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INFLUENCE OF ROAD SALTING MATERIALS ON VEGETATION CLOSE TO ROADS

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This paper deals with the investigation of impact of road salting materials (de-icing salts) to vegetation close to roads. Extensive survey of the present knowledge is submitted in the first part. In the experimental part concentrations of undesirable contaminants in the salting materials (according to a standard in preparation) and chloride ions in the soil samples have bean particularly observed. Amounts of heavy metals and other contaminants were very low on the roadsides, concentration of chlorides rapidly decreased upright to the road.

Introduction

To secure negotiability of roads during winter season in the Czech Republic and also in that part of Europe where snow and ice are a consequential complication of transport, two kinds of protecting materials are generally being used:

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1. Chemical de-icing materials. They cause physico-chemical changes of snow and ice on the road surface leading to melting.
2. Roughing inert sprinkling materials. These are the materials which increase, by a mechanical action, the drag coefficient of a snow layer on the smoothed road surface.

Broad discussions are in progress as a consequence of a car transport increase concerning advantages or suitability of different materials being used with regard to the environmental protection. It cannot be contradicted that highly increased concentration of chemical de-icing materials close to a road negatively affects vegetation there. On the other hand, slightly increased concentration of them suppresses growth of some plant species, however, the growth of some other plants (halophytes) is stimulated.

Reaching the maximum ecological target, i.e. elimination of salting during winter, is not possible from today's knowledge and experience point of view. The use of inert sprinkling materials alone is not sufficient. Results of many research studies confirm that only the application of chemical materials can assure the safe road transport during winter. Analyses of reports from 19 European countries revealed that the most frequently used material (almost exclusively) is natrium chloride NaCl. Alternatives were looked for but up to now a compound suitable in all aspects (price, properties etc.) has not been found. Logically, all European countries preferentially use NaCl for securing the negotiability of roads with the highest intensity of traffic (highways). It must be added that the material is applied to roads in the form of salt wetted with brine because this technology is the most effective.

There have not been any standard postulating requirements for quality of the most frequently used road salt until recently. Therefore, the standard has been set up by a group of experts from the Ministry of the Environment and the Ministry of Transportation and Commerce. The group formulated two proposals of standards to be used for sprinkling materials:

1. Standard of chemical de-icing materials
2. Standard of roughing sprinkling materials

If it proves that limiting concentrations of pollutants contained in salts are suitable, these standards will be declared as the National Standards. With respect to the objective of this paper only the standard of chemical de-icing materials is cited here.

Table I Limits of pollutant concentrations

No.	Pollutant	mg mg^{-1} of dry material
1	Arsenic	5
2	Chromium total	10
3	Chromium hexavalent	1
4	Cadmium	1.5
5	Copper	10
6	Nickel	10
7	Mercury	0.5
8	Lead	10
9	Zinc	50
10	Fluorides	50
11	Sulphides	2
12	Cyanides total	75
13	Cyanides free	8
14	Polycyclic aromatic hydrocarbons (1)	0.2
15	Polychlorinated biphenyls (2)	0.5
16	Nonpolar extractable compounds	50

Notes: Nos. 1 – 11 a part soluble in water
12 – 16 content in a sample

(1) A sum of six hydrocarbons is determined: fluoranthene, benzo[b]fluoranthene, benzo[k]fluoranthene, benzo[a]pyrene, benzo[ghi]perylene, indeno [1,2,3-cd]pyrene

(2) A sum of six congeners is determined: Nos. 28, 52, 101, 138, 153, 180.

Previous Experience and Knowledge

Technology of Winter Road Maintenance with Focus on Snow and Ice Removal

Winter road maintenance consists of mechanical snow removal, using abrasives on ice or beaten snow and snow and ice removal with the help of de-icing chemicals. The regulation for de-icing chemicals [1] allows use of sodium chloride (NaCl, salt), calcium chloride ($CaCl_2$) and mixtures of these two chlorides.

Salt spreading is started, if the snow cover is under 30 mm. If the snow cover is higher, it is needed to use snow remover first. Salt spreading rate depends on snowfall intensity. The rate is 10 $g\,m^{-2}$ for low snowfall intensity (10 – 15 $mm\,h^{-1}$) and 20 $g\,m^{-2}$ for higher snowfall intensity. In the case of long-lasting snowfall it is needed to repeat salt spreading with the rate of 10 $g\,m^{-2}$, but always after using snow remover to allow the salt to get to the road surface [1].

De-icing chemicals are applied only on residual snow layer after mechanical snow removal. With these materials it is possible to effectively and quickly remove snow cover up to 20 mm or glazed ice up to 2 mm thick. For higher cover it is needed to repeat application of de-icing chemicals in combination with mechanical facilities. When removing higher covers of ice, higher salt rates are needed usually. However, the overall rate should not exceed 60 $g\,m^{-2}$ (it is allowed only in exceptional situations to quickly re-establish road passability) [1].

Usage of Salt (Sodium Chloride) for Winter Road Maintenance

An important physical factor of de-icing performance of various salts is its eutectic point. It is the lowest temperature at which the salt is still able to dissolve in water. For sodium chloride it is –21.1 °C (for calcium chloride –51.6 °C).

The actual lowest temperature for effective use of sodium chloride is not uniquely defined [1]. For example:

- Regulation 140/97 Sb. – Appendix No. 7 states: For temperatures down to –5 °C will be used sodium chloride, for temperatures under –15 °C calcium chloride. Between these temperatures a mixture of the two chlorides can be used [1].
- In magazine 'Silniční obzor' (1994) K. Melcher states: From the operating practice it is known, that use of dry NaCl is possible to –7 °C and melting effect stops at –10 °C....The limit for use of wet NaCl could be moved to –15 °C (from experience) [2].
- Retrieval of Czech Nature Protection Institute, Brno, No. 93 – 18 (1993) states: NaCl works effectively down to temperature –10 °C...Wet NaCl woks under –10 °C [3] (successful down to –15 °C [4]).

During the last years pre-wetting salt has become common. This term means salt, which is just before application to the road (on the gritting vehicle) mixed with salt solution (concentration approx. 20 %). Brine is mixed in rated ratio with salt (NaCl) just before spinner input. Mostly used brine weight ratio is 30 % [1,2]. The advantages of pre-wetting are lower salt loss by whiff and faster action [1].

Another possibility is to use a de-icing solution directly. For sprinkling with salt solution the used concentrations are 18 – 21 %.

