



Integrated monitoring in small wooded catchments in Lithuania

Zenonas GULBINAS and Minijus SAMUILA



Zenonas Gulbinas and Minijus Samuila (2002) — Integrated monitoring in small wooded catchments in Lithuania. *Geol. Quart.*, 46 (1): 81–97. Warszawa.

In the background monitoring areas (small wooded catchments) agricultural pollution is negligible and the atmosphere is the only source of widescale pollution. We review the chemical compositions in the soil profiles of Aukštaitija, Dzūkija and Žemaitija in Lithuania. We describe also trends in groundwater level fluctuations, the chemical composition of groundwater in 1994–1999, compare the chemical and physical properties of runoff water and show results of the simulation of successive data series of soil water flow and soil moisture saturation at different depths by the SOIL model. The simulation results may be used to evaluate water movement and element mobility in the soil.

Zenonas Gulbinas and Minijus Samuila, Institute of Geography, Akademijos 2, LT-2600 Vilnius, Lithuania, e-mail: zenonas.gulbinas@geo.lt, minijus.samuila@geo.lt (received: July 10, 2000; accepted: August 10, 2001).

Key words: integrated monitoring, soil, groundwater, runoff, modelling.

INTRODUCTION

During the 1980's four different monitoring programmes resulted from the UN/EEC Convention on Long-range Transboundary Air Pollution, all with the purpose of monitoring and assessing effects from airborne pollutants in the environment. These International Co-operation Programmes (ICP's) were directed towards forests, freshwaters, crops and materials. In 1988 UN/EEC recommended participating countries to contribute to a three year Pilot Programme of "integrated monitoring" (IMP) in small catchments. Sweden was appointed as lead country. An Environment Data Centre (EDC) was established in Helsinki, Finland. Other countries were encouraged to start monitoring and to send data to the EDC. An evaluation of the pilot phase in 1991–1992 served as a basis for decisions about the future of the programme. The evaluation stated that IMP was necessary, and should continue as a permanent international co-operative programme. The Executive Body decided at a meeting in November 1992 on the continuation of the IMP under the name "International Co-operative programme on Integrated Monitoring of Air Pollution Effects on Ecosystems".

Lithuania started participating in this programme in 1993, and 17 subprogrammes within this framework are included in Lithuania's State Environmental Monitoring Programme and treated as global background monitoring.

Integrated monitoring of ecosystems means taking simultaneous physical, chemical and biological measurements over time of different ecosystem compartments at the same location. The principle of integrity is realised by establishing integrated monitoring territory (IMT) in the main types of Lithuanian landscape. Three territories were established in the areas of minimal anthropogenic impact, combining them with the infrastructure of national parks and reservations (background territories).

Integrated stationary investigations of ecosystems, including the monitoring of atmospheric precipitation, surface, ground and soil waters, chemical composition of soils and state of biota, are carried out in small (100–380 ha) catchments with natural (pine-spruce) vegetation in protected territories. The Institute of Geography is responsible for stationary investigations of soil, soil water, groundwater and runoff water chemistry in the integrated monitoring territories. More than 20 hydrological, physical and chemical parameters as geoindicators are measured, analysed and calculated in every subprogramme.

All three catchments belong to the Nemunas river basin, which comprises 73% of Lithuania's territory. The Kuršių Marios lagoon (connected with the Baltic Sea) is the primary recipient of the loads from the Nemunas river. It is important that all catchments are sited in the upper reaches of the Nemunas river basin, not far from its watershed with other big rivers.

After choosing representative catchments their physical-geographical characteristics were examined. Basic

hypsothetic, lithological, geomorphological and soil type maps were compiled at a 1:10 000 scale. According to the dominant soil type an intensive soil monitoring plot was delineated for soil chemistry. For soil water chemistry, lysimeters were arranged in eluvial and illuvial horizons of the soil in the vicinity of the intensive soil monitoring plot. Tubes were arranged for observation of groundwater level and chemistry. 20 parameters are analysed and calculated for soil water and groundwater chemistry in every subprogramme and 26 for soil chemistry.

The main aim of investigations is to determine the accumulation and transformation in the soil of pollutants, the intensity of their leaching, and their migration routes and input into open water basins. The field data are needed to estimate fluxes of biogenic and polluting substances, to track their migration and accumulation, to calculate their budget and to provide analytical and predictive models of anthropogenic effect.

Preliminary data suggested that the input of anthropogenic chemicals is negligible, and further results confirmed that the chosen catchments can serve for background monitoring.

The system of the environmental monitoring may be expanded as techniques improve and funds are made available.

In the background monitoring territories agricultural contamination is negligible, and the atmosphere represents the only source of dispersed contamination. Establishing the impact of this anthropogenic factor on the environment necessitates long term monitoring to balance calculations of water and element fluxes and model the "atmosphere-vegetation-soil-groundwater-surface water-atmosphere" chain.

Absence of reliable data about the water runoff from the catchments, and water and heat flows in the soil makes it impossible to determine the balance of chemical elements in the catchments and to calculate outputs from the catchments. An attempt was made to solve this problem using the WINSOIL model (Simulation Model for Soil Water and Heat Conditions).

OBJECT

Lithuania's first IMTs were established in 1993 in reservation zones of the Aukštaitija and Dzūkija national parks in the southern and eastern parts of Lithuania respectively (Fig. 1). In 1995 the third IMT was established in the Žemaitija National Park in western Lithuania.

LT01. The Aukštaitija integrated monitoring territory lies in the northern part of the Aukštaičiai Upland — Ažvinčiai nature reserve of the Aukštaitija National Park in the catchment of the small river Versminis. The geographical co-ordinates are: longitude 26°03'20''–26°04'50'' E, latitude 55°26'00''–55°26'53'' N. The catchment area is 1.015 km². The lowest place in the catchment is 159.5 m, and the highest is 188.6 m above sea level. The climate is marked by warm winters with a thin snow cover and frequent thaws, rather cold springs, averagely warm summers and rainy autumns. The long-term mean annual air temperature is 5.8°C, and the mean annual precipitation is 682 mm. LT01 is dominated by podzolic forest with weakly podzolised soils. The greatest areas are occupied by coniferous multi-layer

stands (Gulbinas and Samuila, 1999), mostly composed of pines mixed with spruce.

LT02. The Dzūkija integrated monitoring territory lies in the southern Dzūkai Upland — Skroblus nature reserve of Dzūkija National Park in the catchment of the small river Duburiai. The geographical co-ordinates are: longitude 24°15'55''–24°18'02'' E, latitude 53°03'40''–54°05'38'' N. The catchment area makes up 3 800 km², ranging between 80.0 and 134.5 m above sea level. The climate is characterised by warm winters with a thin snow cover and frequent thaws, rather cold springs, averagely warm summers and warm and rainy autumns. The long-term mean annual air temperature is 6.0°C, and the mean annual precipitation is 625 mm. The forest soils of LT02 have developed on the sandy glacial plains. The natural pine forests are dominated by podzolic forest with weakly podzolised sand, poor in nutrients. Pine forests dominate (Gulbinas and Samuila, 1999). There are a few stands of spruce and spruce with pines.

LT03. The Žemaitija integrated monitoring territory lies in the southern part of the Žemaičiai Upland — Plokštinė nature reserve of the Žemaitija National Park in the catchment of the small river Juodupis. The geographical co-ordinates of the catchment are: longitude 21°51'56''–21°53'10'' E, latitude 56°00'19''–56°01'05'' N. The catchment area is 1473 km² ranging between 147.0 and 180.1 m above sea level. The climate is characterised by warm winters with a thin snow cover and frequent thaws, rather cold springs, averagely warm summers and warm and rainy autumns. The long-term mean annual air temperature is 5.9°C. The long-term mean annual precipitation is 788 mm. The investigated catchment is dominated by podzolic forest sands covering more than half of the area (51.3%). Coniferous forests prevail (Gulbinas and Samuila, 1999), of spruce with pines (up to 20–30%). They often include great areas of spruce undergrowth. Pure spruce forests occupy a great area of the catchment.

Taking into consideration the dominant type of soil an area of intensive monitoring of soil (40 x 40 m), subdivided into smaller areas (10 x 10 m), was established near the area of intensive vegetation investigations. Every five years soil samples for chemical analysis are taken from the humus layers of these areas.

Lysimeters for soil water monitoring are installed on three sides of the intensive soil monitoring plot. They are represented by a plate type (40 x 25 cm) surface, which is connected by a tube with a water collector. Three pairs of lysimeters are installed: three lysimeters are installed in the eluvial horizon (at a depth of 20 cm) and the remaining three in the illuvial horizon (at a depth of 40 cm). The soil water runoff and soil moisture saturation is measured at depths of 20 and 40 cm.

A cascade system of groundwater sampling tubes (four tubes in each IMT) was installed between the areas of intensive vegetation and soil monitoring for observation of groundwater level and for water sampling for chemical analysis.

A runoff monitoring station is installed in the mouth of a stream. Water level is regularly registered at this station. Water samples for chemical analysis are also regularly sampled from the stream.

