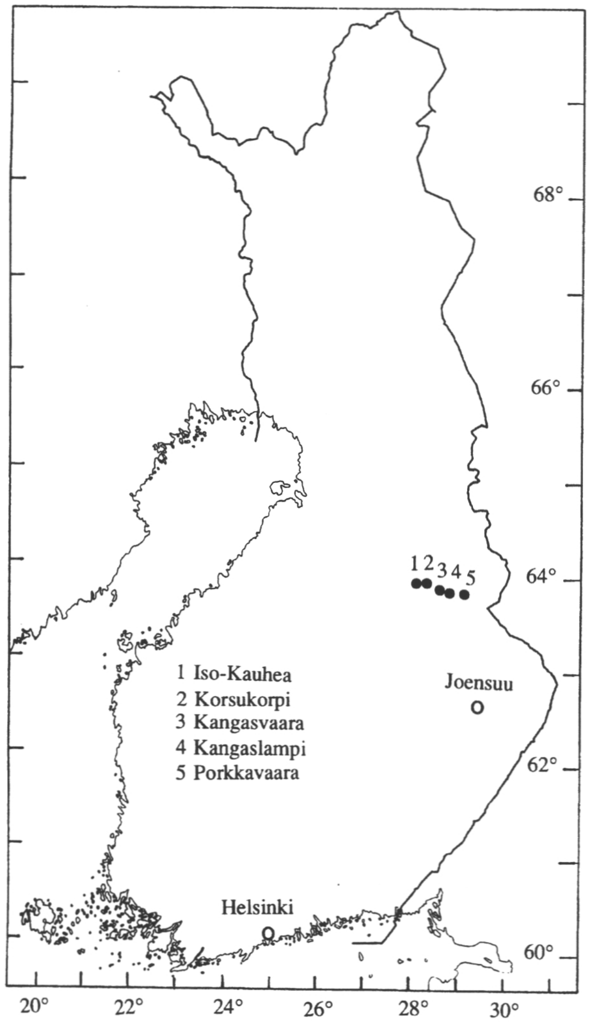

Fig. 1. Map showing the location of the VALU study catchments.

of the two catchments. Precipitation is also recorded 500 m to the west of the outlet of Korsukorpi catchment with a pluviograph as part of the Nurmes study. The Porkkavaara catchment has its own precipitation monitoring station fitted with a pluviograph. The automatic weather station precipitation collectors are located at a height of 1.5 m above the ground and the pluviographs are located at a height of 1.2 m.

Snow depth is measured throughout winter in each catchment. The measurements are made with snow sticks at 6-9 points along snow lines. The water content of the snow and the depth to the soil frost layer is measured at the same points. Snow and soil frost measurements are made once a month, except after February, when they are carried out twice a month until the end of snowmelt.

Air temperature, relative humidity, solar radiation and wind speed are monitored continuously at the automatic weather stations with sensors at 2 m above ground level. Temperature is also recorded at 5 cm above ground level and in the soil at depths of 5, 20 and 50 cm.

Air and soil temperature are also continuously monitored on intensive monitoring plots established in a mature, Norway spruce (*Picea abies* Karst.) dominated, mixed *Vaccinium-Myrtillus* type forest stand within the Kangasvaara catchment (Fig. 3). The temperature sensors are placed at heights of 5 cm, 2 m, 7.5 m and 15 m inside the tree stand and in the soil at three depths: 3 cm (under the humus layer), 12 cm (in the eluvial horizon), and at 35 cm (in the illuvial horizon). The sensors are connected to a datalogger (Campbell Scientific Ltd.).

The monitoring of the climatic variables in the open areas started in autumn 1991 and those within the stand at Kangasvaara, in August 1992 (Table 2).

Table 2. Monitoring programmes and starting dates (month/year) in each of the VALU catchments.

	Iso-Kauhea	Korsu-korpi	Porkka-vaara	Kangas-vaara	Kangas-lampi	
Air temperature	10/91	10/91		10/91	10/91	continuously
Soil temperature				8/92		-"-
Precipitation	10/91	10/91		10/91	10/91	-"-
Air humidity	10/91	10/91		10/91	10/91	-"-
Solar radiation	10/91	10/91		10/91	10/91	-"-
Wind speed	10/91	10/91		10/91	10/91	discontinued 10/95
Depth of snow cover	1/92	1/92	1/92	1/92	1/92	continuously
Water content of snow	1/92	1/92	1/92	1/92	1/92	-"-
Bulk deposition				8/92	8/92	-"-
Throughfall				8/92		-"-
Stemflow				8/92		discontinued 1995
Soil percolation water				8/92		continuously
Soil water content				9/95		-"-
Soil water matric potential				8/92		-"-
Thickness of soil frost layer	1/92	1/92	1/92	1/92	1/92	-"-
Depth and quality of ground water	5/94	5/94	5/94	5/94	5/94	-"-
Stream discharge and quality	9/91	9/91	9/91	9/91	9/91	-"-
Litterfall				8/92		-"-
Site type inventory	6/90	6/90	10/90	7/90	7/90	once
Tree stand variables	6-7/91	8/91	6/92	10/90	8-9/90	-"-
Soil properties	6-7/91	8/91	6/92	10/90	8-9/90	-"-

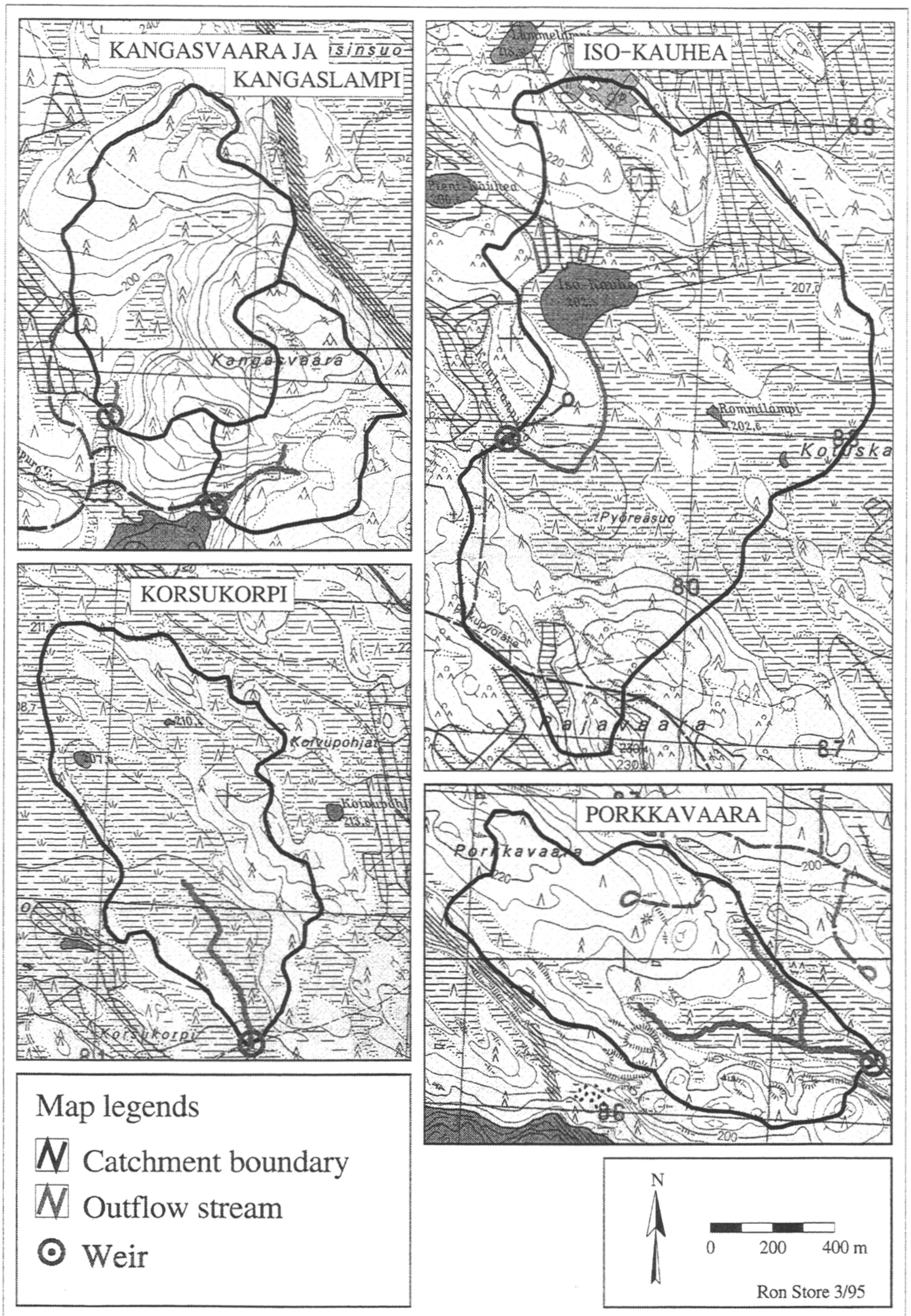

Fig. 2. Basic topographic (Maanmittaushallitus) and land-use map of the VALU study catchments showing the watershed boundaries, outflow streams and location of the runoff gauging stations (each fitted with a V-notch weir and water-stage recorder).