Application of de-icing chemicals is widespread in European countries and all over the world. NaCl in all forms is the mostly used agent. Commonly used form is solid NaCl, but pre-wetted salt sometimes in combination with $CaCl_2$ is also used. Other substances are always significantly more expensive. Moreover, also these substances cause various environmental problems, like huge over-fertilization in road surroundings (e.g. phosphates, urea or ammonium compounds) [1,2].

When assessing effects of chemical road maintenance on nature, it is necessary to take into account the relationship among environment components and other, possibly coinciding, stress factors (nitrogen oxides, sulphur dioxide, lead compounds etc.).

The winter road maintenance with NaCl brings certain problems, but for the safety of traffic, operational sustainability and rate of application, less mineral resources consumption, better performance and prevention of heavy metals migration into air it is considered to be better than abrassives.

Chloride ion has a direct phytotoxic effect and is readily taken up by plant roots. Sodium ion affects adversely the clay-humus complex. It displaces nutrients which causes an additional adverse effect on vegetation [22]. Low road adhesion facilitates salt spread in road surroundings.

Road maintenance with chemicals has significant advantages over other methods and is still unreplaceable, but when applied, all rules and regulations must be followed, especially Regulation of Ministry of Transport and Communications No. 104/97, Supplement 7, which regulates conditions and technology of winter road maintenance.

Information about Other Spreadings Used

Apart from sodium chloride and calcium chloride, other chemicals were tested for winter road maintenance, as for example magnesium chloride, ammonium compounds, phosphates, alcohols and glycols, urea etc. [1].

Omitting special cases (e.g. treatment of airfields with isopropyl alcohol), these substances are almost not used. The reason is negative environmental impact and important is also economic viewpoint (the price of sodium chloride can be 10 to 20 times lower) [1].

Abrasives could be divided into two groups: natural materials (sand, gravel) and waste materials (ash, cinder, slag). These materials are not as harmless for the environment as it was sometimes considered in the past. Especially application of waste materials leads to formation of dust containing toxic substances and heavy metals. At present the application of abrasives is reduced in this country and they are applied mostly in mountain regions with frequent long-term snowfall.

Combined usage of chemicals and abrasives is also possible only in exceptional situations, such as during long-term glazed-frost. The ratio used in these cases is 1 part of chemical to 3 – 6 parts of abrasive. Gritting rate should be adjusted so that the overall rate of the chemical part complies with the above-mentioned limit [1].

Influence of Salt on Vehicles

Chemicals used for winter road maintenance (salts) are aggressive to metal parts of vehicles and cause or quicken their corrosion. Snow, which is melting, forms a salt solution. The solution is spattered by the tyres and the spray strikes chassis and body shell of the vehicle, etches coatings or filters through coating crackings and gets on the metal. The chassis is also attacked by abrasion of coatings and metal parts. These processes result in material damages.

Influence of Road Salting on Soil, Water and Vegetation

The influence of road salting on soil, water and vegetation is varied effects and depends on a number of factors (e.g. quantity of the chemical, road type and traffic, climatic conditions, planting allocation, road surface, vegetation resistance, road ground location, soil type etc.). Salt can influence plants by direct contact, indirectly through roots, and at the same time it influences soil (its structure, chemistry, physical processes dynamics). Both sodium and chloride are responsible for it, because both elements are readily assimilated and both are harmful for the plants. It is known that winter road maintenance with salt damages agricultural plants to the distance of 10 m or more from the road by spatter of brine and outwash. The critical zone width is about 50 – 80 m around the road. The influence on forest and urban vegetation is investigated even more thoroughly.

Salt maintenance influences also the roads, and underground pipelines inside the towns. Water filters into crackings in the road, freezes and breaks the surface. In towns the brine can penetrate deep underground and speed-up corroding process of the underground pipelines [5,6].

Long term observations of sodium and chlorides content in Mohawk river (New York) show the impacts of fifty years of winter road maintenance with salt. The water quality and impacts on fauna and flora were studied. The publication reports [7] an increase in Na^+ and Cl^-concentrations in the river water by 130 % and 243 %, respectively, in 1952 – 1998. The increase is still continuing. Concentrations of other substances either did not change or decreased.

Salt pollution of ground and surface water results in its quality deterioration [8–12]. In consequence, human health may be threatened, especially in the surroundings of drinking water reservoirs [13,14]. There is also negative influence on fauna and flora [12,15–20].

One of the first research studies in former Czechoslovakia, dealing with the salt influence on forests near Brno-Jihlava road, was the research by prof. Pelíšek [30]. Soil samples from various distances up to 50 m from the road were analyzed for humus, sodium, potassium, chlorides and sulphate content. Also samples of damaged spruce needles were analyzed. The results confirm a negative impact of winter road maintenance with salt on the forest.

- Na, Ca, K and Cl content in soil was hundreds or thousands percents higher under the damaged trees than under healthy trees 50 m away from the road
- Na and Cl content in spruce needles was hundreds percents higher in damaged trees
- soil pH under damaged trees was 6.5 – 6.9, while under healthy trees it was 3.5 – 3.37
- Ca content in the needles of damaged trees was significantly decreased, which indicates an influence of salt on plant nutrition.

Changes in Soil Chemical Composition

Chlorides Cl^-

Chlorides content is variable in saline soil, both by site and time [1,23,25,26], which is probably caused by high mobility of Cl^- in the soil and by its easy wash-out. The content found in the saline soil is not equivalent to the Na^+ content, but rates about 25 – 50 %. The content of Cl^- in the soil also does not correlate with the degree of damage to the plant growing on the soil. Although chlorides are the primary cause of plant damage, the concentration of chlorides in the soil is not a reliable indicator of soil salinization [23].

Sodium Na^+

Soil samples analysis in Prague during first years of road salting (1971 – 1972) showed, that Na^+ content is more stable than that of Cl^- and that it correlates with tree damage quite well [23]. The Na^+ content recalculated to equivalent content of NaCl was:

- under 0.25 g NaCl under healthy trees;
- 0.25 to 1 g NaCl under slightly damaged trees;
- 1 to 1.75 g NaCl under medium damaged trees;
- 1.75 to 2.5 g NaCl under badly damaged trees;
- more than 2.5 g NaCl under very badly damaged (dying) trees.

The amount of salt which penetrated into the soil under the trees per square metre was 1.16 to 4.7 $\mathrm{kg\,m^{-2}}$, based on amounts of Na^+ in the soil in various depths.

The soil analysis in following years (1973 – 1979) showed first movement of sodium deeper in the soil. Later this movement stopped slowly, but the sodium content grew between the years and the concentrations was more stable during summer. While in 1972 autumn residual Na^+ content was only 1 – 3 mg in litre of soil, in 1997 it was as much as 50 – 90 $\mathrm{mg\,l^{-1}}$. The correlation between sodium soil content and tree damage deteriorated constantly during these years. In the end it became evident, that sodium content in soil ceased to be a reliable indicator of the tree damage.