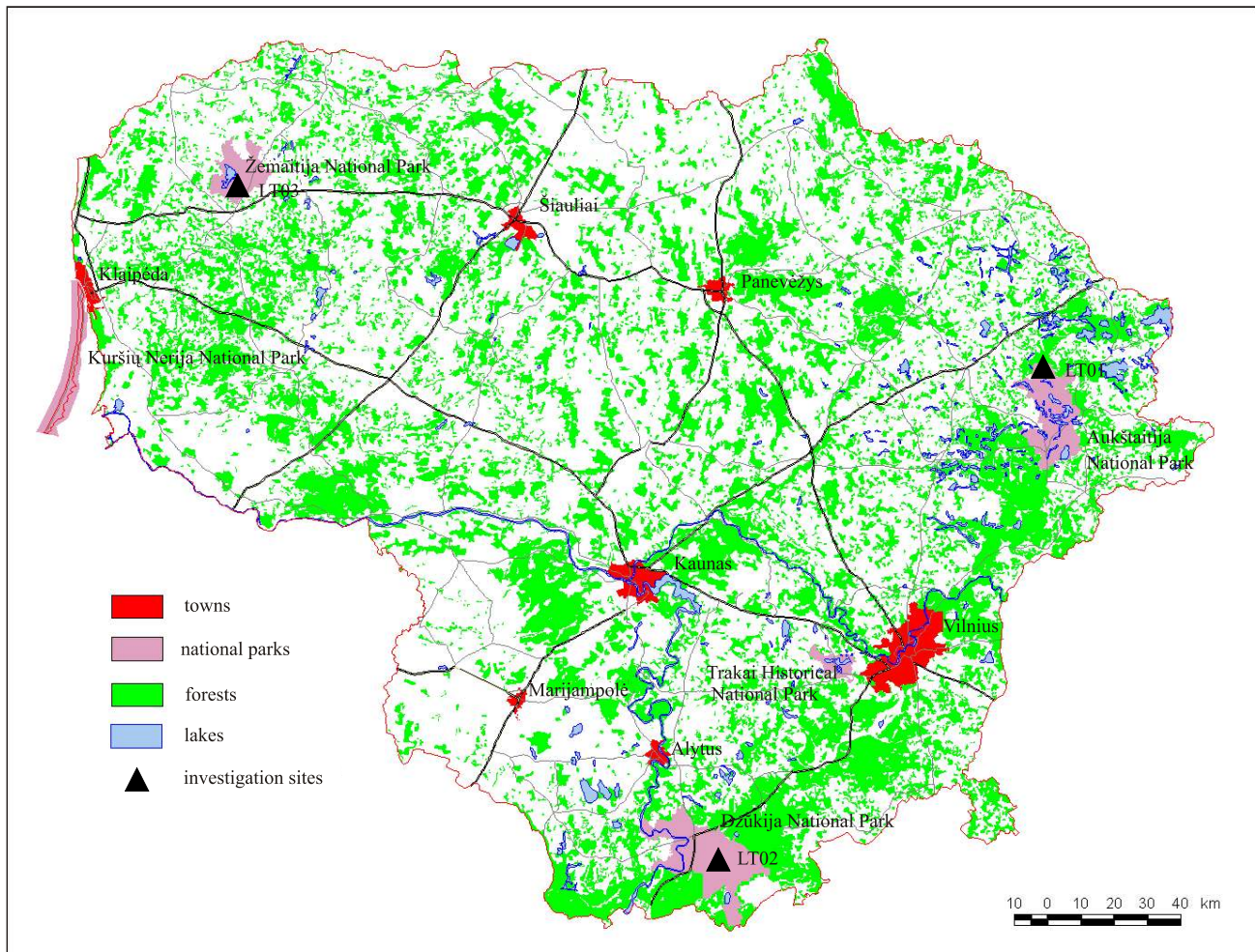


Fig. 1. Integrated monitoring territories in Lithuania

METHODS

Soil samples for chemical analyses are taken from representative sites. Soil profiles are dug and described close by these sites. The investigation site is divided into grids (10 x 10 m), which are further subdivided into smaller (1 x 1 m) plots. For sampling 12–24 fresh plots (1 x 1 m) are used, reflecting the whole soil area. Samples of inorganic soil for chemical analysis and bulk density are taken from the following soil horizons: 0–5, 5–20, 20–40 and 60–80 (where possible) cm. While describing peat soils the degree of humification (decomposition) and peat type are determined. Samples are taken from the same horizons up to a depth of 40 cm.

Samples for chemical composition of soil are taken once in 5 years in August–September.

Lysimeters are used for monitoring of soil water chemical composition. They may be produced from teflon, porcelain or glass. Where possible, they are installed in every observed horizon, firstly in the upper soil horizon (eluvial horizon — 20 cm) and then below the root zone (B horizon — 40 cm). Samples of soil water for chemical analysis are taken every

month during frost-free periods. At the same time the soil water flow from 1 km² at depths of 20 and 40 cm is calculated. When in winter the soil remains frost-free and thaws occur frequently, water samples are taken and soil water flow calculated over the same intervals. When there is snow cover samples are not taken.

Soil water flow and soil moisture saturation was observed at depths of 20 and 40 cm but they are calculated only 4–6 times per year.

As soil water flow is observed only 6 times every year, the calculated values were set to a period of about 60 days, and this value is not very representative.

Soil moisture saturation is observed each month in warm seasons when the soil is not frozen. The survey in LT01 and LT02 was implemented in 1994–1998, in LT03 in 1995–1998.

The groundwater level is measured every two weeks and during sampling for chemical analysis. Groundwater samples are taken every two months. Before taking groundwater samples for chemical analysis the groundwater level is measured with a plummet and the stagnant water pumped out. Fifteen chemical parameters are analysed.

The rivulet water samples for chemical analysis are taken monthly from a depth of 10–15 cm. The daily river discharges are calculated using data from automatic recorders. In the run-off water subprogramme 16 chemical parameters are analysed.

The analysis of all water samples is carried out following unified methods (Working Group for Environmental Monitoring, 1989; Environment Data Centre, 1993; ICP IM Programme Centre, 1998) which are used by all countries participating in the IMP.

Some climatic data necessary for modelling were observed in the monitoring territories. However, due to their insufficient reliability we also used archival data from the Lithuanian Hydrometeorological Survey. The latter data series were complete. They were averaged from data of the Utena and Dukstas meteorological stations for LT01 and data from the Telsiai meteorological station were adjusted for LT03. Total radiation and net radiation data were obtained from the Kaunas meteorological station. This variability of initial data programmed in advance the variances of modelling results.

Full description of the SOIL model is given in its manual (Jansson, 1998). The model has a one-dimensional vertical structure. Soil profile is divided into layers. They may vary in number and thickness depending on the required accuracy. We used the WINSOIL version 1.61 in our work, access to which is free.

For both modelled territories the same structure of the model was used. This structure has been described in detail by Samuila (1999). The parameters used in the model are also the same seeking to unify modelling conditions because the vegetation, soil cover and groundwater bedding conditions in both the territories are similar. The characteristics of soil profile, texture, snow cover and vegetation are stored in the database of the model (Pauliukevichius, 1972).

RESULTS AND DISCUSSION

In the present study the results obtained in 1998 and 1999 are compared with the data from 1993–1997. The data from LT03 reflect the period from 1995 to 1999 inclusive, whereas the data from LT02 represent the period from the autumn of 1993 till June 2, 1999. The data from 1993–1995 on soil water and groundwater were published in “Environmental monitoring in 1993–1995” (Gulbinas and Baužienė, 1996).

The year 1998 in LT01 and LT03 was very humid — 112 and 132% of average precipitation fell respectively (though in LT02 — only 102%). Therefore, the groundwater regime and associated processes began to change. And though the year 1999 was not as humid as 1998 it did not change the trends of processes established in 1998.

SOIL

In situ data are necessary to determine fluxes of biogenic and pollutant materials, and to model their migration and accumulation rates. The Institute of Geography is engaged in this type of research.

We review here the chemical characteristics of soil inorganic layers, emphasising the differences between soil profiles at LT01, LT02 and LT03. Layers thinner than 5 cm were not sampled because the standard methods (Environment Data Centre, 1993) cannot provide full analyses. The soil layers were distinguished according to their morphology; the graphs (Fig. 2) include analytical data from the middle parts of layers (arithmetic means of 6 samples).

In the IMT of LT01, LT02 and LT03 soils of one type (podzolic slightly podzolised pine-forest sands) prevail. However, their bedrock, which determines different contents and distributions of chemical elements, differ. Fluvioglacial deposits are widespread in LT01. For this reason the soils contain gravel; mostly of granite and limestone. Carbonate foam occurs at a depth of 45 cm. Chemical properties of the soil assessed in LT01 range within wide limits, especially as regards acidity, amounts of cation exchange and soil colloid properties (i.e., those directly defined by bedrock type), compared to soils of other catchments (Gulbinas and Baužienė, 1996).

The soils of LT02 have developed on quartz sands and are non-carbonaceous, with homogenous textures and mineral compositions. Cations, degree of base saturation and acidity of the soil profile vary within more narrow limits than in profiles assessed in LT01 and LT03. The soil of LT02 has the least reserve of nutrient elements for plants.

The bedrock of LT03 is bipartite: fine-grained sands cover glacial lake clay. Clay in the soil profiles of LT03 can be met at 145 cm depth, and some properties of this soil type radically differ from properties of other layers. Large amounts of zinc and copper were found in this layer, as well as the smallest amount of exchange calcium a smaller degree of base saturation, and the highest levels of nutrition elements.

Cadmium, as a mobile element, is evenly distributed in the soil profiles of LT01 and LT02. The greatest variations of cadmium occur in the soil profile of LT02, due to the uneven water regime in this profile.

The content of nickel decreases with depth in LT02 and increases in LT03 soils. The content of nickel is greater in layers of greater density. The greatest concentrations of nickel were recorded at the bottom of the LT03 profile, which had a different texture. In the LT01 soil profile nickel is distributed similarly to iron, whereas in the soils of LT02 and LT03 such a tendency is absent.

Normal, eluvial-illuvial processes concentrated copper, in all soils investigated in their lower parts. In the lower part of LT03 the content of copper is higher because of textural factors.

The content of heavy metals in the soils investigated correlates with the content of heavy metals in mosses and does not exceed the MCL (maximum concentration level).

