Measures for Protecting Upland Water Quality: Assessment of Forestry Buffer Strips



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NATIONAL Rivers Authority

MEASURES FOR PROTECTING UPLAND WATER QUALITY: ASSESSMENT OF FORESTRY BUFFER STRIPS

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EXECUTIVE SUMMARY

The objectives of this study were to investigate the effectiveness of buffer strips for the protection of receiving waters from deterioration following forestry activities such as ploughing and fertilization, and to make practical recommendations concerning optimum buffer strip width for use by forestry and water regulatory staff.

The study was undertaken at an upland site near Dalmellington, Scotland, with full collaboration from the Forestry Authority's research division at Wrecclesham and the local district office at Straiton. Two test sites were chosen, one with mineral and the other with peat soils. The effects of the buffer strips on runoff quality were assessed by manual sampling and analysis at intervals down the strips, and using *in situ* suspended solids monitors. Flow rates were also recorded continuously.

The study demonstrated that the effects on runoff water quality of ploughing peat were short-lived compared to that for mineral soils, and that the main mechanism by which the buffer strip effects an improvement on runoff quality is through settlement of particulate material. The factors that control this are velocity of flow, slope, distance travelled, lateral dispersion and the type and nature of the buffer strip vegetation. The vegetation reduces flow velocity and encourages dispersion but the effect declines as the vegetation decays and is flattened by successive winter runoff.

The following recommendations concerning optimisation of buffer strip performance are made:

- Ploughing of the planting area should be undertaken only if essential.
- Cross-drains should be cut as soon as possible after ploughing but not during wet weather.
- The volume of water carried by any one drain should be controlled by limiting the catchment area (e.g. by increasing the frequency of cross-drains). This is particularly important if soils are highly erodable.
- In areas of high erosion risk, or where adequate buffer strips are not practicable, consideration should be given to drain-side buffer strips.
- Cross-drains should discharge on to a buffer strip of low slope (<4°) with thriving vegetation to encourage side dispersion. Drains should not discharge into natural channels, ephemeral streams or old ditches.
- Due consideration should be given to the quality and use of the receiving watercourse in defining the width of a buffer strip.
- The results of this study should be considered during the revision of the 'Forests and Water Guidelines'.

1. INTRODUCTION

1.1 Forestry practices in the UK

Afforestation of upland areas in Britain has shown a steady expansion over the last 60 years and, despite the present ban on upland afforestation in England, this trend is likely to continue in Scotland, Wales and Northern Ireland. Upland soils are frequently peaty and poorly drained and are considered to require ploughing and draining prior to the planting of young trees. Also, fertilizer applications are often needed to achieve satisfactory crop growth. However, studies have shown that such activities and others associated with afforestation can have marked deleterious effects on upland water quality (Swift *et al.* 1990) and biota (Maitland *et al.* 1990).

As a result, interest has focused on the development of measures for protecting waterbodies from the adverse effects of forestry activities. Early forestry practices frequently involved ploughing close to the edges of watercourses and waterbodies before planting. The 'Forests and Water Guidelines' (Forestry Commission 1988, revised 1991) were issued following a workshop organised by WRc and Forestry Commission. These Guidelines recommend that furrows and ditches should stop well short of watercourses and waterbodies. The effectiveness of buffer strips between the planted area and the waterbody/watercourse (in combination with good ploughing and cultivation practices) to control sediment and solute transport is also recognised in the guidelines.

Whilst the application of buffer stips to protect receiving water qualiy is widely accepted, there are no firm data on which to base recommendations for optimising buffer strip width. Several major studies on the effects of afforestation on water quality have been completed or are in progress, but none has concentrated solely on buffer strip width.

1.2 Project Objectives

Evidence for a minimum effective width of buffer strips (i.e. the distance between the discharge of a cross-drain and a watercourse) should reduce conflict between the forestry industry and regulatory authorities responsible for water quality protection. This study is intended to address the above concerns and is being undertaken in full collaboration with the Forestry Commission.

The objectives of the study are:

• To investigate by field experiment the factors influencing the effectiveness of buffer strips in the protection of receiving waters from water quality deterioration resulting from ground preparation for afforestation and fertilization; with particular reference to the effect of buffer strip width on the transport of suspended solids, colour, nutrients, and the metals iron, aluminium, and manganese.

• To make recommendations and derive practical guidelines concerning optimum buffer strip width and other relevant design / operational criteria, for use by water and forestry industry staff.

1.3 Site selection

Only two potentially suitable Forestry Commission sites were due to be developed for afforestation in Scotland during 1990/91, with a possible third in Wales. Following an examination of these sites in conjunction with local Forestry Commission staff, that at Dalmellington in Ayrshire was chosen as the most suitable for this study. Close collaboration was maintained with the Forestry Commission at their Alice Holt Research Station in Surrey and at their district office at Straiton to ensure the best selection of the buffer strip test site and also to ensure that the ploughing and construction of cross-drains was undertaken according to good forestry practices.

2. CHARACTERISTICS OF THE STUDY SITE

The site chosen for this study is near Dalmellington, Ayrshire (Figure 2.1).

2.1 Geology

The study area lies on a low ridge between the Parrie Burn to the northwest and Mossdale Burn to the southeast. The northwest half of the area is underlain by Lower Old Red Sandstone which dips at about 20 degrees to the north-west. This sandstone is well cemented and has a low permeability and storativity; the permeability is restricted to secondary permeability through joints and bedding planes. Groundwater storage is restricted to the joint systems or weathered zone of the rocks. The Old Red Sandstone is faulted against mixed formations to the south-east by a fault running north-eastwards along the line of the low ridge between the two burns. South-east of this fault, along the valley of the Mossdale Burn, is a complex of sedimentary and volcanic rocks. Large felsite sills are interleaved with Lower Old Red Sandstone sandstones, conglomerates and lavas. The rocks of this complex are similar in that they have low permeability and storativity.

The characteristics of the bedrock in this area are that of an aquiclude. Locally water may be stored in, or move along, the better developed joint systems but compared with a true aquifer the volumes of water involved are negligible. By and large, the water falling as rain, after percolating through the soil profile will be shed laterally by the bedrock surface to move as run-off to the burns.

2.2 Soils

The soil data given in this report was obtained from a soil survey map of Scotland (1:63600 map of Ayr, Sheet 14) supplied by the Macaulay Land Use Research Institute, Aberdeen. The majority of the soil above a break of slope consists of hill peat, whilst the soil in the flood plain of the Burn consists of undifferentiated alluvium. Towards the western end of the site several relatively smaller areas of various soil types are present (Figure 2.2). These soils include poorly drained non-calcarous gleys of the Ettrick series and Ettrick association, poorly drained peaty gleys of the Fallaird series and Blair association, and imperfectly drained brown forest soils of the Drumyork series and Blair association. However, as explained in Section 4, examination of the site following ploughing indicated that these soils extend further into the west of the catchment than the soil map indicates.

The following are brief generic descriptions of the soils found within the site (taken from The Macaulay Land Use Research Institute Handbook 8: Organisation and Methods of the 1:250 000 Survey).



FIGURE 2.1 Location of study site - Dalmellington



FIGURE 2.2 Catchment soils distribution Macaulay Land Use Research Institute 1:63600 map of Ayr, Sheet 14

Alluvial soils: Immature soils (which have indistinct or weakly developed horizons, which are generally restricted to surface organic horizons or <u>A</u> horizons resting directly on little-altered parent material or rock) developed on recently deposited freshwater, estuarine or marine alluvium and exhibiting little profile differentiation or modification to the parent material. The presence of an <u>A</u> or <u>O</u> horizon, together with some mottling and weak structure in the subsoil, are characteristic features.

Peat: An organic soil containing more than 60% of organic matter and exceeding 50 centimetres in thickness. Peat is largely derived from decomposed (to varying extents) plant remains that accumulated under water-logged conditions. It can develop in areas of moderate to high rainfall, low mean annual temperatures and high relative humidity, and under the influence of groundwater in depressions or basins.

Gleys: These develop under conditions of intermittent and permanent water-logging. A pale-coloured Eg horizon is often prominent in the upper mineral horizons, beneath which the horizons are grey with greenish and blue tinges and with ochreous mottling. These colours are of secondary origin, replacing those inherited from the parent material.

Non-calcareous gleys: No free calcium carbonate is present in the horizons. An <u>A</u> horizon is often underlain by an <u>Eg</u> horizon which may be well defined in semi-natural soils. The soils are often developed on parent materials of moderately fine texture.

Peaty gleys: As with non-calcareous gleys these soils have no free calcium carbonate in the upper mineral horizons. The \underline{O} horizon may be up to 50 cm thick, beneath which organic staining of the \underline{Eg} and \underline{Bg} horizons is often present.

Brown forest soils: These belong to the major soil group of brown earths and have the properties of this group in having a uniform coloured <u>B</u> horizon, a mull or moder humas type and a moderately acid reaction; usually each horizon merges into the one below.

2.3 Topography and land use

The afforested area is gently sloping with a mean gradient of around four degrees. An abrupt break of slope leads to the flood plain of the river (Mossdale Burn). The general aspect of the slope is south-easterly and, prior to ploughing was vegetated with moorland grass interspersed with heather. There were signs of past grazing, with fencing and poorly maintained sheep drains.

2.4 Forestry capability

The area is classified by the Forestry Commission (1989) as class F6, that is, land with very limited flexibility for the growth and management of tree crops. The principal limitations for tree growth are adverse climate and poor soil conditions. The peaty soil is suitable only for the less demanding conifers, with poor nutrient supplies and water-logging being the main restrictions to species choice.

3. FORESTRY ACTIVITIES

3.1 Ploughing and draining

Cross-contour ploughing (i.e. up and down the hill slope) was carried out according to forestry Commission guidelines using a 45 cm mounted plough with a 60 cm tine. Cross-drains were constructed using a single mould board 'Humpy' plough drawn by two tractors in tandem and hand sorting was carried out to ensure free flow into and in the drains formed by the plough. According to the Forests and Water Guidelines the drains should not have a gradient of greater than two degrees (3.5%) and should end 15-20 metres from main water courses or may be less for smaller streams. For the purposes of this study, the widths of the buffer strips were extended to at least 50 metres, with the cross-drains terminated at natural seepage areas. The drainage density over the site averages approximately 95 metres per hectare. The forestry drainage system (according to the Forestry Commission) is illustrated in Figure 3.1. The areas above the buffer strip test site were ploughed during dry weather on 26 September 1990, and the cross-drains were cut during wet weather on 15 October 1990.

3.2 Planting

Planting of the site took place over an extended period throughout the spring and early summer of 1991. The principal species was Sitka Spruce, and landscaping with small areas of deciduous trees - willow and alder near to the Mossdale Burn, with oak and ash on higher ground.

3.3 Fertilizer application

Aerial application of 'PK' fertilizer (67% rock phosphate, 33% potassium chloride) took place on 21 and 22 August 1991. The weather was dry, with no flow at all at the West site and only a trickle at the East. Application had to be stopped early on the first day due to the possibility of strong winds causing excessive scatter of the fertilizer. There was some light rain overnight before completing application to the West site on the following day.

The method of application - scattering the fertilizer in a circular pattern beneath the helicopter - results in a striped distribution on the ground, with highest application rates immediately below the helicopter and decreasing either side. This is reflected in the results from the collection bags ('traps'), with an opening of 1 m^2 , set out across the whole area being fertilized (though none actually in the catchments of interest) by the Forestry Commission to check the application rate. They indicated an average application rate of 679 kg ha⁻¹ (giving 113 kg K and 56 kg P), with a range from 218 kg ha⁻¹ to 1273 kg ha⁻¹. It is likely that the same sort of variation occurred in the two experimental catchments. A number of trays were placed in the relevant catchment areas and these indicate the application rate was much lower; but these are probably underestimates because of the trays being shallow and some fertilizer bouncing out.

Observation of the application showed that care was taken to spread the fertilizer to only the ploughed areas. This was confirmed by having a tray at each site about 10 m down from the weir and into the buffer strip: at the East site no fertilizer was found in this tray, and only a small amount in the one on the West.

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Figure 3.1 Forestry drainage system





4. **BUFFER STRIPS AND THEIR CATCHMENT AREAS**

Two buffer strip sampling sites, one designated East and one West were selected in collaboration with local Forestry Commission staff. The two buffer strip sites were intended to be duplicates, as far as was practicable, but it became apparent that they differ significantly. The drainage areas for the two sampling sites have been mapped and are illustrated in Figure 4.1. The catchment area for the West site (0.032 km²) is roughly twice that of the East site (0.017 km²). The slopes of the buffer strips are shown in Figure 4.2.

The East site is characterised by deep peat soil both in the ploughed area and in the buffer strip. The vegetation is primarily moorland grass, bog grass and some sphagnum. The drainage area at the West site has a thin peat covering over a soil of a more mineral nature, whilst the soil of the buffer strip appears to be clayey. The vegetation of the West buffer strip is similar to that to the East with a considerable growth of Juncus.



FIGURE 4.1 Drainage areas with height contours



FIGURE 4.2 Schematic diagram of buffer strips and their slopes

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5. EXPERIMENTAL PROCEDURES

The experimental strategy was to sample and analyse runoff down the buffer strip between the end of the cross-drain and the receiving stream. Data was obtained using 'spot' sampling and continuous monitoring, sediment analysis and depth measurement, and field observation. These data provided information on the effects of the buffer strip on runoff water quality under a range of flow conditions during the three years in which the trees became established and re-vegetation of exposed soil took place.

5.1 <u>Rainfall</u>

A Cassella 0.2 mm tipping bucket rain gauge, having a funnel diameter of 225 mm, was installed at the West site. Times of the bucket tipping were recorded to the nearest 10 seconds, giving a maximum measurable rainfall intensity of 72 mm h⁻¹ which occurred on a few occasions. Data was stored in the field in a Technolog 'Baby Newlog' logger, retrieved during visits to the site using a hand-held 'PSION organiser' and then transferred to a personal computer for subsequent interpretation and analysis using Technolog GPS-1 software. The rain gauge and data logging worked without fail throughout the $2\frac{1}{2}$ years of the experiment, the only maintenance being the occasional removal of debris from the funnel. The results are presented in Appendix A.

5.2 Flow measurement

Half-90° thin plate triangular weirs conforming to BS 3680 (Arkon Instruments Ltd) were mounted on PVC sheets and installed across each of the drainage ditches, embedded into the sides and invert, just before they discharged to the buffer strip area. 'Aquatrac' ultrasonic depth gauges were mounted on concrete slabs positioned about 1 m upstream of the weirs, about 100 mm below the level of the notch. Data was stored in Technolog 'Newlog' loggers pending transfer to a 'PSION Organiser'.

During the first few months of the study, both Aquatrac sensors were susceptible to being covered by sediment - when they ceased to function. This became a relatively infrequent occurrence at the East site and the data record is substantially complete. However, the sensor at the West site almost always became buried again so soon after it was cleared (usually in the next rainfall event) that there was very little useful data from it and it was abandoned. (Repeatedly clearing the sediment posed the problem of what to do with it: to clear it from the system altogether removed some of the legitimate sediment load, to place it downstream of the weir imposed an atypical load.)

The results from the East Aquatrac are presented in Appendix A. To compensate for the lack of direct flow measurements at the West site, where necessary the flows there have been estimated from those at the East site. The relationship between the two flows has been based on a comparison of measured flows at sampling times during the 1990/1 winter. Although the samples were not taken simultaneously, but usually about half an hour apart, there seems to be a reasonable correspondence between the flows (see

Figure 5.1), with West flow being approximately $1.25 (\pm 0.07)$ times the East flow (least squares fit through the origin).

5.3 Manual sampling and analysis

Spot samples of the drainage water were taken from each weir and at 10 metre intervals downstream up to a distance of 50 metres; at the West site there is a small waterfall about 100 metres from the weir and samples were taken from here too. These samples have been identified as E0 or W0 (at the weir) to E5 or W5 (at 50 m) and W6 (at the waterfall). Small plastic boxes were sunk into the ground at the sampling points to facilitate taking samples during low flows without disturbing the sediment and contaminating the samples.

Routine sampling was aimed to be at approximately fortnightly intervals, but deliberately biased towards wet weather when flows would be higher and it was anticipated that water quality would be worse, and any effect of the buffer strips more evident. In addition, on a few occasions several sets of samples were taken throughout a rainfall event.

At the same time as sampling, the depth of flow at the weir was measured and this was used to calculate the corresponding flow rate (using the relevant tabulated values in BS 3680).

5.3.1 Analysis

Depending on which determinations were to be carried out, samples were taken into up to three separate bottles: Un-preserved samples were analysed for suspended solids, colour, pH, alkalinity, chloride and sulphate. Details of the analytical procedures, samples bottles and preservatives are given in Table 5.1.

Determinand	Bottle	Preservative	Method of analysis
Colour	A	-	Absorbance of sample, filtered through a GFC filter, at 400 nm in a 40 mm cell, expressed in terms of a 1 m path length.
Suspended solids	Α	2	Gravimetrically, after filtration through a GFC filter and drying at 105 °C.
Total phosphorus	А	-	Hydrolysis using ammonium persulphate, followed by molybdenum blue
Sulphate	А	-	Ion chromatography.
рН	А	-	Electrometrically.
Alkalinity	А	-	Titration to end point or pH 4.5.
Nitrate	В	(i)	Ion chromatography or by reduction to nitrite and azo dye colorimetry using an AutoAnalyzer.
Ammonia	B	(ii)	Indophenol blue colorimetry using an AutoAnalyzer.
SRP	В	(iii)	Molybdenum blue colorimetry using an AutoAnalyzer.
Iron}Aluminium}Manganese}Calcium}Potassium}	С	(iv)	Inductively-coupled plasma atomic emission spectrosopy

Table 5.1 Analytical methods

Key:

A - 11 wide mouth polyethylene bottles with polyethylene cap and insert.

B - 60 ml polyethylene bottles.

C - 125 ml polyethylene bottles.
(i) - mercuric chloride preservative.
(ii) - sulphuric acid fixative.

(iii) - filtered as soon as practicable after sampling.

(iv) - nitric acid as fixative.

The results from the manual sampling, including flow measurements and chemical analyses are tabulated in Appendix B.

5.4 Continuous measurement of suspended solids

In assessing the first year's results it became apparent that the manual sampling programme had missed many rainfall events, including perhaps the most severe ones which are of particular interest to the project. It was also recognised that taking samples along the buffer strips at approximately the same time - even taking them in sequence with the direction of flow - is not necessarily representative of the effect of the buffer strip. There is a flowrate-dependent time taken for the water to travel down the buffer strip; the water itself will be attenuated with varying amounts of transverse and longitudinal mixing, and the solids load may be attenuated even more.

In an attempt to overcome some of the shortcomings of the manual sampling programme continuous suspended solids monitors were installed at the top (W0) and bottom (W6) of the West buffer strip. Partech IR40C sensors were used in conjunction with Technolog interfaces and loggers so that the data could be down-loaded using a PSION Organiser in the same way as the rainfall and flow data.

Before installation the sensors were calibrated (measuring current (mA) against suspended solids concentration) with a range of samples taken from W0 during a major runoff event, the suspended solids concentrations ranging to nearly 1000 mg 1^{-1} . Following installation, the performance of the sensors was monitored by comparing the suspended solids concentration of manual samples (from W0 and W6) with the corresponding record (mA) from the sensors. Early results showed a large discrepancy from the initial calibration. Consequently, the sensors were recalibrated against a range of standardised kaolinite suspensions (100 mg 1^{-1} to 1200 mg 1^{-1}), and regularly after that were checked against a standard of 400 mg 1^{-1} . Also, to enable a closer comparison between manual samples and the continuous measurements, the frequency of recording by the sensors was increased to every five minutes and the times of taking the W0 and W6 samples noted with greater accuracy.

On the whole, the results from calibrations using kaolinite, in the laboratory and in the field, were acceptably consistent - usually varying by less than 10% with slightly higher values when batteries were new and declining towards the end of battery life.

However, comparisons of actual samples with the sensor readings at the times of taking the samples were variable. On 12 February 1992 seven samples were taken from both W0 and W6 throughout a hydrograph, including suspended solids concentrations up to 500 mg l⁻¹, and all 14 results were consistent, also agreeing almost exactly with the kaolinite calibration. Results from other sampling occasions do not agree so well. It is suggested that some of the disparity may be due to the gritty nature of some of the solids, making them settle very rapidly. For example, the deviation of the initial calibration at high concentrations may have been due to inadequate suspension of the larger solids (which is not a problem with *in situ* readings). Also, rapid settling of coarse solids during sub-sampling for suspended solids analyses could lead to low results although care was

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taken to minimize this. Furthermore, the quality of the drainage water can vary quite rapidly, especially during the rising phase of a hydrograph, confounding an exact correspondence between manual sampling and monitored value.

Although calibration of the sensors in terms of drainage water suspended solids remains poorly defined, on all calibrations the two instruments have given very similar responses (batteries were always changed on the same day). As a further check the instruments were interchanged for both W0 and W6; the records continue without any apparent shift. This gives reasonable confidence in the comparison of the results from the top and bottom of the buffer strip, even if there is some doubt as to the absolute values.

Results from the calibrations with kaolinite and checks with actual samples are presented in Figure 5.2. Exact correspondence between real samples and kaolinite is not to be expected because the optical sensors respond differently to particulate matter according to its physical charcteristics. However, kaolinite has the advantage that standards can be reproduced with confidence.



FIGURE 5.1 Comparison of the flowrates at the East and West sites.



FIGURE 5.2 Calibration of the Partech IR40C suspended solids sensors.

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During summer 1992 one sensor failed and its replacement was unreliable, leading to gaps in the data, but there was no recurrence of the problem after a new sensor was installed in autumn 1992. There are also a few gaps in the data record due to grass or other debris getting between the lenses of the sensor. The only other maintenance they required was cleaning of algae etc. from the lenses.

The results from the Partech sensors are plotted in Appendix A.