Plant Nutrients

Nutrients content, especially that of phosphorus and potassium, has great variability in urban soil, but no correlation with road salting intensity was observed [23]. Only on few rural sites increased potassium content was observed around roads. It was probably caused by KCl in the road salt [27]. Nutrient deficiency is a factor often conducive to tree damage in saline urban soil, however. According to [23], nutrient elements — ballast elements ratio is important for plant damage. The average ratio, expressed as NPK : NaCl, is 1 : 6.6 in saline soil and up to 1 : 19 in heavily salinated soil during spring, when the roots receive nutrients intensively. In autumn the average ratio dropped to 1 : 0.45.

The inauspicious NPK : NaCl ratio in spring causes excessive chloride uptake. The quick drop of chloride soil content during the season does not help so much, because the plants do not receive such amounts of nutrients during this time.

Calcium Content and pH Changes

According to most articles, a pH increase is common around salt-treated roads [27–30]. For example Ref. [27] alleges pH 6.6 – 7.9 under damaged trees, but pH 4.2 on a control site. In extreme cases the pH on saline soils was up to 9.2 [29]. At the same time soluble calcium content rises. In a forest stand, 74 mg CaO in water extract from 100 g of soil under healthy trees is reported, while under damaged trees it was 240 mg [30]. The pH value was 3.65 and 6.86, respectively. Paper [27] reports up to 30-times Ca^{2+} build-up in water extract compared to a control site. Soil alkalization caused by soluble calcium is another factor of specific plant damage and may lead to vegetation structure changes.

Oxygen Content in the Soil

Sufficient soil aeration and oxygen content in the soil air are limiting factors of roots breathing and thus of tree growth. Soil oxygen insufficiency causes, that roots are not able to receive nutrients [23].

Salination by NaCl does not reduce the oxygen content in the soil, but soil oxygen insufficiency is another common stress factor conducive to tree damage in saline urban soil, especially to trees growing on asphalt-surfaced or paved areas and dense soils.

Soil oxygen content reduction indeed occurs, when using alternative winter maintenance chemicals based on urine and other organic compounds. The oxygen is depleted during microbial degradation of these materials and carbon dioxide accumulates in soil air [23].

Chemical Composition Changes in Plant Tissues

Sodium Content in Leaves

Papers dealing with Na^+ content in leaves of plants growing on saline soils often report contradicting results. Some relation was found in some cases between sodium content in leaves of certain plant species and soil salinity [32]. Only partial (for part of population) relation is reported in another paper for the same species, while still another one reports no relation at all [28]. In most cases the conclusion is, that sodium content in leaves should not be taken as an authoritative indicator of tree damage on saline soils [25].

Chlorides Content in Leaves

Chlorine content in leaves as Cl^- is always higher in plants damaged by soil salt compared to healthy plants. Up to forty-times Cl^- content increase had been found in trees [32]. However, there are substantial differences between species in this.

In municipal alleys were the highest leaf concentrations found 3 – 5.3 % Cl^- [23] and 2.5 – 4 % Cl^- [27] in damaged linden-tree, while in healthy tree only 0.3 – 0.4 Cl^-.

Other tree species with high chlorides uptake are Baumann horse chestnut and Norway maple [23], where in seriously damaged tree leaves about 2.1 % Cl^- and 1.95 % Cl^-, respectively, and in critically damaged trees 2.65 Cl^- and 2.3 % Cl^-, respectively, was found.

Persistence to salination was found to depend on geographic position. For example plane tree is, in foreign articles [27], considered mostly as relatively persistent. In Prague the tree showed to be rather sensitive, which could be caused by different climatic conditions. In this country the tree lives in climatic conditions, which are at the limit of its tolerance and which are its limiting factor. This increases sensitivity of the tree to other stress factors including salinity. Also content of Cl^- in leaves in Hamburg was lower on highly saline soil.

Locust tree is considerably persistent to soil salinity owing to very low chlorides intake [23]. Even on highly saline soils (3.5 g NaCl in 1 l of soil) the concentration in leaves did not exceed 0.7 % Cl^-. On the other hand, a concentration as low as 0.83 % Cl^- already causes a severe damage, so the locust tree is very sensitive to Cl^- in leaves.

A long-term observations showed, that Cl^- content in leaves is slowly increasing during the season between spring and autumn, but after a rain the concentration drops. Also differences between shroud parts above road and the other side were observed. Especially in trees growing on lawn surface was the Cl^- content on the other side considerably lower:

- Big-leaf linden 2.02 % , 0.87 % respectively.
- Norway maple 1.49 % , 0.77 % respectively and 1.30 % , 0.50 % respectively.

Chlorides Content in Other Parts of Trees

Woods store chlorine in all body organ [23]. Highest concentrations can be found in leaves and current year shoots, a smaller part of chlorine can be found in blooms and fruits. The smallest part is located in wooden parts of the plant.

Chlorine is moving from wood and shoots into leaves during vegetative period. This is usually interpreted as an effort of the plant to get clear of pollutants. An analysis of parts of two dead linden trees brought the following results:

- Roots contained 0.15 % Cl^-, which makes 7.64 % of total Cl^- content in the tree.
- Trunk contained 0.24 % Cl^-, which makes 37.52 % of total Cl^- content in the tree.
- Branch wood contained 0.36 % Cl^-, which makes 14.29 % of total Cl^- content in the tree.
- Twing contained 0.8 % Cl^-, which makes 4.7 % of total Cl^- content in the tree.
- Leaves contained 2.8 % Cl^-, which makes 35.85 % of total Cl^- content in the tree.

Although the leaves feature only 5 % of tree weight, the chlorides content makes more than one third of total Cl^- in the tree.

Critical Level of Cl^- for Tree Damage

From various measurements of chlorides content in trees it is possible to estimate a critical level for the tree damage. According to [27], the critical spring value for broad-leaved trees is 1 % Cl^- in leaves and for conifers 0.5 – 0.7 % Cl^- in needles. Also according [32] the critical value in leaves is 1 % Cl^-.

Critical levels determined [28] in the middle and inner bark were 0.26 % Cl^- and 0.11 % Na^+. Medium or, for sensitive species, severe damage can be assumed at these values.

According to [23] it is needed to lower the critical level to 0.6 % Cl^- for sensitive broad-leaved trees.