SOIL WATER

The water that reaches lysimeters, installed at 20 cm depth below the surface, filters through forest litter and the upper humus layer. This causes the enrichment of lysimetric water by nitrogen compounds, potassium, manganese and organic carbon. Soil water pH is similar to the pH values of the upper mineral layer of the soil and varies from 4.3 in Žemaitija to 6.2 in Aukštaitija. A comparison of the pH of lysimetric water to

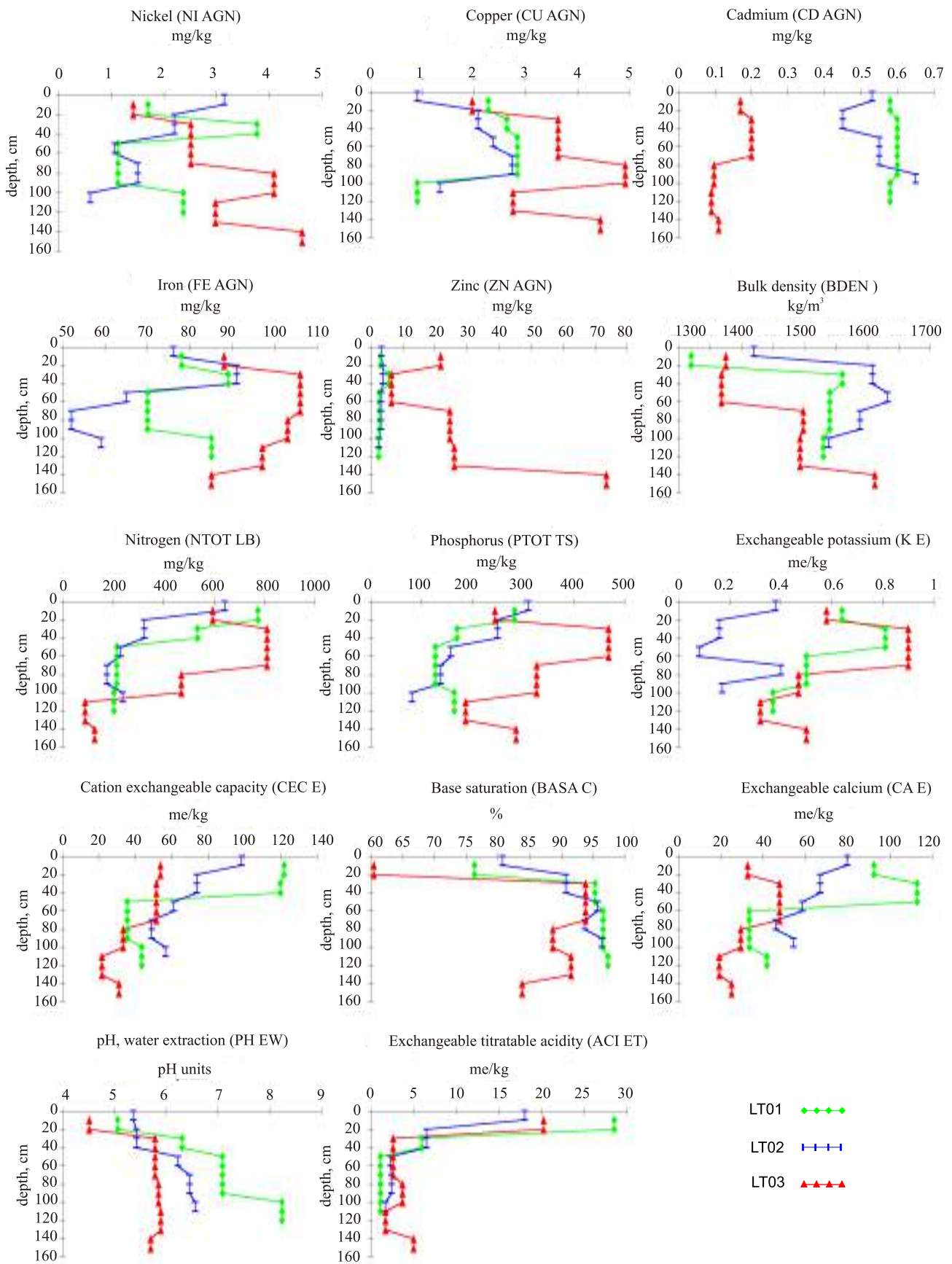


Fig. 2. Distribution of chemical and physical properties of podzolic slightly podzolised pine-forest sands in profile

Table 1

Soil water properties

Parameter	Period	LT01	LT0	LT02	LT02	LT03	LT03
		20 cm depth	40 cm depth	20 cm depth	40 cm depth	20 cm depth	40 cm depth
Soil water flow Q l/(s×km ²)	1993–1998*	3.21	1.48	0.99	0.11	3.90	1.46
	1999	3.43	2.83	–	–	2.92	0.47
SO ₄ (mg/l)	1993–1998*	4.15	4.85	7.85	8.09	2.98	4.03
	1999	3.06	2.00	–	–	2.39	2.40
NO ₃ N (mg/l)	1993–1998*	0.11	0.11	0.27	2.67	0.15	0.17
	1999	0.25	0.06	–	–	0.05	0.22
NH ₄ N (mg/l)	1993–1998*	0.17	0.09	0.44	0.55	0.14	0.08
	1999	0.05	0.04	–	–	0.13	0.20
K (mg/l)	1993–1998*	1.52	1.07	1.73	1.25	1.72	1.57
	1999	1.20	1.76	–	–	0.76	0.56
Cl (mg/l)	1993–1998*	2.84	2.14	2.89	3.45	3.29	3.60
	1999	5.83	1.85	–	–	2.16	2.00
Mn (µg/l)	1993–1998*	151.96	67.97	355.06	175.50	131.29	172.37
	1999	112.26	47.78	–	–	89.94	85.96
pH, pH units	1993–1998*	5.40	6.23	4.53	5.12	4.32	4.75
	1999	5.53	5.99	–	–	4.26	5.32
Specific electrical conductivity (mS/m)	1993–1998*	4.83	8.78	5.06	5.34	4.87	4.67
	1999	7.72	5.66	–	–	4.55	2.67
Alkalinity (mg/l)	1993–1998*	13.99	13.59	9.01	3.85	7.10	6.50
	1999	21.99	27.93	–	–	5.00	5.00
Soil moisture satu- ration (m ³ /m ³)	1993–1998*	0.1316	0.1188	0.0885	0.0845	0.2326	0.2091
	1999	0.1147	0.1119	–	–	0.2216	0.1935

*The data on LT02 were collected in 1993–1998, whereas the data on LT03 — in 1995–1999.

groundwater revealed that the pH values of soil water are 2.0–2.4 units lower.

Soil water, while filter deeper through the sandy B layer down to 40 cm depth, washes out fewer elements, especially the biogenic ones. The concentrations of many others decrease as well (except of Na and SiO₂ in some cases). Comparing of the average concentrations of individual chemical elements in soil water of all three territories, the higher concentrations of most parameters (SO₄²⁻, NO₃⁻, NH₄⁺, Na⁺, P, C_{org.}, Al³⁺, Mn²⁺) were found in the soil water of Dzūkija (Table 1). Dune sand there plays a decisive role, having a good filtration capacity (Gulbinas and Samuila, 1998).

The average yearly soil water flow in 1999, if compared with the average long-term value, was somewhat higher in LT01, whereas considerably lower in LT03, particularly at the depth of 40 cm.

The soil moisture saturation in the soil profile of all IMT was in 1999 somewhat lower than the average long-term value.

The water concentration dynamics of most chemical elements showed no radical trends in 1999. Often in one and the same IMT the variations of the same element at different soil depths were uneven. Nitrates and pH index (Table 1) may serve as the best example of this.

However, it is obvious that the concentrations of chemical elements tend to decrease in comparison with the long-term

average values. It is most evident in the soil water of LT03 where the content of potassium and chlorine ions, as well as the specific electric conductivity, have decreased. In the soil water of LT01 the concentration dynamics of these elements reveals no regularities, though the concentration of ammonium ions has decreased. The sulphates and manganese ions serve at the best illustration of the concentration reduction trend. The long-term average of these elements in the soil water of both territories is higher than the average concentration of 1999.

Acidity of soil water at a depth of 20 cm is lower than the long-term value in both IMT, the opposite of the case at 40 cm depth. The alkalinity of the whole soil stratum of LT01 in 1999 is considerably higher than the long-term average. In LT03 this value does not exceed 5 mg/l and is lower than the long-term average.

This year's trends partly support the reduction of the concentration of chemical elements in the soil water observed over the few previous years. This is particularly true of sulphates and magnesium. Their concentrations in 1998 were considerably lower than in 1997. This suggests a long-term (not yearly or seasonal) phenomenon.

The concentration of calcium, sodium, magnesium, phosphorus and silica ions remains more or less stable.

A comparison of average soil water chemical composition of 1999 with 1998 revealed no changes in all investigated territories.

GROUNDWATER

Trends of groundwater level long-term fluctuations. An analysis of 1993–1997 groundwater level data suggests an overall drop in its level.

The long-term groundwater level fluctuations in LT01 and LT02 serve as a good illustration of this trend. Broadly phenomena were observed also in LT03. Bearing in mind that the year 1992, when measurements were not yet started, was dry and that the year 1995 in LT01 was normally dry [-0.383 (— average square deviation of amount of precipitation; the coefficient marks indicate that the year was dryer (—) or more humid (+))], in LT02 and LT03 dry or very dry (respectively -1.702 , -3.052 and -2.386), the year 1997 in LT02 — dry (-1.397), whereas LT03 and LT01 were humid or normally humid, it is natural that groundwater level decreased in all three IMT (Bukantis *et al.*, 1998).