5.5 Sediments

A significant accumulation of sediment became apparent as the ground dried out in the spring of 1991. Consequently, during the dry summer period the opportunity was taken to estimate the quantity of sediment. This was done by measuring the depth of sediment along a transect, perpendicular to the line of flow, at each 10 m interval corresponding to a sampling point; it was believed that this would give a reasonably representative picture. However it became apparent that there was a lot of variation in the build up of sediment - partly due to the irregularities of the original soil surface, and partly to the sediment itself forming mounds and channels. A further difficulty was that the interface between the underlying soil and overlying sediment is not always clear.

An attempt was made to monitor further accumulations by inserting rulers at each of the sampling points (W1 to W5), in level ground below W6, and near E2.

5.5.1 Particle size analysis

At the time of the initial assessment of the sediments and during the two following summers, samples were taken of the sediment at 10 m intervals down the buffer strip. On the first occasion samples were taken from the centre and side of the watercourse, but only from the centre subsequently. A sample was also taken from the side-stream of sediment corresponding to the route taken by high flows leaving the main channel at 35 m on the West site (see Section 6.1.2).

5.6 Time of travel

Time of travel through the buffer strip was measured by adding a small quantity of rhodamine-wt dye to the drainage water immediately downstream of the weir. Samples were then taken at regular intervals from the lowest sampling point (E5 or W6) and analysed fluorimetrically for Rh-wt. The procedure was carried out at the West site at a flow of 111 s^{-1} , which is roughly in the middle of the range of flows that occurred during the study. The results are plotted in Figure 5.3 from which it can be seen that tracer arrived at W6 after 10 minutes, reached a peak concentration between 14 and 15 minutes, after which it declined exponentially. When the exercise was carried out at the East site the tracer concentrations at E5 were too low to draw definite conclusions and there was no subsequent good opportunity to repeat it.



FIGURE 5.3 Results from time of travel study at the West site.

5.7 Soil water

A perforated 100 mm diameter plastic tube was inserted vertically at about 25 metres from each of the weirs in an attempt to sample sub-surface flow. However, it soon became apparent that most of the water accumulating within the tubes was probably surface water that had seeped down the outside of the tubes and did not represent the quality of the soil water. This, taken with the fact that the flow of soil water was probably negligible compared with the surface flow, lead to the early abandonment of these measurements.

6. **RESULTS FOR THE WEST SITE**

6.1 Vegetation

6.1.1 Ploughed area

When the catchment was ploughed, the furrows and ridges of overturned soil resulted in about two-thirds of the ground area being exposed as bare soil. Ploughing extended through the overlying peat layer over virtually the entire area, the exposed soil varying from resembling a gley to resembling a brown earth on the higher (and steeper) ground.

There was some re-vegetation of the ploughed areas during the following summer (1991), though variable - ranging from very little where the soil is substantially peaty to perhaps 20% on the brown earths. It is estimated that overall about 5 to 10% re-vegetation took place.

During the second summer, perhaps encouraged by the fertilization in 1991, re-vegetation extended such that about 80% of the originally exposed soil was covered with foliage, although the area where vegetation was actually growing was probably only about 50%.

6.1.2 Buffer strip

1990 - 1991

In autumn of 1990, there was a period of at least a month between ploughing of the catchments and cutting- of the cross-drains, during which time there was substantial rainfall and the furrows collected a large amount of water. Hence, when the cross-drains were cut, especially as it was raining quite heavily at the time, they were immediately filled with a large quantity of water. The resultant initial deluge completely flattened the vegetation along the line taken by the drainage water through the buffer zone. The vegetation remained flattened throughout the winter of 1990/91. Throughout the length of its passage through the buffer strip, the drainage water followed a natural depression and flowed in a fairly narrow channel, generally no more than 1 m wide; the main exception to this was that at high flows some water left the main channel at about 35 m and flowed in a fairly wide channel over flat ground alongside, rejoining the main channel at about 75 m.

1991 - 1992

Re-growth began in the late spring of 1991, and by June/July it was clear that the vegetation along the line taken by the drainage water was a much darker green and possibly denser and taller than the surrounding vegetation. This is attributed to the extra nutrients carried down in the drainage water, and perhaps to some irrigation value. There was no large rainfall event, sufficient to produce a high runoff, between mid-April and

October. During this time and the early part of the following autumn, the drainage water flowed between the stems of the vegetation throughout the length of the buffer strip.

Over the next three months, successive large rainfall events resulted in the vegetation being flattened by the runoff, progressively extending further down the buffer strip. Flattening extended to 10 m by the end of October, 30 m by mid-November, 45 m by early January 1992, and reached a maximum of 60-70 m by March. The vegetation was flattened to 30 m for quite a long time during which high flows left the main channel at this point; once the vegetation had flattened, further high flows spilled over at 35 m, as they had done the previous winter. By the end of March 1992, the appearance of the buffer strip resembled that of the first winter, in particular with the water flowing over the flattened vegetation, rather than through it, even at low flows. Throughout the winter period, movement of sediment into and within the buffer strip was evident, corresponding with significant high runoff episodes.

1992 - 1993

During the summer of 1992, the vegetation re-grew much as it had the previous year. In the following autumn and winter, although there were frequent rainfall episodes, especially in September and November, there was not such heavy rainfall as in the previous two winters. Consequently flows were not so high and the vegetation was not knocked down as it had been in the 1991/92 period. Even as late as mid-March 1993 only about the first 10 m of vegetation had been flattened. Then there was a short series of heavier rainfall - on 29 March, 5 and 6 April, resulting in the vegetation being flattened to 20 m and it was not until then that there were clear signs of fresh sediment having entered the buffer strip.

6.2 Water quality issuing from the cross-drain

It is important to bear in mind that these comments are based on spot sampling which was biased towards wet weather, and that water quality is likely to vary throughout a hydrograph. Consequently, the results cannot be expected to be completely representative of the drainage water quality and the conclusions should be seen as indicative only.

6.2.1 Suspended solids

Clearly, the ploughing operation caused substantial soil disturbance and generated large quantities of loose solids and also exposed bare soil to erosion. This resulted in a substantial rise in the solids content of the drainage water. This cannot be demonstrated categorically from the present exercise because of the minimal pre-ploughing data - the effect of ploughing was not the main objective, and is already well documented. However, it is of interest to see how persistent the increased solids are, and the rate at which the soil re-stabilises. For this reason, the data for suspended solids are presented by year/winter because the time since ploughing is a major factor.

1998 - 91

As might have been expected, it was observed that suspended solids concentration generally increased with flow rate (Figure 6.1, note that flows are based on manual measurements at the West weir at the time the samples were taken). From virtually no suspended solids at low flows, the concentration rose to 300-500 mg l⁻¹ at 10 l sec⁻¹ (with a few values much higher) above which the limited data suggests that no further increase in solids concentration occured. The suspended solids concentration is, of course, influenced by factors other than flow, such as rising or falling stage, rainfall intensity, and the availability of erodable material within the catchment. It is not surprising, therefore, that there is substantial variation in the relationship between solids concentration and flow, but interesting that the relationship is generally more consistent on any given day. This general relationship appeared to remain substantially the same throughout the the first winter, but it should be noted that the highest concentrations occurred soon after ploughing.

1991 - 92

The relationship between solids concentration and flow (Figure 6.2) was substantially the same as in the previous winter - generally reaching a maximum of around 400 mg Γ^{I} at a flow of about 10 l sec⁻¹. This indicates that active erosion was still occurring, and at a level comparable with that of the previous winter. (It also suggests that most of solids seen by the sampling programme in the previous winter resulted from erosion, not the washing out of loose material - this is discussed further in comments relating to sediment.)

1992 - 93

The absence of significant rainfall events during the 1992-93 winter has been mentioned already. This, together with the fact that much of the rainfall that did occur was during the night, militated against manual sampling and fewer samples were taken than in the previous winters.

The few manual samples that were taken (Figure 6.3) indicate a much reduced solids concentration compared with the previous years, generally below 20 mg l^{-1} even at flows of 20 l sec⁻¹. This is consistent with enhanced re-vegetation causing a reduction in soil erosion. However, the manual samples probably give a somewhat conservative impression - the Partech sensor at W0 indicated a few responses similar to the previous winter's (about 500 mg l^{-1} at flows approaching 10 l sec⁻¹ in late November).



FIGURE 6.1 Suspended solids v. flowrate at the West weir during winter 1990-91.



FIGURE 6.2 Suspended solids v. flowrate at the West weir during winter 1991-92.

6.2.2 Colour

The colour of the drainage water was usually low - ranging between 4 and 12 AU m⁻¹ and not obviously related to flow or any other water quality parameter. However, colour increased progressively throughout the study, being around 5 AU m⁻¹ soon after ploughing and reaching about 10 AU m⁻¹ by the end of 1992. There were a few particularly high values (25-30 AU m⁻¹) in spring 1992 which gave the impression of a large rise in colour during the 1991/2 winter, but these high values did not persist into the following winter.

6.2.3 Alkalinity and pH

At low flows, pH was generally around 5.5 and decreased progressively as flow increased, being about 4.8 at peak flows (25-30 l sec⁻¹). It is interesting to note the negative correlation with sulphate and nitrate, presumably reflecting the impact of acid deposition; and a positive correlation with chloride suggesting the impact of maritime air.

Alkalinity varied in line with pH: as high as 10 mg l^{-1} at very low flows, but falling rapidly as flow increased, mainly in the range of 3 to 5 mg l^{-1} , but down to 3 at high flows.

6.2.4 Phosphorus

Pre-fertilization

Before fertilization total phosphorus (TP) concentrations were consistently about 0.04 mg 1^{-1} at low flows, but more scattered at high flows, ranging between 0.1 and 0.5 mg 1^{-1} . There was a clear correlation between TP and SS (Figure 6.4), and soluble reactive phosphorus was usually below the detection limit of 3 µg 1^{-1} , so it is evident that most of the phosphorus was particulate. The concentration of phosphorus related to suspended solids was about 1 mg g⁻¹.

Post-fertilization

In the first major (sampled) rainfall event after fertilization TP was nearly 5 mg 1^{-1} . Total phosphorus concentrations declined subsequently, but were close to 1 mg 1^{-1} during high flows on 31 March. It is apparent that, superimposed on the gradual temporal decline of phosphorus concentrations, TP was also affected by flow, as found for the pre-fertilization data. By the 1992/3 winter the levels of phosphorus appeared to be comparable to pre-fertilization levels, but a satisfactory comparison cannot be made because of the lower flows during this period. Phosphorus retention would be expected to be better at the West site compared to the East site because of the higher absorptive capacity of mineral soils compared to peat.

Shortly after fertilization, soluble reactive phosphorus (SRP) was measured at 0.75 mg l^{-1} , a month later it was 0.2 mg l^{-1} , and subsequent values were around 0.05 to 0.1 mg l^{-1} .



FIGURE 6.3 Suspended solids v. flowrate at the West weir during winter 1992-93.



FIGURE 6.4 Total phosphorus v. suspended solids at the West weir before fertilization.

230/16/W

This gradual decline is similar to that of TP and the results indicate that over a range of concentrations the soluble reactive phosphorus (SRP) concentration was often up to 30% of the TP. This is much higher than before fertilization and indicates that at least some of the applied fertilizer was dissolved in the drainage water. In addition, the concentration of insoluble phosphorus (TP minus SRP) had risen to about 2 mg g⁻¹ suspended solids - compared with the pre-fertilization value of about 1 mg g⁻¹.

6.2.5 Potassium

Pre-fertilization

Before fertilization potassium concentration showed a clear relationship to flow: about 0.4 mg l^{-1} at low flows, rising to 1 mg l^{-1} or more by 151 sec⁻¹.

Post-fertilization

After fertilization the concentrations of potassium rose substantially, early results exceeding 60 mg l^{-1} . During the following months there was a steady decrease, illustrated in Figure 6.5, falling to between 1 and 2 mg l^{-1} by April 1992, with similar levels during the 1992/3 winter - which is still about twice the pre-fertilization level.

6.2.6 Calcium

Pre-fertilization

Calcium concentrations were generally about 4-5 mg l^{-1} , showing a slight decrease with increased flow, and a slight increase with pH and alkalinity.

Post-fertilization

The rock phosphate fertilizer applied to the catchments includes calcium. Shortly after fertilization, the concentrations of calcium rose at least ten times higher than before, exceeding 50 mg 1^{-1} . During the following months there was a steady decrease, such that by April 1992 the concentrations were around 5 mg 1^{-1} , and about 4 mg 1^{-1} during 1992/3 - similar to those found before fertilization.

6.2.5 Chloride

Pre-fertilization

Chloride concentrations were mostly between 5 and 10 mg l^{-1} , with concentration tending to be lower at higher flows, but two exceptional values of around 25 mg l^{-1} at a flow of about 10 l sec⁻¹.
Post-fertilization

Samples were analysed for chloride during a major rainfall event about two months after applying fertilizer. The concentrations were greater than 30 mg l^{-1} - at least three times those seen before fertilization - no doubt reflecting the addition of chloride with the potassium. Further analyses in spring 1992 were consistent with a progressive decrease in the chloride concentration, comparable with that found for potassium and calcium; and by comparison with those results it seems likely that the chloride concentration had been even higher soon after fertilization.

6.2.6 Sulphate

Concentrations of sulphate were mainly between 5 and 15 mg l^{-1} , tending to be lower at higher flows, and showing a marked negative correlation with pH. No significant changes with time were evident.

6.2.7 Nitrate

Nitrate concentrations were within the range of 0.1 to 0.5 mg l^{-1} . Occasional higher values (up to 2.5 mg l^{-1}) were always associated with low pH, and there was a positive correlation with sulphate, suggesting that acid deposition was a major source of the nitrate.

6.2.8 Ammonia

Concentrations of ammonia were generally between 0 and 0.5 mg l^{-1} . There were two higher values (about 1.5 mg l^{-1}) during the autumn after fertilization, but these were also associated with higher nitrate (and lower pH) which is thought to be of more significance than the fertilization.

6.2.9 Aluminium, iron and manganese

These three metals are clearly associated with the suspended solids, and varied with flow accordingly. Aluminium and iron were less than 1 mg l^{-1} at low flows, generally rising to around 5 mg l^{-1} at high flows. Manganese concentrations were much lower: about 0.05 mg l^{-1} at low flows, and rising to only around 0.1 mg l^{-1} at high flows. All three metals also show some correlation with colour.

6.3 Effect of the buffer strips on water quality

6.3.1 Suspended solids

1990-91

During the first winter following ploughing, the only water quality data available are from manual sampling. The results for suspended solids are shown in Figures 6.6 and 6.7 which show how suspended solids concentration varied at each of the sampling points down the buffer strip for each sampling occasion. Figure 6.6 gives results for a series of samples taken during a rainfall event on 16 November and Figure 6.7 gives all the other results during this winter period. It is immediately apparent that, based on this data, there was very little change in water quality, at least during the first 50 m, though there was usually a reduction in suspended solids concentration, typically of around 50%, between 50 m and 100 m. Some of this improvement may be due to some flow leaving the main channel at about 35 m, spreading out over a wider area which allowed settlement to occur, and rejoining between W5 and W6; and also from some dilution by less contaminated surface water from ground above the buffer strip which joins the main flow of drainage water between W5 and W6.

The minimal improvement in water quality within the first 50 m was not surprising in view of the appearance of the site during wet weather: the drainage water passed over the flattened vegetation at a high velocity with a transit time of only a few minutes and apparently little opportunity for settlement of solids. However, in the spring it was noticed that there was a layer of sediment, typically 50 mm deep, either side of the watercourse through the buffer strip for a large part of the first. 50 m. The quantity of sediment was estimated at about 2000 kg. It was also estimated that the quantity of solids carried by the drainage water throughout the winter period was about the same amount. This was clearly anomalous in view of the minimal reduction in the concentration of suspended solids. (This is discussed in more detail in Section 6.4 relating to Sediments below.)

One possible explanation was that the major events had been missed, (the flow record showed that this was so) which was significant from two points of view: First, if higher flows were accompanied by higher solids levels, then these could be the periods of greatest impact on quality; and the absence of data at the highest flows could have resulted in underestimation of the solids load. Consequently the Partech suspended solids monitors were installed.

1991-92

Manual samples

The overall pattern of results was broadly similar to that seen in the first year, with a modest decline in suspended solids between W0 and W5, and a more substantial

reduction by W6. However, examination of the data for different times throughout the winter period indicates some changes in the performance of the buffer strip. The suspended solids concentrations from manual samples taken at the sampling points down the buffer strip are illustrated by Figures 6.8 to 6.10 which show the data for autumn 1991, 12 February 1992 and 24 April 1992 respectively.

Figure 6.8 shows that, at least on some occasions during the autumn, there was a substantial reduction of suspended solids within the first 50 m as well as beyond that. Unfortunately, due to the absence of an effect in the first 50 m during the first year, it had been decided to take fewer intermediate samples, so it is not possible to say whether the improvement in water quality occurred uniformly throughout the strip or from some intermediate point. The results for 12 February show that the suspended solids concentration decreased fairly consistently after about 30 m, and on 24 April after 40 m. A typical reduction of suspended solids on these latter occasions would appear to be about 50%.

Taken together, the results indicate that there was a progressive reduction in the effect of the buffer strip - that a progressively larger stretch of the upper part of the buffer strip had negligible impact on water quality. This ties in well with the progressive knock-down of the vegetation, and was not apparent in the previous year's results when all of the vegetation was flattened right from the start and remained so throughout the winter. However, the smaller effect of the buffer strip for the first 30 m could also be due to the slope being steeper (see Figure 4.2).

The five sets of samples taken on 21 September 1991, following a prolonged dry period, clearly illustrate some of the difficulties of interpreting the data, especially based on manual samples: There was no flow in the drain before the onset of rain, and when the first sample was taken from W0 there was still no flow emerging at W6. Fifteen minutes later the flow at W0 had reached about $4 \, l \, sec^{-1}$ but there was only a small flow at W6. At this time the suspended solids concentration at W0 was 212 mg 1⁻¹ and only 10 mg 1⁻¹ at W6, but it would be misleading to conclude that this represents a 95% reduction in the solids load as clearly there was a substantial delay in the water passing over the weir and reaching W6. A further 15 minutes later, the suspended solids at W0 had reached 943 mg 1⁻¹ and 124 mg 1⁻¹ at W6, but it is not possible to determine how much of this reduction is due to retention of solids in the buffer strip and how much to the retention time of the water. Conversely, in the declining phase of the hydrograph, the data indicate a solids reduction of 50% or less, but this could be pessimistic due to the W6 sample not really corresponding to the W0 sample taken at about the same time.

Continuous monitoring

The data from 21 September emphasise the value of continuous monitoring, which has been approximated by using the Partech suspended solids sensors. The results for October 1991 to April 1992 are shown in Appendix B (Figure A2.24 onwards), in which the suspended solids concentration is based on the kaolinite calibration of the Partech sensors described in Section 5.4. As mentioned there, even if the calibration is biased so that the actual suspended solids concentrations were different to that presented in the Figures, it is

thought that the two sensors respond sufficiently similarly for a comparison between the two to be valid. The Figures include the corresponding flow rate at the East site as an indication of the flow at the West site in the absence of an actual West flow record.

Inspection of these Figures reveals two important features that affect the performance of the buffer strip: The first is time through the winter season - attributed to the state of the vegetation, and the second is flow rate. Data for individual events referred to in the following paragraphs are shown in Figures 6.11 to 6.16. It should be noted that these Figures do not represent solids load which is the product of concentration and flow which is not available, and neither can it be assumed that the instantaneous flow rates at WO and W6 are the same.

Effect of time/vegetation

The effect of time is seen most clearly by the major rainfall events - when flow rate at the East site was 201 sec^{-1} or more.

The first major event was on 31 October (Figure 6.11) when the vegetation in the buffer strip was substantially intact. Although there is no flow record for this day, the rainfall event was sampled and manual measurement of the flow at the West site showed a maximum of about 30 l sec⁻¹. The Partech sensor record indicates that suspended solids concentration at the weir peaked at over 700 mg l⁻¹ and remained above 500 mg l⁻¹ for four hours; it was two hours before the SS at W6 rose substantially, reaching 200 mg l⁻¹. Also it is clear from the results that most of the solids must have been retained within the buffer strip, and not simply delayed.

During the next two weeks the grass was flattened to about 20.m. On 12-November there - was a further major event and Figure 6.12 shows the smaller reduction in SS throughout the event, with the peak concentration of 700 mg l^{-1} at W0 falling to 500 mg l^{-1} at W6. Figure 6.12 also shows a clear delay between W0 and W6 in the rise and fall of SS.

On 21 December (Figure 6.13), by which time the vegetation was flattened to 30 m, the SS at W0 and W6 were comparable, peaking at about 650 mg Γ^1 , throughout much of a 4-hour event.

By 12 March (Figure 6.16), when the vegetation was flattened beyond 50 m, the peak SS at W0 of 850 mg l^{-1} was reduced to 750 mg l^{-1} at W6, and then W0 and W6 were much the same for four hours during the declining phase.

It is evident from this sequence of events that during the autumn there was a progressive reduction in the effect of the buffer strip, with the trend persisting into the spring. Also, the performance of the buffer strip corresponds well with the changes in the appearance of the vegetation in the strip during this time.



FIGURE 6.5 Potassium concentration at the West weir after fertilization.



FIGURE 6.6 Changes in suspended solids concentration down the West buffer strip on 16 November 1990.



FIGURE 6.7 Changes in suspended solids concentration down the West buffer strip during winter 1990-91 (except 16 November).



FIGURE 6.8 Changes in suspended solids concentration down the West buffer strip during autumn 1991.



FIGURE 6.9 Changes in suspended solids concentration down the West buffer strip on 12 February 1992.



FIGURE 6.10 Changes in suspended solids concentration down the West buffer strip on 24 April 1992.



FIGURE 6.11 Continuous monitoring of suspended solidsat W0 and W6 on 31 October 1991.



FIGURE 6.12 Continuous monitoring of suspended solids at WO and W6 on 12 November 1991.

Effect of flow rate

The event on 21 December has already been mentioned. There were further significant events on the following two days, but with lower flow rates, and although the peak SS at W0 were similar on each occasion, it can be seen (from Figure A2.31) that the SS at W6 was much less.

