Institute of Hydrology

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Natural Environment Research Council

A hydrological study of the effects of the proposed A34 Newbury bypass on mire and heath at Snelsmore Common

Final Report

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1 INTRODUCTION

The proposed route of the A34 Newbury bypass cuts through the southern end of Snelsmore Common SSSI, an area of heathland containing three small valley mires. Two of the mires lie in a valley which will be crossed by an embanked section of the road. The road will pass through the ridges to east and west of this valley in cuttings (Figure 1.1).

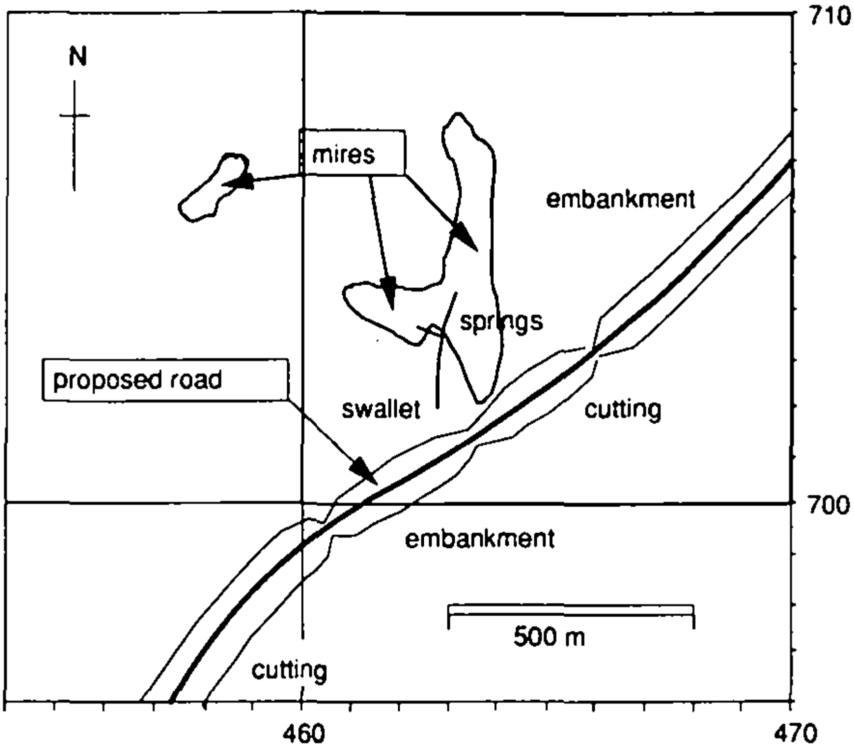

Figure 1.1 Sketch map of Snelsmore Common and the proposed A34 Newbury bypass.

The purpose of this study was to collect information to test the conclusions of an IH report dated 13 May 1988, which stated that the effects of salt spray from the embanked section of the road, and interference with the groundwater system by the cuttings, would be insignificant, owing to the low permeability of the underlying geological units, the London Clay and the Reading Beds, and the distance of the road from sensitive locations such as the mires and the springs feeding them.

The report includes a literature survey of work on the effects of de-icing salt, drawing on studies from the UK, the US and Canada. Many of these studies are linked to damage to trees and plants close to the road edge, and an important aspect of any investigation of salt transport is the range to which road salt in soils and vegetation is measurable, and its effects detectable. In general, the effects are confined to the immediate vicinity of the road, and careful selection of species to be planted on verges and embankments can reduce visual impact.

As part of the hydrogeological study, four new boreholes have been drilled on the ridges flanking the Snelsmore mires. Piezometers have been installed to allow the measurement of water level and sampling for water quality. Correlation of the strata encountered has added to the understanding of the conditions under which groundwater exists in the sandy horizons of the Reading Beds.

Soil samples taken from areas close to two trunk roads have been analysed to determine sodium and chloride concentrations. The influence of de-icing salt has been found to be confined to the area immediately next to the road, possibly within 10 m of the road edge, except where the road is embanked, and transport of salt in spray is possible to greater distances. This has important implications for the proposed road at Snelsmore.

The report is presented in two volumes. The second volume contains the data collected and analysed during the study, under the following headings:

- A.1 1985 geotechnical boreholes
  - A.1.1 Water levels
- A.2 Boreholes A to D
  - A.2.1 Location and construction
  - A.2.2 Lithological logs
  - A.2.3 Water levels
- A.3 Major ion analysis
  - A.3.1 Snelsmore mires and streams
  - A.3.2 Piezometers
  - A.3.3 Bratley Arch streams
- A.4 Soil sampling transects
  - A.4.1 Broadmoor Coppice
  - A.4.2 Bratley Arch heathland
  - A.4.3 Bratley Arch woodland
  - A.4.4 Snelsmore Common

2 LITERATURE SURVEY

It has long been recognised that salt added to highways as a de-icing agent has effects on the soil and plants adjoining the road, as well as causing a water quality problem in surface waters draining the carriageway. At Snelsmore, the road is downstream of the swallet which receives streamflow from the SSSI, and surface waters in the SSSI are not in danger from road runoff. However, the prospect of transport of de-icing salt in spray and in particulate form from the elevated section of the road does give rise to concern that sensitive heathland and mire systems may be affected.

The impact of roads, chiefly of de-icing salt, on the plant communities of verges and central reserves has been the subject of many investigations. While the detail of methods, and the range of plant species and environmental conditions covered, varies from study to study, a consistent picture can be built up of the processes involved, and the distances over which they operate.

2.1 Processes of salt transport

Rock salt, mixed with grit, is applied to road surfaces during and in anticipation of frosty weather and snow, and is mostly removed by runoff generated either by melting snow or rain. A mere 4 mm of rain is sufficient to remove the salt applied (Colwill *et alia* 1984)[1].

If dry weather follows the application, entrainment of crystals or encrusted grit particles by vehicle generated turbulence, exacerbated by crosswinds, results in the lateral transfer of salt from the road on to central reserves and verges. Transport of solid salt in this way, followed by rainfall, has resulted in apparently very high concentrations in rainfall samples taken near roads, occasionally higher than the concentrations found in runoff (Colwill *et alia* 1984).

In wet weather following salt application, salt from the road and from vehicle surfaces mingles with rain and is transported by turbulence. Colwill *et alia* (1984) estimated that losses of water from the road area in the form of spray did not exceed 10% of the total rainfall, so that the majority of salt left the road in runoff, finding its way into the drainage system.

Ploughing, which occurs in combination with salting when the snow depth exceeds 20 mm, deposits salt with snow on the verges, and this is another important process whereby salt can reach roadside soils close to the road edge (Colwill *et alia* 1982)[2].

Spray and salt drift may affect roadside plants directly, by intake from leaf surfaces, but the majority of the salt carried in this way reaches the ground directly, by incorporation into rainfall, by throughfall through the plant canopy or by stemflow down the stems or trunks of vegetation. Sodium and chloride ions, dissociated in solution, display differential behaviour in the soil. The chloride ion, being negatively charged, is not readily fixed by soil colloids, and leaches out relatively rapidly, while sodium is taken up by the cation exchange complex of the soil, though it is not as tightly held as other ions, e.g calcium and magnesium (Schraufnagel 1967)[3]. Sodium accumulates in salt-affected soils twice as fast as chloride, and chloride in soils is not considered a problem (Westing 1969)[4]: this statement is corroborated by the observation by Hutchinson and Olson (1967)[5] that chloride concentrations (expressed in meq/g) were about half that of sodium in the verge of a road that had been salted during one winter.

The leaching rate, and hence the rate of increase of sodium and chloride in the soil adjacent to a road, varies greatly in response to soil type and climatic conditions. Hutchinson and Olson (1967), working on highways in Maine, found increased sodium levels after one winter's salting, 5-fold at the road edge (within 150 mm of the edge), and measurable increases up to 9.2 m from the road. After 2-3 years salt application at a different site, sodium levels had increased 4 to 8-fold at the edge of the road, and were detectable up to 10.7 m away. Next to a road that had been salted for 18 years, there was a 15-fold increase at the road edge, and an 8-fold increase at 13.7 m.

On the other hand, studies at eight sites in the north of England led Colwill *et alia* (1982) to the conclusion that a balance between leaching and deposition was reached after 3 to 4 years for sodium, and 1 to 2 years for chloride. Rutter & Thompson (1986)[6] described the construction of a mathematical model to predict changes in sodium and chloride concentrations with time and depth in the soil of a central reserve. The model took account of application rates, and of the differential vertical movement of sodium and chloride, resulting from the higher mobility of the chloride ion. The accuracy of prediction of the model was sufficient to enable the authors to predict whether given combinations of climate and salt usage would lead to suitable conditions for the establishment of shrubs on the central reserve.

2.2 Effects of salt on roadside plants

Because of the variability in the processes of salt transport, it is difficult to design an intensive investigation of the physical processes themselves. Most field studies have therefore attacked the problem in one of two ways, by measuring the effects on plant communities and attempting to attribute these either to spray drift or changes in soil salinity, or by direct measurement of salt concentrations in the surface soil. It is relevant at this point to consider the effects of salt on plants, insofar as these can be used as an indicator of the spatial range of transport processes and as a means of distinguishing spray and soil effects.

There are several ways in which salt reaching roadside vegetation and soils may have an impact. Many plants absorb nutrients from the surface of the leaves, and direct absorption of sodium and chloride, from solutions on the foliar surfaces, often concentrated by dry weather, can give rise to toxic concentrations in the leaf. Toxicity is usually shown by tip die-back and chlorosis or yellowing of the leaves. Absorption by roots of salt deposited on the soil is another important pathway for the assimilation of salt into the plant, where it may affect the transport of nutrients. Lastly, high concentrations of sodium in the soil as a result of salt deposition reduce the availability of potassium, and in extreme cases, when the exchangeable sodium percentage exceeds 15%, sodium can de-flocculate the soil and reduce its permeability and water-holding capacity. Under the worst conditions, this may occur in a narrow strip along the road edge (Davison 1971)[7], and in central reserves (Colwill *et alia* 1984). Ranwell *et alia* (1973)[8] quoted a study by Hutchinson (1968)[9] which recorded exchangeable sodium percentages as high as 17% in roadside soil in Maine, USA. Concentrations of 275 ppm of sodium and 100 ppm of chloride (relative to dry weight of soil) were between 6 and 100 times greater than the normal soil concentrations.

The spatial variation in damage to roadside trees by airborne salt was investigated by Hofstra and Hall (1971)[10]. Spray drift damage was detected up to 120 m from highways after a particularly severe winter in Ontario (1969-1970). Damage was greatest on trees in exposed positions, as far as 150 m from the road, but there was no injury in dense parts of a stand at 100 m. A clear relationship between leaf damage and height above the ground added further evidence to the hypothesis that the damage was caused by spray, rather than lateral movement of salt through the soil. Injury levels were found to be closely related to foliar concentrations of chloride.

Dickinson (1968[11], quoted by Ranwell *et alia* 1973) described spray drift damage in the form of browned pine needles up to 4 m from the ground, and this is corroborated by Sauer (1967[12], quoted by Ranwell *et alia* 1973), who noted damage to heights of 3 to 4 m or more in Germany.

Leaf absorption is most dangerous with intermittent wetting: Bernstein (1975)[13]stated that as little as 2 or 3 mg/l of sodium or chloride in spray may cause severe leaf damage, as the concentration of ions in solution was increased greatly by evaporation from the leaf surface. However, accumulation in the leaves is partially compensated by leaching from the leaves during rainfall (Westing 1969).

In Ontario, Hofstra and Smith (1984)[14] measured sodium and chloride concentrations in live vegetation, leaf litter and surface soil to a depth of 150 mm in April, August and November, in the central reserve and at distances of up to 200 m from the carriageway. Elevated levels of sodium and chloride were found in the central reserve and within a strip 30 m each side of the carriageway (Figure 2.1). Outside this strip, there was no measurable change from background levels. Chloride was found to be more mobile than sodium, and its concentration decreased over the summer.

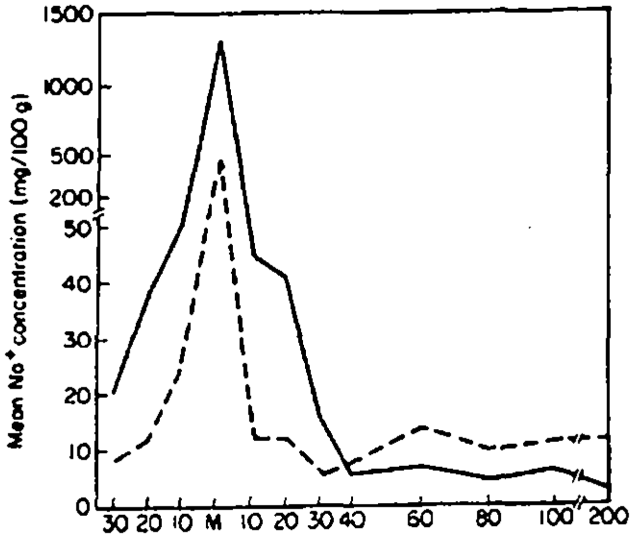

Figure 2.1 (from Hofstra & Smith 1984) Sodium levels (mg/100g dry weight) of litter collected during April (_____) and August (- - - -) 1974. Sample marked 'M' is from the central reserve (median) of the highway: distances along the foot of the graph are in metres from the edge of the carriageway, with north (upwind) at the left of the figure.