However, the abundant precipitation in the late autumn of 1997, large water supplies in the snow and the rainy summer of 1998 (Domaševičius *et al.*, 1996, 1997, 1998) partly restored groundwater levels.

In LT03, as also in other national parks, the lowest groundwater level was recorded in the summers of 1996 and 1997. As in LT03 the measurements were started only in the summer of 1995, we cannot compare groundwater level fluctuation trends there with the trends in the other parks.

From the beginning of the survey until the autumn of 1997 the level of groundwater was permanently falling (though not as considerably as in LT01 and LT02), whereas the data of 1998 and 1999 indicate a rise in groundwater level.

The climatic situation of 1998 in LT01 (Fig. 3) and LT02 (Fig. 4) produced no considerable influence (particularly in LT02) on the long-term trends. Therefore, even today a fall in groundwater level is observed in these parks. In the period of investigation the average fall of groundwater level in both parks was 7 cm, though the long-term amplitude in many cases exceeded 50 cm.

The data of 1998 show that the amount of precipitation by year varied within a wide range in the monitoring territories (LT02 — $+0.171$, LT01 — $+1.072$, LT03 — $+2.513$). Thus, though in all parks the amount of precipitation in 1998 was greater than the standard value, i.e., a coefficient was positive, in LT02 in 1998 the amount of precipitation was only slightly higher than the standard value, whereas in LT01 it was by far higher and in LT03 it was very high.

For this reason, in 1998 the trends of groundwater level fluctuation changed radically: in some groundwater tubes the groundwater level began to rise rapidly. The data collected in LT03 during the whole period of survey reveal the long-term trend of water rise in all groundwater tubes. In the remaining IMT the coefficient of the long-term linear groundwater level fluctuation trend equation approaches zero (Figs. 3 and 4). In some groundwater tubes (particularly in Žemaitija) this coefficient changes from positive to negative (indicating that the level of groundwater begins to rise). This is demonstrated by graphs, compiled using the groundwater fluctuation data of 1998 and trends of water level exposed in them.

Chemical composition of groundwater. The quality of groundwater under natural conditions is determined by many physical-geographical and biological factors. The most shallow groundwater horizon is determined by the properties and genesis of soil through which atmosphere-derived chemical elements penetrate to the groundwater.

In the background monitoring territories agricultural pollution is negligible. Therefore, the atmosphere remains the only source of dispersed pollution. Complete analysis of this anthropogenic factor on the groundwater quality requires: long-term water regime investigations; calculation of the water and element flow balance; and modelling of the chain “atmosphere–vegetation–soil–groundwater–surface water–atmosphere”. The short period of survey means that this has not yet been done.

Analysis of initial data has indicated that the quality of groundwater in background territories of minimal anthropogenic effect directly depends on soil chemical composition. Podzolic pine forest sand soils of LT03 are relatively rich in heavy metals, derived from the bedrock, therefore concentrations in the groundwater of dissolved Al, Mn, Fe ions are by 2–3 times higher compared to LT01 and LT02.

Groundwater located closer to the surface is generally richer in many chemical elements, especially biogenic elements. Analysis shows that, since 1998 in all three IMT the concentration of many chemical elements in the groundwater decreased.

The decrease was particularly obvious in LT03 where the concentrations of all chemical elements in 1998 were lower than in 1997. As the alkalinity of groundwater also decreased, acidity therefore increased, as did the specific electrical conductivity.

The same trends can be observed when the data of 1998 is compared with the long-term average values of 1995–1997 and 1995–1998.

A comparison of LT01 groundwater data of 1998 with the data of 1993–1997 (Fig. 5) revealed only negligible decrease of P_{total} , Ca, Mg and alkalinity, whereas the concentrations of NH_4 , NO_3 , K, Fe and Mn approximately halved. A comparison of the 1998 and 1997 data reveals similar trends by comparison with the long-term data, except that the differences of NO_3 and NH_4 concentrations between 1997 and 1998 are negligible. In general the concentrations of SO_4 and Na in the groundwater of LT01 in 1998 increased very slightly.

We can observe a different trend in the chemical composition of LT02 groundwater. The concentrations of its many parameters in 1998 were higher than the long-term by 2 times on the average. A comparison of the data of 1998 and 1997 reveals greater differences (by 1.5 times) between the concentrations of Na, Mg, Mn and Cl.

The least changed in the course of the year in all three IMT are “marine” chemical parameters — Cl, Na, specific electric conductivity and pH.

In 1999 the trends remain the same and the concentrations of chemical elements continue to decrease. All three IMT the concentrations in the groundwater of ammonium, potassium, chlorine, total phosphorus, iron and silica in particular decreased. Weaker trends of decrease were characteristic of magnesium and manganese ions and groundwater alkalinity. Acidity of groundwater over a number of years was subject to