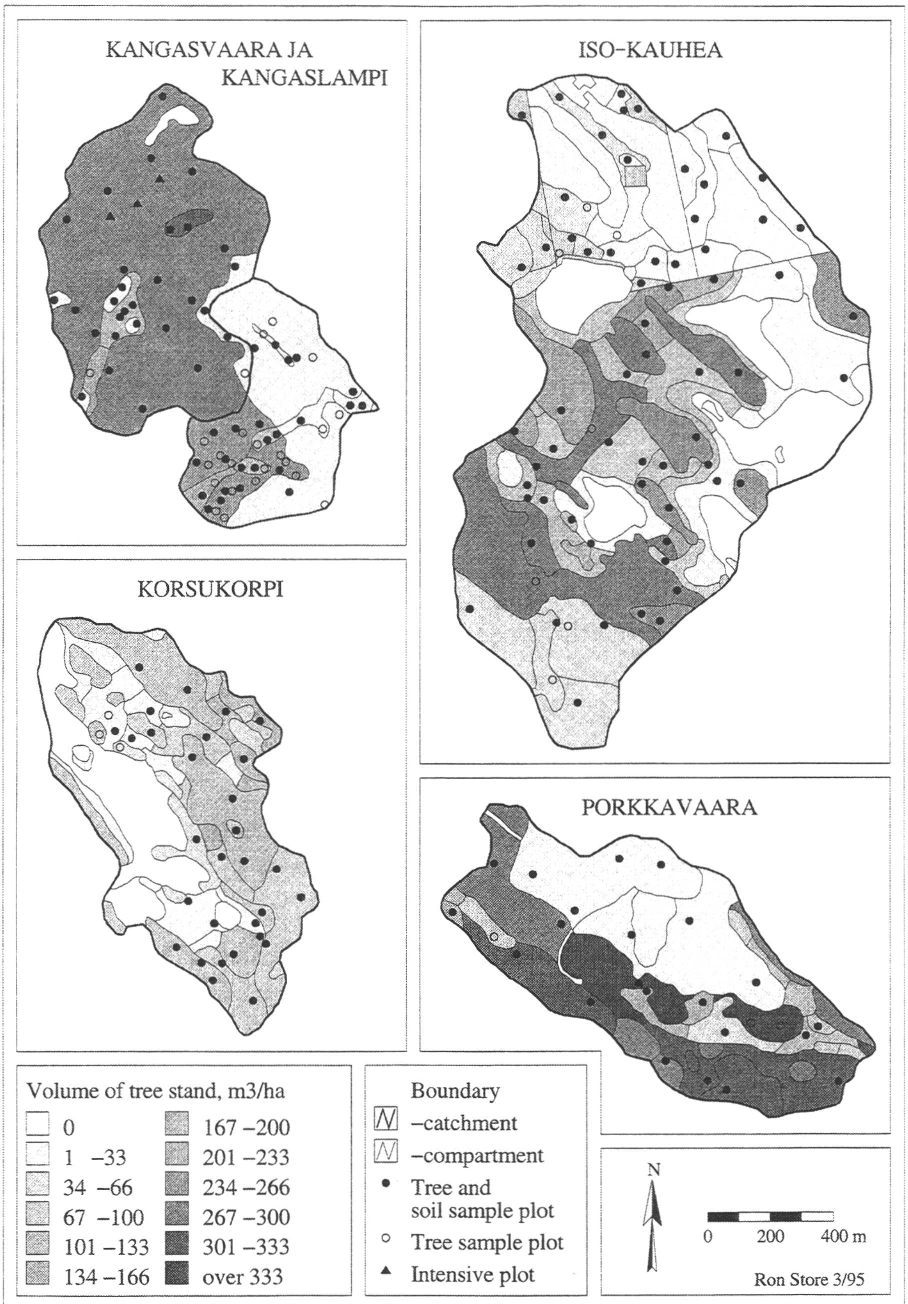

Fig. 3. Thematic map of stand stem volumes for each study catchment and the location of the permanent sample plots.

2.2.2. Tree stands

Tree stand measurements were carried out in order to characterise the structure and the volume of forest compartments within each of the catchments. In addition to measuring the stands, various site characteristics considered important in explaining tree growth were also recorded. The site and tree stand characteristics are to be used to estimate the amounts of nutrients bound up in the tree stand and the water and nutrient fluxes in soil-plant-system.

The measurements were made during 1990-1992 (Table 2). First, all forest compartments were delimited in the field and the boundaries drawn on basic maps (scale 1:10 000). The compartments are considered to be homogenous in respect to tree stand characteristics, site type, and soil. The following site variables were recorded for each compartment: site type, soil type, volume and density of tree stand, tree species composition, the number of canopy layers, the developmental stage of tree stand, any previous silvicultural treatment of the site, and any abiotic and biotic damage of tree stand. Site types were recorded in the Finnish Cajanderian system according to the schemes described by Lehto (1978) for upland (mineral) soil sites and by Laine and Vasander (1996) for peatlands. Soil texture class was determined for the upland sites and the peat type for peatland sites according to the classification used by the National Soil and Land Survey (Maaperäkartan ... 1983).

Tree stand variables for compartments were collected from a network of permanent circular measurement plots during 1990-1992 (Fig. 3, Table 2). The establishment of the permanent measurement plot network was based on a systematic grid (20 m x 20 m) laid out over the basic map of the entire catchment. Within each forest compartment a number of the grid intersections were selected as the centre point of permanent circular sample plots. The number and which grid intersections to use in each compartment were based on a number of selection criteria: the area of the compartment, tree stand density and volume, tree species composition, the number of canopy layers, and resources available. The aim was to measure 15-30 sample trees of each unit formed by tree species, site type and stand developmental class within each compartment. The plots were located only on land classified as "forested land".

The location, breast height diameter (at 1.3 m and in two directions at right angles), tree species, and vitality of all trees (living and dead, standing and fallen) within a radius of 5.64 m (100 m^2) of the plot centre was recorded. The same variables of trees with a breast height diameter > 10.5 cm and within a radius of 9.77 m (300 m^2) of the plot centre were also recorded. The trees with breast height diameter

>10.5 cm within radius of 9.77/2 m and those with breast height diameter < 10.5 cm within radius of 5.64/2 m of the plot centre were taken as sample trees, and also their height, height to the living crown, diameter at 6.0 m height, and bark thickness was measured, and an assessment of damage was made (Metsikkökokeiden...1987). The mean characteristics of the stand at each plot were calculated from the breast height diameter values and sample tree data using KPL, a computer program developed by the Finnish Forest Research Institute (Heinonen 1994).

Tree stand biomass, biomass production, and biomass nutrient store and uptake estimates will be determined from a material collected from the same mature, Norway spruce dominated, mixed forest in the Kangasvaara catchment in which the intensive monitoring plots were established. The material was collected in 1996 before the harvesting operations. A number of living and standing and fallen sample trees were carefully dismantled and the biomass of different compartments will be determined using procedures which will be described more detailed elsewhere.

Tree canopy litterfall collection was started in August 1992 on the three intensive monitoring plots (50 m x 50 m) at Kangasvaara (Fig. 3). The litterfall is collected with 16 funnels (area 0.5 m^2, collecting height 1.3 m) in each plot, which are emptied once a week during summer and once a month during the winter period. In the laboratory, the dry mass and nutrient content of various litter fractions will be determined from the dried and stored samples.

2.2.3. Soils

The aim of the soil chemistry programme was to characterise the soils in the catchments before the harvesting and soil scarification operations. The soil sampling was carried out on only a selection of the permanent circular tree measurement plots in each catchment, as resources did not allow the sampling to be carried out on all of the plots (Fig. 3). The sampling was confined to a 4 m wide zone surrounding each of the circular tree measurement plots. In the case of the upland mineral soil plots, it was attempted to take a set of samples by fixed-depth layers and by pedogenic horizon. For the plots on peatland, only fixed-depth layer samples were taken. A systematic sampling procedure was adopted in order to obtain a good coverage for the plot and the samples were composited by layer/horizon.

The humus layer (Of+Oh horizon) was sampled volumetrically using a 58 mm diameter stainless steel cylinder. Twenty samples were taken systematically from the sampling zone around each plot, recording the thickness of each before compositing. The sampling of the mineral soil at Kangaslampi differed from that at the other catchments. At Kangaslampi, the fixed-depth mineral soil samples (non-volumetric) were taken with an open-sided auger (ca. 2 cm diameter) at subplots located within the sampling zone in the four cardinal points. At each subplot, 25 subsamples of the 0-5 cm layer and 10 subsamples of each of the 5-20 cm and 20-40 cm layers were taken. The mineral soil horizon samples (E, B, and BC/C) were taken at two soil pits dug to describe and classify the soil at each plot. Volumetric samples (2 x 87.3 cm^3) of the same fixed-depth layers as described above plus the 40-60 cm layer were also taken from each of the pits. If a volumetric sample of the 40-60 cm layer could not be taken, e.g. due to stones, a loose sample was taken with a trowel.