The above-mentioned levels equate approx. 2.5 × – 3 × multiple of levels in healthy trees.

According to [33] summer threshold of toxic chloride level in leaves is:

Species	*Cl^- level in dry mass*
Salt-sensitive broad-leaved	0.3 % to 0.5 %
Sensitive conifers	0.2 % to 0.4 %
Persistent broad-leaved	0.6 % to 1.6 %
Persistent conifers	approx. 0.6 %

Effects of Vegetation Damage by Salt

Morphological Changes of Aerial Plant Parts Caused by Salination

Plants on saline soils show symptoms of characteristic disease, especially yellowing and necrosis of non-ligneous parts. Annual plants show less symptoms than wood plants [23].

Typical symptoms on broad-leaved trees:

- Necrosis of leave edges, quickly advancing towards the leave centre. Severely damaged trees show these symptoms as early as during the burst into leaves.
- Premature autumn colouring and litter of leaves. On severely damaged trees it begins up to 6 – 8 weeks sooner than normal.
- Complete necrosis and litter of leaves and new burst into leaves during the whole season on various parts of the tree. The process may pass through several times during one season and it goes asynchronously in different parts of the crown.
- Lowered blooming intensity of slightly damaged trees. Moderately damaged trees may bloom more intensively, on the contrary: if this is the case the flowers are of lower quality.
- Autumn blooming

- Dry up of twigs; with growing salt content dry up of branches and of the whole crown.
- The most damaged trees are dying after the last infrequent flock spring burst into leaves.

Evergreen trees and conifers do not show repeated needle loss during vegetation season, but the exchange rate is greater. The most visible symptom is necrotic brown colour of needles. In [24] the author recommends the following damage degree scale for conifers:

- *1st degree of damage:* Without visual signs of damage.
- *2nd degree of damage:* Slight to moderate damage — spruce with five or more annual volumes of needles, pine with 2 – 3 volumes, color changes almost invisible and local, loss of deep-green colour.
- *3rd degree of damage:* Moderate to severe damage — spruce with three volumes of needles, pine with one volume and possibly remains of the second, appreciable loss of deep-green colour, rusty-brown shroud parts, shorter needles.
- *4th degree of damage:* Severe damage to dying — spruce with up to 2 volumes of needles, pine with at most one volume, needles significantly rusty and short.

Direct contact of salt with the plant has similar effects to those of soil salinity, but only on the part of the plant in contact with salt dust or brine. Typical is affecting of ground-line plant parts on the roadside and deeper damage of young tissues [23].

Also plant root system can be damaged by high soil salinity. A possible effect of high salt content in soil is the so-called physiological drought. It means that the plant is not able to receive the available water from soil. The visible signs of root damage by salt may appear very similar to signs of well known damage by honey mushroom [34].

High salt concentrations can affect also the soil fungi population. A paper [35] experimentally confirmed, that sodium chloride inhibits growth of mycorrhizal fungi germs in pre-symbiotic phase. This can lead to prevention of establishing symbiotic relationship tree-fungi (mycorrhiza), which is important for correct operation of root system.

Salinity has an adverse effect on most plants. The soil alkalinity also grows with the salt content, and the original populations are expelled by species living on saltwater wetlands [31], such as e.g. *Salsola kali* or *Puccinelia distans*. *Puccinelia distans* created, for example, continuous lanes along busy roads under Vysoke Tatry mountains in soil with a content of 53 – 72 mg kg^{-1} Cl and pH from 7.9 to 8.2. Also *Atriplex tatarica* makes such lanes around some streets in Bratislava.

Location Influence on the Disease Intensity

The following scale was designed for evaluation of risk by location properties in non-urban country:

- First degree — *Places of highest hazard:* Places under road-level, terrain depressions, waterloogings, clay soils. High ground-water level or low depth to impermeable bed.
- Second degree — *Places of average hazard:* Places on road-level, plain dry areas. Low depth to impermeable bed within reach of root system.
- Third degree — *Places of low hazard:* Dry places on or above road-level. Depth and permeability of bedrock allows egestion of salt out of root system reach. Slopes above road level could be affected only by brine splashing.

Persistence of Various Plant Species

Persistence of various plant species to salt is different for different species. For specialized plants living on salt marsh in nature, the salt road maintenance may cause even their dominance along roads (see chapter "Effects of soil salinity on plant associations"). According to Ref. [33], species relatively persistent are those living in symbiosis with microorganisms (nitrifying bacteria, mycorrhiza) or deep-root plants with low nutrients demand and alkaline soil tolerance.

In regard of number of plant species, it is not possible to present any representative list of sample species belonging to various persistence groups. Several authors created such lists for trees, however.

In Ref. [24] there is, for example, the following list for forest trees:

- *More persistent:* common spruce (Picea abies), Scotch pine (*Pinus sylvestris*), European larch (*Larix decidua*), silver fir (*Abies Alba*), Douglas fir (*Pseudotsuga menziesii*), Norway and sycamore maple (*Acer platanoides, Acer pseudoplatanus*), rowan (*Sorbus aucuparia*), lime-tree (*Tilia cordata, Tilia platyphyllos*), European hornbeam (*Carpinus betulus*), common beech (*Fagus sylvatica*), elmtree (*Ulmus sp. div.*), European hazel (Corylus avellana), red dogwood (*Cornus sanguinea*), bird-seed (*Ligustrum vulgare*) and brier-rose (*Rosa canina*).
- *Less persistent:* blue spruce (*Picea pungens*), black pine (*Pinus nigra*), mountain pine (*Pinus mugo*), oaks (*Quercus sp. div.*), black locust (*Robinia pseudoacacia*), common ash (*Fraxinus excelsior*), tree of heaven (*Ailanthus altissima*), aspen (*Populus tremula*), grey and black alder (*Alnus incana, Alnus glutinosa*), white and grey poplar (*Populus alba, Populus canescens*), oleaster (*Elaeagnus angustifolia*), sea buckthorn (*Hippophae rhamnoides*), osiers (*Salix sp. div.*), pea-tree (*Caragana arborescens*), bladder senna (*Colutea

arborescens), matrimony vine (*Lycium halimifolium*), blackthorn sloe (*Prunus spinosa*), Japan rose (*Rosa rugosa*), European green alder (*Alnus viridis*).

More Recent Study of Salt Effects on Plant - Benecko, Humpolec

In 1997 a research task "Dynamics of ruderal vegetation in Benecko with focus on spreadings influence on turf associations on highway margins and adjacent meadows" took place. The task was carried out by Dr. Jana Husáková from Institute of Botanics of the Academy of Sciences of the Czech Republic in cooperation with The Krkonoše Mts. National Park Administration.