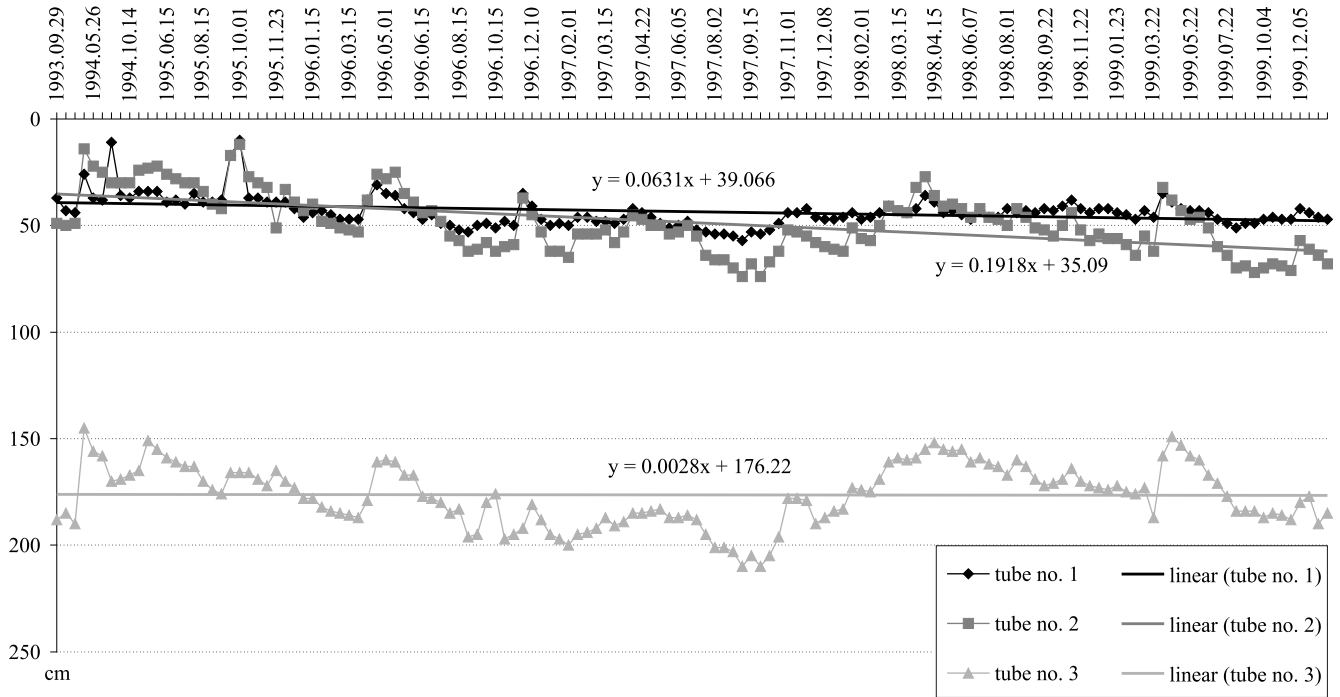


Fig. 3. Groundwater level in LT01 in 1993–1999

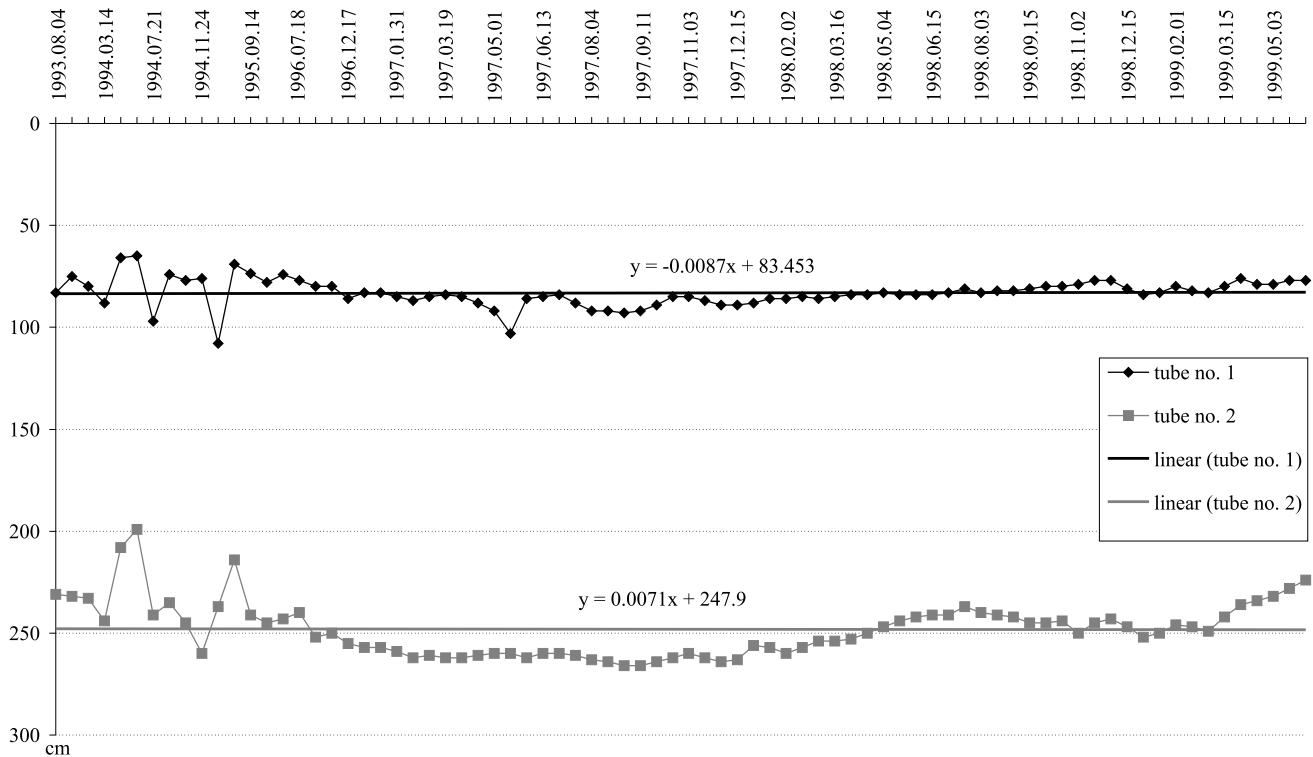


Fig. 4. Groundwater level in LT02 in 1993–1999

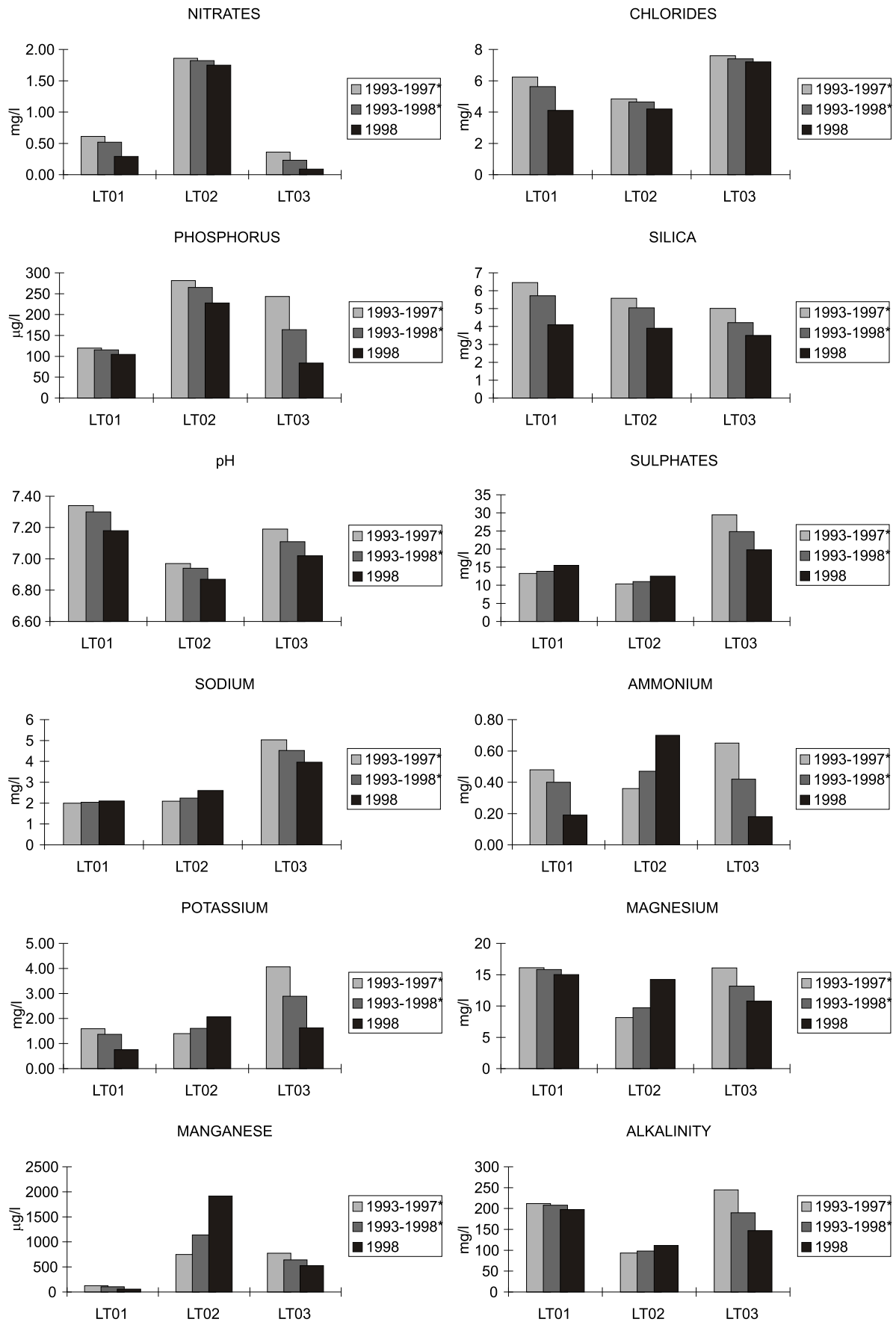


Fig. 5. Chemical composition of groundwater in 1993–1998

* data for LT03 collected since 1995

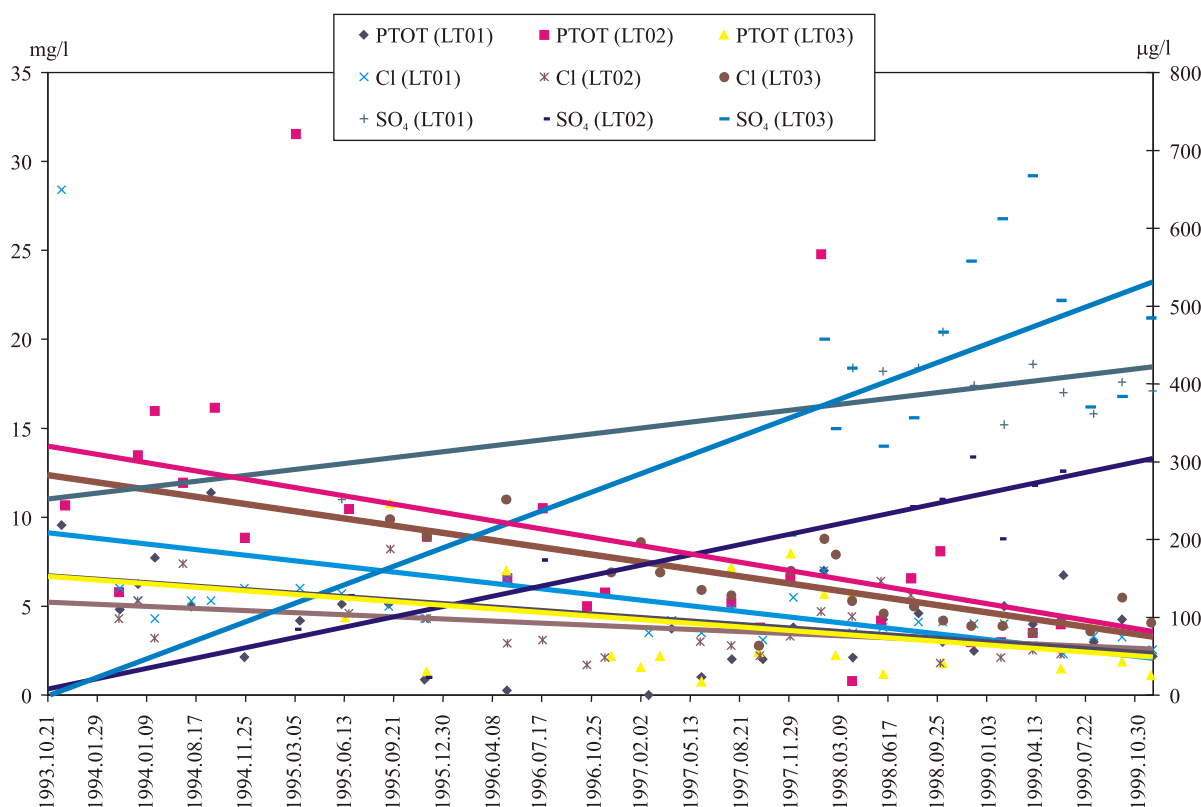


Fig. 6. Phosphorus in shallow groundwater, chlorine in groundwater laying at an average depth and sulphates in deep groundwater in 1993–1999

very slight changes in all IMT. Only the concentrations of sulphates in most boreholes have been increasing.

The concentrations of ammonium, chlorine, total phosphorus (Fig. 6), manganese, iron and silica markedly decrease in the most shallow boreholes i.e., in the near-surface groundwater (up to a depth of 2 m). In the boreholes of average depth (2–6 m) the concentrations of potassium, chlorine (Fig. 6), and silica and water alkalinity markedly decrease. In the deepest boreholes (more than 6 m) the concentrations of ammonium, potassium, chlorine and total phosphorus decrease rather considerably; however, the groundwater acidity remains approximately stable. In these boreholes the concentrations of sulphates (Fig. 6) and nitrates markedly increase.

The amount of precipitation is the key factor influencing the fluctuations of groundwater level. In the investigations site the groundwater table lies at different depths (from 0.5 m to 10 m). For this reason an attempt was made to find a relation between the groundwater level fluctuations and its chemical composition at different depths.

The closest correlation with groundwater level is shown by hydrocarbons, specific electrical conductivity, silica, manganese and calcium: in most cases the correlation coefficient exceeded 0.5. A direct relationship was characteristic of silica, i.e., the concentration of the element decreased with the falling water level. The others showed a reverse relationship: their concentrations increased with an increasing depth of ground-

water. These regularities were mostly decreased in deeper groundwater. In all cases there was no reliable correlation between groundwater depths and nitrates, magnesium, total phosphorus. A particularly low correlation coefficient was characteristic of magnesium. There was no reliable correlation in near-surface groundwater levels (to 1 m).