At the other catchments, four shallow pits were excavated in the sampling zone around each plot, one in each of the four cardinal directions. The 0-5, 5-20 and 20-40 cm fixed-depth layers were sampled by taking soil from the sides of the pit using a trowel. One of the four pits, the one judged to be the most representative of the plot, was then deepened (or sometimes a new pit dug) to make a profile description. The horizon samples and the 40-60 cm layer sample were taken from this soil pit. The fixed volume sampling was confined to the 0-5 cm layer (2 x 204 cm^3 subsamples from each of the four shallow pits) because the stoniness of the till made reliable volumetric samples of the deeper layers impossible. Profile descriptions and sampling by horizons was limited to those plots in compartments with a mature stand, i.e. those which could be potentially harvested. This change in the mineral soil sampling procedure was made to simplify and reduce the field work but is considered to give as representative composite samples as those collected at Kangaslampi.

For the peatland plots, the fixed-depth samples were taken from each of four subplots located within the sampling zone and along the cardinal directions. At each subplot, 10 subsamples of the 0-5 cm and 5-10 cm layers, 5 subsamples of the 10-20 cm layer, and 2 subsamples of the 20-40 cm and 40-60 cm layers were taken using a 7×8 cm box peat sampler. Where the sample was considered to be volumetric (i.e. the volume of some of the samples from the more wetter sites was considered unreliable), the volume/weight relationships of the sample could be used to calculate bulk density.

Only the chemical data related to the composited samples of the humus layer and fixed-depth mineral soil and peat soil layers are presented in this report. The soil chemistry analytical programme is summarised in Table 3. The analyses were carried out at the laboratories of the Finnish Forest Research Institute in Joensuu and Vantaa.

Table 3. Outline of the soil chemistry programme.

Year of sampling	Iso-Kauhea 1991	Korsukorpi 1992	Porkkavaara 1992	Kangasvaara 1991	Kangaslampi 1990
pH[1)]	All	All	All	All	All
Exchangeable acidity[2)]	All	All	All	All	All
Total N[3)]	All	All	All	All	All
Total S[4)]	–	–	–	–	Selected
Total metals[5)]	Humus & peat samples only	Humus & peat samples only	Humus & peat samples only	Humus & peat samples only	All
"Plant available" nutrients[6)]	All	All	All	All	All
Exchangeable cations[7)]	All	All	All	All	All
LOI[8)]	All	All	All	All	All

1) pH in a water suspension and, for Kangaslampi only, also in a 1 M KCl suspension
2) Titration of filtered 0.1 M $BaCl_2$ extraction with 0.05 M NaOH to pH 7
3) Kjeldahl N, except Kangaslampi humus layer and peat samples, which was total N determined by a LECO analyser
4) Total S by a LECO analyser for horizon samples only (one selected profile per compartment)
5) Total=dry ashing + HCl acid digestion; AAS determination of: P, K, Na, Ca, Mg, Mn, Fe, Al, Cu and Zn
6) Filtered NH_4oAc (pH 4.65) extraction; AAS determination of: S, P, K, Na, Ca, Mg, Mn, Fe, Al, Cu and Zn
7) Filtered 0.1 M $BaCl_2$ extraction; ASS determination of: K, Na, Ca, Mg, Mn, Fe and Al
8) LOI=Loss on Ignition. Total C by a LECO analyser was also determined for Kangaslampi humus layer and peat samples

2.2.4. Ground water

The depth and quality of ground water is monitored at 4-9 ground water wells (diameter 30 mm, depth 69-552 cm) on each catchment. The wells are made of polyamide tube and perforated at the lower end. Half of the wells are installed on upland sites and the other half on peatlands. Sampling is done once a month during spring (March-May) and autumn (November-December) and every second month during summer (June-October). Samples are taken from the wells with a plexiglass tube. The analyses (Table 4) are done at the laboratories of the Finnish Forest Research Institute in Joensuu, Muhos and Vantaa. The monitoring started in spring 1994 (Table 2).

2.2.5. The amount and quality of stream discharge

Runoff from the catchments is recorded at a stream discharge gauging station. The gauging stations were constructed during 1990-1991 on the outflow stream at the catchment boundary. The gauging-stations are fitted with a V-notch weir and a continuous water-level recorder (limnigraph). Water samples for chemical analyses are taken a few meters upstream from the gauging stations. During winter (November-

March) and summer (June-September) the samples are taken once a month. During spring (April-May) and autumn (October) samples are taken twice a month. The analyses (Table 4) are done at the laboratory of the North Karelia Regional Environment Centre using the standard methods of National Board of Waters (1981, 1984). The monitoring of stream discharge and its quality started in autumn 1991 (Table 2).

Table 4. Analysis programme for the precipitation, throughfall, stemflow, soil percolation, ground water and stream discharge.

	Deposition	Throughfall	Stemflow	Percolation soil water	Ground water	Discharge
Temperature	-	-	-	-	+	+
Specific conductivity	+	+	+	+	+	-
pH-value	+	+	+	+	+	+
Alkalinity	-	-	-	-	+	+
NO_2-N	-	-	-	-	-	+
NO_3-N	+	+	+	+	+	+
NH_4-N	+	+	+	+	+	+
Total N	+	+	+	+	+	+
PO_4-P (unfiltered)	-	-	-	-	-	+
PO_4-P (filtered)	+	+	+	+	+	+
Total P (unfiltered)	-	-	-	-	+	-
Total P (filtered)	-	-	-	-	+	+
SO_4-S	+	+	+	+	+	+
Cl	+	+	+	+	+	+
Ca	+	+	+	+	+	+
Mg	+	+	+	+	+	+
K	+	+	+	+	+	+
Na	+	+	+	+	+	+
Mn	+	+	+	+	+	+
Zn	+	+	+	+	+	-
Cu	+	+	+	+	+	-
Fe	+	+	+	+	+	-
Total Fe	-	-	-	-	+	-
Water-soluble Al	+	+	+	+	+	+
Total Al	-	-	-	-	-	+
SiO_2	-	-	-	-	-	+
Colour value	-	-	-	-	-	+
COD_{Mn}	-	-	-	-	+	+
Dissolved inorganic C	+	+	+	+	+	-
Dissolved organic C	+	+	+	+	+	-
Dissolved total C	+	+	+	+	+	-
Total organic C	-	-	-	-	-	+
Total C	-	-	-	-	-	-
Particulate solids	-	-	-	-	-	+

2.3. Intensive plot-scale studies at Kangasvaara

2.3.1. Bulk deposition

Bulk deposition is monitored with five plastic rain (area 130.7 cm^2) and three plastic snow collectors (area 298.7 cm^2 during winter 1992-1993 and 1146.1 cm^2 thereafter) (Fig. 4) installed close to the automatic weather station at Kangasvaara. The collectors are emptied once a week during summer and once a month during winter. The deposition measurements at Kangasvaara started in August 1992 (Table 2). The analytical programme (Table 4) is carried out at the laboratories of the Finnish Forest Research Institute in Joensuu, Muhos and Vantaa using standard methods (Jarva & Tervahauta 1993). Monthly bulk deposition values are calculated from the area of the bulk deposition collectors, and the volume and solute concentrations of water collected by the bulk deposition collectors.

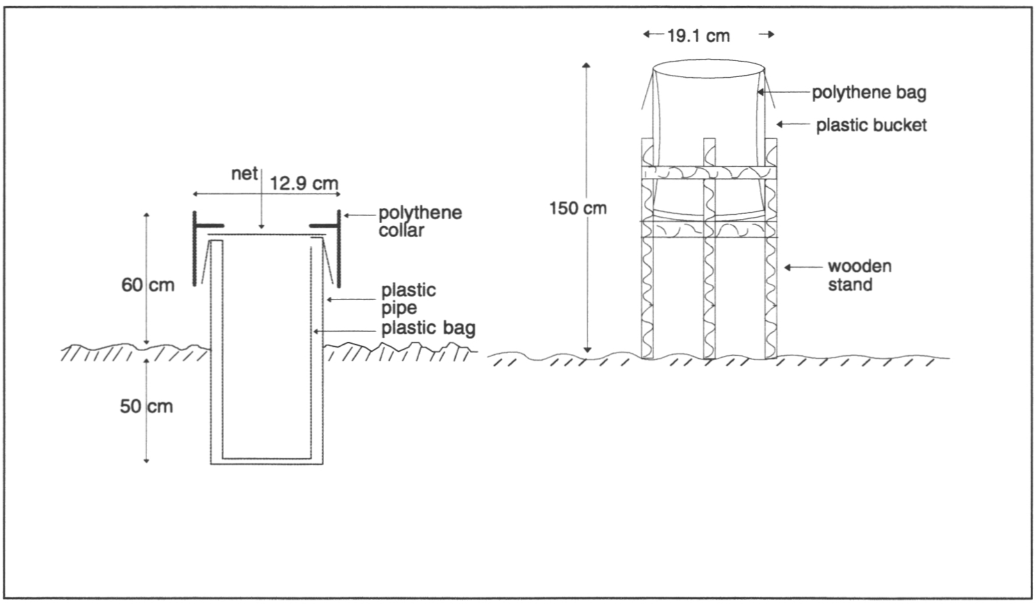

Fig. 4. Schematic diagram of the collectors used for bulk deposition and throughfall. Rainfall collectors (left) and snowfall collectors (right).