A study by Imperial College London was commissioned by the Transport and Road Research Laboratory (TRRL) with the objective of assessing the conditions for plant growth on motorway central reserves and verges, and was carried out in association with trials by TRRL. The first paper in the series (Thompson *et alia* 1986a)[15] concentrated on the extremely severe conditions in the central reserves, subject to the combination of salt transport from both carriageways and buffeting by turbulence from high-speed traffic. The sampling network was designed to cover variations in sodium over the year, with altitude and region, and to correlate this with application rates derived from the logs of salt-distribution vehicles. Sodium was found to be preferentially retained relative to chloride in the soil by cation adsorption, and in general the ionic ratio of chloride to sodium (with both concentrations measured in meq/l) varied between 0.2 and 0.4, with occasional high values of 0.7-0.95 occurring immediately after application and deep in the soil profile in April. Highest concentrations of both sodium and chloride were found in April in the 0-50 mm layer of the soil profile: later in the year sodium had been transported to greater depth, and chloride had been removed from the profile. Spatial and temporal changes in both elements were far more pronounced for northerly sites on the M62 and M63 than for the M1 and M27.

The spatial variation of sodium concentrations across both verges and central reservation was the subject of a second paper by the Imperial College team (Thompson *et alia* 1986b)[16]. Data from a selection of motorways indicated that on the verges background levels of sodium were approached at about 10 m from the carriageway (Figure 2.2). Much higher concentrations in the central reserve were attributed to the higher speed of vehicles in the overtaking lane than in the nearside lane. The transport of sodium from road to verge was found to be strongly related to the alignment of the road: prevailing south-westerly winds would have been expected to give rise to higher concentrations on the northern or eastern verges, and the ratio between soil sodium concentrations on the two sides of roads at six sites was found to vary between 1.22 and 2.68. In the Snelsmore context, the paper presented an important data set relating to the effect of a hedge in the central reserve, which appears to increase the concentration of sodium in the soil beneath the hedge.

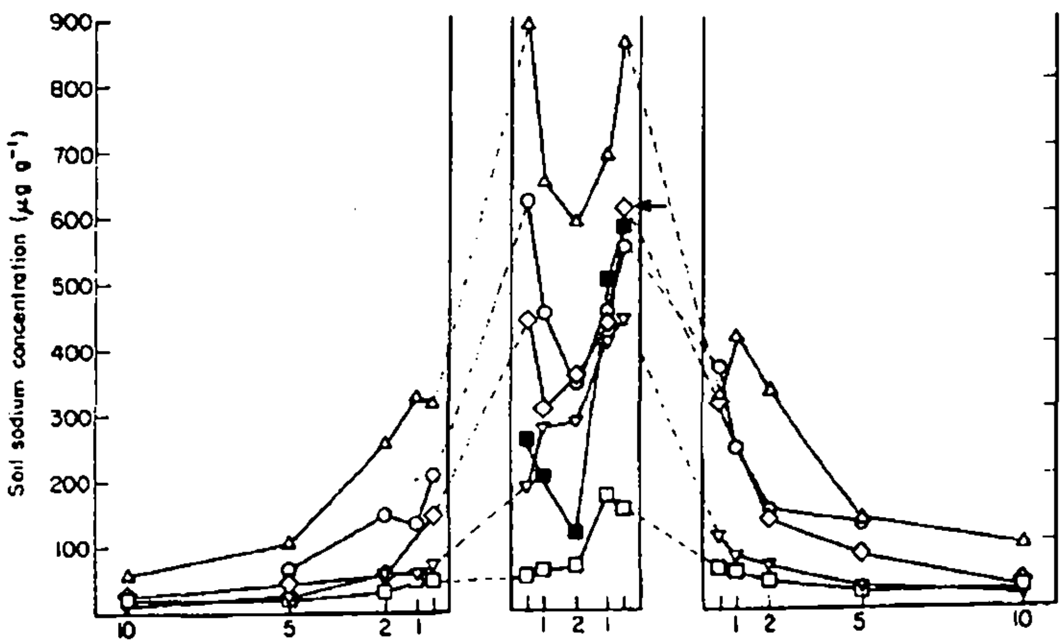

Figure 2.2 (from Thompson et alia 1986b) Distribution of soil sodium concentrations across the verges and central reserve at five sites, April 1974 except where stated. North- or west-bound traffic on left of figure. Distances measured from hard shoulder on verges and from carriageway on central reserve. Drainage outward from central reserve, except where indicated by arrow. Circles M1, 258.4 km; triangles (Δ) M1, 29.1 km; inverted triangles (∇) A1(M), 1.1 km; open squares M4, 18.3 km; Filled squares M4, 18.3 km, April 1975; lozenges M62, 62.8 km.

The construction of a road and driving practice may have effects on the transport of salt as spray. The hard shoulder, present on all motorways in the UK except near bridges, reduces concentrations of salt in the soil of the verge by between 30% and 70% (Thompson *et alia* 1986b), as might be expected from the lack of moving traffic on the hard shoulder. It was also noted that the absence of a hard shoulder led to lower concentrations at a given distance from the edge of the carriageway, presumably because of kerb-shyness at the exceptional sites where there is no reassuring hard shoulder, and crash barriers or fences approach the carriageway.

Where storm drainage is not provided, direct runoff can take place on to low-lying verges. In this case topography can have important effects on the damage to plants. Button (1964[17], quoted by Ranwell *et alia* 1973) found that sugar maple trees within 3 m of the road but on a slope above it were not damaged, while trees downslope of the road were susceptible to brine drainage and injury. A similar result was reported by Fleck *et alia* (1988)[18]: plots were examined above and below a contour road on a 70% hillslope. Far fewer healthy and slightly stressed white birch trees were found on the downslope side. Values of sodium in the soil in April were about 10 times higher than on the upslope side.

2.3 Salt tolerance

Salt tolerance is a complex issue, and it is important to separate out the effects of salt spray impinging directly on foliage, and the effects of salt uptake from the soil and the grosser phenomena of saline soils, where physical properties are affected. Tolerance to spray appears to depend partly on the extent to which nutrients are absorbed by leaf surfaces under normal conditions, and it varies widely among plant species. Grassy vegetation is in general more resistant than woody plants, but it is virtually impossible in this case to distinguish the effects of spray from those of salt in the soil.

There appears to be a difference in the tolerance of evergreen and deciduous trees and shrubs to salt spray. Colwill *et alia* (1982) found little evidence that deciduous trees and shrubs growing on English motorway verges were damaged by spray, while severe browning of needles of Scots pine and larch was noted up to 15 m from the carriageway after the winter of 1978-9, and damage was widespread on conifers and gorse after 1981-2. On the other hand, Hofstra and Hall (1971) found Scots pine to be moderately tolerant of salt spray.

The resistance of oaks to the effects of high concentrations of salt in the soil may be due to the great depth of their root systems (Holmes 1961[19], Westing 1969). Holmes (1961) investigated the effects of intense runoff from salted roads by flooding the ground around trees with saline water: even under these extreme experimental conditions, little chloride found its way into leaves and twigs of white oak *(Quercus alba)* trees, but red maple *(Acer rubrum)*, black birch *(Betula nigra)* and white pine *(Pinus strobus)* were killed. Soil levels of chloride in excess of 200 ppm were considered likely to cause damage.

Colwill *et alia* (1982) considered that salt in the soil was a negligible hazard to plants at distances in excess of 5 m from the hard shoulder of a British motorway. The most sensitive plant species are killed, and growth was markedly reduced in other plants, when sodium in the soil exceeds 1400 ppm, and chloride exceeds 600 ppm (expressed relative to dry weight of soil).

The preparation of lists of trees and shrubs tolerant to environmental factors such as soil salinity or salt spray is fraught with difficulty. There are few controlled experiments which take into account all the factors, and combinations of factors, involved in the survival of plants in the field. Often the best guide is obtained from observations such as that by Colwill *et alia* (1982) that birch, sycamore and hawthorn appear to thrive on the verges of the A1(M), as do oak and beech. Even species listed as salt sensitive on some counts may be suitable for the more sheltered stretches of road along the M27 and M40, for example.

Shortle and Rich (1970)[20] gave lists of tolerant and intolerant tree species found on New Hampshire roadsides. Unfortunately none of these is a native British tree, but the list of tolerant species included two oaks and four birches, while the intolerant species included two pines and an alder.

A more useful list was quoted by Hayward and Bernstein (1958)[21] from a Dutch study by Butijn (1954)[22]: osier, white poplar, hawthorn and elm were relatively tolerant of soil salinity. A similar Dutch study, by van der Linde and van der Meiden (1954)[23], based on studies following the 1953 flooding in the Netherlands, lists the pedunculate oak *(Quercus robur)*, the white poplar *(Populus alba)*, the grey poplar *(Populus canescens)* and the English elm *(Ulmus campestris)* as the most resistant. Beech *(Fagus sylvatica)*, sycamore *(Acer pseudoplatanus)* and hazel *(Corylus avellana)* were very sensitive to salt remaining in the soil after flooding. Mature oaks are known to survive on silts in the Fal estuary in Cornwall, with up to 600 mg/l of sodium in the soil solution (Ranwell *et alia* 1973). Ranwell *et alia* (1973) recommended that beech should not be planted within 10 m of the edge of principal roads.

Important data on the tolerance of various shrub species to salt spray and soil concentrations of sodium chloride were provided by the final phase of the Imperial College study, reported by Thompson and Rutter (1986)[24]. Eleven native British shrub species were used in the experiments, and were subjected to both salt spray and irrigation of the soil under controlled conditions. It was found that the effect of spray falling directly on foliage was less significant than the effect of increased soil concentrations. The results were presented in the form of a table of three groups of high, medium and low tolerance to salt in the soil. The boundaries between groups in this table were used in the preparation of a map of salt hazard to the establishment of shrubs in the central reserves, based on the predictions of the model developed by Rutter and Thompson (1986) and taking account of salt application rates and winter rainfall. In general, the south of England was an area of low to intermediate risk, although the Chalk hills came out as high-risk areas because of high salt application rates and relatively low rainfall.

A similar table of tree species, derived from a literature survey and the results of Department of Transport trials, was presented by Colwill *et alia* (1982). Native trees in their table included:

Tolerant: - the pedunculate oak

Intermediate tolerance: - alder, ash, silver birch. Scots pine is intolerant of salt spray, while willows were especially resistant to spray

Salt sensitive: - Sycamore (resistant to spray), hawthorn (though it has performed well on the M40 and M4). Beech, holly, rowan and yew all respond badly to salt spray.

There was insufficient evidence to place the downy birch *(Betula pubescens)* in the table, but some evidence suggested that it was intolerant of spray. Gorse appeared to have survived well on the M40.

2.4 Investigations of salt transport

The effects of road salt fall off rapidly with distance from the road edge, and are most obvious on surfaces directly exposed to spray. Hall *et alia* (1973)[25] analysed leaves from sugar maples (*Acer saccharum)* between 1 and 7.6 m from a highway at Guelph, Ontario. Leaves on the side of the tree nearer the road were significantly more damaged than those on the far side, and contained higher concentrations of sodium and chloride, but no differences were noted in nitrogen, phosphorus or potassium, suggesting that the injury was not caused by interference with nutrient transport. Higher sodium concentration and electrical conductivity were also noted in soils on the road side of the trees.

Ranwell *et alia* (1973) sampled verges at seven sites distributed about the UK, and found that mean sodium concentrations in soils along the road edge varied between 244 and 904 ppm. By visual inspection, damage to the grass was found to be more severe at sites with a flush kerb as opposed to a raised kerb, suggesting that direct runoff may be important in transferring salt to the soil immediately adjoining the road surface. A more intensive survey at one site with a broad level verge showed that sodium concentrations in soil and vegetation were very high within 2.5 m of the road edge, but relatively uniform and low for distances greater than 2.5 m (Figure 2.3).

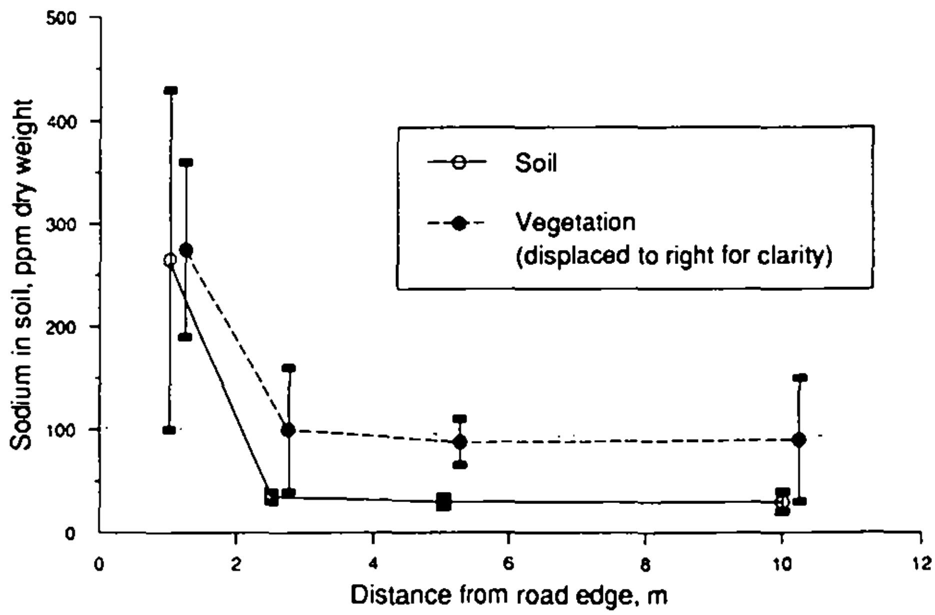

Figure 2.3 Variation of sodium concentration in soil and vegetation on a grass verge (Ranwell et alia 1973). Each point is the mean of 10 samples, and error bars indicate ± 2 standard errors. In the interests of clarity, the points for sodium in vegetation have been displaced slightly to the right.