RUNOFF WATER

A comparison of chemical and physical properties of water in IMT revealed that the Versminis rivulet water of LT01 was richest in sulphates, ammonia, and calcium and magnesium ions. The smallest content of these ions (except ammonia) was recorded in the Juodupis stream (LT03). The lowest index of pH was found in LT03, and the highest in LT02. This is natural because the alkalinity index in LT03 runoff water was also the lowest one. The highest concentrations of sodium, potassium, chlorine and iron ions were recorded in the runoff water of LT03. In other parks the concentration of these ions is twice as low, whereas the concentration of iron ions is even 5 times as low. The specific electric conductivity was the highest one in LT01, and the lowest one in LT03; the difference being two-fold.

Table 2

Output of some chemical elements from catchments (kg/km²/year)

Chemical	Period (year)	LT01	LT02	LT03
Sulphur	1994	1117.58	1067.24	–
	1995	1012.07	1394.62	–
	1996	545.07	739.89	330.76
	1997	500.18	760.59	529.60
	1998	645.00	607.05	569.93
	1999	590.18	–	458.97
Nitrogen (N _{NH₄} + N _{NO₃})	1994	49.69	60.03	–
	1995	36.73	64.62	–
	1996	21.22	37.40	19.31
	1997	13.97	21.09	51.61
	1998	15.24	16.58	28.69
	1999	16.98	–	29.54
Calcium	1994	6112.29	6441.31	–
	1995	6977.28	10018.41	–
	1996	3712.88	5653.73	2699.97
	1997	4276.37	7279.61	3859.98
	1998	4512.91	5255.15	3844.35
	1999	3962.55	–	3696.60
Sodium	1994	558.03	847.81	–
	1995	375.45	632.35	–
	1996	127.51	281.86	238.75
	1997	135.15	325.05	401.85
	1998	159.69	227.73	484.07
	1999	120.12	–	417.66
Potassium	1994	149.58	149.93	–
	1995	98.39	102.19	–
	1996	21.14	71.93	28.58
	1997	21.19	48.42	48.85
	1998	33.19	48.71	74.79
	1999	28.09	–	70.33
Magnesium	1994	1930.80	1687.60	–
	1995	1826.30	2171.35	–
	1996	1112.79	1237.56	631.23
	1997	1037.47	1532.06	879.55
	1998	1358.33	1149.06	1036.97
	1999	1182.34	–	829.85
Chlorine	1994	369.26	655.39	–
	1995	394.90	808.38	–
	1996	257.88	573.98	396.23
	1997	231.35	388.63	494.84
	1998	269.71	392.07	946.17
	1999	233.02	–	705.96
Phosphorus (total)	1994	3.04	20.67	–
	1995	1.93	27.79	–
	1996	1.26	22.40	2.45
	1997	1.43	18.28	4.72
	1998	1.86	10.55	6.56
	1999	1.23	–	5.46
Silica	1994	179.86	316.25	–
	1995	207.45	514.28	–
	1996	124.31	276.37	177.93
	1997	147.06	308.17	212.58
	1998	126.23	189.73	234.03
	1999	110.88	–	253.01

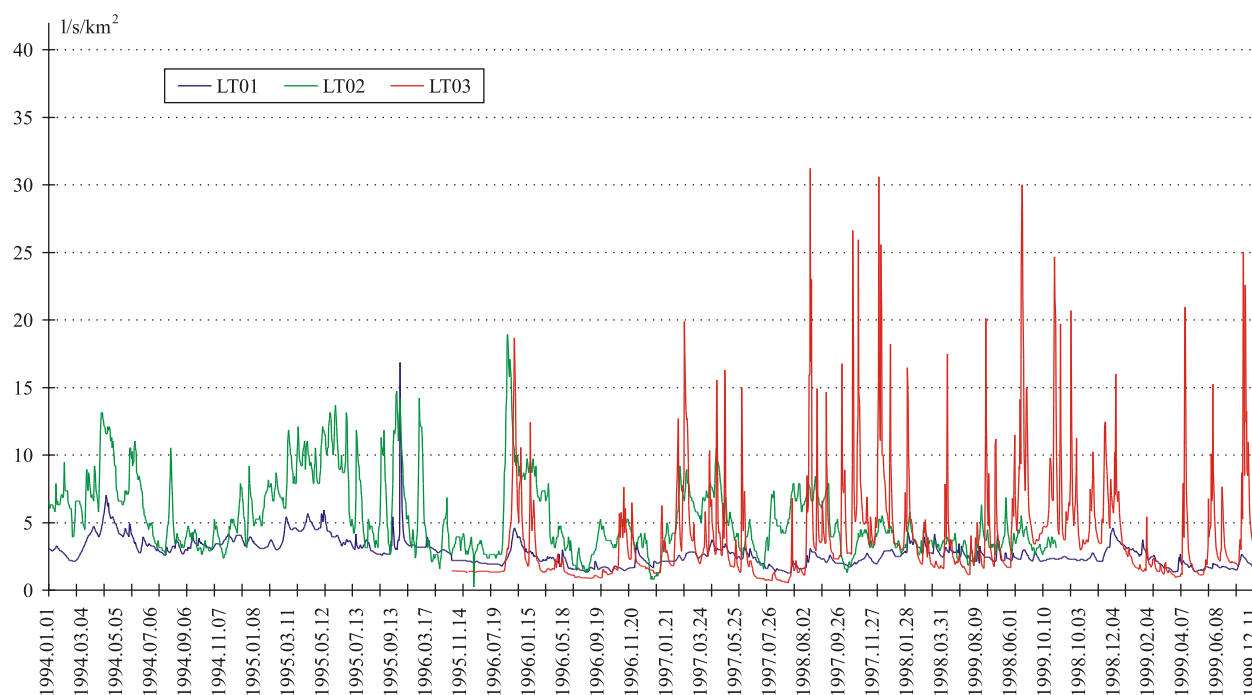


Fig. 7. Water runoff from catchments in 1994–1999

When the changes in 1998 are compared with long-term data, the total mineralisation of the river water shows a decrease, except for sulphur, calcium and nitrate ions, the concentrations of which slightly increase. The river water in 1998, against a background of the previous 4–5 years, is acidifying, while its specific electric conductivity decreases; the alkalisation of the Aukštaitija and Žemaitija waters decreases, even though this indicator in Dzūkija has slightly increased.

Comparing the 1999 data with the long-term data shows a decrease in total mineralisation, except for sulphate, calcium and sodium ions, the concentrations of which slightly increase. In 1999 the concentrations of calcium, sodium, potassium ions remain more or less stable, whereas the concentrations of total phosphorus, chlorine, silica and manganese decrease more obviously, if compared with 1998. 1999 showed no obvious increase of element concentrations in stream waters in the three IMT.

Yearly amounts of chemical elements eliminated from the basins in different years (Table 2) were calculated (for sulphur, nitrogen, calcium, sodium, potassium, magnesium, chlorine, phosphorus and silica). Trends emerged which closely related with river discharge of different years (Fig. 7) and element concentrations in the river water. The water discharge in 1996–1999 (cubic metres from one square kilometre of catchment area) was about 66–75% of the discharge recorded in 1994–1995. The concentrations of chemical elements in the stream water in 1994–1995 were far greater (up to two-fold) than in 1996–1999, correlating with the considerably greater river discharges and element concentrations in the river water. In later years, decreasing river water discharge from the catchment and decreasing concentrations of chemical elements in the river water caused considerably lower outputs of elements from the catchments.

SIMULATION OF WATER BALANCE ELEMENTS BY THE WINSOIL MODEL

The SOIL model is designed to simulate water and heat fluxes in the soil profile (Jansson, 1998), not only in the soil profile as a closed system but also as regards inputs and outputs of water or heat into the system.

The WINSOIL model has a one-dimensional vertical structure. The soil profile is divided into layers, which may vary in number and thickness depending on the required accuracy.

Heat flow in the model is the sum of conduction and convection:

$$q_h = -k_h \frac{T}{z} + C_w T q_w + L_v q_v \quad [1]$$

where: h — heat; v — vapour; w — liquid water; q — flow; k — conductivity; T — temperature; C — heat capacity; L — latent heat; z — depth.

The convective term may be included or not in the solution depending on switches. Normally the convective term is important at high flow rates as during heavy snow melt infiltration. The general heat flow equation is obtained when combining equation 1 with the law of energy conservation:

$$\frac{(CT)}{t} - L_f \frac{i}{t} = -k \frac{T}{z} - C_w T \frac{q_w}{z} - L_v \frac{q_v}{z} - s_h \quad [2]$$

where: i — ice; f — freezing; t — time; ρ — density; L — latent heat; θ — volumetric water content; s — source/sink term; other explanations see equation 1.

Table 3

Parameters for calibrating the WINSOIL model

Investigation site	Groups of parameters		
	Surface water		Soil evaporation
	<i>SoilCover</i>	<i>SurfCoef</i>	<i>MaxSoilCondens</i>
LT01	0.32	0.003	0.01 mm/day
LT03	0.17	0.003	0.01 mm/day

The two terms on the left represent changes in sensible and latent soil heat contents, and the last term to the right accounts for, e.g., the soil heat exchange of a heat pump system.

Water flow in the soil is assumed to be laminar and, thus, obeys Darcy's law as generalised for unsaturated flow:

$$q_w = -k_w \frac{\partial h}{\partial z} - 1 - D_v \frac{c_v}{z} \quad [3]$$

where: h — water tension; c_v — concentration of vapour in soil air; D_v — diffusion coefficient for vapour in the soil; other explanations see equation 1.