2.3.2. Throughfall, stemflow and soil percolate

Throughfall, stemflow and soil water have been monitored at the three intensive plots located in the mature, Norway spruce dominated, mixed stand at Kangasvaara since August 1992 (Fig. 3). The stand is classified in the Finnish Cajanderian system as a *Vaccinium-Myrtillus* type forest. Throughfall is measured with 16 systematically placed rain collectors in summer and with 8 snow collectors during winter on each plot (Fig. 4).

Stemflow was collected from five white or silver birches (*Betula pubescens* Ehrh. and *pendula* Roth.), five Scots pines (*Pinus sylvestris* L.) and ten Norway spruces (*Picea abies* Karst.) representing different diameter classes (> 6 cm) with spiral type stemflow collectors made of silicon tubing.

Water percolating through the soil is collected using zero tension lysimeters installed under the humus layer (at 3 cm depth), under the eluvial horizon (at 12 cm depth), and in the illuvial horizon (at 35 cm depth). The lysimeters under the humus layer are of the Jordan type (Jordan 1968) and made of plexiglass cylinder and the others are made of polythene funnel fitted to a 2 l plastic bottle (Fig. 5).

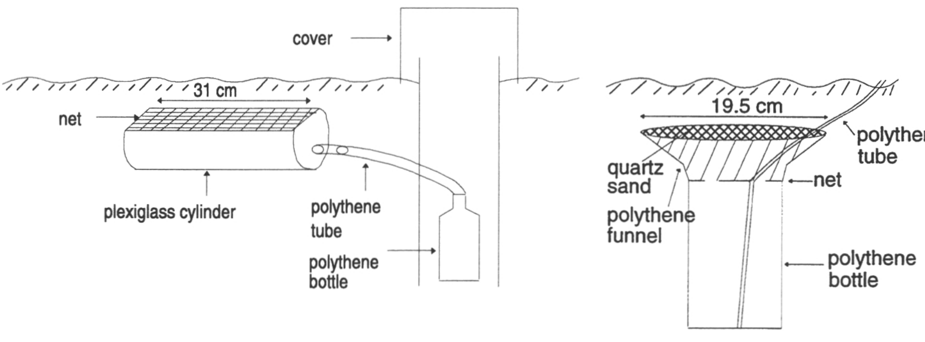

Fig. 5. Schematic diagram of the zero-tension lysimeters installed under the humus layer (left) and in mineral soil layers (right).

The throughfall and stemflow collectors and the lysimeters are emptied once a week during summer period. The throughfall collectors are also emptied during winter, once a month. At the time of sample collection, the amount of water collected is measured.

The analysis of the samples (see Table 4 for programme) is done at the laboratories of the Finnish Forest Research Institute in Joensuu, Muhos and Vantaa using standard methods (Jarva & Tervahauta 1993).

2.3.3. Soil water fluxes in mineral soil

Soil moisture water potential and soil water content are measured along lines laid out along a south-facing slope just below the intensive plots in the mature spruce dominated forest at Kangasvaara (Fig. 3). The data is being collected in order to study the water pathways through the soil and to determine soil water fluxes and hydraulic conductivities in the mineral soil. In 1993 and in 1994 soil moisture matric potential was monitored along a section of the slope with a 7° gradient and from August 1994 also on a section of the slope with a 12° gradient. Starting from September 1995 also the soil water content has been monitored on the 12° slope. The measurements are made at four points along the slope section. The distance between the measurement points is 10 m. At each point pressure transducer tensiometers and TDR probes are installed (1-2 of each) at depths of 10, 20, 40, 60 and 80 cm in the soil profile. The tensiometers and the TDR probes (29 of each) are connected to a datalogger and the values are recorded and stored every second hour.

The soil water characteristic curve for each soil horizon has also been determined. Sixteen small soil cores (5 cm diam. and height) and four large soil cores (diam. 30 cm, height 20 cm) from the same depths as soil water measurements were taken. The small cores were taken to determine the water characteristics using the gas pressure method and the large cores were taken to determine near saturated and unsaturated hydraulic conductivity using the instantaneous profile method. The laboratory work is carried at the University of Joensuu.

2.4. Data storage

The data from the tree stand and soil measurement subprogrammes are held in an INGRESS database and maps digitized for use in a GIS (ARC/INFO). The remaining data are stored into ASCII data files.

3. RESULTS AND DISCUSSION

3.1. Climate

The mean annual temperature at Kangasvaara and Iso-Kauhea during the calibration period (1992-1995) were lower than the long-term (1931-1960) mean annual temperature for the area (Table 5). Monthly mean temperatures during 1992, 1993 and 1995 were also less extreme;

with the mean temperature for July being lower, and for February, higher than the long-term mean values. In 1994, July was average, whereas February was colder than average.

The long-term (1931-1960) average annual precipitation for the area is 700 mm. The annual precipitation recorded at Kangasvaara and Iso-Kauhea during 1992-1995 did not differ greatly from this long-term average (Table 5). The precipitation for June 1993 was, however, exceptionally high. The thickness of snow cover during the calibration period was average or somewhat thicker than the long-term average. The water content of the snow throughout the calibration period, however, was greater than the long-term average.

Table 5. Mean annual climatic variables at Iso-Kauhea (I-K) and Kangasvaara (KV) weather stations (snow and soil frost measurements from catchments) and long term averages for the area (Alalammi 1987). The air temperature and relative humidity of air are annual means.

Variable	1992		1993		1994		1995		1931-1960
	I-K	KV	I-K	KV	I-K	KV	I-K	KV	
Air temperature, °C	1.5	1.6	0.4	0.6	0.7	0.9	1.6	1.6	1.8
Relative humidity, %	80	78	80	79	80	80	82	77	80
Temperature sum, °C	942	964	740	795	925	945	988	983	980
Average temperature June, °C	12.9	13.1	13.9	14.6	16.0	16.4	12.8	12.8	16
Average temperature February, °C	-6.5	-6.9	-8.0	-8.0	-16.7	-17.0	-5.8	-5.8	-11
Solar radiation, MJ m^{-2}	2590	2560	2590	1980	2730	2780	2730	2710	
Precipitation in June, mm	98	85	140	120	69	19	50	69	72
Annual precipitation, mm	762	779	651	620	722	676	671	759	700
Maximum thickness of snow cover, cm	77	72	92	90	92	89	85	80	78
Maximum water content of snow, mm	207	205	272	247	210	204	294	272	170
Maximum thickness of soil frost, cm	6	6	4	3	16	24	5	7	

3.2. Site types and tree stand characteristics

With the exception of a small area in the Porkkavaara catchment, the entire upland area in each of the catchments consists of *Vaccinium-Myrtillus* and *Empetrum-Vaccinium* site types (Table 6). The range in peatland site types, and therefore fertility is wider than the range in upland site types. The peatlands at Porkkavaara and Kangasvaara are also more fertile than those at Iso-Kauhea and Korsukorpi. Some 17% of the peatland area at Iso-Kauhea has been drained for forestry purposes, whereas the peatlands in the other catchments are all pristine. For comparison, 75% of the peatland area in South Finland has been drained; in North Finland, the corresponding percentage is 38% (Aarne 1995).

Table 6. Upland and peatland site types as percentage of the total area of upland and peatland sites on the catchment respectively. The parallel upland site type (in terms of fertility) for peatland site types in parentheses.

	Iso-Kauhea	Korsu-korpi	Porkka-vaara	Kangas-vaara	Kangas-lampi
Upland sites x)					
VMT	50	61	65	96	85
EVT	50	39	29	4	15
ECT					
ClT			6		
Peatland sites xx)					
RhK+VLK, (GOMaT)			44	36	
MK+VLR+KgK+MtkgI+MtkgII, (VMT)	12	10	22	42	76
PK+KR+PsR+PtkgI+PtkgII, (EVT)	35	13	16	22	24
IR+LkR+TR+Vatkg, (ECT)	30	35			
RaR+LkN, (ClT)	23	42	18		

x)GOMaT = *Geranium-Oxalis-Maianthemum* type, VMT = *Vaccinium-Myrtillus* type, EVT = *Empetrum-Vaccinium* type, ECT = Empetrum-Calluna type, ClT = Cladonia type,
xx) *Pristine peatlands:* RhK = Herb-rich hardwood-spruce swamp, VLK = Eutrophic hardwood-spruce fen, MK = *Vaccinium myrtillus* spruce swamp, VLR = Eutrophic pine fen, KgK = Paludified *Vaccinium myrtillus* spruce forest, IR = Dwarf-shrub pine bog, LkR = Low-sedge *Sphagnum papillosum* pine fen, TR = Cottongrass pine bog, RaR = *Sphagnum fuscum* bog, LkN = Low-sedge fen, *Peatland site types, drained for forestry:* MtkgI/-II = *Vaccinium myrtillus* type I and II, PtkgI/-II = *Vaccinium vitis-idaea* type I and II, Vatkg = Dwarf shrub type.