Throughout January and February, when the vegetation within the buffer strip was flattened beyond 40 m, there were several events when the SS at W0 reached about 700 mg 1^{-1} but peaked around 200 mg 1^{-1} at W6 i.e. showing a substantial reduction in solids despite the flattened vegetation. However, for each of these events the flow rate at the East site was only about 10 l sec⁻¹ or less. Figure 6.15 shows two typical events which occurred on 22 February. The only event when flow exceeded 10 l sec⁻¹ (on 3 January) coincided with when SS at W6 reached 600 mg 1^{-1} .

1992-93

The limited data available from the manual sampling (Figure 6.17) show that, despite the substantially intact vegetation, there was little reduction in suspended solids in the first 50 m, though the reason for this may be that the initial solids level was low. There was a consistent decline between W5 and W6.

The suspended solids monitors confirm the limited inputs of solids into the buffer strip. They also show that during the heavy rainfall on 6 December 1992, which resulted in high solids concentrations at the weir, there was no increase in the solids concentration at W6. In fact there was no significant loss of solids from W6 until the high rainfall on the 5 and 6 April 1993. The readings from W0 and W6 for 6 December 1992, 30 March 1993 (when a slight increase in solids at W6 can be discerned), 5 and 6 April are shown in Figures 6.18 to 6.21.

The overall picture that emerges is consistent with that seen in 1991-92, but there is too little data to give substantially more information.

6.3.2 Other insoluble determinands

As might be expected, those determinands thought to be associated with suspended solids showed a similar response to the solids, namely aluminium, iron and manganese, and in particular total phosphorus for which the post-fertilization data are illustrated in Figure 6.22.



FIGURE 6.13 Continuous monitoring of suspended solids at W0 and W6 on 21 December 1991.



FIGURE 6.14 Continuous monitoring of suspended solids at W0 and W6 on 3 January 1992.



FIGURE 6.15 Continuous monitoring of suspended solids at W0 and W6 on 22 February 1992.



FIGURE 6.16 Continuous monitoring of suspended solids at WO and W6 on 12 March 1992.

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FIGURE 6.17 Changes in suspended solids concentration down the West buffer strip during winter 1992-93.



FIGURE 6.18 Continuous monitoring of suspended solids at W0 and W6 on 6 December 1992.



FIGURE 6.23 Changes in colour down the West buffer strip during winter-1991-92.

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6.3.3 Potassium, calcium and chloride

Before fertilization there was virtually no change down the buffer strip in the concentration of potassium, calcium or chloride. However, after fertilization these three elements showed a tendency to decrease slightly down the buffer strip (up to 10%, especially for the earlier samples), which could indicate that they are present, at least in part, in particulate form. For potassium and calcium there were two samples about a month after fertilization which showed a large increase from W0 to W5; both were during low flow rates and it is suggested that the anomaly is due to sampling not being in phase with the flow of water.

6.3.5 Alkalinity and pH

Whereas before fertilization pH and alkalinity were substantially unaffected by the buffer strip, data from an event shortly afterwards indicated a small increase in both (about 0.2 pH units, 0.2 mg CaCO₃ 1^{-1}). This may be attributed to dissolution of some particulate rock phosphate within the strip.

6.3.5 Soluble determinands

Somewhat surprisingly there was a small (about 15%) but fairly consistent decline in the concentrations of the soluble determinands (colour, SRP, ammonia, nitrate and sulphate) between W5 and W6. It is thought that the most likely cause of this is dilution of the drainage water by less contaminated surface water. The results for colour during the 1991-92 winter period are shown in Figure 6.23.

6.4 Sediments

6.4.1 1990 - 1991

By the end of the first winter period it was apparent that, despite only modest observed improvements in the quality of water as it flowed through the buffer strip, there was clearly a significant deposition (typically around 50 mm) of sediment along the channel taken by the water. Further investigations were made to clarify this anomaly.

Quantity

During the dry summer period of 1991 the opportunity was taken to estimate the quantity of sediment. This was done by measuring the depth of sediment along a transect, perpendicular to the line of flow at each 10 m interval corresponding to a sampling point. It was believed that this would give a reasonably representative picture. However it became apparent that there was a lot of variation in the build up of sediment - partly due to the irregularities of the original soil surface, and partly to the sediment itself forming mounds and channels. A further difficulty was that the interface between the underlying soil and overlying sediment was not always clear. Sketches of the transects are shown in Figure 6.24, which illustrates the variation in terms of width and depth of the sediment, and gives the overall area (vertical cross-section) of each. Taking each transect as representative of the preceding 10 m gave the total volume of sediment to be about 1 m^3 , with a mass estimated to be around 2000 kg. It has been mentioned that, during the 1990-91 winter, high flows spilled over from the main channel at about 35 m from the weir. There was clear evidence of sediment extending away from the main channel at this point: it was quite extensive but relatively shallow, and estimated to contain perhaps a further 400 kg. This gives an estimate for the total sediment in the buffer strip of 2400 kg.

Water-borne solids load

Obviously it is important to consider the amount of sediment in the context of the solids load entering the buffer strip. An attempt was made to estimate this solids load during the 1990/1 winter. This was based on a simple rating curve, although it is recognised that this approach can have significant shortcomings.

The rating curve, relating suspended solids concentration to flow rate for the West site, was based on analyses of manual samples and the manual measurements of depth of flow which are always made at the time of taking samples (i.e. this does not rely on the operation of the Aquatracs). A simple linear regression, forced through the origin, indicated a relationship:

$$SS(mg l^{-1}) = 33.6 \text{ x flow } (l \text{ sec}^{-1})$$

Clearly this will be an over-simplification, particularly in not distinguishing between rising and falling stage and, because of the absence of data for the highest flows, relies on extrapolation (rather than interpolation) for predicting high flow values.

Based on the estimated West flow (see Section 5.2) and the rating curve for the West site, the suspended solids concentration, and hence the solids load, was estimated at 15 minute intervals throughout the autumn to spring period of 1990-91. The total load is estimated to be about 1700 kg. The flow record is not quite complete, and a comparison with the rainfall record suggests that perhaps 10% of the rainfall was missed, so the estimate of load could be increased by about 10%. In addition, it is reckoned that repeated clearing of sediment from the Aquatrac - and moving it to just downstream of the weir - could have added about a further 100 kg. this indicates that the total solids load may have been around 2000 kg.

Discussion

Comparing the information derived in the last two sub-sections indicates that the quantity of sediment is of the same order as the solids load - a conclusion which is quite inconsistent with the only modest improvement in water quality observed between the top and bottom of the buffer strip. Some possible explanations are discussed here. It is recognised that the estimate of the amount of sediment is not very accurate and could possibly over-estimate it by as much as 50%, but probably not more than this, so this alone is not an adequate explanation.

Second, it is obvious that the estimation of the solids load involves certain assumptions which could introduce error.

The most likely explanation seems to be that much of the sedimented material entered the buffer strip area when and immediately after the drains were cut: there was a lot of loose soil in the furrows because of the ploughing (a sample of accumulated water in a furrow after ploughing but before cutting the cross-drains had a solids concentration of 710 mg I^{-1}) and it has already been mentioned that it was wet before and during the cutting of the drains. So when the drains were cut they were filled immediately with a large quantity of very dirty water which spilled out over the buffer strip area. There is little doubt that the quantity of soil debris from the ploughing could easily amount to the 1 m³ of sediment found in the buffer strip - 1 m³ is equivalent to a loss of less than 0.1 mm over the exposed soil area.

6.4.2 1991-92

During the summer of 1991, short plastic rulers were inserted near the sampling points to monitor any further accumulations of sediment. An additional ruler was situated in some flat ground below W6, about 150 m from the weir, where the slower flowing water might be conducive to settlement.

During the 1991-92 winter, it was readily apparent that further sediment was being carried by the drainage water - the Aquatrac sensor was buried under sediment after almost every significant runoff event, and some accumulations of sediment were seen within the buffer strip. At an earlier stage, when the vegetation was partially knocked down it tended to form a mesh in which larger particles of sediment became trapped - giving an exaggerated impression of the depth of sediment; as the grass flattened more completely some of the sediment was released while the remainder became more permanently bound in the decaying vegetation. There was clearly a dynamic process of settlement and re-suspension, generating a shifting pattern of mounds and channels, with a gradual movement of sediment down the buffer strip with successive runoff events.

By early January there had been a further accumulation of 20 mm at the 10 m and 20 m rulers, but these were clearly in localised mounds and the sediment did not extend across or along the channel. There were accumulations of about 10 mm at the 30 m and 40 m rulers, but again this depth was not uniform. (On that particular visit, i.e. when the measurements were taken, the flattening of the vegetation had just reached the 40 m mark and there was quite a large amount of sediment supported on partly knocked down juncus, above the level of the ruler; this sediment had been washed away just four days later.) No increase in sediment was noted at the 50 m ruler or on the one placed downstream of W6.



FIGURE 6.24 Sediment sampling transects, 21 August 1991.



FIGURE 6.25 Sediment particle size analysis, 1991, 1992.

6.4.3 1992 - 1993

Throughout this period there was evidence of some sediment movement into and within the upper reaches of the buffer strip. However, the quantity appears to have been very small: there was no change in depth of sediment at W1 and a decrease at W3. This is attributed to the increased vegetation in the planted area protecting the soil from erosion, and that there was much less heavy rain too.

6.4.4 Particle size analysis

During the summer dry periods samples were taken of the sediment at 10 m intervals down the buffer strip, from the centre and side of the watercourse. A sample was also taken from the side-stream of sediment corresponding to the route taken by high flows leaving the main channel at 35 m on the West site and, in 1992, from the flat ground below the waterfall about 150 m from the weir. The results are presented in Table 6.1 and illustrated in Figure 6.25.

There is one exceptional sample: that from the centre of the channel at 20 m has an unusually high proportion of sand. Apart from this, all of the samples from the centre of the channel were substantially similar to corresponding ones at the side.

The data show a consistent decrease down the buffer strip in the coarse sand fraction of the sediments. In the second year, there is generally less coarse sand in all of the samples - in fact none in some of those from the second half of the strip. The diminution in the coarse fraction is compensated for mainly by an increase in the silt fraction. This is more evident in the second year's results which also show more silt in the samples from the side of the channel than from the centre (whereas there was little difference between side and centre samples from the first year).

The data are consistent, therefore, with a gradual settlement of sandy material from the drainage water - the depletion of coarse suspended material resulting in a corresponding increase in the proportion of finer particles further down the strip. The difference between the years is consistent with a stabilisation of the soil exposed by ploughing.

In each year, the quality of sediment from the side stream was comparable with those from the 30 m to 50 m part of the strip.

These data suggest that bedload (gravel and small stones) would be retained by the buffer strip. However, the soils and subsoils of this catchment do not contain appreciable quantities of bed-load material.

Sample	% in each size (micron) fraction			on Silt	Clay
	2000-600	600-211	212-63	63-2	<2
1991 : Centre of flow-path					
W0, Weir pool	17.0	6.5	16.2	36.8	23.5
W1, 10 m	8.7	17.1	. 26.6	32.	15.6
W2, 20 m	25.2	29.0	14.6	20.4	10.8
W3, 30 m	11.8	24.5	16.4	31.4	15.9
W4, 40 m	6.2	20.9	26.8	30.9	15.2
W5, 50 m	2.5	18.3	27.6	34.8	16.8
W6, 100 m	2.2	1.9	24.2	51.2	20.5
'Side stream'	0.2	10.2	31.4	40.9	17.3
1991 : Edge of flow-path:					
W1, 10 m	13.2	21.9	24.1	27.4	13.4
W2, 20 m	3.3	17.0	23.1	37.9	18.7
W3, 30 m	3.0	18.5	34.9	29.6	14.0
W4, 40 m	2.4	14.7	31.9	37.7	13.3
W5, 50 m	1.5	9.7	26.1	44.1	18.6
1992: Centre of flow-path					
W1, 10 m	17.6	31.3	20.9	20.1	10.1
W2, 20 m	6.	26.7	28.5	_ 24.5	14.3
W3, 30 m	.3	13.3	42.7	26.5	17.2
W4, 40 m	9.2	19.3	18.3	32.5	20.7
W5, 50 m	8.4	24.2	20.7	28.4	18.3
W6, 100 m	0.	1.8	22.1	53.5	22.6
150 m	0.	2.	16.9	54.2	26.9
'Side stream'	0.	3.6	26.8	46.7	22.9
1992: Edge of flow path					
wī1	5.1	23.2	31.2	22.6	17.9
W2	.7	18.2	31.5	30.5	19.1
W3	2.7	6.2	14.7	48.1	28.3
W4	4.4	13.7	22.8	41.1	17.7
W5	0.	2.2	22.1	53.5	22.6

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Table 6.1Particle Size Analysis of Sediment from West Site.

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7. **RESULTS FOR THE EAST SITE**

7.1 Vegetation

7.1.1 Ploughed area

As with the West site, ploughing resulted in about two-thirds of the ground area being exposed as bare soil. However, the peat layer here is much thicker and the ploughing did not extend through it.

There was very little re-vegetation of the furrows during the following summer (1991). By the end of the next year, re-vegetation still amounted to no more than about 25%. However, by spring 1993 about 75% of the exposed soil had been covered.

7.1.2 <u>Buffer strip</u>

1990 - 1991

As with the West site, vegetation along the line of flow within the buffer strip was flattened by the initial deluge of drainage water when the cross-drains were cut. Also, a large amount of peaty debris was washed onto the buffer strip. Unlike the West site, the drainage water passed over a spur of land (rather than a depression) so that the flow of water fanned out to a large extent and followed many small channels spreading out at least 5 m wide by 30 m. However, just before 40 m most of the flow collected in an old drain which it followed for the rest of its course.

Substantial re-growth of vegetation occurred during the 1991 summer which, like the West site, was clearly darker than the surrounding vegetation.

1991 - 1992

Through the autumn, about the first 30 m of vegetation was progressively flattened by successive runoff events, although vegetation in the last 10 to 15 m remained substantially intact. The route taken by the drainage water fanned out as in the previous winter but between 20 m and 40 m was about 5 m to one side (further north) of that in the previous winter.

1992 - 1993

The vegetation grew strongly again during the summer of 1992. In the following autumn and winter, rainfall was not as heavy as in the previous two winters and maximum flows were generally much lower. Consequently, most of the vegetation remained standing, although with a fairly clear channel through it for the first 20 m. Between 20 m and 40 m the flow fanned out perhaps even more than in the previous two winters.

7.2 Water quality issuing from the cross-drain

It should be noted that due to the generally better initial water quality at the East site, and the consequent greater interest in the West site, fewer samples have been taken from here.

7.2.1 Suspended solids

1990-91

At low flows, the level of suspended solids in the drainage water was virtually nil. In the first few months after ploughing, there was a substantial rise in suspended solids in line with higher flows, typically reaching around 200 mg l⁻¹ at about 5 l sec⁻¹. However this trend did not persist: from January 1991 there appeared to be a progressively smaller increase in suspended solids as flows increased. Figures 7.1 and 7.2 show suspended solids concentration plotted against flow rate respectively for the autumn of 1990 and the spring of 1991. These results suggest that loose material generated by the ploughing was washed away fairly readily, but that the undisturbed peat (even though exposed) is relatively resistant to erosion. Subsequently, some peat debris did accumulate behind the weir from time to time, indicating that some material was still being carried by the drainage water, but observed suspended solids concentrations were generally well below 50 mg l⁻¹.

1991-92

The overall pattern of data through the 1991-92 winter was similar to that of the preceding spring i.e. with suspended solids below 50 mg l^{-1} even with flows up to 30 1 sec⁻¹. However, there were two samples with solids concentrations around 200 mg l^{-1} , and it was evident from the accumulation of peaty solids behind the weir that at times there was still some transport of appreciable quantities of solids.

1992-93

During the 1992-3 winter no samples had high suspended solids concentrations, but it was apparent that during the wet period in spring 1993 that some solids were carried.

7.2.2 Colour

Colour showed a fairly consistent variation with flow: At very low flows, colour was typically 15-20 AU m⁻¹ and, as flow increased to around 3-5 l sec⁻¹, colour increased to about 25 AU m⁻¹; at even higher flows there was a steady decline in colour, falling to about 10-15 AU m⁻¹ at the highest flows.

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FIGURE 7.1 Suspended solids v. flowrate at the East weir during autumn 1990.



FIGURE 7.2 Suspended solids v. flowrate at the East weir during spring 1991.

In addition to this flow-related variation, there also appears to have been a steady increase in colour throughout the duration of the experiment, perhaps amounting to 5 AU m⁻¹. As for the West site, there were a few very high values during the spring of 1992, but these did not persist into the following winter.

7.2.3 Alkalinity and pH

The pH of the drainage water was generally around 4, but tending to be a little higher at very low flows. The low pH means that the alkalinity was almost always nil.

7.2.4 Phosphorus

Pre-fertilization

Total phosphorus concentrations ranged from 0.05 mg l^{-1} at low flows to around 0.15 mg l^{-1} at high flows, also showing a close correspondence with suspended solids - 1 mg P per g SS - which is similar to the pre-fertilization observations at the West site. Soluble reactive phosphorus was usually below the detection limit of 3 µg l^{-1} .

Post-fertilization

As with the West site, there was a very large increase in the levels of phosphorus following fertilization with a maximum observed concentration of nearly 10 mg l^{-1} which is about twice that found at the West site. There was a progressive decline in the succeeding months to about 1 mg l^{-1} , but this is still 10 times higher than pre-fertilization values. The results are plotted against time in Figure 7.3.

A significant difference from the West site is that at the East it would seem that almost all of the TP was soluble.

7.2.5 Calcium

Pre-fertilization

At low flows, calcium concentrations were about 1 mg l^{-1} and fell to 0.5 mg l^{-1} at high flows, in line with a decline in pH.

Post-fertilization

Resulting from the calcium content of the rock phosphate fertilizer, a very large increase in calcium levels occurred shortly after fertilization, values of nearly 20 mg l^{-1} being found. The concentrations then decreased to about 2 mg l^{-1} by spring 1992, and 1 mg l^{-1} during the following winter.

7.2.6 Potassium

Pre-fertilization

Although the results for potassium concentration were quite widely scattered (having a range of about 0.5 mg l^{-1} at any given flow), there was a definite positive correlation with flow - the average being about 0.4 mg l^{-1} at low flows and twice this at flows around $10 \, l \, sec^{-1}$.

Post-fertilization

As with the West site, very large increases in potassium levels occurred shortly after fertilization, values of nearly 50 mg l^{-1} being found, and then falling to about 3 mg l^{-1} by spring 1992, and 1.5-2 mg l^{-1} during the 1992/3 winter.

7.2.7 Chloride

Pre-fertilization

At low flows, chloride concentrations were around 10 mg l^{-1} and as flows increased the concentration fell consistently to 3-4 mg l^{-1} .

Post-fertilization

Although only a few samples were analysed for chloride, it is clear that chloride concentrations followed a similar pattern to those at the West site. Soon after fertilizer application concentrations reached 30 mg l^{-1} , falling by spring 1992 to 5 mg l^{-1} which is comparable to pre-fertilization levels, and which were maintained during the following winter.

7.2.8 Sulphate

Sulphate concentrations varied between 4 and 20 mg l^{-1} , correlating with pH which varied from 4.5 to 3.75.

7.2.9 Nitrogen

Most nitrate results were below the detection limit of 0.05 mg l^{-1} , and ammonia concentrations varied mostly between 0 and 0.2 mg l^{-1} . There was no significant association with other water quality parameters or flow rate.

7.2.10 Aluminium, iron and manganese

The concentrations of these three elements did not vary greatly, typically being 0.1-0.3 mg l^{-1} for both aluminium and iron, and about 0.005 mg l^{-1} for manganese. Aluminium and iron appeared to be associated with suspended solids.

7.3 Effect of the buffer strip on water quality

7.3.1 Suspended solids

1990-91

The results for the first winter period are shown in Figure 7.4 from which it can be seen that, like the West site, there was very little discernible change in suspended solids concentration down the buffer strip.

1991-92

However, the results for the second winter, plotted in Figure 7.5, show a definite decrease (around 25%) in suspended solids concentration down the buffer strip, from early on in the autumn right through into spring 1992. It is likely that the fanning out of the flow at the East site enhanced the opportunities for solids to settle out. The temporal changes observed at the West site are not so clearly evident; but this is not surprising in view of the lower solids concentration at the weir, fewer samples being taken at the East site, and no continuous solids monitoring. On one occasion there was a very large unexplained fall in suspended solids between E3 and E4.

1992-93

The limited data available for the 1992-93 winter period is shown in Figure 7.6 which shows a substantial decrease in suspended solids concentrations on most occasions, especially over the 20 m to 40 m stretch of the buffer strip.

7.3.2 Phosphorus

Both before and after fertilization there was no substantial reduction in phosphorus concentration - but for different reasons.

Pre-fertilization

Before fertilization the levels of phosphorus were low and were associated with suspended solids; because of the flattening of the vegetation there was little removal of solids or the associated phosphorus.



FIGURE 7.3 Total phosphorus concentration at the East weir after fertilization.



FIGURE 7.4 Changes in suspended solids concentration down the East buffer strip during winter 1990-91.



FIGURE 7.5 Changes in suspended solids concentration down the East buffer strip during winter 1991-92.



FIGURE 7.6 Changes in suspended solids concentration down the East buffer strip during winter 1992-93.

Post-fertilization

Phosphorus concentrations were much higher after fertilization and the results for total phosphorus are shown in Figure 7.7. Samples taken soon after fertilization, when the phosphorus concentrations were relatively high and flows low, show a substantial reduction down the buffer strip. But in most cases there was no change, consistent with the phosphorus being substantially dissolved.

7.3.3 Calcium, potassium and chloride

Pre-fertilization

No change in the concentrations of these elements was seen during the first winter period.