It would be expected that the transport of salt in spray would depend upon the speed of traffic, but only one study, that by McBean and Al-Nassri (1987)[26], has sought to explore the relationship by field measurements. The total salt content of the snow-pack was measured at 1 m intervals up to 37 m from the road edge, along stretches of road with speed limits of 50, 60, 70, 80 and 100 km/h. For all the roads considered, 90% of the salt falling on the verge fell within 13 m of the road. For the three slower roads, there was an increase in the spatial spread of salt, but the practice of ploughing snow to greater distances from the fastest roads may have led to confusing results for roads with 80 and 100 km/h limits.

The most extensive study of the water quality effects of road development was carried out by the US Geological Survey (Harned 1988)[27] in North Carolina. The investigation, which was on a catchment scale and covered 45.3 sq.km and a road length of 7.7 km, was mainly concerned with the chemistry of runoff into the drainage network, but soil sampling and spray and dust collection also formed part of the study. A wide range of pollutants was considered, from major ions and metals to trace organics.

The USGS study did not include the measurement of sodium and chloride in spray, but total particulates, lead and other trace metals were determined in the catches of dust-buckets at various distances from the carriageway. Lead and particulate fall-out fell away rapidly with distance from the road, with background levels being reached at about 12.2 m from the road on the downwind side (Figure 2.4). Lysimeters were used for sampling of soil waters, but inundation from road runoff affected the results, and the concentrations determined, which do not show any consistent variation with distance from the road, may represent soil water or worst-case surface runoff.

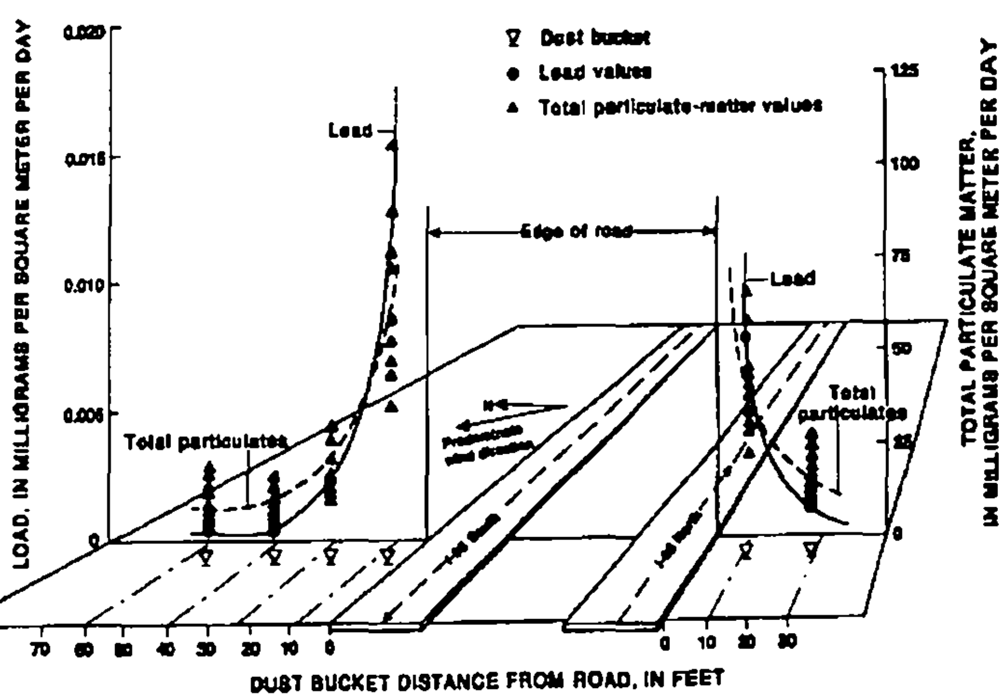

Figure 2.4 (from Harned 1988) Lead and particulate fallout near highway station R2, Sevenmile Creek catchment, North Carolina.

Very close to the road edge, stress on plant communities is clearly visible in floristic changes and even areas of bare soil. Davison (1971)[28] reported a study of two sites alongside the A1 in Northumberland, taking soil samples from the grass verge between 300 mm and 4 m from the edge of the carriageway. Soil sodium, in particular the exchangeable sodium percentage, was extremely high at the road edge, and high sodium levels were also found in mature leaves taken in early autumn, and in seeds. It was concluded that the very high concentrations of sodium near the road edge at the start of the growing season could inhibit the growth of vegetation by causing osmotic stress and altering the nutrient balance.

The transport of particulate matter from road surfaces is of great importance to the issue of pollution by heavy metals, particularly lead in the form of the petrol additive tetraethyl lead. Pasture grasses sampled next to two highways in the US (Cannon and Bowles 1962)[29] showed between 100 and 700 ppm of lead in their ash content within 1.5 m of the road, decreasing to <5 to 50 ppm 150 to 300 m from the road. The scatter of results made it difficult to establish a clear variation with distance: some stations showed 200 ppm of lead at distances in excess of 150 m.

The foliage of roadside trees, shrubs and hedges acts to remove particulate matter from the air: Keller (1979)[30] demonstrated that even very small particles are affected. Moss samples exposed in a field adjacent to a road, in a field protected by a hedge and in deciduous forest showed lead contents falling to one third of the roadside level within 5 m in the hedged field and the forest. The same decrease in concentration occurred over 25 m in the unprotected field.

2.5 Effects of salt on mire vegetation

Roadside salt dumps represent a very intense point input of salt to the drainage system. One such dump, on the edge of what was arguably the most important acid mire in Indiana, gave rise to measurable changes in the vegetation of the mire, reported in detail in a series of papers (Wilcox 1984[31], Wilcox 1986a[32], Wilcox 1986b[33], Wilcox and Andrus 1987[34]).

Pinhook Bog is a basin mire with a floating peat body partly surrounded by a "moat" of open water. Its waters are acid (pH 3.68, electrical conductivity 64 µS/cm). Drainage from the salt dump resulted in a rise in sodium concentration in the impacted area: annual mean concentrations rose as high as 468 mg/l of sodium and 1215 mg/l of chloride. Elimination of the salt source led to a decrease in salt levels from 1979 to 1981, but this was followed by slight rises in 1982 and 1983. The salt load accumulated in the surface peat and dissipated slowly by downward transport. In the dry years 1982 and 1983, evaporative demands resulted in an upward movement of salt, and increasing surface concentrations (Wilcox 1986a).

In the area affected by the salt, mire species were believed to have been killed off, and replaced by more salt-tolerant species such as reedmace. Maps of water chemistry were matched against species distributions to arrive at salt tolerance limits for a range of plants (Wilcox 1986b). Two species and one genus are of possible relevance to Snelsmore: the long-leaved sundew, *Drosera intermedia*, the white beak-sedge, *Rhynchospora alba*, and the bog-moss *Sphagnum*. The tolerance level for *Drosera* and *Rhynchospora* was found to be 360 mg/l of sodium chloride, i.e. 142 mg/l of sodium and 218 mg/l of chloride, that for *Sphagnum* was 770 mg/l of salt, i.e. 303 mg/l of sodium and 463 mg/l of chloride.

More detailed work on the *Sphagnum* mosses showed important differences between species. The growth habit of *Sphagnum* mosses varies between mat-forming and hummock-forming species. While the mat-forming species are in intimate contact with the water, and hence are susceptible to changes in its chemistry, the hummock-forming species can develop a degree of isolation from the main water body. At Pinhook the mat-forming species are represented by *Sphagnum recurvum*. No live *S. recurvum* was found where chloride levels exceeded 500 mg/l. In laboratory experiments (Wilcox 1984) the tips of *S. recurvum* exposed to salt and high evaporation rates became encrusted with salt, and this was thought to be a mechanism leading ultimately to the destruction of the moss. Chloride was found to be a stronger growth inhibitor than sodium, and there was significant reduction in the growth of shoots exposed to chloride concentrations between 300 and 1500 mg/l.

Re-colonisation of the impacted area of Pinhook Bog was partly by the hummock-forming moss *Sphagnum fimbriatum*, which is usually found in minerotrophic peatlands and can grow in moderately calcareous waters (Wilcox and Andrus 1987). Its tolerance level appears to be about 300 mg/l of chloride.

3 HYDROGEOLOGY

The 1988 IH report (Gilman 1988)[35] summarised the geological information available from exploratory drilling which was carried out as part of the geotechnical survey in 1985.

The Tertiary aquifer, the probable source of any springs on the Common, consists of a series of alternating layers of sand and clay. Osborne White (1907)[36] described a profile in a pit at Shaw, which passed through London Clay, Reading Beds and Chalk. The London Clay was composed of a brown clay passing into a Basement Bed of brown sandy clay with ironstone. The Reading Beds were variously coloured mottled plastic clays, with sand near the middle of the layer. The upper half of the 7.6 m thick Reading Beds profile was composed of white and light-coloured sands, with a thin bed of pale bluish grey clay, very coarse at the base, while the lower half was a dark bluish grey shaly clay with green sand, pebbles and oyster shells, sitting on the piped upper surface of the Chalk. The Reading Beds tend to thicken towards the centre of the London Basin: near Reading there is 9 to 15 m of clay overlying 6 to 12 m of sand (Sherlock 1960)[37].

The Plateau Gravels consist of subangular flints, pebbles and coarse yellow, orange, green or white sands, and are the parent material for the soils of the heathland at Snelsmore. Small sarsens embedded in the gravels appear to have been set on end by periglacial processes (Osborne White 1907).

The junction between the London Clay and the Reading Beds is marked by bands of impure flaggy limestone and flint pebbles. This Basement Bed, which also contains concretions of clay-ironstone, is usually distinctly sandy.

3.1 Groundwater conditions

Water level measurements carried out in early 1985 suggested that the piezometric surface followed roughly the form of the ground surface, being within 8 m of the ground surface along the western ridge of the dry valley (Appendix A1).

The cuttings associated with the proposed road intersect the narrow ridges flanking the dry valley: the natural ground surface rises to about 132 mOD in each ridge, the easterly cutting falls eastwards from 123 mOD to 121 mOD, and the westerly cutting falls westwards from 121 mOD to 106 mOD. Uncertainty about present groundwater levels beneath the ridges has been resolved by the installation of four new boreholes, at SU 46097009, SU 46167020, SU 46397029 and SU 46457043 (Appendix A2.1 and Figure 3.1).

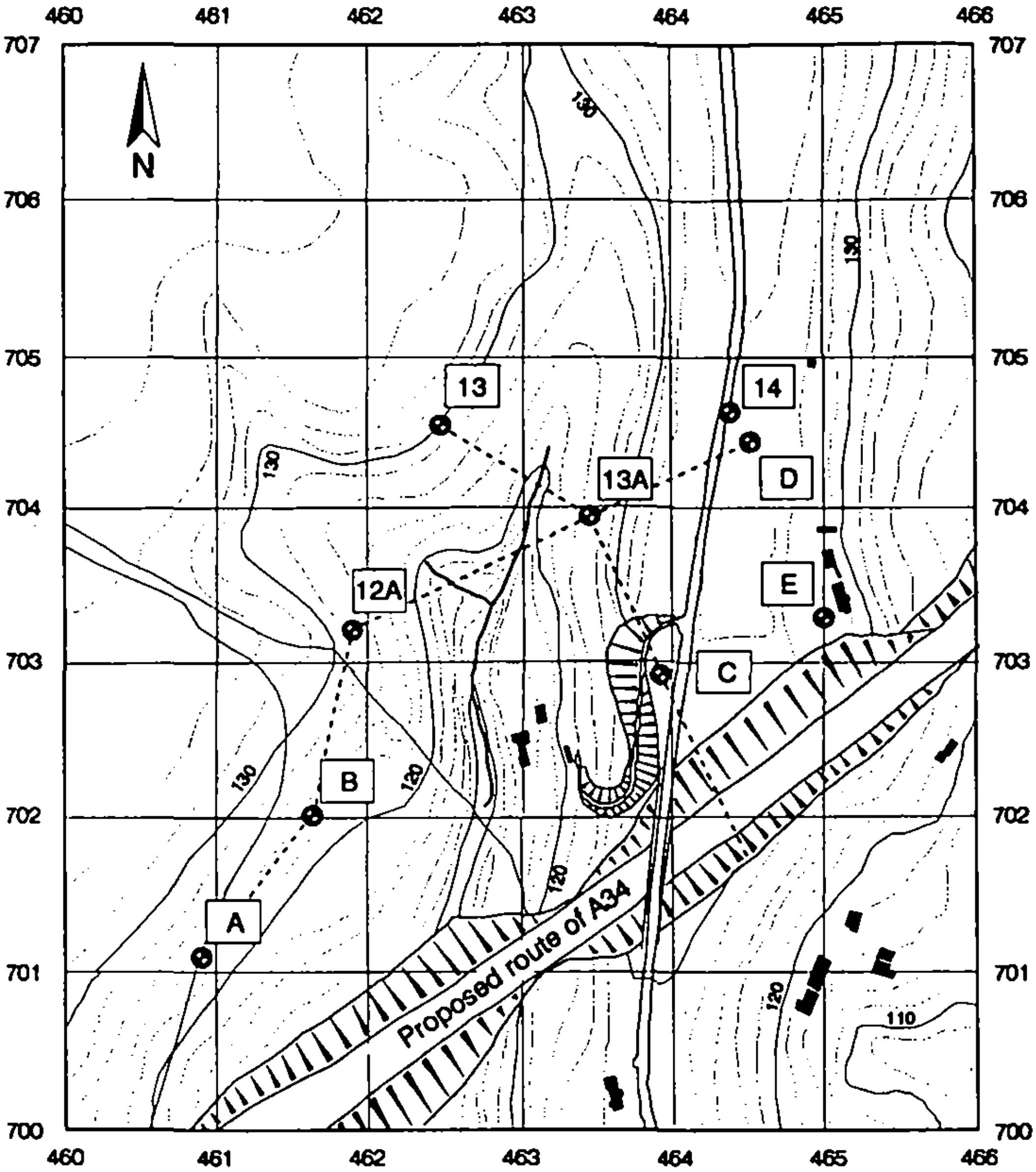

Figure 3.1 Location map of boreholes at Snelsmore. The boreholes numbered 12A, 13, 13A and 14 are from the 1985 geotechnical survey: A, B, C and D were drilled in spring 1991, and E is a well at Woodsprings (SU 46507033) which has been used for water level measurements only.