Norway spruce (*Picea abies* Karst.) is the dominant tree species in each catchment (Table 7). The proportion of Scots pine (*Pinus sylvestris* L.) out of the total tree stand volume varied between 23 and 40%, depending on catchment. The corresponding proportion of birches (*Betula pendula* Roth., and *Betula pubescens* Ehrh.) was 9–17%. The proportion of the other deciduous species (including aspen, *Populus tremula* L.) was small at all catchments. The average stand volume of spruce dominated forests is 163 m^3 ha^{-1} in South Finland and 85 m^3 ha^{-1} in North Finland (Aarne 1995). The stand volume at Porkkavaara and Kangasvaara is therefore considered large.

Table 7. The total volume of tree stands in the study catchments and the percentage by tree species.

	Total stem volume		Spruce	Pine	Birches	Other deciduous tree species
	m^3	m^3ha^{-1}	%	%	%	%
Iso-Kauhea	16704	95	64	26	9	1
Korsukorpi	4157	60	50	38	11	1
Porkkavaara	12907	179	45	40	12	3
Kangasvaara	15394	275	54	30	12	4
Kangaslampi	2449	84	59	23	17	1

Table 8. The area and stem volume of the different developmental stages of tree stands on forestry land in each of the study cathcments.

	Open	Sapling stand (height < 1.3 m)	Mature stand	Mature for final cuttings
Iso-Kauhea				
%[x)]	-	8	42	22
m^3	-	2	5512	10305
m^3ha^{-1}	-	0	53	268
Korsukorpi				
%[x)]	-	-	9	39
m^3	-	-	547	2711
m^3ha^{-1}	-	-	93	102
Porkkavaara				
%[x)]	1	-	44	44
m^3	-	-	1672	10527
m^3ha^{-1}	-	-	54	330
Kangasvaara				
%[x)]	-	-	8	89
m^3	-	-	422	14953
m^3ha^{-1}	-	-	90	300
Kangaslampi				
%[x)]	-	-	72	28
m^3	-	-	312	2137
m^3ha^{-1}	-	-	15	261

[x)] % of total area of catchment

Of the forestry land in the Kangasvaara catchment, 89 % was classified as being mature for final cutting (Table 8). The corresponding percentage at the other catchments was considerably less, 22-39%. All the stands classified as "mature for final cutting" were older than 100 years. With the exception of Korsukorpi, were the forest has been partially cut a few decades ago, the stem volumes involved are large compared to usual stands classified as "mature for final cutting". Little clear-felling has taken place in the catchments and the area of young sapling stands is small.

3.3. Soil nutrient contents

The average nutrient contents in surface soil layers for the upland sites (Table 9) were within the range of those reported by Tamminen (1991) and for the peatlands (Table 10), to values reported by Westman (1981)

Table 9. Average amounts of nutrients (total N and exchangable Ca, Mg, K, P, Fe), kg ha^{-1}, and cation exchange capacity (CEC) and exchangable acidity (EA), kmol$_c$ha^{-1}, by soil layer on upland sites of catchments.

	Layer	Iso-Kauhea	Korsukorpi	Porkkavaara	Kangasvaara	Kangaslampi
Total N	org. layer	617.7	518.6	490.5	575.4	505.2
	0-5 cm	239.8	190.1	173.3	255.7	367.4
	5-20 cm	1053.4	902.1	1004.9	1334.5	757.9
	20-40 cm	683.6	725.8	688.2	914.1	694.0
	40-60 cm	276.1	856.1	349.1	590.4	345.8
	Σ	*2870.6*	*3192.7*	*2706.0*	*3670.1*	*2670.3*
Exch. P	org. layer	10.0	10.6	11.2	9.5	3.5
	0-5 cm	1.3	0.8	1.6	0.8	2.1
	5-20 cm	2.5	1.6	3.1	3.4	1.8
	20-40 cm	3.4	1.7	2.8	3.9	1.9
	40-60 cm	4.2	3.5	5.5	6.1	3.3
	Σ	*21.4*	*18.2*	*24.2*	*23.7*	*12.6*
Exch. Ca	org. layer	124.3	73.3	79.6	93.6	66.6
	0-5 cm	43.0	13.5	22.4	20.8	31.3
	5-20 cm	93.6	63.5	50.3	55.6	113.5
	20-40 cm	70.7	64.8	54.6	59.4	35.4
	40-60 cm	50.7	32.2	34.6	39.5	30.9
	Σ	*382.3*	*247.3*	*241.5*	*268.9*	*277.7*
Exch. Mg	org. layer	20.1	13.9	13.3	18.0	12.3
	0-5 cm	5.9	3.2	3.9	4.8	5.5
	5-20 cm	12.5	8.7	7.8	11.4	15.3
	20-40 cm	9.9	8.5	9.0	11.1	10.4
	40-60 cm	7.3	3.7	6.3	8.1	8.7
	Σ	*55.7*	*38.0*	*40.3*	*53.4*	*52.2*
Exch. K	org. layer	54.3	47.1	41.3	50.6	31.7
	0-5 cm	9.7	7.6	8.0	11.9	13.5
	5-20 cm	32.9	19.2	19.1	35.8	37.2
	20-40 cm	38.3	17.6	20.7	31.7	37.0
	40-60 cm	24.0	12.5	16.3	24.4	39.6
	Σ	*159.2*	*104.0*	*105.4*	*154.4*	*159.0*
Exch. Fe	org. layer	7.2	1.5	1.8	1.1	1.3
	0-5 cm	30.3	33.4	47.0	26.4	40.3
	5-20 cm	101.0	114.5	142.4	113.0	82.7
	20-40 cm	105.2	94.4	121.2	59.7	61.6
	40-60 cm	48.6	94.7	76.5	52.1	43.5
	Σ	*292.3*	*338.5*	*388.9*	*252.3*	*229.4*
CEC [x)]	org. layer	16.2	16.2	13.6	13.0	
	0-5 cm	9.9	11.6	11.2	11.5	
	5-20 cm	15.4	16.0	10.5	16.5	
	20-40 cm	11.7	13.1	9.4	10.3	
	40-60 cm	5.4	5.3	6.6	5.2	
	Σ	*58.6*	*62.2*	*51.3*	*56.5*	
EA [xx)]	org. layer	6.0	8.0	5.0	5.3	4.7
	0-5 cm	8.0	10.2	9.3	9.9	
	5-20 cm	10.8	11.3	7.2	12.5	
	20-40 cm	7.5	8.4	5.9	7.0	
	40-60 cm	2.1	3.2	4.3	3.0	
	Σ	*34.4*	*41.1*	*31.7*	*37.7*	

[x)] CEC = Σ (Ca, Mg, K, Na) + Exchangable acidity,
[xx)] EA = Exchangable acidity (H + Al)

Table 10. Average amounts of nutrients (total N and exchangable Ca, Mg, K, P, Fe), kg ha^{-1}, and cation exchange capacity (CEC) and exchangable acidity (EA), mol$_c$ha^{-1}, by peat layer on peatland sites of cachments.

	Layer	Iso-Kauhea	Korsukorpi	Porkkavaara	Kangasvaara	Kangaslampi
Total N	0-5 cm	375.5	279.8	376.5	455.4	590.7
	5-10 cm	676.4	490.4	538.9	806.0	1013.5
	10-20 cm	1782.4	1845.9	2141.5	2174.9	3502.1
	20-40 cm	4028.5	4271.2	5289.5	4403.7	6544.4
	40-60 cm	3562.9	4745.0	6674.4	3981.5	3312.8
	Σ	*10425.7*	*11632.3*	*15020.8*	*11821.5*	*14963.5*
Exch. P	0-5 cm	4.6	2.7	4.9	6.4	3.3
	5-10 cm	3.9	3.0	4.7	5.5	2.8
	10-20 cm	4.9	7.0	9.4	4.8	3.8
	20-40 cm	2.6	3.7	4.6	1.8	1.5
	40-60 cm	1.3	1.0	1.8	0.6	0.1
	Σ	*17.3*	*17.4*	*25.4*	*19.1*	*11.5*
Exch. Ca	0-5 cm	54.4	36.7	114.2	152.2	64.4
	5-10 cm	78.0	59.3	168.8	233.7	127.9
	10-20 cm	151.6	140.0	543.4	467.9	227.3
	20-40 cm	316.5	289.5	1852.1	852.4	294.7
	40-60 cm	345.2	338.1	2527.8	760.8	85.4
	Σ	*945.7*	*863.6*	*5206.3*	*2467.0*	*799.7*
Exch. Mg	0-5 cm	20.5	14.8	16.5	43.9	27.0
	5-10 cm	28.1	21.8	23.7	65.9	40.7
	10-20 cm	54.7	47.5	68.4	122.1	72.8
	20-40 cm	103.0	84.1	189.4	186.1	91.3
	40-60 cm	103.5	93.7	246.0	156.1	24.0
	Σ	*309.8*	*261.9*	*544.0*	*574.1*	*255.8*
Exch. K	0-5 cm	64.0	27.6	37.4	43.5	42.7
	5-10 cm	30.2	25.3	28.1	25.7	24.3
	10-20 cm	25.0	29.8	37.3	20.5	25.1
	20-40 cm	19.5	20.7	24.8	18.4	13.0
	40-60 cm	14.4	15.3	24.8	11.7	3.9
	Σ	*153.1*	*118.7*	*152.4*	*119.8*	*109.0*
Exch. Fe	0-5 cm	1.0	37.8	0.9	0.7	1.5
	5-10 cm	3.5	29.9	1.1	1.8	2.9
	10-20 cm	3.0	10.4	1.2	2.5	4.3
	20-40 cm	4.6	22.7	0.7	5.4	0.2
	40-60 cm	10.3	31.6	1.4	10.8	0.5
	Σ	*22.4*	*132.4*	*5.3*	*21.2*	*9.4*
CEC x)	0-5 cm	9.8	8.0	11.9	17.4	17.3
	5-10 cm	14.6	11.5	17.9	25.8	23.0
	10-20 cm	25.9	27.2	57.6	50.9	56.4
	20-40 cm	53.3	54.5	162.3	84.0	114.1
	40-60 cm	49.7	61.7	209.2	79.4	60.0
	Σ	*153.3*	*162.9*	*458.9*	*257.5*	*270.8*
EA xx)	0-5 cm	3.2	2.7	2.4	2.1	6.4
	5-10 cm	5.6	4.2	3.1	2.4	7.8
	10-20 cm	10.9	9.6	7.8	5.6	22.2
	20-40 cm	22.6	21.1	12.2	10.5	60.1
	40-60 cm	18.4	24.8	16.5	10.9	36.7
	Σ	*60.7*	*62.4*	*42.0*	*31.5*	*133.2*