Post-fertilization

However, for potassium and calcium, samples taken soon after fertilization and early in the autumn had the largest initial concentrations and show the greatest reduction in calcium and potassium down the buffer strip. Later on, the initial concentrations are much lower and there is hardly any reduction. It seems likely that the difference in response is due to the presence of insoluble fertilizer components early on, but only dissolved species later. The results for potassium are shown in Figure 7.8.

It is to be expeted that chloride would have behaved similarly but too few results are available from soon after fertilization to demonstrate this.

7.3.4 Soluble determinands

Colour, sulphate, nitrate, ammonia concentrations and pH showed no obvious change down the buffer strip during any period of the project.

7.3.5 Aluminium, iron and manganese

As expected, aluminium, iron and manganese behaved in a similar way to suspended solids: no change in their concentrations during the first winter but a small decrease subsequently.

However, for the first three sampling occasions after fertilization there was a definite rise in manganese concentration down the buffer strip (see Figure 7.9). A possible explanation for this is that some manganese is solublised in the stagnant (and anoxic) summer conditions and is leached out of the peat in the early rainfall events. A similar response was not observed in the following autumn, which may be due to the different weather conditions.

7.4 Sediments

During the summer of 1991 samples were taken of the sediment in the buffer strip. However, all were found to be 100% organic so no particle size analysis was possible and no further samples were taken. It was not possible to determine the boundary between the settled material and the original soil surface, so a valid estimate of the quantities which had settled out could not be made.

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FIGURE 7.7 Changes in total phosphorus concentration down the East buffer strip after fertilization.



FIGURE 7.8 Changes in potassium concentration down the East buffer strip after fertilization.



FIGURE 7.9 Changes in manganese concentration down the East buffer strip during winter 1991-92.

8. DISCUSSION

8.1 Impact of ploughing on drainage water quality

Ploughing of previously undisturbed heathland leads to the introduction of solids in surface runoff. Solids are generated by the disruption of the soil when ploughing takes place, and in the longer term by erosion of exposed soil surfaces.

Assessing the loss of solids from the ploughed area was not the prime object of the project here (it has been reported fully elsewhere, reviewed by Swift *et_al.* 1990), and it was not possible to obtain exact controls because the drainage pattern after ploughing is totally different from that before. Prior to ploughing surface water drained from the site in the general direction of the Mossdale Burn but with few identifiable watercourses. The area used for the test buffer strip on the West site is a natural drainage area and during wet weather a flow could be discerned along the line of an old drain. A few samples were taken from this area before ploughing took place to give some indication of the pre-ploughing water quality. The samples had a low suspended solids concentration but insufficient sample was available to measure this.

8.1.1 Post-ploughing water quality

It is to be expected that the water quality during significant runoff episodes soon after installation of the cross-drains will have particularly high concentrations of suspended solids as the loose solids generated by ploughing are washed from the furrows. After this initial period, further loss of suspended solids would depend on the extent of erosion with the catchment.

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Due to the wet weather between ploughing of the furrows and installing the cross-drains and the heavy rain while the drains were cut, it is now thought that at the study site large amounts of loose solids were lost immediately the drains were installed. Unfortunately it was not possible to quantify the initial loss of solids as, clearly, the weir etc. could be installed only after the drains were in place. But a number of factors point to this conclusion: Undoubtedly the furrows contained a large quantity of very dirty water - a sample taken from a furrow had a suspended solids concentration of 710 mg l^{-1} . As the drains were cut, the water held in the furrows was released in a very short time, resulting in very high flow rates.

Also, in rain events shortly afterwards, there were substantial solids concentrations at both sites when flows were high. (This highlights the importance of taking flow into account when monitoring runoff - at low flows the drainage water contained almost no solids.) The persistence of the solids flow response relationship, particularly at the West site which extended into the second winter, suggests

• that during this time most of the solids were derived from erosion rather than loss of initially-disturbed material, and consequently that

• a large proportion of the initially disturbed material was probably lost from the catchment during or very soon after the cutting of the drains (i.e. before the routine monitoring which established the rating curve started).

Clearly, there will not be a clear-cut separation between these two sources of solids, but the data certainly suggests that most of the disturbed soil was lost when the drains were cut, and most of the solids found subsequently in the drainage water arose from erosion.

The substantial layer of sediment in the buffer strip - more than can be readily accounted for by changes in water quality measured throughout the following winter - also suggests that considerable sedimentation occurred before the routine sampling started.

8.1.2 Long term soil stabilisation

This project has further demonstrated the importance of soil type in determining the duration of high solids loss after ploughing.

There was little loss of solids from the East site after the first few months. It is suggested that, during this time, residual loose solids generated by the ploughing were being washed out of the furrows but then the peat was relatively resistant to further erosion despite the absence of vegetation cover.

Conversely, erosion seems to have persisted at the West site until the exposed soil was protected by regenerated vegetation. The data suggests that substantial stabilisation had occurred by the 1992-93 winter, but the less severe rainfall during this period may have also contributed to the reduced loss of solids.

8.2 Impact of fertilization on drainage water quality

In the first major (sampled) rainfall events after fertilization, total phosphorus concentrations of 5 mg l^{-1} and 10 mg l^{-1} were found at the West and East sites respectively. Bearing in mind that 100% of the drained catchments were fertilized, this is in line with the TP concentration of 1 mg l^{-1} found elsewhere (e.g. the Glenorchy study, Swift 1987) shortly after applying fertilizer to about 30% of a catchment.

At both sites, total phosphorus concentrations declined substantially in the subsequent months, returning to approximately pre-fertilization levels after about a year. This is sooner than was found at Glenorchy, but there the pre-fertilization levels were much lower.

It was not possible to quantify the loss of fertilizer in this study because this would have required much more intensive sampling than was carried out.

8.3 Buffer strip performance

8.3.1 Mechanism for water quality improvement

The results indicate that the essential mechanism for water quality improvement on passage through a buffer strip is settlement. The only significant changes in water quality have been in suspended solids and those parameters associated with at least some insoluble component. There are a few exceptions where there was a small reduction in the concentration of essentially soluble components, but these can probably be accounted for by dilution of the main stream with less contaminated inputs. Absorption of nutrients by the vegetation appears to be of little significance in terms of the impact on drainage water quality.

8.3.2 Factors affecting buffer strip performance

Flow rate

Given that the main mechanism for water quality improvement is settlement, it is to be expected that flow rate will have a major impact on the performance of the buffer strip. This was observed very clearly at the West site during the spring of 1992 when much of the vegetation had been flattened: at high flows there was little improvement in quality, but at low flows there was substantial removal of suspended solids. A complicating feature, however, is that initial water quality (before the buffer strip) tends to be better (i.e. lower SS concentration) at low flows. The only practicable management option for avoiding excessive flows is to reduce the catchment area for each cross-drain by increasing the frequency of cross-drians.

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Vegetation

It was the results throughout the 1991/2 winter at the West site that so clearly pointed to the importance of the vegetation in the performance of the buffer strip. As the vegetation was flattened by successive large rainfall events there was a progressive reduction in the improvement effected in the drainage water quality. The limited data from the subsequent winter are consistent with this conclusion but are too limited (due to the much lower runoffs and initial solids concentrations) to provide substantial support.

The limited improvement observed in the quality of the drainage water througout the first winter is attributed to flattening of the vegetation for the full length of the buffer strip at both sites at the time the drains were cut.

Width of flow down the buffer strip

The extent to which the drainage water spreads out as it passes through the buffer strip also affects its performance. The obvious advantage of a wider channel is a reduction in velocity of the water which promotes settlement of solids. But also, a wider channel provides larger storage for sediment so that it is less susceptible to being transported further down the strip before it is stabilised.

At the West site, apart from one or two temporary diversions, the flow of the drainage water through the buffer strip is no more than about 1 m wide for its entire length. At the East site, at least for the first 40 m, the flow is much wider than this, fanning out progressively until the flow extends over a width of 5-10 m. This may well account for the large improvement in water quality between 20 m and 40 m observed at the East site.

Velocity

The link between the preceding factors is the flow velocity. If the main mechanism for water quality improvement is the settlement of suspended solids then it is not surprising that velocity is a major factor. Low velocity is necessary to avoid excessive turbulence so that any settlement can occur at all, and to provide sufficient retention time for a significant proportion of the solids to settle.

Slope

Arising from the above comments it is to be expected that slope will also be relevant, but there is insufficient data from this study to show a definite effect.

Buffer strip width

Assuming that settlement is the principal mechanism for water quality improvement, it is to be expected that wider strips will be more effective in removing solids.

This project has demonstrated the importance of vegetation in enhancing the settlement process, but also that it is liable to being flattened and made ineffective. Because the flattening appears to be progressive along the buffer strip, a further advantage of increasing the buffer strip width is to increase the chance of an effective area of vegetation remaining standing throughout the winter period.

In addition, it is also clear that the sediments are mobile - at least until they are stabilised by growth of new vegetation. A wider buffer strip provides a greater distance over which sediments have to travel before they reach the watercourse - increasing the likelihood that they will be stabilised within the buffer strip.

Impact of initial load

This study has clearly illustrated the severe adverse impact of cutting the cross drains in wet weather.

1. Much of the loose debris arising from ploughing was washed out at a time when flows were high, providing poor conditions for settlement.
2. The initial deluge completely flattened the vegetation thereby severely reducing the effectiveness of the buffer strip throughout the first winter period.

It should be noted that it is the exceptionally high initial flow rates that flattened the vegetation, not the accompanying solids load. If the drains had been cut during dry weather then the first significant rainfall events afterwards would no doubt have resulted in very high solids concentrations in the drainage water - but the lower flow rates (i.e. lower than those of the deluge when the drains were cut) might not have flattened the vegetation to the same extent and would have permitted better settlement of suspended solids.

Nevertheless, there was substantial deposition of solid material on the buffer strips following cutting of the cross-drains, demonstrating a beneficial effect of the strips. Unfortunately, there is no way of quantifying the amount of suspended matter which reached the receiving stream at this time.

8.4 Sediments

The particle size distributions of the sediments at the West site indicate that coarser material tends to settle in the upper areas of the buffer strip. This is consistent with the comments above concerning flow velociy and retention time within the strip. There was little material of greater than 2 mm diameter transported at the West site, and any that was would have been trapped to some extent by the weirs. Nevertheless, it can be assumed that the buffer strips would be effective in retaining some of this bed-load material.

8.5 Comparisan of East and West sites

8.5.1 Water quality before the buffer strip

On the whole, the differences between the East and West sites, in terms of the water quality before the buffer strip, are consistent with the different soil types. The East is exclusively peaty and has a much higher colour than the West. Conversely, the more mineral soil of the West site is associated with a higher pH, alkalinity and calcium concentration; it would also appear to be more erodable in view of the higher suspended solids and associated parameters such as iron, manganese and phosphorus.

8.5.2 Performance of the buffer strips

On a year by year basis, the behaviour of the East and West buffer strips was generally similar, given the difference in soils.

A significant difference between them is the extent to which the drainage water spread out - at the West site it remained within a 1 m wide channel, but was 5-10 m wide in parts of the East site. It is this latter effect that is thought to be responsible for the substantial improvement in water quality in the middle section of the East buffer strip - despite the slope being quite steep here.

Peat soils are potentially less likely to affect run-off quality than mineral soils due to greater resistance to erosion. A narrower buffer strip may therefore be adequate at such sites.

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9. CONCLUSIONS

9.1 Effects of forestry activities on runoff water quality

9.1.1 Suspended solids

This study has confirmed that ploughing can have a substantial deleterious impact on the quality of runoff, particularly in producing high suspended solids concentrations.

- 1. Major solids loss seems to be short-lived following ploughing of peaty soils.
- 2. Losses of suspended solids from mineral soils are likely to persist until substantial re-vegetation has occurred.
- 3. Ploughing, and particularly cutting cross drains, in wet weather results in the release of large volumes of water which can be heavily contaminated. Whilst the buffer strips removed some of the suspended solids at this time, the proportion of the load removed could not be quantified. The large flowrates also flatten the vegetation and impair the buffer strip's performance until regrowth can occur.

9.1.2 Effect of fertilization

It has also been confirmed that during rainfall events following aerial fertilization, large concentrations of nutrients can arise in the runoff (up to 5 and 10 mg l^{-1} respectively for the West and East sites in this study).

9.2 Efficacy of buffer strips

It is concluded that buffer strips are effective in reducing suspended pollutant loads but have only a minor effect on soluble contaminants.

The main mechanism by which they effect improvement in water quality is essentially by settlement, although in the early stage of a winter season when the vegetation is only partly knocked over it can form a mesh which traps larger particles. The sediment is susceptible to re-suspension until it is stabilised by subsequent plant growth.

9.2.1 Factors affecting the performance of buffer strips

The study has indicated that the main factors affecting the performance of buffer strip are as follows:

1. Flow velocity

The performance of the buffer strip declines at high runoff flow rates. Flow rate and

velocity are controlled by a number of inter-related factors including cross-drain frequency, buffer strip slope and lateral dispersion of runoff across the strip.

2. Vegetation

The buffer strip was at its most effective when there was a healthy growth of vegetation on it. This not only acted as a coarse filter, but reduced flow velocities.

3. Catchment soils

The effectiveness of the buffer strip is affected by the physical characteristics of the solids and the contaminant load provided by the runoff. Peat soils are of low density and peat debris is less likely to settle out than mineral material unless trapped by vegetation. Mineral soils are more readily erodable and will provide a greater contaminant load with the coarser materials (bedload and sand) tending to settle out more readily than the finer silts and clays.

4. Width of buffer strip

The greater the width of buffer strip, the greater the opportunity for settlement of the suspended solids and the more effective the strip will be, irrespective of flow rate and the state of the vegetation. In this study, a 50% reduction in solids load was frequently achieved within about 60 to 70 m from the cross-drain at the mineral soil site, under favourable conditions of flow and vegetation. The results at the peat soil site are more difficult to interpret but the indications are that the strip was more effective.

9.3 Buffer strip design

The factors identified in the preceding section should be addressed through the careful design and location of buffer strips within each proposed forestry scheme so that the maximum benefit of the strips is achieved.

9.3.1 Catchment size

The importance of flow rate in determining the performance of a buffer strip clearly points to the need to limit the catchment areas of drains to avoid excessively high flows. Consequently, where high runoff rates are expected - which are likely to be dependent on the incidence of intense rainfall - catchment sizes should be reduced. The results here suggest that the effectiveness of a buffer strip decreases markedly when flows exceed about 101 sec^{-1} .

It is also thought that heavy rain is a major factor in causing soil erosion from furrows, not just the scouring due to high flows (although this project has not provided clear data to support this).

It is however recognised that this policy - of having small catchment areas for each cross drain - will increase the lengths of drains in a ploughed area, increasing the area of exposed soil and the short-term potential for soil erosion.

9.3.2 Buffer strip width

This study has shown that the improvements in water quality through buffer strips is perhaps less than had generally been anticipated. In particular, adopting the previously suggested figure of 20 m would probably be effective only if the flows were small and the other conditions of the buffer strip very favourable. This is supported by results from studies undertaken at Balquhidder which showed that where 20 m buffer strips were used, large amounts of suspended solids still entered water-bodies.

At Dalmellington, during the second winter (which is thought to be the most indicative period) about 50% removal of the suspended solids was typical for each site - with the buffer strip being 50 m or 100 m respectively for the East and West sites. The conditions at Dalmellington are thought to be fairly typical of upland afforestation except that, if anything, the soils are less susceptible to erosion. This indicates the sort of width of that is likely to be required for buffer strips to be effective, unless more favourable conditions for the buffer strip (e.g. less slope and better dispersion) can be achieved.

Buffer strip/no-planting zone

It is important to recognise that 'buffer strip' is not synonymous with 'no-planting zone'. In this report, the term 'buffer strip' relates to the area between the end of a cross drain and a watercourse over which water from the drain must pass in order to reach the watercourse. The work reported here indicates that the width of this strip may need to be substantially greater than previously anticipated if a material improvement in water quality is to be achieved. However, this does not necessarily mean that no planting may occur within a buffer-strip-width of the watercourse: trees (including coniferous) could be planted here if, for example, it were done without ploughing, or using short furrows which did not discharge to a drain but each had a suitably-sized buffer zone around its discharge point.

9.3.4 Furrow-end buffer strips

Where the ploughed area is particularly susceptible to erosion, or where it is not possible to have a satisfactory buffer strip at the end of the cross drain, consideration should be given to having buffer zones at the end of each furrow, i.e. between the furrow and the cross drain. Because there should not be a large volume of water issuing from each furrow, even a modest buffer zone before the cross drain should be quite effective at retaining suspended solids. This would, however, make ploughing much more laborious as it would no longer be possible to plough such long continuous furrows but require repeated lifting of the plough. It would also be necessary to plan the location of drains more precisely beforehand.

9.4.3 Settlement pit

The build-up of solids behind the weirs clearly indicates that a settlement pit of relatively modest proportions at the head of the buffer strip (i.e. at the end of each drain) may remove large amounts of coarse solids. This could be particularly valuable for retaining the solids generated by ploughing.

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10. **RECOMMENDATIONS**

The main objectives of this study relate to the effective design of buffer strips. However, this cannot be entirely divorced from other forestry activities. Accordingly, the results and observations gathered in the course of this study lead to the following recommendations:

- 1. Ploughing should only be carried out where it is essential for satisfactory tree establishment and growth.
- 2. Cross-drains should be cut as soon as possible after ploughing, but not during wet weather.
- 3. Account should be taken of catchment soil erodability. It may be necessary to limit the volume of water carried by each cross-drain in areas with highly erodable soils. In effect this means limiting the catchment area of each drain and may mean increasing the number of drains. The expected rainfall intensity for the region will be a key additional factor.

Where the cultivated area is particularly susceptible to erosion, or where is is not practicable to have a satisfactory buffer strip at the end of a cross-drain, consideration should be given to the use of buffer zones between the furrows and the cross-drain.

- 4. A wide dispersion of drainage water across the buffer strip should be encouraged. Drains should not discharge into old ditches, ephemeral stream beds or depressions where run-off may form a narrow channel. If necessary, splitting the drain end may be desirable.
- 5. Cultivation should be planned such that cross-drains discharge at a site of low slope (preferably less than 4°).
- 6. If practicable, sites where cross-drains discharge should be selected where there is a thriving vegetation (i.e. avoid sites with bare soil).
- 7. The width of the buffer strip (i.e. the distance between the end of the cross-drain and the receiving water) should be adequate. This will depend upon prevailing site conditions; in this study at the mineral soil site, a 50 per cent attenuation was often attained at a width of 60-70 m. The sensitivity of the receiving watercourse should also be taken into account, this should be discussed with local officials of regulatory bodies.

The above considerations are summarised in Table 10.1

Finally, it is recommended that the results of this study are considered during the revision of the 'Forests and Water Guidelines'.¹

This has already been actioned; a summary of findings was passed by the Steering Committee to the Review Group during September 1992

Question		If answer is:		Implication for cultivation practice
1.	Are soils well drained?	Yes		Ploughing may be unnecessary
2.	Are soils readily erodable?	Yes		Consider:
				 (i) reducing catchment area by increasing cross-drain frequency (ii) construction of drain-side buffer strips (iii) increasing buffer strip width
3.	Is cultivated area steeply sloping?	Yes))	Either of these in combination with question 2 increases risks of sediment transport and emphasizes need for
4.	Is area prone to extreme rainfall intensity?	Yes)	ameliorative measures
5.	Are buffer strips steeply sloping?	Yes		Increase buffer width
6.	Do buffer strips have a healthy vegetation?	No		Increase buffer strip width or modify drainage plan so that drains discharge at better point.
7.	Is run-off likely to follow a narrow channel?	Yes		Increase buffer strip width or modify drainage plan so that drains discharge at a better point, or encourage wider flow, e.g. by splitting drain end.

Table 10.1 Summary of recommendations for forestry managers

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ACKNOWLEDGEMENT

WRc acknowledges the Forestry Authority who actively supported this study. Particular thanks are due to Dr T R Nisbet for his contributions to the Steering Committee, and to the Forestry Commission's District Office at Straiton for their co-operation at the study site.

APPENDIX A

RESULTS FROM CONTINUOUS MONITORING OF RAINFALL, FLOW RATE AND SUSPENDED SOLIDS



FIGURE A2.1 Rainfall during November 1990.



FIGURE A2.2 Flowrate at the East site in November 1990.



FIGURE A2.3 Rainfall during December 1990.



FIGURE A2.4 Flowrate at the East site in December 1990.



FIGURE A2.5 Rainfall during January 1991.



FIGURE A2.6 Flowrate at the East site in January 1991.



FIGURE A2.7 Rainfall during February 1991.



FIGURE A2.8 Flowrate at the East site in February 1991.



FIGURE A2.9 Rainfall during March 1991.







FIGURE A2.11 Rainfall during April 1991.



FIGURE A2.12 Flowrate at the East site in April 1991.



FIGURE A2.13 Rainfall during May 1991.



FIGURE A2.14 Flowrate at the East site in May 1991.



FIGURE A2.15 Rainfall during June 1991.



FIGURE A2.16 Flowrate at the East site in June 1991.



FIGURE A2.17 Rainfall during July 1991.



FIGURE A2.18 Rainfall during August 1991.



FIGURE A2.19 Flowrate at the East site in August 1991.



FIGURE A2.20 Rainfall during September 1991.



FIGURE A2.21 Flowrate at the East site in September 1991.



FIGURE A2.22 Rainfall during October 1991.



FIGURE A2.23 Flowrate at the East site in October 1991.



FIGURE A2.24 Suspended solids concentration at WO in October 1991.



FIGURE A2.25 Suspended solids concentration at W6 in October 1991.

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FIGURE A2.26 Rainfall during November 1991.



FIGURE A2.27 Flowrate at the East site in November 1991.



FIGURE A2.28 Suspended solids concentration at WO in November 1991.



FIGURE A2.29 Suspended solids concentration at W6 in November 1991.



FIGURE A2.30 Rainfall during December 1991.



FIGURE A2.31 Flowrate at the East site in December 1991.



FIGURE A2.32 Suspended solids concentration at WO in December 1991.



FIGURE A2.33 Suspended solids concentration at W6 in December 1991.



