THE PERFORMANCE OF NATURAL SOIL COVERS IN REHABILITATING OPENCAST MINES AND WASTE DUMPS IN SOUTH AFRICA

by

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EXECUTIVE SUMMARY

INTRODUCTION

One of the most obvious and practically sustainable methods of limiting the generation of poor quality leachate from sources such as coal discard dumps, waste dumps and opencast mine spoil, is by the provision of natural soil covers to limit the rate of infiltration, and by ensuring the optimum slope so as to attain maximum downslope discharge.

Soil covers are not entirely impermeable. Even after compaction some infiltration will inevitably take place. Covers can therefore never be designed to prevent infiltration entirely. The purpose of the cover is therefore to reduce the waste load generated to an acceptable level.

The efficiency of a soil cover depends on a number of factors of which the meteorological conditions are probably the most important. Evaporation should exceed rainfall by a significant margin where soil covers are used. Also the duration and intensity with which rainfall occurs determines the cover efficiency.

The type of soil used, its pre-conditioning and thickness are all important factors which must be considered in the design of soil covers. As the availability of different soil types is often a practical problem, manipulation of the available materials might result in better soil cover performance.

There is an urgent need to understand the behaviour and to assess the effectiveness of soil covers designed to control the rate of leaching of pollutants from discard dumps and waste piles. Adequate field data does not exist from instrumented large-scale experiments to verify theoretical models that predict the movement of leachate under unsaturated conditions.

The behaviour of soil liners and cover change with time. The suitability of soil barriers should be judged in terms of their long-term properties rather than those prevailing immediately after construction. For this reason it is necessary that covers be monitored in situ for long after construction in order to understand their true behaviour.

Presently there is an inadequate knowledge and experience to allow the advantages, disadvantages and costs of various rehabilitation techniques to be compared. There is also little consensus amongst experts in the mining industry on design criteria or methodology for natural soil covers.

This research project was initiated to address some of these shortcomings alluded to above, by constructing a large scale experiment, and monitoring cover performance over the three years. This data has been used to develop recommendations for the future design of soil covers. Another aim of the project was to identify and evaluate computer models that could be used to predict cover performance.

LITERATURE SURVEY

An extensive literature survey was undertaken. The literature was found to report mainly on theoretical and small-scale experimental results. There is, on the other hand, a lack of well-documented large-scale experiments and virtually no long-term performance data could be found. Further, there is limited information available on the use of soil covers over coal waste. Most literature covered complex multi-layer covers.

The literature does however lead to some conclusions. These include:

- Simple, single layer covers are not as effective as complex multi-layer covers
- The use of natural soil covers for preventing oxygen or water infiltration, is not practical. It can however reduce the rate of acid formation
- Materials like compacted clay, cannot retain their properties for long periods, especially if extreme wetting and drying cycles are prevalent
- The advantage of using vegetation to increase moisture loss by evapotranspiration, is offset by the effects of soil break up and increased infiltration due to root ingress
- Cover performance varies. Outflows from the base of soil covers of between 1% and 60% of rainfall have been documented
- Compaction and moisture content control may reduce the permeability of soil covers.

PRINCIPLES OF UNSATURATED FLOW

Water movement through a soil cover and in the waste underneath generally occurs under unsaturated conditions. This implies that the pores in the soils and waste are partly filled with air. The presence of the air reduces the dimensions of the flow paths. Flow under unsaturated conditions is therefore considerably less than under saturated conditions. Flow dynamics in the unsaturated zone also controls diffusion and transport of oxygen from the surrounding air since a high moisture content in the cover material is required to restrict this transport.

EXPERIMENTAL SETUP

The experimental site for this project was constructed in 1993, at the Ngagane station, near the town of Newcastle in Kwa-Zulu Natal. The site comprised 10 test cells, simulating the cover configuration of coal discard dumps. The cells were designed with the following objectives in mind:

- The cells had to be of a large enough scale to be representative
- The boundary effects had to be known
- The experiment had to be instrumented to provide sufficient data
- Soil properties of the covers had to be known
- The effect of vegetation and slope had to be measurable.

The climatic conditions at the site are typical of that throughout South Africa, with summer rainfall, falling mostly in short high intensity thundershowers. The climatic data was logged electronically on site using a weather station. Hourly readings of rainfall, temperature, relative humidity and net radiation was measured.

Soils typically used as cover materials for discard dumps were selected. These materials as well as the coal discard were tested extensively, both in situ and in the laboratory, to determine physical and hydraulic properties.

Three of the 10 cells were uncovered, one being completely uncompacted and another completely compacted. The third uncovered cell was uncompacted but vegetated. Two simple single layer covers were used, in cells 4 and 5, the first a 300-mm-thick uncompacted Avalon (loam) soil cover, and the other a 500-mm-thick compacted Avalon soil layer.

Cells 6,7 and 8 had 1-m-thick layered covers, two with a combination of uncompacted Avalon and Estcourt (clay) soils and the other with a combination of compacted and uncompacted Avalon. Cells 9 and 10 were covered with Estcourt and Avalon combinations and were sloped at 5% and 10% respectively. All the cells, except two of the uncovered ones, were vegetated with grass.

The cells were designed to drain freely from the base of the coal discard. The volume of outflow was measured by means of tipping buckets. Oxygen and carbon dioxide levels were also measured in the top 150 mm of each coal layer immediately beneath the soil cover. These results give an indication as to the effectiveness of the covers as oxygen inhibitors.

Water samples were taken at regular intervals, to determine how the quality would change with time. Other factors that were monitored intermittently were the soil temperature, and the in-situ moisture content throughout the soil profile.

EXPERIMENTAL RESULTS

The coal particle density (SG) was found to be low. This is consistent with the high carbon content. No significant difference was found between SG for the Avalon and the Estcourt soils.

The coal discard had the lowest bulk density and the lowest porosity. The Estcourt had the highest bulk density and the lowest porosity of the two soils used. The porosity of the compacted coal discard and soils was found to be lower than for the uncompacted materials.

The water retention characteristics of the coal materials were found to be different from that of the Avalon and the Estcourt Soils. Insignificant differences in the retention characteristics were found between the compacted and uncompacted coal discard and Avalon soil. The Estcourt soil was found to have the steepest retention curve, confirming its greater water holding capacity.

The saturated hydraulic conductivity was determined using four different methods. Permeability was found to be one order of magnitude higher for the Avalon than for the Estcourt soils.

The leachate qualities recorded at each cell in the experiment are a function of the various geohydrological, geochemical and biological process associated with the coal discard material. A geochemical and statistical analyses of the leachate quality database revealed that the single-layered dump covers (cells 4 and 5) are less effective in preventing the production of acidity and salinity from the discard material. However, these single-layered dump covers, relative to the uncovered cells, managed to inhibit the oxidation of pyrite and was reflected in a lower increase in salinity with relative neutral pH levels. This means that an acid breakthrough in leachate quality will occur but will only take place in a number of years.

Multi-layered soil covers showed to have the capacity to create permanent anaerobic conditions, which not only inhibits the oxidation of pyrite but actually prevents it. This was reflected in a general improvement in leachate quality recorded at the multi-layered cells (cells 6-10) for most of the monitoring period.

The outflow results generally follow expected trends. As expected, the uncovered cells are the least effective in reducing the outflow, which averaged around 26% of precipitation. The compacted, uncovered cell performed slightly better than the uncompacted cells reducing the outflow to around 21%.

The single layer covers (cells 4 and 5) had an average outflow of 17% of precipitation. The uncompacted cover of cell 4 registered 5% more outflow than the compacted cover of cell 5.

The layered covers performed only slightly better with a combined outflow of around 15%, with the cells containing clay performing worse than the cell covered with only Avalon soil.

The sloped cells (9 and 10) were expected to have the least outflow, but ended up with outflows similar to the near horizontal cells at around 16%. On all the cells an increase in outflow was observed to coincide with the establishment of vegetation. We are however not convinced that this increase was due to the effect of foot penetration alone, grass was established during a period of abnormally high rainfall.

MODELLING

Numerous computer codes claim to model unsaturated flow. Forty-four (44) of these were identified and evaluated. Only 17 were found to simulate evapotranspiration. One was selected for calibration on the basis that it satisfied the minimum requirements and relatively inexperienced users would be able to operate it.

SWACROP is a transient one-dimensional finite difference model for simulation of the flow of water through the unsaturated zone. This model was used to compare the experimental data with theoretical results. The tool was found to have the capability of predicting cover performance to assist in the prediction of cover efficiency.

Modelling calibration proved to be unsuccessful. The model, in all circumstances, predicted significantly higher outflows than observed in the field. Reasons for these discrepancies were postulated to be the timestep and the spreading of all rainfall in any one day over the full day.

CONCLUSIONS

A soil cover of at least 300 mm over coal spoils was found to reduce the potential outflow by at least 50%, to be in the range of 17% of MAP. A further reduction of between 2% and 4% would have been gained by compacting the cover clayey material which is susceptible to desiccation cracking, should not be used. Outflow can be reduced further by reshaping to form steep slopes, which maximise runoff.

It would appear that the multiple layered covers do not perform better than the single-layered covers. The 500-mm compacted Avalon cover was found to outperform the multiple layered covers throughout the duration of the experiment.

Throughout this experiment the Avalon soils appeared to have more potential for reducing outflow than the Estcourt soils, this suggests that the Avalon's high water retention properties, coupled with its low susceptibility to desiccation cracking makes it the most suitable for cover material in semi-arid climates.

1. INTRODUCTION

"... the fields are devastated by mining operations ... Further, when the ores are washed, the water which has been used poisons the brooks and streams, and either destroys the fish or drives them away. Therefore the inhabitants of these regions, on account of the devastation of their fields, woods, groves, brooks and rivers, find great difficulty in procuring the necessaries of life, and by reason of the destruction of the timber they are forced to greater expense in erecting buildings. Thus, it is said, it is clear to all that there is greater detriment from mining than the value of metals which the mining produces." ***(Georgius Agricola: "De Re Metallica", 1556)***

It is clear that impacts of mining on the environment have been identified since mining activities commenced. Doubtless even the earliest mining operations – during the Iron- and Bronze-Ages – caused pollution, though on a limited scale. As the scale of mining activities increased, so did the degree of pollution. We have an obligation to control this pollution, for we would like to maintain and preserve the environment for future generations.

1.1 PROJECT JUSTIFICATION

Coal discard dumps are a feature of both underground and opencast coal mines. These dumps may cover areas of as much as twenty hectares on large mines are sources for various environmental impacts including air pollution, surface water and groundwater pollution. Similarly, the spoils generated by opencast and strip mining methods also represent major sources of contamination

The potential contribution of contaminant load from these sources of pollutants has not yet been satisfactory quantified due to the following reasons:

- The potential for leaching of salts can not be readily predicted
- The quantity of leachate can not be readily predicted

One of the popular and practically sustainable mitigation methods of addressing environmental impacts associated with coal discard dumps is by the construction of natural sustainable soil covers. By constructing an effective soil cover on the discard material and vegetating the cover, the following environmental impacts are addressed to different degrees:

- The potential of coal dust pollution is significantly decreased. If an effective vegetation cover is established on the soil cover, air pollution resulting from dust should be minimal.
- The soil covers reduces the amount of water infiltrating into the discard material. Water is the main vehicle for the production of leachate that impacts on surface and groundwater resources. If the infiltration rate is reduced, the quantity of leachate produced from a discard facility is also reduced.
- Although soil covers have historically been designed primarily to support vegetation, the focus of design has in the last decades shifted towards limiting infiltration and oxygen flux into the discard material. The reason for this is that the availability of oxygen is the main factor of oxidation of pyretic material, which causes the production of acidity. This acidity could potentially leach metals and could be neutralised by base/alkali minerals. The net effect of AMD is acidification and salinisation of the leachate. If a soil cover reduces the

rate of oxygen flux into the discard material, it will cause a reduction in the pyrite oxidation, which will consequently be reflected in improved leachate quality.

- The reduction in infiltration and pyrite oxidation by soil covers will lessen the potential impact and surface and groundwater resources.

The efficiency of a soil cover depends on a number of factors of which climate is an important aspect. For soil covers to perform effectively, evaporation should exceed rainfall by a significant margin which results in a negative soil water volume. Rainfall patterns, duration and intensity of rainfall events, are some of the important aspects to consider when assessing recharge, which varies significantly accordingly. Other factors determining the efficiency of a soil cover is the type of soil used, the compaction and preconditioning of the soil cover. While the choice of soils used at most site would usually be limited to one or two types, the thickness, order of compaction in which the available soils are placed, can be varied to achieve a cost effective design addressing most environmental concerns.

Another important aspect, often overlooked, is that the suitability of soil covers and soil liners should be judged by virtue of their long-term properties rather than by those on placement. For this reason it is necessary that soil covers be monitored for structural unstability for long periods after their original placement.

Degradation of natural soil covers occurs mainly because of desiccation, root penetration and burrowing animals. These causes preferential flow paths to develop within the soil cover and rainwater flows preferentially along these pathways. This results in an increased infiltration rate and hence increased recharge. Although traditional flow mechanisms through unsaturated soils are fairly well understood, very little is known on preferential flow mechanisms.

The largest environmental impact from coal discard dumps is on the surface and groundwater resources. The source for it impact is a combination of various geochemical processes associated with the coal discard material. The main geochemical processes include pyrite oxidation (Aluatic and luatic) and the neutralisation of the acid produced by pyrite oxidation through reactions with base/alkali minerals.

At present, there is an inadequate knowledge and experience to compare the advantages, disadvantages and cost implications of various rehabilitation techniques. There is currently little consensus regarding design philosophy and methodology of soil covers. Some design engineers argue that discard material can be left uncovered, provided that the surface layers are compacted to minimise infiltration while other argue that recharge can only be limited by placing combined geomembrane / geosynthetic covers on the discard material.

1.2 THE GENERIC OPENCAST MINE WATER MODEL

A generic opencast mine water model can be used to simulate and predict leachate generation and waste load emanating from opencast mines for different hydrological scenarios. Mine management and the authorities will require such a modelling tool to determine whether a specific water management strategy will achieve the waste load discharge limit set by the authorities. It has been estimated that the bulk of the leachate generated by rehabilitated and closed mining operations arise from recharge trough the discard materials.

The accuracy of integrated models which predict the total effluent volume and quality from opencast mines will largely depend on the accuracy of predicting the volume of leachate generated from the discard material, various components of the model are in the process of development in South Africa.

The following important aspects to be addressed by such a generic opencast mine water model, includes:

- The importance of pit layout, pit floor runoff, runoff from spoil areas, seepage from unrehabilitated and rehabilitated spoils to the opencast pit.
- The importance of water sources to the pit salt or sulphate balance.
- Mining technique and its impact on water quantity and quality
- The seasonality of South African rainfall.
- Recharge from the regional groundwater regime to the opencast pit.
- Impact of the opencast mining operation on the catchment areas within which mining take place.
- Seasonal long-term trends in water production and quality from the mine complex.
- The implementation of evaporation ponds, irrigation fields and periodic discharge to the public stream and its impact on water quantity and quality.
- Soil cover design will form a vital submodel of the generic opencast mine water model.

The main benefits from the development of a generic opencast mine water model include:

- Optimisation of mine water systems.
- Prediction of impact on water resources and evaluation of different mitigation strategies.
- Quantification of the impact on the total mine water system by different spoils and waste rehabilitation strategies or rehabilitation rates.
- Determination of risk for exceeding a certain allocated waste load based on hydrological rainfall and runoff records.

1.3 PRINCIPLE AIMS

The principle aim of the research project was to calibrate an existing numeric model using data generated from field scale test cells with different soil covers and slopes, such as may be used in practice, for rehabilitation of opencast mines or waste dumps. The following specific objectives were identified for the project:

- Evaluation of the various models available with a view to identifying one or two which are suitable for South African conditions.

- Design and construction of suitable cells for which the boundary conditions can be adequately defined to suite the type of models, which have been selected for calibration.
- Installation of instrumentation that is capable of reliable measurement of the parameters on which the models referred to above depends.
- Monitoring for a long period of time to establish steady state conditions.
- Calibration of the models and evaluation of the results.
- Production of a guideline on the use of the model or models most suited to South African conditions including recommendations, which arise from a practical evaluation of the experimental results.

1.4 WORK ASSOCIATED WITH THIS PROJECT

This project was conducted in combination with another Water Research Commission funded project, entitled; "*An investigation of the occurrence of the bacteria causing acid mine drainage in the outer layers of coal waste dumps*" (Project no. K5/454). The project was conducted by the University of Stellenbosch, Department of Microbiology, under the project leadership of Professor Loos.

In this study, the effects of discard dump construction and rehabilitation techniques on acid mine drainage (AMD) production has been assessed. Studies on the occurrence and population sizes of iron-oxidising bacteria in the outer layer of coal discard dumps, could provide insight to which rehabilitation techniques could successfully limit acid mine drainage.

1.5 REPORT LAYOUT

This report is divided into a number of main headings incorporating an extensive literature survey, experimental procedures, experimental results and a general discussion and conclusions. **Chapter 1** comprises a general introduction, project justification and the project aims. **Chapter 2** comprises an extensive literature review dealing mainly with soil covers and associated aspects. **Chapter 3** entails a literature study on preferential flow, in particular flow, associated with structural instability of the soil cover. **Chapter 4** covers the theory on unsaturated zone modelling and documents and discusses various commercial unsaturated zone modelling software packages. **Chapter 5** describes the experimental set up including monitoring procedures, in *situ* and laboratory procedures. The experimental results are reported in **Chapter 6** and **Chapter 7** discusses of the outflow results. The unsaturated flow modelling methodology and results are covered in **Chapter 8. Chapter 9** discusses general trends in water quality for the various experimental cells. Project conclusions and recommendations are discussed in **Chapter 10**

2. LITERATURE SURVEY

2.1. ACID MINE DRAINAGE

Acid Mine Drainage (AMD) occurs as a result of natural oxidation of sulphide minerals contained in rock that is exposed to air and water. The principle components for AMD production are reactive sulphide minerals, oxygen and water. The oxidation process is often accelerated by biological activity. The chemical and biological reactions result in low pH, which has the potential to mobilise heavy metals contained in the discard material. Elevated metals and sulphate from the acid generation process are transported to the receiving environment with subsequent detrimental effects.

The primary chemical factors that determine the rate of acid generation are:

- pH
- temperature
- oxygen content in either the gas or water phase
- degree of saturation with water
- chemical activity of Fe^{3+}
- surface area of exposed metal sulphide
- chemical activation energy required to initiate acid generation.

Bacterial activity is also an important aspect in acid generation. The sulphur-oxidising bacterium, *thiobacillus thiooxidans* and autotrophic bacterium (*thiosulphate* or *tetrahionate*) uses inorganic sulphur as a source of energy and produces sulphate which is finally converted to sulphuric acid. *Ferro bacillus, ferro oxidants* and *thiobacillus ferrooxidans* are also responsible for acid formation. Loos (1998) and Cleghorn (1997) provides a more detailed account of bacterial action

Both chemical and biological reactions are responsible for the formation of acid mine water and could occur in almost any mine where oxidizable sulphur comes in contact with air and water. The soil cover design should ultimately prevent either one of these components to enter the discard material and thereby preventing or limiting AMD.

2.2. CONTROLLING ACID MINE DRAINAGE

2.2.1. General

The objective of controlling acid generation is to reduce the rate of acid formation at source by inhibiting sulphide oxidation. This could be done by excluding one or more of the main components of the process, or by controlling the environment to impede acid forming processes. Chemical reaction for acid formation cannot proceed if any of these components are not present.

2.2.2. Elements in Controlling AMD

Sulphide Removal or Isolation

If sulphide minerals in the waste materials are removed, reduced to insignificant levels, or isolated by for instance a coating material, acid formation cannot occur. This is typically done by separating discard with the high pyretic content wastes from the other discard, thereby reducing the risk of the other waste of becoming acidic, and also reducing the area and volume of drainage that has to be dealt with. For coal spoils this is usually not a realistic option, since large volumes of the waste do contain sulphides.

Exclusion of Water

The main objective of this approach is to prevent any surface water from entering the sulphuric wastes. This can only be done by constructing an impermeable seal, such as synthetic liners. However, synthetic liners are prone to damage and deterioration with time, resulting in even less effective systems. Some researchers are of the opinion that exclusion of water to the extent that acid formation no longer exists, is not practical (SRK, 1989).

Exclusion of Oxygen

Although it is possible to form acid in anaerobic conditions, it has been shown not to occur easily (SRK, 1989). The exclusion of oxygen to the extent that acid generation is reduced to significantly low levels required the placement of a cover with extremely low oxygen diffusion characteristics. The exclusion of oxygen from wastes is seen by many researchers to be the most effective solution for long-term acid prevention. However, as with water ingress, no soils are impermeable to oxygen influx.

Oxygen is consumed and carbon dioxide is generated by the metabolic activity of micro-organisms and plant roots in the soil. Oxygen, carbon dioxide and water vapour all diffuse into and out of the soil. Well-aerated soil comprise typically of 79% N_2. The remaining 21% comprise mostly of O_2 with CO_2, comprising 0.24%. In poorly aerated soil, O_2 levels can approach zero.

The absorption of nutrients by roots, and the beneficial activity of micro-organisms depend on an adequate supply of oxygen. Soils should therefore be managed to provide adequate aeration. In order to sustain vegetation. Campbell (1995) has shown that O_2 levels below 10-15% can inhibit plant growth.

The rate of respiration of living organisms in the soil depends mainly on the availability of oxygen and carbon dioxide in the soil, with soil temperature and soil moisture being important aspects. Maximum oxygen consumption occurs when organic matter is incorporated into moist, warm soil. Respiration rates in winter are often suppressed because of low temperature and low oxygen concentration. In the summer, low soil water potential may inhibit respiration. Respiration rates are usually highest in spring months when roots are growing rapidly, root exudates are plentiful for micro-organism growth, and moisture and temperature conditions are favourable.

Oxygen concentrations in discard material were shown to decrease soon after the installation of a compacted clay cover over pyretic waste rock dumps in the Rum Jungle Mine in Northern Australia (Bennet *et al*, 1988). Before rehabilitation, a tongue of high oxygen concentrations was evident, indicating that thermal convection was transporting oxygen from the sides and up through hot regions within the discard dumps. After rehabilitation, the oxygen concentrations were low. The clay cover has effectively halted oxygen influx by thermal convection, and greatly reduced diffusion and atmospheric pressure-driven advection.

However, after the covers had been in place for about a year, the oxygen concentrations in the top few metres were found to increase in mornings and the evenings of the wet season. This behaviour is characteristic of advection processes driven by variations in atmospheric pressure. In contrast oxygen concentrations are higher in dry seasons with no diurnal variation. This suggests cracking of the clay layer in the dry season, which provide paths for advection of air by atmospheric pressure variations. Diurnal variations in the oxygen concentrations early in the wet season indicate that most of the cracks close as the moisture content of the clay increases. Further monitoring proved that oxygen concentrations at depth in the dumps continued to be low after rehabilitation.

Aziz & Ferguson (1997), using sub-surface oxygen probes, have shown that the oxygen concentration below a cover of uncompacted till overlying uncompacted till decreased markedly with time, confirming that the cover succeeded in part to reduce the oxygen influx.

Yanful (1993) conducted a number of experiments in Canada where soil covers were tested for effectiveness of oxygen reduction. **Table 2.1** summarises the findings of his work.

Table 2.1: Laboratory Cover Experiments In Quebec, Canada (Yanful, 1993)

Site	Layers (top to bottom)	Period of Data (days)	Diffusion Coefficient ($m.s^{-1}$)
Heath Steel, Newcastle	Natural till	65	8.3×10^{-8} to 6.2×10^{-6}
Waite Amulet, Rouyun-Noranda (Laboratory)	0.15m fine sand 0.30m varied clay 0.15m coarse sand	65	3.9×10^{-9} (clay)
Waite Amulet, Rouyun-Noranda (Field-scale)	0.30m coarse grained layer 0.60m fine grained layer 0.30m coarse grained layer	60	9.9×10^{-9} (clay)

The diffusion coefficients for high saturation conditions are the most important aspects, since it is a required design parameter for effective covers to reduce the oxygen influx into sulphuric mill tailings. Placement of the cover at a high water content and close to the maximum compaction density ensures a reasonably low hydraulic conductivity that would reduce infiltration and oxygen influx into the discard material.

Nicholson *et al* (1989) reported that the most important aspect of a potential soil cover material is the percentage fine material. High percentages of fine material are related to high air-entry pressure heads.

Bussière *et al* (1997) conducted column studies to assess the performance of cover materials based on oxidation rate. They confirmed that the placement of multi-layered covers constructed of desulphurised tailings on acid generating tailings, reduced the oxidation influx by up to a factor of 20. The degree of desulphurisation obviously affected the cover effectiveness, where the cover with the highest concentration of sulphur performed the worst.

Delaney *et al* (1997) reported of two different soil covers used at Bersbo Mine in Sweden, which has been monitored since 1989. A definite decrease in oxygen concentration has been measured.

Farquharson & Marais (1994) reported results of an experiment on the Grootgeluk Mine middlings (waste material) in South Africa. Air permeability measurements of middlings were conducted. In the case of compacted wet of field capacity middlings no air influx was observed. However, in the case of non-compacted soils, air permeability has not been significantly reduced.

Temperature Control

A permanently frozen water body would ensure no acid generation. However, this approach is not feasible in South Africa.

The oxidation of pyrite to sulphuric acid and ferrous sulphate is exothermic and releases significant amounts of heat. The released heat causes elevated temperatures in the region where pyretic oxidation is occurring. Bennet *et al* (1988), reported a case of waste rock where heat production was occurring.

After rehabilitation, comprising of a three layer cover, (225 - 300mm compacted clay, 250 - 300mm sandy clay loam, and 150mm gravelly sand) heat production was either very low or zero. Comparison of heat production distributions before and after rehabilitation showed that oxidation occurring before rehabilitation was effectively halted by rehabilitation. A similar observation was made by Aziz & Ferguson (1997), using a 300mm uncompacted till layer overlying a 500mm compacted till layer. As the amount of oxygen concentration below the cover decreased, lower temperature have been recorded.

Jelinek (1995) reported that soil temperature measurements down to a depth of 6m, below surface, showed moisture transport by vapour diffusion from the capillary block upwards into the capillary layer of the cover. The upward transport is likely to be of the same order as the expected downward gravity driven flow. A high temperature in the waste body could contribute to the sealing effect of the clay border, especially during the wet and cold seasons of the year.

pH Control

If the pH of the water in the waste can be maintained in the alkaline range, acid formation would be inhibited. This can be done by adding alkaline materials to the waste body or by placing a pervious alkaline cover, so that leachate from the discard dump can be neutralised.

Bacterial Action

In the case of a pH of 4 with in the discard dump bacterial oxidation increases the acid forming process at least 5 fold. This is mainly due to the actions of *thiobacillus ferrooxidans*. Anionic surfactants like sodium lauryl sulphate, organic acids and food preservatives (these are all called bactericides) have been used to control bacterial action.

2.3. MITIGATION MEASURES

2.3.1. Conditioning of Waste

If the sulphides can be isolated or contained, acid formation would never occur. In coal discard this approach is not as applicable as in the case of tailings material. If the coal discard can be place systematically in a managed way, to achieve a uniform deposit with maximum density and minimum segregation results in minimum permeability in respect of both air and water. The standard method of placing coal discard in compacted layers of typically 300mm and compacting well to avoid the possibility of spontaneous combustion, would at the same time serve the purpose of reducing the permeability of the discard material and thereby reduce the rate of acid formation. This also result in less steep slopes and traficability on the dump is greatly improved.

Waste Segregation and Blending

Waste segregation involves the removal and separate handling of wastes of the crushing site. The benefits of this process is firstly minimisation of the waste volume that would generate acidic drainage and secondly, waste containing carbonate can be blended with the acid generating waste, and thereby ensuring neutralisation potential be larger than acid forming potential. This practice proved to be effective in the USA and Canada (SRK, 1989).

Blending of acid generating and acid consuming waste implies that water is required to obtain the neutralising effect. However, increased salinity will still occur, possibly enhanced by blending. As collieries normally do not have abundant supply of carbonate waste, this option could be cost intensive, especially if material has to be imported.

Bactericides

As bacteriological growth can increase the rate of acid formation, bactericides are used to create toxic environment for the bacteria thereby limiting bacteria populations resulting in that the rate of acid formation can be reduced. Bactericides will not prevent acid formation though. Research on bactericides are fairly advanced, all showing 50 - 95%, effectiveness in the short term (SRK, 1989). Bactericides does not remain effective indefinitely, as they degrade and are removed by percolating water.

Usually, bactericides are applied to the surface of the waste body by means of a spray on hydroseed system, or by spreading rubber pellets, which times the release of the bactericides. This approach remains a temporary and costly way to reduce the rate of acid formation.

2.3.2 Base Additives

By adding excess neutralising material, particularly carbonate and hydroxide, compounds, neutral to alkaline pH can be obtained by means of neutralisation. Common additives include limestone ($CaCO_3$), lime (CaO) and sodium hydroxide (NaOH). The success of these additions depends mainly on:

- the movement of water through the system
- the nature of contact with the acidic waste
- proportion of excess neutralising material
- the type and purity of the neutralising additive.

The movement of water is the most important aspects and the flow rate of water should be slow to give the neutralising agent opportunity to be absorbed, otherwise the source could be depleted too soon. The nature of contact of the neutralising additives with the acid forming material can be as follows:

- additive lies above the source of acid generation, i.e. on top
- additive is mixed with the acid source, i.e. blending
- additive is below the acid source.

If topsoil is unavailable, the cost of transporting is prohibitive, or the topsoil is simply unsuitable for rehabilitation, then subsoil, overburden, waste rock or similar materials have to be used as substrate for vegetation. This material should be treated to ensure that acceptable organic content and nutrient levels are reached, if a vegetative cover is required (Environmental Protection Agency, 1995).

Chiado *et al* (1988) reports on the successful application of a phosphatic clay slurry as a cover for acid producing spoils in West Virginia, USA. The phosphatic clay comprised mainly of aspetite and smetic clay minerals, which are waste products of fertiliser production. The montmorrilonite in the slurry provided the first line of defence in the form of a hydraulic barrier, and any water that does flow through would be neutralised, effectively halting acid mine drainage.

Laboratory and field studies have shown that blending soil with sewage sludge, and the use of biofilters, including myconrhizae, can restore spoil fertility successfully (Juwarkar *et al*, 1994; Maiti &

Banerjee, 1994). This is supported by Norton (1988) who states that sewage sludge is a potential good cover as it exhibits high moisture retention characteristics properties and release nutrients slowly.

It has been well documented that alkaline wastes should be used to cover acidic spoils. Where possible, pyretic spoils should be placed below the groundwater surface (Barth *et al*, 1988; Bell, 1988). Bell (1988) reports that a 300mm layer of limestone will inhibit acid formation in the top 3m of spoils, effectively arrest acid formation. However, this confidence is not supported by other researchers who prefers soil covers in excess of 600mm above ameliorates such as lime, limestone or sludge.

Murray *et al* (1988) reports on laboratory experiments in Halifax, Nova Scotia, Canada, where pyretic slate was covered with a topsoil and clay cap overlying a salt layer. The purpose of the salt was to neutralise acid formation through bacteriostatic activity. This salt, supplemented by the clay cover resulted in an initial decrease acidity levels of acidity and heavy metal concentrations. In addition, a gradual decrease in leachate volume with time has been observed.

The United Kingdom has formulated a guiding standard in respect of soil cover design of metal wastes (Bell *et al*, 1984). The soil cover should comprise of a three-layer system varying in thickness of 300 - 500mm. Besides a sealing and capillary barrier, the guidelines also require a chemical barrier, which should neutralise any leachate flowing through the waste.

2.3.2. Covers and Seals

The purpose of covers and seals are to restrict the ingress of oxygen and water into the waste. The cover should have a low permeability and have no imperfections. The resistance of the cover to cracking, the borrowing effects of roots and animals, erosion and degradation due to weathering and frost action would determine the long-term effectiveness of covers.

Various materials can be used as covers or seals, depending on the availability of covering material and site conditions. These include natural soils, synthetic membranes, water, and a combination of the above such as saturated soil or bog. Other synthetic materials such as asphalt and concrete can also be used. However, given the usual large areas, this would be the exception rather than the rule.

The most effective means of excluding oxygen influx into discard material is by means of a water cover, since the solubility of oxygen in water and the diffusion rate of oxygen through water are both very low. The main objective is to place the waste material in such a way, so that it is permanently covered with water. This approach will generally not be feasible in water-poor countries such as South Africa.

An alternative to this approach is to create a system where the soil cover will be permanently saturated. This could be done by artificially damming water over the waste area thinly covered with soil. In the event of a drop in the water level, the soil would still act as a cover minimising the acid generation process.

The more traditional covers such as soil covers and synthetic membranes will be discussed in the following sections.

2.4 SYNTHETIC COVERS

Synthetic membranes such as polyvinyl chloride (PVC) and high-density polyethylene (HDPE) could be used as covers with extremely low permeability to both water and oxygen. This has been shown to be a good mid-term solution, although costly. However, long-term degradation could result in the effectiveness to be significantly lower.

2.4.1 Geomembranes

Geomembranes such as polyethylene (PE), high-density polyethylene (HDPE), polyvinyl chloride (PVC) and butyl rubber are flexible membrane liners. The main advantages its ability to minimise seepage and resistance to chemical and bacteriological deterioration. Permeabilities of 1 x 10^{-10} cm/s and less have been reported (SRK, 1989).

The major disadvantage in using geomembranes is its susceptibility to damage during installation and maintenance. This can be prevented by proper subgrade preparation and construction. The membranes are also susceptible to tearing resulting from large settlement and differential deformations in the subgrade. Similar problems can be encountered when the membrane is placed close to the surface, where excess hydrostatic or gas build-up could put stress on the membrane.

Membranes are usually nearly impermeable, with seepage occurring through deflects such as, tears and punctures. Geomembranes are therefore usually used in combination with a complex soil cover to act as a barrier layer.

Geomembranes are not often used when covering pyretic wastes, but is frequently used in landfill cover design. The hazardous toxic pollutants associated with landfills warrant an impervious seal, against water infiltration and gas migration. The pollution threat associated with a pyretic discard dumps does not warrant such extreme and expensive rehabilitation measures

Rollin *et al*, (1993) reported on the successful use of a 1.5mm thick high-density polyethylene (HDPE) textured geomembrane sandwiched between two thin layers of sand to prevent puncturing during installation. The layer was covered by a sand and gravel layer (150mm) to act as drainage layer, and a topsoil layer of 300mm.

The United States Environmental Protection Agency (USEPA) has set requirements for the design of final covers for hazardous- and municipal waste sites. These require that, in addition to topsoil and drainage layers, a barrier layer of extremely low permeability have to be placed on top of a 0.5mm geomembrane (Wallace, 1993).

2.4.2 Asphaltic and Spray-on seals

Asphaltic and spray-on seals are very seldom used to cover mine waste. Surface sealants can be formulated as either flexible or rigid linings or covers. They are placed *in situ* by a chemical covering process, heat application or using a surface drying effect. These seals can be designed to withstand design loads of vehicular traffic and does not generally degrade with time.

Spray-on seals do not have disadvantages associated with geomembranes, namely structural deficiency at the joints leaking occur at areas not sufficiently covered during construction. Researchers measuring radon flux through asphaltic seals, have proved that the covers are highly effective in reducing the flux and due to its low permeability (10^{-20} m/s) (SRK, 1989).

2.4.3 Geopolymers

Geopolymers is a compound of minerals, containing silica, phosphate and oxygen, which bond to form a ceramic type product. Little is currently known about geopolymers, but the objective is that it would be mixed with the waste product to form a solid mass which would prevent oxygen and water ingress into the waste (SRK, 1989).

2.4.4 Shotcrete

Shotcrete is pneumatically delivered through a hose at a high velocity. One of the major drawbacks of this technique is its susceptibility to cracking due to waste settlement and consolidation. This drawback can be overcome by using steel mesh in combination with the shotcrete, but this increases the already expensive procedure. Another drawback of this method is its poor resistance to chemical attack and care has to be taken to ensure that the correct mixture of additives is added to the shotcrete. This expensive sealing technique is not used in the mine industry.

2.5. SOIL COVERS

Contaminants are mainly transported to the groundwater regime by means of advection processes. By placing low permeable soil covers, recharge through the discard dumps can be significantly reduced. While soil covers show promise as oxygen inhibitors, they have traditionally been applied to limit infiltration. Climate, design and construction are important factors affecting the efficiency of soil covers.

2.5.1 Simple Covers

Since soil covers needs to be cost effective, single layer soil covers are preferred. A fine textured soil, such as clay or silt, is required to limit infiltration and oxygen influx.

Simple, single-layer soil covers are prone to large seasonal variations in moisture content. This could result in desiccation cracking and subsequent increased permeability. Similarly, the decrease in moisture content results in an increase the oxygen diffusion rate. Since seasonal changes are most prominent near the surface, thin soilcover is most susceptible to desiccation cracking. Single soil covers therefore need to be of appropriate thickness to maintain a saturated zone throughout the dry season. In regions such as British Columbia, Canada, this minimum thickness is 2m (SRK, 1989). Given the seasonally of South African rainfall, it is unlikely that a saturated zone can be maintained throughout the dry season.

Bews *et al* (1997) reported that, in selecting a single fine soil cover, it should not be compacted, to provide higher porosity and storage capacity. This could be advantageous in a semi-arid climate where the soil cover should retain as much water as possible to ensure that the cover does not dry out during the dry season. However, rainfall could flow preferentially along large pores during high intensity rainfall events.

Simple covers can not prevent moisture moving upward from underlying waste by capillary action, with the exception of coarse grained waste. As such, it might not prevent salts from migrating upwards through the cover to the surface by evapotranspiration processes.

However, since many single layer soil covers are covered by topsoil, designers believe that it could mitigate against these processes. Examples of this technique include the Collinvale coal mine in Australia where rehabilitation comprised of placing a 1000mm layer of inert material and a topsoil layer on the waste material. Pulles *et al* (1996) also reported on a similar methodology adopted at Hunter Valley coal mine in Australia. The choice of cover was based on the post-closure land use. In low land use areas, a single topsoil layer was seen to be sufficient as final cover, while in high land use areas, a topsoil was placed over 1200mm inert soil cover material.

Another limitation of single layer covers is that they may not adequately resist wind and water erosion or burrowing and root action. Some vegetating or rip-rap is required as erosion protection.

In countries where extremely cold weather is experienced, fine-grained soils might be frost susceptible. The subsequent ice segregation could result in increased soil cover permeability due to soil cover degradation.

Abundant examples of where simple soil covers have been applied are mentioned in literature: Thompson *et al* (1997), describes the use of a 100mm clay soil (till) used to cap the waste dump Caminco's Sullivan Mine in Canada. The waste residue originates from lead, zinc and silver mining. The bottom half of the till has been compacted to between 90% and 95% of Mod AASHTHO, while the top half was placed loose to allow it to be seeded with legumes and grass. However, no records of the actual soil cover performance have been provided.

A similar cover comprising of 1000mm uncompacted till over a back-filled opencast pit at the Equity Silver mine, Canada, has been replaced by a two-layer cover. A 40% recharge has been measured through the cover. The two-layer soil cover comprised of 500mm of compacted till overlying 300mm of uncompacted till, which provided as a growth medium for legumes and grasses. Long-term tests using lysimeters indicated recharge through the new cover of less than 5% (Aziz & Fergusson, 1997).

Legislation in Germany forces soil cover designers of municipal solid waste sites to use clay covers with a permeability that may not be more than 5×10^{-12} cm/s (Münnich, 1993). The Alaskan Department of Environmental Conservation (ADEC) regulations stipulates that a final landfill cover must have a minimum topsoil layer of 150mm overlying a "low permeability" fill material (Cabalka & Newton, 1998)

2.5.2 Complex Covers

Due to the limitations associated with single-layer soil cover design, a complex soil cover comprising of several layers, each performing a specific function has gained credibility in limiting infiltration and oxygen influx.

<u>Erosion Control Layer</u>

Erosion protection can be provided by vegetation or by a layer of coarse gravel or rip-rap. Environmental conditions generally favour the use of vegetation.

Most researchers are in agreement that vegetation should be re-established on rehabilitated spoils, and a great deal of laboratory and field expertise have been gained in this regard. This report will not attempt to discuss extensively on the establishment of vegetation, but will rather discuss the effect that vegetation in soil cover performance

Atkinson & Mitchell, 1994 reported that without a vegetative cover, the sulphides in the spoils would oxidise thereby producing sulphuric acid and water-soluble metal sulphates (Atkinson & Mitchell, 1994).

A number of researchers (Bell, 1988; La Gory *et al*, 1988; Environmental Protection Agency, 1995) reported that direct vegetation on reactive tailings or pyretic waste does not restrict pyrite oxidation, nor does it limit water infiltration, and most often does not germinate at all, due to the hostile conditions.

Anglo American Corporation, (1986) established a research programme in 1980 to provide criteria for depths of soil for crops and pastures on rehabilitated opencast mines. The results showed that maize and stover performed best with 400-600mm of topsoil, and that after 800mm no additional benefit was gained. Sorghum performed best at with 700mm, topsoil while pasture was the least affected by topsoil thickness, performing best at 400mm of topsoil.

Similar experiments were undertaken at an abandoned coal mine, 10 years after initial rehabilitation, in Staunton, Illinois, USA (LaGory *et al*, 1988). The effects of different soil cover thickness and liming rates were tested. Soil thickness appeared to have a greater effect on vegetative cover than did the lime application rate. Plots with a 600mm soil cover had the highest percentage of vegetative cover. Liming rate had no impact at this depth. On plots with only 300mm of soil cover performed better with a higher lime application rate. A 600mm cover also performed better during dry years due to its higher water retaining ability.

The penetration of deep roots of surface vegetation into the barrier layers can cause preferential flowpaths, leading to increased leachate production (Knox & Gronow, 1993). The USEPA suggested that a biotic barrier of at least 300mm of cobbles be used to prevent this phenomena (Wallace, 1993). They further require a soil cover capable of sustaining vegetative growth, of at least 600mm and 150mm for hazardous and municipal waste sites respectively. Bell *et al* (1984) that biotic barriers will reduce deep root penetration. Bell *et al* (1984) reported high metal uptakes by plants established on a clay cover placed on metallic rich wastes. This occurs because of roots penetrating through the clay cover into the waste body, or because of upward metal transport into the clay where roots could continue the uptake.

Another important role of vegetation is the removal of potential leachate by means of evapotranspiration. Nyhan *et al* (1990) reported that between 88% and 96% of precipitation received was lost by evapotranspiration in experiments on covers in Los Alamos, USA. In a soil cover experiment in Hamburg, Germany, Melchior *et al* (1993) reported that over a three year period 64% of the average precipitation was lost due to evapotranspiration.

Moisture Retention Zone

The moisture retention layer has two purposes namely to keep the infiltration/oxygen barrier moist, and thereby preventing desiccation cracking while also reducing oxygen diffusion. Secondly, by retaining moisture after a precipitation event, it supports vegetative growth and allows time for evapotranspiration to occur, thereby reducing infiltration. Typically a loamy soil with a large sand fraction will be used for this layer.

Upper Drainage/Suction Breach Layer

The purpose of the upper drainage layer is to drain water that could build up at the contract of the barrier layer. In addition, it prevents moisture loss from the barrier layer occurring due to upward moisture movement, thereby reducing the risk of desiccation cracking. In the case of the layer comprising of large gravel, it could further reduce the effect of burrowing animals.

The capillary barrier comprises of an upper, fine particle layer (capillary layer) and a lower, coarse particle layer (capillary block). The sealing effect of a capillary barrier derives from the unsaturated flow of water in the capillary layer that resulting in capillary forces retaining the water in the fine particle layer. Due to the low unsaturated hydraulic conductivity of sand at low moisture contents the capillary block remains almost dry. Limited amounts of water percolate into the capillary block, and further into the waste body. The capillary barrier will only be successful provided it exceeds hydrostatic pressure, and a suitable gradient ensures lateral water drainage. Since the capillary barrier is sensitive to hydraulic overload caused by high intensity precipitation, it need to be protected by a water balancing layer of loamy material to reduce infiltration intensity into the capillary layer. The layer of loamy material will increase soil-moisture storage capacity of the systems and this water can be removed by evaporation. Grain-size distribution, rate of flow, gradient and length of slope as well as lateral flow rate are all-important factors in considering this alternative. In the case of coarse grained coal discard, the discard material could act as a capillary block.

The long-term effectiveness of the capillary barrier could be jeopardised by plant roots clogging, or organic debris and fines entering the capillary block. Significant settlement could also affect drainage.

Capillary barriers are a useful alternative to landfill, tailings and spoils covers due to their high resistance to thermal and mechanical (desiccation and settlement) effects, which are often only visible after a significant time period after initial placement of the cover (Megges *et al*, 1995). However, capillary barriers are not impermeable to oxygen influx and therefore allow oxygen migration, which is not advantageous if covering pyretic wastes.

Megges *et al* (1995) reported that the optimum thickness for the different capillary layers should be; 400mm for the capillary layer, and 300mm for the capillary block. Both the sand used for the capillary layer and the gravel used for the capillary block should be well graded. A minimum slope gradient of between 1:10 and 1:5 is recommended.

The University of Dormstadt undertook field research into five different covers for two landfill sites, in Frankfurt and Marburg, Germany (Jelinek, 1995). All the covers comprised of capillary barriers. The results are reported in **Table 2.2.**

The results showed that flow rates through the water balancing layer to be low (0.5mm/*d*), compared to flow through the capillary layers. Discharges measured from the capillary block showed a rapid decline in flow rate after short hydraulic overloads caused by heavy rainfall, resulting in the saturation of the balancing layer.

The compacted soil layer underneath the drainage and water balancing layers significantly reduced the discharge to the capillary block in Testfield 2. The reduced lateral hydraulic conductivity in Testfield 3 caused a high hydraulic to develop within the compacted soil layer resulting to higher capillary layer discharge.

Table 2.2 : Marburg And Frankfurt Test Sites (Jelinek, 1995)

Site	Layers (top to bottom)	Slope	Period of data (mths)	Rain (mm)	Percolation Rate	
					Peak (mm/d)	Annual (mm/yr)
Marburg Testfield 1	2.0m water balancing (WB) 0.4m capillary layer (CL) 0.3m capillary block (CB)	1:3.5	36	No data	WB - 0.6 CL - 2.5 CB - 2.5	WB - 40 CL - 220 CB - 3
Frankfurt Testfield 1	2.0m water balancing (WB) 0.4m capillary layer (CL) 0.3m capillary block (CB)	1:5	12	517	WB - 0.4 CL - 1.75 CB - 0	WB - 10 CL - 16 CB - 0
Frankfurt Testfield 2	1.3m water balancing (WB) 0.4m drainage layer (DL) 0.6m compacted soil (CS) 0.4m capillary layer (CL) 0.3m capillary block (CB)	1:5	12	517	CS - 2.5 CL - 0.2 CB - 0	CS - 150 CL - 2.5 CB - 0
Frankfurt Testfield 3	1.7m water balancing (WB) 0.6m compacted soil (CS) 0.4m capillary layer (CL) 0.3m capillary block (CB)	1:5	12	517	CS - 0.25 CL - 1.0 CB - 0.1	CS - 40 CL - 60 CB - 0.4
Frankfurt Testfield 4	1.7m water balancing (WB) 0.4m capillary layer - upper (CLu) 0.3m capillary block - upper (CBu) 0.4m capillary layer - lower (CLl) 0.3m capillary block - lower (CBl)	1:5	12	517	WB - 0.1 CLu - 1.7 CLl - 0.3 CBl - 0	WB - 0.4 CLu - 75 CLl - 0.6 CBl - 0

No significant differences between Testfields 1 and 4 were observed. Water flowing from the upper capillary layer to the upper capillary block, flowed directly into the lower capillary layer, most of these water was drained. It can be concluded that unless a collection system, are in place, a double capillary barriers hold no additional benefit.