x) CEC = Σ (Ca, Mg, K, Na) + Exchangable acidity,

xi) xx) EA = Exchangable acidity (H + Al) and Kaunisto and Paavilainen (1988). The average contents of exchangeable calcium and magnesium in peat were noticeably higher at the Porkkavaara and Kangasvaara catchments and that of exchangeable iron at Korsukorpi than on the other catchments.

3.4. Bulk deposition at Kangasvaara

The annual bulk deposition values measured at Kangasvaara are presented in Table 11. The amount bulk deposition collected was considerably less than the amount of precipitation recorded by the automatic weather station (Table 5). This discrepancy was assumed primarily to be due to evaporation losses related to the design of the bulk deposition collectors (Fig 4). However, solute concentrations would have been correspondingly concentrated and the values for nutrient deposition corrected.

Table 11. Bulk deposition at Kangasvaara (KV) and at the Finnish Environment Institute monitoring stations Kuhmo and Valtimo (Järvinen & Vänni 1994b, 1996) during 1993-1994.

		1993 KV	Kuhmo[x)]	Valtimo[xx)]	1994 KV	Kuhmo[x)]	Valtimo[xx)]
NO_3-N	kg $ha^{-1}a^{-1}$	0.97	1.37	1.70	1.04	1.94	1.84
NH_4-N	-"-	0.95	1.39	2.03	1.70	2.06	2.06
tot. N	-"-	4.31	3.72	4.87	4.73	5.10	4.78
tot. P	-"-		0.19	0.17		0.16	0.08
SO_4-S	-"-	1.84	3.12	3.12	2.55	3.24	3.60
Cl^-	-"-	2.17	1.72	2.05	2.79	1.52	1.52
Ca	-"-		0.73	1.20		1.09	2.18
Mg	-"-		0.20	0.23		0.21	0.25
K	-"-	0.84	1.38	1.63	1.80		

x) 63°47'N, 28°29'E, xx) 64°16'N, 29°50'E

The deposition of sulphate sulphur and ammonium and nitrate nitrogen was smaller at Kangasvaara than at Kuhmo and Valtimo during 1993-1994. Kuhmo and Valtimo deposition stations are run by the Finnish Environment Institute 57-75 km and 11-24 km, respectively, from the VALU catchments. The deposition of total nitrogen did not differ much between Kangasvaara and Kuhmo and Valtimo. The deposition of sulphate sulphur, total nitrogen, ammonium and nitrate nitrogen, potassium and magnesium during 1993-1994 at Kangasvaara were smaller than the long-term average (1971-1982) at the Kuhmo and Valtimo deposition stations (Järvinen 1986). The depositions of total nitrogen, sulphate sulphur, calcium, potassium and magnesium in 1992-1994 were smaller in Kuhmo and Valtimo than the average for southern Finland, whereas that of phosphorus was almost the same (Järvinen & Vänni 1994ab, 1996).

3.5. Water and nutrient fluxes at Kangasvaara

The results of the throughfall, stemflow and soil leachate measurements carried out at the intensive plots in the Kangasvaara catchment are presented in Table 12. The amount of throughfall averaged 89-100% of the annual amount of bulk deposition (Table 12). Although the amount of bulk deposition was less than the amount of recorded precipitation (see 3.4.), the bulk deposition and troughfall water and nutrient fluxes are comparable to the extent that they were collected with the same type of collector. The canopy interception (calculated as bulk deposition minus throughfall) was smaller than reported by Päivänen (1966), Hyvärinen (1990) and Starr (1995) for Norway spruce dominated stands.

Table 12.The amount of precipitation, throughfall and stemflow and the amount of percolation water collected under the different soil horizons, mm a^{-1}, in 1993 and 1994 on the intensive plots in mature spruce dominated forest at Kangasvaara.

	1993 mm	1994 mm
Precipitation[x)]	429	541
Throughfall	431	480
Stemflow	6	6
Percolation water under the humus layer	235	264
Percolation water under the elluvial horizon	140	162
Percolation water under the illuvial horizon	26	70

x) measured with bulk deposition collectors

The amount of stemflow was small, only 1 % of the annual amount of bulk deposition. Similar results for Norway spruce dominated forests have been presented by Päivänen (1966) and Starr (1995).

The amount of soil leachate collected under the humus layer was 49-55% of the annual amount of precipitation. The amounts of leachates collected under the eluvial and illuvial horizons were 30-33 % and 7-13 % of the annual amount of precipitation, respectively.

The soil water content and soil water matric potential at one of the slope sites over a 5 day period during which a total of 40 mm of rain fell are presented in Figure 6 as an example of the kind of data that has been collected. Soil water contents in the 10, 20 and 40 cm layers reached a maximum on day 2 and represented an average increase in soil moisture of 3.1 %. The maximum soil water content in the 60 and 80 cm layers occurred on day 3 and day 4, respectively. The average increase in moisture content of these layers was 3.9 %. The greater increase in soil water content in the deeper soil layers can be explained by the lower hydraulic conductivity and related greater soil bulk density at depth. The soil water storage to a depth of 80 cm increased by 32 mm during the observation period (i.e. 80 % of the rainfall). The soil moisture potential in the 10 to 60 cm layers increased (became wetter) during the first two days and thereafter progressively decreased (became drier). At 80 cm depth the increase in soil moisture matric potential was delayed until day 3, i.e. one day longer than the surface layers. The soil moisture matric potential fluctuated much less at depth, corresponding to a slower soil water flow deeper in the soil.

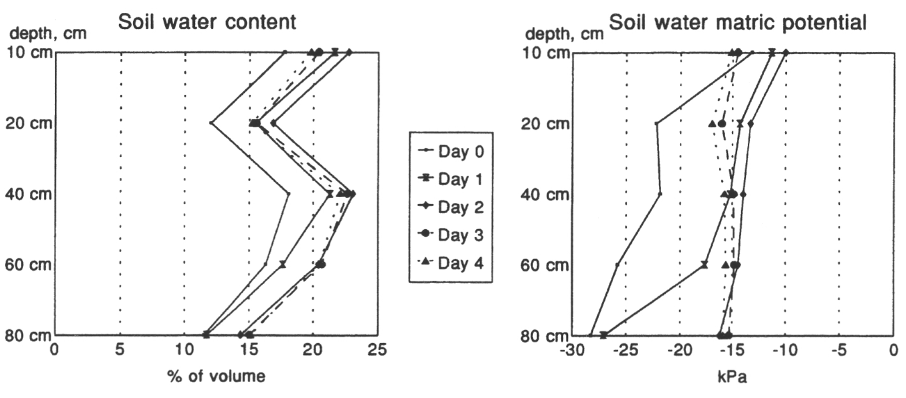

Fig. 6. Soil water content and soil water matric potential at one of the slopes at Kangasvaara during a five day period (from 24th to 28th of September 1995). Values were taken at 18.00 o'clock each day. The last intensive rain stopped at 16.00 o'clock on day 3.