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FIGURE A2.34 Rainfall during January 1992.



FIGURE A2.35 Flowrate at the East site in January 1992.



FIGURE A2.36 Suspended solids concentration at WO in January 1992.



FIGURE A2.37 Suspended solids concentration at W6 in January 1992.



FIGURE A2.38 Rainfall during February 1992.



FIGURE A2.39 Flowrate at the East site in February 1992.



FIGURE A2.40 Suspended solids concentration at WO in February 1992.



FIGURE A2.41 Suspended solids concentration at W6 in February 1992.



FIGURE A2.42 Rainfall during March 1992.



FIGURE A2.43 Flowrate at the East site in March 1992.



FIGURE A2.44 Suspended solids concentration at WO in March 1992.



FIGURE A2.45 Suspended solids concentration at W6 in March 1992.



FIGURE A2.46 Rainfall during April 1992.



FIGURE A2.47 Flowrate at the East site in April 1992.



FIGURE A2.48 Suspended solids concentration at WO in April 1992.



FIGURE A2.49 Suspended solids concentration at W6 in April 1992.



FIGURE A2.50 Rainfall during May 1992.



FIGURE A2.51 Flowrate at the East site in May 1992.


FIGURE A2.52 Suspended solids concentration at WO in May 1992.



FIGURE A2.53 Suspended solids concentration at W6 in May 1992.



FIGURE A2.54 Rainfall during June 1992.

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FIGURE A2.55 Suspended solids concentration at WO in June 1992.



FIGURE A2.56 Suspended solids concentration at W6 in June 1992.



FIGURE A2.57 Rainfall during August 1992.



FIGURE A2.58 Flowrate at the East site in August 1992.



FIGURE A2.59 Suspended solids concentration at WO in August 1992.



FIGURE A2.60 Suspended solids concentration at W6 in August 1992.



FIGURE A2.61 Rainfall during September 1992.



FIGURE A2.62 Flowrate at the East site in September 1992.



FIGURE A2.63 Suspended solids concentration at WO in September 1992.



FIGURE A2.64 Rainfall during October 1992.



FIGURE A2.65 Flowrate at the East site in October 1992.



FIGURE A2.66 Suspended solids concentration at WO in October 1992.



FIGURE A2.67 Rainfall during November 1992.



FIGURE A2.68 Flowrate at the East site in November 1992.



FIGURE A2.69 Suspended solids concentration at W0 in November 1992.



FIGURE A2.70 Suspended solids concentration at W6 in November 1992.



FIGURE A2.71 Rainfall during December 1992.



FIGURE A2.72 Flowrate at the East site in December 1992.



FIGURE A2.73 Suspended solids concentration at WO in December 1992.



FIGURE A2.74 Suspended solids concentration at W6 in December 1992.



FIGURE A2.75 Rainfall during January 1993.



FIGURE A2.76 Flowrate at the East site in January 1993.



FIGURE A2.77 Suspended solids concentration at WO in January 1993.



FIGURE A2.78 Suspended solids concentration at W6 in January 1993.



FIGURE A2.79 Rainfall during February 1993.



FIGURE A2.80 Flowrate at the East site in February 1993.



FIGURE A2.81 Suspended solids concentration at WO in February 1993.



FIGURE A2.82 Suspended solids concentration at W6 in February 1993.



FIGURE A2.83 Rainfall during March 1993.



FIGURE A2.84 Flowrate at the East site in March 1993.



FIGURE A2.85 Suspended solids concentration at WO in March 1993.



FIGURE A2.86 Suspended solids concentration at W6 in March 1993.



FIGURE A2.87 Rainfall during April 1993.



FIGURE A2.88 Flowrate at the East site in April 1993.



FIGURE A2.89 Suspended solids concentration at WO in April 1993.



FIGURE A2.90 Suspended solids concentration at W6 in April 1993.

APPENDIX B

TABULATED RESULTS OF MANUAL SAMPLING

Date		Time	ls	-1 -1	SS	AU	Cl	SO4
<u> </u>	rgh	16.00					11.00	0.01
51190	1	16.30	0.3	WU	38.0	5.50	11.00	9.21
12 11 90	I	11.30	0.3	WU	5.3	5.30	10.30	7.50
				WI	10.0	5.30	10.20	7.50
				W2	7.6	5.80	10.30	7.60
				W3	12.8	5.40	10.20	7.60
				W4	7.2	5.30	10.10	7.40
				W5	7.2	5.40	10.30	7.30
			_	W6	2.4	4.90	10.20	6.30
15 11 90	1	11.20	1.0	W 0	3.5	6.45	10.70	8.30
				W 1	5.0	6.30	10.90	8.70
				W2	6.0	6.30	10.70	8.30
				W3	4.0	6.40	10.90	8.90
				W4	3.5	6.20	10.90	8.70
				W5	4.5	6.30	10.80	10.60
				W6	2.0	6.00	10.70	7.90
16 11 90	1	6.30	0.6	W0	5.0	5.90	10.70	8.70
				W1	11.0	5.98	10.80	8.40
				W2	5.0	5.80	10.70	9.90
				W3	2.5	5.75	10.70	8.40
				W4		5.75	10.60	7.80
				W5	7.5	5.85	10.70	8.90
	2	9.30	1.7	W0	298.0	8.00	9.20	11.40
				W1	476.0	7.95	9.10	8.80
				W2	560.0	8.60	9.30	7 90

Table B1.1 Results of manual sampling from the West site

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230/16/W

TP	SRP NH ₄	NO ₃	рН	alk	Ca	К	Al	Fe	Mn
0.09	0.09	0.06		5.6					
0.04	0.09	< 0.05		9.5	5.7	0.4	0.40	0.547	0.106
0.04	0.17	<0.05		10.1	5.3	0.4	0.43	0.604	0.107
0.04	0.15	< 0.05		8.8	5.0	0.4	0.41	0.572	0.101
0.04	<0.04	<0.05		8.8	5.0	0.4	0.44	0.583	0.097
0.05	0.17	< 0.05		7.6	4.9	0.4	0.40	0.509	0.076
0.04	0.15	< 0.05		9.0	4.9	0.3	0.40	0.497	0.094
0.04	0.07	< 0.05		8.9	4.8	0.3	0.30	0.352	0.022
0.03	<0.04	0.11	5.7	7.6	5.4	0.4	0.35	0.485	0.086
0.03	0.28	0.11	5.5	7.9	5.3	0.4	0.37	0.495	0.088
0.14	0.11	0.11	5.7	4.9	5.3	0.4	0.36	0.470	0.088
0.03	< 0.04	0.11	6.2	6.7	5.3	0.4	0.36	0.446	0.087
0.04	0.14	0.11	5.5	7.0	5.2	0.4	0.33	0.442	0.085
0.03	<0.04	0.10	5.5	7.1	5.2	0.4	0.47	0.692	0.096
0.03	0.12	0.07	5.8	7.1	4.7	0.5	0.37	0.368	0.056
0.02	0.18	0.08	5.6	8.8	6.0	0.4	0.38	0.531	0.089
0.03		0.08	5.8	8.1					
0.03		0.07	5.8	8.1					
0.03		0.08	5.6	8.3					
0.04		0.06	5.6	8.0					
0.03	0.04	0.06	5.6	8.1	5.3	0.4	0.34	0.408	0.086
0.29	0.16	0.09	5.4	3.3	5.0	0.4	3.25	2.930	0.110
0.31	< 0.04	0.09	5.4	3.7	5.7	0.4	5.12	4.640	0.152
0.35	0.12	0.08	5.8	4.0	5.7	0.5	5.55	5.210	0.192

Table B1.1 continued

Date		Time	1 s	-1	SS	AU	Cl	SO4
				W3	592.0	9.13	9.40	11.20
				W4	576.0	8.28	9.50	9.40
				W5	424.0	8.80	9.60	8.50
				W6	100.0	7.28	10.20	8.10
	3	10.30	8.0	W0	560.0	7.88	6.50	6.70
				W2	706.0	6.18	6.20	6.60
				W4	706.0	7.30	6.40	7.20
				W6	5.0	8.38	8.10	4.90
	4	12.30	7.0	W0	1352.0	9.18	8.10	12.00
				W2	261.0	13.23	8.20	7.90
				W 4	289.0	7.93	8.30	8.20
				W6	111.0	9.45	8.90	6.20
	5	15.20	5.5	W0	36.5	12.13	9.90	8.90
				W 1	38.5	8.35	10.00	8.40
				W2	5.0	7.48	10.00	12.20
				W3	56.0	8.35	10.00	
				W4	118.0	7.48	10.00	8.10
				W5				
				W6	120.0	6.35	9.90	8.40
23 11 9 0	1	14.45	3.5	W0	103.0	4.03	11.50	8.30
				W1	118.0	2.98	11.50	7.80
				W2	220.0	4.90	12.90	8.60
				W3	184.0	3.40	12.30	8.80
				W4	80.0	3.90	13.00	8.40
				W5	260.0	2.10	13.20	7.60

ТР	SRP NI	H ₄	NO ₃	pН	alk	Ca	K	Al	Fe	Mn
0.55	<0.()4	0.08	5.5	4.6	6.0	0.5	5.40	4.850	0.234
0.41	0.0)7	0.08	5.4	4.8	6.8	0.5	5.81	4.400	0.342
0.34	0.1	12	0.09	5.4	4.8	6.2	0.5	5.14	4.850	0.425
0.10	0.0)5	< 0.05	5.4	7.3	5.2	0.5	1.48	1.470	0.206
0.55	0.0)9	0.11	5.2	2.6	4.4	0.5	6.85	5.840	0.130
0.58	<0.0)4	0.09	5.1	2.6	4.5	0.5	7.24	5.620	0.138
0.64	<0.0)4	0.10	5.1	2.9	4.6	0.5	7.32	5.580	0.155
0.35	0.0)9	< 0.05	5.3	3.9	4.1	0.7	4.29	3.610	0.157
0.25	0.1	16	0.17	5.4	2.8	4.6	0.5	3.37	3.100	0.092
0.24	<0.0)4	0.16	5.3	3.5	4.8	0.5	4.00	4.070	0.110
0.25	0.0)9	0.15	5.3	3.1	4.8	0.5	3.50	3.470	0.120
0.12	0.1	11	0.10	5.3	5.2	4.1	0.6	1.68	1.610	0.101
0.04	0.1	13	0.27	5.3	5.2	4.9	0.6	0.81	0.940	0.070
0.05	0.3	16	0.34	5.5	4.5	4.7	0.6	0.87	0.993	0.072
0.07	<0.0) 4	0.28	5.7	4.7	4.9	0.6	1.54	1.680	0.109
0.06	<0.0)4	0.26	5.5	4.5	4.7	0.6	0.88	0.965	0.075
0.14	0.0)9	0.26	5.8	4.8	5.3	0.6	2.12	2.180	0.150
	0.0)5				5.4	0.7	1.17	1.690	0.131
0.10	0.0	00	0.25	5.8	4.6					
0.11	0.	17	0.25	5.7	5.4	4.7	0.4	1.44	1.200	0.090
0.15	0.1	18	0.25	5.4	4.3	4.7	0.4	1.58	1.300	0.098
0.20	<0.0)4	0.26	5.3	4.6	5.0	0.4	1.69	1.540	0.112
0.23	0.3	31	0.32	5.4	4.9	5.1	0.5	1.68	1.410	0.121
0.09	<0.0)4	0.26	5.7	7.1	5.1	0.8	0.97	0.868	0.131
0.26	0.2	22	0.18	5.1	2.8	5.5	1.3	0.82	0.796	0.130

Table B1.1 co	ontinu	ved					;											
Date		Time	1 s ⁻¹	SS	AU	CI	SO ₄	ТР	SRP	NH ₄	NO ₃	рН	alk	Ca	K	Al	Fe	Mn
							4								<u> </u>			
< 10 00			W6	15.0	8.83	16.10	10.10	0.07		< 0.04	0.22	5.7	11.8	5.0	0.8	0.33	0.655	0.043
6 12 90	1		0.3 W0	1.0	4.40	10.80	8.79	0.02		<0.10	0.08	5.7	10.2	6.3	0.3	0.32	0.392	0.096
			W1	1.0	4.63	10.70	7.67	0.03		< 0.10	0.08	5.2	9.8	5.9	0.3	0.35	0.425	0.091
			W2	0.5	5.23	10.80	7.17	0.03		< 0.10	0.38	5.5	9.9	6.1	0.3	0.35	0.419	0.087
			W3	0.5	5.13	10.70	7.23	0.03		< 0.10	0.07	6.1	11.2	5.7	0.3	0.34	0.357	0.084
			W4	3.5	5.10	10.70	6.85	0.03		< 0.10	< 0.05	5.5	11.2	5.7	0.3	0.40	0.411	0.116
			W5	4.0	4.70	10.60	6.79	0.03		< 0.10	< 0.05	5.4	12.1	5.9	0.3	0.35	0.320	0.086
			W6	3.0	4.03	10.10	6.18	0.03		< 0.10	< 0.05	5.4	10.5	5.2	0.5	0.28	0.232	0.021
28 12 90	1	9.15	9.0 W0	163.0	2.68	25.40	18.30	0.07		< 0.10	0.42	5.0	4.2	5.2	0.9	2.35	2.540	0.070
			W1	231.0	2.63	26.60	6.80	0.12		< 0.10	0.44	5.2	3.7	5.9	0.9	5.00	8.460	0.196
			W2	221.0	2.65	25.40	10.90	0.13		<0.10	0.43	5.3	3.3	5.6	0.9	3.28	3.390	0.089
			W3	169.0	2.58	25.30	9.70	0.10		0.26	0.52	5.2	3.9	5.7	0.8	3.37	3.340	0.140
			W4	173.0	2.68	25.30	8.60	0.09		0.24	0.42	5.0	3.6	5.5	0.8	3.11	3.170	0.089
			W 5	128.0	2.63	24.20	6.50	0.08		<0.10	0.39	5.2	4.8	5.4	0.8	2.96	3.360	0.056
			W6	94 .0	2.95	25.90	7.10	0.03		<0.10	0.42	5.2	3.0	4.5	0.9	1.51	1.590	0.081
	2	10.30	1 3.0W0	230.0	3.18	21.20	13.40	0.16		0.29	0.45	5.1	2.0	5.0	1.0	4.55	5.070	0.207
			W1	302.0	3.30	21.00	7.60	0.19		<0.10	0.44	5.0	3.2	5.2	1.0	5.36	6.200	0.109
			W2	454.0	3.15	21.20	8.40	0.32		<0.10	0.44	5.0	2.1	6.0	1.1	6.64	7.140	0.149
			W3	392.0	3.15	21.60	6.10	0.22		0.25	0.34	5.2	2.2	5.4	1.0	6.27	6.350	0.130
			W4	52.0	1.68	21.20	6.10	0.35		0.48	0.47		3.1	5.7	1.0	6.57	6.490	0.169
			W5	610.0	3.23	20.90	8.70	0.33		<0.10	0.43	4.9	3.1	5.9	1.0	6.75	6.260	0.170
			W6	215.0	3.13	21.60	8.10	0.13		<0.10	0.38	4.9	3.6	4.8	1.1	3.43	3.490	0.124
9 01 91	1	12.00	0.5 W0	<0.5	2.40	12.00	6.10	0.02		< 0.10	0.45	5.3	9.3	5.9	0.4	0.18	0.191	0.047
			W2	2.3	2.40	12.00	6.00	0.02		< 0.10	0.44	5.6	9.1	5.8	0.4	0.17	0.178	0.052
			W3	5.7	2.45	12.00	6.00	0.02		0.34	0.42	5.3	8.9	5.8	0.5	0.24	0.210	0.056
			W 5	<0.5	2.48	12.00	6.00	0.06		0.22	0.41	5.3	9.2	5.6	0.5	0.19	0.211	0.063

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Table B1.1 continued

Date		Time	1 s ⁻¹	l	SS	AU	Cl	SO4
18 01 91	1		,	w0	141.0	6.15	7.90	8.50
			١	W2	100.0	7.28	8.00	7.70
			١	W5	102.0	7.15	7.90	7.20
4 02 91	1		١	W6	9.0	2.58	9.70	5.30
			١	W6	9.0	2.58	9.70	5.30
12 02 91	1	12.30	١	W0	6.0	5.63	11.20	10.70
			,	W5	17.0	2.43	9.70	4.20
			,	W6	1.0	2.60	8.80	4.40
19 02 91	1	14.00	0.3	W0	12.7	4.13	9.90	7.30
			١	W1	10.7	3.80	10.10	7.50
			١	W2	13.7	3.78	10.10	7.80
			,	W3	6.7	3.90	9.70	7.70
			۲	W4	4.3	3.78	10.00	7.80
			١	W5	5.7	3.9 3	10.00	7.50
			١	W6	<0.5	4.83	9.60	7.00
22 02 91	1		١	W0	128.0	5.98	7.14	13.20
			١	W1	57.0	5.65	6.95	11.50
				W2	19.0	5.93	7.02	10.20
				W3	56.0	5.68	7.00	9.49
			,	W4				
			,	W5	27.0	5.65	7.05	7.97
4 03 91	1	14.00	6 .0 V	W0	374.0	4.40	5.79	7.60
			1	W1	378.0	5.20	5.89	8.03
			١	₩2	482.0	3.80	5.75	9.53
			١	W3	378.0	4.60	5.84	8.73

TP	SRP	NH4	NO ₃	pН	alk	Ca	К	Al	Fe	Mn
0.44		0.29	0.19		3.3	4.2	0.5	7.09	6.020	0.123
0.47		0.32	0.19		3.1	5.1	0.6	7. 9 1	6.700	0.147
0.56		0.29	0.27		3.8	4.7	0.6	6.21	4.240	0.131
0.03		0.19	0.09	5.4	11.0	3.1	0.3	0.22	0.202	0.023
0.03		0.19	0.09	5.4	11.0	3.1	0.3	0.22	0.202	0.023
0.03		0.18	0.29	5.2	3.0	3.3	0.4	1.16	1.040	0.063
0.04		0.11	0.18	5.6			0.5	0.58	0.715	1.310
0.01		0.09	0.20	5.8		5.0	0.4	0.26	0.192	0.029
0.04		0.22	<0.10	5.3	3.7	3.9	0.4	0.82	0.924	0.049
0.03		0.09	<0.10	5.2	3.7	4.1	0.4	1.34	1.450	0.061
0.06		< 0.02	<0.10	5.2	4.2	4.0	0.4	0.99	1.120	0.068
0.03		0.14	<0.10	4.7	15.0	4.0	0.4	0.62	0.701	0.078
0.03		0.19	<0.10	5.0	4.6	4.1	0.4	0.49	0.618	0.101
0.03		0.16	<0.10	5.2	5.6	4.2	0.4	0.54	0.579	0.120
0.03		<0.02	<0.10	5.3	6.4	4.2	0.4	0.34	0.367	0.055
0.07		0.37	0.14	4.4	0.0	1.6	0.8	1.58	0.603	0.133
0.07		0.43	0.12	4.6	1.9	2.3	0.7	1.39	1.170	0.119
0.05		0.28	0.15	4.8	2.5	2.5	0.6	1.52	1.290	0.115
0.05		0.30	0.11	5.1	3.8	2.8	0.6	1.38	1.180	0.110
						3.1	0.7	1.17	1.050	0.094
0.05		0.31	0.10	5.2	4.1	3.2	0.7	0.83	0.528	0.096
0.48		0.16	0.49	5.1	3.6	4.5	0.6	6.37	5.450	0.114
0.49		0.15	0.40	5.0	3.9	4.7	0.5	2.08	0.172	0.092
0.53		0.14		4.7	3.2	4.9	0.6	7.08	6.740	0.138
0.47		0.19	0.39	5.1	3.6	5.0	0.5	7.36	6.680	0.139

Table B1.1 continued

Date		Time	1 s ⁻¹	SS	AU	CI	SQ4	
							i	
			W 4	340.0	4.40	5.81	9.38	
			W 5	396.0	4.50	5.77	8.27	
	_	_	W6	230.0	4.30	5.87	7.70	
	2	16.00	10.0W0	454.0	4.90	5.56	7.46	
			W1	342.0	5.30	5.49	8.49	
			W 2	450.0	5.30	5.46	9.27	
			W3	634.0	5.60	5.50	8.83	
			W4	774.0	5.90	5.42	8.58	
			W5	858.0	5.70	5.45	7.93	
			W6	394.0	5.90	5.28	7.20	
18 03 91	1	11.30	0.3 W0	<0.5	4.40	8.33	7.86	
			W1	4.0	4.30	8.31	7.41	
			W2	7.5	4.58	8.17	7.22	
			W 3	8.5	4.38	8.24	7.31	
			W4	10.0	4.48	8.17	7.43	
			W5	6.4	4.40	8.10	7.11	
			W6	4.7	4.38	7.85	6.88	
	2	13.30	1.5 WO	65.0	6.28	6.78	7.23	
			W1	85.0	5.90	6.89	7.30	
			W2	10.9	6.05	6.88	7.26	
			W3	76.0	5.98	6.79	6.78	
			W 4	56.5	5.98	6 .69	7.02	
			W5	42.0	5.85	6.78	7.04	
			W6	12.5	5.15	6.79	6.63	
	3	14.30	2.5 W0	249.0	8.35	5.89	6.99	