Experiments regarding soil covers on sulphuric mill tailings (Yanful *et al,* 1993) have shown that a compacted clay layer placed between sand layers, prevented the clay from losing moisture due to evaporation and drainage.

Infiltration Barrier

The purpose of this layer is to prevent downward ingress of moisture and oxygen into the waste. The lower the permeability of this material, the more effective is the barrier, and therefore the barrier usually comprises fine-grained soils or synthetic materials. This layer provides a barrier while upper drainage layer ensures that lateral drainage can occur, thereby preventing hydraulic overloads.

Lower Capillary Barrier

In the case of soil covers placed on fine-grained waste deposits, such as tailings, a capillary barrier beneath the infiltration barrier could prevent upward movement from the tailings up into the cover during dry periods. The long-term efficiency of this layer is subject to the degree fines can be prevented entering this layer.

Basic Layer

Another attempt to neutralise the effect of water passing through the soil cover into the waste is to place a basic layer comprising of acid reducing material on the surface of the waste. Alkaline materials such as lime would then neutralise the acid formed in the waste material. However, the acid reducing material could be leached out of the system long before acid is being produced.

2.6. SOIL COVER EFFECTIVENESS

A study of cover effectiveness for simple covers was conducted by Steffen Robertson & Kirsten in 1987 (SRK, 1989). These results which were calculated using a computational model can be summarised in **Table 2.3**. However, no field experiments were conducted to verify these results.

Table 2.3: Cover effectiveness as calculated for different waste types

Cover Type	Thickness	Outflow Reduction
Waste rock (inert)	0.6m	22.5%
Depyritized tailings (soil)	2m	72.5%
Depyritized tailings and limestone (soil)	2m	89.7%

Another study regarding simple covers was conducted by Wates and Rykaart (1994), the results of which are shown in **Table 2.4**. Again, these results have not been verified.

Table 2.4 : Recharge rates for particular homogeneous soil covers

Soil Cover	Permeability (cm/sec)	Recharge rate	
		Without vegetation	With vegetation
Coal spoils (1 000mm)	2.9×10^{-3}	74,6%	35,2%
Loam (1 000mm)	2.3×10^{-5}	49,0%	24,1%
Clay (1 000mm)	7.1×10^{-6}	11,0%	1,1%
Layered (300m loam, 7 000mm clay)		24,1%	12,7%

Additional analyses have been conducted, and the effect of soil layers of varying thickness was recalculated. See **Table 2.5**.

Table 2.5 : Recharge rates for a soil cover configuration with varying thickness

Configuration	Recharge rate	
	Without vegetation	With vegetation
0 cm loam – 100 cm clay	10,3%	0.2%
10 cm loam - 90 cm clay	19,9%	3,0%
20 cm loam - 80 cm clay	22,2%	12,4%
30 cm loam - 70 cm clay	24,1%	12,7%
40 cm loam - 60 cm clay	26,2%	12,7%
50 cm loam - 50 cm clay	27,6%	12,3%
60 cm loam - 40 cm clay	39,2%	12,2%
70 cm loam - 30 cm clay	30,4%	12,6%
80 cm loam - 20 cm clay	31,6%	13,3%
90 cm loam - 10 cm clay	41,5%	18,9%
100 cm loam - 0 cm clay	48,6%	24,5%

The HELP model was applied to evaluate for acid generating tailings at Elliot Lake and the results indicated considerable benefits of a complex cover design compared to simple covers. Considerable benefit could be attained by adding a synthetic liner. The results of this study are shown in **Table 2.6.**

Table 2.6 : Effect of cover type on the infiltration rate (SRK, 1989)

Cover	Permeability (cm/s)	Thickness	ET	Seepage	Runoff
No cover - no grass	6×10^{-5}		63.5%	17.5%	19%
No cover - fair grass	6×10^{-5}		73.6%	17.4%	9%
No cover - good grass	6×10^{-5}		77.1%	19.6%	3.3%
Low permeability Till soil - fair grass	2×10^{-6}	1m	59.1%	1.3%	39.6%
High permeability Till soil - fair grass	1×10^{-4}	1m	69.8%	25.2%	5%
Rip-rap	1×10^{-2}	0.5m	60.8%	37.8%	1.4%
Cover Soil	1×10^{-4}	1m	70.9%		3.1%
Capillary Break	1×10^{-3}	0.3m			19.4%
Barrier Soil	1×10^{-7}	1m		6.6%	
Rip-rap cover	1×10^{-2}	1m	61.8%		1.4%
Capillary Break	1×10^{-3}	0.3m			31.4%
Barrier Soil	1×10^{-7}	1m		5.4%	
Cover soil – fair grass	1×10^{-4}	1m	61.4%		3.1%
Capillary Break	1×10^{-3}	0.3m			35.5%
Liner	-				
Barrier Soil	1×10^{-7}	0.6m		0.1%	

The water balance and long-term performance of different soil covers (for a landfill site in Hamburg, Germany) have been monitored for a five-year period, and are reported by Melchior *et al* (1993). The results are shown in **Table 2.7.**

Table 2.7 : Georgewerder landfill site, Hamburg, Germany (Melchior *et al, 1993)*

Site	Layers (top to bottom)	Slope	Period of data (mths)	Rain (mm)	Peak percolation rate ($mm.d^{-1}$)
Testfield 1	0.75m topsoil and vegetation 0.25m drainage layer 0.60m compacted glacial till	1:5	60	830	1988 = 0.0 1989 = 0.1 1990 = 0.2 1991 = 0.3 1992 = 1.5
Testfield 2	0.75m topsoil and vegetation 0.25m drainage layer 1.50m flexible HDPE geomembrane 0.60m compacted glacial till	1:5	60	830	1988 - 1992 = 0.1
Testfield 3	0.75m topsoil and vegetation 0.25m coarse sand/fine gravel 0.40m compacted glacial till 0.60m fine sand	1:5	60	830	1988-1992 = 0.1

During the first three years, 64% of the average precipitation of 830mm were lost due to evapotranspiration. 34% lost by run-off, while recharge through the covers amounted to almost 2%. Even in the worst case, cover reduced leachate generation has been reduced to less than 6% of precipitation.

The compacted soil liners had performed well in 1988 and in the first half of 1989. However, the covers performed not as well following years. Peak leachate recharge suggested a saturated hydraulic conductivity of $2 \times 10^{-9} m.s^{-1}$ in 1990 and 1991, compared to $2.4 \times 10^{-10} m.s^{-1}$ in 1989. In 1992 this volume exceeded $5 \times 10^{-8} m.s^{-1}$. The observed flow pattern proved that continuous preferential flow paths occur in the cover, which allow rapid downward flow. Desiccation occurred during the summer, months. These cracks remained well into the rainfall season.

The volume of water flowing trough the waste material have been reported to be equivalent to 2.0 - 2.5% of the incident rain (Bennet *et al*, 1988; Gibson & Pantelis, 1988). This was calculated by ten lysimeters installed beneath the clay layer of a pyretic waste rock dump in Northern Australia. Measurements were made during the wet seasons between 1985 and 1987. In another discard dump with similar covered soil, the collected water amounted to 4.8% of the particular rainfall event. However, this only accounts for one wet season. Before rehabilitation it was estimated that about 50% of the incident rain peculated through these dumps. The cover had a total thickness of 600mm comprising of with loam and sandy gravel layers overlying the clay barrier and the top layer has been vegetated. Bennet *et al* (1988) also reported that it took at least four years before improved groundwater quality was observed.

A research program was established at the Sullivan Mine, British Columbia, Canada to select a most suitable soil cover for the reactive tailings waste (Gardiner *et al*, 1997). The results of the field study are indicated in **Table 2.8.**

Table 2.8 : Sullivan Mine, British Columbia, Canada (Gardiner *et al*, 1997)

Site	Layers (top to bottom)	Year	Rain (mm)	Outflow (mm)	Recharge (5)
Plot 2	0.35m uncompacted till 0.25m compacted till 0.20 – 0.60m float rock	1995	608	10	2
Plot 2	0.35m uncompacted till 0.25m compacted till 0.20 – 0.60m float rock	1996	620	40	6
Plot 3	0.45m uncompacted till 0.20 – 0.60m float rock	1995	608	49	8
Plot 3	0.45m uncompacted till 0.20 – 0.60m float rock	1996	620	174	28

The computer program, SoilCover, was used to determine the most effective soil cover for these two test sites. It was found that the recharge would remain less than 5% if compacted layers could be included. By increasing the thickness of the uncompacted till layer in plot 3 to 2100mm would result in lower recharge, but not less than 5%. In the case that the thickness of the compacted till layer are increased to 1650mm, low saturation conditions within the specified layer would be delayed, but not prevented. It would therefore reduce, but not prevent oxygen diffusion.

SoilCover was also used to assist in the Kidston Gold Mine, North Queensland, Australia to decide which soil cover would be the most effective in limiting recharge and oxygen flux. The first cover type comprised of 500mm compacted oxidised waste rock, being overlain by 1500mm of uncompacted oxidised waste rock. For the worst case scenario, i.e. very wet year, the predicted recharge never exceeded 4%. The second soil cover which comprised of 2500mm of uncompacted oxidised waste rock only, had a maximum infiltration of 5% (Bews *et al*, 1997).

Wilson *et al* (1996) have showed, by applying SoilCover that by placing a cover of 300mm of uncompacted till overlying 500mm of compacted till, infiltration could be reduced to less than 1% of the mean annual rainfall. This is compared to 60%, 68% and 78% outflow through uncovered waste material for low average and high rainfall seasons. A similar experiment was conducted at a second site where a soil cover of 600mm of topsoil overlies a 600mm of oxidised waste rock (oxide cap). The results of this experiment are shown in **Table 2.9.**

Table 2.9 : Possible outflow results for different waste site configurations and based on the results of SoilCover

Site	Dry year (MAP = 159mm)		Medium year (MAP = 263mm)		Wet year (MAP = 509mm)	
	Inflow (mm)	Recharge (%)	Inflow (mm)	Recharge (%)	Inflow (mm)	Recharge (%)
Uncovered	12.0	7.5	20.0	7.6	80	15.7
Covered Bare Vegetation	-	-	0.0	0.0	50	9.8
Covered – Good Vegetation	-	-	-	-	35	6.7
Covered – low permeability	-	-	-	-	0	0
Covered – high permeability	1.0	0.6	3.0	1.1	30	5.9

Wilson *et al* (1997), reported on the results of the soil cover research programme at Equity Silver Mine, British Columbia, Canada. The cover comprised of 300mm of uncompacted, vegetated till overlying 500mm of compacted till. For the period May to September, recharge through this cover was found to be almost 0% of the 380mm of rain recorded. 95mm was measured as runoff, 280mm was evaporated, leaving 5mm of recharge.

Field and laboratory tests proved that a maximum thickness of the clay layer to ensure minimum acid flux to be 300mm. Thicker layers are however used in the field as a safety factor against adverse climatic conditions such as freezing and thawing (Yanful, 1993). Nawrot *et al* (1988) reports that state legislation in Illinois, USA require a four feet soil cover for reclamation of recently inactivated coal processing wastes (gob and slurry).

In another experimental programme at Los Alamos, in the United States of America, Nyhan *et al* (1990) reported significant leachate reduction by introducing a complex six-layer cover design. According to Nyhan *et al* 88% of all precipitation has been lost by evapotranspiration on conventional plots, 96% have been lost with the improved design. Leachate generation was reduced from 6% to 2.6% of precipitation.

Research by Murray *et al* (1988) in Halifax, Nova Scotia, Canada, regarding the use of a salt supplemented clay cap. Reported monthly average unit discharges of between a high of $160m^3.mm^{-1}$ of rainfall prior to rehabilitation, to less than $40m^3.mm^{-1}$ after being rehabilitated for one winter season. After an extremely dry winter, discharges increased to between 60 and $80m^3.mm^{-1}$.

Pulles *et al* (1996) reported that a Mt. Leyson Gold Mine in Australia, a 100mm thick layer of compacted inert material reduced infiltration to less than 3% of rainfall, and it was observed oxygen ingress was also significantly reduced.

Recharge of between 50 and 60% through unrehabilitated discard have been reported by Anglo American Corporation (1986).

2.7 RECHARGE MEASURMENTS

Blight (1997) presented a graph where recharge was plotted for various waste, discard, landfill, ash and co-disposal sites throughout South Africa. The recharge is plotted against net rainfall is expressed as the actual rainfall (plus any irrigation) less 50% of the evaporation for that specific area. This graph is shown in **Figure 2.1.** This indicates recharge values can be estimated using only two simple climatic variables, i.e. rainfall and evaporation.

2.8. CONSTRUCTION OF COVERS

Construction of soil covers on mine sites is complicated by difficulties of access, traficability and the surfaces onto which the cover is to be placed. Coal discard is usually stockpiled, and depending on the age and construction of the stockpiles two distinctly separate sections can be identified i.e. the surface area, and the slopes.

Before continuing to the cover construction a quick overview of the dump construction techniques is required as they ultimately affect the cover design. AMD can be limited not only by cover design, but also by dump construction.

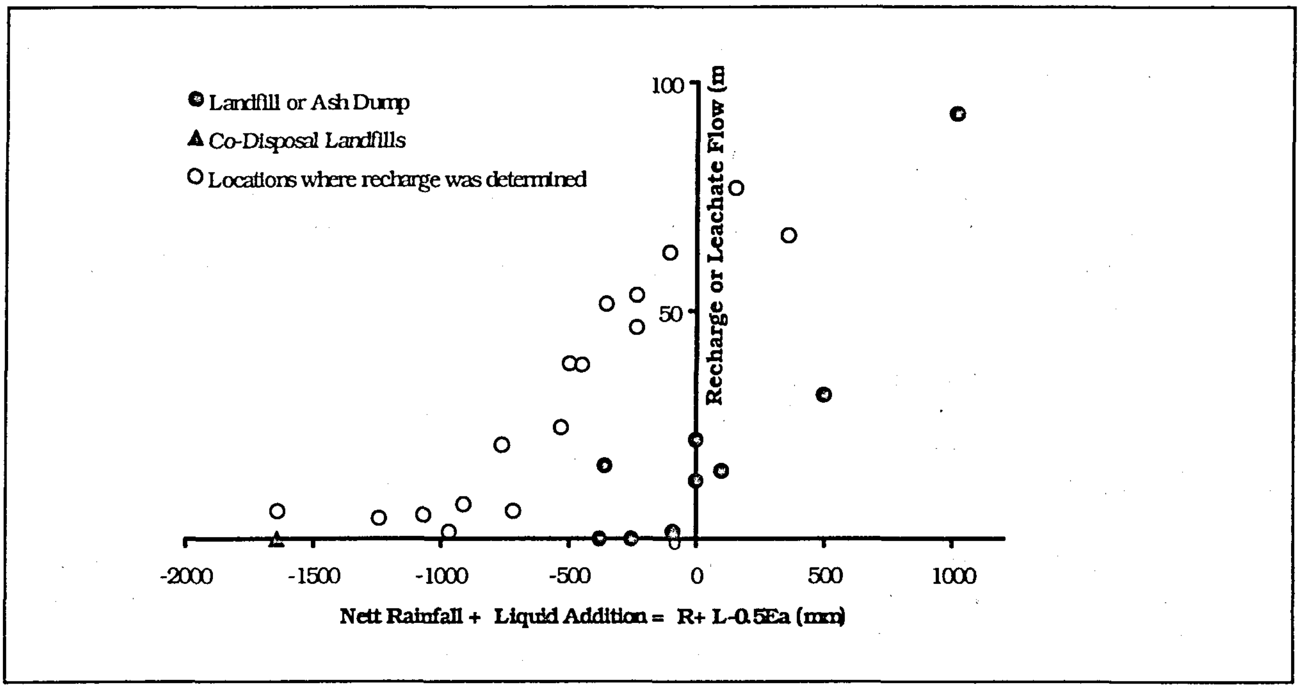


Figure 2.1: Recharge vs. climatic variables for selected waste disposal facilities in South Africa (modified after Blight, 1997)

Compaction of thin layers waste material, will reduce settlement, increase dump stability and reduce the permeability, thereby minimising the acid generating process.

Cellular construction could be considered, and the area exposed to precipitation could be significantly reduced. However this approach will only be beneficial during the construction period and not the post-closure situation.

Recharge through the waste material can be significantly reduced by mixing low permeable material with the waste, and acid formation can be prevented or delayed by adding non-acid generating material to the waste.

Existing coal discard dumps can be classified into two categories according to their design namely conveyor belt tipping technique, and the compacted layer technique.

2.8.1 Conveyor Belt Tipper Technique

In the past, discard dumps have been constructed by tipping waste on the dump by means of a conveyor belt. The conveyer belt moved progressively as the dump increased in height. These dumps are characterised by significant segregation of grain size, and because the waste was not compacted, the dumps are highly permeable and subject to spontaneous combustion. Placement of soil cover on such a dump is extremely difficult and could be prohibitively expensive, due to steep slope.

2.8.2 Compacted layer technique

Today coal discard dumps are constructed in layers of ± 300mm, which are well compacted. The dumps are shaped in a whaleback fashion to prevent steep slopes and be esthetical pleasing. Placement of soil covers on these dumps is much easier.

2.8. CONCLUSIONS

The findings of the literate survey can be summarised as follows:

- AMD can be limited by means of natural soil covers but can only be effective if either oxygen or water can be prevented from entering the pyretic spoils.
- Covers must have a low permeability and have no imperfections. The susceptibility of the cover to cracking, burrowing effect of roots and animals, erosion and degradation due to weathering and frost action determine its long term effectiveness.
- Low oxygen ingress in soils has been showed to inhibit plant growth. This occurs at oxygen levels below 10 - 15%.
- Compacted clay soil layers have been showed to be good oxygen inhibitors, but desiccation cracking could result in increased oxygen flux.
- In order to perform effectively as oxygen inhibitors, soils should have at high water contents and placed close to maximum compaction density.
- Single layer covers have been shown not to retain moisture, thereby resulting in desiccation cracking.
- Complex soil covers comprise of erosion control layers, moisture retention layers, drainage layers and/or capillary breaks. Complex covers have been shown to be effective in limiting ingress of water and oxygen. However, complex soil covers are more expensive then single layer soil covers.
- Erosion protection is traditionally provided by vegetation. Vegetation reduces recharge by removing soil moisture by means of evapotranspiration.
- Some researchers believe that vegetation could cause preferential flow and hence higher permeability due to root penetration, while others believe that the increased evapotranspiration could result in reduced infiltration by as much as 65%.
- The effectiveness of soil covers varies greatly. Reported recharge through covers range from as low as 1% to 60% MAP
- Well constructed layered and compacted discard dumps would assist cover effectiveness
- Some researchers suggest that recharge can be estimated using only two climatic parameters, i.e. rainfall and evaporation.
- The effectiveness of soil covers, in limiting ingress of water and oxygen into the discard material will mainly be a function of climate (in particular rainfall patterns), the physical soil properties of the soil cover and design on construction of the discard dump and soil cover.

3. PREFERENTIAL FLOW

Preferential flow is the process by which water and solutes move along preferred pathways through a porous medium (Helling and Gish, 1991). In the case of flow through the unsaturated zone, water and solutes bypass large parts of the soil matrix. Conventional convection equations may not be valid and water flow may be faster (or slower) than anticipated. In addition, monitoring devices, such as suction lysimeters, may be located outside (or inside) preferential flowpaths and may not give representative readings. Van Schalkwyk and Vermaak (1998) provided a literature review on the different preferential flow processes.

Preferential flow is in many cases an important aspect in flow of water through field soils. It may be the predominant aspect in groundwater recharge as has been shown by Van Tonder and Kirchner (1990) in their investigation of recharge in the Karoo area. Flury *et al* (1994) conducted field experiments on various soils in Switzerland to study the effect of preferential flow. Flury *et al.* stated that preferential flow is "the rule rather than the exception". In most soils, water bypassed a portion of the soil matrix.

Preferential flow is also an important determinant of the performance of clay liners and soil cover material. Since these structures are constructed of soils containing a high percentage of clay, preferential flow usually occurs due to flow through desiccation cracks, cracks formed due to freeze/thaw cycles and cracks formed in shrinking/heaving clays. Daniel and Koerner (1993) stated that several disadvantages are associated with clay barriers that "...make the long-term performance of a compacted clay liner questionable as a barrier layer in many cover systems". Major disadvantages are associated with the barrier layer not being adequately protected against desiccation resulting in preferential flow along macropores.

3.1. CLASSIFICATION OF PREFERENTIAL FLOW

The following types of preferential flow have been identified:

- Preferential flow in heterogeneous soil;
- Macropore channelling;
- Fingering;
- Funnelled flow;

Preferential flow in heterogeneous soils occurs due to the spatial variability in pore sizes. Little is known of these types of flow. Since soil covers are generally uniformly compacted, it is not anticipated that this type of flow will be dominant in soil covers.

Macropore channelling refers to the rapid movement of water and solutes along macropores, such as desiccation cracks and plant root holes. Due to the usually small thickness of soil cover materials, macropores might extend right through the soil covers resulting in rapid infiltration into the underlying material. Macropore channelling is one of the most important aspects to consider for compacted clay as covers or liners. (Daniel & Koerner, 1993).

Fingering refers to the finger-like flow of water in, usually, a sandy soil and is caused by the wetting front becoming unstable due to differences in pore water pressures within the profile. This process might also occur in the case of a low permeable material overlying a high permeable material. In the case of complex soil covers comprising of a clayey layer overlying a sandy layer acting as a capillary break, fingering flow may occur in the sandy soil thereby reduce the capillary break effect.

Funnelled flow refers to the funnelling of water on top of a more permeable soil layer or a less permeable layer, depending on the moisture content of the soil. Research by Miyazaki (1993) indicate that funnelling processes are closely linked to fingering processes in alternating low permeable/high permeable soil layers with funnelled flow along the interface of the two soil layers causing wetting front instability and fingering flow.

3.2. MACROPORE CHANNELLING

Macropore channelling refers to liquid bypassing the soil matrix via macropores. It may cause rapid movement of water through the soil, bypassing soil matrix and increase the flux value resulting in a higher recharge or outflow rate. This process is analogues to water flowing along the bottom of an inclined material, occasionally dripping into the layer below.

3.2.1. Types of macropores

Macropores refer to openings in soil, larger than pores occurring in the soil matrix. These voids are readily visible and may be continuous for several metres, both in vertical and horizontal directions. Macropores are generally classified according to morphology and origin of pore:

Pores caused by soil fauna are normally tubular with diameters of 1 – 500 mm (Beven and Germann (1982)). Various animal species, including insects (ants and termites), earthworms, moles, rodents and aardvarks, are responsible for burrowing holes. Pores caused by soil flora are also generally tubular in form. These pores are generally caused by plant roots, alive or decayed (Beven and Germann (1982)). The extent and depth of the macropore network, caused by soil flora, depends on the plant species that depends on the climate of the area. These aspects are very important when considering vegetation of soil covers. Plant roots might extend into the (moist) clay liner. When the plant root dies off, water might be channelled into the underlying material via the root hole.

Fissures and fractures are generally prevalent in expansive and clays subject to desiccation. Chemical weathering and freeze/thaw cycles (Beven and Germann (1982) can also induce fissuring.

3.2.2. Formation of discontinuities in clayey materials

Processes causing the formation of discontinuities in clay are dynamic. In the case of desiccation, cracks appear during dehydration of the soils caused by evaporation processes. These cracks will close during hydration processes caused by precipitation events. During their investigation regarding infiltration into fractured compacted clay, McBrayer *et al* (1997) observed that cracking and shrinking occurred with dehydration. Subsequent rehydration caused the cracks to close. With second and third dehydration cycles, initial cracks reopened, often with greater lengths and wider apertures. New cracks also appear. The sequence of opening and closing of cracks was repeated with each dehydration/rehydration cycle.

3.2.3. The Representative Elementary Volume (REV)

The heterogeneity of soils is defined in terms of the spatial variability in physical soil properties such as bulk density, water content, grain-size distribution, pore-size distribution, consistency and other properties. Since all these properties are defined and measured with respect to an elementary volume, the definition of soil heterogeneity is expressed in terms of an elementary volume. In general, the larger the elementary volume, the more physical properties are averaged in each elementary volume. On the other hand, the smaller the elementary volumes in the same field, the larger the differences of the physical properties between the elementary volumes (**Figure 3.1**).

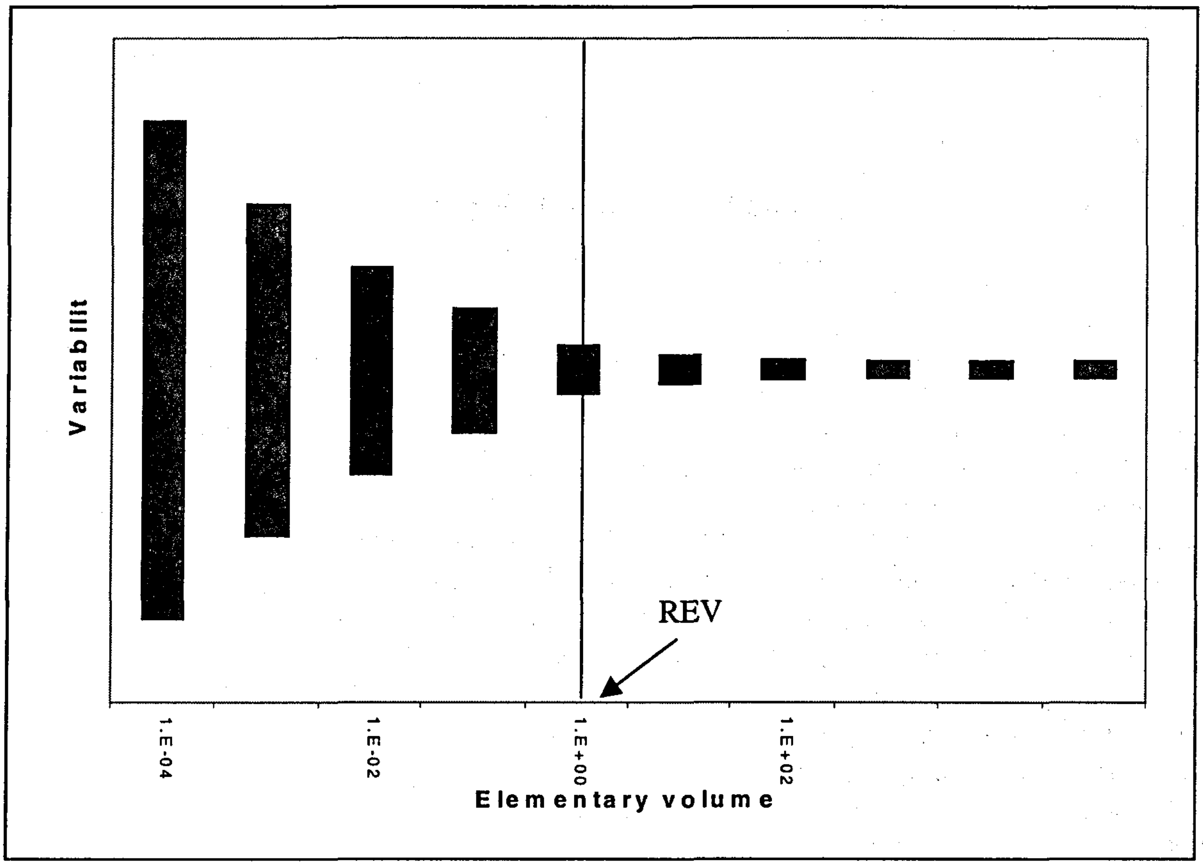


Figure 3.1: The Representative Elementary Volume (REV) of a soil containing macropores

According to a Lauren *et al* (1988), a REV of soil containing macropores will be 0.125m^3. This implies that accurate estimations of hydraulic conductivity will be obtained if large volumes of soils are tested (by means of double-ring infiltrometer tests and other *in situ* tests). When smaller volumes are tested (undisturbed laboratory tests, Guelph permeability tests), hydraulic conductivity values will vary significantly depending if macropores have been intersected or not. However, chances are that macropores will not be intersected and hydraulic conductivity values will be significantly lower than "actual" field hydraulic conductivity.

Daniel (1984) found that, during an investigation on macropore channelling in clay liners, *in situ* permeability tests matched the back-calculated values almost perfectly, indicating the *in situ* methods applied in these case studies are representative of the respective entire clay liners. The *in situ* methods applied include a large-diameter (2.4 and 2 m respectively) single ring infiltrometer test and a double-ring infiltrometer test (16 cm inner ring).

Fourie and Strayton (1996) found that, during an investigation near Delmas, South Africa, that the Guelph permaemeter could not be used to determine the *in situ* hydraulic conductivity of an expansive clay soil profile. They attributed the poor results to the desiccated nature of the soil where high flow rates coincides with the apparatus intersecting a discontinuity and low flow rates coincided with the apparatus not intersecting any discontinuity.

3.2.4. Macropore Channelling in Clay Liners

It has been well recorded that clay liners compacted dry of optimum water content tends to perform poorly. This can be ascribed to desiccation cracking. Work by Lambe (1954), Bjerrum and Huder (1957), Mitchell *et al* (1965) and others has shown that hydraulic conductivity of clays compacted dry of optimum water content is typically 10 –1000 larger than clays compacted wet of optimum. Daniel (1984) stated that "neither compacted nor small, undisturbed samples are likely to contain a representative distribution of desiccation cracks, fissures, slickensides, or other hydraulic defects that may be present in the liner". For this reason, laboratory permeability tests tend to significantly under estimate the hydraulic conductivity of the clay liner. Daniel recommended that *in situ* tests be done as part of the final design process or construction verification.

Daniel (1984) investigated possible preferential flow occurring in a clay liner of two polluted water ponds. Laboratory permeability tests on compacted samples revealed a hydraulic conductivity of between 1.4×10^{-8} and 9×10^{-9} cm/s at hydraulic gradients of 100 to 200. However, after commissioning of the ponds, hydraulic conductivities of between 2×10^{-5} and 5×10^{-5} cm/s or 1 000 times higher than the laboratory values, has been calculated from known pumpage rates and estimated rate of evaporation. Subsequent tests by a large-diameter single ring infiltrometer method confirmed a hydraulic conductivity of 4×10^{-5} cm/s. Laboratory permeability tests on undisturbed samples revealed hydraulic conductivities of between 1×10^{-7} and 8×10^{-9} cm/s. Visual inspection revealed no obvious defects to the liner but desiccation was evident throughout the liner. The difference in hydraulic conductivity was attributed to desiccation cracks and the lower values derived from laboratory tests were contributed to samples not representative of the liner and therefore not intersecting desiccation cracks. The liner was removed and recompacted wet of optimum. This resulted in a decrease of the hydraulic conductivity (5×10^{-6} cm/s).

Daniel reported on three additional case studies similar to the above situation. For the four case studies investigated, Daniel found that the ratio of field to laboratory hydraulic conductivities ranged between 5 and 100 000. Daniel noted that in all four cases, liners were all between 20 and 60 cm in thickness, regarded as thin by many engineers and regulatory agencies. He also noted that in all four cases, desiccation cracking could have contributed to poor performance. In none of the four cases was a well-documented record on construction inspection and quality control testing recorded.

3.2.5. Macropore Channelling in Soil Covers

Problems regarding preferential flow through soil covers have long been recognised. The different types of macropores are:

- Desiccating cracking due to wet/dry cycles. Drying of the soil might occur from above or below the barrier layer
- Crack development due to freeze/thaw cycles. This type of crack development might not be significant in South Africa. However, to the author's knowledge, this phenomenon has not as yet been investigated in South Africa.
- Crack development due to shrinking/heaving cycles. This type of crack development might occur in clayey material with significant smectite type clay minerals
- Macropore channelling by means of biopores. This process might occur if plant roots and burrowing animals have significantly penetrated the barrier layer.

Daniel and Koerner mentioned major disadvantages associated with clay covers include desiccation cracking and crack development due to freezing. In addition, crack development due to differential settlement has also been identified as a major problem concerning clay covers.

Montgomery and Parsons (1989) tested the effectiveness of using a topsoil layer to protect the barrier layer against desiccation. Topsoil with thicknesses of 150 and 450 mm has been used to cover a 1 200 mm compacted clay layer. After three years, excavations into the clay layer revealed cracks of up to 12 mm wide and extending up to 1 000 mm into the clay layer. Roots penetrated up to 250 mm into the clay layer. This situation was observed in both cases of 150 and 450 mm topsoil. They concluded that neither 150 mm nor 450 mm of topsoil was enough to protect the layer adequately.

Daniel and Koerner concluded that the best, and possibly the only practical way to protect a compacted clay from desiccation is by cover the clay layer with both a geomembrane and a layer of cover soil.

In their investigation of infiltration into fractured compacted clay, McBrayer *et al* (1997) have shown that infiltration rates for desiccated clay were up to four orders of magnitudes higher than air-dried, intact clay. This infiltration rate decreased up to two orders magnitude within the first hour of ponding due to cracks closing with rehydration. In spite of the apparent healing of the cracks, the infiltration rate was still two orders of magnitude higher than air-dried, intact clay.

In the case of sulphide-bearing tailings, soil covers are sometimes constructed to act as oxygen barriers and thereby preventing pyrite oxidation processes (Nicholson *et al*, 1989; Yanful, 1993). Oxygen enters the tailings mainly by means of diffusion (Kimball and Lemon, 1971). Water-filled pores significantly reduce the rate of oxygen diffusion into the tailings. The rate of oxygen diffusion therefore is a function of the soil-water retention characteristics and water content of the clay liner. No literature could be found on the effect of macropores on the rate of oxygen diffusion but it is expected that highly fractured clay would result in an increase of oxygen diffusion rate.

Compacted clay covers are also vulnerable to damage from differential settlement. A number of authors (Murphy and Gilbert, 1985; Jessberger and Stone, 1991; Daniel and Koerner, 1993) have defined the term "distortion" to quantify this phenomenon:

$$distortion = \Delta / L$$

where Δ is the differential settlement that occurs over a distance, L. Murphy and Gilbert (1985) calculated that compacted clays cannot sustain maximum tensile strains larger than 0.1 to 1%. This has been verified by experimental studies conducted by Jessberger and Stone (1991) that have shown that flow rates through the clay liner remained low until a distortion of 0.1% is reached.

3.2.6. Macropore Channelling Mechanisms

Flow in the matrix can be predicted reasonably accurately by applying the Richard's equation for one-dimensional flow based on Darcian principles. Darcian expressions may not adequately describe flow in soils containing macropores since the assumption of homogeneity is no longer valid. Predictions based on Darcian principles may have significant errors. A flow concept based on average hydraulic gradients is therefore not valid. The domain concept combines macropore and matrix systems. The matrix model can be described by traditional Darcian based expressions. The domain concept is further complicated by the interaction of soil matrix flow with macropore flow.

Direct flow into soil macropores consists of two phases (Wang *et al*, 1994). In the first phase, a relative constant and high flow rate (Q1) is usually observed. In the second phase, a slower flow rate (Q2) is usually observed. This two-phase mechanism can be explained in that the first phase involves predominantly infilling of the macropores and to a lesser degree, infiltration from the macropores into the soil matrix. During the second phase, macropores are already filled and infiltration into the soil matrix predominates. In the case of thin soil covers, macropores might extend trough to the underlying material. If the cracks extends through to an underlying highly permeable material, the second phase (Q2) might never occur.

In the case of desiccating and expansive clays, flow into macropores is more complicated. Although the domain concept still applies for these clays, the first phase high flow rate (Q1) will not be constant, but will decrease with time as the cracks close. The second phase (Q2) will be associated with flow through the soil matrix along tightly closed cracks. If the cracks extends up to an underlying highly permeable material, flow through cracks (Q1) might still dominate but the infiltration rate will be significantly lower than initial flow through open cracks.

Flow through compacted clay layers might be closely linked to the method used in preparation and compaction of the soils. **Figure 3.2** illustrates the pattern of flow through cracks in a compacted clay layer. Water flow through a series of "lifts" and "interlifts" zones (Benson and Daniel, 1994). Water flow along macropores within the lift zone and then spread horizontally along an interlift zone. The water continues spreading until it reaches another macropore and flows down the lower lift. However, this pattern of flow is not necessarily representative of the flow through compacted soils

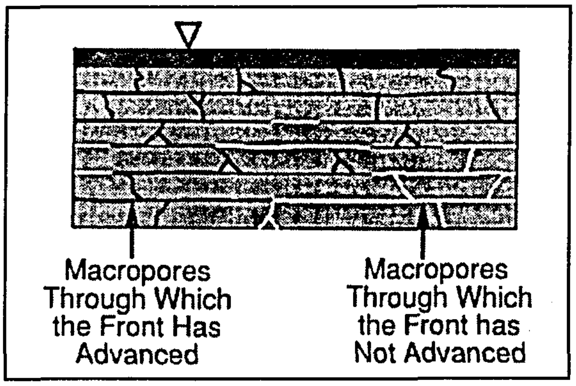


Figure 3.2: Flow through macropores in a compacted soil liner (after Benson and Daniel, 1994)

3.2.7. Factors having an effect on macropore channelling

Not all macropores are effective in channelling of water. Macropore channelling will only take place if a number of conditions have been met. Factors influencing macropore channelling are: (Beven and Germann, 1982):

- Size of the macropores;
- Regularity of the size of macropores;
- Connectivity of macropores;
- Extent of macropore network (macropore porosity);
- Depth to macropore network;
- Variability of macropore network with depth;
- Rainfall intensity;
- Cyclicity of rainfall;
- Initial water content.

The size of macropores is an obvious factor affecting macropore channelling. Harrison et al. (1992) noticed that leachate flow in fractured clay was observed in apertures as small as 0.01 mm width. Fractures with width of up to 0.05 mm beneath a landfill resulted in the development of a significant pollution plume in the underlying sandy aquifer within tens of years. Harrison et al. concluded that hydraulic active fractures are very difficult to detect with traditional borehole sampling techniques but may cause large-scale contamination.

Flow of water will be controlled by the void of the smallest size in any continuous macropore space and excess water in a continuous macropore will be affected by 'bottle-necking'.

Macropore channelling involves a degree of continuity. Disconnections within a macropore network will result in 'bridging'. The rate of water flow in a discontinuous macropore network will be controlled by the rate of flow through the matrix.

The extent of a macropore network in soil can be defined by the macropore porosity of the soil. The macropore porosity is the ratio volume of voids in macropores to the total volume. A typical value of macropore porosity in a soil characterised by biopores is 0.01 to 0.05. A soil characterised by a high macropore porosity value does not necessarily indicate a high degree of macropore channelling.

High rainfall intensities may contribute to macropore channelling, as the infiltration capacity of the soil matrix may be too low to absorb all the water. Beven and Germann (1982) found that rainfall intensities of 1-10 mm/h are sufficient to initiate macropore flow.

Intermittent precipitation can enhance the rate of infiltration through macropores. If precipitation is continuous, run off water will increase as macropores are filled with water. With intermittent precipitation, water in macropores has time to infiltrate laterally in the soil matrix. Beven and Germann (1982) found that salts in the topsoil layers were more effectively leached with intermittent water applications than through ponding. They concluded that the salts were effectively leached through the macropores with intermittent applications.

When water flows down the walls of the macropore, the water is absorbed in the soil matrix that slows the movement of water towards the soil. The rate of absorption in the soil matrix will depend on the initial water content in the soil matrix. The higher the initial water content, the less water absorbed in the soil matrix and the faster it moves down the macropore.

3.3. MACROPOROSITY IN UNSATURATED SOILS

Unsaturated hydraulic conductivity can be accurately estimated using statistical methods (Campbell, 1974; Brooks and Corey, 1964, van Genuchten, 1980; Hutson, 1984; Fredlund *et al*, 1994). The unsaturated hydraulic conductivity is obtained from the shape of the soil-water characteristic curve. This implies that the soil-water characteristic curve has to be described by a numerical function. Van Schalkwyk and Vermaak (1998) provides a review on the different statistical methods that have been developed to determine unsaturated hydraulic conductivity as a function of soil moisture and soil suction.

Errors in predicted unsaturated hydraulic conductivity values may stem from two sources:

- Errors due to inaccurate description of the soil-water characteristic curve;
- Errors stemming from the prediction model.

A number of authors have verified that the unsaturated hydraulic conductivity can be accurately predicted by means of statistical methods provided that the soil-water characteristic curve are accurately described by the numerical function (van Genuchten, 1980; Mualem, 1992; Fredlund *et al*, 1994; Leong and Rehardjo, 1997 and van Schalkwyk and Vermaak, 1998). Leong and Rehardjo (1997) concluded that exponential and sigmoidal type functions best describe the soil-water characteristic curve. To obtain absolute values, the hydraulic conductivity curve must be scaled with at least one real hydraulic conductivity value. This matching value is usually the saturated hydraulic conductivity value.

The soil-water characteristic curves of soils containing multi-modal pore systems, such as soils containing macropores, are not accurately described by sigmoidal and exponential function. Pore systems, not conforming to simple sigmoidal functions may be the result of specific grain size distributions. (Durner, 1994). Aggregation processes in clayey sand may also result in fitting problems. Biological processes and heaving/shrinking clays may lead to secondary pore systems in the large-pore (macropore) range.

Durner (1994) proposed multi-modal retention functions to describe soil with multi-pore systems. This multi-modal retention function is based on the Van Genuchten retention function but include the "subsystems" present in heterogeneous soil. Although Durner's multi-modal retention function has not yet been confirmed by experimental evidence, Durner's approach could be useful in distinct bimodal pore systems, especially in the macropore range.

Van Genuchten and Mualem proposed that the soil-water characteristic curve of soils containing macropores could be described by incorporating a second term to the van Genuchten function. Campbell (1974) developed an empirical function that could allow for dual porosity in predicting unsaturated hydraulic conductivity. The empirical function is incorporated in the SWIM model. The additional fitting parameters allow degrees of freedom in which hydraulic conductivities near saturation can be modelled (Lorentz *et al,* 1995). However, the dual-porosity nature of the soils implies that at least two matching hydraulic conductivity values have to be determined, one value representing near saturated flow through soil macropores and the other representing unsaturated flow through the soil matrix. The Van Genuchten & Mualem and Campbell models are described and discussed by Lorentz *et al* (1995).

Lorentz *et al* (1995) noted that although the Van Genuchten & Mualem macroporosity model best describe the soil-water characteristic curves of soils containing macropores, the function also comprises of more fitting parameters that require an adequate data-set to be applied successfully.

Predictions of unsaturated hydraulic conductivity from soil-water characteristic curves incorporating dual-porosity models have not been as thoroughly verified compared to the traditional sigmoidal and exponential type functions.

4. MODELLING THE UNSATURATED ZONE

4.1. INTRODUCTION

Reduction of infiltration into waste rock is most commonly achieved by the placement of compacted vegetated topsoil. There is at present no consensus on the best practice for placement of soil covers with solutions lying between the use of the most impervious material, which is usually not easily vegetated, and the use of the most arable soil, which is usually more permeable, therefore resulting in more outflow. In order to determine the effectiveness of a proposed covering system, many numerical models have been developed. It was intended one of these models should be selected and calibrated to simulate unsaturated flow at the experimental site. Selection of the models was based on appropriateness of the model for our final objective, enabling users determine the effectiveness of a proposed rehabilitation system based on readily available properties for the soils and vegetation. In evaluating the models, a reference model was required to which the other models could be compared. Since all authors have made assumptions during the development of their model, evaluation was based on conformity to the present state of the art knowledge on unsaturated flow.

A number of analytical, empirical and numerical models have been developed and each are based on a number of assumptions. The theory described in this chapter is, to our knowledge, the best to description of actual behaviour of water flowing through soil. This theory can be divided into distinct sub-models, each of these sub-models are described in this chapter.

Flow in the cover material and discard occurs generally under unsaturated conditions. This implies that the porous material is partly filled with air. Water statics and dynamics in the unsaturated zone are also important aspects in oxygen diffusion in to the discard. High moisture content in the cover material is needed to restrict oxygen influx. A general description of water flow in the unsaturated zone follows. For a more detailed account see Bear & Verruijt (1992)

4.2. THEORY

4.2.1. Upper Boundary

Figure 4.1 indicate a conceptual upper boundary of vegetated soil. The upper boundary can be defined as follows;

$$I = (P - P_i) - (T + E) - R \qquad [3.1]$$

where I is the net precipitation, P the total precipitation, P_i the precipitation intercepted by vegetation, T the transpiration from the leaves of the vegetation, E the evaporation from the soil surface, and R is the surface runoff. On reaching the soil surface the upper layer of soil initially absorbs water rapidly until a near saturated zone is formed.

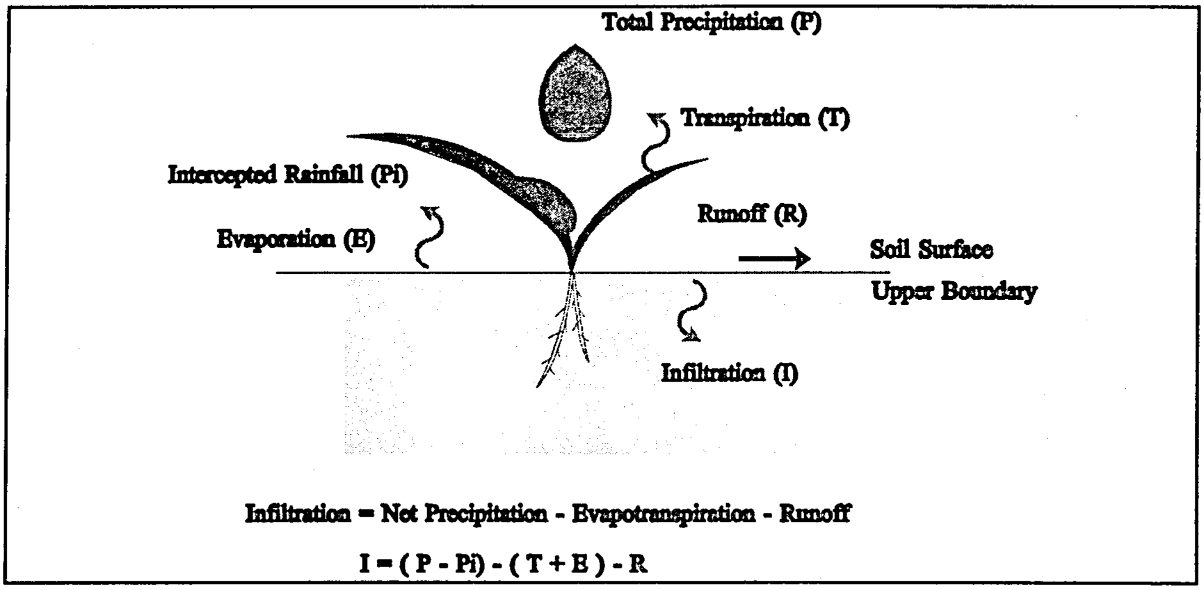


Figure 4.1: Conceptual upper boundary for a soil

Since water falling on the soil layer cannot be absorbed until additional capacity is formed by the downward movement of the saturated layer, the excess water leaves the system as runoff.

Below the near saturated zone, is the transition zone characterised by a sharp decrease in moisture content in the water content to the precedent. It is not necessary for saturation to be reached before downward flow of water occurs. The rate at which the water moves downward is functions of moisture content and physical properties of the soil layer.

Infiltration is limited to the amount of water the soil is able to absorb. Soil moisture is constantly lost through the upper boundary by means of evaporation and transpiration processes (evapotranspiration).