Throughfall+stemflow amounts of total nitrogen, ammonium and nitrate were smaller than those in bulk deposition (Fig. 7). This indicates that canopy has taken-up nitrogen, a feature shown by most northern coniferous forests. In contrast, the deposition of sulphate, potassium, calcium and magnesium was higher under the canopy than

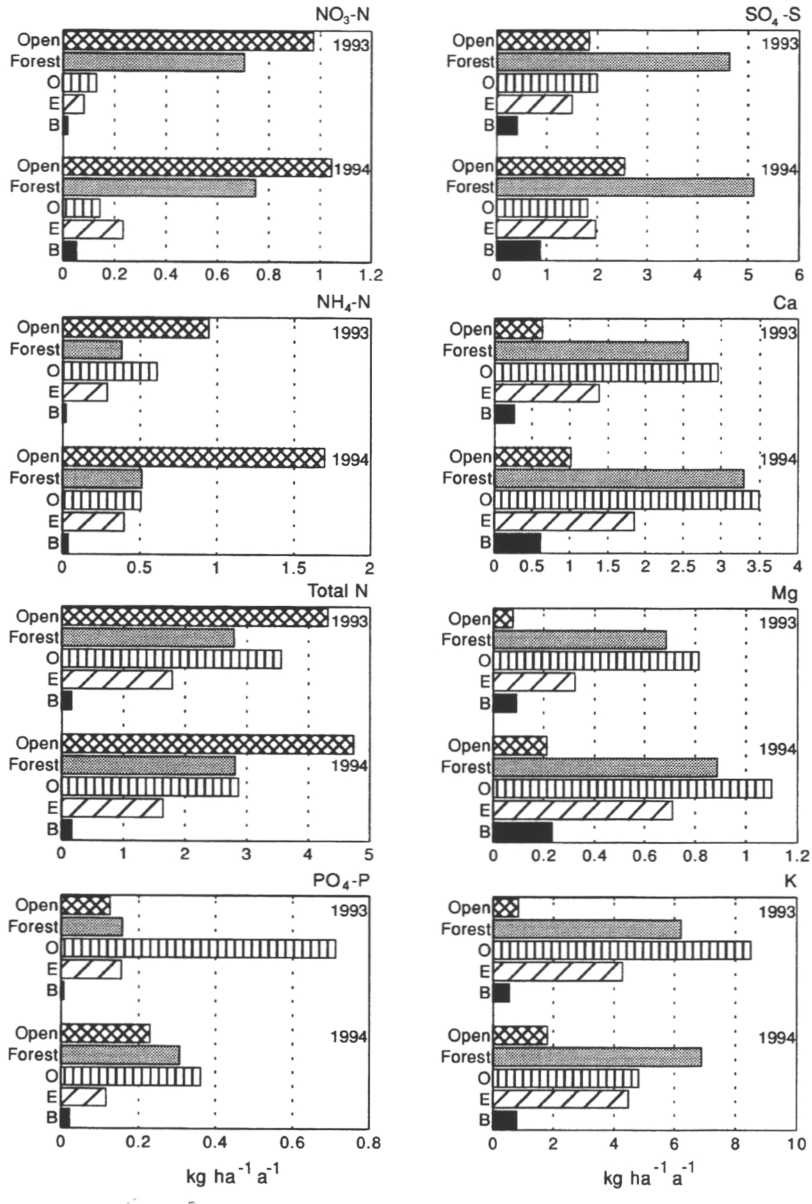

Fig. 7. Mean annual amounts of various solutes in bulk deposition (open), throughfall+stemflow, and soil leachates collected from under the humus layer (O), eluvial horizon (E) and illuvial horizon (B) in 1993 and 1994.

in the bulk deposition. The extra input of these solutes to the forest floor arises as a result of crown leaching and/or the wash-off of dry deposition accumulated in the canopy (e.g. Nihlgård 1970, Mayer & Ulrich 1980, Helmisaari & Mälkönen 1989, Hyvärinen 1990, Starr 1995). In a mature spruce forest studied by Hyvärinen (1990), the canopy interception of ammonium varied between 37 and 43% and that of nitrate from 4 to 23% during the growing season. In our study, the annual interception of ammonium was higher, being 60 to 70%, and that of nitrate nitrogen, 28%. Grennfelt and Hultberg (1986) have also reported that the spruce canopy uptake of ammonium can be as high as 70% and that of nitrate over 50%.

The annual amounts of phosphate, calcium and magnesium collected from underneath the humus layer were higher in both years than those in the throughfall+stemflow, i.e. the amounts which reach the ground vegetation and humus layers, indicating a net leaching of these nutrients (Fig. 7). Helmisaari and Mälkönen (1989) had also reported the leaching of calcium and magnesium from the humus layer of Scots pine stands. However, for each solute, the amount leaving the B horizon was smaller than that reaching the ground vegetation and humus layers (Fig. 7), indicating retention of these nutrients within the soil-plant system. The leaching of N and phosphate, in particular, from the solum was small.

3.6. Catchment runoff and input/output budgets

The annual runoff varied between 34 % (Kangaslampi 1995) and 67 % (Korsukorpi and Kangasvaara 1993) of precipitation (Table 13). Kangasvaara and Kangaslampi catchments had annual runoff/precipitation ratios of <0.5; whilst the ratio for the other catchments was >0.5, with Korsukorpi catchment having the highest ratios. This indicates that the proportion of precipitation lost as evapotranspiration is greater in the Kangasvaara and Kangaslampi compared with the other catchments. This grouping of catchments corresponds to the coverage of peatland: with Kangasvaara and Kangaslampi having the lowest percentage cover of peatlands and Korsukorpi having the highest (Table 1). Evapotranspiration per unit area may thus be less for peatlands, particularly treeless peatlands, than for forested upland soils.

Runoff rates ($l\ s^{-1}\ km^{-2}$) were also lower for the upland dominated catchments (Kangasvaara and Kangaslampi) than from the peatland dominated catchments (Porkkavaara, Iso-Kauhea and Korsukorpi) (Table 13). The highest rates and amount of runoff were for 1992, the same year precipitation was the highest (Table 5). The maximum runoff rates were also less for the upland dominated catchments compared to the peatland dominated catchments. There were no big differences in the minimum runoff rates between the catchments however.

The annual mean acidity of streamwater varied between pH 4.4 and 6.2. The lowest median pH values were measured in the output stream from the Iso-Kauhea catchment (4.6), and increased among the catchments in the following order: Korsukorpi (4.9)<Kangaslampi (5.3)<Kangasvaara (5.8) <Porkkavaara (6.1).

Table 13. Minimum, maximum and mean stream runoff rates (ls^{-1} km^{-2}) and total annual runoff during 1992-1995 for each study catchment.

	Maximum, $l\ s^{-1}\ km^{-2}$		Minimum, $l\ s^{-1}\ km^{-2}$		Mean annual,	Total runoff
	Winter	Summer	Winter	Summer	$l\ s^{-1}\ km^{-2}$	mm
1992						
Iso-Kauhea	209.30	138.40	3.24	0.53	13.87	437
Korsukorpi	259.81	155.61	2.29	0.78	14.84	468
Porkkavaara	129.46	80.34	2.06	4.41	15.62	492
Kangasvaara	78.98	43.08	2.08	2.01	10.20	321
Kangaslampi	156.49	75.80	1.58	1.36	9.90	312
1993						
Iso-Kauhea	310.25	58.07	1.83	6.39	12.65	399
Korsukorpi	350.22	84.98	2.08	7.33	13.84	436
Porkkavaara	186.78	36.89	2.52	7.53	13.15	414
Kangasvaara	133.68	20.65	1.70	5.13	10.04	316
Kangaslampi	194.60	37.86	1.39	3.56	8.75	276
1994						
Iso-Kauhea	234.70	43.80	1.11	1.07	12.30	387
Korsukorpi	334.80	49.30	0.63	1.98	13.16	415
Porkkavaara	139.90	28.60	0.68	1.76	11.70	369
Kangasvaara	86.57	21.10	0.66	1.46	9.19	290
Kangaslampi	158.80	34.30	0.34	0.45	8.16	257
1995						
Iso-Kauhea	143.12	36.11	2.86	0.66	10.92	344
Korsukorpi	119.24	38.81	2.24	0.73	11.80	372
Porkkavaara	132.15	33.44	2.69	3.41	11.67	368
Kangasvaara	127.57	22.01	2.12	2.58	10.05	317
Kangaslampi	108.95	32.16	1.39	1.50	8.20	259

The five-year mean annual concentrations of particulate solids were low in all streams during the calibration period (0.2-2.1 mg l^{-1}), indicating little erosion within the catchments. The colour values of stream water, which are largely related to the content of organic matter and iron, varied from 62 mg Pt l^{-1} at Kangasvaara to 324 mg Pt l^{-1} at Korsukorpi. The lowest COD_{Mn} -value and concentrations of total organic carbon were measured at Kangasvaara (9.8 mg l^{-1} and 7.4 mg l^{-1} respectively) and the highest at Iso-Kauhea (38.6 mg l^{-1} and 25 mg l^{-1}

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respectively). The lowest COD_{Mn}-value and concentrations of total organic carbon were measured at Kangasvaara (9.8 mg l^{-1} and 7.4 mg l^{-1} respectively) and the highest at Iso-Kauhea (38.6 mg l^{-1} and 25 mg l^{-1} respectively). The lowest concentrations of iron were measured at Porkkavaara (176 mg l^{-1}) and the highest at peatland dominated Korsukorpi (2936 mg l^{-1}). Streamwater concentrations of total aluminium varied between 74 µg l^{-1} and 250 µg l^{-1}.