On the western ridge, two boreholes, A and B, were drilled to depths of 14.6 m through silt, clay and sand into the Chalk.

Water was struck in borehole A (SU 46097009) at 7.6 and 9.7 m below ground level (bgl), i.e. at 114.7 and 112.6 mOD. Between 4 m and 8.5 m the driller's log indicated fine-medium sand, and the hole was gravel-packed and screened from 8.0 to 8.5 m, to allow ingress of water from the base of this layer. Below 8.5 m the deposits were a rapidly alternating sequence of clayey silt, fine-medium and silty sand and clay bands, none of which was judged to constitute an aquifer, even by the rather relaxed standards normally applied in the context of the provision of minor spring flow. The Chalk was reached at 14.1 m bgl (108.2 mOD).

Water was struck in borehole B (SU 46167020) at 7.3 and 8.4 m bgl, (115.3 and 114.2 mOD). The hole was screened between 7.3 and 7.5 m and between 8.8 and 9.1 m, to sample bands of fine-medium sand and fine sand respectively. The upper layer, of fine-medium sand, extended from 3.6 to 7.5 m, and can probably be correlated with the thick sand layer in borehole A. Two piezometers were inserted, B/1 in the upper layer and B/2 in the lower fine sand layer. Subsequent measurements of water level between May and September 1991 have demonstrated that the upper and lower sand layers are hydraulically isolated, the water levels differing by about 0.7 m. The Chalk was reached at 14.1 m bgl (108.5 mOD).

To the east of the dry valley, two boreholes, C and D, were drilled. Both passed through gravel overlying a mainly sandy sequence. The Chalk was not reached, and drilling was terminated at about 113 mOD, when a clayey silt layer was encountered in both holes. It was not considered worthwhile to screen the boreholes where they passed through the gravel, as no appreciable groundwater was encountered in this horizon, and the gravel capping of the Common is at too high an altitude to provide spring flow to the mires.

Water was struck in borehole C (SU 46397029) at 9.6 and 20.1 m bgl (124.9 and 114.4 mOD). The hole was screened between 9.7 and 10.1 m, and between 20.0 and 20.3 m, in prominent layers of fine sand. The lower sand layer extended from 14.2 to 20.4 m, while the upper layer was thinner, from 8.9 to 10.1 m. Two piezometers were inserted, C/1 in the upper layer and C/2 in the lower layer. Water level measurement has shown that only about 0.6 m of the lower layer is saturated, and that the upper layer is a perched aquifer, in which the saturated depth is about 0.8 m.

Water was struck in borehole D (SU 46457043) at 9.82, 19.54 and 20.18 m bgl (125.8, 116.0 and 115.4 mOD). The hole was screened between 10.0 and 10.3 m, 19.8 and 20.1 m, and 21.4 and 21.6 m in fine sand layers. Of these, the two upper layers are thicker, extending from 9.5 to 10.4 m and from 15.1 to 20.3 m. Three piezometers were inserted, D/1 to D/3. The middle layer, which can probably be correlated with the lower sand horizon in borehole C (piezometer C/2), though thick, is only partly saturated: water level measurements have shown a saturated depth of 0.6 m. The lowest horizon is hydraulically confined by a horizon of grey silty clay, and has a piezometric surface about 1.45 m above the top of the sand layer.

Lithological logs, presented in Appendix 2.2, suggest that the majority of the Tertiary unit can be identified as Reading Beds, brown clays and silts indicative of London Clay being present only in the upper 4 m. A band of light grey silt is found in each of the profiles, but only in boreholes C and D does it, and associated silty clays, separate the sands of the Reading Beds into two distinct units. The light grey silt occurs at depths between 2 and 4 m in boreholes A and B, with no appreciable sand unit above. The variability in thickness of the London Clay unit is consistent with the description offered by Osborne White (1907):

> "The long hill" [of Snelsmore Common] "stretching from the south of Chievely to Donnington, consists of the Reading Beds, capped ***in parts*** by London Clay, and nearly the whole thickly covered with flint gravel."

Probable correlations of the sand and silt horizons in the various boreholes, based on the three major sand beds, are shown in Figures 3.2 and 3.3, which are based on the two section lines shown in Figure 3.1. Bedding is seen to be approximately horizontal.

The Chalk was encountered at about 108 mOD in boreholes A, B and 12A. The basal bed of the Reading Beds, indicated by shell debris and flints, was found at 110 mOD in borehole 13 and 111 m in borehole 13A of the 1984 survey. Drilling of boreholes C and D ceased when grey clayey silt was encountered at 20.4 m and 21.6 m bgl respectively, i.e. at 114 mOD. This silt can probably be correlated on the grounds of colour and texture with the stiff laminated dark grey silty clay that was reached at 113.5 mOD in borehole 12 and 114.7 mOD in boreholes 13 and 13A. In borehole 13 drilling was terminated at 20.5 m bgl after 1.6 m of the basal shelly sand: drilling of borehole 13A ceased after 0.9 m of the basal sand. Thus the upper surface of the Chalk at the locations of boreholes C and D would be expected to lie at or below 109 mOD.

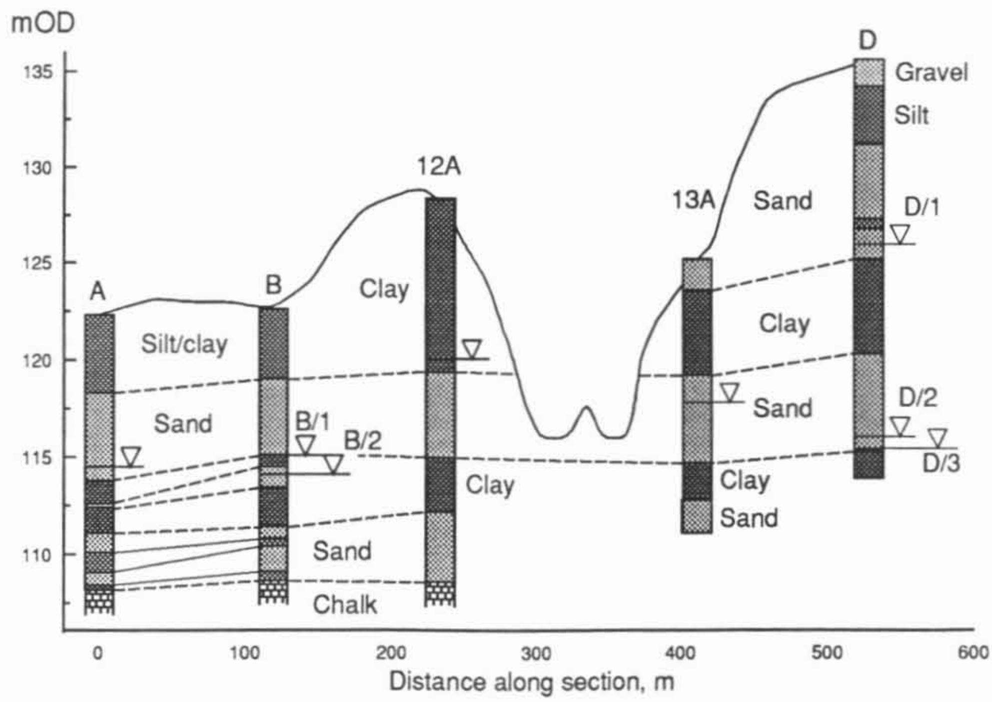

Figure 3.2 Lithological correlations between boreholes of the 1984 and 1991 surveys, for the SW-NE section between boreholes A and D.

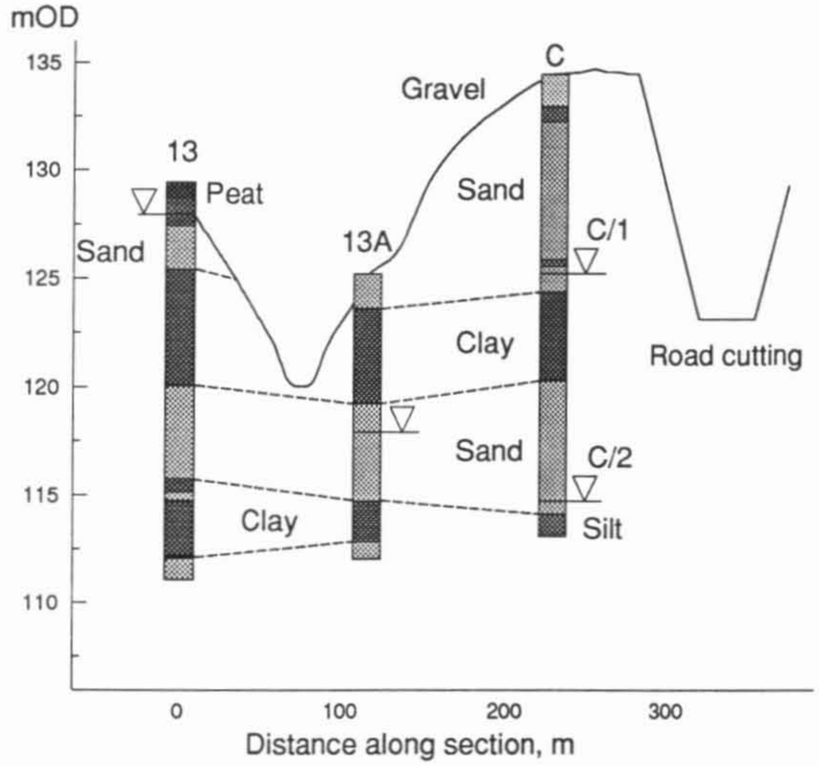

Figure 3.3 Lithological correlations between boreholes of the 1984 and 1991 surveys, for the NW-SE section between boreholes 13 and C. The section line is continued across the proposed road cutting.

3.2 Water level measurements

During the study, it has proved possible to locate and re-commission two of the 1984 boreholes, 12A (SU 46197032) and 13A (SU 46367040). In addition, a shallow well at Woodsprings (SU 46507033) has been surveyed and incorporated into the water level network. Surface expressions of boreholes 13 and 14, data from which were used in the 1988 report, appear to have been obliterated, and the cap of borehole 12A was destroyed in summer 1991 during tree-felling operations.

The piezometers in the network were read at two-weekly intervals during the summer of 1991: the records from the piezometers are presented in Appendix A2.3. Water levels in boreholes 12A and 13A were within 0.4 m of those recorded in 1985, and the well at Woodsprings (E) follows piezometer D/1 very closely, suggesting that it taps the same perched aquifer. Average water level measurements have been added to Figures 3.2 and 3.3 to show the general variation in water levels over the southern tip of the Common.

The aquifer system is a stack of sand horizons separated by silt and clay. Although the lower aquifer units, for example the sand layers tapped by piezometers D/2 and D/3, probably contribute springflow to the stream near Cromwell's Glen (Gilman 1988, p4), any springs feeding the mire system must drain aquifer units above 121 mOD. This limits the field to the uppermost sand aquifer unit represented by piezometers C/1 and D/1 and the well at Woodsprings, and the Plateau Gravels. Borehole 13 probably intercepted the lowest part of the sand unit, and the high water level in this borehole suggests that spring flow may be occurring at this point.

The proposed road cutting will intercept the C/1 sand layer, and some drawdown may result. However, available information suggests that the upper surface of the clay layer below dips towards the mire, and drawdown towards the road cutting, even if it lowered the water level in piezometer C/1 by 0.8 m, would not act to intercept infiltrating water from the surface which would have otherwise flowed towards the mire.

Seven of the eight piezometers were subjected to variable head tests to determine the permeability of the deposits (Table 3.1).

Table 3.1 Results of variable head tests on piezometers. Tests undertaken according to BS 5930.