4.2.2. Unsaturated Flow

Flow through a porous medium has been studied in great detail and the well-known equation derived empirically by Darcy and verified many times for homogeneous isotropic material. Flow in the unsaturated zone has been shown to be similar to saturated flow except for two significant aspects. Firstly, the hydraulic conductivity is a function of the moisture content of the soil. This occurs because of increased flow path since part of the voids are filled with air and are therefore not conductive. Secondly the driving force or flow potential is a combination of gravity force and the pore pressure gradient. This pore pressure gradient occurs mainly because of matrix forces. However, in acid forming material, a substantial component of the total suction could be attributed to osmotic potential.

Other assumptions underlying this conceptual model describing unsaturated flow, is that the soil is isotropic, homogeneous, incompressible and that there is no flow potential derived from thermal or air pressure gradients. The simulation of flow through the unsaturated zone, as opposed to the saturated zone, requires a description of two distinct functions unique to the soil. These include the hydraulic conductivity versus moisture content curve and the soil moisture retention curve or pF curve, also referred to as the soil-water characteristic curve.

4.2.3. Lower Boundary

Since flow in an unsaturated soil is a function of water content, the groundwater surface is an important lower boundary. Due to capillary action, water could move upwards, downwards or be retained in the soil pending on the time-specific soil suction forces.

In the case of no evaporation and precipitation events, the transition in water content from full saturation (groundwater surface) to the field capacity follows the profile of the adsorption moisture retention curve shown in **Figure 4.2.**

In the case water is allowed to drain from the soil profile, and equilibrium is reached, the water retention profile will be different compared to when the soil profile is wetted from below. This is indicated in **Figures 4.2** and **4.3**. This phenomenon is known as hysteresis and is caused by the entrapment of air during wetting.

Moisture retention, or pF curves, describe the relationship between the water content of a soil and its corresponding pore water pressure or soil suction. Gravitational drainage will continue up to field capacity after which no drainage will occur. However these moisture can be removed by evapotranspiration.

4.2.4. Moisture Retention Curve

Figure 4.2 displays only the portion of the moisture retention up to field capacity. However, moisture can be removed by transpiration up to the wilting point and evaporation could remove moisture up to zero moisture content. The soil suction head of an oven-dried soil is generally accepted to be 10^{-7} cm. For this reason, the entire moisture retention curve is plotted of on one scale, requiring the definition of the term, pF which is equal to the logarithm of the soil suction head in cm (i.e. 10e7 cm = pF 7). **Figure 4.3** depicts the moisture retention curve indicating field capacity, wilting point, and hysteresis for a typical sandy soil. The adsorption and desorption curves in **Figure 4.3** are the section A and B as shown in **Figure 4.4**, with the vertical scale in cm as opposed to pF.

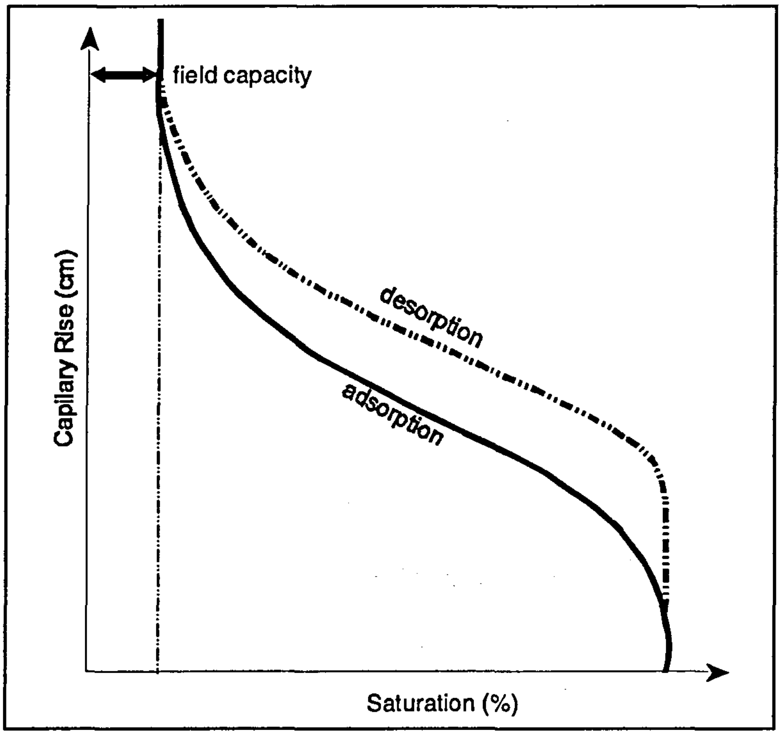


Figure 4.2: Soil moisture retention curve (field capacity to saturated conditions) for a specific soil

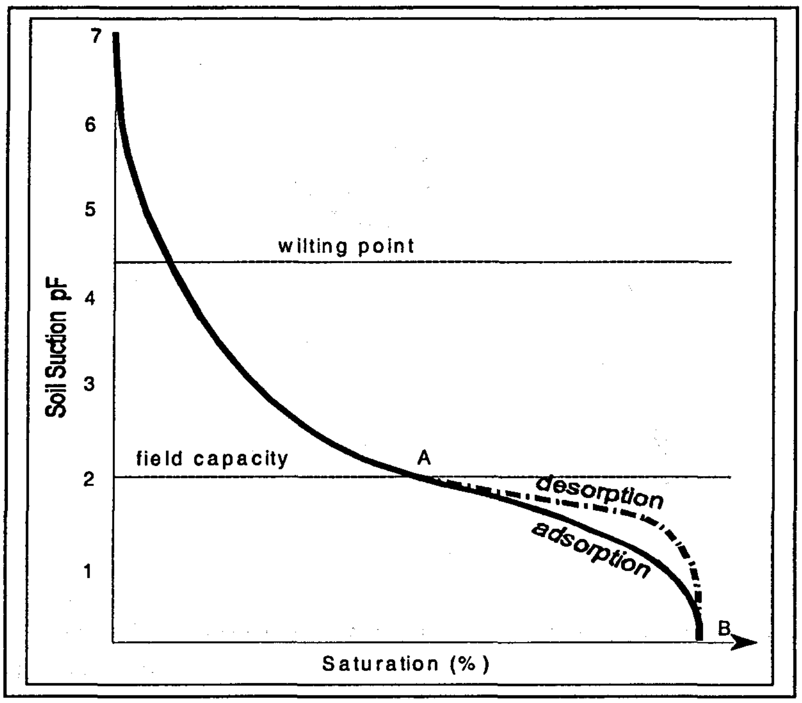


Figure 4.3: Soil moisture retention curve indicating field capacity and wilting points for a specific soil

4.3. NUMERICAL SIMULATION MODELLING

4.3.1. General

The mentioned conceptual model is currently the best model available for describing the movement of water through unsaturated soil, translation of a conceptual model to a mathematical model requires assumptions to be made. The most accurate translation as obtained from the literature is described below.

Due to our present inability to describe flow around individual soil particles or calibrate at the microscopic level, exact equations for flow around each particle is not possible. The continuum approach at the macroscopic level is therefore adopted. This entails determining the average properties of a representative elementary volume and assuming them to be acting at the centre of this element, be it solid, liquid or air (Bear *et al*, 1992). While the theory below is applicable to three dimensions, the mathematical model is described in one dimension.

4.3.2 Upper Boundary

Various equations have been proposed to estimate the potential evapotranspiration. These include Priestly and Taylor, Penman and Monteith-Rijtema equations (Belmans *et al*, 1983). All the equations describe a sink term with the variation being in the required meteorological data and plant parameters used in the calculation. One important consideration is the translation of the global radiation into the net radiation required by all of the relationships. These relationships can be approximated by a linear relationship as shown in **Figure 4.4**. However, a poor correlation between these aspects exists (**Figure 4.4**). Research on this relationship is currently being undertaken by various researchers. A sensitivity analysis should be employed when describing this relationship. In addition, plant parameters are also not well defined. These equations calculate the potential evapotranspiration S_{max} while the actual evapotranspiration $S(h)$ is a function of water content in the evaporation zone. The relationship can be describe as

$$S(h) = \alpha(h)\, S_{\max} \qquad [3.2]$$

where $\alpha(h)$ is a dimensionless function of the pressure head reaching a maximum between the plant oxygen deficiency level and the wilting point.

4.3.3 Unsaturated Flow

Flow in the unsaturated zone where the hydraulic conductivity and the pore pressure gradient are functions of the water content, can be described by the Richards equation (Richards, 1931). This flow equation originates from conservation of mass laws, and Darcy's equation. It is evident that upward flow is possible. Free drainage is assumed, and therefore hydraulic equals. Inclusion of the capillary head accommodates the possibility of upward flow. Darcy's equation includes the hydraulic capillary head and hydraulic conductivity as a function of water content can be defined as;

$$q = K(h)\left(\frac{\partial h}{\partial z} + 1\right) \qquad [3.3]$$

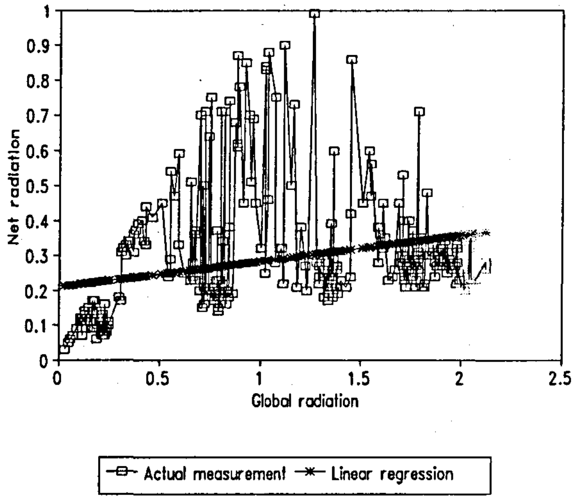


Figure 4.4: Comparison of global vs. net radiation for KwaZulu-Natal - June 1991

The change of water storage with time $\partial W/\partial t$ over the vertical distance z can be expressed as:

$$\frac{\partial}{\partial z}\left(\frac{\partial W}{\partial t}\right)=\frac{\partial \theta}{\partial t} \qquad [3.4]$$

where q is the volumetric flux. In addition, conservation of mass for the soil-root system requires that:

$$\frac{\partial \theta}{\partial t}=\frac{\partial q}{\partial z}-S \qquad [3.5]$$

S represents the volume of water taken up by the roots. Equation 3.4 can also be expressed as:

$$\frac{\partial \theta}{\partial t}=C(h)\left(\frac{\partial h}{\partial t}\right) \qquad [3.6]$$

with C being the differential soil water capacity. With substitution we to obtain the Richards equation:

$$\frac{\partial h}{\partial t}=\frac{1}{C(h)}\frac{\partial}{\partial z}\left[K(h)\left(\frac{\partial h}{\partial z}+1\right)\right]-\frac{S}{C(h)} \qquad [3.7]$$

The solution of this second differential equation can easily be obtained by means of numerical methods available and requires specification of the initial soil moisture content of the soil, the upper and lower boundary conditions. However, in order to obtain the two fundamental relationships, hydraulic conductivity and moisture retention versus water content, requires extensive laboratory work. Many of the unsaturated flow models including the very popular, Hydrological Evaluation of Landfill Performance (HELP) model (Schroeder *et al*, 1989), deviate from the theory to allow modelling with the readily available parameter, the saturated hydraulic conductivity.

The HELP model assumes that the unsaturated hydraulic conductivity can be approximated by a linear function. The second assumption is that the flow in the unsaturated zone occurs as a result of gravitation alone. However, it is known that the matrix potential may cause upward flow. These approximations work in opposition to each other and the error in calculation. At high water contents the flow rate may be underestimated while at low water contents the flow rate may be overestimated.

Unsaturated hydraulic conductivity and moisture retention curves of a typical sandy soil with a saturated hydraulic conductivity of 33 cm.day^{-1} were used to illustrate this phenomenon. **Figure 4.5** shows the two laboratory determined curves. A change in water content per unit time was calculated for the full range of the possible water content differences. Both the Feddes equation (Feddes *et al*, 1988) and the typical linear approximation were used, and these are shown in **Figure 4.5**. The figure shows that flow has been overestimated by 550% at 90% saturation. This can be attributed by the typical steep unsaturated hydraulic conductivity curve.

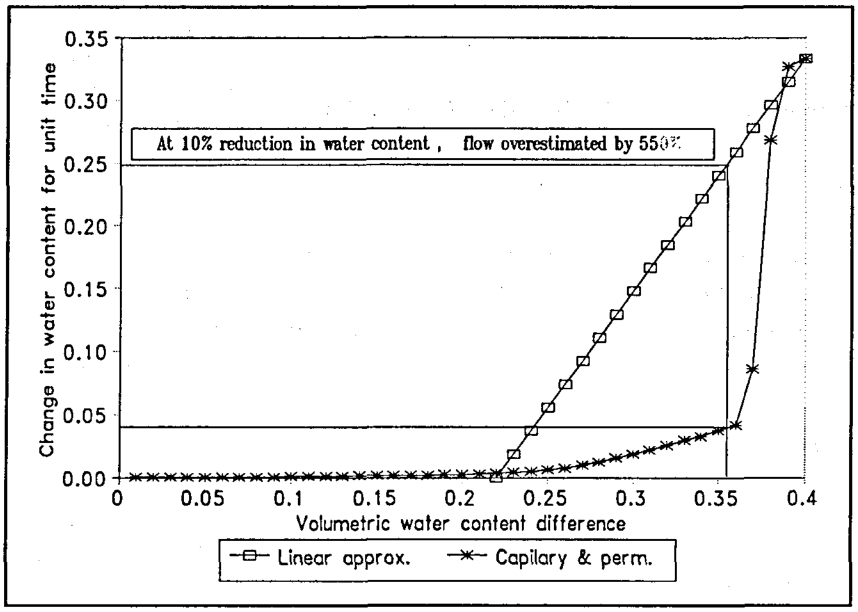


Figure 4.5: Richards' equation vs. linear approximation for sandy soil

The extensive laboratory work required in determining moisture retention and unsaturated hydraulic conductivity relationships with water content has encouraged many researchers to employ models that could exhibit inherent errors. In many cases, these errors could be acceptable provided a probabilistic approach is adopted. However, accurate modelling of the unsaturated zone could allow one, for example, to employ a readily available but more permeable material as a soil cover with the same long-term infiltration objective.

In many cases, models are employed where input requirements are available and the outputs monitoring data have been collected. However, this "black box" approach is generally suspect since all factors influencing flow has not been accounted for. A thorough understanding of the translation of the conceptual model into the mathematical model is a fundamental prerequisite required for evaluation of any model.

4.4 COMPUTER MODEL EVALUATION

Forty five (45) models have been identified claiming the ability to simulate unsaturated flow and these models are listed in **Appendix A**. Seventeen of these which allow for simulation of evapotranspiration have been highlighted. Very few of these 17 however, appear to undertake a detailed simulation of the upper boundary characterised by varying meteorological and vegetation parameters. The models applied in such an analysis are generally one-dimensional and aimed specifically at calculating a water balance of the soil cover layers. Since the evaluation of a soil cover in its ability to reduce the amount of water flowing in to the waste, a 2D model incorporating the water balance features are ideal. The program TRUST, among others, do incorporate 2D scenarios. However, the inclusion of surface geometry could render a model too complex for use by the mining industry. A user-friendly one-dimensional water balance model could prove the best option since flow into unsaturated zone is mainly downwards, or upwards, it is postulated that a one-dimensional flow model could adequately address flow in discard dumps and rehabilitated opencast mines. More detailed discussions on seven of the most promising models follows.

The computer room program HELP seems to enjoy enormous popularity amongst designers in the USA. With the continual reference to this model in literature and by experts, this seemed to be the ultimate solution warranting immediate investigation. HELP - Hydrologic Evaluation of Landfill Performance however seems to have serious underlying assumptions, which do affect the reliability of the results. The main concerns are as follows:

The HELP computer is a quasi-two-dimensional, deterministic, computer-based water budget model. The model has been developed to assist sanitary and hazardous waste landfill designers and evaluators to estimate components of, the water budget. The typical landfill cover design adopted in the USA for which the program was developed is depicted in **Figure 4.6**. The HELP model performs a sequential daily analysis to determine runoff, evapotranspiration, percolation and lateral drainage for the specific landfill.

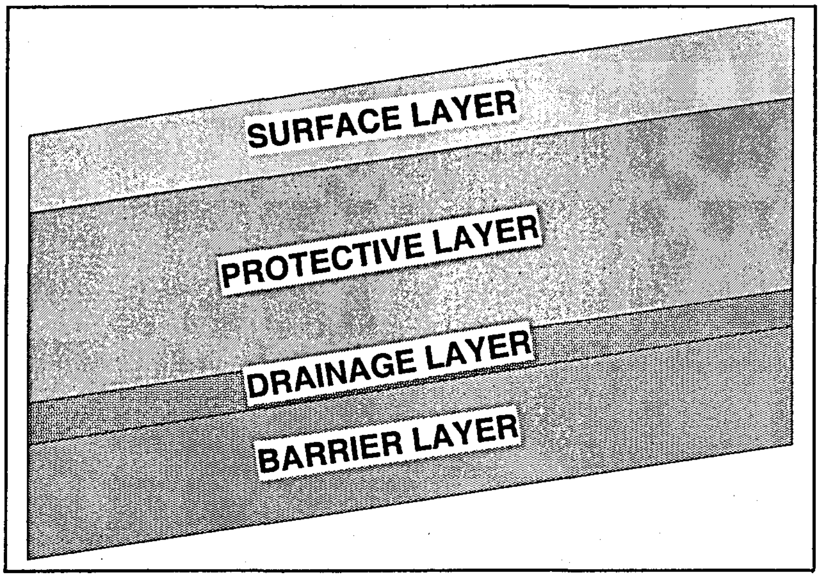


Figure 4.6: Typical landfill cover design adopted in the USA

Required inputs are limited to relatively easily available parameters. Historical climate data for most large cities in the USA has been included in the program. However, other climate data have to be manually created. Climate input data comprises of daily precipitation values, mean monthly temperatures and mean monthly solar radiation values. Other input requirements are leaf area indices, root zone or evaporative zone depths and winter cover factors. Soil characteristics include porosity, field capacity, wilting point, saturated hydraulic conductivity, water transitivity evaporation coefficient and Soil Conservation Service (SCS) runoff curve number.

This input seems very extensive and therefore accurate simulation is expected. Comparison of this method with the sate of the art method already mentioned indicates otherwise. The HELP model computes using the Soil Conservation Service (SCS) runoff curve number. It was mentioned that runoff occurs only when precipitation exceeds the intercepted precipitation, evapotranspiration and infiltration. The SCS curve technique, which, although proven a reliable technique in hydrology, has basic shortcomings in modelling the water balance of the upper soil layer.

The inaccuracy of this approximation is confirmed, when examining the initial development of SCS curves. Initial absorption, retention and maximum retention could be obtained empirically based on observed runoff – rainfall relationships for *large* storms on small watersheds. The maximum retention is equivalent to the infiltration required to develop the saturated layer described in **Section 4.2**. Compared to the large storms monitored, this infiltration would appear to be a maximum as the runoff approached the precipitation value yielding a linear relationship with a slope of close to 45°. Initial abstraction has been determined to be 20% of the retention parameter and therefore the maximum retention was chosen to be 120% of the retention factor. Standardised runoff - rainfall curves were developed in terms of a retention parameter alone.

The retention parameter is defined as soil-water retention available before precipitation and therefore equals the storage capacity of the soil less the current soil-moisture content in the root zone. A depth weighting parameter was introduced to account for the uniform distribution of the water throughout the soil profile and to allow for the large effects of infiltration on soil moisture near the surface. The potential maximum retention parameter was transformed by a simple relationship into a runoff curve number, CN, in order to make interpolating, averaging, and weighting a linear approximation. In the field of hydrology, this number has been associated with a particular soil type and land use and a Manning number is assigned to a specific channel surface. The calculation of the daily runoff by the HELP model is as follows:

a) With the CN number known for the specific site, the maximum retention potential can be calculated.
b) The daily depth weighted retention parameter is calculated.
c) The daily runoff is calculated.

This method is used to obtain the maximum infiltration and is equal to the total precipitation less the evapotranspiration and runoff for a 24-hour time step. The infiltration rate is used to estimate the vertical flow starting with the upper layer. Vertical flow is calculated by Darcy's equation based on the linear approximation as described in **Section 4.2.**

The total vertical flow in 24 hours through the layers is calculated sequentially starting with the upper layer, assuming free drainage of the lower layer. After this downward calculation has been completed and the flow through the lower layer been calculated, the water remaining in the lower segment is calculated. If this exceeds the saturated storage capacity of the layer then continuity is restored by the addition of the excess water to the layer above. This is repeated for upper layers until any excess water in the upper layer is added to runoff.

The following deviations from the "state of the art" must be emphasised which would appear to seriously affect the models' ability to simulate flow through the unsaturated zone:

- The maximum infiltration is determined by the SCS method, which was developed from data on large storms on small catchments where the near saturated layer at the surface will develop quickly. This will yield a much reduced total infiltrated volume, i.e., a large volume of infiltration will occur when 100 mm of precipitation occurs over 24 hours as opposed to 1 hour.

- Numerical modelling of the vertical water flow results in two contradicting approximations. Because the pore pressure gradient is ignored, the flow rate will be lower than in field soils. The linear approximation of the variation in unsaturated hydraulic conductivity could overestimate flow. Therefore, at water contents less than saturation, the flow rate will be overestimated while at lower water contents the flow rate is underestimated.

The many inaccurate inherent assumptions HELP are based on assumptions that could render the model very unreliable. However, after calibration remarkable similar results to field data have been achieved. (Verification of the HELP model. 1987)

3.4.2 SWIM

SWIM (Ross, 1990) is a software package developed to simulate water infiltration and movement into soils. SWIM allows for addition of water to the system by means of precipitation and irrigation and removal of water from the system by means of runoff, drainage, evaporation from the soil surface and transpiration by vegetation. SWIM allows simulation on soil water balances applying numerical solutions based on the fundamental unsaturated flow equations. The SWIM simulation program applies the conservation of mass laws by making the following assumptions:

- The soil layers are uniform.
- Flow is governed by the Richards equation.
- Hydraulic properties of the soils can be easily described.

The required inputs for the program is as follows:

<u>Vegetation Characteristics</u>

The model allows up to four vegetation types. Each vegetation type has particular characteristics determining its water extraction pattern. A fraction of the potential evapotranspiration is assigned to each vegetation type and the resultant is assigned to evaporation. The fraction of the evapotranspiration potential and the root length density of particular vegetation are a sigmoidal function with time. The distribution of roots with depth is assumed to be exponential, up to a particular soil depth.

Soil Surface Conductance

Although SWIM can incorporate impending soil layers, a special condition is assigned for layers at the surface. A surface seal or crust can be represented as a surface conductance, and its value could decrease exponentially with cumulative rainfall energy.

Surface Storage

Runoff occurs when the surface water depth exceeds the surface storage. Since rainfall result in reduction of surface roughness, the storage decreases exponentially with precipitation energy from the given minimum in exactly the same way as the surface conductance. Initial surface water depth can be changed and allows the simulation of surface ponding.

Runoff

For a water depth that is a particular height above the storage, the runoff rate is equal to, x^P, where P is the given runoff rate power and x is the height of ponding.

Soil Properties

The hydraulic properties important in unsaturated flow include: water content at field capacity, air entry potential, the slope of the straight line approximating the water retention curve on a log-log plot, an hydraulic conductivity at field saturation. By increasing the number of soil compartments, better accuracy can be obtained, but at the expense of simulation execution speed.

Precipitation And Potential Evapotranspiration

Cumulative precipitation and cumulative potential evapotranspiration are functions of time and linear interpolation is used to values between those given.

Assumptions

A number of simplifications and assumptions are made by the SWIM model, which are as follows:

- Soil air flow is ignored and rigid soil matrix is assumed. SWIM is therefore not applicable in swelling soils.
- Vapour flow in the soil is ignored.
- Temperature effects in the soil are ignored.
- Hysteresis in the relationships between pressure head and moisture content and between unsaturated hydraulic conductivity and moisture content is ignored. Hysteresis for unsaturated hydraulic conductivity / moisture content to be small, but for unsaturated hydraulic conductivity pressure head function it can be large for sandy soils.

- Easily obtainable hydraulic properties are used mainly because data are usually too limited to justify more detail, especially when field variability of hydraulic properties is considered. In particular the power laws applied for the properties may not be true for air dryness in clayey soils.
- The results for such soils where evaporation from a dry soil surface is an important factor, should be treated with caution.
- "Saturation" refers to the saturation normally attained under filed infiltration. Some air is always trapped in soil, reducing the conductivity substantially below the attained when the air is removed. It is therefore important to ensure that such values apply to the saturated moisture content and the saturated hydraulic conductivity.
- The following approximations can be made it porosity and saturated hydraulic conductivity is not known. Saturated moisture content equals 0.93 × porosity Saturated hydraulic conductivity equals 0.5 × hydraulic conductivity at saturation
- Many soils contain relatively macropores resulting from plant roots or borrowing animals and fractures along site soil structural units. These pores are filled with water only at potential higher than nil where they could contribute for most of the conductivity, with water flowing along preferential pathways. SWIM allows for such a contribution to the conductivity. However, if these pores are sparse, then the basic assumption that the soil can be treated as a continuum is not true and Darcy's law is no longer applicable. Water moves form the macropores, to the soil matrix, and the assumption that water at the same depth is at equilibrium is not true any more. A two or three-dimensional model is necessary to simulate flow through preferential pathways.
- The actual evapotranspiration rates is calculated using the equations provided by Campbell, (1985). However the xylem potential for each vegetation type can be obtained exactly by iteration in stead of using the simplifications of Campbell. Transpiration rates are calculated from steady-state radial flow to roots during each print interval (or each day if the print interval is longer than a day). These rates are assumed constant sink term in the Richard's equation. The evaporation rate from the soil surface is calculated as a fraction of the potential using the humidity in equilibrium with the surface metric potential. Clearly, these methods introduce many simplifications. However, more accurate models would require detailed data on plant and soil properties and these data are seldom available.

4.4.3 MIKE SHE WM – Release 5.1

MIKE SHE (Anon-1) is a comprehensive deterministic, distributed and physically based modelling system that simulate of all major hydrological processes of the land based part of the hydrological cycle. MIKE SHE is a further development based on the SHE modelling concept developed by European consortium of three organisations namely: the Institute of Hydrology (UK), SOGREAH and DHI.

The program is applicable to a wide range of water resources and environmental problems related to surface water and ground water systems and the dynamic interaction between these. MIKE SHE WM (Water Movement) is the basic module of the entire MIKE SHE system. It provides the water flow framework for the computations performed by other modules, e.g. the Advection-Dispersion Module, the Hydrogeochemical Equilibrium Module and the Soil Erosion Module.

MIKE SHE WM simulates the variations in hydraulic heads, flows and water storage in the entire land phase of the hydrological cycle, i.e. the ground surface, rivers and unsaturated and saturated subsurface zones. The system solves the governing differential equations using finite-difference methods.

MIKE SHE WM has been designed with a modular program structure comprising six process-oriented components, each describing the major physical processes in individual parts on the hydrological cycle:

- Interception/evapotranspiration
- Overland & channel flow
- Unsaturated zone
- Saturated zone
- Snow melt
- Exchange between aquifer and rivers

The modular form of system structure, or architecture, ensures a great flexibility in the description of individual physical processes. Data availability or specific hydrological conditions may favour one model description compared to another. By ensuring that the data flow between components are unchanged, alternative methods which are generally accepted in a certain geographical region or a country can be included in the system, if required.

Individual components can be operated separately to describe individual processes. This could be relevant to a range of applications, where only rough estimates of data exchange of parts of the hydrological cycle are required. An example being a groundwater study where only approximate recharge estimates could be required and a full description on the interaction with the unsaturated zone above the groundwater surface is not important

The ability to provide an integrated description of the various processes, despite different time scales, is the most attractive feature of the program. The integration has probably been the largest challenge encountered during its development and provides a unique feature. Perhaps the most difficult part of programming has been the integration between the unsaturated zone and the groundwater components.

Interception And Evapotranspiration Component

During rainfall, part of the water will be intercepted by the vegetation and subsequently lost by evaporation. It is assumed that the interception is either dependant on the rainfall rate and/or the interception capacity. The importance of interception depends very much on vegetation type, development stage, density of vegetation and the climatic conditions. Dense forest canopies may account for a considerable interception loss, whereas for shorter and sparser vegetation, such as grass and agricultural crops, the evaporation loss could be much smaller and often insignificant.

Evapotranspiration involves the transfer of large quantities of water. In temperate areas, approximately 70% of the annual precipitation is returned to the atmosphere, while under arid conditions it is almost equal to rainfall. For this reason, the prediction of the actual evapotranspiration plays a key role in many water resource studies.

The evapotranspiration is the total process of evaporation form the soil and water surfaces and transpiration, the water uptake by plant roots that is transpired from the leafy parts of the plants. The spatial and temporal variation in the evapotranspiration rate in catchment depends on multiple factors such as water availability in the root zone, the aerodynamic transport conditions and plant physiological factors.

Two formulations of the interception/evapotranspiration process are available in the program:

- **Rutter Model/Penman-Monteith Equation**

  The interception is modelled by a modified Rutter model, which calculates the evaporation, the actual storage on the canopy, and the net rainfall reaching the ground surface as canopy drainage and through-fall. The actual evapotranspiration rates are calculated by the Penman-Monteith equation using canopy resistance. The potential evapotranspiration is calculated directly applying climatological and vegetation data.

- **The Kirstensen-Jensen Model**

  The interception storage is calculated based on leaf area index and interception capacity coefficient. The net rainfall is calculated by a simple water balance approach. The actual evapotranspiration is calculated on the basis of potential rates and the actual soil moisture status in the root zone.

Unsaturated Zone Component

The unsaturated zone is a crucial part of the hydrological system in a catchment. It plays an important role in many modelling applications, e.g. for recharge estimation, surface groundwater interaction and agricultural contamination. The unsaturated zone refers to the mostly-unsaturated soil profile extending from the land surface down to the groundwater table. The profile comprises of usually heterogeneous horizons with distinct differences in the physical properties of soil.

The unsaturated zone is characterised by cyclic fluctuations in the soil moisture as water is removed from the soil profile by evapotranspiration and downward flow and replenished by rainfall. Recharge could result in a rise in the groundwater level, whereas upward flow from the groundwater resulting from capillary rise could occur in areas with a high groundwater level and high evaporation demands.

Unsaturated flow can usually be considered vertical since gravity is the dominating factor in the downward movement of water. The unsaturated flow is therefore only represented in MIKE SHE WM by a vertical flow component, which fulfils the requirements of most situations. However, this assumption may limit the validity of the flow description in some special cases, e.g. on very steep hillslopes with contrasting soil properties.

MIKE SHE WM solves the Richards equation for one-dimensional vertical flow, which includes the effects of gravity, soil suction, soil evaporation and transpiration. The equation is solved numerically by implicit finite difference technique using the double sweep algorithm. The variables are defined at every computational node in the vertical.

The transient upper boundary at the land surface is automatically selected as either a flux-controlled boundary (net rainfall) or a soil-controlled head boundary during ponding. The variance lower boundary is usually defined by the groundwater surface and defined by a positive value of the pressure head at the computational node just below the groundwater table. If unsaturated conditions develop in the entire soil profile, a zero-flux boundary is defined at the impermeable interface until saturated conditions develop from the bottom.

4.4.4 HYDRUS Version 5.0

HYDRUS (Vogel *et al,* 1996) is a program designed to simulate one-dimensional water flow, single-species solute transport and heat movement in unsaturated porous media. Since solute transport and heat transfer aspects of the program falls not within scope of the research, it will not be considered. The program uses Galerkin finite-element techniques to numerically solve the Richards equation for water flow, and convection-dispersion type equations for both solute transport and heat movement. The flow equation considers liquid-phase water flow (no vapour phase transport), hysteresis in the unsaturated soil hydraulic functions, scaled unsaturated soil hydraulic properties, and root water uptake.

4.4.5 ACRU 3.00

The ACRU (Schulze, 1995) agrohydrological model is a physical conceptual model in that it conceives of a system in which important processes and interactions are estimated, and physical to the degree that physical processes are represented explicitly. ACRU is not a parameter fitting or optimising model and variables (rather than optimised parameters) are, by and large, estimated from physical characteristics of the catchment.

ACRU is a multipurpose model which integrates the various water budgeting and runoff producing components of the terrestrial hydrological system including risk analysis, and can be applied in design hydrology, crop yield modelling, reservoir yield simulation, irrigation water demand/supply, regional water resources assessment. Planning optimum water resource utilisation and resolving conflicting demands on water resources.

The model uses daily time steps and thus daily rainfall input, thereby making optimal use of a valuable data. Certain cyclic, conservative and less sensitive variables (e.g. temperature, reference potential evaporation), for which values are input at monthly level are transformed by ACRU to daily values applying Fourier Analysis. In routines in which sensitive intra-daily information (e.g. of rainfall distribution) is required, this is obtained by synthetic desegregation of daily input within the model.

The ACRU model revolves around daily multi-layer soil water budgeting and the model has been developed essentially into a versatile total evaporation model. It has therefore been structured to be highly sensitive to climate and to land cover/use changes in the soil water and runoff regimes, and its water budget is responsive to supplementary watering by irrigation, to changes in tillage practices or to the onset and degree of plant distress.

ACRU has been designed as a multi-level model, with either multiple options or alternative pathways (or a hierarchy of pathways) available in many of its routines, depending on the level of available input data available or the detail of output required. A number of aspects can be estimated by various methods according to the level of input data at hand or the relative accuracy of the simulation required. These include: reference potential evaporation, interception losses, values of soil water retention constants, maximum (i.e. "potential") as well as total evaporation ("actual evapotranspiration'), leaf area index, components of the peak discharge estimation, hygrograph routing, reservoir storage; area relationships or the length of phonological periods in crop growth.

ACRU can operate as a point or a lumped small catchment model. However, for large catchments or in areas of complex land uses and soils, ACRU can operate as a distributed cell-type model. In distributed mode, individual sub-catchments (ideally not exceeding $30km^2$) can be identified, discretesised and flows can take place from "exterior" through "interior" cells according to a predetermined scheme. Each sub-catchment are able to generate individually requested outputs which could be different to those of other sub-catchments able to generate individually requested outputs which could be different to those of other sub-catchments with different levels of input/information.

The model includes a dynamic input option to facilitate modelling the hydrological response to climate or land use or management changes in a time series. These include long term/gradual changes (e.g. forest growth, urbanisation, expansion of irrigation project or climate trends), abrupt changes (e.g. tree felling, fire impacts, construction of a dam, development of an irrigation project, or introduction of new land management strategies such as tillage practices) or changes of intra-annual nature (e.g. crops with non-annual cycles, such as sugarcane). A dynamic input file is then accessed each year with the new variable inputs to be used from that year onwards, e.g. crop coefficients, root mass distributions, planting dates or soils properties.

That rainfall and/or irrigation application not abstracted as interception or as storm-flow (either rapid response or delayed), first enters through the surface layer and "resides" in the topsoil horizon. When that is "filled" to beyond its drained upper limit (field capacity) the "excess" water percolates into the subsoil horizon(s) as saturated drainage at a rate dependant on representative horizon soil textural characteristics, wetness and other drainage related properties. Should the soil water content of the bottom subsoil horizon of the plant root zone exceed the drained upper limit, saturated vertical drainage/recharge into the intermediate soil zones and eventually into groundwater occurs, from which base-flow could be generated. Unsaturated soil water redistribution, both upwards and onwards, also occurs but at a rate considerable slower that the water movement under saturated conditions, and is dependant, *inter alia*, on the relative wetness of adjacent soil horizons in the roots zone.

Evaporation occur from intercepted water and from various soil horizons simultaneously, in which case it is either split into separate components of soil water evaporation (from the topsoil horizon only) and plant transpiration (from all horizons in the root zone), or combined, as total evaporation. Evaporation demand on the plant is estimated, *inter alia*, according to atmospheric demand (through a reference potential evaporation) and the plants' stage of growth. The roots absorb soil-water in proportion to the distribution of root mass density of the respective horizons, except when conditions of low soil water content prevail.

In this case the relatively wetter horizons provide higher proportions of soil water to the plant in order to obviate plant stress as long as possible.

It is vital in land use and crop yield modelling to determine at which point in the depletion of the plant available water reservoir plant stress actually sets in, since stress implies a soil water extraction below optimum. This necessitates irrigation (if irrigation is applied) and also implies a reduction in crop yield. In modelling terms, this problem may be expressed as the critical soil water content at which total evaporation is reduced to below the vegetation maximum evaporation (termed "potential evapotranspiration"). Experimental evidence points to total evaporation equalling maximum evaporation until a certain fraction of maximum (profile) available soil water to the plant, is exhausted. Research show that the critical soil water fraction at which stress commences varies according to atmospheric demand and the critical leaf water potential of the respective vegetation, the latter being an index of the resilience of the vegetation to stress situations. The implications of stress setting in at such different levels of soil water content are significant in terms of total crop evaporation, crop production modelling and irrigation scheduling.

The generation of storm-flow in ACRU is based on the premise that, after initial abstractions (through interception, depression storage and infiltration before runoff commences), the runoff produced is a function of the magnitude of the rainfall and the soil water deficit from a critical response depth of the soil. The soil water deficit antecedent to a rainfall event is simulated by ACRU's multi-layer soil water budgeting routines on a daily basis, The critical response depth has been found to depend, *inter alia*, on the dominant runoff producing mechanism. This depth is therefore generally shallow in more arid areas characterised by eutrophic (i.e. poorly leached and drained) soils and high intensity storms which would produce predominantly surface runoff, and is generally deeper in high rainfall areas with dystrophic (highly leached, well drained), soils where inter-flow and "push-through" runoff generating mechanisms predominate. Not all the storm-flow generated by a rainfall event is same day response at a catchment outlet; storm-flow is therefore split into quick-flow (i.e. same day response) and delayed storm-flow, with the "lag" (which may be conceptualised as a surrogate for simulating inter-flow dependent, *inter alia*, on soil properties, catchment size and drainage density.

4.4.6 SoilCover

SoilCover (O'Kane *et al*, 1993) is a one-dimensional transient analysis program which can be used in tandem with other commercially available software packages to model the flow of water across the soil atmosphere boundary. The model is based on the well-known principals of Darcy's law and Fick's law and describes the flow of liquid water and water vapour in the soil profile blow the soil atmosphere boundary. A modified Penman equation is used to compute the rate of evaporation to the atmosphere above the soil atmosphere boundary.

SoilCover predicts the actual rate of evaporation from both saturated and unsaturated soil surfaces. The model accounts for atmospheric conditions, soil properties, and the effects of vegetation. In addition, SoilCover performs a water balance on the basis of infiltration, evapotranspiration, surface runoff, surface ponding and the soil profile. The change in water content, suction, vapour pressure, temperature, and hydraulic conductivity with respect to time and depth within the soil profile are also calculated.

SoilCover provides a one-dimensional transient analysis, which can be used interactively with other commercially available software packages for modelling groundwater flow in mine tailings and waste rock. The two-dimensional flow system is modelled using the transient flux boundary conditions at the soil cover atmosphere boundary predicted by SoilCover.

Two key features of SoilCover are that the model is a fully integrated heat and mass transfer model, which thereby allows for calculation of vapour flow, and interaction with atmosphere processes can be simulated applying the modified Penman equation. The second key feature is that SoilCover is able to calculate transient heat and mass flux boundary conditions base on routine climate parameters and the tailings profiles. SoilCover can calculate the actual evaporation (or evapotranspiration if vegetation is present), from the soil surface. SoilCover is also capable of modelling freezing and thawing soils, predicting oxygen diffusion coefficients of the tailings material, and hence the flux of oxygen to the oxidation front. The interaction between the tailings material and atmosphere is of paramount importance since the long-term performance of the tailings impoundment is a function of site climatic conditions.

4.4.7 SWACROP

SWACROP (Soil Water and Crop production model) (Wesseling *et al*, 1989) is a transient one-dimensional finite difference model for simulation of flow through he unsaturated zone. It incorporates the process of water uptake by roots. The soil profile is divided into several layers (containing one or more compartments of variable thickness) having different physical properties.

The partial differential equation for flow in the unsaturated system is solved using an implicit finite-difference scheme. An explicit linearisation of the hydraulic conductivity and the soil water capacity is used.

With the initial conditions (i.e. water content or pressure head distribution profile and top and bottom boundary conditions known, the system of equations for all the compartments is solved for each (variable) time step by applying the Thomas-tridiagonal algorithm. The integration procedure within each time step allows calculation of all water balance terms for each time period selected.

Data on rainfall, potential soil evaporation, and potential transpiration are required to define the top boundary. When the soil system remains unsaturated, one of three bottom boundary conditions can be applied namely pressure head, zero flux, or free drainage. When the lower part of the system remains saturated, one can either provide the groundwater level or the flux through the bottom of the system as input. In the latter case, the groundwater level is computed.

The rate of vegetative growth, both potential and actual, can be simulated in the crop growth sub-model, which is dynamically linked to the main water model. This sub-model provides data regarding the vegetation characteristics to the main water model throughout the simulation period. However, both models can be run separately.

4.5 COMPUTER MODEL SELECTION

It has been extremely difficult to single out one specific model that would be the most suitable for this project and it was impossible to compare each model on an equal basis. The models have been evaluated mainly base don their ability to model unsaturated, and specifically, which procedures was used to do this. One condition of paramount importance is that the final selected program should model the unsaturated flow applying the Richards equation, and the top boundary condition should include a calculation of evapotranspiration, using on of the accepted evapotranspiration models (Smith *et al*, 1990).

SWACROP was eventually selected as the most appropriate model for use in this project. All documentation regarding the model was extremely transparent, simplifying model operation procedures. SWACROP contains all the elements that was required for soil cover design, although its developers had never considered using SWACROP for this aspect. The source code for SWACROP was also made available, lending itself to re-programming should the model calibration prove to be successful.

It is important to note that SWACROP is not considered the "perfect" model, and that any of the models in **Appendix A**, specifically the seven listed above could prove to be as effective. SWACROP is not without its inherent flaws, as is HELP, ACRU and the other programs. SWACROP does however lend itself to being flexible enough to be used for the purpose of the project, probably better than some of the more user-friendly models such as SWIM and ACRU.

5. EXPERIMENTAL SETUP AND PROCEDURES

5.1. INTRODUCTION

A major shortcoming in the study of soil cover performance to date is the lack of sufficient long-term data from instrumented large-scale experiments. The experimental set-up for this project was therefore designed to obtain continuous climate outflow and water quality data for a long-term period, thereby addressing the problem.

It was decided to construct experimental cells simulating actual waste dumps, rather to using actual waste dumps as experimental sites. This ensured a controlled environment and well defined boundary conditions. In addition it was possible to design the experiment as such that all the necessary instrumentation could be installed.

In order to fill the knowledge gaps identified in the preceding chapters, a purpose made field experiment set-up was designed. The design of the experiment had to account for the following:

- The experiment should be of large enough scale to be representative, so that the results can be readily extrapolated to practical situations.
- The boundary conditions (edge effects) of the experimental cells had to be well defined.
- The experiment had to be instrumented sufficiently to ensure correct data interpretation.
- The experiment had to determine different soil cover scenarios and the effect of vegetating the covers.
- The soil properties of the specified covers had to be well defined. Both laboratory and in-situ field tests was done to determine these properties.

The experiment was constructed in 1993, at the Ngagane station (opposite the Kilbarchan colliery), approximately 10 kilometres south-east of the town Newcastle, in KwaZulu-Natal. Coal mining in South Africa is centred in two areas namely Northern KwaZulu Natal and Western Mpumalanga. It was decided to construct the experiment within the Natal coalfields in order to get representative conditions in which to monitor the experiment. This would ultimately assist in the calibration of the data and could easily be extrapolated to the Natal and Mpumalanga coalfields. It was felt that the results of the experiment would be applicable considering climatic and soil cover differences.

The climate at the site is typical of that throughout South Africa coalfields, with seasonal rain, mostly occurring as short high-intensity thundershowers.

The soil types used in the experiment as soil cover of the discard was chosen because of its proximity to the experimental site, and the fact that it is representative of the soil types found in the area, and which is currently being used for capping the old discard dumps. The intention was to have two distinctly different covers, one representing a sandy material and another representing clay.

The coal discard used in the experiment is fairly homogeneous in nature and was obtained from the nearby Kilbarchan Colliery Discard dump. Typically, the coal discard tends to be highly heterogeneous, ranging from large boulders to fines. However, it was decided that due to the scale of the experiment, the large discard could have significant boundary effects which could skew the results. Although it is accepted that the discard used in the cells might not be entirely representative of that normally comprise of, it would not affect the objectives of the experiment. Since the objective was to understand the performance of the cover material, and the flow of water through it, we could eventually make a correction for more representative discard.

Mineralogical and acid-base accounting tests performed on the experimental discard did prove that the coal discard do have high potential for acid formation and is therefore representative of coal discard with regard to pollution potential. By 1998, one experimental cell did indeed result in acid formation.

Another aspect that had to be considered in the experimental set-up was the effect the final slope of the cover would have on the cover performance. For this reason two cells were constructed with slopes typical of that used in practice.

Since it is practice to vegetate the covered cells the experiment was designed to test the effect of vegetation on the cells regarding the generation of leachate, resulting from anticipated evapotranspiration losses.

5.2. PHYSICAL CELL CONSTRUCTION

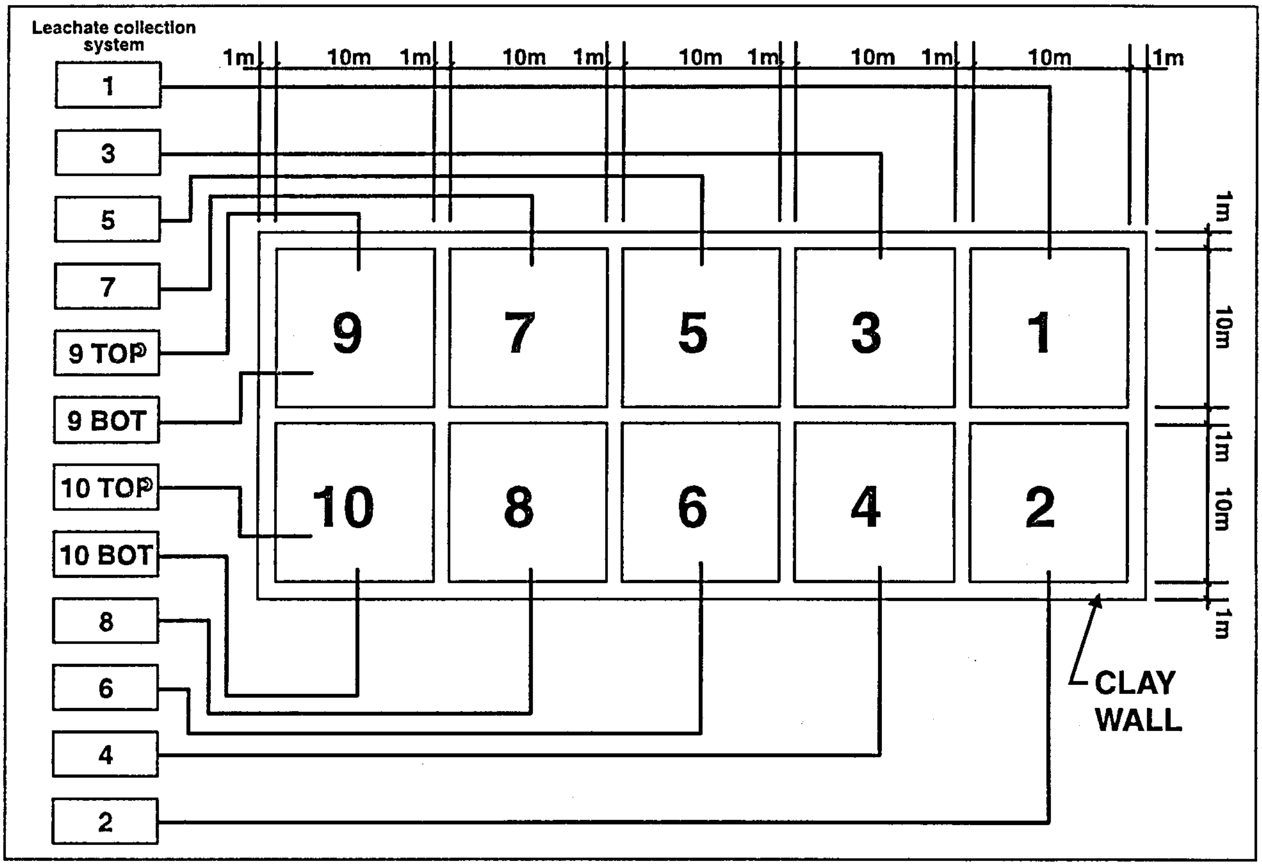
Ten experimental cells were constructed. The cells were designed to include the following features:

- All the leachate generated through the cover material had to be allowed to drain freely, and be measured.
- The cells would be isolated from each other so that they act as individual entities.
- The cells had to have varying slopes to test the effect of run-off. Run-off would however not be measured directly.
- The cells had to be capable of sustaining vegetation.
- The experiment had to be able to be self-sustainable to ensure long term monitoring.