Benecko was chosen as a model area, because there is a heterogeneous network of roads — from both points of view: traffic type and intensity and type and intensity of winter road maintenance. In the past cinder was used here. Now, to comply with hygiene requisitions, limestone or melaphyre grit is used. Both rock materials have high alkalies content (Ca, Mg), which lowers natural soil acidity and thus changes the vegetation composition. Moreover, the grit from road sides impedes cultivation of adjacent meadows. Recently, also sand was used in the area, which is the best nature-saving material. Unfortunately, it was used as a mixture with salt and that is a new chemical stress factor.

Another reason of the choice Benecko is, that in 1970 there took place a botanic exploration of the area. The results can now serve as good-quality reference material. Another exploration took place in 1996 and 1997. Not only streaks around roads, but also changes in vegetation somewhat distant from road on surrounding meadows were covered. Samples for chemical analysis were taken on several places. From among elements, Calcium, magnesium, nitrogen, phosphorus and lead were analyzed, and so were also pH and humus had.

Comparison of results from the seventies and nineties revealed quantitative and qualitative changes in vegetation around roads towards ruderal associations. Chemical assays showed increased content of available nutrients in water channels and road shoulders, originating probably from spreadings extract. This nutrients content effect is sometimes apparent also in the soil on slopes under roads (base of road banks etc.). In contrast, no dependence of lead content on traffic intensity and distance from road was found [21].

Plants in our climatic conditions and those growing on common soils are not adapted to high salt content in the soil. Direct influence of salination on plants includes such effects as buds, shoots and bark damage; cambium atrophy; necrosis and premature leaf fall. Indirect effects include ion stress (Cl^- and Na^+ tissue accumulation); osmotic stress, leading to lower water intake and sudden drying up; lowered intake of important ions. Most of the damage of woody species is caused by indirect salt influence, through soil condition changes.

In order to avoid the influence of salt on woody species it is possible to:

lower the salt dose; substitute salt by another substance; prevent direct site salination (barriers, elevation of site above surrounding terrain); enhance soil properties (permeability); fertilize appropriately (add Ca and acidity — $CaSO_4$); do prevernal soil wash (wash away salt with at least 100 l m^{-2} of water).

A study of influence of salting of highway D1 near Humpolec on a water supply and related geobotanical research were carried out recently by a research unit of GeoVision company [36]. Mapping of vegetation and recognition of anomalies caused by antropogeneous activities (especially road maintenance) was the main task. One of the targets of the studies was to determine the extent of salt spreading influence on environment components. The degree of influence was measured by phytoindication, not, e.g., by chemical analysis of soil. Monitoring took place on 12 localities, 4 of which were on the highway bank.

Important findings include:

- Not negligible area contamination by ionic substances (salts) originating from winter road maintenance.
- Spreading of contamination in rain and melting water out from the road surface is facilitated by improper civil engineering and by insufficient upkeeping of rain-water downcomers.
- The air-borne spread of contaminants is indicated by specific tree damage in adjacent ecosystems.

The report suggests also arrangements to reduce negative impacts. One of the suggestions is to deepen collecting ducts on highway road sides. The report also warns that it is necessary to discard seducement of rain-water into sensitive sites, as spring areas or habitats of protected herbs.

Experimental Chemical Part

Field and laboratory experiments conducted according to this research programme should have answered three questions:

a) To what distance from a road can chemical substances contained in road salt, whose concentration was limited by the proposed standard, influence the environment.
b) To what distance from a road can ions, originated from road salt (Na^+, Cl^-, $N(NO_3^-)$, $N(NH_4^+)$, SO_4^{2-} etc.), influence the vegetation.
c) Botanical evaluation of vegetation in the same sites as in the items a) and b).

It can be seen from the results of the reviewed literature that the contaminants from road salt can disseminate far from the road but only in coincidence of some conditions. Those are above all the cases when the road is situated on the causeway so that the water solution of salt formed by snow thawing or by rain run down to the surrounding environment. If the road leads through a flat terrain or through a cutting, the salt solution is retained by a drain usually built along the road. On the other hand, soil is to be impermeable to prevent soaking and to make water flow (for example rural lanes).

In the experiments, soil was sampled for analyses according to the items a) and b) at two places where the road was situated on the causeway. From the time point of view, the samples were taken during the spring months (March – April), in period when the maximum contamination of soil could be expected after winter salting. In the same sites the botanical evaluation was done as well.

Sampling Points

In order to fulfil the above mentioned intention, the sampling was done according to the following scheme:

Road I/11 — see Fig. 1

Samples marked 1/I/11 – 10/I/11 — first sampling (realized on 7 March, 2003). The sample No. 1/I/11 was withdrawn close to the road, next ones successively by 1 m perpendicularly to the road. Altogether 10 samples were taken.

Samples marked 1/I/11 – 10/I/11 — the second sampling (realized 2 April, 2003), the same sampling points.

Samples marked 1/I/11 and 10/I/11 — the third sampling (realized 10 April, 2003, two samples only)

Samples marked 1/I/1, 5/I/11 and 10/I/11 — the fourth sampling (realized 18 April, 2003, three samples only).

Road I/36 — see Fig. 2

The sampling scheme and sampling time were the same as in the case of I/11, only number 36 road was examined instead of number 11.

Analytical Methods and Summarization of Results

Results of analyses of the samples are summarized in Tables II – XI. The data in Tables II – V were obtained by analyzing the extract with 2 M HNO_3, the data in Tables VI – IX by water extraction. The results in the last tables were obtained by relevant complex methods including a special treatment of the samples.