Well No.	Test interval		Hydraulic conductivity (m/d)
	m bgl	mOD	
A	7.5 - 8.5	113.8 - 114.8	1.07
B/2	8.6 - 9.2	113.4 - 114.0	0.78
C/1	9.7 - 10.1	124.4 - 124.8	0.31
C/2	19.8 - 20.4	114.1 - 114.7	2.41
D/1	9.8 - 10.4	125.2 - 125.8	0.26
D/2	19.7 - 20.3	115.3 - 115.9	1.08
D/3	20.9 - 21.6	114.0 - 114.7	0.06

The highest permeabilities, 1.07 m/d, 0.78 m/d, 2.41 m/d and 1.08 m/d, were encountered in the sand layers represented by piezometers A, B/2, C/2 and D/2 respectively, all of which are between 113.4 mOD and 115.9 mOD. The higher sand layers have low permeabilities, ranging from 0.06 m/d (D/3) to 0.31 m/d (C/1). The Plateau Gravels probably have a relatively high permeability, but there is little sign of their sustaining spring flow in the vicinity of the mires. Water was not encountered in the gravel in boreholes C and D.

The evidence is that a number of groundwater mounds exist in sand layers beneath the high ground, each one sitting on a relatively impermeable horizon of silt or clay, and sustained by leakage from above. The amount of infiltration appears to be small: in spite of the low permeability of the sand deposits, which is a consequence of the presence of clay and silt, groundwater generally occupies only the lowest part of the thicker sand horizons. Only the larger area of high ground to the northwest of the mires is likely to provide significant spring flow. The groundwater bodies beneath the narrow ridge east of the mire drain to east and west: the cutting will lead to a slight increase in flow towards the south, but this is not likely to have any serious effect on the water balance of the mire or wet heath.

A similar argument applies to the ridge which is intersected by the western cutting. Data from boreholes A and B indicate the presence of a shallow groundwater mound in the upper, thicker sand layer, while in 1986 the geotechnical borehole 12 showed a water level of about 124.5 mOD, which suggests a parallel with piezometer D/1 on the eastern ridge. The western cutting is at least 400 m from the nearest mire habitat, and it is not expected that there will be any measurable effect on spring discharge to the mire systems.

4 WATER QUALITY STUDIES

4.1 Major ion analysis

Major ion analysis of waters at Snelsmore offers the opportunity to explore the relationship between the Tertiary groundwater body and the mires and streams. Samples of surface water have been taken from several points at Snelsmore, ranging from the main valley mire to the swallet at SU 46277021 and the pond at SU 45937055. These samples, after filtration, have been subjected to a full major ion analysis in the IH laboratory at Wallingford. In addition, major ion samples have been taken from the eight piezometers A to D/3.

The results are presented in tabular form in Appendix A3.1, and in this section of the report as Maucha diagrams, in which the area of each sector of the diagram is proportional to the concentration of the cation or anion, expressed in milliequivalents per litre. The number next to each diagram is the total ionic concentration in meq/l. An example, with a key, is presented in Figure 4.1.

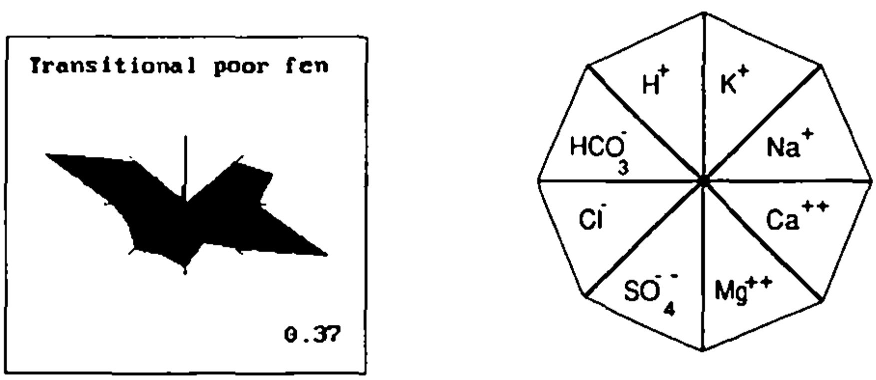

Figure 4.1 The Maucha diagram, with key. The major water types, for instance waters rich in sodium chloride or calcium bicarbonate, can be distinguished by noting the prominent "wings" of the figure. The diagram shows the percentage ionic composition: the total ionic strength, in meq/l, is shown by the number to the lower right of the diagram.

There are three mires at Snelsmore: the principal mire occupies the axis of a southward-trending valley upstream of Cromwell's Glen. The downstream end of this mire is the source of a surface stream which flows through a deeply incised channel before entering the Chalk through a swallet. A side valley enters this channel from the west, and the axis of this valley is occupied by a wooded mire. The third mire has its outflow to the west of the ridge, and also enters a swallet into the Chalk. All three mires carry an acidophilous vegetation community including for example *Eriophorum angustifolium* (common cotton-grass), *Narthecium ossifragum* (bog asphodel), *Erica tetralix* (cross-leaved heath) and *Sphagnum* mosses.

The crest of the ridge between the two mire systems, which is mantled by plateau gravels, is pock-marked with small gravel pits, and the pond is one of these.

Waters from the principal mire were sampled on 8 March 1991. Water quality at three points on the mire, and in the stream channel draining it, was very closely similar (Figure 4.2). The major ion concentrations were low, with sodium and chloride, at about 1 meq/l, being the most significant components. The waters were acid, with pH ranging from 3.9 to 5.2. A confirmatory sample was taken from the mire outflow on 25 May 1991.

Paradoxically, the May sample, taken at a time when there was a much smaller discharge from the mire and surface water could not be found in the centre of the mire, had a lower ionic strength, and calcium and magnesium, indicators of spring flow, were also lower, both in absolute concentration and as a proportion of the total. The implication is that summer flows from the mire originate from the peat rather than from springs from the Plateau Gravels or the Tertiary sands.

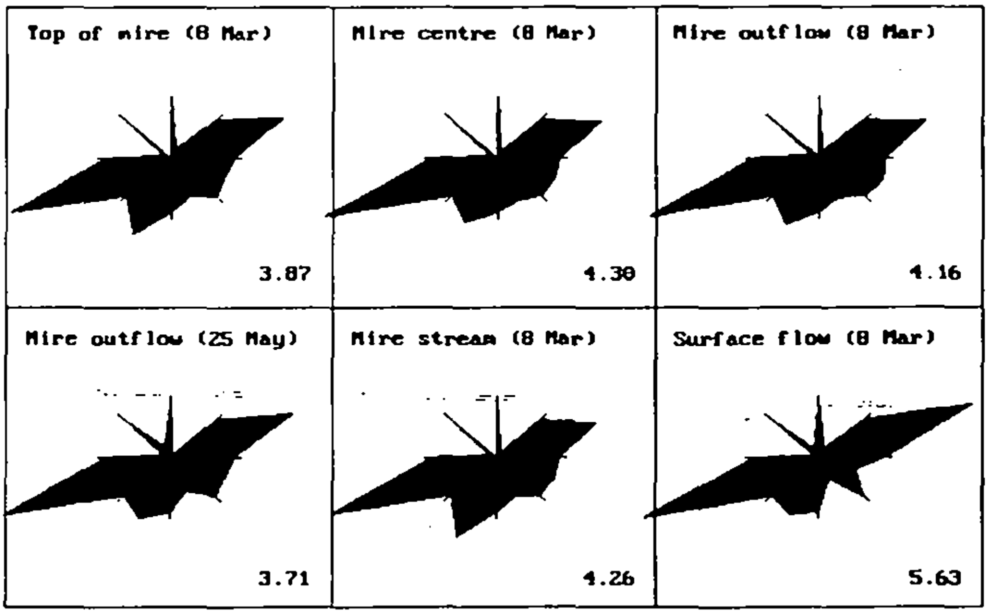

Figure 4.2 Major ion concentrations of waters from the principal mire. The upstream tip of the mire is marked by an area of tussocky Molinia caerulea (purple moor-grass). Surface flow draining down the footpath following the overhead power-line was also sampled shortly after rain: it is believed from the sampling location and its chemistry that this represents lateral flow through the heath soil (throughflow), an important contributor to the mire.

The side valley bog waters (Figure 4.3) are distinguished from those of the main bog by a decrease in total ionic strength from about 4 meq/l to 2.5 meq/l, a pronounced increase in sulphate concentration, and a decrease in the importance of sodium and chloride ions. A hollow on the valley axis, marked by a *Sphagnum* lawn overhung by a large oak tree, is the site of a spring inflow carrying calcium and bicarbonate (2nd diagram). The effects of this inflow, though diluted by inflow of mire waters, are detectable as far downstream as the swallet.

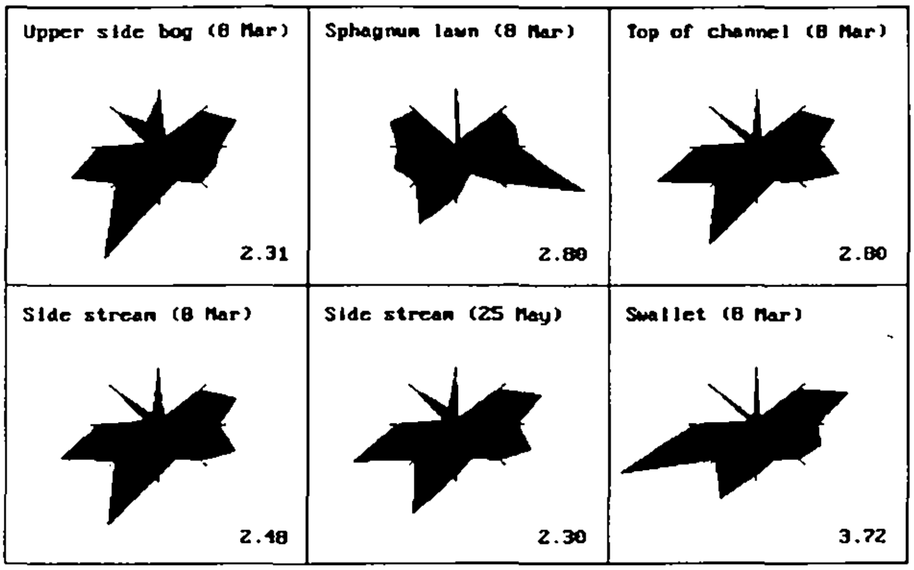

Figure 4.3 Major ion composition of waters from the side valley mire. Note the major change in chemistry associated with the Sphagnum lawn, and the steady downstream decrease in the importance of calcium. The water sample taken at the swallet is a mixture of waters from the two streams: its similarity to water from the main bog indicates that the main bog contributes more flow than the side valley bog.

A sample from the west bog (Figure 4.4) shows a major ion composition intermediate between the two other mires. The diagram shows that it is very similar in its proportional concentrations to the water entering the swallet, but with a total ionic strength of 1.95 meq/l compared with 3.72 meq/l. Water from the pond, an old gravel pit, shows a completely different constitution, with sodium and chloride almost swamped by the high concentrations of calcium and bicarbonate. The pond shows most similarity with water from the piezometers, to be considered below.

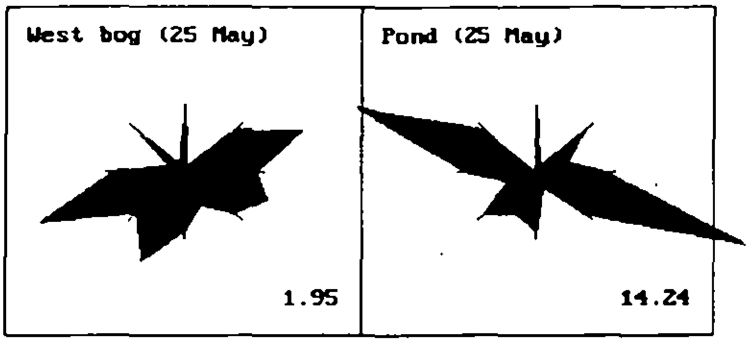

Figure 4.4 Major ion composition of waters taken from the west bog and from the pond at SU 45937055.

A water sample was obtained from each of the piezometers installed in boreholes A to D, by inserting and partially filling a semi-rigid plastic tube, sealing the top and then withdrawing it from the borehole. Owing to the depth to water level, it was not possible to pump the water from the surface, and the piezometers are too narrow for a submersible pump. Yellow clay and silt suspended in the samples was removed by decantation and filtration through GF/C glass-fibre filters and 0.45μm membrane filters. The results are presented in Figures 4.5 to 4.8, and in tabular form in Appendix A3.2.

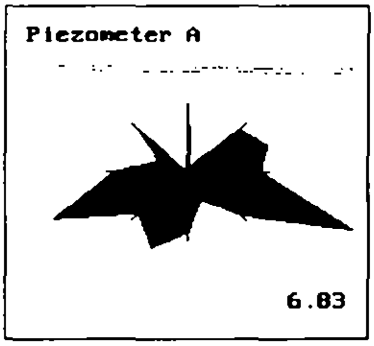

Figure 4.5 Major ion composition of waters taken from piezometer A, screened at 8.0 to 8.5 m bgl.

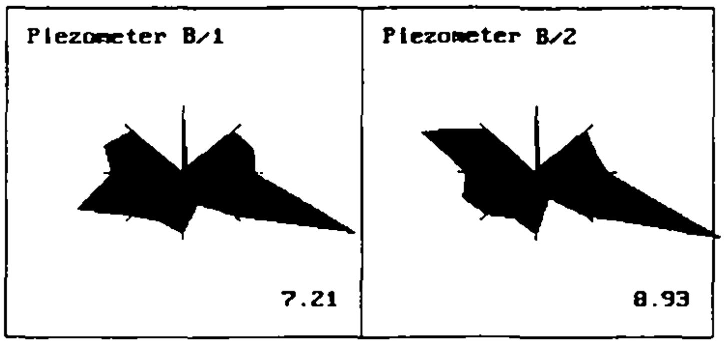

Figure 4.6 Major ion composition of waters taken from piezometer B/1 (screened at 7.3 to 7.5 m bgl), and piezometer B/2 (screened at 8.8 to 9.1 m bgl).