The experiment comprises of 10 experimental cells, each measuring a surface area of $100m^2$ ($10 \times 10m$), the cell configurations are indicated in **Table 5.1** and **Figures 5.1, 5.2** and **5.3** schematically depict the design of the test cells.

Table 5.1: Ngagane field experiment cell configuration

Cell	Layers (top to bottom)	Slope
1	No cover, unvegetated, spoils uncompacted	2% (1:50)
2	No cover, unvegetated, spoils compacted	2% (1:50)
3	No cover, vegetated, top spoils layer treated with lime, spoils uncompacted	2% (1:50)
4	300mm Avalon soil, uncompacted, vegetated	2% (1:50)
5	500mm Avalon soil, compacted, vegetated	2% (1:50)
6	300mm Avalon soil, uncompacted, vegetated; 700mm Estcourt clay, compacted	2% (1:50)
7	300mm Avalon soil, uncompacted, vegetated; 700mm Avalon soil, compacted	2% (1:50)
8	700mm Avalon soil, uncompacted, vegetated; 300mm Estcourt clay, compacted	2% (1:50)
9	300mm Avalon soil, uncompacted, vegetated; 700mm Estcourt clay, compacted	10% (1:10)
10	300mm Avalon soil, uncompacted, vegetated; 700mm Estcourt clay, compacted	20% (1:5)



igure 5.1: Plan layout of the ten experimental cells and their leachate collection systems.

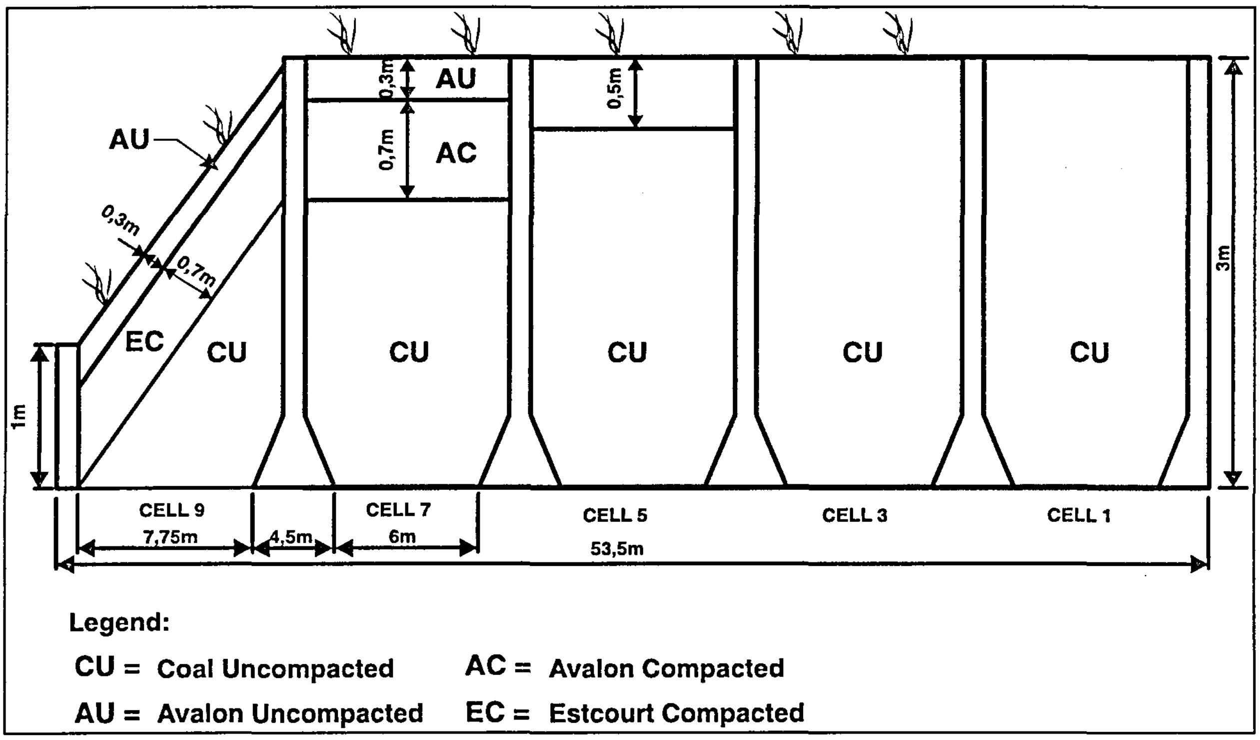


Figure 5.2: Typical section through five experimental cells (1, 3, 5, 7, and 9 depicting layer configuration.

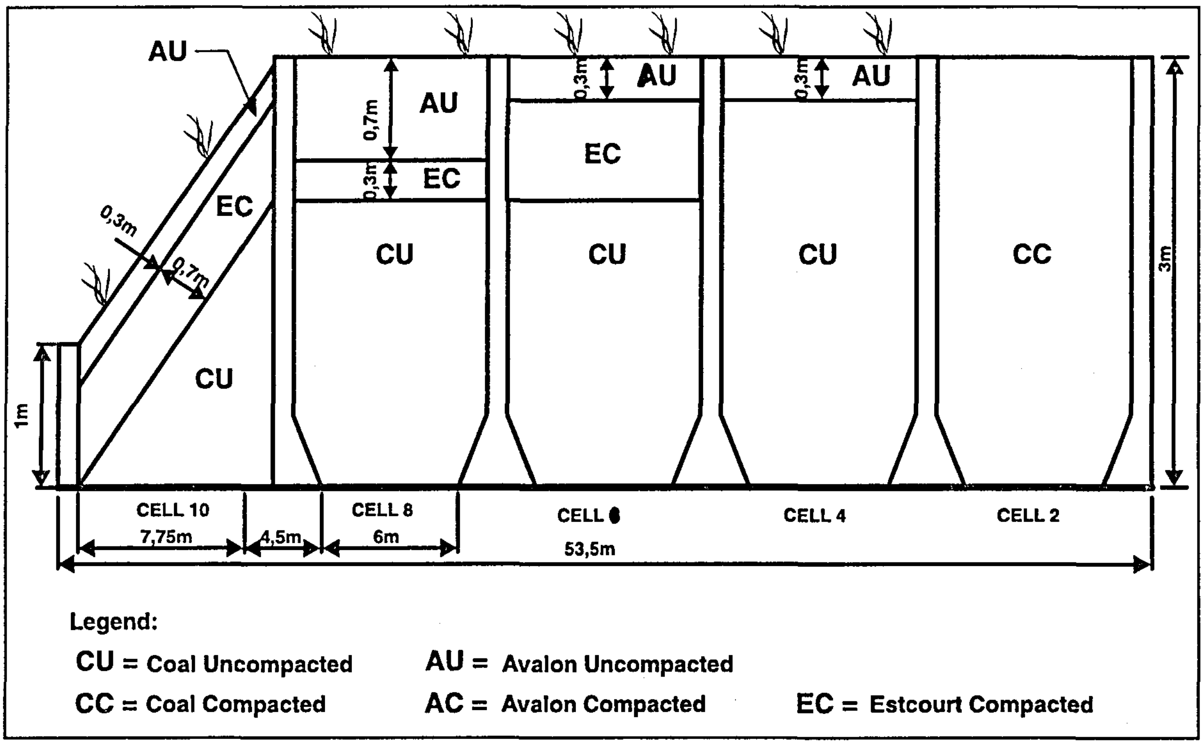


Figure 5.3: Typical section through 5 experimental cells (2, 4, 6, 8 and 10) depicting layer layout

The cells are separated from each other by means of 1m thick compacted clay walls. The bottom of the cells is constructed from compacted clay shaped to ensure drainage of each layer into a separate leachate collection system. In order to prevent any loss of leachate, a 500 micron HDPE liner was installed in the bottom of each cell. On top of the liner, a 150mm thick leachate collection layer of river sand was placed. This sand layer collects the leachate which drain into a perforated geopipe, and eventually to the leachate collection system.

The clay cell walls were compacted to 93% of Mod AASHTO at optimum moisture content, and all the cover layers compacted at 90% of Mod AASHTO at optimum moisture content.

Eight of the cells (1 to 8), represented the top section of a rehabilitated discard dump, with a slope of 1% (1:50) which is the smallest slope that would ever be used in discard dump rehabilitation. Cell number 9 was constructed with a side slope of 10% (1:10), whilst cell number 10 has a slope of 20% (1:5).

5.3. VEGETATION OF THE CELLS

The objective of vegetating the rehabilitated spoils was firstly to act as erosion protection, and secondly to increase evapotranspiration, thereby reducing infiltration. Unfortunately these two principles work against each other, as grass type effective as erosion protection is not effective in increasing evapotranspiration and *visa versa*.

As erosion protection, the ideal plant type will have to be a perennial stolan type such as Kikuyu (*Pennisetum clandestinum*), since they provide a very good basal cover which prevents soil erosion during winter seasons and after burning. Stolan type grass, however, are not conducive to good evapotranspiration rates, as they have a relatively low biomass.

Tufted grasses, such as the Blue buffalo grass (*Cenchus cilioris*) do have a high biomass, and are conducive to high evapotranspiration rates. These plants typically have large broad leaves, which constitutes their large biomass. The top cover can be highly effective (100%) but the basal cover is usually extremely low (20%) which constitutes to a large exposed area of ground in the dry season and after grazing or burning. This would result in soil capping (crusting), subsequent poor seeding and large erosion potential. Soil capping (crusting) not only result in increased erosion, but can increase the infiltration rate due to water being entrapped in the cracks of the crusted surface.

Another catch-22 aspect is that when designing a vegetation cover for erosion protection, the objective is to reduce the runoff as much as possible, whilst the principle of reducing infiltration relies on the exact opposite condition. Tufted grass types have an advantage in reducing runoff due to the spread of catchments it causes between the tuffs. This standing water can infiltrate into the soil cover, and if the evapotranspiration potential of the grass is not sufficient, it could flow through the discard material.

The seed cocktail used on the experimental cells 4 - 10 composed of five tufted grass types, two stolon types and one type which is a combination between tufted and stolon type. Cell 3 was eventually only planted with one tufted grass type with some stolineferous properties.

Based on the above discussion, and assuming cover percentages achieved during the last growth season, a significant amount of evapotranspiration from the cells can be expected since grasses with a large biomass will increase evapotranspiration.

Vegetating rehabilitated spoils is common practice (typically to prevent erosion). A seed cocktail, including foreign gasses, has been used as vegetation. It was anticipated that the indigenous grasses would eventually take over, and the foreign grasses would die off. Foreign grasses grow much easier on disturbed ground, and are therefore used to initially protect the indigenous grasses. No irrigation took place and the vegetation was allowed to grow under natural conditions.

The cells were first seeded early in November 1993. The seed cocktail was recommended by a specialist soil scientist from Loxton, Venn & Associates, based on the soil chemical composition. The seeds were broadcasted by hand on the surface that was lightly raked. The following seed cocktail used are presented in **Table 5.2**.

Table 5.2: Seed Cocktail Used At the Kilbarchan Experimental Site

Common Name	Scientific Name	Application Rate	Type
Oulandsgras	*Eragrostis curvula*	5 kg/hectare	tufted
Smuts finger	*Digitaria eriantha*	5 kg/hectare	tufted
Rhodes	*Chloris gayana*	5 kg/hectare	tufted/stolon
Teff	*Eragrostis teff*	5 kg/hectare	tufted
Kweek	*Cynodon dactylon*	5 kg/hectare	stolon
Paspalum	*Paspalum notatum*	5 kg/hectare	tufted
Kikuyu	*Pennisetum clandestinum*	5 kg/hectare	stolon
Blue buffalo grass	*Cenchus ciliarus*	5 kg/hectare	tufted
Total seed mix	**Total cocktail**	**40 kg/hectare**	**mixed**

The vegetation from this seeding never established well, and seeding was repeated in October 1994, by the Chamber of Mines Vegetation Unit. On the cells 4 to 9 the vegetation established well attaining a cover percentage of 90%, with an average grass height of 50cm. However, an uneven distribution caused by erosion of seed to the bottom of the slope was noted on cell 10, with highest (95%) and lowest (5%) vegetation cover at the top and bottom respectively.

Cell number 3 which was constructed without a soil cover was supposed to be treated with 20kg of lime before seeding, but this was not done during the first seeding period and the grass never established. In November 1995, the Chamber of Mines Vegetation Unit once again treated the cells. All vegetated cells were fertilised with 500kg/ha 2:3:2 fertiliser. Bare areas on the vegetated cells were lightly scarified, seeded with a grass cocktail and lightly cultivated to cover the seed and fertiliser. In addition to this treatment, cell 3 was limed (30tons/ha dolomitic lime) and planted with stargrass (*Cynodon ethiopicus*). The stargrass plants were planted in shallow holes prepared on a grid of approximately 0.3m by 0.3m and watered. The 1995/1996 rainy season was particularly wet and the grass covers on the cells became well established.

The grass had been mown and removed from the site at the end of each growing season (about May). Since a self perpetuating system have been envisaged, the grass was not fertilised any more than necessary, but allowed to revert to natural state, thereby producing a preferable environment for the indigenous grasses.

Throughout the experiment the tufted grasses seemed to perform the best. At the peak of the rainfall season, top covers on all the cells, except cell no. 3, were in excess of 98%. In the winter season however, cover was reduced to between 60 and 70%. The main reason for this vast difference is that the stoloniferous grass types never established well. The maximum cover achieved in cell no. 3 was about 70%, decreasing to about 50% during the dry season.

5.4. WEATHER DATA

A crucial aspect that had to be known was the boundary condition at the top of the soil cover, i.e. the climatic data, since it is the area where water enters and leaves the soil profile. To ensure that sufficient continuous data was measured, a self-logging weather station has been installed. Rainfall, relative humidity, temperature and nett radiation were logged hourly. This data was then transformed electronically, to allow for analysis thereof. Two standard 100mm rain gauges were installed on the site as a backup rainfall measuring system, in the event of a logger failure. The rain gauge was read once a week, before emptying it. Without this data it would not be possible to make accurate predictions of the evapotranspiration and rainfall.

An A-pan evaporation pan was installed on site. Measurements could only be taken weekly, resulting in poor data which eventually were of no use. **Figure B.1** and **B.2** in **Appendix B** shows the weather station and the data logger respectively and the evaporation pan is depicted in **Figure B.3**.

The weather data was captured using an MC Systems 120-02EX electronic data logger. The logger is powered from a battery pack, which in turn is conveyed via a solar panel. The data is stored on MCS 187A memory modules, which each has a storage memory of 16 000 data points. The memory module is replaced every week with a new one, and the data is retrieved using a MCS 430-memory module reader. The reader is linked to a PC, and the data is transferred in ASCII format for use in a spreadsheet. When the data has been safely stored on disk, the memory module is erased using the MCS 190 Ultraviolet eraser.

Solar radiation is measured using an MCS 155 Pyrometer. Rainfall is measured using a MCS 160 0.2mm tipping bucket rain gauge. Relative humidity is measured using a MCS 174 relative humidity sensor with a built in temperature sensor.

These instruments have been all installed in the immediate proximity of the experimental cells, at a height that is similar to the top of the cells. All the data was logged continuously, and hourly maximums, minimums, averages, and in the case of rainfall, cumulative readings were recorded. An hourly increment was chosen since it was believed that short duration rainfall in particular could influence the results of the experiment significantly. However, severe changes within an hour, are not often encountered with the exception of rainfall.

5.5. MOISTURE CONTENT AND DENSITY MEASUREMENT

It is important to understand how the moisture content changes within the soil profile in order to calibrate the unsaturated flow model. For this reason two permanent access tubes have been installed in each cell. The locations of the access tubes were chosen as such to minimise boundary effects. Two access tubes were installed to ensure accurate results. A nuclear probe was used periodically to measure the *in-situ* moisture content in the soil profile (see **Figure B.4** and **Figure B.5** in **Appendix B**).

Measurements were taken every two weeks. Three measurements were taken at each depth increment of 300mm through the soil profile. This data was used to calculate an average reading of moisture content and *in-situ* soil density at each depth for each cell.

The CPN 501DR Depth probe increment was used in the experiments. This instruments measures the sub-surface density and moisture content by means of a gamma source and a GM detector for density, and a fast neutron source and thermal neutron detector for moisture.

The aim of these measurements was to obtain a moisture content profile through the cells at any point in time. This would assist in understanding the flow of water through the unsaturated zone. Unfortunately, due to the infrequency of the monitoring, as well as the limited degree of refinement in the readings, the results were not of much use in calibrating the data.

5.6. OUTFLOW MEASUREMENT

The leachate collection system originally comprised of collection drums which collected the leachate for one week, after which the volume was measured and the containers emptied (see **Figure B.6** in **Appendix B**). This method proved to be inadequate as the volumes of leachate though the cells exceeded the collection drum capacity, causing the cells to develop a phreatic level, i.e. they were not free draining.

This problem was overcome by changing the leachate measurement technique to a continuous tipping bucket, using mechanical counters (see **Figure B.7** in **Appendix B**). The tipping buckets were constructed from mild steel plate, and joints and connections were welded together. The buckets were painted with a rust and corrosion resistant paint prior to commissioning.

The volume contained in each bucket prior to tipping was carefully measured and recorded. This volume ranged between 3.2 and 3.8 litre. Every bucket was installed with a mechanical counter that would advance one number on every second tip of the bucket. The bucket was left to run continuously, and the cumulative total on the counter was recorded once every week. The difference between the reading and that of the previous week was calculated, and multiplied by two times the volume contained in each bucket. This was the actual volume of water that flowed through the cell for any specific week.

On every tip of the bucket, the water is funnelled through a pipe system, into a pipe flowmeter. The flowmeter registers a cumulative water volume through the instrument, and was used to calculate the volume of outflow as a backup to the tipping bucket counters. Unfortunately, the flowmeters were not reliable, as the high suspended solids content of the leachate resulted in rapid clogging of the flowmeters and high acidity and salinity caused extensive corrosion.

5.7. WATER QUALITY MEASUREMENTS

Although it was not within the scope of this project, water quality measurements are taken at all experimental cells. It was anticipated that the quality of the water would have negligible impact on the flow of water through the soil covers and coal discard. The purpose for measuring the water quality was to determine if the leachate would in fact acidify as the coal mineralogical results showed, and if so, in what time frame.

Initially weekly results were taken and analysed by the Institute for Water Quality Studies at Roodeplaat Dam. The relative small change in water quality resulted in the sampling being changed to bi-weekly after about 6 months. The variables that were analysed for are:

pH, ammonia (NH_4) as N, nitrate ($NO_3 + NO_2$) as N, fluoride (F), total alkalinity (TAL), sodium (Na), magnesium (Mg), filtered (dissolved) aluminium (Al), silica (Si), phosphate (PO_4) as P, sulphate (SO_4), chloride (Cl), potassium (K), calcium (Ca), filtered (dissolved) manganese (Mn), filtered (dissolved) iron (Fe), electrical conductivity (EC), hardness (as $CaCO_3$) and Total Dissolved Solids (TDS).

The samples obtained are grab samples taken at the end of each second week, of water flowing from the cells at that day and are therefore not necessarily representative of the water quality over the entire week. Two 300mℓ samples from each cell is taken. One is prepared using a preservative, while the other is unpreserved. The analyses are carried out by the Institute for Water Quality Studies in Pretoria. This data will eventually be a crucial source of information for further research into Acid Mine Drainage.

5.8. OXYGEN AND CARBON DIOXIDE MEASUREMENTS

Oxygen and carbon dioxide measurements were taken at two fixed locations within each experimental cell at a depth of 150mm below the top level of the coal, irrespective whether it had a cover or not.

Stainless steel canisters with perforated sides were installed at these locations, and small diameter (5mm) stainless steel tubes, which protruded about 10cm from the top of each cell was used to connect the gasmeter when taking readings (see **Figures B.8** and **B.9** in **Appendix B**). The readings are expressed as a volumetric percentage.

A Gastech Model 3252 infrared carbon dioxide Gastechtor was used for the measurements. An internal pump draws the air sample from below the soil cover into a non-dispersive infrared sensor which detects the presence of carbon dioxide and expresses it in a by volume percentage. The reading is almost instantaneous.

A rubber plug was inserted into the top opening of each of the access tubes, to ensure that they are sealed from outside air which could affect the results. Once a week, when the readings were taken, the caps would be removed and the gasmeter would be connected to the aluminium tube via a small diameter flexible hose. The readings would then be taken.

Both the oxygen and carbon dioxide volumetric percentages would be recorded for each tube, and the average for each cell would then be calculated for use in the data analysis. Differences in the two tubes for each cell never exceeded more than 1%.

5.9. SOIL TEMPERATURE MEASUREMENTS

It was not part of the scope of this project to measure soil temperatures, but since the weather station data logger (see Section 4.4) was capable of logging more information, it was decided to install three MC151 temperature sensors in one cell. This data could be used to understand the radiation effect within the deep soil profile.

The soil temperature probes were subsequently installed at the following depths, in cell number 6:

- No. 1 at 1.65m
- No. 2 at 0.72m
- No. 3 at 0.30m.

It was decided to install the soil temperature probes in experimental cell number 6 since it was the only cell where the soil profile would allow for an equal spread of the temperature probes, and ensure that each probe lies within a different soil type.

The temperature for each of the probes was recorded every two minutes, and an hourly average was logged. This data was stored electronically and downloaded simultaneously with the weather data.

5.10. SOIL PROPERTY MEASUREMENTS

Two soil types have been used in the experimental cells namely Avalon and Estcourt soil types. These soils occur naturally in the area and is commonly used for rehabilitating old discard dumps. The Avalon was chosen for the purposes of a drainage layer and the layer that would sustain the vegetation. The Estcourt was chosen to be the barrier layer, in the experiment. In locating a soil for use in the experiment, Avalon an Estcourt horizons were mixed, and generalised properties cannot be ascribed to these soils. Detailed soil tests were carried out. **Figure B.10** in **Appendix B** shows small samples of each of these soils.

In order to understand the movement of moisture through the soil profile, it is important to have a good understanding of the physical and hydraulic properties of the materials. The physical, hydraulic and chemical properties of the soils have been tested, by means of laboratory and *in-situ* techniques. To ensure complete understanding of the system, similar tests have been done on the coal material used in the experiment. The following physical, hydraulic and chemical properties have been determined.

- Physical properties
  - bulk density
  - particle size analysis
  - particle density
  - porosity

- Hydraulic properties
  - unsaturated hydraulic conductivity (*in-situ* and laboratory)
  - saturated hydraulic conductivity (*in-situ* and laboratory)
  - water retention characteristics

- Chemical properties
  - clay mineralogy – on the soil cover material
  - acid-base accounting – on the coal discard
  - chemical composition – on the soil cover material.

5.10.1. Physical Properties

A number of laboratory experiments have been conducted on the different soil covers and coal material to determine the physical soil properties thereof. The physical properties were determined by standard geotechnical methods, which include the foundation indicator, bulk density and void ratio tests.

A total of 13 particle size distribution tests were conducted on the coal material, 15 on the Avalon soil, and 7 on the Estcourt soil. **Table 5.3** indicates the properties for each material. The best-fit curve has been obtained by standard curve fitting techniques through the data. **Figures 5.4** to **5.6** depict these particle size distribution curves. **Figure 5.7** depicts the particle distribution curves for all three-soil types.

Table 5.3: Cumulative results of foundation indicator tests on experiment materials

Description	Coal	Avalon	Estcourt
Sieve Size	Sieve Analysis (% Passing Through)		
19.000	100	100	100
13.200	100	100	100
4.750	96	100	100
2.000	90	100	100
0.425	50	97	95
0.250	34	93	89
0.150	24	86	82
0.075	12	74	71
0.050	8	55	52
0.005	4	35	35
0.002	3	32	32
Atterberg Limits			
Liquid Limit (LL)	32.0	33.2	36.6
Plastic Limit (PL)	25.0	16.2	16.9
Plasticity Index (PI)	7.1	16.9	19.7
Linear Shrinkage (LS)	3.1	8.5	9.2
Soil Classification			
PI of total sample	3.5	16.4	18.6
% Gravel	10	0	0
% Sand	80	37	40
% Silt	7	31	28
% Clay	3	32	32
Textural Chart Classification	Gravelly Sand	Clay	Clay

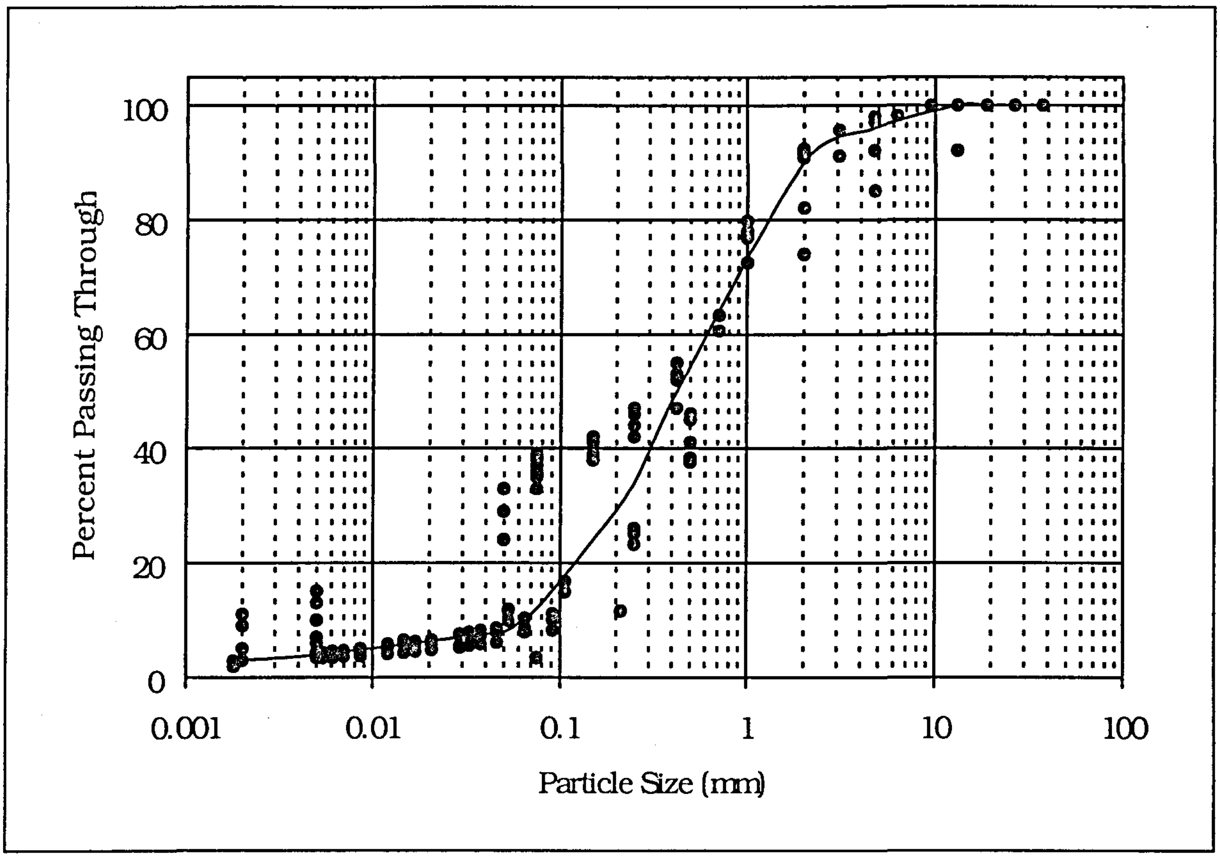


Figure 5.4: Particle size distribution curve fitted for coal material used in the Kilbarchan experiment.

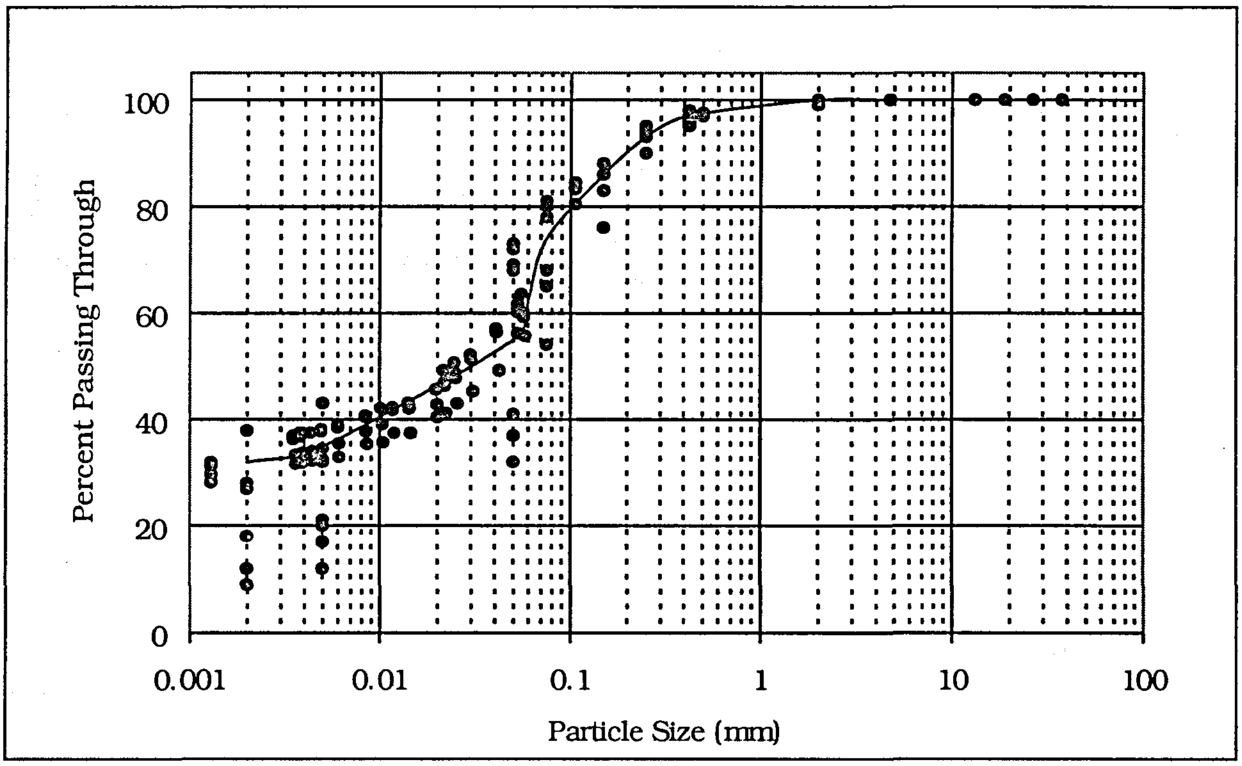


Figure 5.5: Particle size distribution curve fitted for the Avalon soil used in the Kilbarchan experiment.

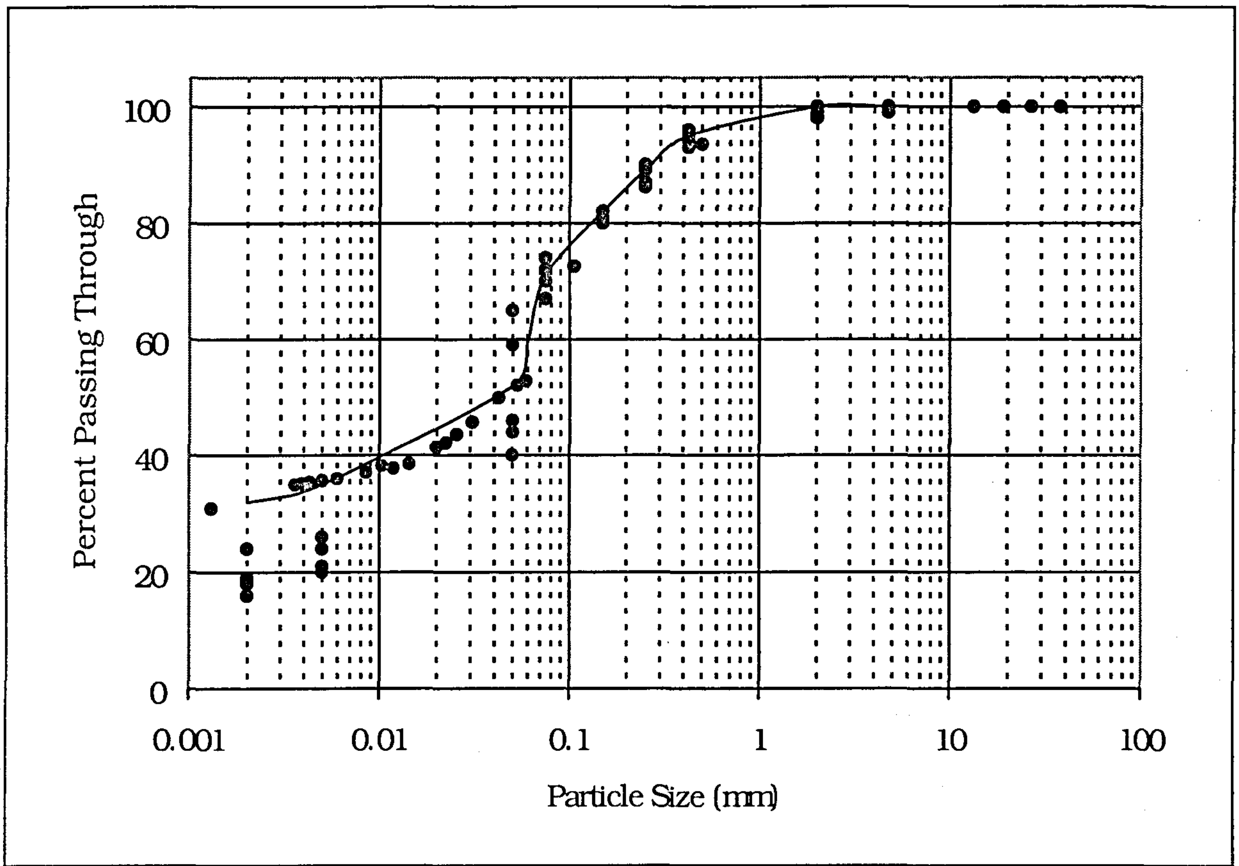


Figure 5.6: Particle size distribution curve fitted for Estcourt soil used in the Kilbarchan experiment.

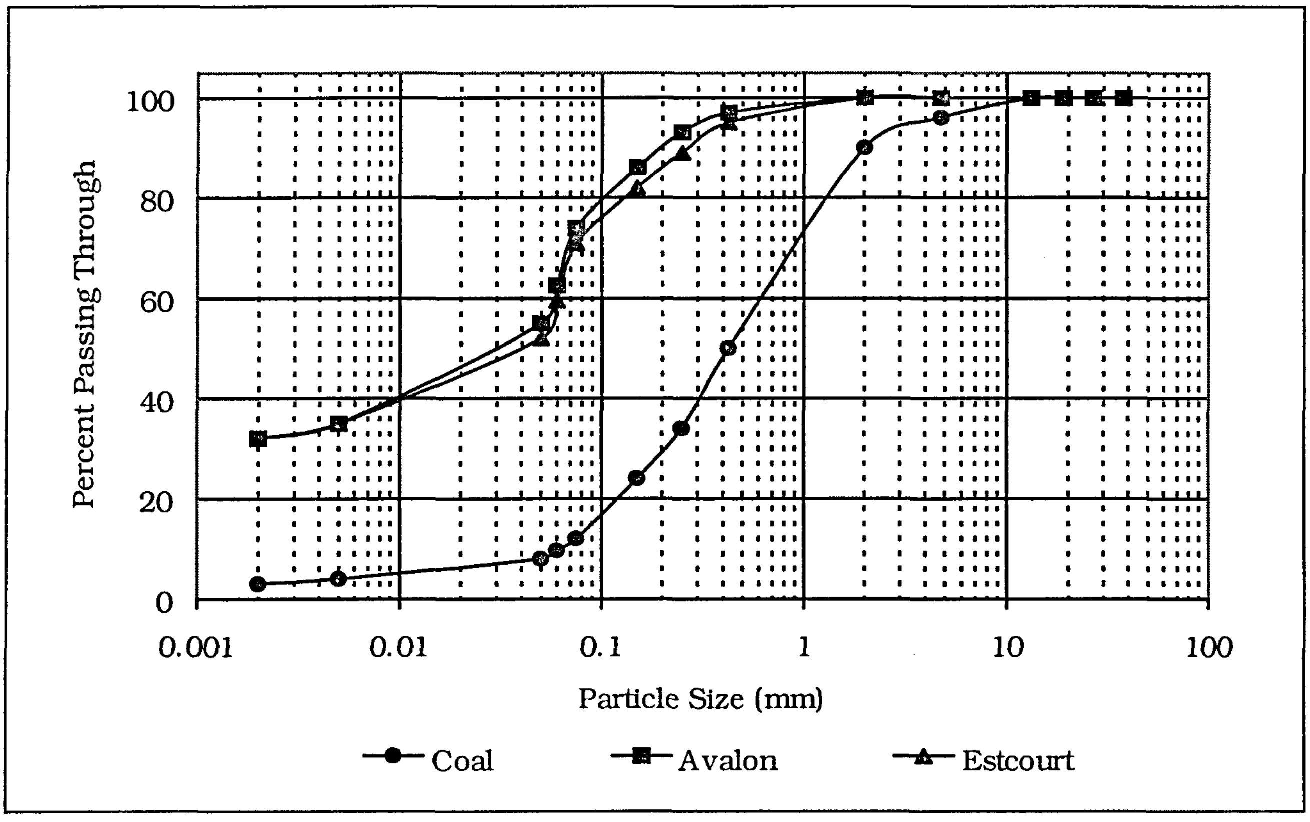


Figure 5.7: Combined particle size distribution curves for the coal, Avalon and Estcourt material used in the Kilbarchan experiment.

The coal material comprises of more than 90% sand and gravel, and less than 10% clay. The Avalon soil contains only 3% more sand and gravel than the Estcourt soil, although in both instances the gravel percentage is negligible. Estcourt soil contains 3% less silt material than the Avalon soil. According to soil classification norms, the Estcourt and Avalon soils appear the same, both being classified as clay, based on their physical properties.

A detailed report by Lorentz *et al* (1995), was conducted on material from the experimental site, specifically to determine the physical properties of the soils. The main findings with regard to the physical properties of the soils as reported in this document are listed in **Table 5.5**, and are summarised as follows:

Table 5.4: Physical characteristics of materials used in the experiment.

Soil	Bulk Density (g/cm^3)	Porosity (cm/cm^3)	Particle Density (g/cm^3)
Uncompacted Coal	1.026	0.290	1.69
Compacted Coal	1.063	0.300	1.68
Uncompacted Avalon	1.601	0.366	2.52
Compacted Avalon	1.669	0.344	2.55
Compacted Estcourt	1.776	0.301	2.55

5.10.2. Hydraulic Properties

A number of laboratory and field experiments have been undertaken to determine the hydraulic properties of the cover and coal material of the test cells. These tests include:

- Saturated permeability tests on disturbed remoulded samples recompacted to 90% Mod AASHTO.
- Moisture retention and hydraulic conductivity curves obtained from controlled outflow experiments on the Estcourt and Avalon soils and coal discard.
- Large diameter double-ring (1000mm) tests to determine the *in-situ* permeability (saturated hydraulic conductivity).
- Small-diameter (300mm) double ring infiltrometer tests to determine the in-situ permeability.
- *In-situ* tension infiltrometer tests with a minimum of three tensions to determine the unsaturated hydraulic conductivity as a function of hydraulic head.
- Laboratory tests to determine the water retention characteristics and unsaturated hydraulic conductivity of the soils using undisturbed samples in a controlled outflow cell.

The results of all the permeability (saturated hydraulic conductivity tests are indicated in **Table 5.5** and represented in **Figure 5.8.** The following comments can be made regarding these results.

Table 5.5: Comparative results of saturated hydraulic conductivities for material used in the Kilbarchan experiment

Soil Type	Undisturbed Permeability (cm/sec)			Distributed Permeability (cm/sec)	Average (cm/sec)
	Geulph Permeameter	1 000mm Double Ring Infiltrometer	300mm Double Ring Infiltrometer	Falling Head Test	(Excluding Falling Head Test)
Uncompacted Coal	5.65×10^{-3}	1.00×10^{-2}	6.08×10^{-3}	3.20×10^{-5}	7.24×10^{-3}
Compacted Coal	5.00×10^{-3}	2.78×10^{-3}	4.47×10^{-3}	4.70×10^{-5}	4.08×10^{-3}
Uncompacted Avalon	2.28×10^{-3}	2.72×10^{-3}	3.18×10^{-3}	No Test	2.75×10^{-3}
Compacted Avalon	3.00×10^{-5}	4.17×10^{-4}	3.63×10^{-4}	2.35×10^{-8}	2.70×10^{-4}
Compacted Estcourt	5.00×10^{-6}	3.33×10^{-4}	1.22×10^{-4}	6.15×10^{-8}	1.53×10^{-4}

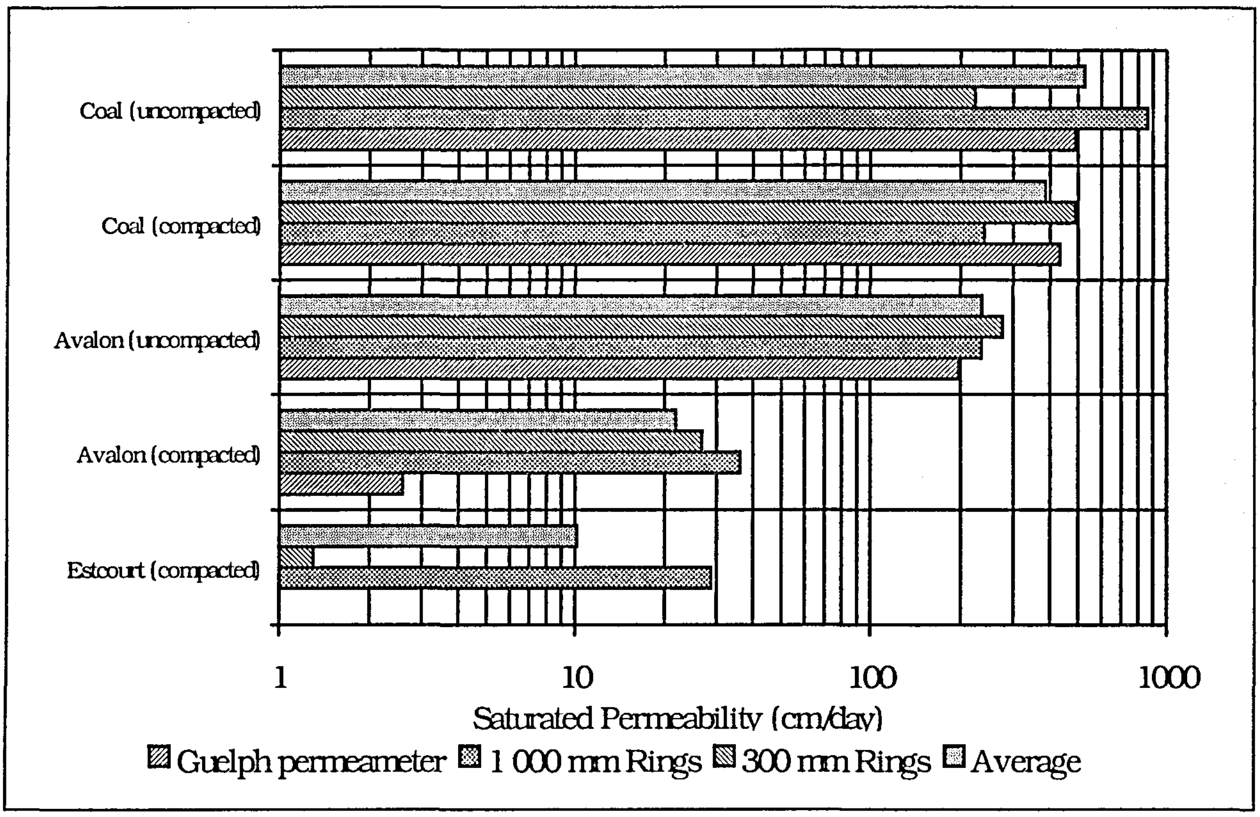


Figure 5.8: Comparative saturated hydraulic conductivities for the coal, Avalon and Estcourt material used in the Kilbarchan experiment.

- The laboratory determination of saturated hydraulic conductivity, was determined from a disturbed recompacted sample, and would therefore be the lowest permeability estimate of the material. The reason for the compacted Avalon having a lower permeability than the compacted Estcourt can be ascribed to the clay content in the material. Soils with a higher clay content are generally compacted to a lesser degree, resulting from the higher plasticity.

- In the case of the compacted Estcourt and Avalon soils, the Geulp tests permeabilities results were much lower than the double ring infiltrometer tests. This could be expected, since the permeability in a low permeability material, such as clay is dominated by the macrostructure thereof. In the more permeable material, such as coal discard, the permeability is less susceptible to structure, and therefore, the Geulp permeameter gives more reliable results.

- A similar trend has been observed in comparing the small diameter double ring test results with that of the large rings. The smaller rings recorded lower permeabilities in the lower permeability soils, but very similar results were observed in the high permeable materials.

- Notwithstanding the differences measured, accurate measure of the permeabilities have been obtained. The umcompacted Avalon appears to have similar permeabilities compared to coal, which is only marginally less permeable than the uncompacted coal.

- The permeabilities of compacted Avalon and compacted Estcourt appear to differ by one order of magnitude, which is what one would intuitively expect. The compacted Avalon in turn differs by the same margin from the uncompacted Avalon.

Figures 5.9 to **5.12**, indicate the hydraulic results for the coal, Avalon and Estcourt material respectively. The main findings of the report by Lorentz *et al* (1995), with regard to the hydraulic properties of the soils can be summarised as follows:

- The water retention characteristics of the coal materials are clearly different to the soils. Approximately 60% of the pore water have drained from the coal at a matrix pressure head of 100cm, whereas the soils are still close to saturation at 100cm. The coal materials reach residual water content of approximately 0.06 at 1000cm, while the residual water contents for the soils is much higher, approximately 0.22 at 6000cm. No significant difference between the compacted and uncompacted coal retention characteristics is immediately evident. The compacted coal sample from cell 2 does, however, exhibit higher matrix pressures between water contents of 0.12 and porosity than do the uncompacted coal samples.