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ТР	SRP	NH4	NO3	рН	alk	Ca	К	Al	Fe	Mn
0.49		0.07	0.57	5.1	4.2	5.5	0.5	8.33	7.700	0.163
0.52		0.13	0.61	5.2	3.6	5.3	0.6	7.59	7.480	0.142
0.25		0.09	0.35	5.2	4.6	4.1	0.6	3.52	3.110	0.094
0.38		0.08	0.66	5.4	3.8	5.1	0.7	8.72	8.460	0.135
0.51		0.05	0.55	5.0	3.5	5.9	0.7	11.90) 14.800	0.360
0.54		0.18	0.55	5.1	3.6	6.5	0.9	13.70) 14.800	0.249
0.70		0.17	0.64	5.4	3.3	6.3	0.8	12.90) 13.700	0.203
0.75		0.16	0.54	5.2	3.8	6.9	0.9	14.20) 14.300	0.293
0.58		0.16	0.57	5.2	4.2	6.8	0.8	12.50) 10.900	0.259
0.50		0.04	0.43	5.1	4.5	5.0	0.8	7.41	6.760	0.159
0.01		0.21	0.53	5.3	8.3	5.4	0.5	0.28	0.265	0.041
0.01		< 0.05	0.49	5.1	7.6	5:3	0.4	0.27	0.242	0.041
0.02		0.29	0.48	6.1	7.9	5.2	0.5	0.34	0.337	0.050
0.02		0.26	0.49	5.5	8.2	5.3	0.4	0.32	0.341	0.086
0.02		0.18	0.51	5.1	8.1	5.3	0.4	0.38	0.513	0.142
0.01		0.13	0.47	5.2	8.7	5.4	0.5	0.29	0.287	0.143
0.01		0.17	0.33	5.6	8.9	4.8	0.5	0.24	0.210	0.088
0.07		0.12	0.33	5.5	5.0	4.2	0.5	1.14	0.842	0.050
0.07		0.16	0.42	5.2	4.6	4.4	0.5	1.42	1.190	0.060
0.10		0.26	0.44	5.3	5.6	4.5	0.5	1.31	1.100	0.067
0.08		0.21	0.34	5.8	5.0	4.6	0.5	1.42	1.210	0.087
0.06		0.18	0.30	5.3	6.0	4.4	0.5	1.06	0.998	0.086
0.05		0.21	0.29	5.3	6.3	4.5	0.5	0.99	0.939	0.094
0.02		0.19	0.23	5.4	6.7	4.5	0.5	0.56	0.334	0.098
0.24		0.26	0.33	5.1	4.0	4.4	0.5	3.02	2.330	0.067

Table B1.1 continued

Date		Time	l s ⁻¹	SS	AU	CI	SO4
			W1	205.0	8 25	5 83	6.98
			W2	200.0	8 38	5.81	696
			W3	262.0	873	5.01	6.81
			WA	202.0	7 40	5.00	6 54
			W5	200.0	7.40	5.72	6 56
			W6	74 0	6.98	5.87	613
4 4 91	1	8 30	72 W0	149.0	5 50	5.07	5 36
7771	1	0.50	7.2 W0	237.0	5.63	5.01	5.20
			w2	353.0	5 5 5	4 90	5.20
			W3	298.0	5.68	4.95	5.17
			W4	450.0	5.00	4 84	5.24
			WS	211.0	5.68	4.04	5.12
			W6	246.0	5.00	4 68	4 75
	2	9 30	14 1 WO	371.0	6 50	4.00	4.75
	-	7.50	WI	421.0	5.95	4.49	5.13
			W2	486.0	5.93	4.47	5.14
			W3	471.0	5.90	4.49	5.03
			W4	506.0	6.18	4.44	5.19
			W5	523.0	5.90	4.36	5.00
			W6	307.0	6.35	4.33	4.56
	3	11.00	17.7W0	337.0	7.25	4.76	5.27
			W1	272.0	7.25	4.84	5.40
			W 2	282.0	7.23	4.79	5.36
			W3	257.0	7.10	4.90	5.47
			W4	269.0	7.13	4.49	5.30

TP	SRP	NH4	NO ₃	pН	alk	Ca	К	AI	Fe	Mn
0.25		<0.05	0.37	5.3	3.7	4.6	0.5	3.42	3.790	0.073
0.28		0.25	0.38	5.0	4.8	4.7	0.6	3.33	2.640	0.081
0.35		0.23	0.35	5.4	4.2	4.5	0.5	2.74	2.080	0.080
0.23		< 0.05	0.30	5.4	4.7	4.7	0.6	2.93	2.440	0.132
0.21		0.29	0.32	5.4	4.5	4.5	0.5	2.68	2.360	0.126
0.08		<0.05	0.15	5.2	6.0	4.4	0.5	1.48	1.250	0.084
0.35	<.003	0.22	0.52	5.4	3.2	4.3	0.7	3.16	2.030	0.081
0.38	<.003	0.12	0.55	5.0	3.9	4.2	0.7	3.89	2.760	0.072
0.47	<.003	0.23	0.54	5.1	3.3	4.5	0.7	4.24	3.280	0.087
0.48	<.003	0.08	0.53	5.1	3.7	4.6	0.7	3.63	1.280	0.108
0.44	<.003	0.45	0.53	5.2	3.9	4.6	0.7	3.96	2.650	0.103
0.39	<.003	0.31	0.52	5.2	3.9	4.5	0.6	3.68	2.410	0.106
0.35	0.006	0.46	0.36	5.1	5.4	4.2	0.7	3.76	2.430	0.123
0.54		0.34	0.51	5.1	4.1	4.2	0.9	6.01	3.880	0.094
0.57		< 0.05	0.51	5.0	3.7	4.6	0.9	6.94	5.200	0.136
0.55		0.19	0.53	5.1	3.2	4.8	0.9	6.79	3.710	0.149
0.58		<0.05	0.53	5.1	3.8	4.9	0.9	7.14	5.810	0.132
0.63		0.17	0.52	5.1	4.1	5.0	0.9	7.65	5.170	0.199
0.44		0.71	0.50	5.1	4.3	4.8	0.9	6.92	4.710	0.179
0.40		< 0.05	0.37	5.2	3.9	4.5	0.8	4.97	3.420	0.180
0.27		0.10	0.61	5.1	3.9	3.6	1.1	3.55	2.560	0.075
0.25		0.37	0.63	5.2	3.3	4.1	1.1	5.34	4.450	0.123
0.24		0.27	0.64	5.0	3.2	3.9	1.1	4.43	3.310	0.093
0.30		0.22	0.64	4.9	3.8	4.1	1.1	4.79	6.670	0.101
0.28		0.56	0.56	5.0	3.8	4.4	1.1	5.01	3.710	0.143

Table B1.1 continued

Date		Time	1 s	-1	SS	AU	Cl	SO4
					· -			í.
				W5	356.0	7.15	4.71	5.24
				W6	172.0	7.03	4.52	4.93
	4	13.20	7.2	W0	100.0	7.68	5.44	5.88
				W1	71.0	7.53	5.50	5.95
				W2	102.0	7.30	5.45	5.86
				W3	91.0	7.35	5.51	5.98
				W4	108.0	7.18	5.42	5.85
				W5	108.0	7.33	5.73	6.17
				W6	37.0	7.03	4.62	5.11
13 5 91	1	10.00	.1	W0	6 .0	2.65	6.74	8.40
				W1	7.0	3.18	9.00	7.54
				W2	2.0	3.53	9.13	6.46
				W3	2.5	5.03	8.61	5.38
				W4	11.5	8.78	7.95	3.88
				W5	23.0	4.28	6.35	4.20
				W6	2.0	3.80	6.39	3.77
23 7 91	1	13.00	0.1	WO	37.0	4.95	8.16	13.80
	-		W =	WI	81.0	4.78	9.29	15.60
				W2	44.0	5 30	8 02	20.80
				W3	28.0	5.03	7.94	12.40
				W4	27.1	5.05	7.78	12.10
				W5	25.7	5.05	7.37	11.70
				W6	25.0	6 10	3 66	6 35
9 8 91	1	5 30	25	wn	163	5 52	<u>4</u> 30	10 10
/ 0 / 1		5.50	2.5	W5	72	7 7 0	4.00	11 10
				¥¥ .J	1.5	1.20	4.00	11.10

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ТР	SRP N	NH4	NO3	рH	alk	Ca	К	Al	Fe	Mn
0.35	C).59	0.59	5.0	3.6	4.1	1.0	4.38	3.190	0.128
0.26	C).50	0.50	5.1	3.9	4.3	1.0	3.97	2.310	0.179
0.10	C).79	0.79	5.2	3.4	3.9	1.0	1.30	0.879	0.047
0.11	C).76	0.76	5.0	3.7	3.8	1.0	1.61	1.240	0.052
0.16	C).82	0.82	5.1	3.4	3.8	1.0	1.76	1.230	0.058
0.12	C).19	0.78	5.2	3.2	3.8	1.0	1.65	1.210	0.059
0.12	<0).05	0.74	5.0	4.0	3.8	1.0	1.59	1.190	0.073
0.13	<0).05	0.76	5.1	4.3	3.7	0.9	1.80	1.460	0.070
0.07	C).19	0.57	4.7	2.7	3.5	0.9	1.07	0.827	0.061
0.02	<0	0.05	0.55	5.3	5.0	4.2	0.4	0.69	0.602	0.052
0.02	<0	0.05	0.39	5.1	7.7	4.1	0.4	0.62	0.422	0.032
0.01	<0).05	0.30	5.4	11.5	5.0	0.5	0.45	0.947	0.291
0.01	<0).05	0.19	5.5	20.3	5.8	0.4	0.33	0.606	0.989
0.01	<0).05	0.13	5.6	28.8	6.4	0.5	0.30	2.110	2.220
0.01	<0).05	0.12	5.6	31.7	7.5	0.5	0.23	0.666	1.880
<0.01	<0).05	<0.10	5.6	16.5	4.9	0.3	0.24	0.203	0.098
0.14	0).14	0.47	5.0	3.8	3.5	0.6	2.10	1.760	0.104
0.13	<0	0.05	0.36	5.1	3.7	4.3	0.6	2.23	2.230	0.098
0.14	0	80.0	0.44	5.2	4.8	4.8	0.6	1.46	1.350	0.071
0.12	<0).05	0.50	5.3	5.5	5.2	0.7	0.87	0.425	0.136
0.12	<0).05	0.55	5.3	8.2	5.4	0.6	1.05	1.260	0.422
0.09	<0).05	0.53	5.4	12.8	6.2	0.7	1.12	2.350	0.990
0.09	<0).05	<0.10	6.0	26.1	7.1	0.5	0.67	0.880	0.490
0.08	C).34	1.75	4.8	3. 9					
0.04	C).59	1.59	6.6	3.2					
0.03	C).33	1.32	4.9	5.5					

Table	e 81.	.1 a	ontinued
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Date		Time	l s ⁻¹	SS	AU	Cl	SO4
	2	6.00	W 0	12.4	6.08	4.40	10.10
			W 5	7.5	6.93	4.20	11.70
			W6	9.5	6.83	4.30	10.60
	3	6.30	2.0 WO	14.8	6.25	4.70	12.40
			W 5	5.5	7.13	4.30	11.70
			W6	8.8	6.70	4.20	11.40
	4	7.00	1.5 WO	10.0	7.50	4.70	14.90
			W5	5.3	6.83	4.60	14.60
			W6	5.8	6.45	4.10	11.70
	5	7.30	1.5 WO	8.8	5.88	4.80	13.90
			W5	9.3	7.28	4.50	12.90
			W6	9.5	6.60	4.20	12.00
	6	8.00	1.1 WO	5.4	10.00	5.30	15.40
			W5	5.5	6.85	4.60	14.70
			W6	5.5	5.63	4.20	12.40
	7	8.30	1.0 WO	5.3	5.48	4.90	15.20
			W 1	7.3	8.05	4.90	15.40
			W 2	11.3	5.83	4.90	15.20
			W 3	11.3	6.45	4.80	15.30
			W4	8.3	7.10	4.70	15.40
			W5	11.3	7.28	4.40	13.20
			W6	6.5	6.80	4.10	12.20

<Fertilizer Application>

23 8 91 1 18.00 0.1 W0 5.0 0.88

230/16/W
ТР	SRP	NH4	NO ₃	pН	alk	Ca	К	Al	Fe	Mn
0.06		0.58	1.79	4.7	2.9					4
0.04		<0.20	1.65	4.8	3.9					1
0.04		0.39	1.41	5.1	4.9					
0.06		0.33	1.88	4.7	2.9					
0.04		0.45	1.72	4.7	4.4					
0.04		0.20	1.40	4.8	6.0					
0.05		0.49	1.85	4.6	2.5					
0.04		0.59	1.74	4.9	3.9					
0.03		0.17	1.36	5.0	6.1					
0.05		0.68	1.84	4.7	3.0					
0.04		0.57	1.69	4.7	3.9					
0.03		<0.10	1.36	5.0	5.8					
0.04		0.31	1.87	4.7	3.2					
0.03		0.46	1.70	4.7	4.3					
0.03		<0.10	1.24	4.9	6.5					
0.05		<0.20	1.84	4.7	3.0	4.3	0.5	0.67	0.432	0.046
0.05		<0.20	1.85	4.8	3.4	4.3	0.4	0.70	0.486	0.055
0.18		0.39	1.81	4.8	3.6	4.6	0.6	0.87	0.697	0.064
0.17		<0.20	1.79	4.8	4.0	4.6	0.5	0.75	0.629	0.060
0.05		<0.20	1.82	4.9	3.5	5.1	0.4	0.67	0.529	0.052
0.05		<0.10	1.83	5.0	4.2	5.7	0.4	0.57	0.418	0.060
0.03		< 0.10	1.28	4.9	5.8	5.2	0.3	0.45	0.437	0.163

0.22

Table B1.1 continued

Date		Time	1 s ⁻¹	SS	AU	Cl	SO ₄
							4
			W5	10.3	0.80		9
			W6	5.9	2.38		16
18991	1	6.00	0.3 WO	5.0	9.50		
			W5	9.0	1.40		I
			W6	3.0	1.80		
21 9 91	1	14.30	0.2 W0	24.0	4.40		t
	2	14.45	3.9 WO	212.0	4.20		
			W5	22.0	3.50		
			W6	10.0	1.50		
	3	15.00	14.1 WO	943.0	3.80		
			W5	548.0	6.60		-
			W6	124.0	3.80		- N
	4	15.15	8.4 WO	148.0	3.60		
			W5	143.0	2.80		1
			W6	72.0	3.80		
	5	15.45	5.0 WO	65.0	3.30		
			W5	37.0	3.80		1
			W6	43.0	2.60		
8 10 91	1	9.25	2.2 W0	2.7	1.93		1
			W5	4.0	2.50		i
			W6	1.8	1.73		1
31 10 91	1	8.00	32.0W0	74.0	7.33	33.90	12.60
			W1	103.0	7.28	34.40	12.80
A.			W2	83.0	7.33	33.80	13:10
			W3	65.0	7.43	33.30	12:40

143

230/16/W

ТР	SRP	NH4	NO3	рН	alk	Ca	к	Al	Fe	Mn
<0.01										
0.03										
0.28	0.100					31.4	64.6	7.46	0.131	0.641
0.57	0.010					50.2	63.3	1.13	0.098	0.792
0.38	0.002					40.6	10.1	0.09	0.029	0.281
0.79										
2.60						16.2	45.6	7.60	2.810	0.621
0.39						26.7	56.4	3.15	0.478	0.776
0.11						22.9	5.5	0.28	0.700	0.411
4.45	0.75					21.7	23.0	21.00	21.600	0.493
2.94	0.76					17.4	26.4	9.53	10.6	0.383
1.38	0.47					16.3	24.2	4.87	5.73	0.387
1.87										
2.94										
0.62										
0.99										
0.80										
0.45										
0.10						12.9	8.2	0.78	0.128	0.111
0.08						12.2	7.7	0.68	0.175	0.126
0.04						11.8	6.7	0.50	0.129	0.115
0.61	0.22	1.70	2.91	4.8	3.0	10.3	8.0	2.59	2.650	0.148
0.57	0.20	1.45	3.08	4.8	2.7	11.3	8.1	3.97	4.670	0.177
0.77	0.20	1.53	2.89	4.6	2.7	11.8	8.1	2.11	1.790	0.146
0.51	0.18	1.47	2.87	4.6	2.0	10.0	7.9	2.33	2.310	0.145

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Table B1.1 continued

Date		Time	l s ⁻¹	SS	AU	CI	SO ₄
			W4	51.0	7.60	33.60	12.40
			W5	22.0	7.58	35.00	13.20
			W6	33.0	7.50	32.60	12.20
	2	9.30	22.0W0	59.0	7.65	33.50	13.20
			W5	23.0	8.18	34.00	12.60
			W6	21.0	7.68	31.90	12.30
12 11 91	1	15.15	24.5W0	142.0	7.68		
			W5	115.0	7.20		
			W6	40.0	6.75		
	2	16.00	29.5W0	383.0	8.08		
			W 5	284.0	7.55		
			W6	85.0	6.98		
9 1 92	1	9.30	9.8 WO	32.8	3.08		
			W 1	43.7	3.08		
			W2	41.5	3.05		
			W3	55.7	2. 9 8		
			W4	49.3	3.08		
			W 5	56.0	2.98		
			W6	15.2	2.75		
2 2 92	1	18.15	0.4 WO	225.0	7.05		
			W 1	55.5	6.55		
			W2	23.5	6.15		
			W3	27.5	6.20		
			W4	9.2	6.48		
			W 5	15.8	4.98		
			W6	19.4	4.93		

ТР	SRP	NH ₄	NO ₃	pН	alk	Ca	К	Al	Fe	Mn
0.49	0.15	1.28	2.61	4.8	3.3	9.9	7.7	1.46	0.914	0.132
0.33	0.16	1.40	2.87	4.7	3.3	10.7	7.9	0.87	0.469	0.123
0.36	0.10	0.68	2.31	4.9	2.8	8.6	7.2	1.16	0.972	0.145
0.30		1.23	3.26	4.6	2.6	10.3	8.0	1.73	1.200	0.135
0.34		1.28	3.08	4.9	3.0	10.0	7.5	1.05	0.758	0.120
0.27		0.94	2.65	5.0	3.2	9.2	7.2	0.91	0.648	0.123
0.31		011		0.00	2.14			0.7 -	01010	01120
0.37										
0.20										
0.87	0.06					6.4	3.8	2.04	1.240	0.069
0.67	0.03					5.9	3.5	1.68	1.310	0.067
0.37	< 0.01					5.6	3.4	0.78	0.436	0.060
0.33	0.03					5.3	2.7	0.88	0.541	0.044
0.19	0.02					5.5	2.7	0.91	0.475	0.046
0.19	0.03					5.3	2.7	0.85	0.437	0.045
0.20	0.02					6.1	2.7	1.10	0.643	0.056
0.17	0.03					6.1	2.8	1.08	0.493	0.053
0.20	0.01					5.7	2.7	0.93	0.553	0.048
0.11	0.03					5.5	2.5	0.59	0.389	0.038
0.46	0.01					6.3	2.7	1.05	0.178	0.079
0.14	0.01					6.4	2.7	1.00	0.412	0.080
0.13	0.01					6.5	2.7	0.81	0.371	0.073
0.13	0.01					6.5	2.6	0.85	0.485	0.079
0.06	0.01					6.7	2.7	0.61	0.340	0.062
0.07	0.01					9.0	2.4	0.49	0.283	0.116
0.13	0.01					6.3	2.2	0.54	0.506	0.138

Table B1.1 continued

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Date		Time		;-1	SS	AU	Cl	SO4	ТР
								4	
12 2 92	11	2.00	2.5	W0	91.9				
				W1	112.0			i	
				W2					
				W3	126.0				
				W4	62.8				
				W5	62.4				
				W6	28.3				
	2	12.30	2.8	W0	157.0	7.80			0.31
				W1	190.0	7.60			0.37
				W2	222.0	8.60			0.42
				W3	201.0	8.40			0.41
				W4	202.0	8.15			0.35
				W5	159.0	8.40		,	0.27
				W6	56.8	6.70			0.11
	3	13.00	2.8	W0	157.0			Ŧ	
				W 1	173.0			:	
				W2	203.0			1	
				W3	214.0			1.00	
				W4	149.0			1.2	
				W5	110.0				
				W6	51.3				
	4	13.30	3.2	W0	142.0				
				W1	159.0				
				W2	179.0			1	
				W3	207.0				
								1	

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SRP	NH	NO ₂	рH	alk	Ca	ĸ	Al	Fe	Mn
					Q.				
0.08					6.5	2.5	1.77	1.060	0.059
0.06					6.1	2.6	1.46	0.686	0.066
0.10					0.7 64	2.5	2.54	1.300	0.087
0.07				•	5.9	2.4	2.03	0.931	0.075
0.05					6. 6	2.4	1.90	1.240	0.073
0.03					7.9	2.3	0.92	0.438	0.066
									6
					5.4	2.3	1.99	1.400	0.059
					5.6	2.3	2.03	1.360	0.066
					6.5	2.4	1.86	0.660	0.069

Table B1.1 continued

Date		Time	1 s ⁻¹	SS	AU	Cl	SO4
				*			
			W4	140.0			
			W5	124.0			
			W6	56.8			
	5	14.00	4.7 W0	335.0			
			W1	235.0			
			W2	384.0			
			W3	382.0			
			W4	349.0			
			W5	270.0			
			W6	106.0			
	6	14.30	6.6 W0	515.0			
			W 1	603.0			
			W2	543.0			
			W3	630.0			
			W4	544.0			
			W5	487.0			
			W6	182.0			
	7	15.00	5.6 WO	230.0			
			W1	235.0			
			W2	264.0			
			W3	247.0			
			W4	252.0			
			W5	210.0			
			W6	85.0			

			5.9	2.3	1.61	0.880	0.059
			6.6	2.4	1.45	0.566	0.059
			5.4	2.2	0.90	0.567	0.049

6.3	2.4	4.57	2.850	0.096
6.4	2.4	4.53	1.910	0.109
7.5	2.4	4.88	2.520	0.108
6.7	2.4	5.67	3.920	0.131
7.2	2.4	5.10	3.460	0.119
6.5	2.3	3.62	2.370	0.087
5.0	2.5	2.05	1.410	0.077