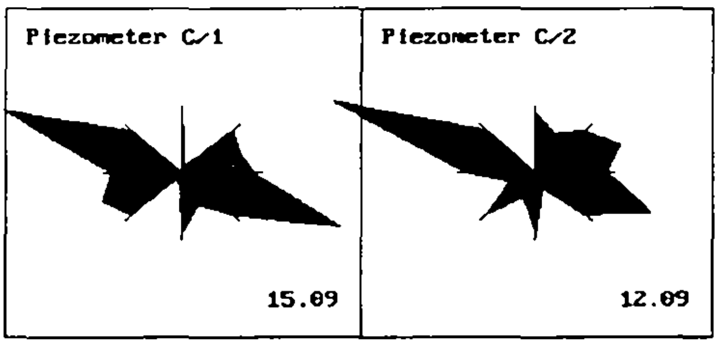

Figure 4.7 Major ion composition of waters taken from piezometer C/1 (screened at 9.7 to 10.1 m bgl), and piezometer C/2 (screened at 20.0 to 20.3 m bgl).

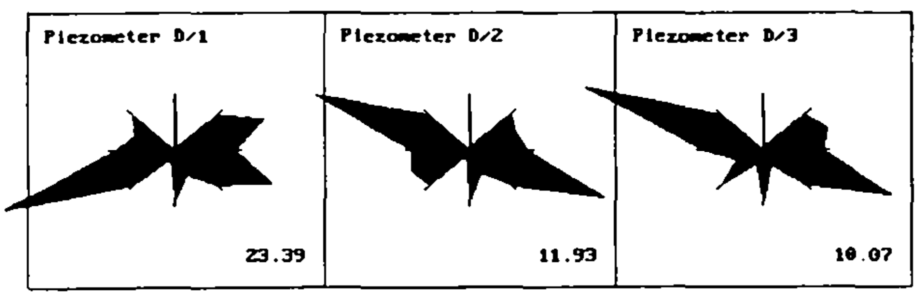

Figure 4.8 Major ion composition of waters taken from piezometer D/1 (screened at 10.0 to 10.3 m bgl), piezometer D/2 (screened at 19.8 to 20.1 m bgl) and piezometer D/3 (screened at 21.4 to 21.6 m bgl).

The piezometer samples are distinguished from the surface water samples by their relatively high calcium concentrations, which exceed 1 meq/l in all cases but do not approach the 6 meq/l concentration shown by the pond. It is clear from an examination of the results that the mire waters contain little or no spring flow from the geological units sampled by the piezometers: pH values as low as 3.8 indicate that the mire is ombrotrophic, i.e. its water supply is almost completely from rainfall. The topographic setting of the mire suggests an input from lateral flow through the heathland soils, but spring flow, either from the Plateau Gravels (perhaps represented by the pond sample) or from the Tertiary sands, whose calcium concentrations indicate infiltration from the gravels, cannot be a major contributor to the discharge from the mire system.

4.2 The influence of road de-icing salt

It was proposed at the start of the project that soil water sampling would be carried out at a nearby site adjacent to an existing major road and affected by similar prevailing wind direction. Analysis for chloride would indicate the effects of salt transport from the road, and provide evidence of the likely impact of the proposed road on the Snelsmore heathland and mire systems. Sodium analysis would provide a valuable backup measurement. The importance of the Snelsmore SSSI stems in part from the scarcity of mire and heath in the county, and it was not possible to locate a suitable site nearby, but two sites were found, one in Hampshire and one in Dorset, where soils were similar and samples could be taken on the north or northwest side of a trunk road.

The A31 Folkestone-Honiton trunk road crosses the New Forest between Cadnam and Ringwood, and bypasses Ferndown to the north-west of Bournemouth. The road passes through several heathland and woodland areas on Tertiary deposits: after an examination of the route of the road and consultation with NCC and Forestry Commission staff, two sites were selected for soil sampling, Broadmoor Coppice (SU 077021) on the Ferndown bypass and Bratley Arch (SU 232095) in the New Forest.

4.2.1 Broadmoor Coppice

The Ferndown bypass was constructed in 1986, and runs east-west alongside the Slop Bog and Uddens Heath SSSI. The road is elevated above the natural ground surface on a low embankment about three metres high. Broadmoor Coppice is a mature oak/birch/alder woodland, lying between the road and the Uddens Water, a tributary of the Moors River. The Coppice has an understorey of hazel, hawthorn and holly: the 12 m wide verge has been colonised by seedling trees and gorse. The soils are generally silty alluvium built up by overbank flows from the Uddens Water to the north of the Coppice, becoming more peaty close to the road and the former boundary of the Bog.

Water samples taken from the Uddens Water in the early 1980's, by the Wessex Water Authority, showed chloride concentrations between 30 and 82 mg/l (0.85 to 2.31 meq/l), and electrical conductivity between 330 and 565 µS/cm.

On 6 August 1991, soil samples each weighing around 250 g were taken from 0-50 mm and 50-100 mm depths at points between the fence (12 m from the road edge) and the Uddens Water (Figure 4.9). Sampling points were along three transects 30 m apart, aligned at right angles to the road, i.e. along 20° (magnetic), and distances from the road edge varied between 12 m and 125 m. Additional samples were taken along the fence line on 19 September, making a total of 28 pairs of samples. Brief descriptions of vegetation at each sampling station are given in Appendix A4.1.

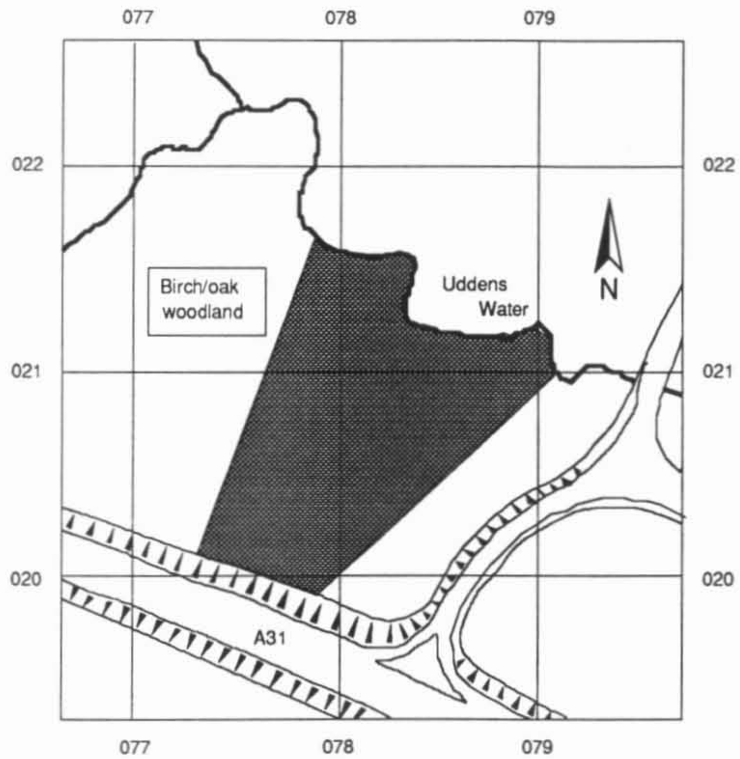

Figure 4.9 Broadmoor Coppice sampling area.

4.2.2 Bratley Arch heathland

The area immediately north of the A31 at Bratley Arch provides an opportunity to sample both open heathland and mixed woodland adjacent to a slightly elevated trunk road (Figure 4.10). On 19 September 1991, soil was sampled from 0-50 mm and 50-100 mm depths in wet heathland to the east of Slufters Inclosure, along three transects 30 m apart and extending along 295° (magnetic) to a distance of 62 m from the road edge. In all 17 pairs of samples were taken. Brief descriptions of vegetation at sampling stations are given in Appendix A4.2.

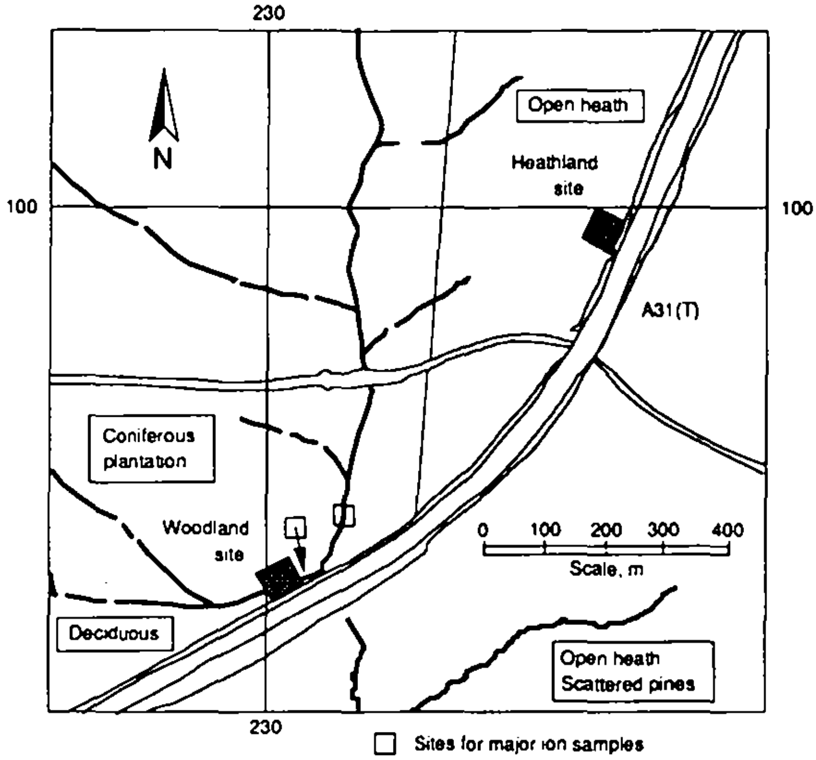

Figure 4.10 Bratley Arch heathland and woodland sampling areas

4.2.3 Bratley Arch woodland

The woodland sampling site at Bratley Arch was the southern tip of Slüfters Inclosure. Near the road the trees are oak, alder, birch and sallow, and this wet woodland, occupying a poorly drained valley bottom, grades into an open pine plantation with bracken. On 19 September 1991, 19 pairs of samples were taken along three transects 30 m apart, perpendicular to the fence line, on a bearing of 340° (magnetic), at distances up to 62 m from the road edge. The carriageway adjacent to the woodland is elevated about 4.5 m above the natural ground surface, and the orientation of the road, the general topography and the height of trees are generally similar to Snelsmore. Vegetation descriptions are given in Appendix A4.3.

Surface water samples were taken from two streams flowing through the woodland in August and September, and subjected to a full major ion analysis. Water sampling sites are indicated in Figure 4.10. The results of the analysis are presented as Figure 4.11: the water is less acid than that at Snelsmore, and has higher calcium concentrations, though the total ionic strength is still quite low. The notable increase in calcium and bicarbonate concentrations was the main contributor to the change in total dissolved solids as the flow declined over the late summer and the contribution from groundwater became more important.

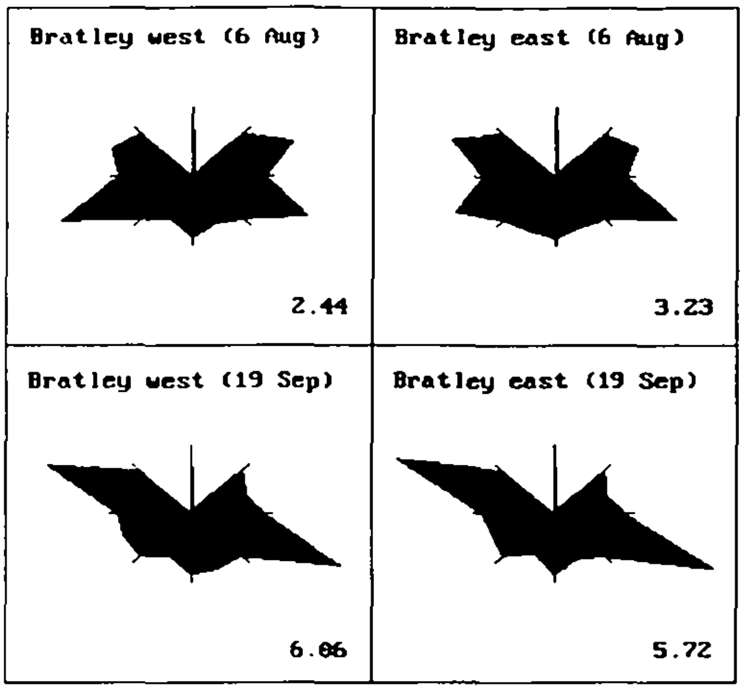

Figure 4.11 Major ion composition of waters taken from streams at Bratley Arch. Two streams join upstream of the culvert under the A31. The eastern stream is the larger: both streams arise in springs and valley mires around the periphery of the Inclosure.

4.2.4 Snelsmore Common

To provide a comparison between sites, and to indicate the background levels present at Snelsmore, samples were taken on 5 August 1991 from 22 stations in the southern part of the SSSI, ranging from woodland to heath and mire. Samples were taken along four transects running roughly southeast-northwest. The locations of these transects are shown in Figure 4.12, and descriptions of the vegetation are given in Appendix 4.4.