Determination of heavy metals in the soil extracts by the ICP OES method:

Heavy metals were determined by means of an optical emission spectrometer INTEGRA XL 2 (GBC Australia), and the demineralised water was prepared in an apparatus MILLI-Q$^+$ (Millipore, USA). The calibration lines for all the elements determined were prepared by diluting the commercial standard solutions (Analytika s.r.o., CR) and stabilized by adding conc. HNO_3 (1 ml to 100 ml of the solution). Experimental conditions of the ICP OES determination were as follows:

Element	λ, nm	Mono/order	PTM, V
Cu I	327.3	1/1	600
Zn I	213.8	2/1	520
Cr II	283.6	1/1	600
Ni II	231.6	2/1	600
Cd II	226.5	2/1	600
Pb II	220.4	1/3	600
As I	193.7	1/3	600
Ca II	393.4	1/1	260
Na I	589.0	1/1	530
Hg I	184.9	1/3	600

Mono/order	monochromator used/spectral order
PTM	photomultiplier voltage

The device and measurement parameters for the routine procedure — see next table

Parameter	Value
Plasma power supply	1.1 kW
Nebulizer gas flow	0.65 l min^{-1}
Observation height	8 mm
Plasma gas flow	10 l min^{-1}
Auxiliary gas flow	0.5 l min^{-1}
Sample uptake rate	10min^{-1}
Sample time delay	30 s
Integration time	1 s

A) Anodic stripping voltammetric method (voltammetric apparatus EP 100, HSC Bratislava) was used for quantitative determination of mercury in acid extract of soil. The rotating disc electrode AuRDE was used as a working electrode.
B) Apolar extractable substances were isolated from the soil by means of Ledon 113 (1,1,2- trichlorotrifluoroethane). After drying of the extract with anhydrous sodium sulphate and elimination of polar substances by means of silica gel, the infrared spectra were measured with an FTIR spectrophotometer VECTOR 22 (Bruker).
C) The presence of fluorides and sulphates was detected with anionic isotachophoresis. As a leading electrolyte 0.01 M hydrochloric acid and 0.003 M BTP was used. The alue of pH 3.6 was adjusted by addition of recrystalized β-alanine, and 0.01 M lithium citrate was used as a terminating electrolyte.
D) The quantity of cyanides and sulphides were determined voltammetrically with a hanging mercury drop electrode as the working electrode. The supporting electrolyte was 0.01 M 0.1 M LiOH.
E) The determination of PCB and PAH was realized by standard methods in a special laboratory.
F) pH/H_2O and pH/KCl were measured with a pH combination electrode (MONOKRYSTALY Turnov) that was calibrated with two standard buffers, and a potentiometer RADELKIS OP-208/1 was used
G) The concentration of chlorides was determinated by precipitation with $AgNO_3$ and Ag^+ concentration was monitored with an electrode.
H) The nitrates and ammonium ions were determinated by photometric microtitration [37]. The samples were prepared according to standard ISIO 14256.

Conclusion of the Chemical Part

This report contains a relatively extensive summary of information concerning the effect of road salt on the environment, particularly on the vegetation near the road. The information was obtained both from literary reviews and analyses of our samples. Some conclusions can be formulated on this basis.

A) Pollutants included in the Standard
There are several metals on the Standards list with limited concentration of the road salting materials. It can be concluded from Tables II – V that the concentration of metals decreases considerably in the direction away from the road. Unfortunately, the amount of experiments did not allow any detailed determination of threat of changes or the extent of contamination. The exact source of contaminants can not be also determined, i.e. if they originate from the spreading of salt or other "inert" material or from traffic. When the detected

concentrations of metals are compared with the values mentioned in the Directive of the Ministry of the Environment of the Czech Republic "Criteria of pollution of soils and groundwater" it can be concluded:

- The criterion B (i.e. when the value is exceeded, contamination must be tackled) was not exceeded in any case.
- Metals Cd, Pb and Zn in the point 1 (close to the road) exceeded the criterion A (natural background content) only in some samples.
- The concentration of all other metals did not exceed the criterion A.
- Time changes in concentrations were not observed (with regard to sampling on the four days only).
- According to the above facts, the effect of heavy metals concentrations on vegetation near the road can not be confirmed. Because the criterion B was not exceeded and the criterion A was in a very few cases only, it can be stressed with all probability that the concentration of heavy metals in deicing materials on investigated parts of roads did not affect the vegetation near the roads
- In the case of Pb the use of leaded gas in the last period must be considered, but decrease in its concentration is evident at present.
- Concentration of Na is also summarized in Tables II – V. Sodium concentration is understandably not limited in road salts but its amount is of a great importance for vegetation near the road. Concentration of Na logically decreases further from the road and at the distance of 10 m from the road its concentration reaches only a small fraction of that close to the road (see item 2).
- Experimentally measured concentrations of main representatives of polycyclic aromatic hydrocarbons (PAH), polychlorinated biphenyls (PCB) and nonpolar extractable substances (NES) are summarized in Table XI. The conclusions deduced from the results are similar to those for the metals concerned.
- Concentration of PCB in the samples close to the roads exceeded the criterion A, but did not exceed the criterion B. Their concentration in the samples far from the roads did not reach the criterion A either. We suppose, therefore, that the observed area is, from this point of view, relatively clean. The same conclusions can be made also for PAH and NES.
- Concentrations of ions F^-, S^{2-} and CN^- did not reach the detection limit of the analytical methods used.

2) The second part of analyses was focused on determining the concentrations of substances important for plant growing, whether positively or negatively (Tables VI – IX). These data were used preferably in the part dealing with the botanical evaluation. Unfortunately, our data cannot be simply compared with those of Ref. [illegible] because of the different procedures of soil leachate

preparation. Owing to this, it can be considered that increased amount of Na^+ and Cl^- close to the road may have a deleterious effect on vegetation.

3) When evaluating the application of road salts generally from the chemical point of view, the important conclusion can be made: in the case when road salt is not disseminated to areas adjacent to roads specifically by water stream (formed by rain or snow thawing), in 10 m distance down from the causeway the amount of salt constituents in soil is not increased and the effect on vegetation can be eliminated.

Tables

Table II Elementary composition of soil extracts — 1. sampling. Method of analysis: ICP

Sample	Pb mg kg^{-1}	Ni mg kg^{-1}	Cd mg kg^{-1}	Na mg kg^{-1}	Zn mg kg^{-1}	As mg kg^{-1}	Ca mg kg^{-1}	Cu mg kg^{-1}	Cr mg kg^{-1}
Blank experiment	<	<	<	<	<	<	<	<	<
1/I/11	93.3	5.53	1.28	341	150.7	3.28	8960	24.7	9.13
2/I/11	93.8	6.93	1.18	173	159	6.03	10440	24.3	8.55
3/I/11	43.5	4.43	0.880	73.0	67.3	< 2	10700	11.4	5.76
4/I/11	22.9	3.41	0.582	29.5	29.6	2.70	10200	7.41	4.19
5/I/11	18.3	3.15	0.554	24.7	22.6	3.05	9100	6.63	3.88
6/I/11	13.3	2.58	0.487	17.8	17.2	< 2	6970	5.22	3.35
7/I/11	8.85	2.43	0.461	18.2	13.6	< 2	6530	4.25	3.05
8/I/11	14.6	2.58	0.526	15.0	14.0	< 2	5700	5.05	3.72
9/I/11	15.8	2.70	0.595	14.1	15.1	2.62	6660	5.36	4.19
10/I/11	12.1	4.28	0.662	72.3	19.2	2.77	11900	7.89	4.74
1/I/36	66.7	4.27	0.985	1034	83.8	3.75	8540	15.9	7.16
2/I/36	20.4	2.79	0.759	[illegible]	26.2	3.73	6680	7.14	4.97
3/I/36	16.6	4.02	0.686	393	23.4	< 2	9710	7.10	4.57
4/I/36	15.9	3.48	0.648	414	[illegible]	3.28	9610	7.17	4.72
5/I/36	15.7	5.93	0.672	140	18.9	< 2	12900	6.84	5.13
6/I/36	13.9	5.45	0.674	129	20.8	[illegible]	12700	7.16	5.16
7/I/36	15.1	5.21	0.734	25.4	22.2	< 2	10900	8.22	5.67
8/I/36	14.2	5.23	0.733	25.6	20.2	2.08	[illegible]	8.19	5.43