The general equation for unsaturated water flow follows from equation 3 and the law of mass conservation:

$$\frac{\partial q_w}{\partial t} = -\frac{\partial q_w}{\partial z} + s_w \quad [4]$$

for explanations see equations 1 and 2.

The aim of this work was to simulate a successive data series of soil water flow and soil moisture saturation at different depths because field data of these parameters are scarce. All these data series were simulated for LT01 and LT03. The simulation results may be used for evaluation of water movement in the soil stratum and movement of water-transported chemical element flows.

The model was calibrated using accurately measured soil water flow and soil moisture saturation values.

A full description of modelling data (Molchanov, 1961, 1971; Pauliukevichius, 1972; Vaičys *et al.*, 1979; Motuzas *et al.*, 1996, 1997; Torstensson and Johnsson, 1996; Persson, 1997; Integrated monitoring..., 1998) and other technical details of simulation are given in Samuila (1999, 2000).

Although the conditions of simulated catchments are similar there are certain differences in the geographical situation, genesis of soil-generating rocks, and vegetation (unfortunately, this does not influence the operation of the model through the parameters). Some climatic conditions (the influence of the sea, amount of precipitation) differ considerably.

The model was calibrated on the basis of published data on soil water balance elements (Ignataviciene, 1969; Dilys, 1995).

During the calibration procedure some model parameters (Table 3) were selected.

The calibration procedure included alternation of Surface water and Soil evaporation groups.

SoilCover. The degree of *SoilCover* will govern how much precipitation, throughfall, and drip from the canopy will infiltrate into the soil. The parameter can be considered as a physical barrier that covers the soil and causes losses as surface runoff instead of infiltration into the soil. A value of 0 means that no physical barrier exists for infiltration of water into the soil. A value of 1 will prevent the soil from any type of wetting because of precipitation.

SurfCoef. This coefficient is used for calculation of surface runoff from the maximum water amount which theoretically may stay on the soil surface.

MaxSoilCondens was considerably diminished because the 2 mm/day proposed by the program user's manual produces a strong influence on soil water flow and the modelled soil water flow becomes unreal.

Other parameters were taken from the standard model structure.

The model used in this study was verified with the results of some methodically accurately measured parameters. Recognised statistical methods (Coleman and De Coursey, 1976; Janssen and Heuberger, 1995; Sakalauskas, 1998) were employed for model verification. By these methods model system behaviour/association, consistence, coincidence were evaluated. Individual pairs of observed and predicted values were compared. The obtained results are satisfactory (Samuila, 1999).

Soil water flow. The WINSOIL model enables calculation of the movement of water flow between different soil layers. The simulated values of soil water flow may even become negative — this means that at certain time intervals the water flow moves towards the surface and not towards the deeper layers. This happens when the soil is drying as a result of interrupted water uptake. Whereas the in situ measured values of the soil water flow never acquire a negative value — the value is either positive or equals 0.

The differences between the simulated and observed values of soil water flow are considerable (Fig. 8). The columns indicate the soil water flow, accumulated at certain periods. The daily flow values cannot be correctly compared because the observed soil water flow values were applied for methodical purposes for the whole period when soil water was collected into lysimeters. For this reason the simulated daily soil water flow values were summed within the same period which was represented by the soil water flow observed.

The observed and simulated results at the same depth reveal that the accuracy of simulation is higher at smaller depths. In LT01 the correlation coefficient of the observed and simulated, at a depth of 20 cm, runoff modules equal to about 0.6, whereas at a depth of 40 cm this value becomes by far smaller. In LT03 this value is 0.57.

Simulation results are better when the period chosen is longer, when observed and simulated values of water flow are closer.

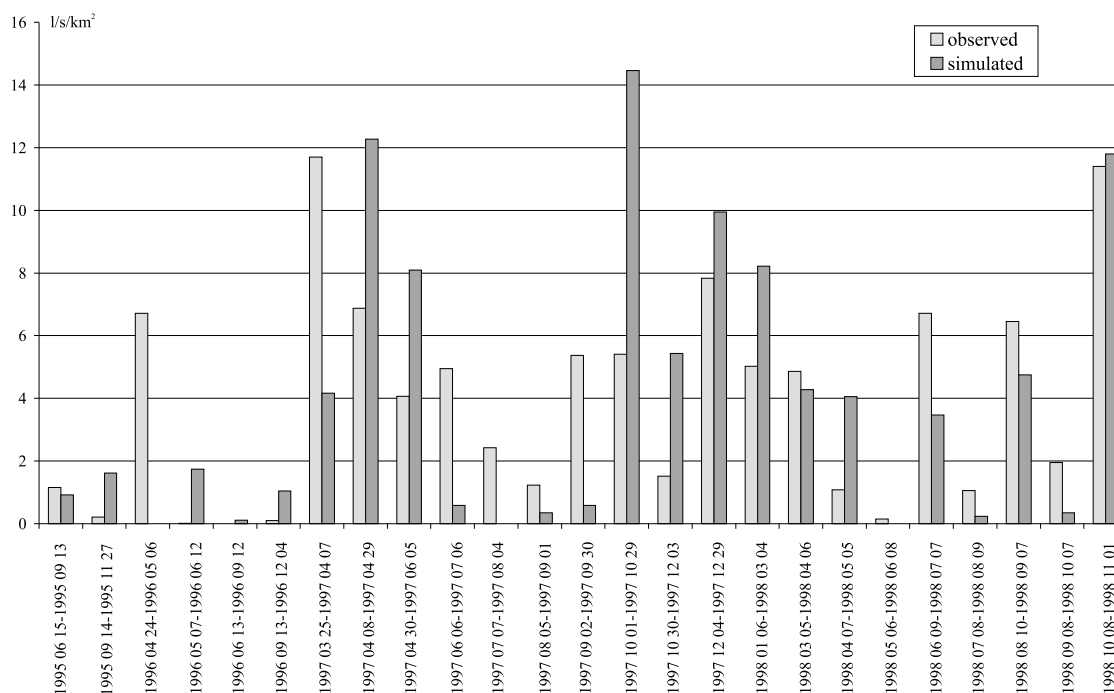


Fig. 8. Observed and simulated soil water flow at a depth of 20 cm in LT03

The seasonal analysis revealed that the simulation results are better in summer. In spring and autumn the differences between the measured *in situ* and simulated values become more marked. This might be accounted for by permanent model parameters, determining the transpiration and evaporation from the topsoil, which remain stable for all measuring periods. Whereas in spring and autumn, when transpiration and evaporation from the topsoil and canopies decrease, these parameters should be changed because in these seasons the soil water flow depends more on the intercepted soil water content than on the above-mentioned factors.

Soil moisture saturation. Figure 9 includes the results of observing soil moisture saturation and simulation in both the territories investigated. They contain the daily simulated soil moisture saturation and (measured at a given moment) soil moisture saturation in 1996–1998 (field investigations were started in May of 1996).

As the soil moisture saturation is precisely determined by integrated monitoring methods and accurately represents the temporal moment, the observed and simulated values can be effectively compared.

The simulation introduced only the total water content because the water content reflects only the liquid water phase in the soil. It would not be expedient to compare this parameter with the observed soil moisture saturation because in early spring and late autumn the samples taken *in situ* include ice.

In LT01, the soil moisture saturation simulated at a depth of 20 cm exceeds the observed one by 2.5% on the average, whereas at a depth of 40 cm the observed soil moisture saturation exceeds the simulated one by 0.09%.

In LT03, the soil moisture saturation simulated at a depth of 20 cm exceeds the observed one by 0.65% on the average, and at a depth of 40 cm the simulated soil moisture saturation exceeds the observed one by 0.77%.

Great discrepancies of observed and simulated values in LT01 at a depth of 20 cm may be accounted for by the fact that, closer to the surface, the soil moisture saturation is apt to change in space more actively. For this purpose more samples should be taken and their mean value would be more representative. This is particularly obvious in LT03 where soil moisture saturation was observed more frequently than in LT01.

The simulated results show a response to precipitation. The measured results show that soil moisture saturation at both depths (at a depth of 20 cm somewhat sooner) does not change so dramatically as is suggested by the model.

The agreement of observed and simulated values of soil moisture saturation at depths of 20 and 40 cm is better than the agreement of soil water flow.