- Similar behaviour is evident in comparing the compacted and uncompacted Avalon soils. The uncompacted Avalon matrix pressures remain relatively low until a water content of 0.25, after which a rapid rise in pressure occurs with continued desorption. The compacted Avalon soils, on the other hand, reveal a significant matrix pressure head prior to a water content of 0.25 on the desorption cycle. The residual water contents at 6000cm for the Avalon soils are slightly higher (0.25) for the compacted materials than for the uncompacted (0.22). It should be noted here that these phenomena for the compacted soils are most noticeable in cell 7 in which the Avalon soil has a 300mm overburden of uncompacted Avalon.

- The compacted Estcourt soil has the steepest retention characteristic of all the materials tested, exhibiting the greatest water holding capacity. The residual water content at 6 000cm for the compacted Estcourt is 0.26, which is equivalent to 90% saturation for this material, whereas for the Avalon soils, the residual water content is equivalent to a saturation of 60%.

- Differences between materials, types and between compacted and uncompacted materials are evident to a far greater degree in the hydraulic conductivity characteristics than in the retention characteristic. While the saturated hydraulic conductivities for the coal materials are similar, the conductivity of the compacted coal material is almost an order of magnitude less than the compacted materials at a very small matrix pressure head of 1cm. The compacted coal, therefore, is assumed to have large void spaces of the same order of magnitude as the uncompacted materials to allow rapid saturated flow. At a small tension, however, when the larger void spaces no longer conduct water, the compacted material has a conductivity that is significantly lower than that for the uncompacted coal materials. With further reduction in water content and increase in matrix pressure, the characteristics of the coal materials become similar. The coal materials exhibit a hydraulic conductivity characteristic that is an order of magnitude greater than the compacted Avalon soils but have saturated conductivities similar to the uncompacted Avalon soils. The coal conductivities are at least two orders of magnitude greater than the compacted Estcourt soil.

- Comparison of the compacted and uncompated Avalon soils also reveal significant differences. The saturated hydraulic conductivity of the compacted Avalon soils are an order of magnitude less than the uncompacted soils signifying that the large pore sizes are significantly reduced by the compactive effort. However, at a small tension of 1cm, the hydraulic conductivities of the compacted and uncompacted Avalon soils are similar. The elevated saturated conductivities of the uncompacted Avalon soils means that significant macropores and aggregates are present in these uncompacted materials. The hydraulic conductivity characteristic of the compacted Estcourt soil is significantly lower than the other soils. This difference is most obvious in the saturated hydraulic conductivity, which is one and a half orders of magnitude less than the compacted Avalon soils and two and a half orders of magnitude less than the uncompacted Avalon soils.

- The hydraulic conductivities measured in the controlled outflow cell fit directly into the characteristic suggested by the in-situ measurements. This method of hydraulic conductivity measurements and to extend the characteristics into the higher matrix pressure range, where conductivity measurements are extremely difficult by traditional methods.

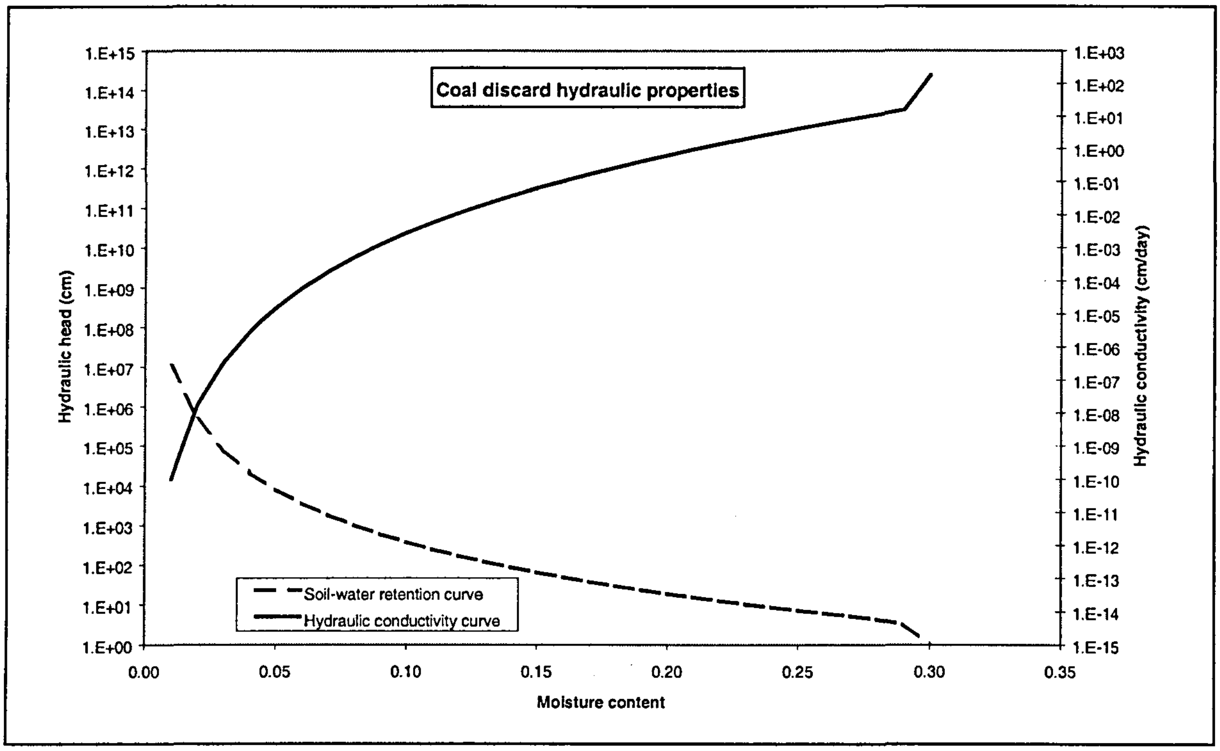


Figure 5.9: Field water retention and hydraulic conductivity curves for the coal material

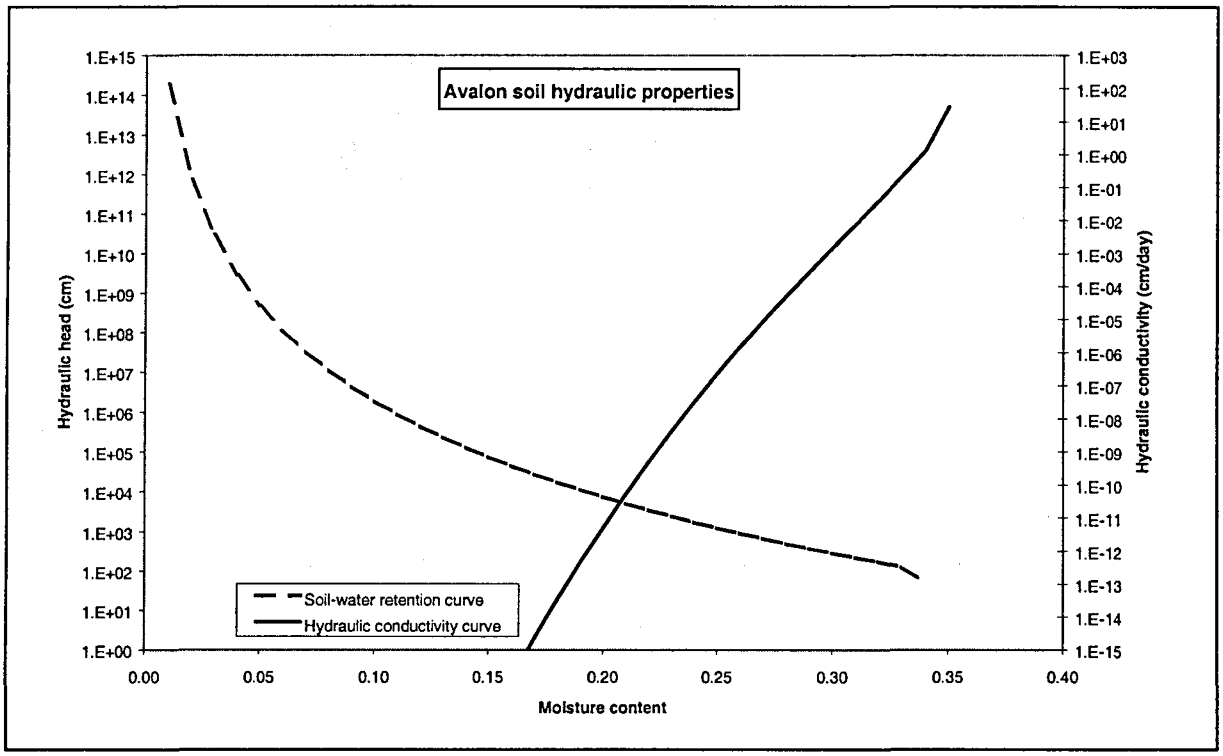


Figure 5.10: Field water retention and hydraulic conductivity curves for the Avalon soil material

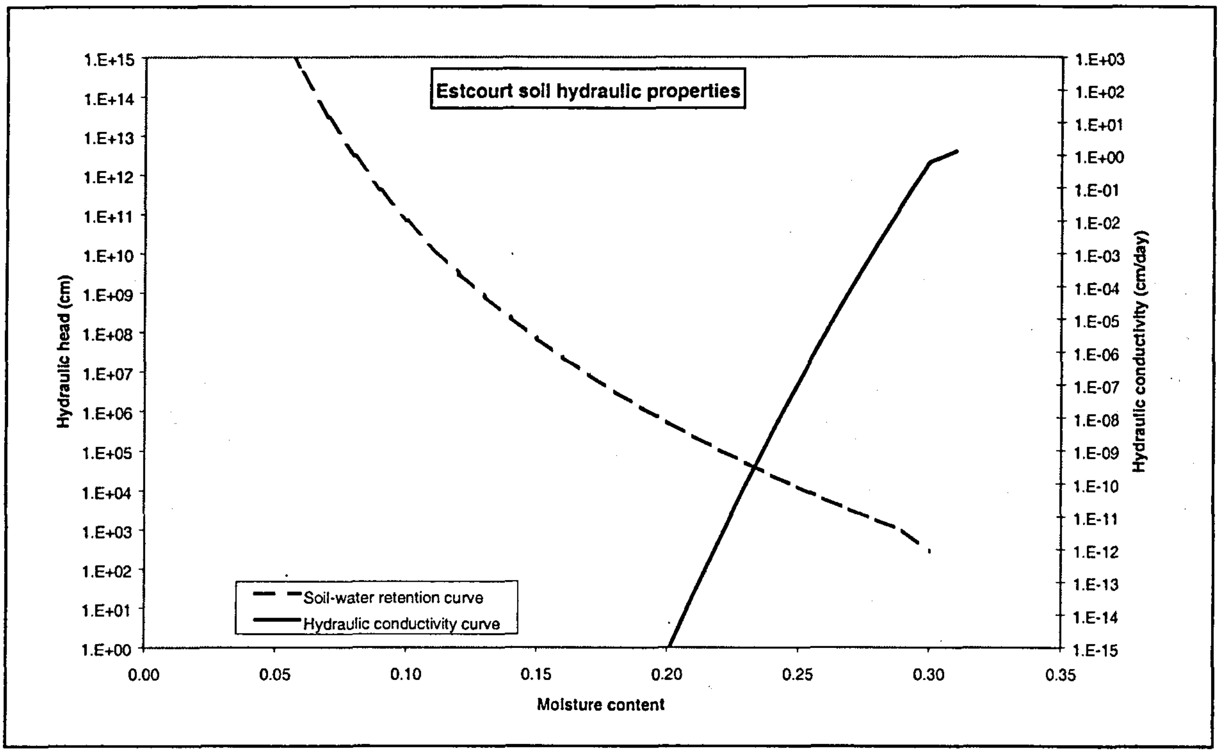


Figure 5.11: Field water retention and hydraulic conductivity curves for the Estcourt soil.

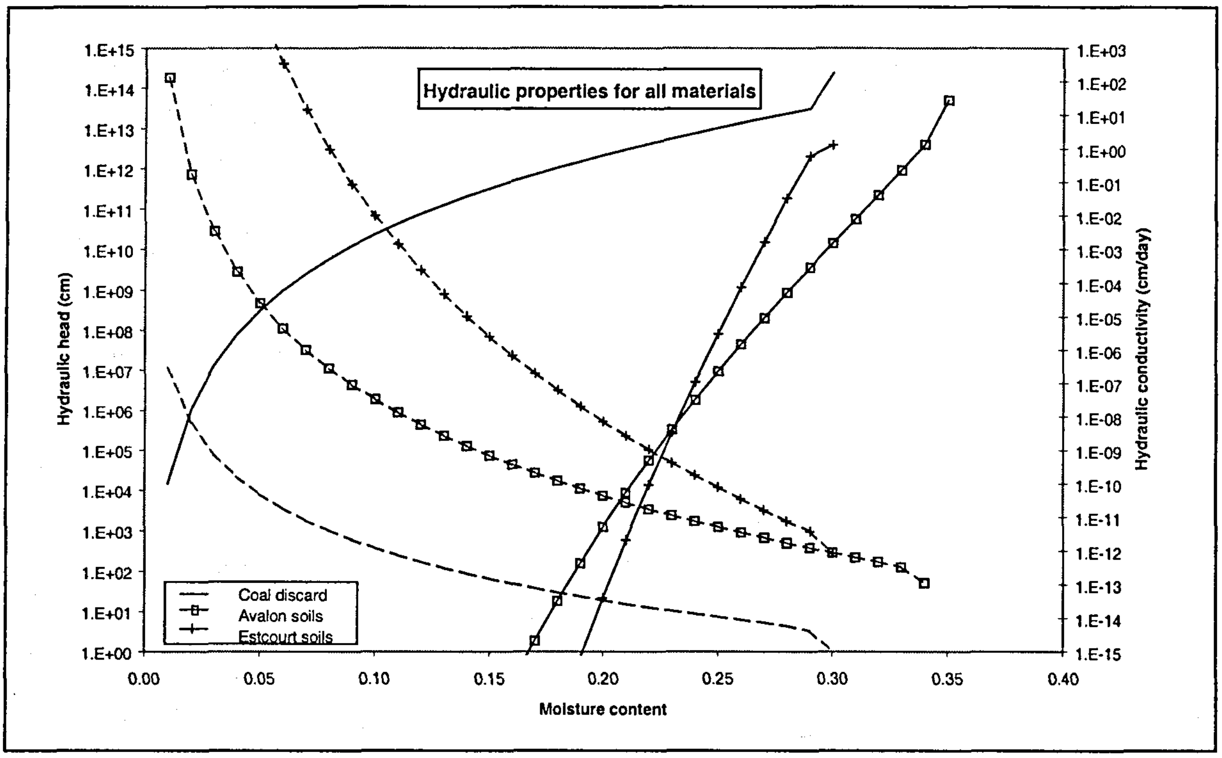


Figure 5.12: Comparative level water retention and hydraulic conductivity curves for the coal, Avalon and Estcourt

5.10.3. Chemical Properties

The coal material was chemically analysed to determine whether it could be regarded as representative discard material. Two samples taken on site were analysed by Trans-Natal Laboratories for the calorific value, proximate analysis and sulphur content. The results are summarised in **Table 5.6.**

Table 5.6: Calorific value, proximate and sulphur analysis of coal waste used to construct the cells of the Kilbarchan experiment.

Sample No.	Calorific Value) (MJ/kg)	Inherent Moisture[a] (%)	Ash Content[a] (%)	Volatile Content[a] (%)	Fixed Carbon[a] (%)	Total Sulphur (%)
Test 1	14.69	1.9	48.1	16.4	33.7	1.54
Test 2	18.27	1.5	40.8	18.8	39.0	0.91

[a] All percentage values are g/100g of dry coal waste.

Additional analysis of the sulphur content of two samples of the waste by Strydom of the Department of Metallurgical Engineering, University of Stellenbosch, showed 4.15% and 0.81% sulphur. The analyses were performed using a Leco Sulphur Analyser (Leco Corporation, London, U.K.), which combusts the coal in a stream of oxygen to yield sulphur dioxide. The latter is titrated with iodine, produced as required for the titration from potassium iodate, the consumption of which is measured.

Chemical analyses of the coal waste by Professor Hodgson and colleagues of the Institute for Ground Water Studies, University of the Orange Free State, Bloemfontein, are indicated in **Table 5.7**. The acid potential which appeared on oxidation of the waste by excess hydrogen peroxide (neutralised by 24.5mg $CaCO_3$/g) is equivalent to 0.77% unoxidized sulphur in the untreated coal waste (an additional 0.35% sulphur was present as water soluble sulphate). This acid potential far exceeded the total base potential (equivalent to 0.7804mg $CaCO_3$/g), indicating that chemical and bacterial mechanisms for the generation of acidity from the sulphur would result in the production of acid drainage.

In order to determine whether there would be any difference between the characteristics of the Avalon and Estcourt soils as a cover material, in lieu of the similar physical properties observed, a detailed clay mineralogical analysis have been conducted. These analyses have been conducted by the Institute for Soil Climate and Water. The results are listed in **Table 5.8.**

Table 5.7: Chemical analyses of coal waste used to construct the cell of the pilot scale dump rehabilitation experiment near the Kilbarchan mine.

Elemental Analysis (mg/kg)	Water-soluble components (aqueous extract)	Components liberated by H_2O_2 oxidation
Aluminium	ND	693.0
Boron	3.3	ND
Barium	1.0	ND
Calcium	3380	2700
Cadmium	ND	4.3
Cobalt	ND	3.5
Copper	ND	6.3
Iron	0.9	9929.1
Potassium	68.8	135.1
Magnesium	284.2	290.5
Manganese	13.4	48.4
Sodium	141.5	126.1
Nickel	ND	ND
Strontium	72.9	35.0
Zinc	0.7	7.7
Acid potential as $CaCO_3$ (mg/g)[b]	10989.6	24500.4
Base potential as $CaCO_3$ (mg/g)[b]	540.0	240.4
PH	7.20	1.90

Table 5.8: Clay mineralogy analysis samples of Avalon and Estcourt soils of less than 2mm in particle size.

Element Analysed	Avalon Soil	Estcourt Soil
Clay Mineralogy		
pH (H_2O)	6.69	7.84
pH (KCl)	5.47	6.38
Carbon (Walkeley-Black)	0.56%	0.62%
Quartz	54%	52%
Kaolinite	24%	30%
Smectite	8%	14%
Mica	9%	4%
Goethite	5%	ND
Exchange sodium percentage (ESP)	2.59%	1.97%
Exchangeable/Extractable Cations [me/100g soil] (Amm). Acetate Method)		
Sodium (Na)	0.38	0.41
Potassium (K)	0.27	0.32
Calcium (Ca)	5.08	7.54
Magnesium (Mg)	5.23	6.90
S value	10.96	15.17
T value (CEC)	14.67	20.86
Saturation Extract Soluble Cautions [me/100g soil] (Water Soluble Extr.)		
Sodium (Na)	0.25	0.10
Potassium (K)	ND	ND
Calcium (Ca)	0.13	0.09
Magnesium (Mg)	0.17	0.12
Conductivity (mS/m)	100.00	57.00
Anion	ND	ND
Cation	9.88	5.44
Sodium absorption ration (SAR)	2.72	1.33
Saturation	55.06%	56.36%

The difference between the Avalon and the Estcourt soil in the context of the experiment is that the one might be expected (in terms of its classification). Avalon soils are more resistant to dispersion and more permeable than the Estcourt soils. This difference would normally be explained in terms of the clay mineralogy of the two soil materials. The clay fraction mineralogy is quite similar in both soils, although Estcourt does seem to contain more smectitie (which, through swelling, can contribute to structural instability and impermeability) and, more significantly, it does not contain goethite (a structural stabilising iron hydroxide), whereas the Avalon does.

Beyond this, the chemical differences between the two soils are minor, with the Avalon actually having a slightly higher ESP and SAR than the Estcourt, but also having a high EC, which favours the maintenance of a more flocculated condition during rainwater impact of the soil surface. Overall, the iron oxide content of the Avalon soil is probably the main reason for the physically different character compared with the Estcourt soil of similar clay content. The other properties are not sufficiently dissimilar to be implicated in the differences in physical behaviour of the two soils.

6. EXPERIMENTAL RESULTS

6.1. OXYGEN AND CARBON DIOXIDE DATA

The results of the oxygen and carbon dioxide are indicated in **Appendix E.** **Table 6.1** indicates averaged oxygen concentrations for the ten seasons and **Table 6.2** indicates similar data for the carbon dioxide concentrations.

Table 6.1: Oxygen concentrations for seasons Oct 93, Mar 94 to Oct 97, Jan 98

Season	Cell									
	1	2	3	4	5	6	7	8	9	10
Oct 93 - Mar 94 (%)	17.0	17.0	19.0	13.3	0.9	1.2	0.7	0.7	0.0	0.0
Apr 94 - Sep 94 (%)	18.2	18.1	19.5	15.6	1.9	0.2	0.0	0.0	0.0	0.1
Oct 94 - Mar 95 (%)	19.0	18.7	18.9	16.8	2.6	0.5	0.0	0.2	0.2	0.5
Apr 95 - Sep 95 (%)	18.9	19.0	19.6	16.2	6.3	4.0	3.9	3.4	3.4	5.2
Oct 95 - Mar 96 (%)	16.5	15.8	17.7	15.3	11.4	10.3	9.9	10.0	10.3	11.2
Apr 96 - Sep 96 (%)	19.0	19.1	19.5	17.4	6.8	0.8	0.7	0.1	0.0	0.0
Oct 96 - Mar 97 (%)	18.5	18.6	19.8	15.3	0.0	0.0	0.0	0.0	0.0	0.0
Apr 97 - Sep 97 (%)	17.9	18.3	19.8	15.8	0.0	0.0	0.0	0.0	0.0	0.0
Oct 97 - Jan 98 (%)	17.6	17.9	19.7	14.9	0.0	0.0	0.0	0.0	0.0	0.0
Total period (%)	18.1	18.0	19.3	15.5	2.9	1.6	1.4	1.4	1.4	1.7

Table 6.2: Carbon dioxide concentrations for seasons Oct 93, Mar 94 to Oct 97, Jan 98

Season	Cell									
	1	2	3	4	5	6	7	8	9	10
Oct 93 – Mar 94 (%)	1.2	1.2	0.5	2.0	4.3	3.8	4.1	3.4	4.7	5.0
Apr 94 - Sep 94 (%)	1.2	1.2	0.3	2.1	4.7	5.0	5.0	5.0	4.9	5.0
Oct 94 - Mar 95 (%)	1.4	1.5	0.5	1.5	4.5	5.0	5.0	5.0	5.0	5.0
Apr 95 - Sep 95 (%)	1.3	1.4	0.3	2.4	4.8	5.0	5.0	5.0	5.0	5.0
Oct 95 - Mar 96 (%)	1.1	1.3	0.8	1.6	2.9	4.0	3.7	4.0	4.4	4.2
Apr 96 - Sep 96 (%)	1.2	1.2	0.3	1.5	3.5	4.9	4.9	5.0	5.0	5.0
Oct 96 - Mar 97 (%)	1.1	1.2	0.3	1.6	5.0	5.0	5.0	5.0	5.0	5.0
Apr 97 - Sep 97 (%)	1.2	1.2	0.3	1.5	5.0	5.0	5.0	5.0	5.0	5.0
Oct 97 - Jan 98 (%)	1.2	1.2	0.2	1.6	5.0	5.0	5.0	5.0	5.0	5.0
Total period (%)	1.2	1.2	0.4	1.7	4.5	4.7	4.7	4.7	4.9	4.9

Tables 6.3 and **6.4** depict variations in oxygen and carbon dioxide concentrations with respect to slope and vegetation, i.e. accordance with the cover type and **Figures 6.1 – 6.6** depicts these results for the different cover configurations.

Table 6.3: Oxygen concentrations

Cover Type (Cell no.)	Unvegetated		Vegetated		Total period	
	Flat	Sloped	Flat	Sloped	Flat	Sloped
Uncovered cells (1,2)	18.0%	-	-	-	18.0%	-
Uncovered (3)	19.3%	-	19.3%	-	19.3%	-
Covered cells (4 - 10)	3.4%	0.0%	5.2%	2.2%	4.6%	1.5%
Cover less 300 mm (4)	14.4%	-	16.0%	-	15.5%	-
Cover more 300 mm (5 - 10)	0.7%	0.0%	2.5%	2.2%	1.8%	1.5%
Soil only covered (4,5,7)	5.4%	-	6.0%	-	6.6%	-
Soil and clay covered (6,8,9,10)	0.5%	0.0%	2.1%	2.2%	1.5%	1.5%

Table 6.4: Carbon dioxide concentrations

Cover Type (Cell no.)	Unvegetated		Vegetated		Total period	
	Flat	Sloped	Flat	Sloped	Flat	Sloped
Uncovered cells (1,2)	1.2%	-	-	-	1.2%	-
Uncovered (3)	0.4%	-	0.4%	-	0.4%	-
Covered cells (4 - 10)	3.9%	4.9%	4.1%	4.9%	4.1%	4.9%
Cover less 300 mm (4)	2.0%	-	1.7%	-	1.7%	-
Cover more 300 mm (5 - 10)	4.4%	4.9%	4.7%	4.9%	4.7%	4.9%
Soil only covered (4,5,7)	3.7%	-	3.9%	-	3.7%	-
Soil and clay covered (6,8,9,10)	4.3%	4.9%	4.8%	4.9%	4.7%	4.9%

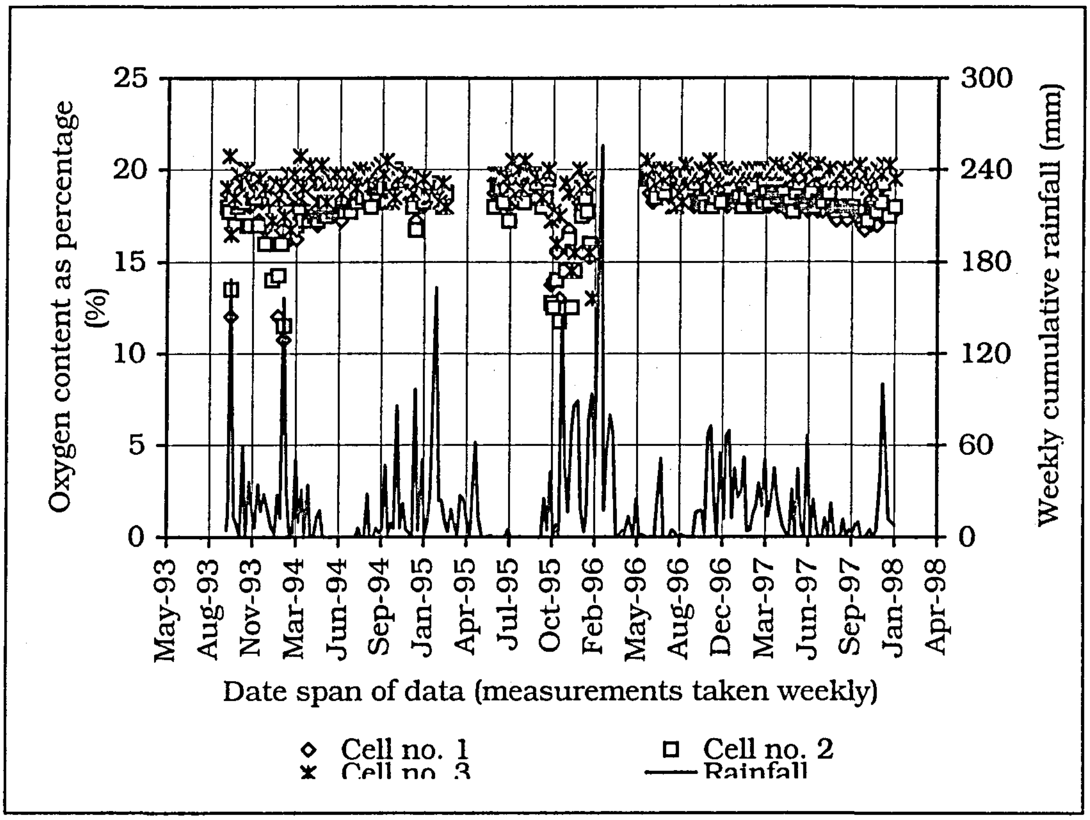


Figure 6.1: Oxygen concentrations measured in the uncovered cells (1 – 3) from October 1993 – January 1998 plotted against the rainfall for the same period.

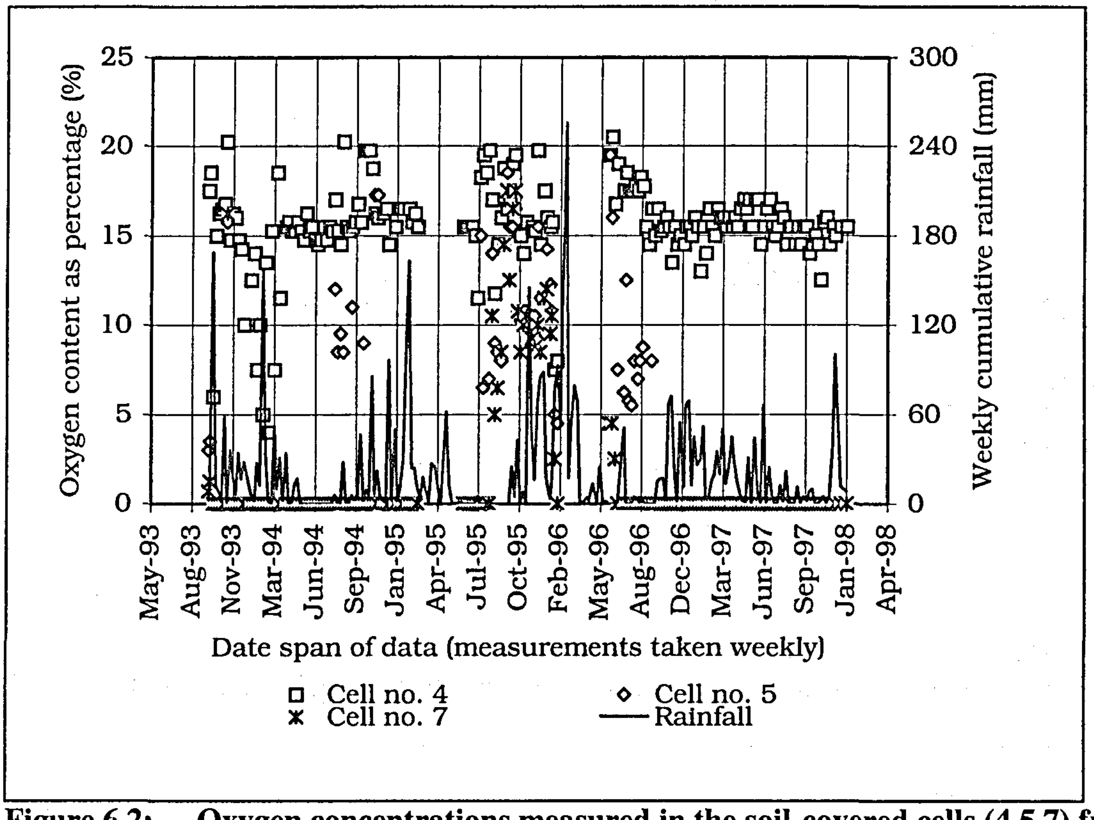


Figure 6.2: Oxygen concentrations measured in the soil-covered cells (4,5,7) from October 1993 – January 1998 plotted against the rainfall for the same period.

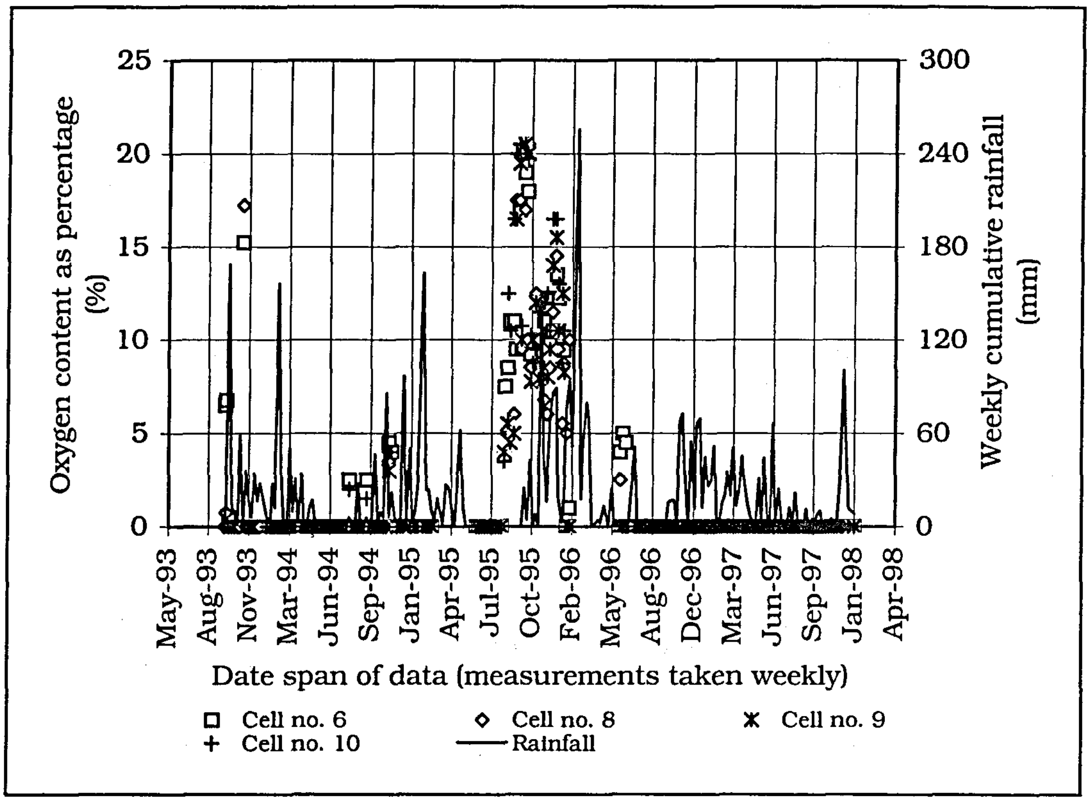


Figure 6.3: Oxygen concentrations measured in the soil and clay covered cells (6,8,9,10) from October 1993 – January 1998 plotted against the rainfall for the same period.

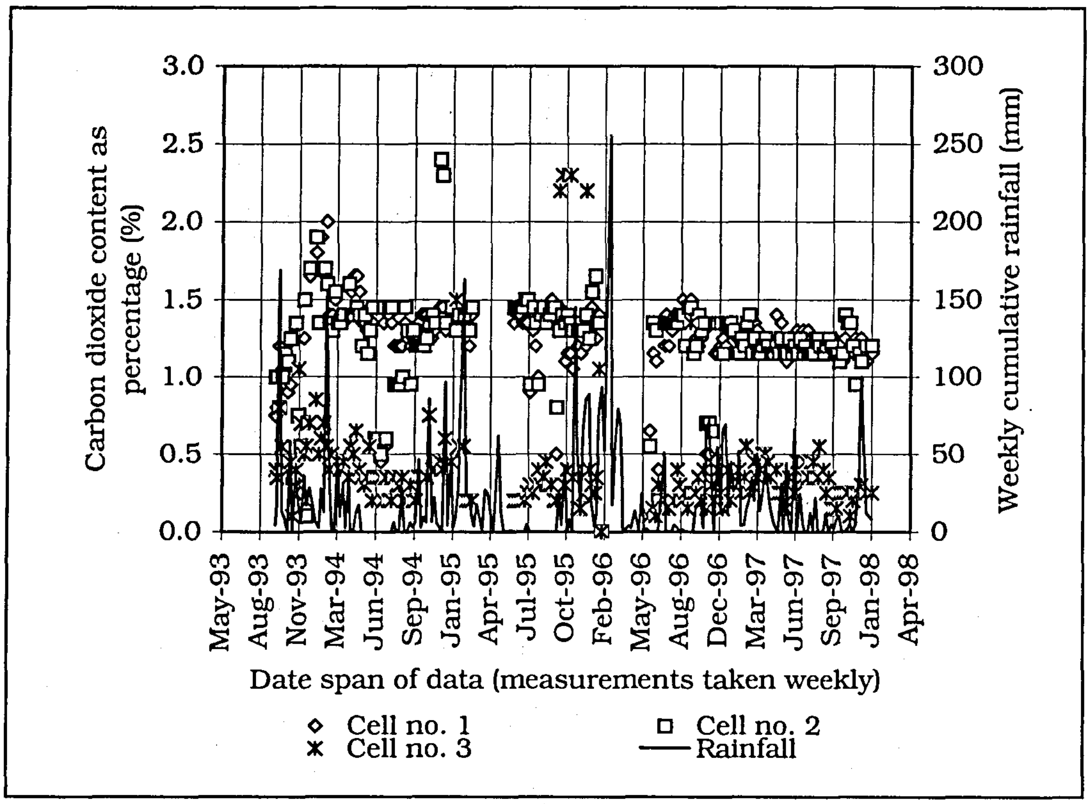


Figure 6.4: Carbon dioxide concentrations measured in the uncovered cells (1 – 3) from October 1993 – January 1998 plotted against the rainfall for the same period.

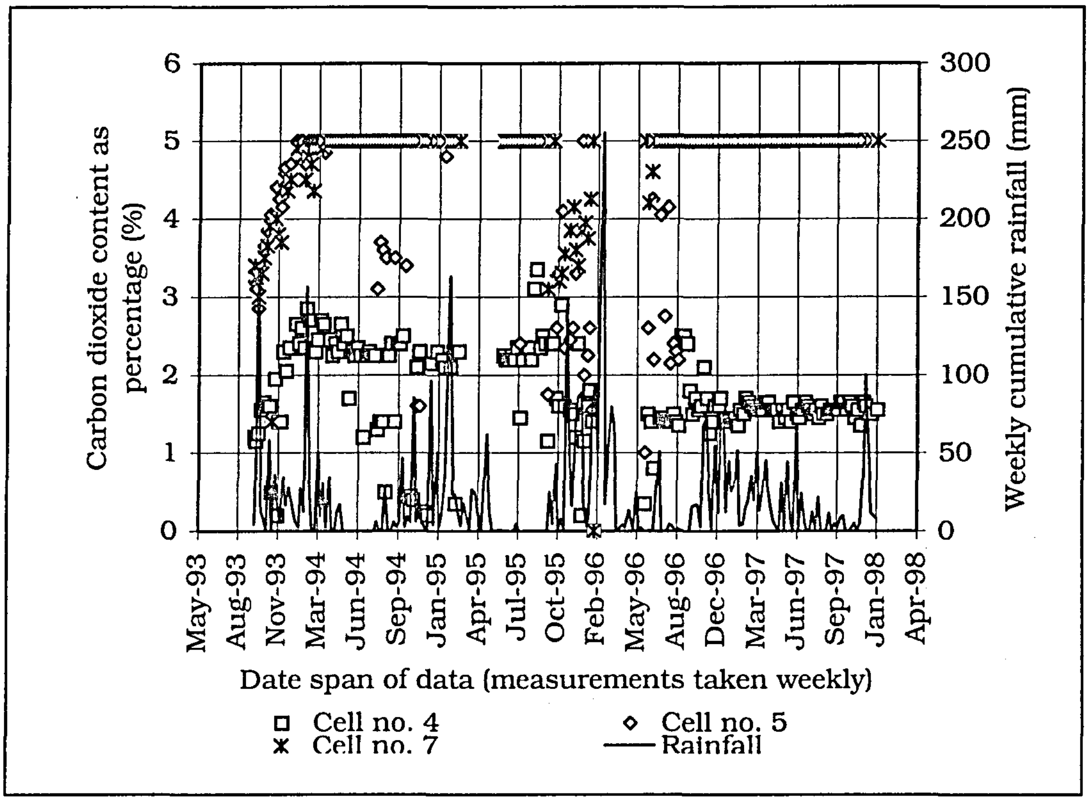
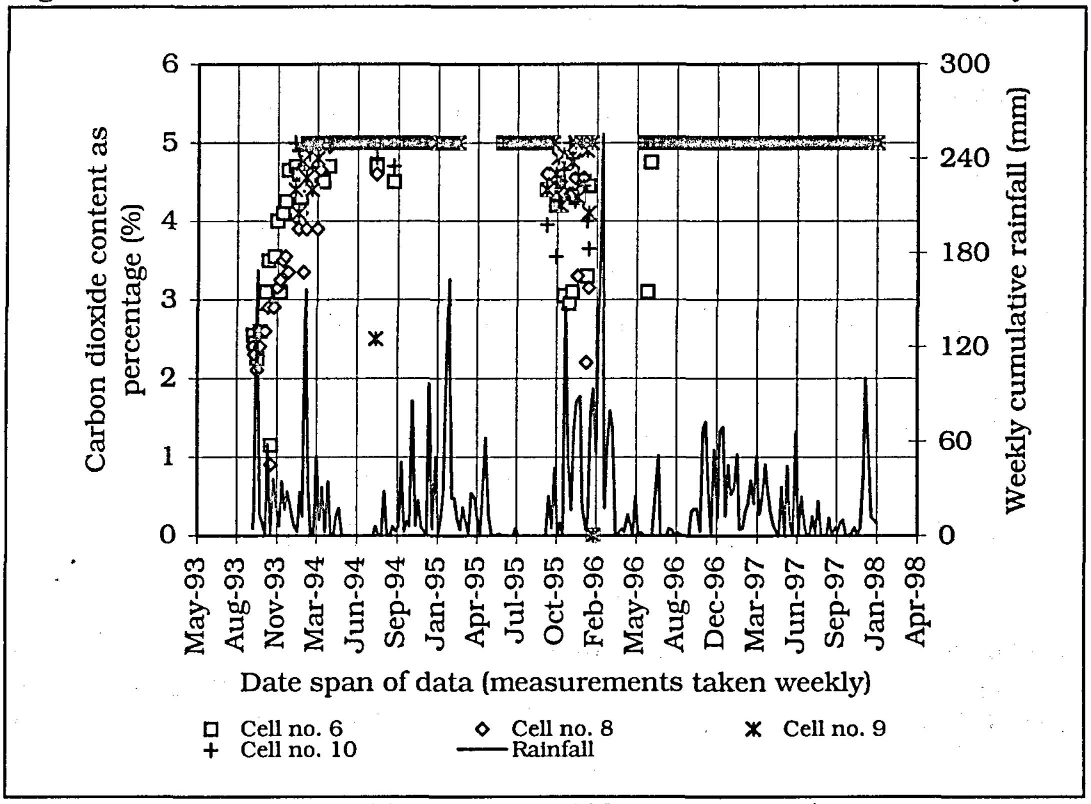


Figure 6.5: Carbon dioxide concentrations measured in the soil covered cells (4,5,7) from October 1993 – January 1998 plotted against the rainfall for the same period.

Figure 6.6: Carbon dioxide concentrations measured in the soil and clay covered cells (6,8,9,10) from October 1993 – January 1998 plotted against the rainfall for the same period.



6.2. WEATHER DATA

The experimental site is equipped with a data logger measuring rainfall, relative humidity, net radiation and temperature continuously. Average relative humidity, temperature and radiation are logged every hour, while the cumulative rainfall for each hour is logged. This data is too voluminous to include in an Appendix, but graphs depicting the general patterns are included in **Figures 6.7 – 6.10** (see **Tables 6.5 – 6.9**).

The weather station on the experimental site operated continuously from February 1994 to January 1998 giving hourly readouts of average air temperature. Extremely large fluctuations (as much as 30°C in July 1994) were sometimes noted over a 24-hour period. Temperatures as high as 30°C during the day in summer and as low as -7°C during the early morning in winter were recorded.

The rainfall is highly seasonal. Rainfall occur mainly during summer, with the rainy season starting in September or October and lasting until April or May. The winters are dry with very little or no rainfall occurring from May to September. Exceptional winter rainfall of 4.5 and 23.0 mm occurred in August 1994. The 1994/1995 rainy season was relative dry. This, combined with the dry winters in 1994 and 1995, caused the soil covers to dry out by September 1995. Because of the clayey nature of the cover materials, large cracks appeared in the covers as well as in the walls separating the individual cells.

Although the 1995/1996 rainy season started late (October), it was particularly wet. The cracks in both the covers and the separating walls closed by the middle of the rainy season. **Table 6.6** summarises rainfall events that occurred at the site and also, indicate the frequency of rainfall events of certain magnitudes.

Irregular results for all the climatic variables were observed for the 1996, 1997 season. Closer evaluation led to the conclusion that the data was unusable, as a result of all the instruments recording faulty data. A probable lightning could have been the cause. The rainfall data was however still available.