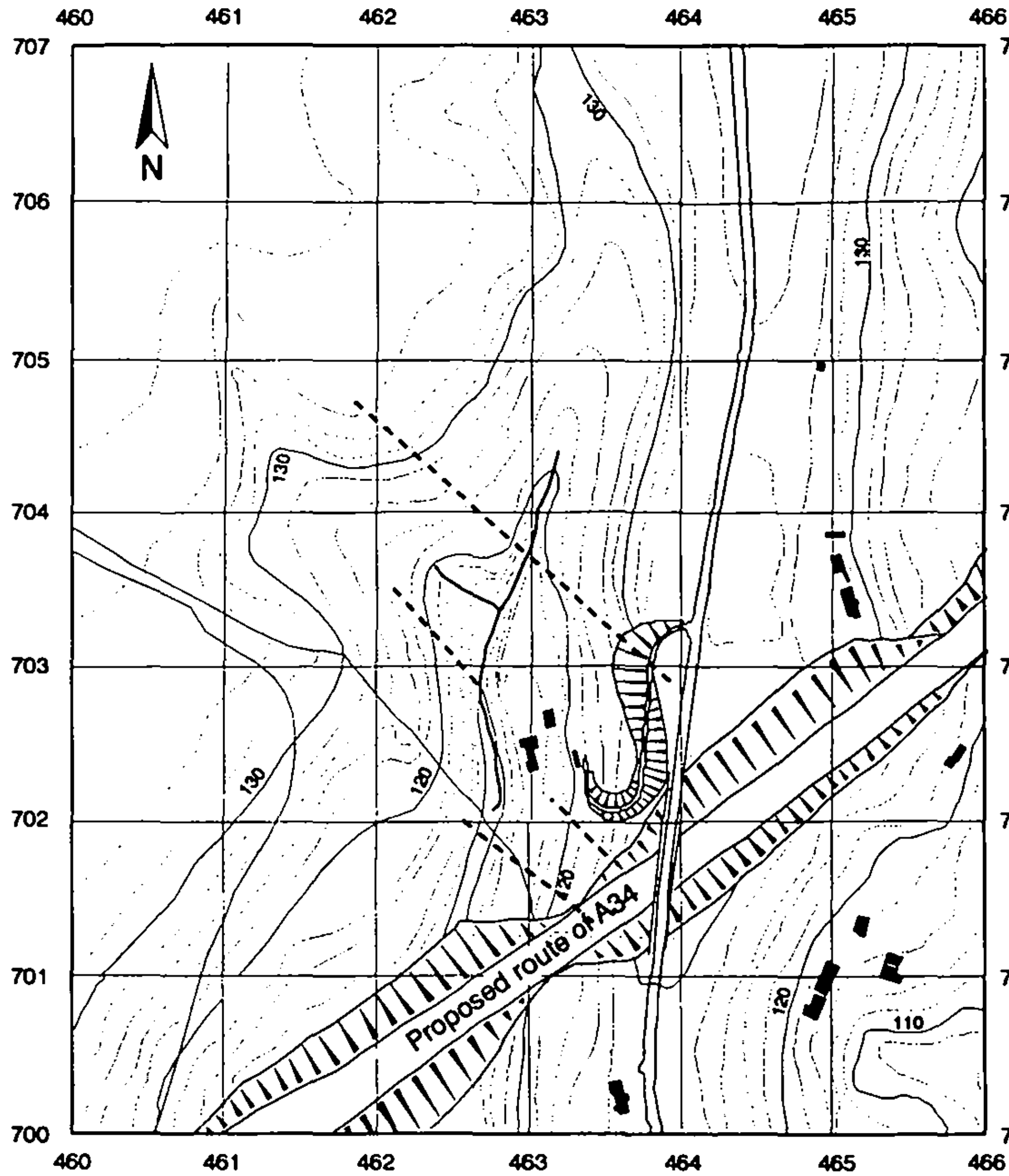

Figure 4.12 Snelsmore Common soil sampling transects. Samples were taken at 25 m intervals along four transects. In order from south to north, the transects are SC 1 to SC 5, SC 6 to SC 7 (two points 50 m apart), SC 8 to SC 11, and SC 12 to SC 22.

4.2.5 Analysis

The soil samples were split, and a sub-sample air-dried so that the percentage moisture content by weight could be determined. Extracts were obtained from moist soil by adding sufficient demineralised water to dilute the soil water by a factor of between 10 and 20. After stirring and decantation, considerable difficulty was experienced in removing suspended matter to obtain a clear water sample for analysis: the addition of a drop of saturated aluminium potassium sulphate solution to each 50 ml of suspension was found to clear clay particles from stubborn samples. The clear solutions were then filtered through 0.45μ membrane filters, and analysed for sodium and chloride at the IH laboratory in Wallingford.

The presentation of soil solute data is open to some debate. Most authors quote solutes as a proportion of dry weight of soil, though it has been pointed out that the effects on plants are almost certainly determined by the concentrations in the soil solution. Dry weight of organic soils can be extremely low, and it was decided that, for the purposes of this study, it would be preferable to refer the contents of sodium and chloride to the weight at the prevailing moisture content. Concentrations obtained by analysis of the extracts were therefore multiplied by the dilution factor to obtain the concentration in the soil solution, then by the moisture content.

It is not possible to discern a pattern of decreasing concentration away from the road in the results from Broadmoor Coppice (Figure 4.13), though several high values were obtained for supplementary samples along the fence line (at 12 m). Relatively high concentrations of sodium to the right of the diagram may be due to the influence of flooding by the Uddens Water. The range of concentrations is close to background levels, and is well below the values quoted in the literature for points close to salted roads. There is no indication that soil levels of sodium and chloride have been increased by the road, but this may be a consequence of the scrubbing effect of trees or of the short time over which the road has been open.

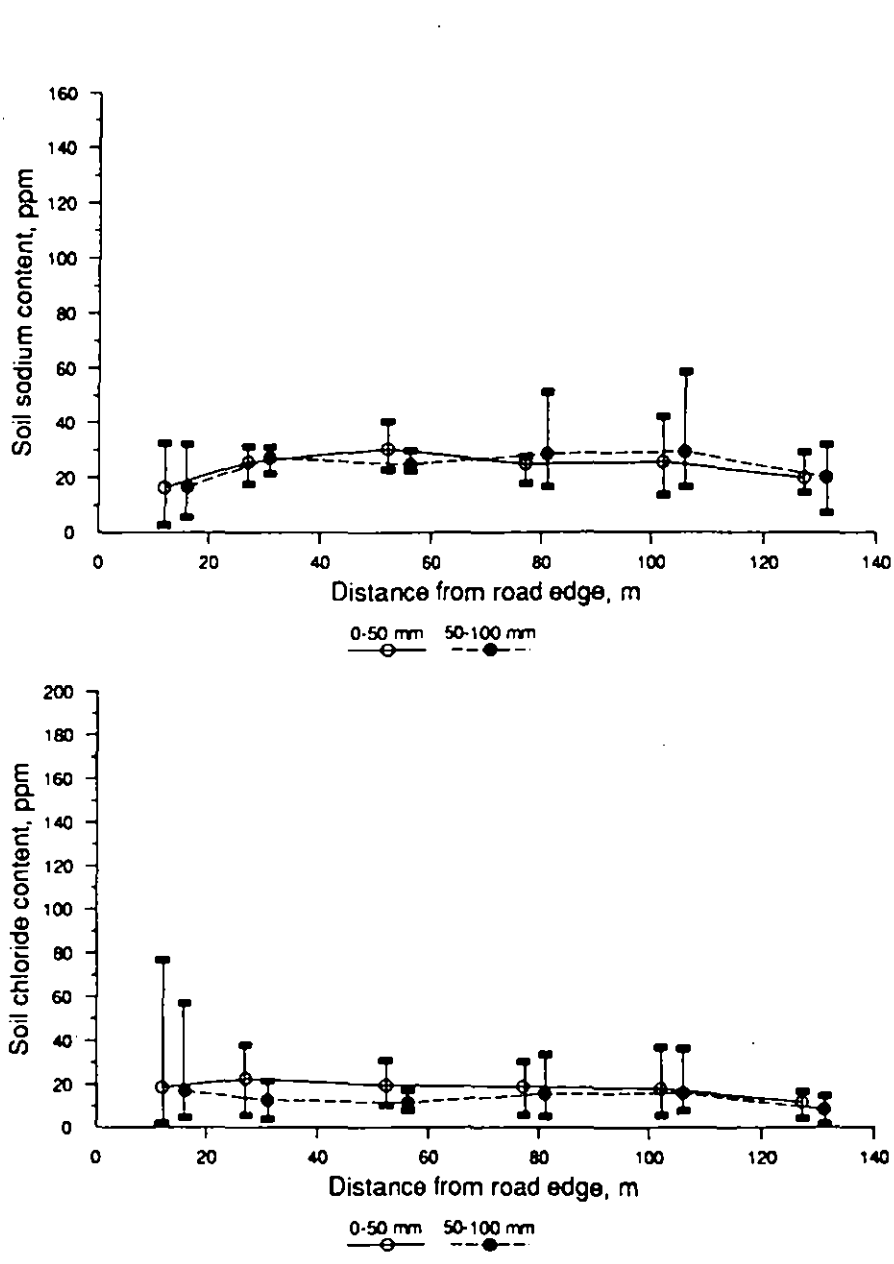

Figure 4.13 Broadmoor Coppice soil sodium and chloride concentrations. The concentrations of sodium and chloride in soil waters have been determined by saturating the soil sample with demineralised water. Allowance has been made for the dilution involved in this process, by measuring the moisture content of a sub-sample. The points for the deeper soil layer have been displaced to the right for clarity. Error bars show the maximum and minimum values at each station, and the central point is the mean, in general of 3 or more samples.

Heathland samples from Bratley Arch (Figure 4.14) appear at first sight to show high background levels of sodium and chloride: low figures at the fence line probably result from a very gravelly disturbed soil with little capacity to retain solutes. The high values at 17 m may be due to a pipe drain which emerges in the sample area, and may carry runoff from the road or a layby.

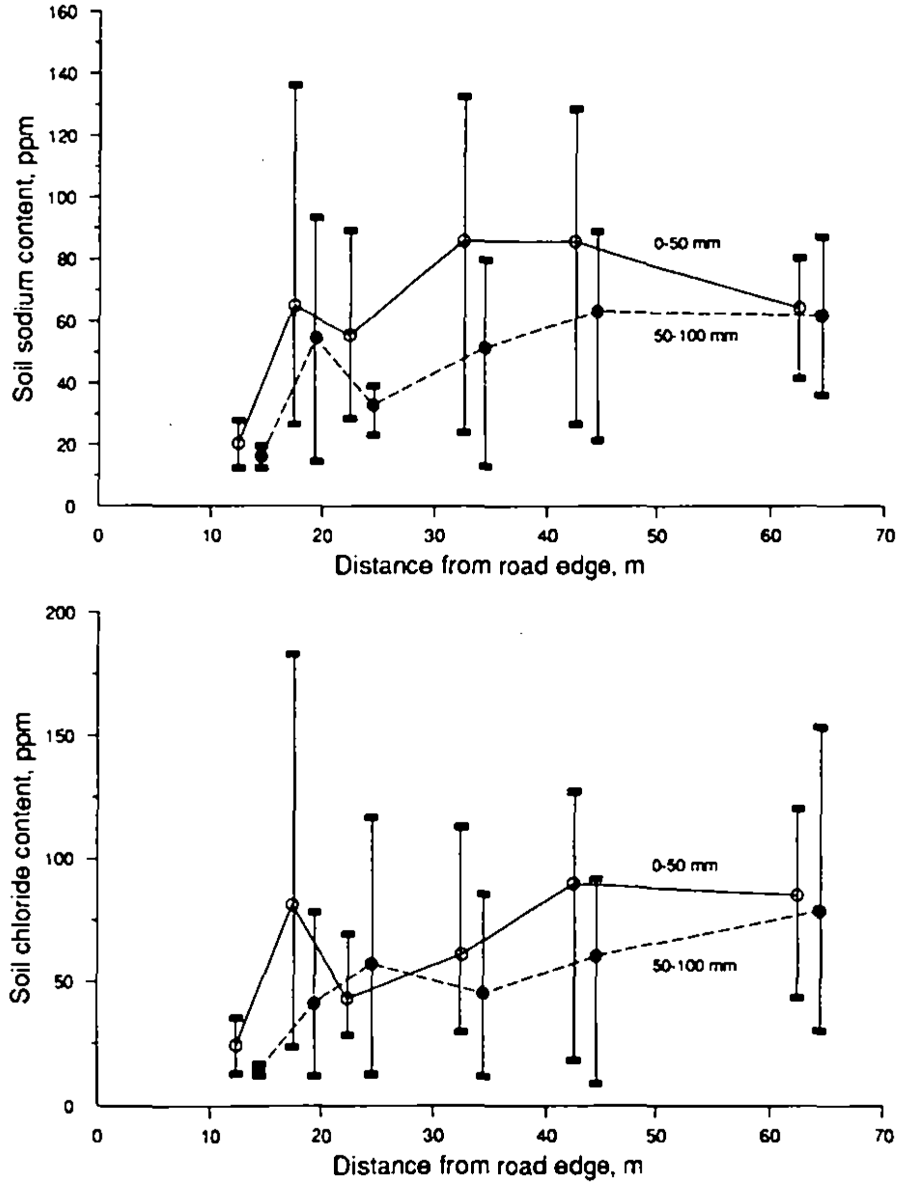

Figure 4.14 Bratley Arch heathland soil sodium and chloride concentrations. Plotting conventions as in Figure 4.13.