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Table B1.1 continued

Date		Time	1 s	ş ⁻¹	SS	AU	Cl	SO4
6 3 92	1	18.00	1.7	W0	10.8	7.73	13.20	
				W1	14.4	7.30	13.00	
				W2	41.0	8.08	13.40	
				W3	20.6	6.98	12.80	I
				W4	19.2	7.28	12.70	
				W5	8.2	7.33	12.60	*
				W6	5.8	6.13	11.80	1
31 3 92	1	10.00	7.2	W 0	548.0	14.55	6.30	5.82
				W1	655.0	13.28	6.30	6. 0 1
				W2	561.0	13.43	6.40	5.80
				W3	505.0	12.58	6.30	5.78
				W4	499.0	13.80	6.50	5.74
				W5	400.0	11.98	6.50	5.74
				W6	127.0	9.48	6.50	5.54
14 4 92	1	7.30	1.7	W0				٠
				W1				1
				W 2				- 5
				W3				
				W4				
				W5				Ĩ.
				W6				- i -
24 4 92	1	7.30	3.5	W0	53.5	24.70		
				W1	55.0	24.70		1
				W2	50.0	24.88		,
				W3	86.0	24.65		
				W4	45.0	23.68		

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ТР	SRP	NH ₄	NO ₃	pН	alk	Ca	К	Al	Fe	Mn
0.10						56	1.8	0.68	0 302	0.043
0.16						5.6	1.0	0.00	0.372	0.043
0.16						5.8	19	0.70	0.470	0.050
0.12						6.8	19	0.82	0.690	0.050
0.12						6.1	17	0.02	0.376	0.031
0.12						5.8	1.8	0.68	0.475	0.069
0.08						5.4	1.6	0.44	0.281	0.032
0.96	0.03		1.32			7.3	1.8	6.36	5.330	0.117
1.07	0.02		2.15			7.1	1.8	3.71	0.525	0.101
0.96	0.03		1.42			7.2	1.8	6.01	4.500	0.122
0.92	0.05		1.09			7.0	1.7	4.82	2.520	0.110
0.82	0.05		1.03			7.0	1.7	4.66	3.760	0.118
0.69	0.03		1.09			6.3	1.7	4.32	3.740	0.105
0.30	0.04		0.55			4.8	1.6	1.55	0.977	0.088
						4.6	1.6	0.94	0.609	0.044
						4.4	1.6	0.95	0.625	0.048
						5.8	1.5	1.03	0.672	0.052
						5.4	1.6	1.08	0.753	0.055
						4.7	1.5	0.83	0.561	0.048
						5.5	1.5	0.84	0.586	0.052
						5.7	1.2	0.59	0.389	0.037

Table B1.1 continued

Date		Time	l s ⁻¹	SS	AU	Cl	SO4	ТР
			W5	35.1	23.08			
			W6	20.0	19.20			
	2	9.30	5.2 W0	116.0	11.65	5.30		0.25
			W 1	127.0	11.85	5.30		0.30
			W2	153.0	12.88	5.12		0.31
			W3	133.0	12.20	5.30		0.33
			W4	142.0	11.55	5.18		0.32
			W5	107.0	11.38	5.15		0.30
			W6	63.3	6.28	5.36		0. 19
	3	10.00	7.2 WO	225.0	27.00			
			W 1	240.0	26.25			
			W2	238.0	26.75			
			W3	231.0	27.25			
			W4	217.0	26.25			
			W5	167.0	24.75			
			W6	57.0	20.00			
	4	10.45	8.4 W0	151.0	27.25			
			W1	181.0	27.75			
			W2	26.1	27.00			
			W3	222.0	27.25			
			W4	214.0	26.75			
			W S	180.0	27.25			
	5	11 15	W6	22.5	21.58			0.51
	2	11.15	11.0WU	331.0	9.15			0.56
			WI	301.0	8.15			0.54

	1 1								_
SRP	NH ₄	NO3	рН	alk	Ca	К	Al	Fe	Mn
									1.
0.09		0.26			4.4	1.4	1.26	0.829	0.040
0.08		0.27			5.2	1.4	1.43	0.823	0.048
0.08		0.35			4.3	1.4	1.47	0.869	0.058
0.09		0.32			4.0	1.4	1.55	1.080	0.052
0.09		0.34			5.8	1.5	1.56	1.020	0.061
0.08		0.30			4.3	1.4	1.70	1.200	0.060
0.07		0.11			3.9	1.2	0. 79	0.587	0.047

6.0	1.5	2.22	0.772	0.063
6 .1	1.5	3.08	2.320	0.064

Table B1.1 continued

Date		Time	l s	-1	SS	AU	Cl	SO4
				W2	430.0	8.73		
				W3	337.0	7.60		
				W4	357.0	7.68		· 1
				W5	292.0	8.15		
				W6	133.0	2.88		
	6	12.00	11.0)W0	115.0	5.05		1
				W1	113.0	5.30		r
				W 2	217.0	5.10		î.
				W 3	188.0	5.25		
				W4	151.0	4.93		ţ
				W5	113.0	4.35		
				W6	49.0	1.43		,
24 9 92	1	11.50	.1	W0	15.7	3.43		*
				W6	12.8	2.13		•
	2	12.43	9.3	W0	3.0	2.73		1
				W 6	1.8	1.98		L
9 11 92	1	8.10	6.1	W0	7.7	11.20	7.30	!
				W1	13.0	11.20	6.90	1
				W2	15.0	11.30	6.90	
				W 3	39.7	11.30	6.90	1
				W4	9.3	11.00	6.00	
				W 5	19.7	10.80	7.30	
			9	W6	3.2	10.80	6.90	

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ТР	SRP	NH4	NO ₃	pН	alk	Ca	К	Al	Fe	Mn
0.71				_		4.5	1.5	3.36	1.840	0.092
0.70						5.1	1.5	2.62	1.070	0.072
0.65						4.9	1.5	2.57	0.945	0.075
0.49						5.3	1.4	1.62	1.400	0.074
0.29						3.7	1.3	1.53	0.699	0.062

0.07	0.02	3.7	1.0	0.48	0.40	0.02
0.06	0.02	3.7	1.0	0.53	0.47	0.03
0.06	0.02	3.8	1.0	0.53	0.44	0.03
0.09	0.02	3.8	1.1	0.62	0.49	0.06
0.22	0.02	3.7	1.0	0.46	0.41	0.03
0.08	0.02	3.8	1.0	0.53	0.50	0.04
0.07	<0.01	3.4	1.0	0.39	0.32	0.02
		C-40				

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Date		Time	l s	-1	SS	AU	Cl	SO4
22 11 92	1	16.00	2.2	W0	7.4	8.83		
	-			W1	6.8	8.55		
				W2	17.6	8.53		
				w3	25.0	8.63		
				W4	17.8	8 4 3		
				ws	42.8	8 4 8		
				W6	73	7 20		
24 11 92	1	20.05	66	wn	523	9.58		
24 11 72	1	20.05	0.0	wi	47 3	9.83		
				w2	35.0	9.23		
				w3	51.0	9.50		
				W4	34.0	9.50		
				W5	44.3	8.98		
				W6	11.3	678		
15 1 93	1	7.20	18.	WÖ	13.0	16.00		
				W1	18.7	7.05		
				W2	56.5	7.48		
				W3	18.8	7.25		
				W4	11.5	7.48		
				W5	26.2	13.90		
		7.25		W6	3.0	7.40		
19 1 93	1	15.00	13.	W0	10.5	7.15		
				W1	20.0	8.15		
				W2	12.4	8.25		
				W3	13.5	8.15		

ТР	SRP	NH ₄	NO ₃	pН	alk	Ca	К	Al	Fe	Mn
0.04								0.44	0.30	0.03
0.04								0.45	0.31	0.03
0.04								0.53	0.41	0.05
0.05								0.62	0.50	0.06
0.04								0.42	0.30	0.05
0.08								0.74	0.70	0.09
0.02								0.34	0.25	0.04
0.12								0.39	0.31	0.04
0.11								0.75	0.66	0.05
0.09								0.60	0.51	0.04
0.12								0.79	0.70	0.06
0.09								0.63	0.54	0.05
0.10								0.71	0.66	0.07
0.03								0.39	0.33	0.05
0.09						3.7	1.9	0.40	0.27	0.03
0.10						3.7	1.9	0.43	0.28	0.04
0.13						3.8	1.8	0.61	0.46	0.06
0.09						3.8	1.9	0.44	0.32	0.04
0.07						3.8	1.9	0.36	0.26	0.03
0.09						3.9	1.9	0.47	0.38	0.05
0.06						3.5	2.0	0.31	0.20	0.03
0.06						3.5	1.4	0.46	0.29	0.03
0.06						3.5	1.3	0.51	0.34	0.04
0.05						3.6	1.4	0.47	0.31	0.03
0.06						3.9	1.4	0.47	0.31	0.03

Table B1.1 continued

Date		Time	l s ⁻¹	SS	AU	Cl	SO4
			W4	12.8	14.10		
			W5	26.7	11.63		
			W6	5.3	11.35		
	2	16.00	17. WO	12.4	8.20		r.,
			W1	24.6	8.45		1.
			W2	23.6	8.38		
			W3	9 .5	10.83		4
			W4	11.5	11.93		
			W 5	17.8	14.20		
			W6	5.8	12.63		
30 3 93	1	07.00	6.1 W0	21.0	9.00		
			W1	83.0	8.78		
			W2	62.0	8.68		
			W3	31.6	8.70		
			W4	22.0	9.50		
			W 5	27.0	9.10		1
			W6	10.3	8.53		
	2	08.10	14.1 W0	99.0	8.80		
			W1	130.0	7.95		,
			W2	136.0	8.40		
			W3	124.0	8.43		
			W4	73.5	9.70		
			W 5	99.5	9.48		
			W6	36.8	8.70		

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TP	SRP	NH4	NO3	рН	alk	Ca	K	Al	Fe	Mn
0.05						3.6	1.4	0.42	0.31	0.03
0.07						4.0	1.4	0.56	0.40	0.05
0.03						4.0	1.4	0.30	0.21	0.03
0.06										
0.07										
0.06										
0.05										
0.05										
0.06										
0.04										
0.10										
0.14										
0.13										•
0.09										
0.09										
0.08										
0.06										
0.15						4.3	1.8	0.99	0.72	0.07
0.17						4.2	1.7	1.37	1.24	0.09
0.20						4.3	1.8	1.49	1.30	0.12
0.18						4.2	1.7	1.33	1.15	0.11
0.15						4.2	2.0	0.92	0.75	0.07
0.18						4.7	2.0	1.14	1.06	0.12
0.11						3.9	2.1	0.68	0.64	0.15

					_		
Date		Time	1 s ⁻¹	SS	AU	Cl	SO4
5 11 90	1	16.00	02 F0	25	18.00	7 22	11 30
12 11 00	1	10.00	0.2 E0	2.5 A 5	21 10	7 50	13.60
12 11 70	1	10.50	0.2 E0 E1	110	21.10	7.50	15.00
			E1 E2	70	20.40	7.50	14.40
			E2	11.5	21.30	7 50	14.40
			EJ EA	10.0	21.30	7.30	13.80
			E5	12.5	24.50	9.00 9.00	12.00
15 11 00	1	10.15	10 E0	60	24.00	8.00	12.70
15 11 50	1	10.15		0.0	21.20	8 70	21.60
			E1 E2	9.0	20.10	0.70	16.60
			E2 E2	J.J 7 5	20.10	0.00	10.00
			E) EA	1.5	21.10	0.00	20.60
			E4 E5	<i>J.J</i>	21.00	0.70	20.00
16 11 00	1	< 00	E) 0.4 EO	10.0	21.78	ð./U	18.10
10 11 90	I	0.00	0.4 EU E1	4.5	21.43	8.50	17.20
			E7	<i>J</i> .0	21.55	8.00 8.50	10.70
			E2	4.0	22.00	0.JU 8 50	17.00
			E3 E4	5.5	21.90	0.JU 8 60	10.60
			E4 E5	12.0	23.30	8.00 8.60	18 20
	2	0.30	3 2 EO	180.0	18 53	6.00	17.20
	2	9.50	5.2 EU E1	188.0	18.55	6.80	18.40
			E7	204.0	18.00	6.00	15.40
			E2 E2	276.0	10.05	6.00	15.20
			E1	1920	10.70	0.70 7 10	14.70
			C 4	102.0	19.30	1.10	14.70

Table B1.2 Results of manual sampling from the East site

ТР	SRP NH ₄	NO ₃	pH alk	Ca	К	Al	Fe	Mn
	<u> </u>				<u></u>		1.0	
0.08	0.19	< 0.05						
0.08	< 0.04	< 0.05		1.2	0.4	0.10	0.380	0.009
0.08	0.09	< 0.05		1.0	0.3	0.16	0.372	0.009
0.07	< 0.04	< 0.05		1.0	0.4	0.15	0.399	0.011
0.08	0.04	< 0.05		1.0	0.5	0.14	0.407	0.011
0.07	0.04	< 0.05		1.0	0.5	0.17	0.659	0.018
0.07	0.04	< 0.05		1.4	0.5	0.20	0.657	0.025
0.07	0.04	< 0.05	4.0	1.0	0.5	0.11	0.313	0.007
0.07	0.05	< 0.05	3.9	1.1	0.5	0.13	0.324	0.009
0.06	0.34	< 0.05	3.9	1.3	0.5	0.11	0.313	0.008
0.06	0.04	<0.05	3.9	1.0	0.5	0.12	0.319	0.009
0.06	0.08	< 0.05	3.9	1.0	0.6	0.16	0.414	0.014
0.05	0.11	< 0.05	3.9	1.0	0.5	0.12	0.453	0.017
0.04	< 0.04	< 0.05	3.9	1.0	0.4	0.13	0.357	0.008
0.06		<0.05	3.9		-			
0.07		< 0.05	3.9					
0.06		< 0.05	4.0					
0.07		< 0.05	3.9					
0.06	0.04	< 0.05	3.9	1.0	0.5	0.16	0.558	0.019
0.16	< 0.04	< 0.05	3.9	1.0	0.3	0.22	0.736	0.006
0.16	0.21	< 0.05	3.9	1.2	0.3	0.25	0.791	0.007
0.21	0.04	< 0.05	3.9	1.1	0.3	0.28	0.895	0.009
0.25	0.11	< 0.05	3.9	1.2	0.4	0.29	0.869	0.011
0.14	0.12	< 0.05	4.0	1.1	0.4	0.27	0.864	0.015

Table B1.2 continued

Date		Time	1 s	-1	SS	AU	Cl	so,4
								 I
	~	10.00	• •	E5	256.0	21.58	7.40	13.40
	3	10.30	3.9	EO	168.0	17.23	5.90	14.90
				El	182.0	17.38	6.00	15.40
				E3	216.0	17.38	6.10	14.20
				E5	140.0	19.60	6.00	13.40
	4	12.00	3.5	E0	160.0	17.53	5.60	16.20
				E1	152.0	17.20	5.70	14.70
				E3	220.0	17.05	5.80	15.60
				E5	94.0	19.00	6.10	13.80
	5	15.15	3.2	E0	19.0	18.80	6.90	15.90
				E1	30.0	19.10	7.00	17.70
				E2	40.0	19.23	6.90	15.80
				E3	41.0	18.80	6.90	15.30
				E4	116.0	19.15	6.80	15.10
				E5	16.5	19.83	6.80	15.50
3 11 90	1	13.30	1.0	E0	7.0	15.30	11.40	5.60
				E1	42.0	15.45	8.40	14.90
				E2	35.0	15.70	9.90	16.30
				E3	67.0	15.68	9.80	15.50
				E4	73.0	16.00	9.50	14.50
				E5	53.0	16.13	9.70	14.10
5 12 90	1	8.30	0.2	E0	3.0	18.60	9.05	5.37
				E 1	2.0	18. 9 3	8.92	17.00
				E2	5.0	18.55	8.81	17.70
				E3	13.5	18.68	8.86	17.50

230/16/W

TP	SRP NH ₄	NO3	pН	alk	Ca	к	Al	Fe	Mn
0.15	< 0.04	< 0.05	3.9		1.0	0.4	0.19	0.665	0.017
0.14	0.10	< 0.05	3.9		0.9	0.2	0.24	0.547	0.006
0.15	< 0.04	< 0.05	3.9		0.9	0.3	0.25	0.575	0.007
0.18	< 0.04	< 0.05	3.9		0.9	0.4	0.25	0.602	0.008
0.12	0.10	< 0.05	4.0		0.9	0.4	0.21	0.617	0.014
0.13	0.05	< 0.05	4.0		0.7	0.3	0.19	0.471	0.005
0.13	< 0.04	< 0.05	3.9		0.9	0.3	0.23	0.607	0.006
0.14	< 0.04	<0.05	3.9		1.0	0.4	0.22	0.602	0.008
0.10	0.15	<0.05	3.9		0.9	0.4	0.19	0.569	0.012
0.08	< 0.04	<0.05	3.8		0.9	0.4	0.10	0.273	0.006
0.08	0.09	<0.05	3.9		0.8	0.5	0.12	0.314	0.007
0.09	0.18	<0.05	3.8		0.8	0.5	0.13	0.342	0.007
0.08	< 0.04	< 0.05	3.9		0.9	0.5	0.15	0.434	0.017
0.11	0.08	<0.05	4.0		0.9	0.5	0.19	0.557	0.012
0.06	0.04	<0.05	3.9						
0.08	< 0.04	0.22	3.9		0.7	0.4	0.13	0.312	0.007
0.08	< 0.04	0.07	3.9		0.7	0.4	0.12	0.381	0.007
0.07	0.19	0.15	4.0		0.8	0.3	0.10	0.323	0.008
0.10	0.39	0.09	3.9		0.8	0.4	0.10	0.306	0.009
0.09	0.26	<0.05	3.9		0.8	0.5	0.10	0.375	0.014
0.07	<0.04	< 0.05	3.9		0.8	0.5	0.11	0.465	
0.07	<0.10	<0.05	4.2		1.0	0.4	0.08	0.361	0.009
0.07	<0.10	<0.05	4.1		1.0	0.4	0.08	0.346	0.009
0.06	<0.10	< 0.05	4.0		1.0	0.4	0.09	0.336	0.009
0.07	<0.10	<0.05	4.0		1.5	0.5	0.13	0.360	0.010

Table B1.2 continued

Date		Time	l s ⁻¹	SS	AU	CI SO4
			E4	2.0	21.10 8	8.89 16.80
			E5	2.5	19.78 8	8.84 15.90
28 12 90	1	8.30	5.0 E0	246.0	9.88 29	0.20 19.90
			El	217.0	28	3.90 22.60
			E2	210.0	10.05 28	3.80 20.20
			E3	282.0	9.78 28	3.30 21.40
			E4	86.0	9.38 27	.90 21.60
			E5	26.0	9.13 27	.60 21.60
	2	11.00	9.0 E0	162.0	9.10 22	2.00 19.50
			E1	452.0	8.98 22	2.00 18.40
			E2	398.0	8.68 22	2.10 18.20
			E3	428.0	8.70 22	.20 18.90
			E4	416.0	8.53 22	.50 18.40
			E5	252.0	8.13 22	2.80 17.00
9 1 91	1	12.00	0.4 E0	<0.5	10.40 14	.90 11.40
			E5	1 9 .0	10.13 15	.10 15.70
18 1 91	1		E0	14.0	5.78 7	.50 5.30
			E2	7.0	6.60 7	.50 10.60
			E5	<1.0	6.73 7	.80 10.20
4 2 91	1		E0	5.0	14.53 15	.00 3.50
12 2 9 1	1	11.00	0.1 EO	2.0	12.45 12	2.00 2.60
			E4	5.0	14.88 14	.50 12.20
19 2 91	1	14.30	0.1 EO	1.3	9.93 9	0.10 10.50
			E1	1.3	9.90 9	.20 12.00
			E2	1.0	9.65 9	.30 12.30

ТР	SRP	NH ₄	NO ₃	pН	alk	Ca	K	Al	Fe	Mn
0.06		<0.10	< 0.05	3.9		0.9	0.4	0.15	0.648	0.016
0.06		< 0.10	< 0.05	4.0		0.9	0.5	0.17	0.576	0.018
0.08		0.22	< 0.05	3.8		1.7	0.9	0.44	1.050	0.012
0.08		< 0.10	< 0.05	3.8		1.6	0.9	0.34	0.989	0.012
0.09		0.23	< 0.05	3.9		1.5	0.9	0.29	0.820	0.011
0.10		<0.10	< 0.05	3.8		1.4	0.9	0.21	0.634	0.011
0.04		< 0.10	< 0.05	3.8		1.3	0.9	0.13	0.404	0.012
0.01		< 0.10	< 0.05	3.8		1.2	1.0	0.08	0.271	0.015
0.24		<0.10	< 0.05	3.8		4.0	1.0	1.67	3.730	0.029
0.15		< 0.10	< 0.05	3.8		2.9	0.9	1.09	2.410	0.020
0.12		<0.10	< 0.05	3.8		2.2	0.9	0.89	1.840	0.017
0.16		<0.10	< 0.05	3.8		2.3	0.9	0.83	1.890	0.017
0.12		<0.10	<0.05	3.8		1.8	0.9	0.57	1.430	0.018
0.07		< 0.10	< 0.05	3.8		1.6	0.9	0.44	1.120	0.018
0.05		< 0.10	< 0.05	3.9		1.0	0.7	0.06	0.184	0.008
0.05		0.24	< 0.05	3.9		0.9	0.8	0.12	0.241	0.011
0.07		0.27	0.08			0.6	0.5	0.08	0.216	0.004
0.08		0.25	0.06			0.7	0.5	0.13	0.317	0.005
0.05		0.26	0.05			0.5	0.5	0.06	0.144	0.006
0.04		0.34	0.06	4.4		1.5	0.8	0.08	0.539	0.018
0.05		0.27	0.07	4.6		1.4	0.7	0.09	0.533	0.017
0.08		0.14	0.08	4.1		2.1	0.8	0.17	0.460	0.026
0.08		0.09	<0.10	4.1		0.9	0.5	0.05	0.185	0.007
0.08		0.03	<0.10	4.1		0.8	0.5	0.04	0.171	0.008
0.08		0.09	< 0.10	4.1		0.8	0.5	0.07	0.162	0.008