Table II – Continued

Sample	Pb	Ni	Cd	Na	Zn	As	Ca	Cu	Cr
	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}
9/I/36	13.6	5.60	0.728	28.7	19.7	3.35	11300	9.01	5.85
10/I/36	13.7	5.79	0.731	28.3	18.6	3.37	11600	8.79	5.95
Domoradice	14.9	3.93	0.627	55.4	41.0	11.0	13900	7.45	4.87
Hradec n. Sv.	9.11	4.38	0.447	78.6	92.9	< 2	15300	5.68	3.34

The content of Hg was under the detection limit of analytical method in all samples (< 0.5 mg kg^{-1})

Table III Elementary composition of soil extracts — 2. sampling. Method of analysis: ICP

Sample	Pb	Ni	Cd	Na	Zn	As	Ca	Cu	Cr
	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}
Blank experiment	<	<	<	7.44	<	<	173	<	<
1/I/11	71.0	3.32	1.17	312.6	159	4.22	7917	18.8	5.08
2/I/11	158	4.32	1.21	153.6	136	6.70	8317	19.1	5.00
3/I/11	18.8	2.53	0.806	19.2	21.9	< 2	7837	6.38	2.25
4/I/11	4.91	1.65	0.706	20.3	16.5	< 2	6187	4.46	1.59
5/I/11	6.79	1.57	0.763	10.1	13.1	< 2	4977	3.81	1.43
6/I/11	11.7	1.91	0.817	14.0	13.1	3.56	5407	4.93	1.84
7/I/11	11.2	1.61	0.730	13.1	12.5	< 2	4507	4.34	1.86
8/I/11	16.3	1.84	0.536	14.5	16.1	< 2	4647	5.10	2.10
9/I/11	11.9	1.64	0.362	11.4	12.5	< 2	4757	4.41	1.93
10/I/11	6.56	2.07	0.556	75.3	26.1	3.22	12277	7.11	3.11
1/I/36	94.0	4.02	0.907	933	109	3.68	5657	19.7	5.69
2/I/36	28.9	3.30	0.717	336	32.6	< 2	5687	7.46	3.63
3/I/36	14.5	2.75	0.643	4667	21.6	2.73	6057	5.67	3.07
4/I/36	16.4	2.51	0.468	268	11.9	2.51	6127	4.83	2.30
5/I/36	12.9	3.57	0.510	117	21.9	3.21	7047	5.89	2.63
6/I/36	9.63	4.44	0.481	75.9	20.7	2.70	9147	6.48	2.87
7/I/36	9.67	3.62	0.470	73.4	24.4	2.19	7767	5.31	2.56
8/I/36	9.91	4.89	0.504	136	17.2	< 2	7977	5.64	2.70

Table III – Continued

Sample	Pb mg kg^{-1}	Ni mg kg^{-1}	Cd mg kg^{-1}	Na mg kg^{-1}	Zn mg kg^{-1}	As mg kg^{-1}	Ca mg kg^{-1}	Cu mg kg^{-1}	Cr mg kg^{-1}
9/I/36	10.7	5.36	0.573	16.8	23.1	< 2	8577	6.50	2.82
10/I/36	10.7	5.28	0.566	42.2	24.6	3.41	8507	6.60	2.89

Table IV Elementary composition of soil extracts — 3. sampling. Method of analysis: ICP

Sample	Pb mg kg^{-1}	Ni mg kg^{-1}	Cd mg kg^{-1}	Na mg kg^{-1}	Zn mg kg^{-1}	As mg kg^{-1}	Ca mg kg^{-1}	Cu mg kg^{-1}	Cr mg kg^{-1}
1/I/11	11.4	4.77	0.549	115.6	15.3	2.44	8537	7.50	3.11
10/I/11	11.9	1.92	0.397	14.3	17.8	< 2	5347	4.81	2.29
1/I/36	73.4	4.25	1.03	364	128	4.11	7417	21.1	5.61
10/I/36	58.7	3.43	0.804	913	88.4	2.06	5197	13.2	4.59

Table V Elementary composition of soil extracts — 4. sampling. Method of analysis: ICP

Sample	Pb mg kg^{-1}	Ni mg kg^{-1}	Cd mg kg^{-1}	Na mg kg^{-1}	Zn mg kg^{-1}	As mg kg^{-1}	Ca mg kg^{-1}	Cu mg kg^{-1}	Cr mg kg^{-1}
1/I/11	68.5	3.81	1.01	491.6	429	4.75	8027	29.7	5.89
5/I/11	8.59	1.68	0.317	15.5	14.72	2.04	5357	4.44	1.55
10/I/11	12.5	1.81	0.448	13.7	13.6	2.43	8787	5.41	2.31
1/I/36	91.1	4.44	0.951	1026	109	3.12	5917	29.9	6.50
5/I/36	9.17	4.74	0.461	105	12.7	2.32	8777	5.63	2.80
10/I/36	10.8	4.82	0.585	94.5	15.7	< 2	7587	6.64	3.06

Table VI Selected soil parameters — 1. sampling

Sample	pH/H_2O	pH/KCl	Cl^-, mg kg^{-1}	$N(NH_4^+)$, mg kg^{-1}	$N(NO_3^-)$, mg kg^{-1}	Content of soluble salts, mg kg^{-1}
1/I/11	7.07	6.87	301.2	0.4	6.7	1650
2/I/11	7.25	7.25	217.2	1.0	8.1	1350
3/I/11	7.42	7.54	172.8	1.5	3.4	1538
4/I/11	8.59	8.30	221.1	0.4	4.9	863