High concentrations along the woodland transects at Bratley Arch (Figure 4.15) are more consistent with the expected pattern. A distinct peak in concentration coincides with the first mature trees (oak, alder, beech and pine). It appears that the forest canopy may be acting to increase deposition of salt at these points, and to reduce the penetration of salt spray further into the forest. The effect of interception of spray by the forest canopy, and subsequent evaporation, is to further increase the concentration of dissolved salts in water reaching the forest floor by throughfall or stemflow, above the levels reached in a heath community.

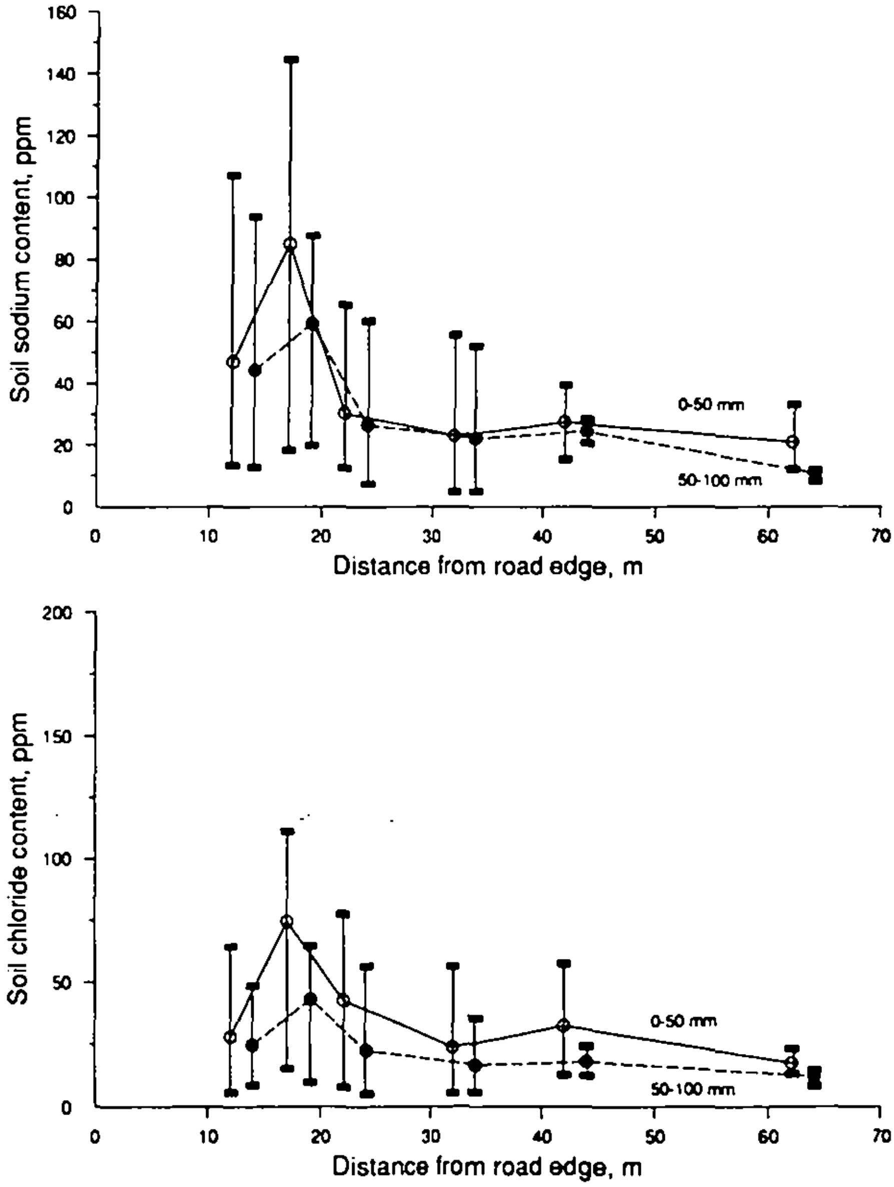

Figure 4.15 Bratley Arch woodland soil sodium and chloride concentrations.

At Snelsmore (Figure 4.16), there is as yet no road to increase salt deposition above natural levels, and the observed sodium and chloride concentrations must have arrived at an equilibrium between weathering, rainfall input concentrated by evaporation, and loss by leaching. The range of concentrations is comparable with background levels observed at those points at Broadmoor Coppice and Bratley Arch most distant from the road. There appears to be a consistent increase in concentrations of sodium and chloride from southeast to northwest: this may be a consequence of an increasing organic component in the soils towards the mire and heath, leading to more effective retention of ions, or of the increasing influence of spring flow towards the northwest. The precise cause would take a larger and more intensive study to establish.

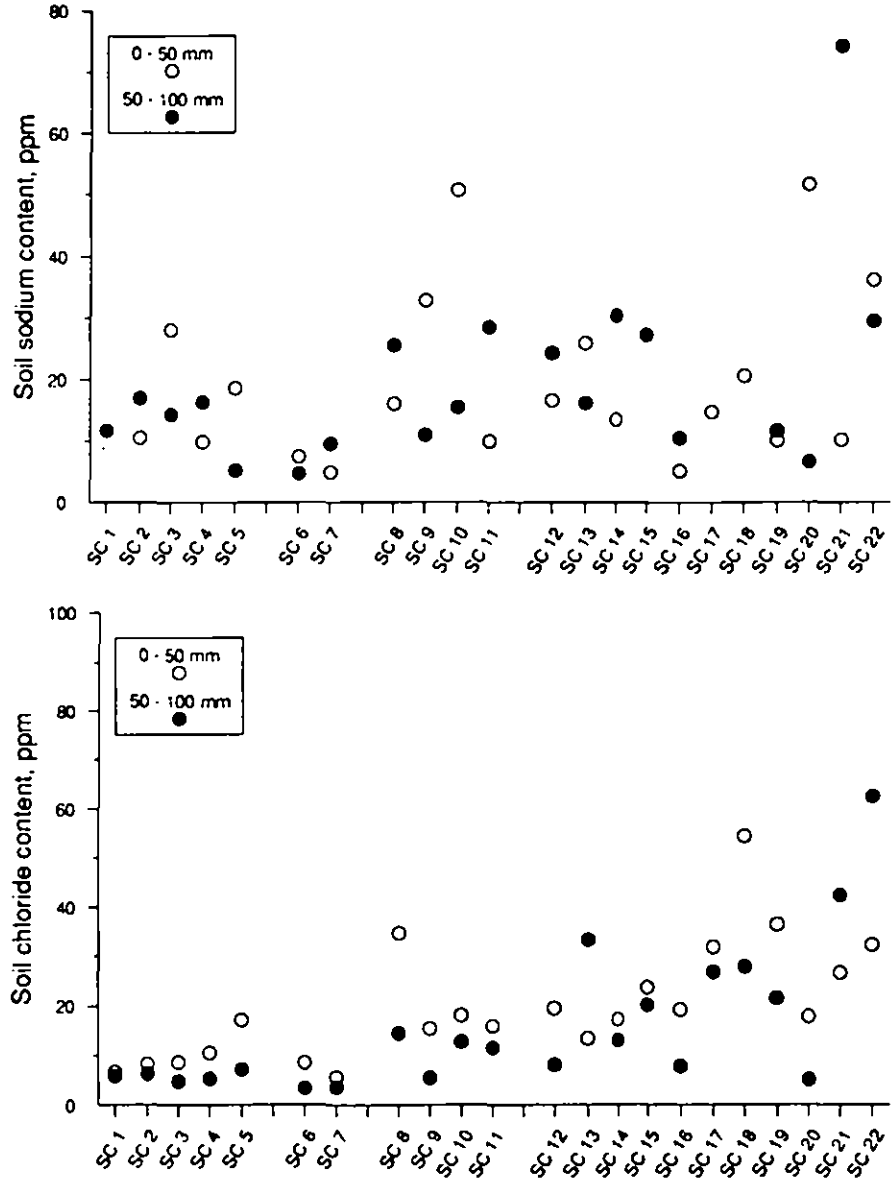

Figure 4.16 Snelsmore Common soil sodium and chloride concentrations.

5 CONCLUSIONS

The literature survey shows that spray drift has been a problem, particularly to salt-sensitive tree species in severe winters. Injury to plants may result from direct impact of spray on leaf surfaces, or from absorption from the soil, and the effects are highly variable between species. In general the damage, shown by symptoms ranging from tip die-back and early leaf fall to the loss of branches and death, has been most severe very close to the road, where high levels of sodium in the soil may even have effects on soil physical properties.

Salt accumulates in vegetation and soils, but is leached by rainfall, and an equilibrium is eventually reached. Although sodium is only weakly retained in the cation exchange complex of the soil, it accumulates twice as fast as chloride, which is a highly mobile ion. The seasonal pattern of salt in the oil is dominated by applications in late winter, and levels are usually highest in spring. Several studies have taken advantage of the integrating effect of retention in the soil to measure the range to which salt is transported, and there is general agreement that the most serious effects are felt within 10 m of the road, with little detectable change in soil sodium concentrations outside a strip 30 m wide. Some studies have shown a long-term increase in soil concentrations of sodium, which also has the effect of increasing the range over which salt in the soil is detected.

The problem of spray drift at Snelsmore is complicated by the embanked section, which reaches a maximum of 13 m above the natural ground surface. There is no consistent data set relating to embanked roads, though intuition suggests that spray entrained by crosswinds or vehicle-generated turbulence would travel further from an embanked road. The studies which showed a difference in salt damage uphill and downhill of roads (Button 1964, Lacasse and Rich 1964[38], Fleck *et alia* 1988), were rather complicated by the effects of road drainage. Data obtained at Bratley Arch, in the New Forest, add some weight to this, though local soil factors cannot be entirely ruled out. In the woodland site at Bratley, where the road is embanked about 4.5 m above the natural ground surface, sodium and chloride in the soil are enhanced up to about 25 m from the road edge.

In the absence of any better information, a very simple model may serve to make rough predictions of the drift from embanked roads. If it is assumed that spray is generated up to 4 m from the road surface, and spreads in a plume up to 10 m from the road edge (Figure 5.1), the effect of elevating the road surface is to elevate the origin of the plume. For a 4.5 m embankment, the spread of the spray plume is given by

$$(4 + 4.5) \times 10 / 4 = 21.25 \text{ m}$$

At Snelsmore, under similar conditions, the spread would be

$$(4 + 13) \times 10 / 4 = 42.5 \text{ m}$$

Obviously there are many complicating factors, not least the effect of exposure and local topography on the speed of cross-winds and the scrubbing effect of the woodland canopy, but the model suffices to demonstrate that the potential for the propagation of spray is enhanced by the embankment.

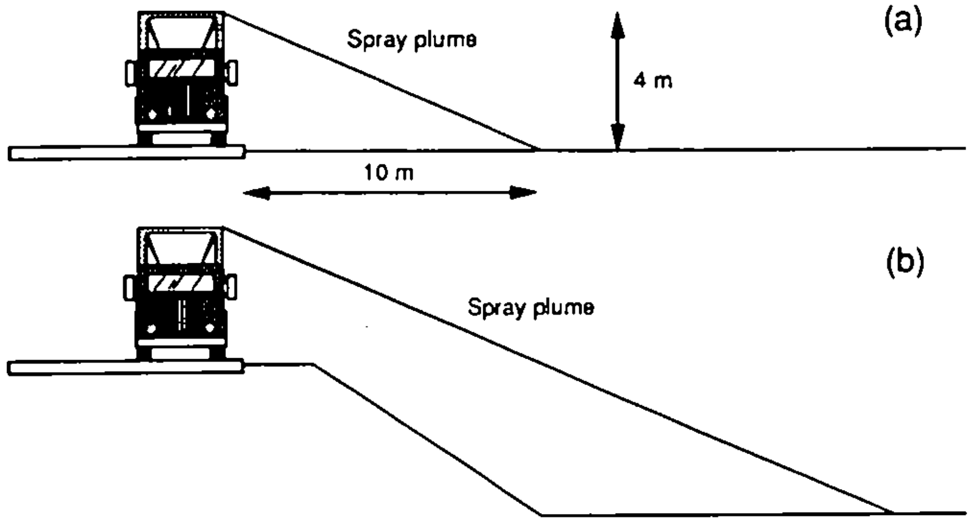

Figure 5.1 A simple model of spray propagation from (a) a road at natural ground level, (b) an embanked road.

At Bratley Arch, the effects are confined to relatively short distances from the road by the presence of mature trees. At Snelsmore, woodland will have the effect of reducing the distance of penetration into the SSSI, but close to the road soil concentrations may be high as a result of concentration by interception on the forest canopy. It is recommended that a tree planting programme, using salt-tolerant and quick-growing species, should be implemented as soon as possible after construction to establish a shelter belt to protect the mature trees, particularly beeches, of the SSSI.

Groundwater exists in the Reading Beds at Snelsmore in the form of shallow groundwater mounds sitting on relatively impermeable silt and clay horizons. Permeabilities of the sand aquifers are generally low. Water quality considerations indicate that the mires are receiving the majority of their water supply from throughflow in the heath soils, rather than from springs from the Reading Beds or the Plateau Gravels, and it is concluded that the excavation of road cuttings will not have an effect on the water balance of the mires.

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