Table B1.2 continued

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Date		Time	1 s ⁻¹	SS	AU	Cl	SO4	TP	SF
		<u></u>		·			1		
			E3	<0.5	10.10	9.20	12.00	0.08	
			E4	<0.5	10.88	9.60	12.10	0.08	
			E5	<0.5	11.03	9.70	11.20	0.08	
22 2 91	1		E0	2.5	12. 9 5	7.54	6.37	0.08	
			El	19.00	13.15	8.96	14.30	0.17	
			E2		12.23	8.72	14.70	0.30	
			E3		13.45	8.74	13.30	0.26	
			E4	18.0	12.80	8.68	12.20	0.12	
			E5	24.0	11.60	8.17	10.30	0.30	
4 3 91	1	14.30	5.0 E0	<1.0	3.80	4.83	15.20	0.10	
			E1	2.7	3.30	4.76	16.10	0.09	
			E2	6.0	3.40	4.71	16.30	0.09	
			E3	4.0	13.50	4.79	16.30	0.09	
			E4		13.50	4.80	16.30	0.10	
			E5	17.0	13.50	4.88	16.20	0.07	
4 3 91	2	16.30	8.0 E0	32.0	13.90	4.15	16.00	0.11	
			E1	93.0	15.30	4.23	16.00	0.14	
			E2	158.0	13.90	4.17	15.90	0.17	
0			E3	129.0	13.70	4.12	16.10	0.16	
			E4	76.0	13.60	4.22	16.00	0.15	
			E5	42.0	13.40	4.15	15.80	0.12	
18391	1	12.00	.3 E0	8.0	20.48	5.29	7.29	0.03	
			E 1	< 0.5	20.78	5.08	16.40	0.03	
			E2	3.0	20.65	5.11	16.60	0.03	
			E3	8.0	20.68	4.99	14.00	0.04	

230/16/W

RP NH4	NO ₃	pH al	k Ca	K	Al	Fe	Mn
0.03	<0.10	4.0	1.0	0.7	0.06	0.196	0.009
0.09	< 0.10	4.0	0.7	0.8	0.06	0.264	0.010
< 0.02	< 0.10	4.1	0.8	0.7	0.17	0.322	0.016
0.25	< 0.10	4.0	0.5	0.4	0.08	0.188	0.006
0.20	< 0.10	3.9	0.7	0.4	0.09	0.229	0.006
0.20	<0.10	3.9	0.9	0.6	0.18	0.611	0.011
0.19	<0.10	4.0	0.9	0.6	0.07	0.313	0.011
0.13	<0.10	4.0	0.7	0.5	0.07	0.365	0.011
0.19	<0.10	3.9	0.9	0.5	0.24	0.715	0.015
0.05	<0.10	3.9	0.6	0.4	0.80	0.248	0.004
< 0.05	< 0.10	3.9	0.6	0.4	0.80	0.246	0.004
0.07	<0.10	3.9	0.6	0.3	0.90	0.257	0.008
0.05	<0.10	4.0	0.6	0.3	0.90	0.240	0.004
0.05	< 0.10	3.9	0.6	0.5	0.17	0.325	0.007
< 0.05	<0.10	4.0	0.6	0.4	0.09	0.253	0.007
0.07	<0.10	4.0	0.6	0.4	0.14	0.371	0.005
< 0.05	<0.10	3.9	0.7	0.5	0.21	0.590	0.005
0.07	<0.10	3.9	0.9	0.4	0.33	0.939	0.007
< 0.05	<0.10	4.0	0.8	0.5	0.27	0.735	0.007
0.08	<0.10	3.9	0.7	0.4	0.18	0.587	0.007
0.07	<0.10	3.9	0.6	0.4	0.11	0.323	0.007
0.17	<0.10	4.0	0.7	0.4	0.09	0.252	0.005
0.24	<0.10	4.0	0.7	0.4	0.09	0.247	0.005
< 0.05	<0.10	4.0	0.6	0.4	0.09	0.255	0.005
< 0.05	< 0.10	3.9	0.7	0.4	0.09	0.270	0.005

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Table B1.2	contin	lued																
Date		Time	l s ^{-l}	SS	AU	Ω	SO_4	TP	SRP	NH_4	NO3	pН	alk	Ca	×	A	-	e
															2			
			E4	2.4	22.33	4.95	14.30	0.04		0.10	<0.10	4.0		0.7	0.6	0.11	0	417
			E5	4.0	23.43	5.03	14.20	0.03		<0.05	<0.10	4.0		0.7	0.5	0.12	0	453
18391	2	14.00	.9 E0	20.7	20.10	4.74	16.20	0.04		<0.05	<0.10	3.9		0.6	0.3	0.10	0	252
			E	11.0	20.00	4.67	16.20	0.04		0.16	<0.10	3.7		0.6	0.3	0.05	0	241
			E2	7.3	20.20	4.64	16.10	0.04		0.07	<0.10	3.9		0.6	0.3	0.09	0	240
			E3	1.5	19.78	4.70	14.00	0.03		0.13	<0.10	4.0		0.6	0.4	0.09	0	252
			E4	2.5	19.78	4.80	14.20	0.03		<0.05	<0.10	4.0		0.6	0.4	0.17	0	332
			E5	34.7	21.98	474	14.00	0.03		0.11	<0.10	4.0		0.7	0.5	0.11	0	385
18391	ω	15.00	2.2 EO	1.3	20.25	4.42	16.00	0.04		0.17	<0.10	4.0		0.7	0.3	0.09	0.2	31
			El	17.0	20.40	4.30	16.10	0.04		<0.05	<0.10	3.9		0.6	0.4	0.10	0.2	ί Ω
			E2	6.0	20.43	4.34	13.00	0.03		<0.05	<0.10	4.0		0.6	0.4	0.10	0.2	ώ 4
			E3	5.0	20.23	4.31	14.10	0.05		0.16	<0.10	4.0		0.6	0.4	0.10	0.2	61
			E4	3.0	20.65	4.45	14.00	0.04		<0.05	<0.10	3.9		0.6	0.4	0.10	0.2	92
			E5	5.0	21.05	4.47	14.20	0.03	ł	<0.05	<0.10	3.9		0.6	0.4	0.11	0.3	57
4491	-	9.00	9.0 E0	51.0	16.65	3.35	3.59	0.10	0.010	<0.05	<0.10	4.0		0.6	0.5	0.20	0.4	52
			E1	45.0	16.20	3.31	3.14	0.17	<.003	0.12	<0.10	4.0		0.7	0.6	0.17	0.4	11
			E2	69.0	16.23	3.45	3.54	0.14	<.003	0.13	<0.10	4.0		0.9	0.6	0.21	0.5	6
			E3	68.0	16.28	3.48	3.47	0.12	<.003	<0.05	<0.10	4.1		0.9	0.6	0.18	0.4	58
			E4	86.0	16.45	3.50	3.51	0.17	<.003	0.19	<0.10	4.0		0.6	0.5	0.17	0.5	35
			ES	34.0	16.18	3.54	3.45	0.09	<.003	<0.05	<0.10	4.0		0.6	0.6	0.15	0.4	83
	2	10.00	14.1E0	22.0	15.43	3.21	3.48	0.15		0.08	<0.10	4.1		0.7	0.7	0.18	0.3	21
			El	54.0	15.43	3.12	3.38	0.13		<0.05	<0.10	4.0		0.5	0.6	0.16	0.3	62
			E2	55.0	15.53	3.16	3.43	0.12		0.13	<0.10	4.0		0.5	0.6	0.16	0.3	83
			E3	53.0	15.48	3.20	3.42	0.11		<0.05	<0.10	4.0		0.6	0.6	0.16	0.4	78
			E4	100.0	15.65	3.23	3.42	0.14		<0.05	<0.10	4.0		0.7	0.6	0.20	0.5	82

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E5	(10		
	04. U	15.60	3.2
E0	28.0	15.93	3.3
E1	21.0	15.75	3.4
E2	32.0	15.70	3.4
E3	39.0	16.35	3.
E 4	100.0	15.95	3.4
E5	36.0	15.73	3.4
E0	<1.0	17.15	3.'
El	8.0	17.38	3.:
E2	9.0	17.68	3.'
E3	17.0	17.18	3.1
	E2 E3 E4 E5 E0 E1 E2 E3	E2 32.0 E3 39.0 E4 100.0 E5 36.0 E0 <1.0	E2 39.0 16.35 E3 39.0 16.35 E4 100.0 15.95 E5 36.0 15.73 E0 <1.0

					1											
Time	1 s ⁻¹	SS	AU	Cl	SO4	ТР	SRP	NH4	NO ₃	рН	alk	Ca	К	Al	Fe	Mn
		(10	15 (0)	2 20	2 40	0.12		-0.05	-0.10	4.0		0.5	0.6	0.10	0.522	0.007
11 20	ED	04.0	15.60	3.29	3.48	0.12		< 0.05	<0.10	4.0		0.5	0.0	0.19	0.322	0.007
11.30	11.0E0	28.0	15.93	3.39	3.33	0.10		0.11	<0.10	4.1		0.4	0.7	0.13	0.257	0.003
	EI	21.0	15.75	3.45	3.07	0.15		0.39	<0.10	4.0		0.4	0.7	0.13	0.233	0.003
	E2	32.0	15.70	5.47	3.07 - 2.07	0.11		0.12	<0.10	4.0		0.5	0.7	0.11	0.203	0.004
	E3	39.0	16.35	3.18	3.07 +	0.10		0.10	<0.10	4.0		0.5	0.7	0.13	0.347	0.004
	E4	100.0	15.95	3.40	3.34	0.10		0.18	<0.10	4.0		0.0	0.7	0.10	0.437	0.000
10.45	ED C C DO	30.0	15.75	3.48	3.371	0.24		0.07	<0.10	4.0		0.5	0.7	0.12	0.380	0.007
13.45	6.5 EU	<1.0	17.15	3.11	3.80	0.08		<0.05	<0.10	4.2		1.0	0.7	0.12	0.202	0.004
	EI	8.0	17.38	3.33	3.60	0.08		0.12	<0.10	4.0		0.6	0.7	0.11	0.204	0.004
	E2	9.0	17.68	3.12	3.76	0.08		0.05	<0.10	4.0		0.5	0.7	0.11	0.209	0.004
	E3	17.0	17.18	3.75	3.68	0.10		0.07	<0.10	4.0		0.6	0.7	0.13	0.290	0.005
	E4	18.0	17.68	3.75	3.73	0.09		<0.05	< 0.10	3.9		0.6	0.7	0.11	0.261	0.005
	E5	12.0	17.15	3.26	3.44	0.08		0.25	<0.10	4.0		0.5	0.6	0.13	0.341	0.006
10.30	0.1 E0	8.0	17.90	6.74	4.091	0.01		< 0.05	< 0.10	4.2		0.9	0.1	0.10	0.277	0.007
12.30	0.1 EO	<0.5	14.63	7.17	7.22	0.14		< 0.05	< 0.10	4.2		1.1	0.2	0.08	0.272	0.009
	E 1	<0.5	16.80	7.23	7.651	0.13		0.06	<0.10	4.2		1.0	0.2	0.08	0.281	0.009
	E2	<0.5	18.13	7.02	7.24	0.12		< 0.05	< 0.10	4.1		0.8	0.3	0.08	0.269	0.008
	E3	<0.5	28.40	7.81	7.86	0.17		0.25	<0.10	4.0		0.7	0.6	0.15	0.682	0.011
	E4	3.0	25.78	7.58	8.83	0.19		0.25	<0.10	4.1		0.8	0.6	0.16	0.813	0.014
	E5	2.0	25.50	7.42	8.40	0.22		0.23	<0.10	4.0		0.8	0.6	0.15	0.827	0.015
7.45	1.3 EO	9.7	22.68	5.00	19.90 ,	0.09		0.64	0.17	4.1	0.0	1.2	0.6	0.12	0.303	0.007
	E1	10.0	24.70	5.10	19.80	0.07		0.67	0.18	4.0	0.0	1.7	0.7	0.13	0.335	0.008
	E2	10.5	26.60	5.00	19.00	0.07		0.68	0.16	3.9	0.0	0.9	0.6	0.11	0.317	0.007
	E3	11.5	24.93	4.80	18.50	0.09		0.76	0.15	3.9	0.0	1.1 +	0.6	0.14	0.368	0.009
	E4	10.5	24.58	4.70	19.20	0.07		0.71	0.12	3.9	0.0	0.9	0.4	0.11	0.493	0.010
	E5	5.5	24.18	4.60	18.50	0.05		0.55	0.12	3.9	0.0	0.9	0.5	0.13	0.514	0.012

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Table B1.2 continued

Date		Time	l s ⁻¹	SS	AU CI	SO4
<fertilize< td=""><td>r ap</td><td>plication</td><td> ></td><td></td><td></td><td></td></fertilize<>	r ap	plication	>			
23 8 91	1	18.30	0.1 E0	7.2	13.68	
			E5	3.1	12.48	
18991	1	6.30	0.3 E0	12.0	8.70	
	-		E5	7.0	7.50	
21991	1	15.30	10.0E0	40.0		
	-		E5	17.0		
31 10 91	1	8.30	27.0E0	28.0	14.00 28.90	10.60
	-	0.00	E1	30.0	13.40 28.40	11.10
			E2	26.0	13.25 27.60	12.00
			E3	24.0	13.73 28.20	10.90
			E4	9.0	11.50 24.60	9.00
			E5	12.0	13.40 30.90	11.00
9 1 92	1	10.00	6.2 E0	11.7	6.33	
	-	10.00	E1	10.7	6.35	
			E2	10.3	6.48	
			E3	49.5	6.35	
			E4	16.7	6.30	
			E5	5.6	6.33	
2 2 9 2	1	18.30	0.3 EO	4.8	20.08	
			E5	2.8	19.38	
12 2 92	1	15.30	3.5 EO	8.0	24.40	
			E1	8.0	24.70	
			E2	15.5	25.00	
			E3	6.0	24.50	

ТР	SBD	NH	NO	H	alk	Ca	ĸ	Δ1	Fo	Mn
		4	NO ₃		ain 		<u>м</u>			
6.25										
<0.01										
9.72	9.300					18.2	47.3	0.95	0.284	0.044
0.67	0.760					9.6	30.3	0.50	0.294	0.143
7.36	7.450					12.7	35.2	0.62	0.363	0.029
5.46	5.300					7.1	26.4	0.55	0.311	0.084
1.96	1.730	2.47	0.53	4.0	0.0	3.3	9.8	0.22	0.299	0.018
1.93	1.740	1.70	0.53	3.9	0.0	3.3	10.0	0.20	0.333	0.019
1.91	1.750	2.43	0.52	3.9	0.0	3.7	10.0	0.21	0.199	0.018
2.04	1.740	2.21	0.52	3.9	0.0	3.3	9.8	0.22	0.299	0.018
1.43	1.520	1.49	0.41	3.9	0.0	2.7	8.5	0.20	0.292	0.039
1.85	1.740	1.53		3.9	0.0	3.5	10.3	0.19	0.240	0.022
0.98	0.740			•		1.3	3.3	0.12	0.263	0.004
0.97	0.780					3.3	3.3	0.08	0.265	0.005
0.97	0.770					2.2	3.4	0.15	0.280	0.005
1.08	0.780					1.4	3.4	0.17	0.400	0.008
1.00	0.770					2.3	3.4	0.16	0.488	0.007
0.97	0.760					2.2	3.2	0.12	0.324	0.005
2.50	2.250					1.6	4.8	0.20	0.254	0.006
2.26	1.900					1.7	4.8	0.21	0.496	0.009
1.17	1.480					2.4	4.0	0.18	0.282	0.006
1.35	1.490					2.0	4.2	0.17	0.259	0.006
1.15	1.490					3.2	4.1	0.19	0.284	0.007
1.18	1.510					3.3	4.1	0.17	0.308	0.006

Table B1.2 continued

Date		Time	1 s ⁻¹	SS	AU	Cl	SO4
					<u> </u>		
			E	1 I.3	24.90		
<pre>< 2 02</pre>		10.00	E:	5 3.0	24.60	10.10	
6392	I	18.30	1.3 E) 5.4	28.75	19.10	
			E:	6.0	27.50	14.70	a
31 3 92	1	11.00	5.2 E) 144.0	25.13	5.69	2.82
			E	1 182.0	26.48	5.93	3.20
			E	2 191.0	26.13	5.87	3.48
			E	3 172.0	25.43	5.74	3.64
			E	4 31.5	23.68	5.88	3. 9 3
			E	5 10.7	23.55	5.90	4.16
14 4 92	1	9.00	9.3 E	0			
			Ε	1			
			E	2			
			E	3			
			E	4			
			E	5			- 1
24 4 92	1	9.00	2.8 E	0 9.0	36.00	5.89	- 1
			Е	1 11.5	35.50	5.95	4
			E	2 15.5	35.75	6.01	1
			E	3 9.6	35.75	5.89	
			E	4 6.8	36.25	5.83	I.
			E	5 1.5	35.25	6.07	1
24 9 92	1	13.10	0.1 E	0 11.5	9.10		
,,,	-		E	5 28	9.50		
9 11 92	1	8.50	5.2 E	0 20	25.40	4.80	
/ 11 /6	•	0.00	L	<i>L.</i> 0	2 0.40	1.00	

ТР	SRP	NH4	NO ₃	рН	ałk	Ca	К	Al	Fe	Mn
1.19	1.540					1.9	4.3	0.18	0.363	0.007
1.16	1.480					1.9	4.2	0.18	0.391	0.008
1.09										
1.11										
0.67	0.740		0.15			1.9	2.5	0.26	0.598	0.011
1.05	0.750		0.14			2.4	2.4	0.27	0.698	0.006
1.12	0.760		0.15			1.6	2.4	0.30	0.769	0.008
1.12	0.760		0.14			1.6	2.5	0.23	0.689	0.007
0.93	0.760		0.14			1.2	2.4	0.15	0.336	0.005
0.88	0.770		0.14			1.1	2.4	0.11	0.309	0.005
						1.8	2.7	0.18	0.255	0.005
						1.7	2.7	0.18	0.261	0.005
						2.2	2.7	0.19	0.300	0.006
						1.4	2.7	0.17	0.285	0.005
						1.3	2.8	0.18	0.414	0.005
						1.4	2.7	0.18	0.448	0.007
1.24	<0.01		<0.10			1.2	2.3	0.18	0.291	0.005
1.40	<0.01		< 0.10			1.3	2.3	0.16	0.300	0.005
1.12	<0.01		<0.10			1.9	2.3	0.15	0.322	0.005
1.18	<0.01		<0.10			2.9	2.3	0.15	0.316	0.005
1.06	<0.01		<0.10			1.5	2.3	0.17	0.401	0.005
0.80	<0.01		<0.10			1.5	2.2	0.16	0.429	0.006
0.44	0.30					0.8	1.2	0.13	0.240	0.010
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Table B1.2 continued

Date		Time	l s ⁻¹	SS	AU	Cl	SO4
			E 1	2.7	25.70	4.90	
			E2	4.4	25.80	4.70	
			E 3	5.6	26.10	4.70	
			E4	3.0	26.30	4.70	
			E5	4.8	26.10	4.70	
22 11 92	1	15.30	1.3 E0	5.0	23.05		
			El	8.5	22.93		
			E2	9.0	22.78		
			E4	4.4	21.70		
			E5	1.6	20.68		
24 11 92	1	8.30	6.1 EO	15.0	17.65		
	-		E1	18.0	17.48		
			E2	44.3	17.63		
			E3	14.3	17.43		
			E4	5.0	17.70		
			E5	3.4	17.65		
25 1 93	1	7.40	11. EO	5.6	11.03		
			E 1	7.0	11.10		
			E2	7.5	11.23		
			E3	14.3	11.28		
			E4	3.2	11.25		
			E5	3.8	14.65		
19 1 93	1	15.30	14. EO	7.2	17.78		
			E 1	7.2	18.18		
			E2	9.7	18.40		

230/16/W

ТР	SRP	NH ₄	NO ₃	рН	alk	Ca	К	Al	Fe	Mn
0.42	0.31			_		0.8	12	013	0 240	0.010
0.45	0.31					0.0	1.2	0.13	0.240	0.010
0.43	0.31					15	1.2	0.13	0.250	0.010
0.46	0.32					0.8	1.2	0.18	0.270	0.010
0.38	0.31					0.8	1.3	0.15	0.280	0.010
0.30						0.0		0.11	0.240	0.010
0.32								0.12	0.250	0.010
0.34								0.13	0.250	0.010
0.36								0.12	0.300	0.010
0.34								0.15	0.330	0.010
0.31								0.11	0.200	0.010
0.29								0.10	0.220	0.010
0.31								0.11	0.250	0.010
0.28								0.09	0.200	0.010
0.29								0.12	0.200	0.010
0.29								0.09	0.230	0.010
0.41						1.0	1.9	0.06	0.100	0.010
0.40						0.8	1.9	0.06	0.110	0.010
0.41						0.9	1.9	0.07	0.110	0.010
0.41						1.0	1.9	0.08	0.130	0.010
0.39						1.0	1.9	0.08	0.120	0.010
0.47						1.1	2.0	0.08	0.130	0.010
0.28						1.0	1.6	0.07	0.140	0.010
0.30						1.0	1.6	0.06	0.140	0.010
0.30						0.8	1.6	0.08	0.140	0.010

Table B1.2 continued

	l'ime	1 s ⁻¹	SS	AU	Cl	SO4	ТР	SRP	NH ₄	NO ₃	pН	alk	Ca	K	Al	Fe	Mn
30 3 93 1	07.25	E3 E4 E5 6.1 E0 E1 E2 E3 E4 E5	16.4 2.5 1.0 18.4 20.8 34.4 86.0 3.7 1.0	18.63 18.08 18.05 15.30 18.48 16.83 14.95 14.93 14.60		1	0.31 0.28 0.27 0.49 0.48 0.48 0.52 0.46 0.42						0.8 0.8 1.0 1.0 0.9 1.2 1.2 1.0 0.9	1.5 1.6 1.6 1.6 1.6 1.6 1.6 1.5 1.6	0.07 <0.0 0.07 0.11 0.12 0.11 0.16 0.10 0.10	0.140 4 0.120 0.140 0.220 0.240 0.310 0.410 0.210 0.210	0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010
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