Table VI – Continued

Sample	pH/H_2O	pH/KCl	Cl^-, mg kg^{-1}	$N(NH_4^+)$, mg kg^{-1}	$N(NO_3^-)$, mg kg^{-1}	Content of soluble salts , mg kg^{-1}
5/I/11	7.28	7.40	88.8	0.6	4.1	1838
6/I/11	6.71	6.76	113.4	1.3	4.4	2213
7/I/11	6.93	6.65	72.9	2.6	3.4	2700
8/I/11	5.74	5.37	43.2	2.5	5.6	1688
9/I/11	6.32	6.20	30.9	1.6	20.4	1500
10/I/11	7.69	7.42	26.1	3.4	12.3	375
1/I/36	6.24	6.18	188.1	11.7	3.7	2062
2/I/36	6.40	5.59	73.2	2.4	0.7	1013
3/I/36	6.54	6.0	41.4	0.7	3.8	3263
4/I/36	6.52	5.92	41.4	4.6	3.8	938
5/I/36	7.35	6.86	34.5	6.5	2.8	1838
6/I/36	7.09	6.78	27.0	1.5	7.6	1913
7/I/36	7.00	6.62	23.1	1.5	2.4	450
8/I/36	7.10	6.58	44.1	1.7	1.2	1125
9/I/36	7.19	6.63	21.9	1.5	2.9	2373
10/I/36	7.23	6.74	26.7	3.0	3.3	1688
vz. 1 Domoradice	7.36	7.07	20.0	0.0	17.3	1425
vz. 2 Hradec n. Sv.	7.27	7.16	27.4	1.6	10.0	900

Table VII Selected soil parameters — 2. sampling

Sample	pH/H_2O	pH/KCl	Cl^-, mg kg^{-1}	$N(NH_4^+)$, mg kg^{-1}	$N(NO_3^-)$, mg kg^{-1}	Content of soluble salts , mg kg^{-1}
1/I/11	7.07	6.91	214.7	1.03	1.7	825
2/I/11	7.08	6.87	88.9			750
3/I/11	7.43	7.23	28.8			638
4/I/11	7.25	7.02	26.5			638
5/I/11	6.85	6.55	26.0	0.51	1.79	488

Table VII – Continued

Sample	pH/H_2O	pH/KCl	Cl^-, mg kg^{-1}	N(NH_4^+), mg kg^{-1}	N(NO_3^-), mg kg^{-1}	Content of soluble salts, mg kg^{-1}
6/I/11	6.40	6.12	17.6			713
7/I/11	6.30	5.92	22.3			600
8/I/11	5.78	5.32	16.7			863
9/I/11	6.07	5.67	17.6			713
10/I/11	7.61	7.56	16.7	0.90	8.50	1163
1/I/36	7.12	6.23	141.6	2.11	7.01	1575
2/I/36	5.97	5.35	144.4			1463
3/I/36	5.88	5.70	500.4			2025
4/I/36	6.13	5.84	167.1			1350
5/I/36	6.33	6.15	86.8	1.41	10.3	2063
6/I/36	6.87	6.66	66.4			2588
7/I/36	6.92	6.69	77.5			2100
8/I/36	6.53	6.33	87.7			1125
9/I/36	6.80	6.53	45.9			938
10/I/36	6.78	6.63	37.2	3.07	13.1	1988

Table VIII Selected soil parameters — 3. sampling

Sample	pH/H_2O	pH/KCl	Cl^-, mg kg^{-1}	N(NH_4^+), mg kg^{-1}	N(NO_3^-), mg kg^{-1}	Content of soluble salts, mg kg^{-1}
1/I/11	6.86	6.68	87.6	0.96	7.86	1425
10/I/11	6.35	5.96	47.6	2.06	9.63	1350
1/I/36	7.07	6.66	282.6	1.10	8.13	1275
10/I/36	6.65	5.84	80.7	1.37	10.14	1650

Table IX Selected soil parameters — 4. sampling

Sample	pH/H_2O	pH/KCl	Cl^-, mg kg^{-1}	N(NH_4^+), mg kg^{-1}	N(NO_3^-), mg kg^{-1}	Content of soluble salts, mg kg^{-1}
1/I/11	7.27	6.84	180.5	0.96	4.17	1125
5/I/11	6.62	6.35	32.5	1.37	6.27	1200
10/I/11	7.06	7.00	31.3	1.52	8.68	975
1/I/36	6.86	5.87	158.9	2.26	8.83	1800
5/I/36	6.97	6.70	84.1	2.13	9.05	1838
10/I/36	6.49	6.07	47.6	1.12	7.86	1763

Table X Concentration of selected contaminants mentioned in "standard" in some oil samples

Sample/ Sampling	NEL, mg kg^{-1}	Hg, mg kg^{-1}	SO_4^{2-}, mg kg^{-1}	F^-, mg kg^{-1}	S^{2-}, mg kg^{-1}	CN^-, mg kg^{-1}
1/I/11 - 1.	129.6	0.55	25.6	< 0.1	< 0.01	< 0.04
1/I/11 - 2.	185.3		28.3	< 0.1	< 0.01	< 0.04
1/I/11 - 3.	145.25		6.2	< 0.1	< 0.01	< 0.04
1/I/11 - 4.	317.6		38.4	< 0.1	< 0.01	< 0.04
1/I/36 - 1.	83.1	0.08	32.2	< 0.1	< 0.01	< 0.04
1/I/36 - 2.	173.9		13.0	< 0.1	< 0.01	< 0.04
1/I/36 - 3.	218.8		15.4	< 0.1	< 0.01	< 0.04
1/I/36 - 4.	115.5		38.4	< 0.1	< 0.01	< 0.04

Table XI Concentration of PCB and PAH in selected soil samples

Sample	Content of PCB (congeners 28, 52, 101, 138, 153, 180) mg kg^{-1} of sample	Content of PAH (the sum of hydrocarbons: fluoranthene, benzo[b]fluoranthene, benzo[k]fluoranthene, benzo[a]pyrene, benzo[ghi]perylene, indeno[1,2,3-cd]pyrene)
1/I/11	386	3.393
5/I/11	33.8	0.304
10/I/11	15.7	0.217
1/I/36	1220	1.677
5/I/36	5.4	1.454

Table XI – Continued

Sample	Content of PCB (congeners 28, 52, 101, 138, 153, 180) mg kg^{-1} of sample	Content of PAH (the sum of hydrocarbons: fluoranthene, benzo[b]fluoranthene, benzo[k]fluoranthene, benzo[a]pyrene, benzo[ghi]perylene, indeno[1,2,3-cd]pyrene)
10/I/36	3.4	0.116
HnS	3.3	0.418
Domoradice	3.1	0.197

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