Sources of errors. The differences between the observed and simulated values are not large; therefore, the model may be successfully used in Lithuania in small wooded catchments. The discrepancies between simulated parameters and measured va-

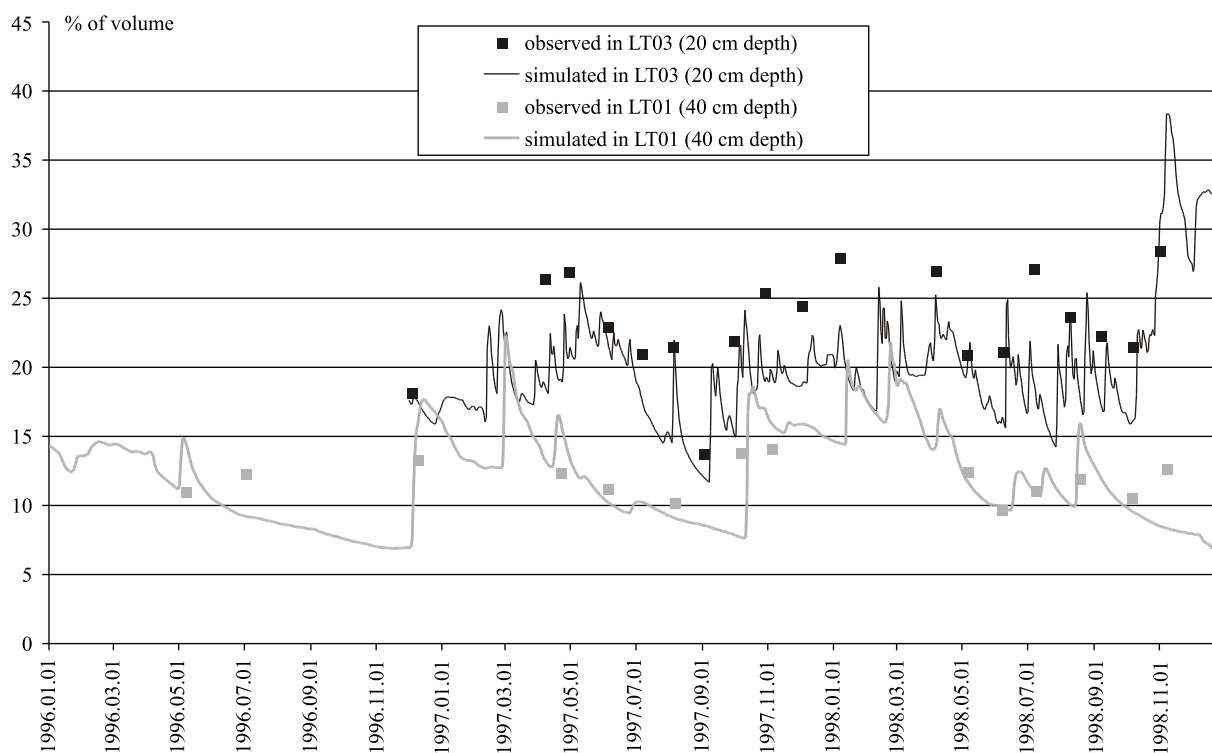


Fig. 9. Observed and simulated soil moisture saturation at a depth of 20 cm in LT03 and at a depth of 40 cm in LT01

lues are conditioned by many factors. The result obtained is greatly affected by the fact that the model was calibrated not by water balance but by its discrete elements because the total balance was not determined. The measurements of radiation, precipitation and other meteorological parameters in the simulation area are not accurate.

In winter the frozen soil greatly affects the soil water flow. It is methodically impossible to accurately measure this value because of a lack of daily information about soil freezing and melting. Therefore, one must critically interpret the *in situ* measured values of the soil water flow.

CONCLUSIONS

1. Soils of one type (podzolic slightly podzolised pine-forest sands) prevail in all three IMT, but their bedrock differs. Chemical properties of the soil assessed in LT01 range within the widest limits, as regards acidity, amounts of exchange cations and some properties of soil colloids compared to soils of other catchments. The supplies of nutrient elements in the soil of LT03 are the highest. The content of heavy metals in the soils investigated correlate with the content of heavy metals in mosses and does not exceed the MCL.

2. The higher concentrations of most parameters (SO_4^{2-} , NO_3^- , NH_4^+ , Na^+ , P, C_{org} , Al^{3+} , Mn^{2+}) were found in the soil water of LT02. Dune sand, which has good filtration capacity,

plays a decisive role there. The concentrations of chemical elements in soil water tend to decrease in comparison with the long-term average values.

3. Notwithstanding the groundwater table levels in the period of investigation (six years) an overall fall of groundwater was observed in all boreholes of IMT. The water tables determine the amount of chemical elements in the groundwater: a correlation analysis has revealed that groundwater located closer to the surface is richer in many chemical, especially biogenic, elements. The concentration of many chemical elements in the groundwater decreased in the last years of observation.

4. Yearly water runoff in 1996–1999 was about 66–75% compared with the yearly water runoff mean in 1994–1995. The concentrations of chemical elements in the stream water in 1994–1995 were considerably higher than in 1996–1999, and so in 1994–1995 the output of elements was by 2 and more times higher.

5. The simulation revealed that the SOIL model could be applied in Lithuania. However, it requires an accurate calibration procedure in every area. For this purpose it is necessary to have at least a few methodically correctly observed parameters *in situ*. Discrepancies between the simulated and measured values may appear when the model is calibrated not by water balance but by its separate elements; meteorological data included in the simulation were measured not *in situ* but in the nearby Lithuanian meteorological stations.

REFERENCES

- BUKANTIS A., KAZAKEVIČIUS S., KOTKUTIS P., MARKEVIČIENĖ I., RIMKUS E., RIMKUTĖ L., STANKŪNAVIČIUS G., VALIUŠKEVIČIENĖ L. and ŽUKAUSKAITĖ L. (1998) — Klimato elementų kintamumas Lietuvos teritorijoje. Geograf. Inst. Vilnius.
- COLEMAN G. and De COURSEY D. (1976) — Sensitivity and model variance analysis applied to some evaporation and evapotranspiration models. *Water Resour. Res.*, **12**.
- DILYS A. (1995) — Vandens apytaka kalvotame Rytu Lietuvos agro- ir miško landšafte. *Geograph. Yearbook*, **28**: 5–40.
- DOMAŠEVIČIUS A., GIEDRAITIENĖ J. and ARUSTIENĖ J. (eds.) (1996) — Lietuvos požeminės hidrosferos monitoringas 1995. Lietuvos Geol. Tarnyba. Vilnius.
- DOMAŠEVIČIUS A., GIEDRAITIENĖ J., KRIUKAITĖ J. and KARMAZINAS B. (eds.) (1997) — Lietuvos požeminės hidrosferos monitoringas 1996. Lietuvos Geol. Tarnyba. Vilnius.
- DOMAŠEVIČIUS A., GIEDRAITIENĖ J., KADŪNAS K., ARUSTIENĖ J., KRIUKAITĖ J. (eds.) (1998) — Lietuvos požeminės hidrosferos monitoringas 1997. Lietuvos Geol. Tarnyba. Vilnius.
- ENVIRONMENT DATA CENTRE (1993) — Manual for Integrated Monitoring. Programme Phase 1993–1996. National Board of Waters and the Environment. Helsinki.
- GULBINAS Z. and BAUŽIENĖ I. (1996) — Dirvožemių, dirvožemio ir gruntinio vandens cheminė sudėtis kompleksinio monitoringo foninėse stotyse. In: *Aplinkos monitoringas 1993–1995* (ed. L. Stoškus). Lietuvos aplinkos apsaugos ministerija: 8–14.
- GULBINAS Z. and SAMUILA M. (1998) — Water quality monitoring in the National Parks of Lithuania. In: *XX Nordic Hydrological Conference*. NHP Report (ed. J. Kajander). *Nordic Co. Com. Hydrol.*, **1** (44): 183–193.
- GULBINAS Z. and SAMUILA M. (1999) — Dirvožemio ir vandens cheminė sudėtis. In: *Lietuvos miškų būkle ir ją sąlygojantys veiksniai* (eds. R. Ozolinčius *et al.*): 182–185. Lututė.
- ICP IM PROGRAMME CENTRE (1998) — Manual for Integrated Monitoring. Finnish Environ. Inst. Helsinki.
- IGNATAVIČIENĖ I. (1969) — Atmosferinių kritulių cheminės sudėties klausimu Lietuvoje. *Geograph. Yearbook*, **10**: 169–179.
- INTEGRATED MONITORING: ENVIRONMENTAL ASSESSMENT THROUGH MODEL AND EMPIRICAL ANALYSIS (eds. M. Forsius *et al.*) (1998) — Finnish Environ. Inst. Helsinki.
- JANSSEN P. and HEUBERGER P. (1995) — Calibration of process-oriented models. *Ecolog. Model.*, **83**: 55–66.
- JANSSON P. E. (1998) — Simulation model for soil water and heat conditions. Description of the SOIL model. SLU. Uppsala.
- MOLCHANOV A. A. (1961) — Les i klimat. AN SSSR. Moscow.
- MOLCHANOV A. A. (1971) — Produktivnost organicheskoi masy v lesakh razlichnykh zon. AN SSSR. Moscow.
- MOTUZAS A. J., BUIVYDAITĖ V., DANILEVIČIUS V. and ŠLEINYS R. (1996) — Dirvotyra. Mokslo ir enciklopedijų leidykla. Vilnius.
- MOTUZAS A., VAIČYS M., BUIVYDAITĖ V. and ZAKARAUSKAITĖ D. (1997) — Sisteminis dirvotyros terminų žodynelis. Mokslo ir enciklopedijų leidybos institutas. Vilnius.
- PAULIUKEVICHIUS G. (1972) — Gidrologicheskije i geokhimicheskije svoistva kholmystykh lesnykh landshavtov. AN LSSR. Vilnius.
- PERSSON G. (1997) — Comparison of simulated water balance for willow, spruce, grass ley and barley. *Nordic Hydrol.*, **28**: 85–98.
- SAKALAUSKAS V. (1998) — Statistika su Statistica. Margi Raštai, Vilnius.
- SAMUILA M. (1999) — Simulation of some hydrological indices in the Aukštaitija integrated monitoring territory. *Geograph. Yearbook*, **32**: 260–277.
- SAMUILA M. (2000) — Simulation of some hydrological parameters in small wooded catchments. In: *XXI Nordic Hydrological Conference*. NHP Report (ed. T. Nilsson). *Nordic Co. Com. Hydrol.*, **1** (46): 291–298.
- TORSTENSSON G. and JOHNSSON H. (1996) — Simulation of water and nitrogen dynamics in a five year leaching experiment with varying fertilisation and manure treatments. Swedish Univ. Agricultural Sc. Uppsala.
- WORKING GROUP FOR ENVIRONMENTAL MONITORING (1989) — Methods for Integrated Monitoring in the Nordic Countries, Nordic Council of Ministers. Copenhagen.
- VAIČYS M., RAGUOTIS A. and ŠLEINYS R. (1979) — Miško dirvožemių žinynas. Mokslo, Vilnius.