The five-year mean annual concentrations of total phosphorus varied between 4.9 µg l^{-1} (Kangasvaara) and 15.6 µg l^{-1} (Iso-Kauhea). The concentrations of phosphate phosphorus in the same streams were 2.1 µg l^{-1} and 4.6 µg l^{-1} , respectively. The concentrations of total nitrogen varied between 163 µg l^{-1} (Kangasvaara) and 508 µg l^{-1} (Iso-Kauhea 1). The concentration of nitrate+nitrite nitrogen varied between 11 µg l^{-1} (Porkkavaara and Kangaslampi) and 24 µg l^{-1} (Iso-Kauhea). The concentrations of ammonium nitrogen were 3 µg l^{-1} in the streamwater from the upland soil dominated catchments and 9-11 µg l^{-1} in the streamwater from the peatland dominated catchments.

The mean annual nutrient losses from the catchments are presented in Table 14. Total organic carbon (TOC) values increased as the proportion of peatland in the catchment increased. The highest loss of organic matter, particularly at Iso-Kauhea, occurred in 1992, when runoff was the greatest (Table 13). The annual catchment losses of total carbon and particulate solids were comparable with those measured from other small forested - although mainly managed - catchments in Finland (Saukkonen & Kortelainen 1995).

The export of nitrogen was greater from the peatland dominated Iso-Kauhea and Korsukorpi catchments than from the upland dominated catchments. This relationship with peatland cover has also been observed by Saukkonen & Kortelainen (1995). However, the exports of total nitrogen, as well as ammonium and nitrate nitrogen, from our VALU catchments were lower than reported by Saukkonen and Kortelainen. This may be because the forests in the catchments included in Saukkonen and Kortelainen's study were mainly managed.

The export of phosphate phosphorus and that of total phosphorus was greater from peatland dominated Iso-Kauhea and Korsukorpi catchments. Phosphate phosphorus constituted 41% of the total dissolved phosphorus load at Kangasvaara. At the other catchments, this proportion varied between 21 and 29 %. Saukkonen and Kortelainen (1995) report catchment losses of total phosphorus of 0.04-0.20 kg ha^{-1} a^{-1} . Their lowest value, which was similar to that measured in this study, was for an unmanaged catchment. Our values were also similar to those reported from the Nurmes study during the calibration period (Ahtiainen & Huttunen 1995).

The runoff losses of iron and manganese was greater from the peatland dominated catchments, particularly Korsukorpi, than from the upland soil dominated catchments. Except for Korsukorpi, the leaching of iron was smaller than reported by Saukkonen & Kortelainen (1995). The runoff export of aluminium varied less among the catchments than that of iron and manganese. The leaching of base cations, particularly calcium, was much greater from Porkkavaara catchment than from the other catchments.

The mean input of nutrients as deposition measured at the nearby weather stations was compared to the export of nutrients measured at the streamflow (Fig. 8). Nearly all of the inorganic nitrogen in deposition is retained within the catchment and losses are very low. Most of the phosphorus arriving in the bulk deposition is also retained within the soil. There was a net output of calcium, magnesium and potassium from the catchments.

Table 14. Mean annual exports (kg ha^{-1} a^{-1}) of various solutes, chemical oxygen demand (COD), total organic carbon (TOC) and particulate solids with streamflow during 1992-1995 from each study catchment. Standard deviation are given in parentheses.

	Iso-Kauhea		Korsukorpi		Porkkavaara		Kangasvaara		Kangaslampi	
NO_3+NO_2-N	0.016	(0.00)	0.011	(0.00)	0.009	(0.00)	0.007	(0.00)	0.006	(0.00)
NH_4-N	0.023	(0.01)	0.017	(0.00)	0.013	(0.00)	0.009	(0.00)	0.009	(0.00)
Total N	1.89	(0.28)	1.56	(0.20)	1.04	(0.34)	0.52	(0.10)	0.85	(0.21)
PO_4-P	0.013	(0.00)	0.013	(0.00)	0.009	(0.00)	0.007	(0.00)	0.007	(0.00)
Total P	0.061	(0.01)	0.052	(0.01)	0.031	(0.01)	0.017	(0.00)	0.034	(0.01)
Ca	4.47	(0.70)	3.50	(0.41)	10.08	(2.17)	3.36	(0.68)	2.99	(0.84)
Mg	1.85	(0.25)	1.50	(0.18)	1.97	(0.32)	1.40	(0.23)	1.19	(0.25)
K	1.42	(0.23)	1.20	(0.19)	2.12	(0.42)	0.89	(0.18)	1.04	(0.20)
Mn	0.14	(0.03)	0.22	(0.04)	0.08	(0.04)	0.05	(0.02)	0.08	(0.03)
Fe	2.94	(0.32)	9.22	(1.70)	0.70	(0.21)	0.58	(0.18)	0.85	(0.17)
Al	0.89	(0.29)	0.50	(0.15)	0.41	(0.16)	0.24	(0.07)	0.59	(0.21)
COD_{Mn}	146.51	(21.72)	126.14	(20.00)	71.61	(27.67)	30.53	(9.27)	58.30	(16.87)
TOC	94.49	(9.46)	82.24	(14.14)	47.44	(19.64)	22.07	(4.92)	38.56	(11.89)
Particulate solids	6.95	(8.17)	15.20	(10.50)	2.49	(1.65)	1.00	(0.60)	3.02	(1.07)

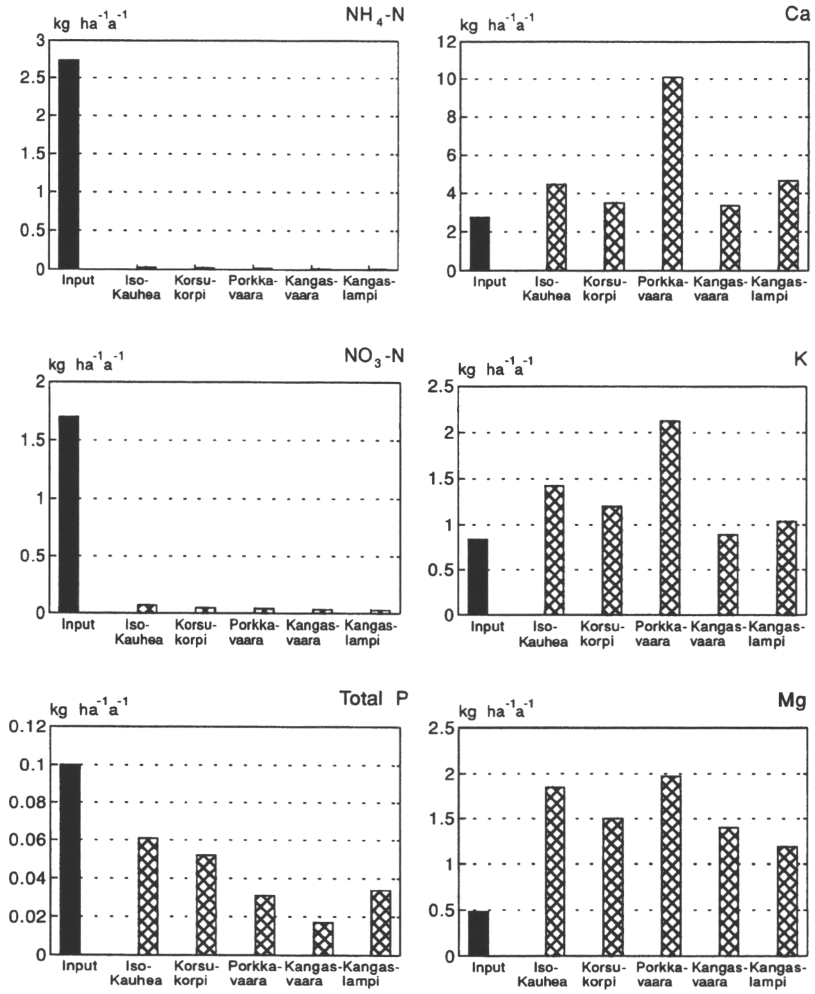

Fig. 8. The mean annual input (bulk deposition) and output budgets for various solutes from the VALU catchments during the calibration (1992-1995) period. The inputs are the long term mean of values taken from the Finnish Environment Institute's stations at Kuhmo and Valtimo.

4. SUMMARY

The catchments included in this study are all forested and either upland or peatland dominated. With the exception of a small area in one of the catchments, the upland forests have not been managed for a long time and now represent old-growth forests. Norway spruce dominated mixed stands with large stem volumes. The upland soils are podzolic and developed on till material. Soil analyses shows them to be typical for forested soils in southern Finland. The proportion of peatland cover has an important affect on catchment runoff quantity and quality.

The calibration period was colder than the long-term average for the area. The amount of precipitation was normal, but the water content of snow was greater than the long term average. During the calibration period, approximately 52 % of the annual precipitation left the catchments as stream runoff.

The bulk deposition of nitrogen and base cations is low. Nearly all of the nitrogen in bulk depositon is retained within the catchment, primarily in the soil-plant system, and catchment losses are very low. Most of the phosphorus arriving in the bulk deposition is retained within the soil. There is net output of calcium, magnesium and potassium from the catchments due to weathering.

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