Table 6.5 : Summary of seasonal rainfall data

Season	Total (mm)	Maximum Event (mm)
Annual MAP (1941 - 71)	873.0	-
Summer MAP (Oct - Mar)	721.6	-
Winter MAP (Apr - Sep)	151.4	-
Oct 93 – March 94	767.6	79.9
Apr 94 – Sep 94	124.4	33.8
Oct 93 - Sep 94 (Total for 1994)	892.0	79.9
Oct 94 – Mar 95	633.7	107.0
Apr 95 – Sep 95	95.4	39.2
Oct 94 - Sep 95 (Total for 1995)	729.1	107.0
Oct 95 – Mar 96	1256.9	110.4
Apr 96 – Sep 96	125.7	22.4
Oct 95 - Sep 96 (Total for 1996)	1382.6	110.4
Oct 96 – Mar 97	872.4	No data
Apr 97 – Sep 97	243.0	No data
Oct 96 - Sep 97 (Total for 1997)	1115.4	No data
Oct 97 – Jan 98	190.0	No data
Oct 93 - Jan 98 (Total period)	4309.1	110.4

Table 6.6 : Summary of daily magnitude rainfall events (Oct 93 - Jan 97)

Rainfall condition	No. of events	% of events
Total no. of days	1176	100.0%
No. of rainfall days	369	31.4%
Rainfall days < 5 mm	220	59.6
Rainfall days > 5 mm	149	16.5%
Rainfall days > 10 mm	88	5.7%
Rainfall days > 15 mm	67	3.5%
Rainfall days > 20 mm	54	3.8%
Rainfall days > 25 mm	40	1.9%
Rainfall days > 30 mm	33	4.1%
Rainfall days > 40 mm	18	1.7%
Rainfall days > 50 mm	12	2.4%
Rainfall days > 75 mm	3	0.3%
Rainfall days > 100 mm	2	0.5%

Table 6.7: Summary of seasonal temperature data

Season	Average Temperature (°C)	Maximum Temperature (°C)	Minimum Temperature (°C)
Oct 93 – Mar 94	20.6	28.7	11.50
Apr 94 – Sep 94	12.6	25.0	2.45
Oct 93 - Sep 94 (Total for 1994)	16.8	28.7	2.45
Oct 94 – Mar 95	20.0	27.4	10.50
Apr 95 – Sep 95	13.8	24.7	3.92
Oct 94 - Sep 95 (Total for 1995)	17.4	27.4	3.92
Oct 95 – Mar 96	20.0	28.4	10.90
Apr 96 – Sep 96	13.2	25.2	0.95
Oct 95 - Sep 96 (Total for 1996)	16.6	28.4	0.95
Oct 96 – Mar 97	19.7	26.2	11.05
Apr 97 – Sep 97	No data	No data	No data
Oct 96 - Sep 97 (Total for 1997)	No data	No data	No data
Oct 97 – Jan 98	No data	No data	No data
Oct 93 - Jan 98 (Total period)	17.1	28.7	0.95

Table 6.8: Summary of seasonal net radiation data

Season	Average Radiation (W/m^2)	Maximum Radiation (W/m^2)	Minimum Radiation (W/m^2)
Oct 93 - Mar 94	162.1	579.7	9.6
Apr 94 - Sep 94	119.7	254.6	11.0
Oct 93 - Sep 94 (Total for 1994)	141.5	579.7	9.5
Oct 94 - Mar 95	172.8	255.2	24.5
Apr 95 - Sep 95	125.5	196.7	16.2
Oct 94 - Sep 95 (Total for 1995)	149.1	255.2	16.2
Oct 95 - Mar 96	156.6	262.0	23.7
Apr 96 - Sep 96	109.5	197.3	9.6
Oct 95 - Sep 96 (Total for 1996)	133.1	263.0	9.6
Oct 96 - Mar 97	155.3	251.2	42.8
Apr 97 - Sep 97	No data	No data	No data
Oct 96 - Sep 97 (Total for 1997)	No data	No data	No data
Oct 97 - Jan 98	No data	No data	No data
Oct 93 - Jan 98 (Total period)	141.8	331.3	9.6

Table 6.9 : Summary of seasonal relative humidity data

Season	Average Humidity (%)	Maximum Humidity (%)	Minimum Humidity (%)
Oct 93 - Mar 94	64	100	30
Apr 94 - Sep 94	53	94	12
Oct 93 - Sep 94 (Total for 1994)	58	100	12
Oct 94 - Mar 95	60	93	24
Apr 95 - Sep 95	59	100	21
Oct 94 - Sep 95 (Total for 1995)	59	100	21
Oct 95 - Mar 96	71	100	18
Apr 96 - Sep 96	62	100	9
Oct 95 - Sep 96 (Total for 1996)	66	100	9
Oct 96 - Mar 97	68	100	30
Apr 97 - Sep 97	No data	No data	No data
Oct 96 - Sep 97 (Total for 1997)	No data	No data	No data
Oct 97 - Jan 98	No data	No data	No data
Oct 93 - Jan 98 (Total period)	62	100	9

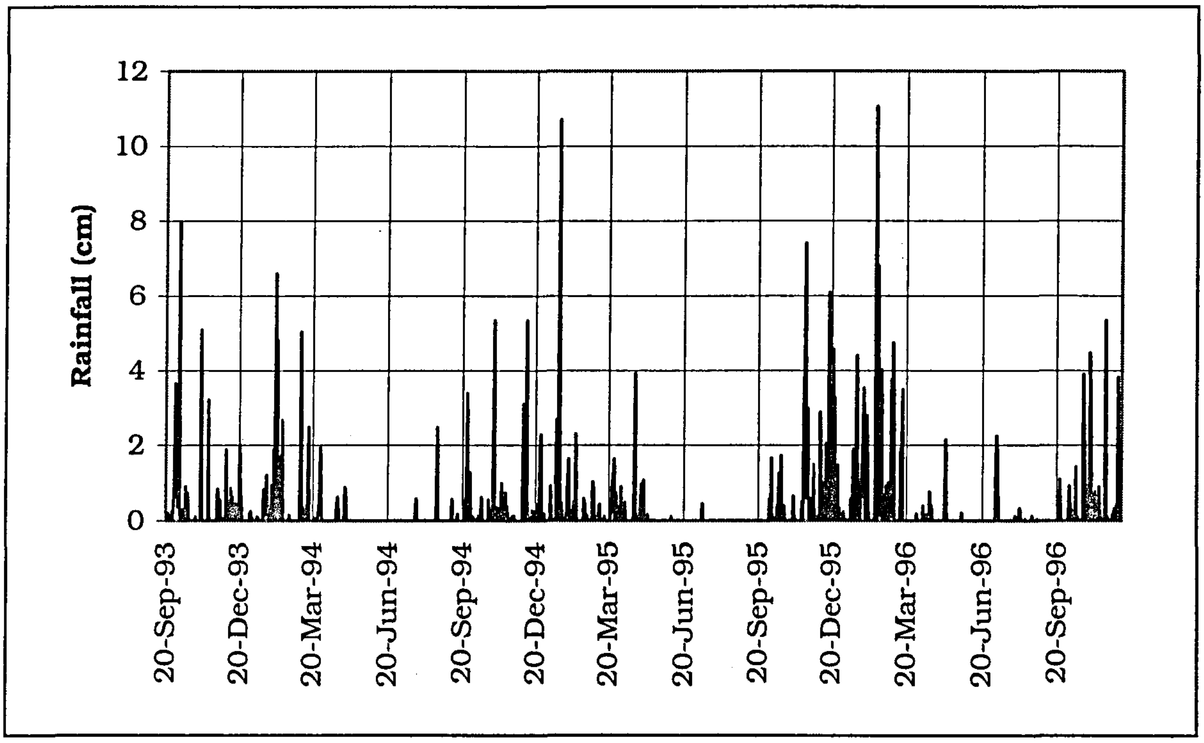


Figure 6.7: Cumulative 24-hour rainfall data for the period Oct 93 – Jan 97.

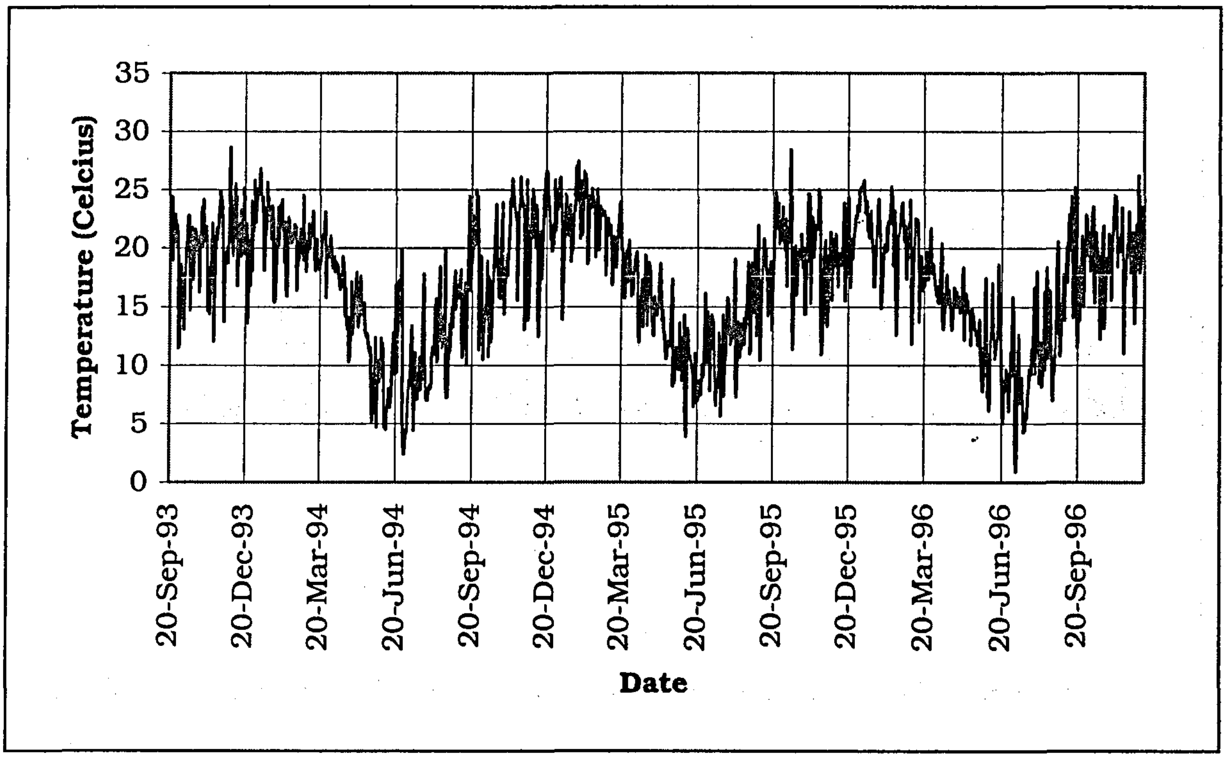


Figure 6.8: Average daily temperatures for the period Oct 93 - Jan 97.

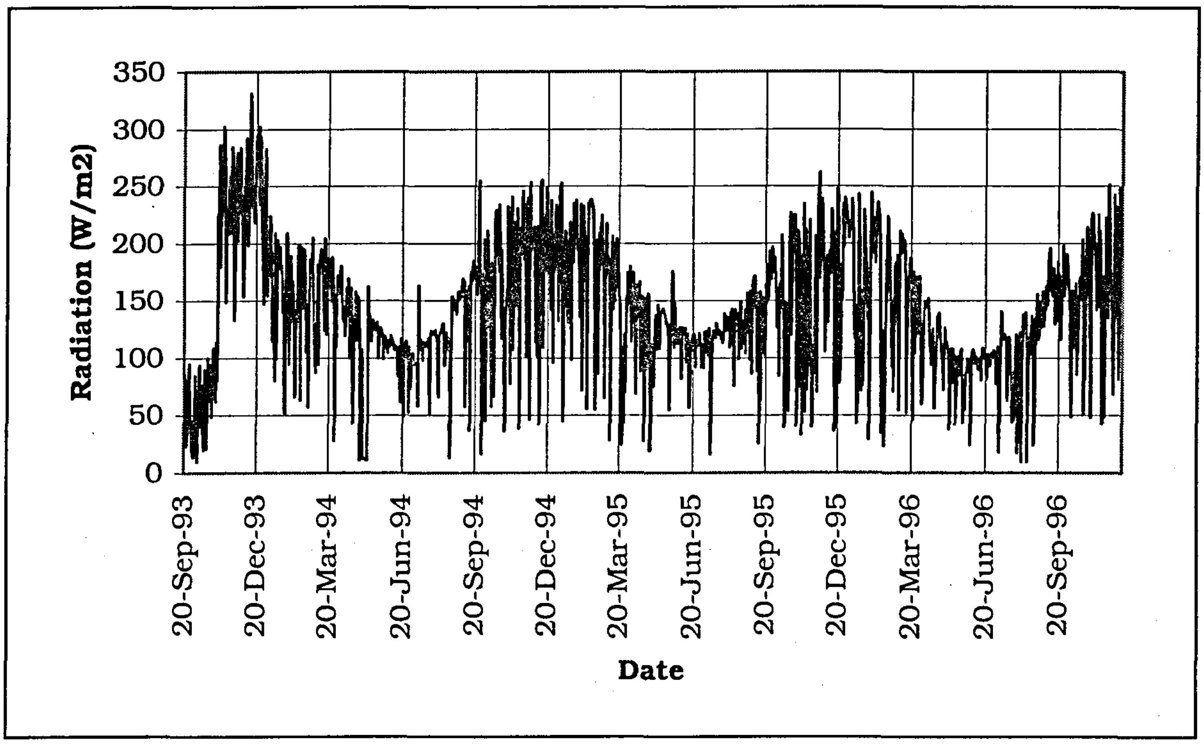


Figure 6.9: Average daily net radiation for the period Oct 93 - Jan 97.

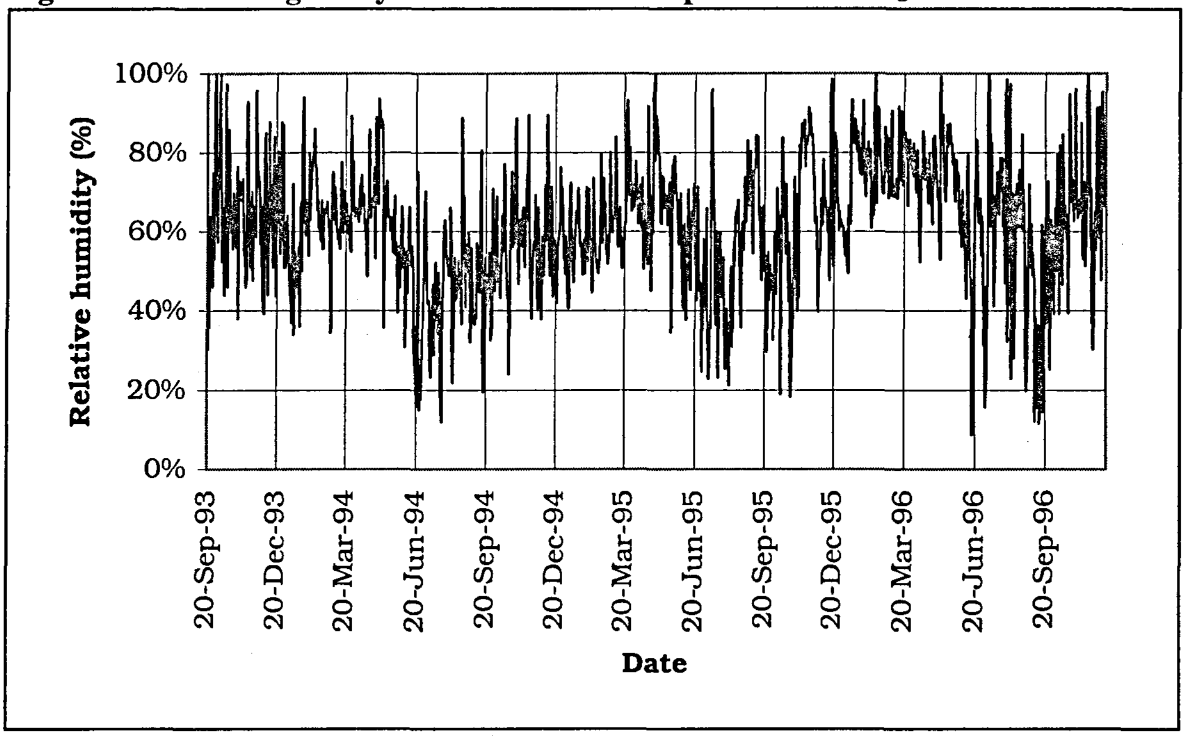


Figure 6.10: Average daily relative humidity for the period Oct 93 - Jan 97.

6.3. SOIL TEMPERATURES

The soil and coal discard temperatures has been measured at depths of 0.30 m and 0.72 m in cell 6 from March to December 1994 and at a depth of 1.65 m from March 1994 to May 1995. The interface at 0.3 m depth between the top and the lower soil layers showed considerable temperature fluctuations (up to 5°C) over a 24-hour period. A maximum temperature of 29°C in March 1994 and a minimum of 9°C in July 1994 were measured in cell 6. Long term seasonal variations have been noted, but the soil temperatures never reached as low or as high levels as the atmospheric temperatures.

At the 0.72 m depth in the Estcourt layer, differences between the corresponding day and night temperatures were less pronounced than at the 0.3 m depth, being almost negligible. However, long-term seasonal temperature variation was observed at this depth.

Corresponding day and night temperatures were almost identical (differences of less that 0.5°C) in the coal discard at 1.65 m depth. The seasonal changes were also less pronounced than at shallower depths, but mean temperatures of 24°C during summer and 16°C during winter were recorded.

6.4. OUTFLOW MEASUREMENTS

Outflow was measured weekly, giving cumulative outflow results for periods of approximately 7 days at a time. The complete results are shown in **Appendix F**, and seasonal summaries are presented in **Tables 6.10 – 6.11** and **Figures 6.11 - 6.13.**

Table 6.10 : Outflow results for Cell 1 - 5

Season	Cell				
	1	2	3	4	5
Oct 93 - Mar 94	10.2%	9.7%	6.0%	5.1%	3.2%
Apr 94 - Sep 94	57.3%	34.4%	55.7%	29.8%	15.5%
Oct 93 - Sep 94 (Total for 194)	16.8%	13.1%	13.0%	8.5%	4.9%
Oct 94 - Mar 95	10.9%	12.1%	12.1%	2.6%	0.7%
Apr 95 - Sep 95	18.7%	34.7%	57.2%	0.0%	0.0%
Oct 94 - Sep 95 (Total for 1995)	11.9%	15.0%	18.0%	2.3%	0.6%
Oct 95 - Mar 96	18.5%	16.7%	18.2%	11.2 %	10.9%
Apr 96 - Sep 96	87.2%	68.6%	29.8%	83.8%	17.8%
Oct 95 - Sep 96 (Total for 1996)	24.8%	21.4%	19.3%	17.8%	11.5%
Oct 96 - Mar 97	27.4%	20.3%	27.7%	9.1%	9.3%
Apr 97 - Sep 97	60.2%	89.3%	159.5%	101.1%	74.8%
Oct 96 - Sep 97 (Total for 1997)	34.5%	35.3%	55.8%	29.2%	23.6%
Oct 97 - Jan 98	78.1%	1.9%	125.4%	82.9%	60.1%
Oct 93 - Jan 98 (Total period)	25.8%	21.3%	31.9%	19.0%	13.6%

Table 6.11 : Outflow results for Cell 6 - 10

Season	Cell				
	6	7	8	9	10
Oct 93 - Mar 94	3.6%	4.7%	3.8%	0.1%	0.9%
Apr 94 - Sep 94	26.0%	39.1%	27.6%	0.0%	0.0%
Oct 93 – Sep 94 (Total for 1994)	6.8%	9.5%	7.2%	0.1%	0.8%
Oct 94 - Mar 95	3.4%	4.0%	3.3%	0.0%	0.0%
Apr 95 - Sep 95	0.0%	0.0%	0.0%	0.0%	0.0%
Oct 94 – Sep 95 (Total for 1995)	3.0%	3.5%	2.9%	0.0%	0.0%
Oct 95 - Mar 96	14.2%	12.6%	15.1%	15.1%	10.3%
Apr 96 - Sep 96	32.9%	38.4%	32.2%	42.4%	64.9%
Oct 95 - Sep 96 (Total for 1996)	15.9%	15.0%	16.7%	17.6%	15.3%
Oct 96 - Mar 97	2.2%	0.8%	11.0%	9.4%	7.2%
Apr 97 - Sep 97	32.8%	3.2%	91.9%	70.6%	129.1%
Oct 96 - Sep 97 (Total for 1997)	8.8%	1.3%	28.6%	22.8%	33.7%
Oct 97 - Jan 98	121.9%	40.3%	108.7%	44.6%	68.0%
Oct 93 - Jan 98 (Total period)	14.6%	9.5%	19.5%	13.5%	16.8%

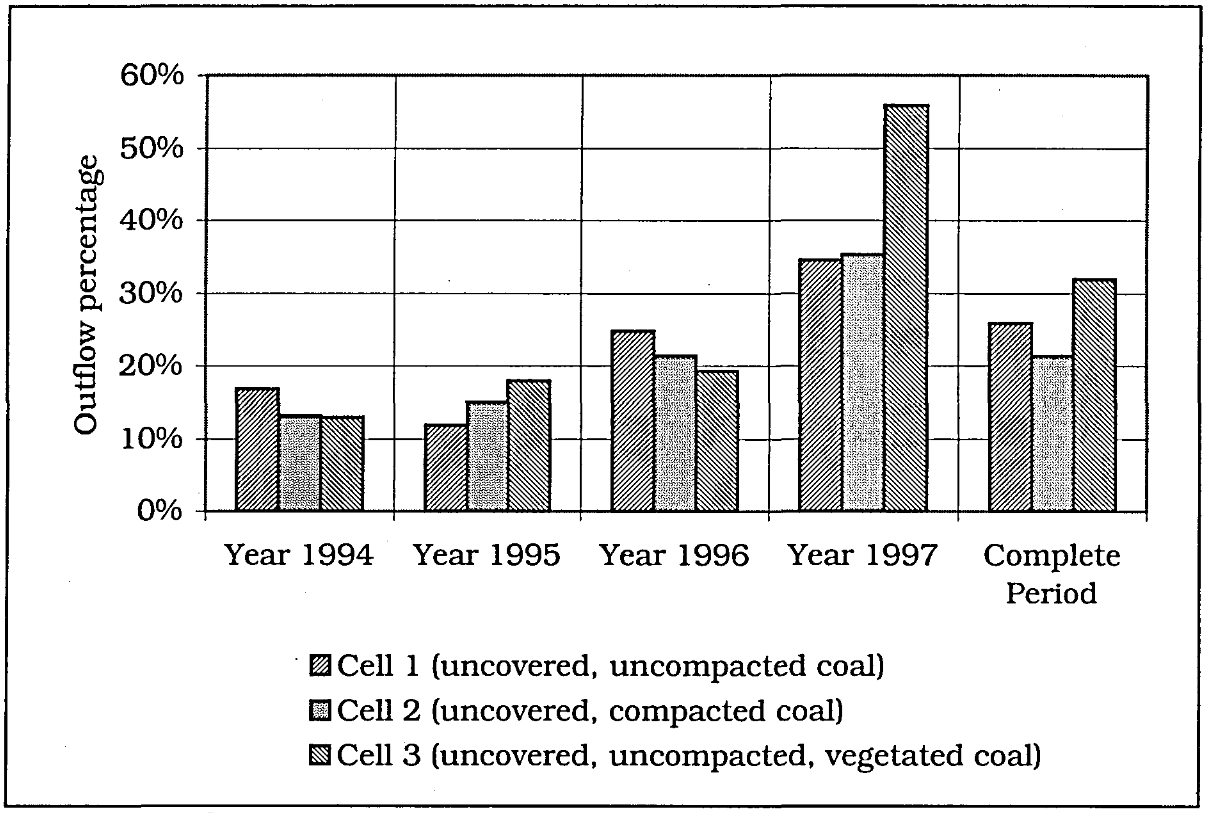


Figure 6.11: Outflow through cells 1 - 3

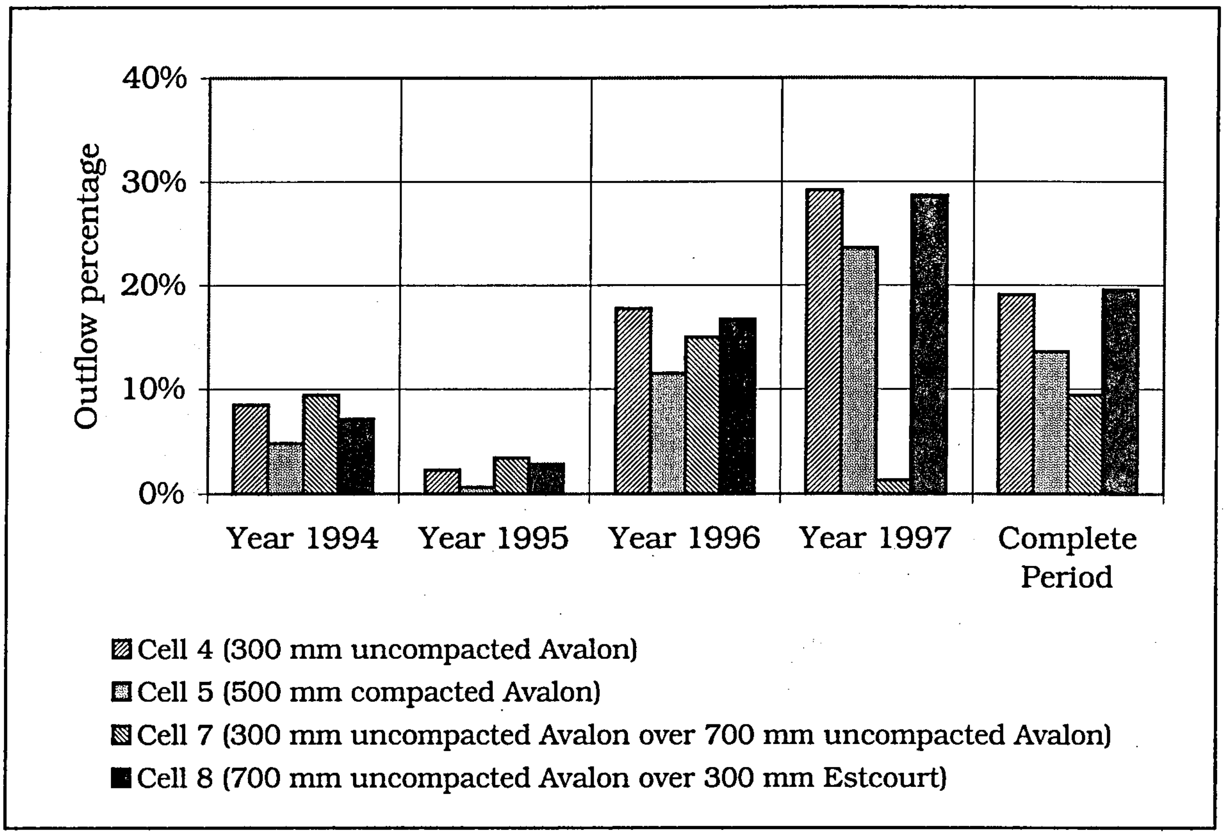


Figure 6.12: Outflow through cells 4, 5, 7, 8

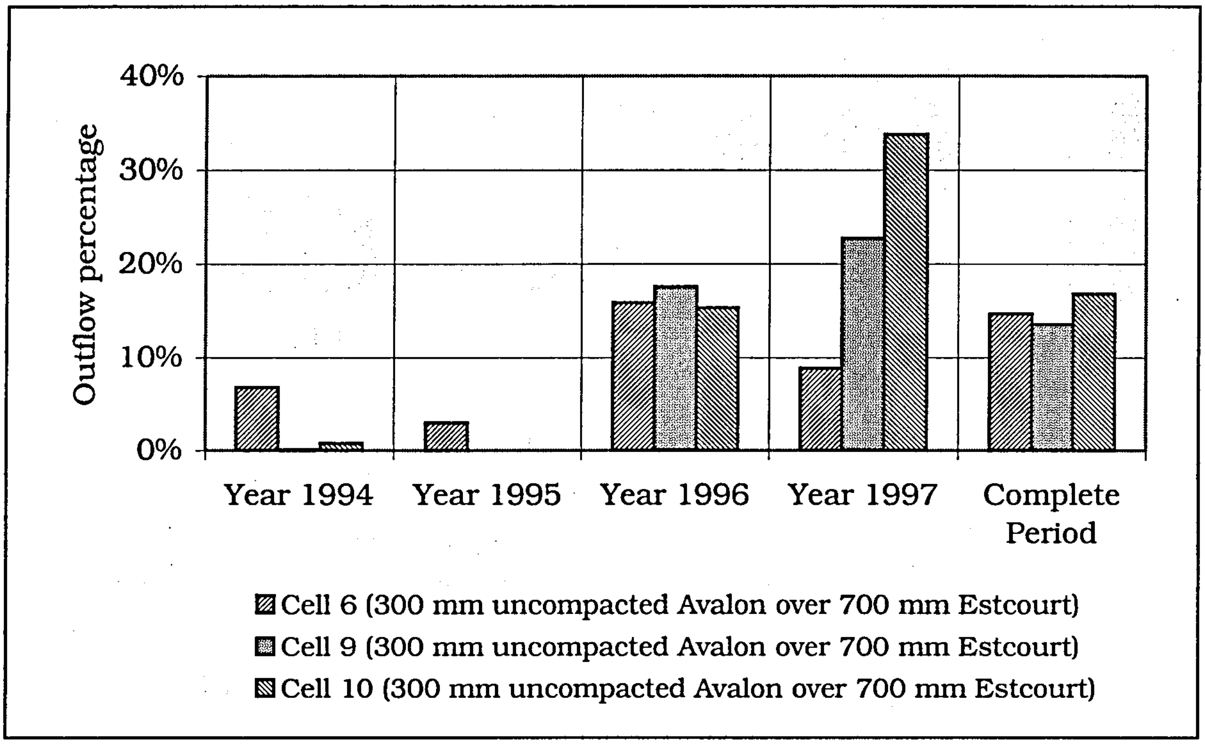


Figure 6.13: Outflow through cells 6, 9, 10

7. DISCUSSION OF OUTFLOW RESULTS

7.1 HYPOTHESIS

The experimental cells have been chosen as such that certain physical attributes could be monitored and compared namely :

- Cover vs. no cover
- Vegetation vs. no vegetation
- Effect of slope
- Single soil covers vs. layered covers
- Clay vs. sandy-loam material
- Compaction vs. no compaction
- Long-term degradation of soil covers
- Climatic conditions (variable climatic aspects).

In **Chapter 2** reported results on soil cover effectiveness have been discussed, and based on that information, the theory of unsaturated flow and the above conditions, the experimental cells would be expected to perform in an order of effectiveness indicated in **Table 7.1**:

Table 7.1 : Hypothesised order of effectiveness for the experimental cells

Least effective	Cell 1	Uncovered uncompacted
↓	Cell 2	Uncovered compacted
	Cell 3	Vegetated uncompacted
	Cell 4	Thin uncompacted sandy-loam cover
	Cell 5	Medium compacted sandy-loam cover
	Cell 7	Thick layered cover of compacted and uncompacted sandy-loam
	Cell 8	Thick layered cover of medium uncompacted sandy-loam and thin compacted clay
	Cell 6	Thick layered cover of thin uncompacted sandy-loam and thick compacted clay
	Cell 9	Similar to cell 6 but with a slope of 5%
Most effective	Cell 10	Similar to cell 6 but with a slope of 10 %

In addition, it would be expected that the cover effectiveness to increase with increased vegetative cover, and therefore, for cells 4 – 10, the cover effectivity have been expected to be lower prior to December 1994, due to the poor vegetative cover to that date. For cell 3 it was expected that cover effectivity would increase only after December 1995.

In contrast, although it has been expected that a good vegetative cover will result in increased evapotranspiration, increased infiltration rates was also expected resulting from preferential flow paths occurring as a result of root penetration. On visual inspection this was never found to be a problem.

The fact that the grass cover have been cut once a year could have resulted in the higher evapotranspiration rates compared to natural conditions because grass uses more soil moisture when it is growing than compared to a mature plant. Mowing ensures that the grass remains in the growth stadium and therefore uses more soil moisture than older adult grass would loose via evapotranspiration.

Another aspect to consider is the residence time of the flow of water through the experimental cells. It was expected that water does infiltrate into, and migrate downwards through the soil cover and coal discard under gravitational forces. This infiltration, which is not intercepted by evapotranspiration will move down at a rate governed by the soil hydraulic properties. Based on the actual soil hydraulic measurements, the expected residence time for water when the profile is completely saturated is indicated in **Table 7.2**. Simple piston-like-flow has been considered and evapotranspiration has not been taken in account.

Table 7.2 : Residence time of water flowing through the experimental cells

Cell	Time (days)	Time (hours)
1, 3	0.51	12.26
2	0.91	21.76
4	0.59	14.15
5	1.87	44.98
6, 9, 10	4.97	119.18
7	0.77	18.55
8	2.53	60.68

Table 7.2 implies an almost immediate response time in cells 1 - 4 and 7 and between 2 and 5 days for the other cells. This response time for outflow to emerge after a rainfall event would be indicative of the lag time that has been observed. However since the soil profile will not always be at saturation throughout, this lag time will be entirely dependant on climatic conditions which determines how the soil moisture profile changes.

Rainfall events of short duration and high intensity do not constitute to high infiltration rates, but rather high runoff. Since South African climatic conditions are characterised by these rainfall patterns, threshold rainfall event would be expected, whereby no infiltration would occur.

It is expected that outflow would occur mainly in the summer rainfall months, and only some time after the first rainfall occurs. This is the result of long dry seasons, which result in that moisture content in the soil profile to decrease significantly thereby necessitating a wetting period before outflow will occur. Given the relatively thin (1000mm) soil covers, outflow is not expected to continue throughout the dry season, since the available soil moisture would either evaporate or drain to the bottom in a relatively short period.

Another complicating factor in trying to predict the outflow, is the fact that the two soil types used as cover material are fairly homogenous, regarding their hydraulic properties and layers might act as a simple single layer cover. Since the coal spoil comprises of fine-grained material, moisture in the soil profile have been retained by capillary action. Normal coal spoils are highly heterogeneous, which could result in a zone of free drainage between the cover and the waste. Water that enters the waste cannot move back into the soil cover by means of capillary action.

The effect of slope on potential infiltration rates does seem obvious. Steep slopes would favour large runoff, but if the slopes are not protected against erosion, the cover will loose its ability to reduce infiltration. Normal erosion protection by vegetation could result in a false sense of success, since small catchments tend to originate along the grass tufts thereby concentrating infiltration. In this experiment this was not found to be a significant factor and severely reduced outflow results, resulting from increased slope would be expected.

One important aspect that has been considered, yet not been well investigated is the degree to which cover properties change with time. It was expected that cover effectiveness would reduce with the time because the cover hydraulic properties will change as a result of degradation. This degradation is due to desiccation cracking as a result of the wetting and drying of the soil (both seasonally and between single rainfall events), vegetation growth with its associated root penetration, burrowing animals and erosion.

7.2 CELL-BY-CELL DESCRIPTION OF RESULTS

7.2.1 Cell 1 - Uncompacted, uncovered, unvegetated Coal

Table 7.3 lists the seasonal outflow results for cell 1 and graphs depicting these results are included in **Appendix E.**

Table 7.3 : Outflow Results for Cell 1

Season	Rainfall (mm)	Outflow (mm)	Outflow (%)
Oct 93 - Mar 94 (Summer 1994)	768	79	10
Apr 94 - Sep 94 (Winter 1994)	124	71	57
Oct 93 - Sep 94 (Total for 1994)	892	150	17
Oct 94 - Mar 95 (Summer 1995)	634	69	11
Apr 95 - Sep 95 (Winter 1995)	95	18	19
Oct 94 - Sep 95 (Total for 1995)	729	87	12
Oct 95 - Mar 96 (Summer 1996)	1257	233	19
Apr 96 - Sep 96 (Winter 1996)	126	110	87
Oct 95 - Sep 96 (Total for 1996)	1383	343	25
Oct 96 - Mar 97 (Summer 1997)	872	239	27
Apr 97 - Sep 97 (Winter 1997)	243	146	60
Oct 96 - Sep 97 (Total for 1997)	1115	385	35
Oct 97 - Jan 98 (Summer 1997)	190	148	78
Oct 93 - Jan 98 (Complete period)	4309	1113	26

The outflow for the summer seasons (excluding the 1998 season, which was not a complete season) ranged between 10% and 27% with an average of 17%. The outflow increased every season, indicating a possible change in soil property with time. For the winter period it ranges between 19% and 87% with an average of 56%. Together this constitutes to an overall outflow of 26% over the entire period of monitoring. The decrease in outflow for the 1995 season, when compared to the 1994 season, can be ascribed to the lower rainfall experienced. Outflow increases in the 1996 season, with a corresponding increase in annual rainfall. However, the trend is not followed in the 1997 season, with the rainfall being marginally less than in 1996, but the outflow is more.

The results suggest that the outflow through this uncovered cell is increasing with time, even though the rainfall is less. This supports the hypothesis that a deterioration of the in-situ material is occurring, and since no steady state seems to have been reached, the further extent of deterioration is unknown.

The high outflow percentages for the winter periods is deceiving since the actual outflow volumes are very low, as can be seen from **Table 6.2.1.** Outflow in this cell never completely stops, suggesting that it retain its moisture for a long period of time. The winter season of 1996 was a particularly wet year, which could ascribe for the large outflow during this season.

The response time of outflow measured after a rainfall event would appear to be between one and two weeks. However, it must be noted that these results are weekly cumulative results and thus the response time refers to the weekly cumulative rainfall as an event, as opposed to a single shower.

7.2.2 Cell 2 - Compacted, uncovered, unvegetated Coal

The seasonal outflow results for cell 2 is listed in **Table 7.4** and presented in **Appendix E.**

The outflow for the summer seasons (excluding the 1998 season, which is not complete) ranged between 10% and 20% with an average of 15%. For the winter season it ranges between 34% and 89% with an average of 57%. This constitutes an overall outflow percentage of 21%. As was observed in cell 1, the Oct 94 - Sep 95 seasons resulted in lower outflows, caused by the lower rainfall. Similarly the 1996 season resulting from outflows and have been characterised by high rainfall than did the previous seasons. Higher outflows continued through to the 1997 season, however the rainfall was marginally lower than in 1996.

Again it would appear that a deterioration of the compacted coal material occurring, which result in a higher infiltration rates. This is further substantiated by the fact that the overall outflow percentage exceeds all of the individual season's readings.

Outflow through cell 2 continued through the winter season suggesting that significant amounts of water are retained in the profile. However, all the dry seasons have had minor rainfall events resulting in outflow. Overall, it would appear that the response time for outflow events after rainfall events is somewhere between one to two weeks.

Table 7.4: Outflow Results for Cell 2

Season	Rainfall (mm)	Outflow (mm)	Outflow (%)
Oct 93 - Mar 94 (Summer 1994)	768	74	10
Apr 94 – Sep 94 (Winter 1994)	124	43	34
Oct 93 - Sep 94 (Total for 1994)	892	117	13
Oct 94 - Mar 95 (Summer 1995)	634	76	12
Apr 95 – Sep 95 (Winter 1995)	95	33	35
Oct 94 - Sep 95 (Total for 1995)	729	110	15
Oct 95 - Mar 96 (Summer 1996)	1257	210	17
Apr 96 – Sep 96 (Winter 1996)	126	86	69
Oct 95 - Sep 96 (Total for 1996)	1383	296	21
Oct 96 - Mar 97 (Summer 1997)	872	177	20
Apr 97 – Sep 97 (Winter 1997)	243	217	89
Oct 96 - Sep 97 (Total for 1997)	1115	394	35
Oct 96 - Jan 98 (Summer 1998)	190	4	2
Oct 93 - Jan 98 (Complete Period)	4309	920	21

7.2.3 Cell 3 - Uncompacted, uncovered, vegetated Coal

Table 7.5 lists the outflow results for cell 3 and **Figure E 3.1 – E 3.5** depicts these data graphically. (These graphs are included in **Appendix E**)

The summer season outflow for cell 3 (excluding the summer 1998 season which is not representative of an entire season) ranges between 6% and 28%, increasing progressively with each season, with an average of 16%. A different pattern is observed during the winter season, with the outflow ranging between 125% in the 1996 season and 56% in the 1994 season. The average winter outflow is 75%.

The results is similar to the pattern observed in cell 1 and 2 with respect to outflow increasing or decreasing as a function of rainfall. The total outflow over the monitoring period is 32%, which is higher of all those observed for any individual summer season, except for 1997. The excessive winter outflow skews the result.

Table 7.5 : Outflow Results for Cell 3

Season	Vegetated	Rainfall (mm)	Outflow (mm)	Outflow (%)
Oct 93 - Mar 94 (Summer 1994)	no	768	46	6
Apr 94 - Sep 94 (Winter 1994)	no	124	69	56
Oct 93 - Sep 94 (Total for 1994)	no	892	116	13
Oct 94 - Mar 95 (Summer 1995)	no	634	77	12
Apr 95 - Sep 95 (Winter 1995)	no	95	55	57
Oct 94 - Sep 95 (Total for 1995)	no	729	131	18
Oct 95 - Mar 96 (Summer 1996)	yes	1257	229	18
Apr 96 - Sep 96 (Winter 1996)	yes	126	38	30
Oct 95 - Sep 96 (Total for 1996)	yes	1383	267	19
Oct 96 - Mar 97 (Summer 1997)	yes	872	242	28
Apr 97 - Sep 97 (Winter 1997)	yes	243	380	157
Oct 96 - Sep 97 (Total for 1997)	yes	1115	622	56

Season	Vegetated	Rainfall (mm)	Outflow (mm)	Outflow (%)
Oct 97 - Jan 98 (Summer 1998)	yes	190	238	125
Oct 93 - Jan 98 (Complete period)	yes/no	4309	1374	32
Oct 93 - Sep 95 (Complete period)	no	1621	247	15
Oct 95 - Jan 98 (Complete period)	yes	2688	1127	42

Another anomaly observed is that the period between Oct 93 and Sep 95, where no vegetation was established on the cell, the outflow was 15% as opposed to 42% for the rest of the period where the vegetation was established. This suggests that the presence of vegetation on the cell has not resulted in reduced outflow due to evapotranspiration, but rather increased the outflow as a result of either preferential flow paths due to penetrating roots and borrowing animals or, reduced surface runoff resulting in higher infiltration. Preferential pathways were never observed on site, and the increased outflow could rather be ascribed to deterioration of the material.

The decreasing outflow during the winter season, and the fact that poor response has been observed with regard to winter rainfall events, does suggest that the evapotranspiration is in fact contributing towards lower infiltration. In the summer seasons the response time for cumulative weekly rainfall events appear to be about two weeks, depending on the preceding moisture conditions of the profile.

7.2.4 Cell 4 - 300mm Uncompacted Avalon covered, vegetated

The outflow results of this cell are tabled in **Table 6.2.4** and graphically presented in **Figures F4.1 - F4.5, Appendix F.**

Table 7.6: Outflow Results for Cell 4

Season	Vegetated	Rainfall (mm)	Outflow (mm)	Outflow (%)
Oct 93 - Mar 94 (Summer 1994)	yes (poor)	768	39	5
Apr 94 - Sep 94 (Winter 1994)	yes (poor)	124	37	30
Oct 93 - Sep 94 (Total for 1994)	yes (poor)	892	76	9
Oct 94 - Mar 95 (Summer 1995)	yes	634	17	3
Apr 95 - Sep 95 (Winter 1995)	yes	95	0	0
Oct 94 - Sep 95 (Total for 1995)	yes	729	17	2
Oct 95 - Mar 96 (Summer 1996)	yes	1257	140	11
Apr 96 - Sep 96 (Winter 1996)	yes	126	105	84
Oct 95 - Sep 96 (Total for 1996)	yes	1383	246	18
Oct 96 - Mar 97 (Summer 1997)	yes	872	80	9
Apr 97 - Sep 97 (Winter 1997)	yes	243	246	101
Oct 96 - Sep 97 (Total for 1997)	yes	1115	325	29
Oct 97 - Jan 98 (Summer 1998)	yes	190	158	83
Oct 93 - Jan 98 (Complete period)	yes/yes (poor)	4309	821	19
Oct 94 - Jan 98 (Complete period)	yes	3417	745	22

The summer season (with the exception of the 1998 season, which is not a complete season) outflows varied between 5% and 11% with an average of 7%. The correlation between rainfall and outflow are indicated by that the lowest outflow coinciding with the lowest rainfall and vice versa. The final outflow for the cell is 19%, which is more than the individual year-end results for each year, and is ascribed due to the unusually high outflow observed during the 1997 winter season.

The winter outflow varies between 0% and 84%, with an average of 54%. No outflow was measured in the Oct 94 - Sept 95 season, suggesting that the cell dried out completely. The response time of the outflow for cell 4 would appear to be at least two weeks, and after the long drying seasons, this response time could appear to be about 3 weeks. This is indicated in **Figure F4.5** where the first rainfall event occurred in early October, followed by major events in early November 1996. However the first significant outflow was only measured in the last week of November 1996.

The outflow during the first year when the vegetation was extremely poor, were almost 3% less than the total outflow for the period that the cells were vegetated. This was expected, and can be ascribed to a dry year following vegetation. The dry year resulted in desiccation cracking to develop at the top of the soil profile, which increased its permeability. With the following abnormally wet season the outflow increase substantially, and moisture could not be removed at this rate by means of evapotranspiration. Outflow decreased in the 1997 season, which suggests that the system probably returned close to its original state.

7.2.5 Cell 5 - 500mm Compacted Avalon, vegetated

Table 7.7 lists the seasonal outflow results for cell 5 and are presented in **Figure F5.1 – F 5.5** in **Appendix F**.

Table 7.7: Outflow Results for Cell 5

Season	Vegetated	Rainfall (mm)	Outflow (mm)	Outflow (%)
Oct 93 - Mar 94 (Summer 1994)	yes (poor)	768	24	3
Apr 94 - Sep 94 (Winter 1994)	yes (poor)	124	19	16
Oct 93 - Sep 94 (Total for 1994)	yes (poor)	892	44	5
Oct 94 - Mar 95 (Summer 1995)	yes	634	5	1
Apr 95 - Sep 95 (Winter 1995)	yes	95	0	0
Oct 94 - Sep 95 (Total for 1995)	yes	729	5	1
Oct 95 - Mar 96 (Summer 1996)	yes	1257	127	11
Apr 96 - Sep 96 (Winter 1996)	yes	126	22	18
Oct 95 - Sep 96 (Total for 1996)	yes	1383	159	12
Oct 96 - Mar 97 (Summer 1997)	yes	872	81	9
Apr 97 - Sep 97 (Winter 1997)	yes	243	182	75
Oct 96 - Sep 97 (Total for 1996)	yes	1115	263	24
Oct 97 - Jan 98 (Summer 1998)	yes	190	114	60
Oct 93 - Jan 98 (Complete period)	yes/yes (poor)	4309	585	14
Oct 94 - Jan 98 (Complete period)	yes	3417	541	16

The summer outflow for cell 5 (except for the 1998 summer season, which is not complete) varies between 1% and 11% with an average value of 6%. The fact that outflow corresponds to rainfall suggests a direct correlation. This is not as clearly indicated by the winter seasons results.

The increasing outflow, over the years suggests a deterioration of the soil cover hydraulic properties. However the overall outflow of 16% as opposed to the uncovered cells, which were all in excess of 20%, does suggest that the cover was successful in reducing infiltration.

The low winter outflows indicated that the soil profile dried out completely or that moisture contained in the profile was retained for a long period. For most of the period, no significant pattern could be seen regarding response time, except that the sporadic winter events, which had virtually no effect on the outflow. In the summer 1997 season, just after the dry season outflow only emerged about 3 weeks after the first rainfall event.

Very little vegetation was in place during 1994, but the outflow was 2% lower compared vegetated period. This was not expected, and it can only be assumed that the increased infiltration is a result of the combined effect of increased rainfall and preferential flow caused by root penetration and borrowing animals

7.2.6 Cell 6 - 300mm Uncompacted Avalon, 700mm Compacted clay, vegetated

The seasonal outflow results for cell 6 is tabled in **Table 7.8** and presented in **Figures F 6.1 – F 6.6, Appendix F**.

Table 7.8: Outflow Results for Cell 6

Season	Vegetated	Rainfall (mm)	Outflow (mm)	Outflow (%)
Oct 93 - Mar 94 (Summer 1994)	yes (poor)	768	28	4
Apr 94 - Sep 94 (Winter 1994)	yes (poor)	124	32	26
Oct 93 - Sep 94 (Total for 1994)	yes (poor)	892	60	7
Oct 94 - Mar 95 (Summer 1995)	yes	634	22	3
Apr 95 - Sep 95 (Winter 1995)	yes	95	0	0
Oct 94 - Sep 95 (Total for 1995)	yes	729	22	3
Oct 95 - Mar 96 (Summer 1996)	yes	1257	178	14
Apr 96 - Sep 96 (Winter 1996)	yes	126	41	33
Oct 95 - Sep 96 (Total for 1996)	yes	1383	219	16
Oct 96 - Mar 97 (Summer 1997)	yes	872	19	2
Apr 97 - Sep 97 (Winter 1997)	yes	243	80	33
Oct 96 - Sep 97 (Total for 1997)	yes	1115	98	9
Oct 97 - Jan 98 (Summer 1998)	yes	190	232	122
Oct 93 - Jan 98 (Complete period)	yes/yes (poor)	4309	631	15
Oct 94 - Jan 98 (Complete period)	yes	3417	571	17

The summer season outflow (excluding the incomplete 1998 season) varied between 2% and 14% with an average of 6%. The pattern of outflow is consistent with the rainfall pattern, with the highest outflow corresponding to the highest rainfall season. This trend was also found by in the winter season outflow results, which ranged between 0% and 33% with an average of 23%.

The overall outflow for the cell increased annually, though marginally, suggesting that the outflow observed might be at equilibrium for the system.

For the 1994 season, the cell can be regarded as having a cover with no vegetation, resulting in outflow of 7%. This is almost 10% less than the combined outflow for the cell over the period that was well vegetated and suggests that the vegetation does not contribute towards reducing the infiltration, and might even constitute greater infiltration due to root penetration. However, the increased rainfall over the following seasons could have overwhelmed the effect of vegetation.

The graphs in **Appendix F** indicates that the outflow through cell 6 is not associated with the sporadic rainfall events, but rather tends to flow continuously for approximately 4 to 5 weeks of the wetting period. The clay does have considerable water retaining properties and outflow only occurred after a number of rainfall events. Similarly, flow stops as soon as the layer is undersaturated, even if it is not the last rainfall event of the season. Soil moisture is then removed by means of evapotranspiration.

Although significant desiccation cracking has been observed at the surface, outflow results does not suggest significant short circuiting, indicating that the cracks did not extent through the soil cover.

7.2.7 Cell 7 - 300mm Uncompacted Avalon, 700mm Compacted Avalon, unvegetated

The seasonal outflow results for cell 7 is tabled in **Table 7.9** and presented in **Figures F 7.1 – F 7.6, Appendix F.**

The summer season outflow (excluding the incomplete 1998 season) varied between 1% and 13% with an average of 6%. The outflow pattern is consistent with the rainfall pattern, except for the 1997 season. This trend is not observed for the winter season, which vary between 0% and 38% with an average of 20%.

No vegetation has been established during 1994, and the outflow of 10% for this season can be compared with that for the rest of the period of similar outflow percentages. Although a decrease in outflow was expected with the presence of vegetation, no change was observed.

The response time of outflow events after rainfall events does not follow any consistent pattern. There are indications that the moisture profile dried out significantly during the dry season, resulting in outflow to occur up to 6 weeks after the start of the rain season. No outflow has been associated with rainfall events during the dry season suggesting that the soil cover retains the moisture and is then removed by evapotranspiration.

Table 7.9 : Outflow Results for Cell 7

Season	Vegetated	Rainfall (mm)	Outflow (mm)	Outflow (%)
Oct 93 - Mar 94 (Summer 1994)	Yes (poor)	768	36	5
Apr 94 - Sep 94 (Winter 1994)	Yes (poor)	124	49	39
Oct 93 - Sep 94 (Total for 1994)	Yes (poor)	892	84	10
Oct 94 - Mar 95 (Summer 1995)	yes	634	25	4
Apr 95 - Sep 95 (Winter 1995)	yes	95	0	0
Oct 94 - Sep 95 (Total for 1995)	yes	729	25	4
Oct 95 - Mar 96 (Summer 1996)	yes	1257	159	13

Season	Vegetated	Rainfall (mm)	Outflow (mm)	Outflow (%)
Apr 96 - Sep 96 (Winter 1996)	yes	126	48	38
Oct 95 - Sep 96 (Total for 1996)	yes	1383	207	15
Oct 96 - Mar 97 (Summer 1997)	yes	872	7	1
Apr 97 - Sep 97 (Winter 1997)	yes	243	8	3
Oct 96 - Sep 97 (Total for 1997)	yes	1115	15	1
Oct 97 - Jan 98 (Summer 1998)	yes	190	77	40
Oct 93 - Jan 98 (Complete period)	yes/yes (poor)	4309	408	10
Oct 94 - Jan 98 (Complete period)	yes	3417	324	10

7.2.8 Cell 8 - 700mm Uncompacted Avalon, 300mm Compacted clay, vegetated

The seasonal outflow results for cell 8 is tabled in **Table 7.10** and presented graphically in **Figures F 8.1 – F 8.6, Appendix F.**

The summer season outflow (excluding the incomplete 1998 season) ranged between 3% and 8% with an average of 8%. The outflow pattern is consistent with the rainfall pattern. The winter season outflow also mimics the rainfall pattern, ranging between 0% and 92% with an average of 38%.

A 14% increase of outflow has been measured before vegetation was established in 1994 compared to the period thereafter. As before, it is assumed that this is the result of either increased rainfall for the following seasons, or, the establishment of the vegetation that could have altered the hydraulic properties of the soil by means of root penetration.

As was observed in the other thick-layered covers, the response time for outflow from specific rainfall events are not well defined. This could be due to the moisture retaining properties of the soils. This is also indicated by the fact that once outflow stops, significant moisture is needed to restart outflow.

Table 7.10 : Outflow Results for Cell 8

Season	Vegetated	Rainfall (mm)	Outflow (mm)	Outflow (%)
Oct 93 - Mar 94 (Summer 1994)	yes (poor)	768	29	4
Apr 94 - Sep 94 (Winter 1994)	yes (poor)	124	34	28
Oct 93 - Sep 94 (Total for 1994)	yes (poor)	892	64	7
Oct 94 - Mar 95 (Summer 1995)	yes	634	21	3
Apr 95 - Sep 95 (Winter 1995)	yes	95	0	0
Oct 94 - Sep 95 (Total for 1995)	yes	729	21	3
Oct 95 - Mar 96 (Summer 1996)	yes	1257	190	15
Apr 96 - Sep 96 (Winter 1996)	yes	126	41	32
Oct 95 - Sep 96 (Total for 1996)	yes	1383	231	17
Oct 96 - Mar 97 (Summer 1997)	yes	872	96	11
Apr 97 - Sep 97 (Winter 1997)	yes	243	223	92
Oct 96 - Sep 97 (Total for 1997)	yes	1115	320	29
Oct 97 - Jan 98 (Summer 1998)	yes	190	207	109
Oct 93 - Jan 98 (Complete period)	yes/yes (poor)	4309	841	20
Oct 94 - Jan 98 (Complete period)	yes	3417	777	23

7.2.9 Cell 9 - Layered, vegetated, sloped 5%

The seasonal outflow results for cell 9 is listed in **Table 7.11** and presented in **Figures F9.1 - F9.5, Appendix F**.

Very little outflow occurred during the whole of Oct 1993 to September 1995. Significant outflow only became evident from October 1995. The higher outflow since 1995 can only be explained by a significant degradation of the soil cover, resulting in increased permeability. In addition, the cell cover dried out completely in the 1995 winter season. Thereafter, abnormally high rainfall has been experienced. Since then, however, a pattern of outflow, which is consistent with the rainfall pattern, has been observed.

Table 7.11 : Outflow Results for Cell 9

Season	Vegetated	Rainfall (mm)	Outflow (mm)	Outflow (%)
Oct 93 - Mar 94 (Summer 1994)	yes (poor)	768	1	0
Apr 94 - Sep 94 (Winter 1994)	yes (poor)	124	0	0
Oct 93 - Sep 94 (Total for 1994)	yes (poor)	892	1	0
Oct 94 - Mar 95 (Summer 1995)	yes	634	0	0
Apr 95 - Sep 95 (Winter 1995)	yes	95	0	0
Oct 94 - Sep 95 (Total for 1995)	yes	729	0	0
Oct 95 - Mar 96 (Summer 1996)	yes	1257	190	15
Apr 96 - Sep 96 (Winter 1996)	yes	126	53	42
Oct 95 - Sep 96 (Total for 1996)	yes	1383	243	18
Oct 96 - Mar 97 (Summer 1997)	yes	872	82	9
Oct 93 - Mar 97 (Winter 1997)	yes	243	172	71
Apr 97 - Sep 97 (Total for 1997)	yes	1115	254	23
Oct 96 - Sep 97 (Summer 1998)	yes	190	85	45
Oct 97 - Jan 98 (Complete period)	yes/yes (poor)	4309	582	14
Oct 94 - Jan 98 (Complete period)	yes	3417	581	17

The graphs in **Appendix F** depict a response time of around 12 weeks after the first rainfall events of the 1995 season. The soil cover therefore retains significant amounts of moisture before outflow occurs. As the rainfall events starts to became less intense, outflow ceased, and only started 4 weeks after the first rainfall event of the 1996 season.

7.2.10 Cell 10 - Layered, vegetated, sloped 10%

Table 7.12 lists the seasonal outflow results for cell 10, and **Appendix F** contains **Figures F10.1 - F10.5** depicting the data.

As with cell 9, the first two years, resulted in virtually no outflow being measured, but this changed dramatically during 1995 in which significant outflow has been recorded. This change can only be ascribed to significant degradation of the soil profile, thereby increasing its permeability. The increased rainfall in 1996 after a dry winter period could have accelerated the degradation process resulting in higher outflow rates.

Table 7.12: Outflow Results for Cell 10

Season	Vegetated	Rainfall (mm)	Outflow (mm)	Outflow (%)
Oct 93 - Mar 94 (Summer 1994)	yes (poor)	768	7	1
Apr 94 - Sep 94 (Winter 1994)	yes (poor)	124	0	0
Oct 93 - Sep 94 (Total for 1994)	yes (poor)	892	7	1
Oct 94 - Mar 95 (Summer 1995)	yes	634	0	0
Apr 95 - Sep 95 (Winter 1995)	yes	95	0	0
Oct 94 - Sep 95 (Total for 1995)	yes	729	0	0
Oct 95 - Mar 96 (Summer 1996)	yes	1257	130	10
Apr 96 - Sep 96 (Winter 1996)	yes	126	82	65
Oct 95 - Sep 96 (Total for 1996)	yes	1383	211	15
Oct 96 - Mar 97 (Summer 1997)	yes	872	63	7
Apr 97 - Sep 97 (Winter 1997)	yes	243	314	129
Oct 96 - Sep 97 (Total for 1997)	yes	1165	376	34
Oct 97 Jan 98 (Summer 1998)	yes	190	129	68
Oct 93 – Jan 98 (Complete period)	yes/yes (poor)	4309	724	17
Oct 94 – Jan 98 (Complete period)	yes	3417	717	21

The response time for outflow after the first rainfall event of 1995 was approximately 12 weeks, and in 1996, about 4 weeks. Outflow ceased during the winter 1996 season, indicating no response to the single events that did occur during this period. This is indicative of the water retaining properties of the cover material.

7.3 UNCOVERED CELLS (CELLS 1 - 3)

Outflow results of cells 1 – 3 have been presented in **Figure 6.11**. No significant pattern with regard to the performance of the three cells performed in relation to each other is evident. The outflow in cell 3 is higher compared to cell 2. This suggests that although the vegetation on the cell does appear to reduce outflow, the effect of compacted coal is greater in reducing outflow. It has been believed that vegetation have a positive effect on reducing infiltration, but this has been contradicted by the results of cell 1 and 3 which is similar in construction, except for the vegetation. Outflow form cell 1 was 26% over he entire period compared to 32% of cell 3

Outflow through uncovered cells ranged between 6% and 28% during the summer season, with an average of 16%. The outflow for the winter season ranged between 30% and 157% with an average of 63%. The combined average outflow for the uncovered cells is 26%.

In conclusion it can be said that uncompacted, uncovered discard produced an outflow of 26%, which is 5% higher than that of compacted, uncovered discard. Vegetation resulted in an increased outflow through the uncompacted cell by almost 6%. However, the increase outflow could have resulted from the top surface of the vegetated cell being disturbed significantly during the vegetation operations, In addition, vegetation could have resulted in a significantly lower runoff.

7.4 SINGLE LAYER COVERS (CELLS 4 AND 5)

The outflow results of cells 4 and 5 as depicted in **Figure 6.12** is consistent with what was expected given the cover configurations. Cell 4 which comprised of 300mm uncompacted

Avalon, has produced almost 5% more outflow than cell 5, which comprised of 500mm compacted Avalon.

In summary, the outflow for single layer covers varied between 1% and 11% in the summer season with an average of 7%. Outflow for the winter season ranged between 0% and 101% with an average of 41%. Annual outflow for single layer covers was measured at 17%.

7.5 LAYERED COVERS (CELLS 6,7,8)

The outflow results of cells 7 and 8 have been presented in **Figure 6.13** and cell 6 is presented in **Figure 6.12**. For the first two years the outflow pattern was consistent to the original hypothesis with cell 7, which comprised of layered compacted and uncompacted Avalon soils producing the highest outflow. Cell 8, which comprised only 300mm Estcourt soils underlying 700mm Avalon produced the second highest outflow while cell 5 with the 700mm of Estcourt soils producing the lowest outflow. After 1995 the pattern changed with cell 7 producing consistently lower outflows than cell 6 and 8.

7.6 SLOPED CELLS (CELLS 9 AND 10)

Cells 9 and 10 are similar in construction at the layered cell 6, except for top slopes of 5% and 10% respectively, as opposed to the 1% slope of cell 6. Outflow results for these cells are presented in **Figure 5.6(c)**. Cell 9, constructed with a less steep slope produced higher outflow, measuring 3% more than cell 10. The combined outflow for the sloped cells were 16%.

7.7 VEGETATED CELLS

In **Section 6.2** the outflow results for the seasons where the cells have been vegetated have been compared to seasons where cells have been unvegetated. On average, there was an increase of approximately 3% in outflow results after vegetation. However it cannot be conclusively stated that this increase is solely due to soil cover degradation as a result of root penetration, since abnormally high rainfall coincided with the vegetated seasons, which could have dominated the increase in outflow. No conclusive evidence statements can be made regarding whether vegetation has any effect on reducing outflow.

7.8 COMPARATIVE RESULTS (CELLS 1 - 10)

At the outset of this chapter a hypothesis has been made on how we would expected outflow results, based on hypothesised effectiveness of the cover. **Table 7.13** indicates the actual order of effectiveness as annually compared to the original hypothesis.

A one denotes most effective, while ten denotes least effective experimental cells.

Table 7.13 : Order of Effectivity of Covers

Cell	Hypothesis	Rank (Outflow (%))				
		Oct 93 - Sep 94 (Year 1994)	Oct 94 - Sep 95 (Year 1995)	Oct 95 - Sep 96 (Year 1996)	Oct 96 - Sep 97 (Year 1997)	Oct 93 - Jan 98 (Complete period)
1	10	10 (17%)	8 (12%)	10 (25%)	8 (35%)	9 (26%)
2	9	9 (13%)	9 (15%)	9 (21%)	9 (35%)	8 (21%)
3	8	8 (13%)	10 (18%)	8 (19%)	10 (56%)	10 (32%)
4	7	6 (9%)	4 (2%)	7 (18%)	6 (29%)	6 (19%)
5	6	3 (5%)	3 (1%)	1 (12%)	4 (24%)	3 (14%)
6	3	4 (7%)	6 (3%)	4 (16%)	2 (9%)	4 (15%)
7	5	7 (9%)	7 (3%)	2 (15%)	1 (1%)	1 (9%)
8	4	8 (13%)	5 (3%)	5 (17%)	5 (29%)	7 (20%)
9	2	1 (0%)	2 (0%)	6 (18%)	3 (23%)	2 (14%)
10	1	2 (1%)	1 (0%)	3 (15%)	7 (34%)	5 (17%)

Cells 1 - 3 remained the three least effective cells with a combined average outflow of 26%. No specific pattern emerged for these three cells, which identifies one as having a consistently better performance. However cell 2 never performs worse than both the two uncompacted cells, suggesting that the compaction does indeed increase the effectivity of the cell, reducing outflow.

The single layer simple soil covers of cell 4 and 5 performed better than expected in the hypothesis. Cell 4 ranked 6th overall, outperforming the layered cover of cell 8, and the cover of cell 5 ranked 3rd, being more effective than the sloped layered cell 10. The combined outflow for the simple covers is 17%. The results are encouraging since this implies a considerable saving for the mining industry.

Cells 6, 7 and 8, which comprised of layered soils with either different soil types or soils with different compaction. Initially they performed as expected, although not in the exact order, but in the correct sequence, with cell 6 outperforming cell 7 and 8. Cell 6 continues to outperform cell 8 throughout the monitoring period, but cell 7 started to outperform both cells 6 and 8 from October 1995. Cell 7 is in fact ranked as the most effective cell overall by a margin of 5%. The combined outflow for the layered cells were 15%. These results and the results of cell 5 suggest that the Avalon soil is the best material for reducing outflow in this experiment.

The poor performance of Estcourt soils, compared to Avalon soils, could be attributed to its chemical composition and mineralogy. Since Estcourt soils do contain higher smectite contents compared to the Avalon soils, and contain no goethite, the structural stability of the soils are low and therefore, the soils are prone to desiccation cracking, resulting in an increased permeability.

The two sloped cells with thin layered covers on cell 9 and 10 was the most effective up to September 1995, after which their performance deteriorated and finally only rank 2nd and 5th respectively. The combined outflow for the sloped cells is 16%. The poor performance could be attributed to soil cover deterioration.

It is also possible, that the poor performance of cell 9 and 10 could be attributed to preferential flow, more specifically a combination of funnelled, fingering and macropore flow. It is speculated that, during the wet 1995/1996 rain seasons, funnelled flow occur at the interface between Avalon and Estcourt soils. As the interface between Avalon and Estcourt soils became saturated, the water moved down-slope thereby saturating down-slope areas. Since the dry season, preceding the 1995/1996 rain seasons was particularly dry, it is highly likely that desiccation cracks developed within the structurally unstable Estcourt soils. The water concentrated on the Estcourt Avalon soil interface could have flow rapidly via these preferential flow paths. In addition, funnelled flow could have caused wetting front instability at the Estcourt – Avalon soil interface and fingering flow could have resulted. The fact that very little outflow was measured for the top compartments of cells 9 and 10, support the above hypothesis.

Table 7.14 lists the combined data for the cells, grouping together the various elements tested in the experiments.

Table 7.14 : Combined Outflow Results for Cells 1 - 10

Cover Type	Outflow				
	Total	Compacted	Uncompacted	Vegetated	Unvegetated
Uncovered	26%	21%	29%	32%	24%
Single layer cover (300mm - 500mm)	17%	14%	19%	17%	7%
Layered cover (1000mm total)	15%	-	-	15%	10%
Sloped cover (1000mm layered)	16%	-	-	16%	1%

The following comments can be made regarding **Table 7.14**. None of these data have been statistically evaluated, and as such differences are evaluated on face value.

- The uncovered cells produced the highest outflow of 26%. A 4% improvement was found with the compacted material suggesting that the decreased permeability caused by compacting the material are beneficial in reducing outflow.

- The presence of vegetation directly on the uncovered cell 3 appears to have caused a substantially increased outflow. This anomaly is ascribed due to the difficulties experienced in vegetating the discard, and the subsequent disturbance of the top 500mm of the cell. This disturbance probably caused the discard to be more permeable than the state in which it was placed.

- The single layer covers performed better overall compared to the layered covers, by over 2%. The 500mm compacted Avalon cover of cell 5 proved to be the most efficient single layer cover of all those tested, producing only 14% outflow. This is almost half of the outflow measured through the uncovered cells.

- The layered covers performed as well as would be expected, except for the layered cell 7 comprising of only Avalon material, which outperformed the covers containing Estcourt layers. The combined outflow for the layered cells is almost half of that through the uncovered cells. Cell 7 outperformed not only the layered covers, but also the sloped cells.

- The sloped cells initially dramatically outperformed all the other covers, but after 1995 this changed significantly, resulting in a combined outflow almost equal to single layer covers.

- Throughout the monitoring period, the seasons where no vegetation was established resulted in lower outflows to that where vegetation was well established. Although this might imply that vegetation caused the outflow to increase, this could be as a result of the overwhelming effect of increased rainfall in 1995/1996 and also possibly soil cover degradation.

- The increased outflow from cell 9 and 10 is possible the result of long-term degradation. However, it is also possible that the increased outflow have been the result of preferential flow, especially funnelled flow, within the soil cover.

- The good performance of the single layer covers compared to the layered covers could be ascribed to the extreme drying out cycle which resulted in Estcourt soils, which is structurally less stable than Avalon soils, developing desiccation cracking and thereby increased permeability.

8. MODELLING USING SWACROP

8.1 MODEL DESCRIPTION

SWACROP (Soil **WA**ter and **CROP** production model) is a transient one-dimensional finite difference model for simulation of flow through the unsaturated zone. It incorporates the process of water uptake by roots. The soil profile is divided into several layers (containing one or more compartments of variable thickness) characterised by different physical properties. The partial differential equation for flow in the unsaturated system is solved using an implicit finite difference scheme. An explicit linearisation of the hydraulic conductivity (K) and the soil water capacity (C) is used.

With the initial conditions (i.e. water content vs. hydraulic head distribution profile) known, and top and bottom boundary conditions well-defined, the system of equations for all the compartments is solved for each (variable) time step by applying the Thomas-tridiagonal algorithm. The integration procedure within each time step allows calculation of all water balance terms for each time period selected.

In the case of the top boundary, data on rainfall, potential soil evaporation and potential transpiration are required. When the soil system remains unsaturated, one of three bottom boundary conditions can be used namely pressure head, zero flux, or free drainage. When the lower part of the system remains saturated, one can either give the ground water level or the flux through the bottom of the system as input. In the latter case, the ground water level is computed. For the purposes of this project, all modelling was conducted using a free-drainage bottom boundary condition.

The rate of vegetative growth, both potential and actual, can be simulated in the crop growth sub-model which is dynamically linked to the main water model. This sub-model supplies information about the vegetation characteristics to the main water model throughout the simulation period. However, both models can be run separately, and for the purposes of this study, the crop growth sub-model has not been used.

8.2 MATHEMATICAL MODEL

8.2.1. Soil Water Balance

The one-dimensional water balance of the soil accounts for the incoming and outgoing water fluxes. The change in water storage, ΔW for a given period of time, Δt can be written as the difference of inflow, i.e. infiltration (including irrigation) I, net upward flow through the bottom Q, minus outflow, i.e. soil evaporation E and crop transpiration T:

$$\Delta W = I + Q - (E + T) \qquad [8.1]$$

8.2.2. Basic Flow Equation

The change of water storage with time $\partial W/\partial t$ over the vertical distance z can more generally be expressed as:

$$\frac{\partial \theta}{\partial z}\left(\frac{\partial W}{\partial t}\right) = \frac{\partial \theta}{\partial t} \qquad [8.2]$$

where θ is volumetric soil water content ($cm^3.cm^{-3}$). Conservation of mass laws for the soil-root system requires that:

$$\frac{\partial \theta}{\partial t} = \frac{\partial q}{\partial z} - S \qquad [8.3]$$

where q is volumetric (Darcy) flux ($cm^3.cm^{-2}.d^{-1}$) and S represents the volume of water taken up by the roots per unit bulk volume of soil per unit time ($cm^3.cm^{-3}.d^{-1}$). Equation 8.3 can be rewritten in terms of soil water pressure head h. As $\partial\theta/\partial t = C(h)\ (\partial h/\partial z + 1)$, with C being the differential soil water capacity, and $q = K(h)\ (\partial h/\partial z + 1)$, with K being the hydraulic conductivity ($cm.d^{-1}$) and height z taken positive upwards, equation 8.3 can be rewritten as:

$$\frac{\partial h}{\partial t} = \frac{1}{C(h)} \frac{\partial}{\partial z}\left[K(h)\left(\frac{\partial h}{\partial z} + 1\right)\right] - \frac{S}{C(h)} \qquad [8.4]$$

8.2.3. Water uptake by roots

In order to be able to solve equation 8.4 for specified initial, upper and lower boundary conditions one has to define a function for S. Feddes described this function as:

$$S(h) = \alpha(h)\, S_{max} \qquad [8.5]$$

where $\alpha(h)$ is a dimensionless function of hydraulic head and S_{max} is the maximum possible water extraction by roots. In the case of a homogeneous distribution of S_{max} with depth it is assumed that:

$$S_{max} = \frac{T_p}{|z_r|} \qquad [8.6]$$

where T_p is the potential transpiration rate ($cm.d^{-1}$) and z_r (cm) is the lower limit of the root zone (e.g. if $T_p = 0.4\ cm.d^{-1}$ and $z_r = -40$ cm, then from each 10 cm layer a maximum possible rate of 0.1 $cm.d^{-1}$ water can be extracted). If the root distribution is non-homogeneous with depth one could incorporate a root distribution function, for example, the weight fraction of the roots relative to the total weight of roots.

Under non-optimal conditions, i.e. either too dry or too wet conditions, S_{max} is reduced by means of the pressure head-dependant α-function (see equation 8.5). Water uptake below the oxygen deficiency - anaerobisis point $|h_1|$; and above the wilting point, $|h_4|$, is set equal to zero. Between $|h_1|$ and $|h_2|$ a linear approximation is assumed while between the reduction point - limiting point $|h_3|$ and $|h_4|$ a linear or hyperbolic approximation is assumed. The value of $|h_3|$ is dependent on the evaporative demand and varies with T_p. The shape of this function is shown in **Figure 8.1.**

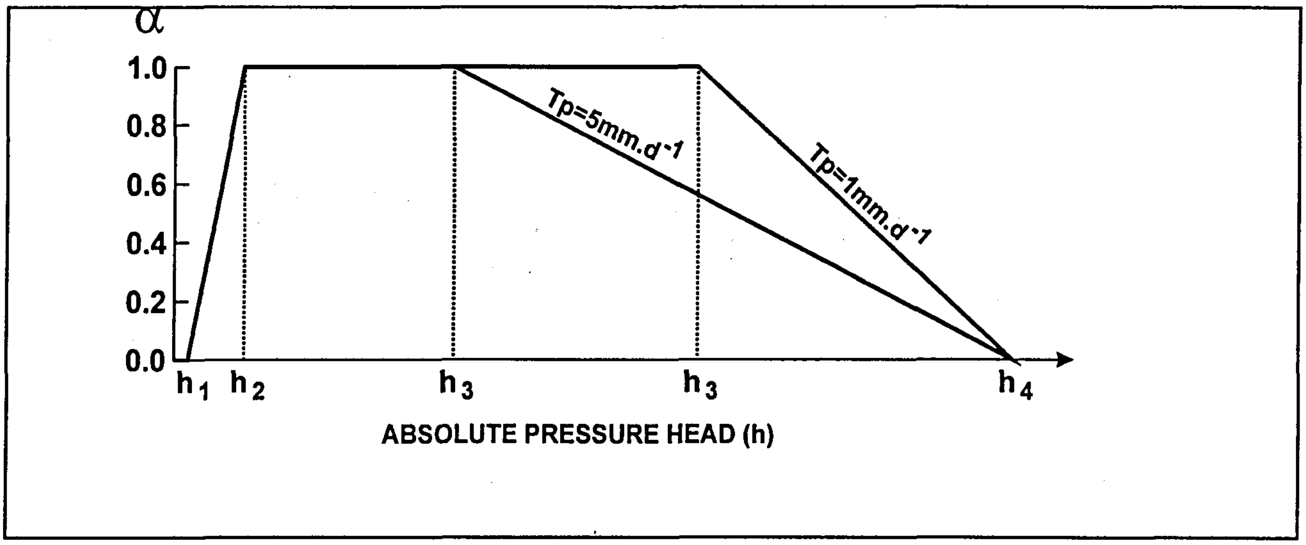


Figure 8.1: Dimensionless sink term variable, α, as a function of the absolute value of the soil water pressure head, *h*

The hydraulic head limits, used to characterise the sink-term function, were established during preliminary model calibration runs and are shown in **Table 8.1.**

Table 8.1: Experimentally determined values of the hydraulic head limits, used in defining the sink term for plant roots (kPa)

Constants	De Jong and Kabat (1990)	Belmans *et al* (1984)	De Laat (1985)
$\lvert h_1\rvert$	-1	-	-10
$\lvert h_2\rvert$	-2.5	-	-25
$\lvert h_3\rvert$	-20	-	-200
$\lvert h_3^*\rvert$	-80	-	-800
$\lvert h_4\rvert$	-800	-400	-15830

De Laat (1985) stated that typical rooting depths for grass is 30 cm, for potatoes and sugar beet are 40 cm, and for cereals and maize are 60 cm.

8.2.4. Boundary Conditions At The Top Of The System

Daily values of potential transpiration, T_p are needed to define the maximum possible flux through the canopy, as well as daily values of precipitation and potential evaporation, E_p to define the maximum possible flux through the soil surface. The sum of T_p and E_p is potential evapotranspiration, ET_p, which can be estimated using any one of four methods supported in SWACROP namely the Priestly and Taylor method, the modified Penman equation, the Monteith-Rijtema equation or the Makink equation. Since wind speed was not measured at the experimental set-up, the Priestly & Taylor (1972) equation was used to calculate potential evapotranspiration. However, a comparative analysis by Smith *et al* (1991) indicated that the Priestly & Taylor method are not particularly suited to arid conditions. It is recommended that the Penmann equation be used in future studies.

The Priestly & Taylor equation is expressed as;

$$ET_p = \alpha \frac{\delta}{\delta + \gamma} R_n \qquad [8.7]$$

This equation is valid for all leaf area indexes (LAI) with α an empirical constant (1.35 ± 0.10). The LAI can generally be related to soil cover and is calculated in SWACROP using the following equation:

$$LAI = aS_c + bS_c^2 + cS_c^3 \qquad [8.8]$$

where S_c is the soil cover expressed as a fraction (between 0 and 1), and *a*, *b* and *c* are parameters to be determined experimentally. Various laboratory and field studies yielded values for these parameters, and some have been presented in **Figure 8.2** as a function of soil cover.

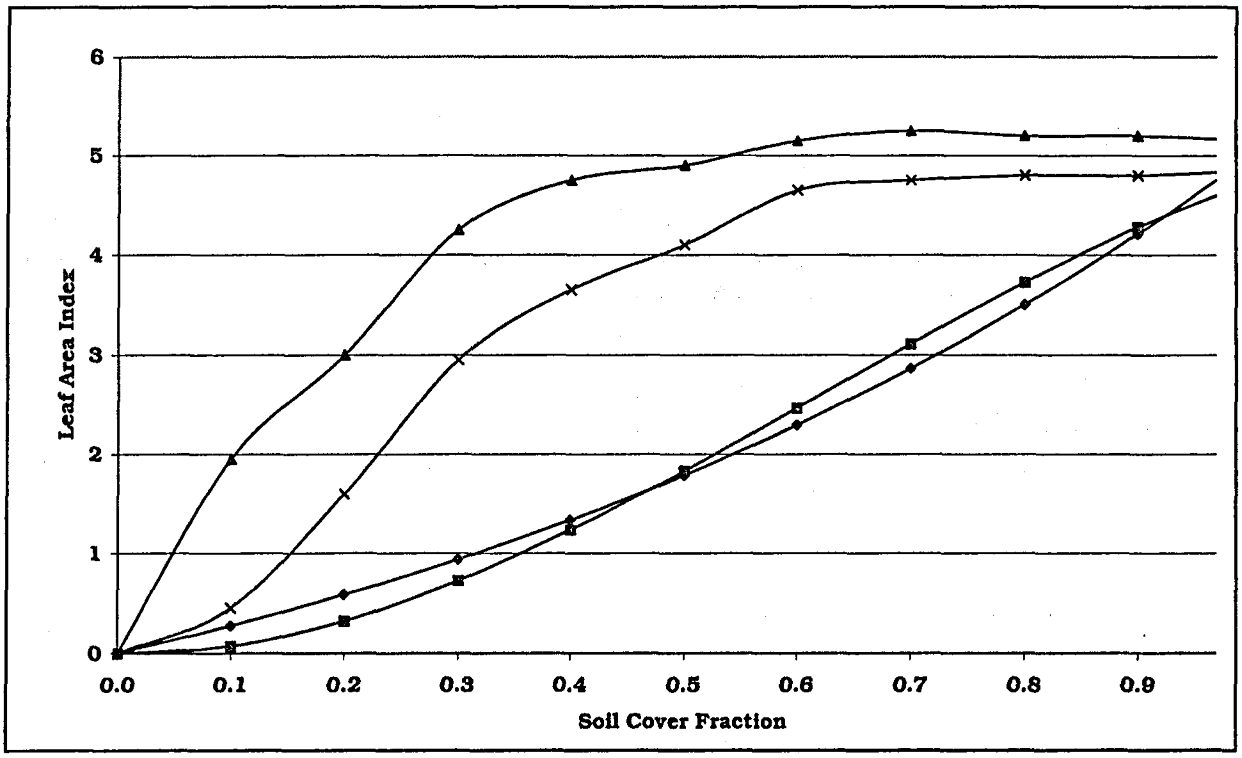


Figure 8.2: Leaf area index (LAI) plotted as a function of soil cover for different coefficients of different vegetation types reported in the literature

The parameter, γ, in equation 8.7, psychrometer constant with a value of 0.66713 mbar. K^{-1} as used by SWACROP. The parameter, δ, is the proportionality constant, expressed in mbar.K^{-1}, and is a function of the air temperature on any specific day. **Figure 8.3** indicate the potential evapotranspiration as a function of net radiation and air temperature. ET_p is not a function of vegetation, and therefore, vegetation has no effect on the value thereof. As the air temperature increases the effect of radiation becomes more significant.

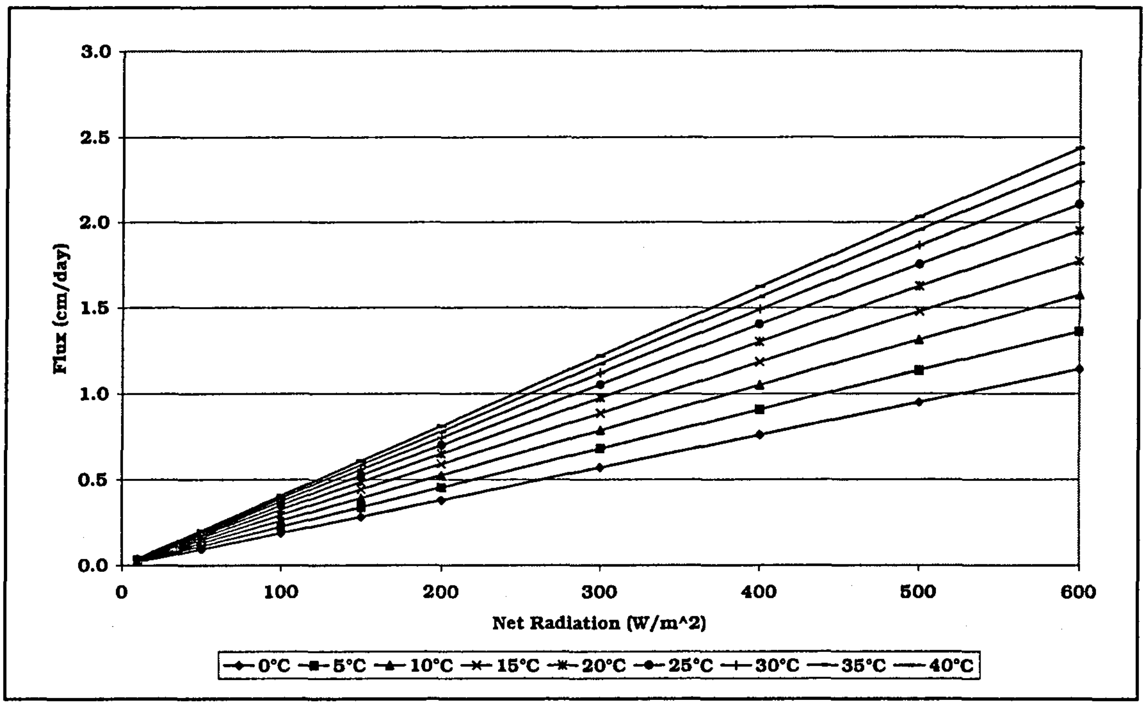


Figure 8.3: Potential evapotranspiration plotted against temperature and net radiation, depicting its sensitivity to the variables

The potential evaporation of a soil under crop cover can be computed using the Ritchie (1972) equation.

$$E_p = \frac{\delta}{\delta + \gamma} R_n e^{0.39\,LAI} \qquad [8.9]$$

When no vegetation is present, the potential evaporation is only a function of air temperature and net radiation, and its sensitivity to these values is depicted by **Figure 8.4**. As with the potential evapotranspiration, the greatest radiation effect is observed at higher temperatures.

The potential transpiration T_p, which is the maximum possible flux through the top boundary, is then calculated by:

$$T_p = ET_p - E_p \qquad [8.10]$$

Figure 8.5 depicts the way potential transpiration is calculated by applying equation 8.10, varying with air temperature and the net radiation.

The actual flux through the soil surface, q^*_s comprises of two components:

$$q^*_s = E^*_r - (P - E_{int}) \qquad [8.11]$$

where P is the daily rainfall, E_r^* is the reduced potential evaporation and E_{int} is the flux of intercepted rainfall. The actual soil evaporation for any day in a dry period is calculated using the method described by Black *et al* (1969):

$$E = \lambda \left[\sqrt{t} - \sqrt{t-1}\right] \qquad [8.12]$$

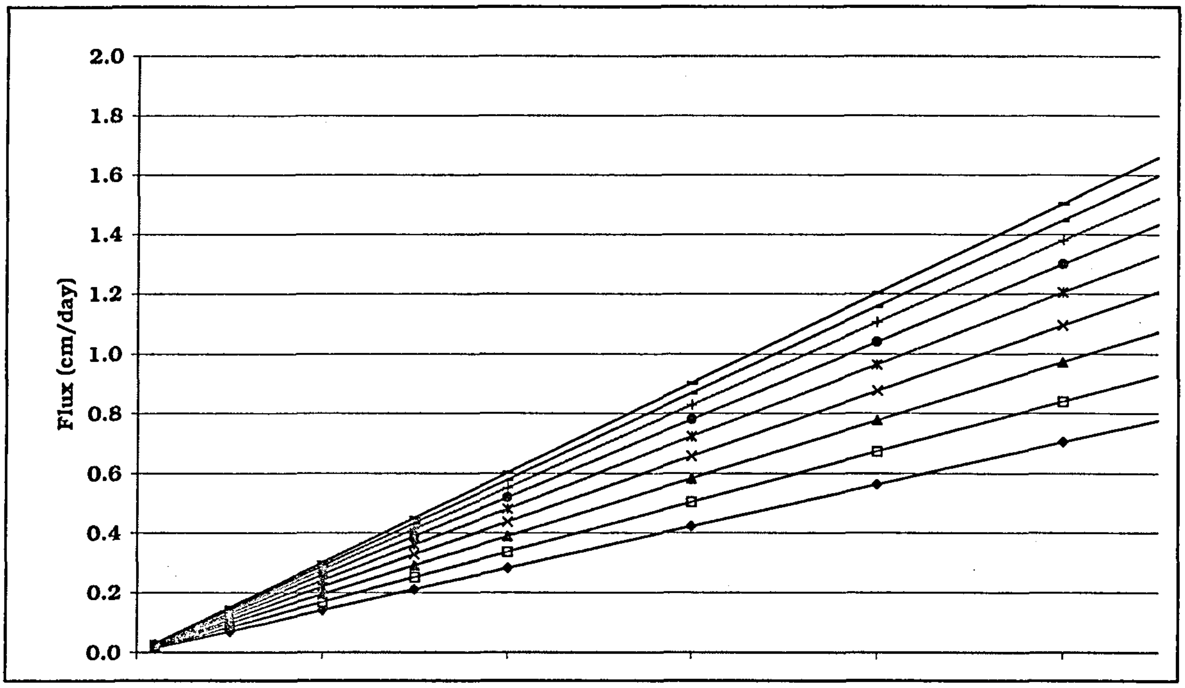


Figure 8.6: Potential evaporation plotted against air temperature and net radiation in the case no vegetation is present

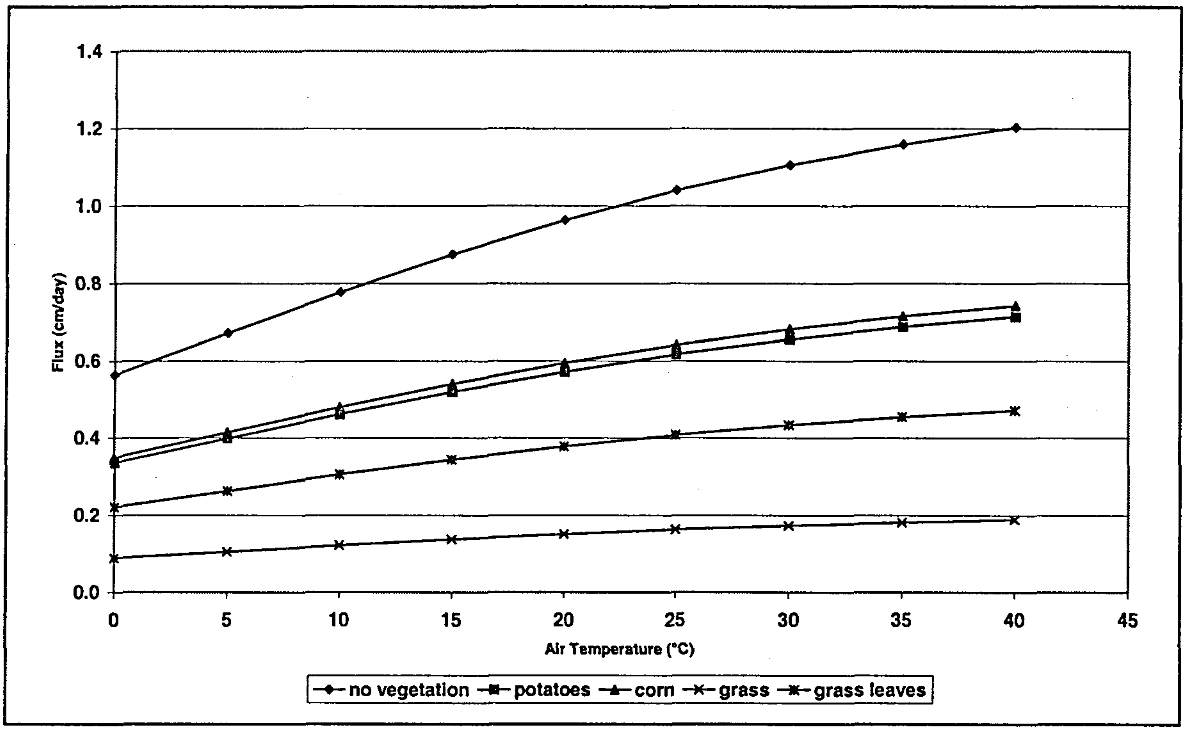


Figure 8.7: Potential evaporation plotted against air temperature in for four different vegetation types

where λ is a soil dependant parameter which is a constant with a value of 0.35 cm.d^{-1} in SWACROP, and t is the time (in days) after a dry period started. In the model, any dry period ends the day after $P \geq 1$ cm.d^{-1}. The day after a dry period ends means that t=1 and E has its maximum value of 0.35 cm.d^{-1}. This value could be too low since the average daily evaporation for the Newcastle area is 0.47 cm.d^{-1}, and the maximum daily evaporation, based on a monthly maximum is 0.96 cm.d^{-1}. Therefore the total actual evaporation allowed by equation 8.12 could be underestimated.

Figure 8.8 shows the change in actual evaporation with changing λ at variable net radiation values for a given temperature. As λ increases, the range over which the net radiation affects the actual evaporation also increases. **Figure 8.9** depicts how far a given λ of 0.35 the actual evaporation varies with temperature and radiation.

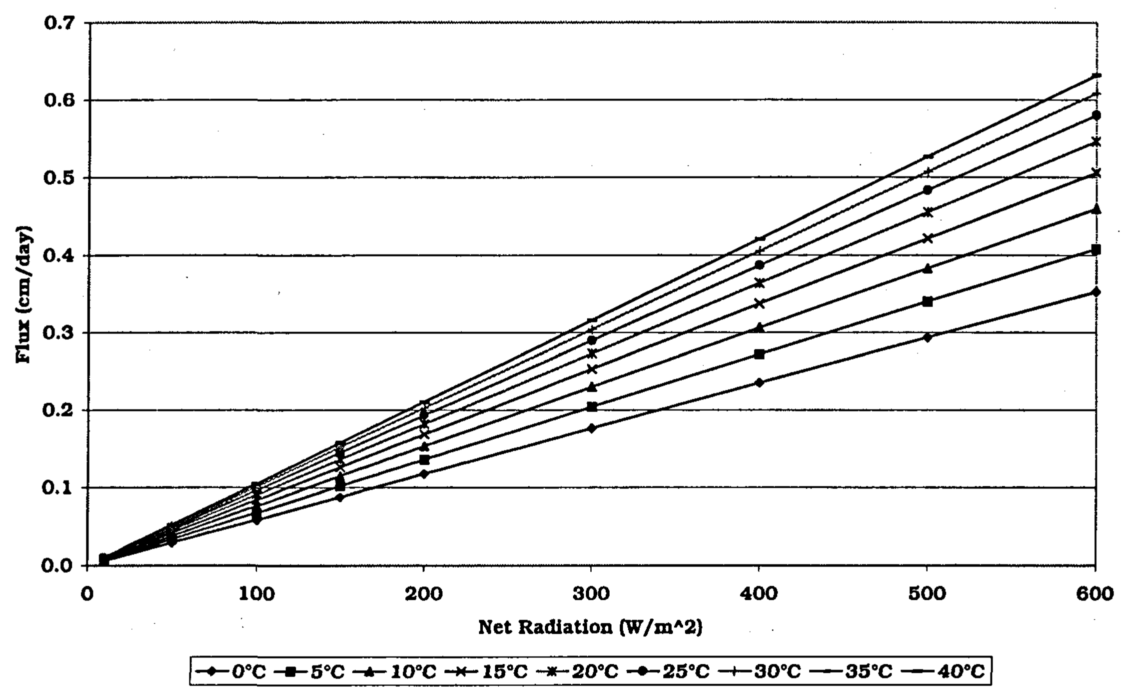


Figure 8.8: Potential transpiration plotted against air temperature and net radiation, depicting its sensitivity to the variables when no vegetation is present.

The interception function E_{int} is also a function of soil cover and is calculated by two different equations depending on the amount of rainfall for any given day.

$$E_{int} = S_c \cdot e \quad for \quad P > 2\,cm \cdot d^{-1}$$

$$E_{int} = S_c \cdot a \cdot P^{(b-c(P-d))} \quad for \quad P < 2\,cm.d^{-1} \qquad [8.13]$$

where a, b, c, d and e is experimentally determined parameters. Jong & Kabat (1990) measured the precipitation - interception data for grass and assigned the following values to these parameters, which is used by SWACROP:

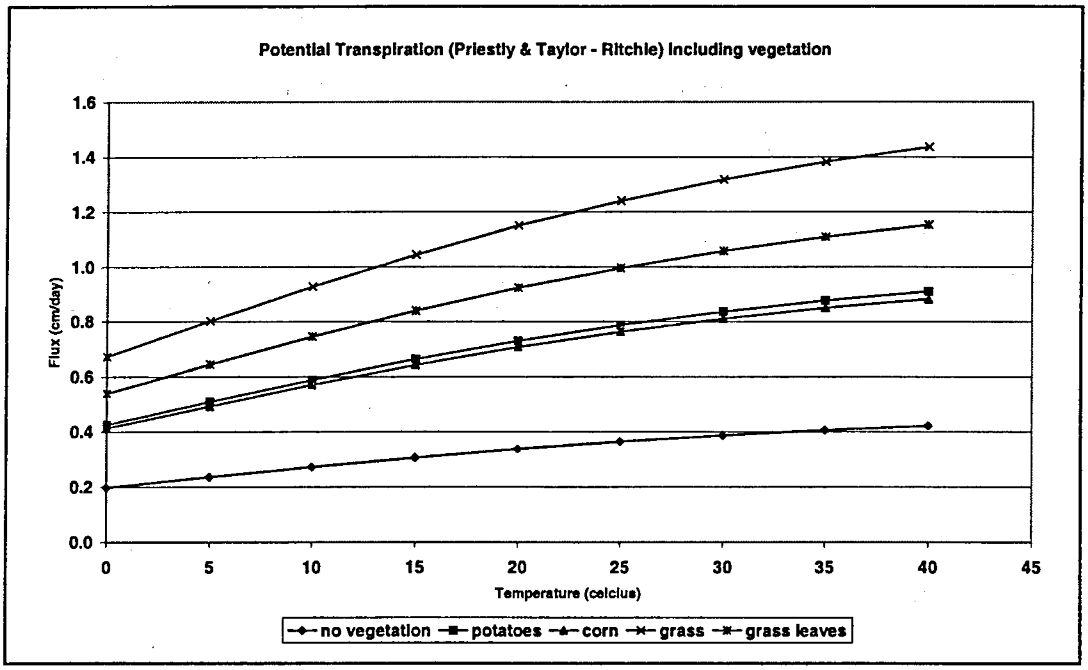


Figure 8.9: Potential transpiration plotted against air temperature for four different crop types.

$a = 0.169$
$b = 0.516$
$c = 0.1787$
$d = 0.0593$
$e = 0.19$

The cut-off precipitation of 2 cm.d^{-1} was also experimentally determined by Jong & Kabat (1990).

Figure 8.10 indicate the interception function of affected as a function of variable soil cover and increasing daily rainfall. As could be expected, the greatest interception occur with increasing soil cover and increasing rainfall, up to a maximum where $P > 2$ cm.d^{-1}.

In the case of evaporation (q_s^* is positive), the actual evaporation rate is governed by the actual transmitting properties of the soil, i.e. the Darcian flux q_1 from the top nodal point to the soil surface. The hydraulic head h_o is assumed to be in equilibrium with the surrounding atmosphere. This limiting hydraulic head is calculated by:

$$h_{lim} = \frac{RT}{Mg} \ln(f) \qquad [8.15]$$

where R is the universal gas constant, T is absolute temperature, M is the mole weight of water, g is the gravitational acceleration, and f is the relative air humidity fraction.

Figure 8.11 indicate the limiting hydraulic head as a function of relative humidity and temperature. These hydraulic heads is related to moisture content and hydraulic conductivity of the top soil layer, which becomes the limiting condition for top boundary flux.

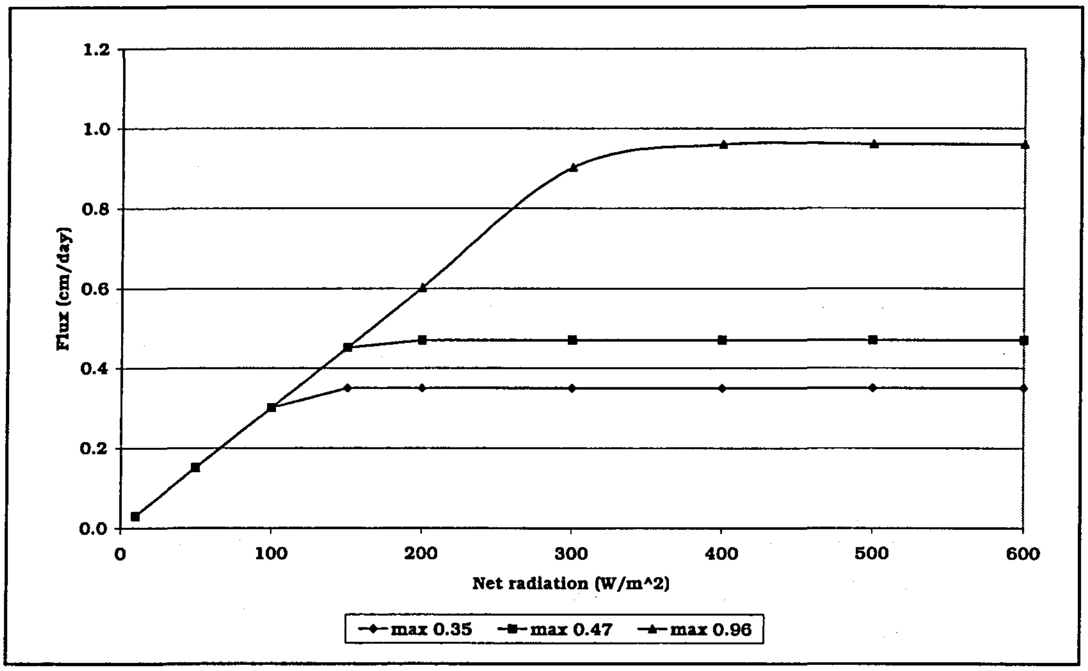


Figure 8.10: Actual evaporation plotted as a function of λ values from the Black equation, where no vegetation is present

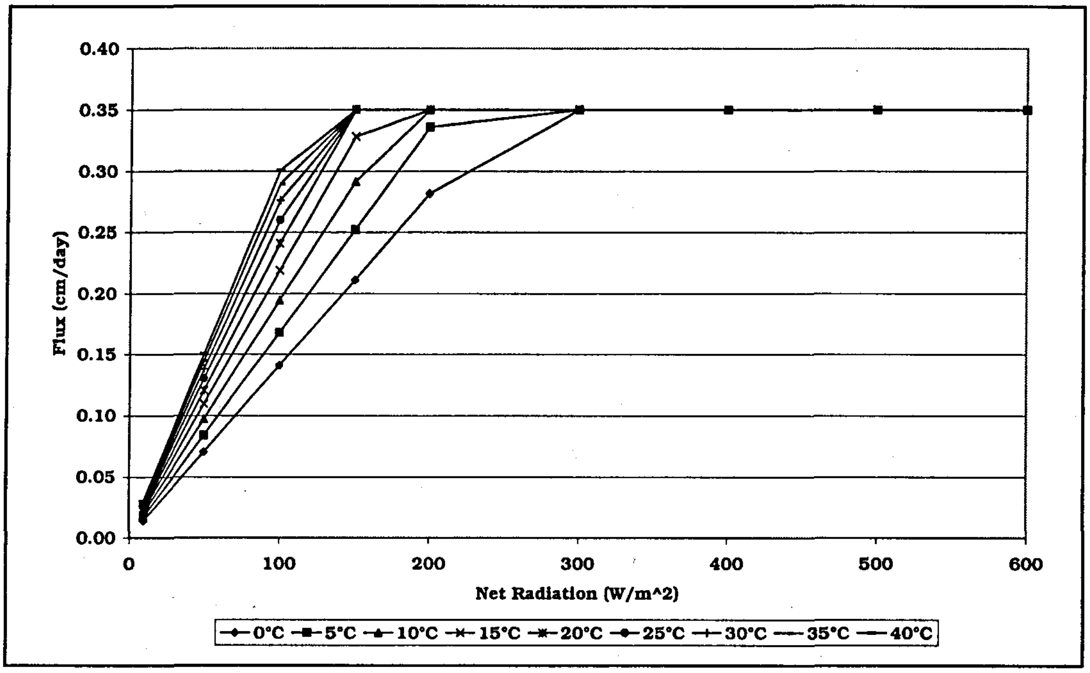


Figure 8.11: Actual evaporation at a constant λ of 0.35 as a function of net radiation and temperature

However, this procedure only reduces evaporation when the hydraulic head at the top nodal point is in the same order of magnitude as h_o. Thus the size of the compartment (Δz) is an important aspect. Actual soil evaporation rate is either q_s^* or q_1, whichever is lower.

In the case of infiltration (q_s^* is negative) the actual infiltration rate is governed again by the Darcian flow from the soil surface ($h_o = 0$) to the top nodal point, q_1. Actual infiltration is the either of q_s^* or q_1, whichever is the lower.

The flux q at the upper boundary is governed by the meteorological conditions. The soil can release water to the atmosphere by evaporation or gain water by infiltration. While the maximum potential rate of evaporation from a given soil depends only on atmospheric conditions, the actual flux across the soil surface is limited by the ability of the porous medium to transmit water from below. Similarly if the potential rate of infiltration (e.g. the rain or irrigation intensity) exceeds the absorption capacity of the soil, part of the rainfall will be result in surface run-off. Again, the potential rate of infiltration is controlled by atmospheric external conditions, whereas the actual flux depends on antecedent moisture conditions in the soil. Therefore, the actual flux through the top boundary will be governed by:

$$q^* \geq q = -K(h)\left(\frac{\partial h}{\partial z} - 1\right) \qquad [8.16]$$

In the case of rainfall, $h \leq 0$ [$\theta \leq \theta_s$], and in the case of evaporation, $h \geq h_{lim}$; thus $h_{lim} \leq h \leq 0$

8.2.5. Boundary conditions at the bottom of the system

The bottom boundary of the system could either be saturated or unsaturated whereby the condition of the hydraulic head or flux can be provided as input or can be calculated. In the case the system is unsaturated, the groundwater level (hydraulic head) can be provided as input. The groundwater level can also be calculated provided the flux from/towards the saturated zone is prescribed as input, or is calculated as input as a result of in/outflow from/to ditches and downward/upward flow to/from deep aquifers from Hooghoudt/Ernst type of equations. Similar calculations can be made when a flux-groundwater level relation is known.

In the case that the system remains unsaturated, the hydraulic head can be prescribed, zero flux can be prescribed at an impermeable bottom or free drainage (unit hydraulic gradient) can be applied. This last condition is applicable to the experiment.

8.2.6. Numerical Solution Scheme

The soil system is divided into a number (maximally 40) of compartments of equal height. The profile can be split up into (maximally 5) layers (containing one or more compartments) with different physical properties (i.e. $h(\theta)$ and $K(h)$-relations). Equation 8.4 is solved by a finite difference scheme, which is implicit and implies an explicit linearisation of hydraulic conductivity, K, and soil water capacity, C, (Kabat & Wesseling, 1988). With the initial conditions (i.e. water content and hydraulic head distribution with depth) known and the top and bottom boundaries well defined, the system of equations for all compartments is solved for each time step by applying the Thomas tri-diagonal algorithm. The length of the time step is variable and estimated as:

$$\Delta t^{j+1} = \frac{\Delta \theta_{max}}{(\Delta \theta / \Delta t)^j_{max}} \qquad [8.17]$$

where $0.002 \leq \theta_{max} \leq 0.03$ and

$$\left(\frac{\Delta \theta}{\Delta t}\right)^j_{max} = \mathrm{Max}_{j=1,\ldots,n}\left[S_i^j + \left(\frac{\Delta q}{\Delta z}\right)_i^j\right] \qquad [8.18]$$

where S_i^j is the sink term and q_i^j is the flux through boundaries of various components

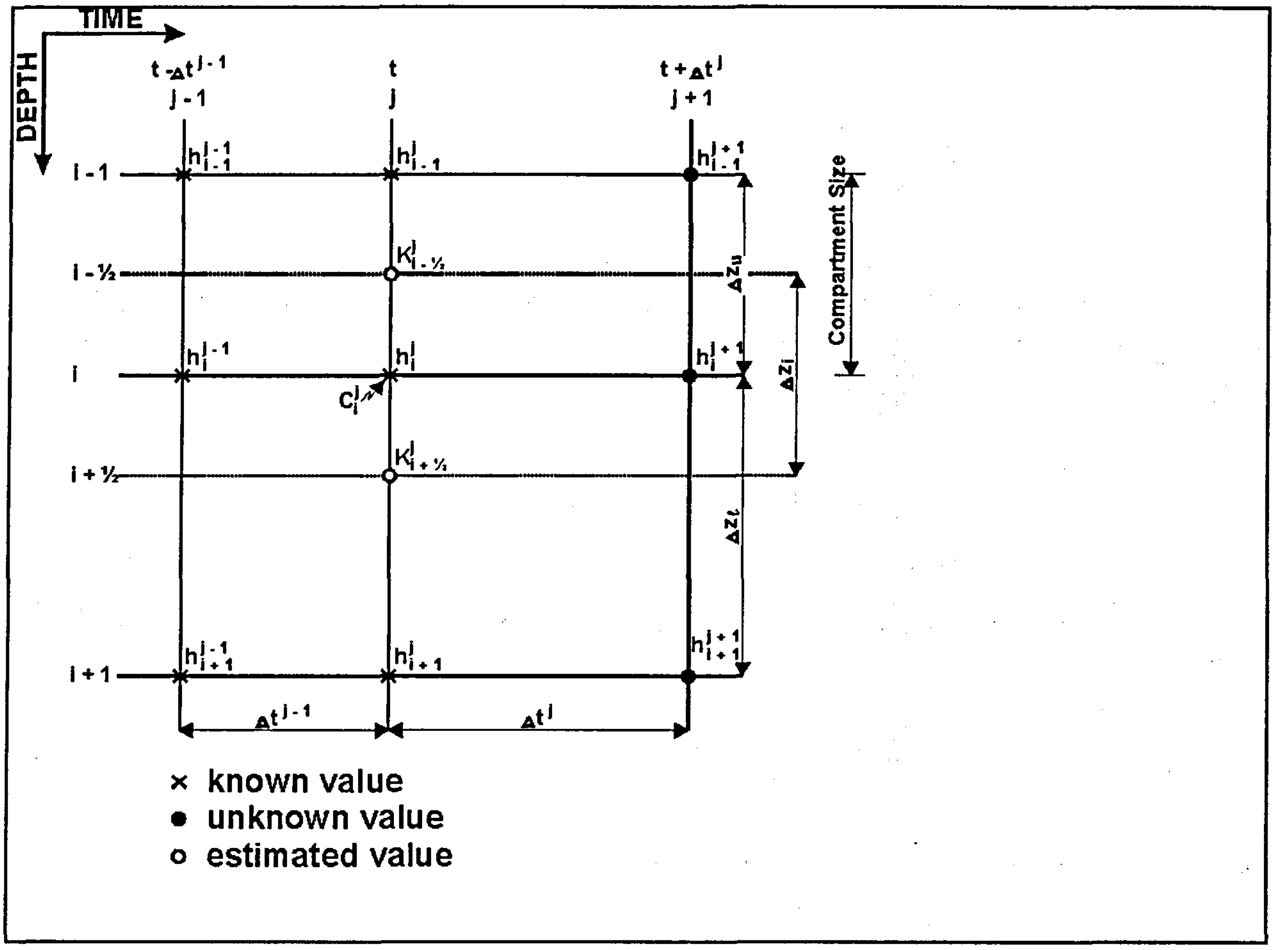
the time step Δt^j is further restricted by the following conditions:

- $\Delta t_{max} = 0.5$ day
- Δt^j is taken so small that at least five time steps between two printed plots are performed.
- $\Delta t_j \leq 1.2\ \Delta t^{j-1}$

8.2.7. Finite Difference Technique to Solve Extended Richard's Equation

Equation 8.4 is solved by a finite-difference scheme as proposed by Haverkamp *et al* (1977), which is implicit and applies an explicit linearisation. **Figure 8.12** shows the depth time relationship for the independent variables z (index i) and t (index j) for the general case of compartments of unequal size. The numerical approximation of equation 8.4 leads to the following finite-difference expression which is valid for all nodal points except the top and bottom point of the unsaturated zone:

Figure 8.12: Finite difference mesh superimposed on the depth-time zone of the unsaturated zone



$$\frac{h_i^{j+1} - h_i^j}{\Delta t^j} = \frac{1}{C_i^j} \cdot \frac{1}{\Delta z_i} \left[K^j_{i-\frac{1}{2}} \left(\left(\frac{\Delta h}{\Delta z_u} \right)^{j+1}_{i-\frac{1}{2}} + 1 \right) - K^j_{i+\frac{1}{2}} \left(\left(\frac{\Delta h}{\Delta z_l} \right)^{j+1}_{i+\frac{1}{2}} + 1 \right) \right] - \frac{S_i^j}{C_i^j} \qquad [8.19]$$

Equation 8.19 can be rearranged to a linear algebraic equation:

$$- A_i h_{i+1}^{j+1} + B_i h_i^{j+1} - D_i h_{i-1}^{j+1} = E_i \qquad [8.20]$$

where

$$A_i = \left(\frac{\Delta t^j}{C_i^j \Delta z_i \Delta z_l} \right) K^j_{i+\frac{1}{2}} \qquad [8.21]$$

$$B_i = 1 + \left(\frac{\Delta t^j}{C_i^j \Delta z_i \Delta z_u} \right) K^j_{i-\frac{1}{2}} + \left(\frac{\Delta t^j}{C_i^j \Delta z_i \Delta z_l} \right) K^j_{i+\frac{1}{2}} \qquad [8.22]$$

$$D_i = \left(\frac{\Delta t^j}{C_i^j \Delta z_i \Delta z_u} \right) K^j_{i-\frac{1}{2}} \qquad [8.23]$$

$$E_i = h_i^j - \left(\frac{\Delta t^j}{C_i^j \Delta z_i} \right) K^j_{i+\frac{1}{2}} + \left(\frac{\Delta t^j}{C_i^j \Delta z_i} \right) K^j_{i-\frac{1}{2}} - \left(\frac{\Delta t^j}{C_i^j} \right) S_i^j \qquad [8.24]$$

The values of hydraulic conductivity, *K*, and differential moisture capacity, *C*, are obtained by explicit linearisation. This implies that *K* and *C* are determined for time *t*. The geometrical mean for *K* are determined as proposed by Vauclin *et al.* (1979):

$$K^j_{i-\frac{1}{2}} = \sqrt{K_i^j \cdot K_{i-1}^j} \qquad [8.25]$$

$$K^j_{i+\frac{1}{2}} = \sqrt{K_i^j \cdot K_{i+1}^j} \qquad [8.26]$$

The solution for the top nodal point $i = 1$ is obtained by introducing as boundary condition a flux in equation 8.19:

$$K^j_{1-\frac{1}{2}} \left[\left(\frac{\Delta h}{\Delta z_u} \right)^{j+1}_{1-\frac{1}{2}} + 1 \right] \rightarrow q_l \qquad [8.27]$$

The coefficients of equation 8.20 can be defined provided the compartments is of equal size, i.e., $\Delta z_u = \Delta z_l = \Delta z$:

$$A_1 = \left[\frac{\Delta t^j}{\{C_1^j (\Delta z)^2\}} \right] K^j_{1+\frac{1}{2}} \qquad [8.28]$$

$$B_1 = 1 + A_1 \qquad [8.29]$$

$$D_1 = 0 \qquad [8.30]$$

$$E_1 = h^j_1 - \left(\frac{\Delta t^j}{C^j_1 \Delta z}\right) K^j_{1+\frac{1}{2}} - \left(\frac{\Delta t^j}{C^j_1 \Delta z}\right) q_1 - \left(\frac{\Delta t^j}{C^j_1}\right) S^j_1 \qquad [8.31]$$

For the intermediate nodal points, one has a system of (n - 2) linear equations with n unknowns (the hydraulic heads at the n nodal points of the unsaturated zone h_i^{j+1}, i = 1,...,n). The solution for the top nodal point provide one equation more, which leads to (n - 1) equations. For the bottom compartment of the unsaturated zone, a distinction between the hydraulic head- and the flux-type condition can be made. In the case the hydraulic head is known, one has a system of (n - 1) equations with (n - 1) unknowns, which can be solved. If the flux through the bottom of the unsaturated zone is known an additional equation is required. In this case the solution for the bottom nodal point, $i = n$, can be obtained by introducing a flux as boundary condition in equation 8.19, i.e.:

$$K^j_{n+\frac{1}{2}} \left[\left(\frac{\Delta h}{\Delta z_l}\right)^{j+1}_{n+\frac{1}{2}} + 1 \right] \rightarrow q_n \qquad [8.32]$$

where q_n is the flux through the bottom of the unsaturated zone. The coefficients of equation 7.20 can then be defined as:

$$A_n = 0 \qquad [8.33]$$

$$B_n = 1 + D_n \qquad [8.34]$$

$$D_n = \left[\frac{\Delta t^j}{\{C^j_n \Delta z \Delta z_n\}}\right] K^j_{n-\frac{1}{2}} \qquad [8.35]$$

$$E_n = h_n{}^j - \left(\frac{\Delta t^j}{C^j_n \Delta z_n}\right) K^j_{n-\frac{1}{2}} + \left(\frac{\Delta t^j}{C^j_n \Delta z_n}\right) q_n - \left(\frac{\Delta t^j}{C^j_n}\right) S_n{}^j \qquad [8.36]$$

In the case the bottom of the system is allowed to drain fully, $\Delta h/\Delta z$ is set equal to zero so that $q_n = -K(h_n^j)$. The hydraulic head of the bottom compartment n is thus taken at the beginning of the time step considered. This procedure leads to n equations with n unknowns, which can be solved.

In solving the system of equations, a direct method was used by applying the Thomas (tri-diagonal) algorithm.

8.2.8. Output of the model SWACROP

The output of the model comprises of all terms of the water balance, the distribution of the moisture contents/hydraulic heads/fluxes over depth and time, including the water uptake by roots. One of the significant outputs is actual transpiration, calculated as the integral of the sink term over the rooting depth.

8.3 PREPARATION OF INPUT FILES FOR SWACROP

The input files for the model have to be prepared manually for each run, and is dependent on the physical dimensions of the cells, the soil properties of the cover materials, the climatic data, as well as vegetative cover and rooting depth of the grass.

8.3.1. Cell Dimensions

The model calculates the water balance for a unit area, and therefore, horizontal dimensions of the cells are not required. The number of soil layers, and the number of compartments within each soil layer, has to be defined. The compartments can vary in size, but a maximum of 40 compartments is allowed. The water balance is calculated for each compartment in sequential order from top to bottom. In the case of many compartments, computational time is longer, but greater accuracy is achieved.

8.3.2. Assumptions and conditions

The following assumption have been made and conditions been set in modelling the experimental cells:

- Free drainage is allowed at the bottom of the unsaturated profile. The flux at this point is equal to the hydraulic conductivity of the bottom compartment.
- In the case of free drainage, the initial moisture content input may not equal be equal to saturated moisture content.
- The potential evapotranspiration is calculated applying the Priestly and Taylor equation.
- Net radiation is used as input and no conversion to global radiation was made.
- An initial condition of the moisture content (cm^3/cm^3) as input at each nodal point has been defined (i.e. in each compartment).
- The upper boundary, i.e. the climatic data, varies with time. Actual climate data have been used.
- Irrigation is not simulated, since only natural rainfall occurred.
- All compartments are of equal size. A maximum of 40 compartments is allowed and a minimum of 3, which comprised of an upper, mid and lower compartment to satisfy the top and bottom boundary conditions.
- The maximum value of time-step allowed in the calculations is 0.2 day.
- The maximum change of moisture content that is allowed within one time-step is 0.005 cm^3/cm^3.
- The maximum number of iterations allowed during a time-step is 10.
- The maximum number of decrements of the time-step when the iteration criteria is not reached is 5.

- If the relative difference between two successive iterations exceeds 0.001, another iteration is started.
- The empirical constant α used in the Priestly and Taylor equation is 1.35.
- The data is run in batches of 365 days. The initial moisture content is iterated until steady state is reached. From that point on the end result of one batch run is used as the input for the next.

8.3.3. Soil Properties

SWACROP accepts two methods to enter the hydraulic properties of the soil. It can either be done by specifying the Van Genuchten parameters, whereby the moisture retention curve is predicted through the model, or the moisture retention curve can be input using a table of actual data. (The top compartment may not have a maximum hydraulic of between 1×10^{-6} and 1×10^{-9}cm).

Applying the experimental results reported in Chapter 5 for the soil types and the coal material, tables of the moisture retention curves have been established. These data is represented in **Appendix B.**

Research done by Lorentz *et al* (1995) using the experimental data obtained from samples of this experiment, indicated that the dual porosity model of van Genuchten is very effective in predicting both the retention and the hydraulic characteristics of soils.

8.3.4. Climatic Data

SWACROP applies 24-hour daily total and average climatic data in tabular form as input for the top boundary condition. The total rainfall for each 24-hour period, together with the average radiation, temperature and relative humidity for a 24-hour period was used as input data. The format of input for rainfall is in cm, temperature in degrees Celsius, humidity as a fraction and radiation as W/m^2.

8.3.5. Vegetation Data

Two basic input requirements are needed to accurately model the evapotranspiration from the covers, i.e., .the vegetation cover at any specific day expressed as a fraction and the rooting depth of the vegetation at any specific day.

This experimental cells have been vegetated only by grass. A maximum rooting depth of 30 cm was assumed during the best growth season. There is evidence of deeper root penetration, but it was the exception rather than the rule, and was therefore not considered. **Tables 8.2** below list the rooting depths for cells 3 -10 as have been used in the model.

Table 8.2 : Rooting Depths for Cells 4 - 10

Period	Cell 3	Cell 4-10
	Depth (cm)	
Sep 93 – Nov 93	0	0
Nov 93 – Dec 93	0	10
Dec 93 – Jan 94	0	20
Feb 94 – Oct 95	0	25
Oct 95 – Dec 95	15	30
Dec 95 – Jan 96	25	30
Jan 96 – Jan 98	30	30

Table 8.3 indicates the grass cover fraction of the experimental cells:

Table 8.3 : Grass cover (percentage) for Cells 3 - 10

Period	Cell 3	Cell 4-10
Sep 93 - Nov 93	0	0
Dec 93	0	5
Jan 94	0	15
Feb 94 - May 94	0	40
Jun 94 - Nov 94	0	15
Dec 94	0	25
Jan 95 - Mar 95	0	60
Apr 95 - Sep 95	0	45
Oct 95 - Nov 95	0	55
Dec 95 - May 96	40	75
Jul 96 - Sep 96	35	65
Oct 96 - Apr 97	60	85
May 97 - Sep 97	40	65
Oct 97 - Jan 98	60	85

8.4 MODEL OUTPUT

After the input data have been captured, the program was run for the 51 months. This was done using batch data spanning over 365 days. The end condition for any batch run was used as the starting condition for the following batch. Correlations between the modelled data and the actual field data were poor. The model consistently overestimated the outflow compared to what was actually measured.

Upon closer inspection of the program code, it was concluded that the main reason for the overestimation of the outflow was the way in which it distributes the daily rainfall. SWACROP uses a daily rainfall total and distributes that equally over the 24-hour period. It is known that many of the rainfall events occur as short-duration high-intensity thundershowers, which tend to cause considerable runoff as opposed to infiltration.

Attempts to correct this by using hourly data as opposed to daily totals, could contribute towards more reliable predictions, although this is a very tedious task, as hourly data must then be run as if daily data is used, i.e. hourly inputs of all the variables are required.

The results have shown that the soil cover material does exhibit dual flow processes with preferential mechanisms probably being an important process, transporting water through the soil cover. This very important aspect was not adequately dealt with by the model. Unsaturated hydraulic conductivity is generally scaled with the saturated hydraulic conductivity. However, this common scaling technique should not be used in dual porosity soils, since the hydraulic conductivity are highly sensitive to moisture content ate near saturation conditions, with the hydraulic conductivity decreasing rapidly with small decreases in moisture content. This probably resulted in an over-estimation of the unsaturated hydraulic conductivity at lower water contents, which could explain the generally higher predicted outflow during the winter months.

Another important aspect is the effect of the large day-night variations in temperature and relative humidity. A 24-hour average of temperatures and radiation are not characteristic of that during the day, when evapotranspiration is the most prevalent. It is difficult to assess how much of an impact this could have on the final results.

An unknown factor, which may or may not affect the results, is the presence of dew and frost on the cells covers early mornings. This constitutes to a rather substantial amount of water, which is not incorporated into the model. However, it is expected that its contribution to outflow will be marginal.

The assumptions made for vegetation had to be considered. Earlier in this chapter, it was indicated that the vegetation does have an effect on outflow. Since no tests or investigations have been undertaken to determine the exact rooting depths of the grass on the cells of determining the LAI on a scientific basis, various assumptions have been made based on research by other authors. The effect of these assumptions on the outflow is unknown, especially considering that assumptions often are based on other assumptions.

Based on the inconclusive modelling results, it was decided not to further investigate the results of the model. The main aim of the this project was to calibrate an existing numerical model to be used to predict outflow through the experimental cells, that should eventually be used by the mining industry. The conclusion reached is that existing models can not be calibrated because of the large number of inherent errors and assumptions made by the various models. It is believed that empirical and analytical models are currently more accurate in predicting long-term recharge trends. However, it appears that no model is currently able to predict the large variations of recharge events.

While it has been concluded that no existing model can be calibrated, it does not mean that numerical models should be discarded. The numerical model did correlate very well with actual outflow results. The good correlations observed include:

- Peak outflow events have been well predicted, especially for cells 1, 2 and 3. The peak outflow events generally coincide with high rainfall events. However, the magnitude of such outflow events have not been well predicted
- Low outflow has been predicted for the winter season, which correspond to low actual outflow measured.
- Outflow patterns for both predicted and actual data is similar, indicating that the most important aspects in the calculation of outflow have been considered

The authors are confident that there is enough information gathered during this research that warrant further research into this topic. It is recommended that existing models be modified, in order to incorporate rainfall patterns and dual porosity, typical of South African conditions.

9. WATER QUALITY ANALYSIS

9.1 INTRODUCTION

The quality of leachate that is produced from a coal discard or spoils facility is a function of various biological, geochemical and physical processes taking place in the discard and spoils material. These processes include: migration of water, gas flux, dissolution (kinetic or equilibrium controlled), complexation (determined by equilibrium and stoichiometry of several complexes), precipitation (formation of complexes and secondary minerals), dissolution (thermodynamic and sorption equilibrium), absorption/adsorption and co-precipitation of metals.

The two main geochemical processes involved in the deterioration of water percolating through a coal discard or spoil pile is pyrite oxidation and pH buffering (base/alkali mineral dissolution). These processes, in general, have the effect of acidification and salinisation of water percolating through these waste materials, producing acid and/or saline leachates.

Table 9.1 lists the key factors affecting the oxidation of pyrite and neutralisation of acidic water (pH buffering), and where data was available, have been taken into account in the analyses of the leachate water qualities:

Table 9.1.: Key factors affecting pyrite oxidation and acidic water neutralisation.

Pyrite Oxidation	Neutralisation of acidic water
• Presence of bacteria	• Type of base minerals
• Microscopic texture and crystal form of the sulphide mineral	• Particle size
• Presence and availability of oxygen and oxidants such as Fe^{3+}	• Reaction rate and contact time
• Temperature and pH	• Presence of secondary oxidation minerals to armour the base mineral
• Particle size distribution	• pH / Acidity
• Presence of water	• Presence of oxygen

The leachate qualities recorded at each cell in this investigation have been influenced by the above mentioned processes. It can therefore be assumed that the recorded leachate qualities are indicative of the ability of the different dump covers to inhibit or accelerate the various geochemical processes active in each case. In order to evaluate the performance of the different dump covers with respect to leachate quality, statistical and comparative analyses were conducted on the recorded leachate quality.

9.2 OBJECTIVES

The objectives of this chapter are twofold and are listed below:

1. To statistically analyse the leachate quality database in order to characterise average conditions, to give an indication of how the leachate quality has changed over time, and to examine extreme conditions.

2. To use the results of the statistical analyses for a comparative analysis between the leachate characteristics and the physical arrangements associated with each type of dump cover.

Key attributes of the water quality data sets are given in **Table 9.2.**

Table 9.2: Key attributes of the water quality data sets.

Cell Data Set	Data Range	Sampling Frequency	Missing Values	Outliners	Sample Size
1	14/12/93 – 17/08/98	2 Weekly	Yes	Yes	118
2	14/12/93 – 17/08/98	2 Weekly	Yes	Yes	118
3	14/12/93 – 17/08/98	2 Weekly	Yes	Yes	112
4	14/12/93 – 17/08/98	2 Weekly	Yes	Yes	104
5	14/12/93 – 17/08/98	2 Weekly	No	Yes	120
6	14/12/93 – 17/08/98	2 Weekly	Yes	Yes	119
7	14/12/93 – 17/08/98	2 Weekly	Yes	Yes	116
8	21/02/94 – 17/08/98	2 Weekly	Yes	Yes	76
9A	28/02/94 – 12.09.96	2 Weekly	Yes	Yes	34
9 B	14/12/93 – 17/08/98	2 Weekly	Yes	Yes	85
10B	14.12.93 – 17/08/98	2 Weekly	No	Yes	120
10A	18/01/94 – 09/12/96	2 Weekly	Yes	Yes	8

9.2.1. *Statistical Analysis*

The methodologies applied in the statistical analyses were:

1. Average conditions
   Estimation: Mean, Minimum, Maximum, Median, Standard deviation
   Graphical: Time series plots.

2. Trends and changing conditions
   Estimation: Regressional analysis, slope calculations, percentile calculations.
   Graphical: Time series plots, best fit lines.

Missing values were left as blanks in the record and no effort was made to patch by inserting estimated values.

No statistical techniques were used to remove outliers.

Only sample sets longer than 50 entries were statistically analysed. Samples 9A and 10 A were therefore excluded from the statistical analyses.

9.2.2. Comparative analyses

Correlation matrices were used to identify statistically significant correlation between different water quality variables and between the water quality variables and the dump cover configuration.

9.3 STATISTICAL AND COMPARATIVE ANALYSIS

The results of the statistical and comparative analyses are presented in this section together with a description of key trends. Tables of all water quality data for each cell are given in Appendix D. At the bottom of each table, various statistical parameters such as minimum, maximum, mean, 95 percentile and median for each of the chemical parameters in the database have been calculated.

Time series plots of pH, EC, SO_4, TDS, Al, Fe, Mn, ALK, Ca and Mg are given for each cell with its associated table of data. Where regressional analyses have been conducted, the best fit lines and associated correlation coefficient values are given on the time series plots.

Table 9.3 presents a summary of the key trends in chemical parameters reflected in the time series plots of each cell.

Table 9.3 Summary of key trends in water quality data.

Cell 1: Uncovered, uncompacted, unvegatated

- Acid breakthrough reflected by a sharp decrease in pH during the latter part of 1997.
- Increasing trends in EC, SO_4, and TDS concentration levels.
- Initial increase in Mg concentration followed by a decrease in during low pH period.
- Increase in metal concentrations with a decrease in pH.
- Relative to other metals, high initial Mn concentrations.
- Very low concentration levels of NH_4, PO_4 and NO_3. However, an increase in NH_4 has been recorded during low pH conditions.
- Initial increase in alkalinity followed by drop to zero levels during low pH conditions.

Cell 2: Uncovered, Compacted, Unvegetated

- Relative stable neutral pH levels with similar early signs of an acid breakthrough.
- Increasing trends in Mg, EC, SO_4 and TDS concentration levels.
- Initial high Mn concentrations (10 – 13 mg/*l*.) that decrease to levels below 2 mg/*l*.
- Characteristic increases in alkalinity flattening out at levels of approx. 480 mg $CaCO_3$/*l* eqv.
- Low concentration levels of NH_4, PO_4, NO_3 and metals.

Cell 3: Uncovered, vegetated (lime treatment)

Cell 4: 300mm Avalon soil, uncompacted, vegetated

Cell 5: 500mm Avalon soil, compacted vegetated

- Relative stable pH levels (7.5 avg.) with no sign of acid breakthrough.
- Increasing trends in EC, SO_4 and TDS.
- Characteristic increases in alkalinity flattening out at levels of approx. 480 mg $CaCO_3$/*l* eqv.
- Low levels of NH_4, PO_4 and metals.
- Fluctuations in Mg concentrations recorded at Cell 4.
- Initial high Mn concentrations (10 – 13 mg/*l*.) that decrease to levels below 2 mg/*l*.

9.3.1. Cell 6: 300 mm Avalon soil, uncompacted, vegetated + 700mm Estcourt clay, compacted

Cell 7: 300mm Avalon soil, uncompacted, vegetated, +700mm Avalon soil compacted

Cell 8: 300 mm Avalon soil, uncompacted regulated, +300 mm Estcourt clay, compacted

- Relative stable pH levels (7.5 avg.) with no sign of acid breakthrough.
- Decreasing trends in EC. SO_4 and TDS.
- Decreasing trends in Mg and Mn.
- Initial increases in alkalinity flattening out at levels of approx. 420 mg $CaCO_3$/*l* eqv.

Cell 9B: 300 mm Avalon soil, uncompacted, vegetated, +700mm Escort clay, compacted 5% slope.

Cell 10B: 300mm Avalon soil, Uncompacted, Vegetated, 700mm Estcourt Clay, Compacted 10% slope.

- Relative stable pH levels (7.5 avg.) with no sign of acid breakthrough.
- EC, TDS and SO_4 levels did not show any significant trends.
- Characteristic increase in alkalinity that flattens out at levels of approx. 450mg$CaCO_3$/*l* eqv.

The key trends summarised in the above table, and their relationship with the associated geochemical processes are discussed in more detail in section 8.4. Regression analyses were conducted on the time series plots to quantify how trends vary over time. All the results of regression analyses are indicated on the time series plots with best-fit lines and R^2-values. The results of the comparative analyses are presented in the following 4 tables. The tables give correlation matrixes calculated for the combined database of all cells, excluding 10A and 9A. The first correlation conducted included the following chemical determinants: EC, Na, Ca, Cl, SO_4, and Mg. The reason for the chosen suite of chemical determents was to evaluate the correlation between EC and the major ions in solution. The only significant correlation obtained (correlation coefficient > 0.7) was between EC and SO_4, Mg and EC, and SO_4 and Mg (see **Table 9.4**).

Table 9.4: Correlation matrix for salinity related variables.

Correlation Coefficient	EC	Na	Ca	Cl	SO_4	Mg
EC	1.0	0.38	0.331	-5.3E^{-2}	**0.858**	**0.774**
Na		1.0	-6.5E^{-2}	-0.139	0.261	7.0E^{-2}
Ca			1.0	-3.1E^{-2}	0.33	0.17
Cl				1.0	-0.22	-6.6E^{-2}
SO_4					1.0	**0.772**
Mg						1.0

The second correlation configuration was between pH, Al, Fe, Mn and EC. The reason for this selection of chemical determinants was to evaluate and confirm the correlation between acidity and metal solubility. Conductivity did not have any significant correlation with any of the metals, but pH, as expected, had significant negative correlation with Fe, Al and Mn. The metals also had significant correlation with one another except for Fe and Mn. The reason for the latter could be related to the relative high initial Mn concentrations recorded at all the cells. The results of the correlation calculations are presented in **Table 9.5**.

Table 9.5: Correlation matrix for acidity related variables.

Correlation Coefficient	PH	Al	Fe	Mn	EC
pH	1.0	**-0.841**	**-0.781**	**-0.674**	-8.1E^{-2}
Al		1.0	**0.876**	**0.724**	0.237
Fe			1.0	0.466	0.219
Mn				1.0	0.125
EC					1.0

To evaluate the relationship between the production of alkalinity and the dissolution of base minerals such as feldspars, aluminium silicate and carbonate minerals, correlation was computed for the following chemical determinants: Al, Mg, Ca, K, Si and SO_4. **Table 9.6** show that the only significant correlation calculated was between Mg and SO_4 (see Section 4 for discussion).

Table 9.6: Correlation matrix for Al, Mg, Ca, K, Si and SO_4.

Correlation Coefficient	ALK	Mg	Ca	K	SI	SO_4
ALK	1.0	0.288	0.251	0.281	0.37	0.269
Mg		1.0	0.17	0.211	-0.128	**0.772**
Ca			1.0	$7.8E^{-2}$	$1.1E^{-2}$	0.33
K				1.0	$4.9E^{-3}$	0.214
Si					1.0	0.328
SO_4						1.0

Figure 9.1 presents two Piper diagrams showing the different water types for Cells 1 – 3 (uncovered cells) and Cells 4 – 8 (covered cells). From the Piper diagrams it can be seen that, in general, the leachate can be classified as Mg-Ca-ALK-(SO_4) type water. The only deviation to this observation is the leachate from Cell 1, which migrated from a Mg-Ca-ALK-(SO_4) type water to a Mg-Ca-SO_4 type water after the leachate turned acid.

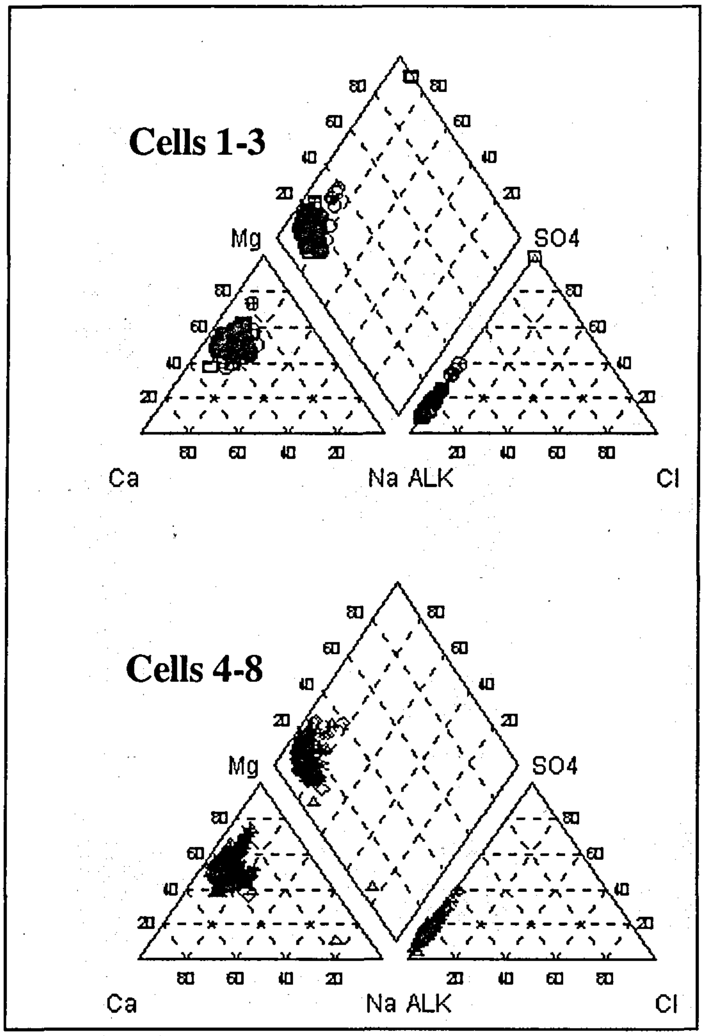


Figure 9.1: Piper diagrams for Cells 1-3 (uncovered cells) and Cells 4-8 (covered cells)

9.4 DISCUSSION

The quality of leachate produced from the experimental cells is a function of various biological, physical and geochemical processes taking place in the coal discard. The main geochemical processes that are associated with the experimental layout are:

1. Dissolution of existing salts.

2. Generation of acidity:
   - Oxidation of Fe S_2 and related minerals.
   - Establishment of *Ferrooxidans* bacterial populations.
3. Precipitation of secondary oxidation minerals.

4. Absorption and de-sorption of ions from and into the matrix solution.

5. Mobilisation of base/alkali minerals.

The effectiveness of the different discard covers to inhibit or accelerate these geochemical processes are discussed in detail under the headings of acid generating processes and pH buffering processes, listed below:

9.4.1. Acid Generating Processes.

The main driving force for the production of acidity from discard material is the oxidation of sulphide minerals such as pyrite. The acidity generated by this well documented reaction process, reacts with base/alkali minerals in the discard matrix which causes the production of salinity (Faure, 1992). The latter process is discussed in section 8.4.2.

One process mainly drive the oxidation of pyrite and is related to the presence of oxygen near sulphide mineral surfaces. The presence of sulphide oxidising bacteria such as *Thiobacillus Ferrooxidans* can catalyse the oxidation rate of pyrite up to 100 times faster than would be the case where oxygen is the only oxidant.

pH is the key chemical parameters used to detect and monitor the presence of acid generating processes associated with coal discard material. Acid Base Accounting (ABA) of 4 samples of the discard material used in the experiment indicated that the discard material has a greater acid producing potential than a neutralising potential (AP > NP). This means that, given suitable circumstances and time, that the discard will turn "acid". The pH time series plot for Cell 1 is clearly demonstrating how, once all neutralising potential of the discard material is consumed, the pH level drops to an average pH of 2.9. It is also interesting to note how suddenly this change occurred (within 2 weeks after three years of monitoring). During the period of low pH, high metal concentrations were recorded and this is a result of dissolution of metal containing minerals under acidic conditions. None of the other cells showed pH breakthrough curves. However this does not mean that acid generating processes are absent, it only means that the acidity produced has not yet consumed all the available base minerals in the discard material. Slower rates of acid production may also be explained by the role played by the more effective dump covers. The microbiological analyses conducted by the Microbiology Department at the University of Stellenbosch, indicated that significant populations of *Ferrooxidans* bacteria were present in the composite samples from Cells 1-4 (A very small population was present at Cell 5). It is therefore expected that the leachate collected at these cells will turn acid in the same way, as did the leachate at Cell 1. However, the study has also shown that permanent anaerobic conditions were established at the multi layered dump cover cells (Cells 6-10), which will prevent the establishment of viable *Ferrooxidans* populations, and hence reduce the rate of acid generating processes significantly.

Sulphate ions are produced as a by-product of the oxidation of pyrite. Sulphate can therefore be used as an indicator of the rate production of acidity within the discard material. The SO_4 time series plot for Cell 1 confirms that the accelerating trend in SO_4 correlates with the production of acidity. A higher rate of SO_4 production was also recorded during the low pH period, which confirms that higher rates of acid production takes place in low pH environments. The reason for the higher acid production rate could be related to accelerated oxidation of Fe^{2+} to Fe^{3+}at low pH's and an increase in bacterial activity at the lower pH level. The latter seems to be the case since a similar increase in NH_4 concentration was recorded just prior to the acid "breakthrough" indicating bacterial activity.

In Cells 2, 3, 4, and 5, trends of either increasing SO_4 concentration or elevated SO_4 concentration were recorded although the pH did not turn acid. This confirms the presence of pyrite oxidation, but at a slower rate than in Cell 1. The effect of the soil cover and vegetation (single layer) appear to have reduced the rate of acid production as a result of reduced ingress of water and oxygen and lower activity of bacteria. Cells 6,7 and 8 show trends of progressively decreasing SO_4 concentration over time, suggesting that the acid generating rate is progressively reduced over time. This trend appears to be related to the multi layered discard covers acting as effective barriers to the ingress of water and oxygen into the discard.

9.4.2. pH Buffering Processes.

Acid buffering refers to the stabilisation of leachate from discard material pH, resulting from the interaction of the acid leachate produced by pyrite oxidation and base minerals in the discard matrix. These base minerals in the discard matrix include carbonates, hydroxide, oxides, and silicates. The buffering capacity of a mineral is dependant on various factors such as the overall solution chemistry, gas composition in contact with solution, and contact time relative to equilibrium constants (Drever, 1982). There are no mineralogical analyses results for the discard material used in the experiment, but the following common base minerals are expected to be present: $CaMg(CO_3)_2$ (Dolomite), $CaCO_3$ (Calcite), Mg CO_3 (Magnesite), and various silicate minerals incorporating Ca, Mg, Na, K, Fe and Al into the mineral structure, such as Wallastonite ($CaSiO_3$) and aluminium silicate clay minerals.

A key parameter indicating the buffering capacity of a solution is alkalinity. An interesting trend of an initial increase in alkalinity has been recorded for all cells. Because this trend of initial increase in alkalinity cannot be related to salts washed from the soil covers (same observation at all cells), it seems to be related to the dissolution of salts that was already deposited in the discard, before it was used in the experiments. Once the initial increase in alkalinity has taken place, the alkalinity levels level out at levels of approximately 420-480 mg $CaCO_3$/*l* eqv. At Cell 1, the acid breakthrough co-incides with a sudden drop in alkalinity. It seems therefore that the production and level of alkalinity are governed by acid producing processes as well as other processes such as salt and mineral dissolution due to natural weathering.

When acid matrix water reacts with base minerals, the consumption of protons(H^+) by anions such as CO_3, results in the dissolution of ions such as Ca and Mg. This is confirmed by an observed increase in Mg concentration at cells 1, 2, 3, 4 and 5. The increase in Mg concentration is correlated with an increase in SO_4 concentration (correlation coefficient = 0.772) which in turn is indicative of pyrite oxidation. At cells 6, 7 and 8 the recorded Mg concentrations decreases over time again following the same SO_4 concentration trend. The reason for the correlation between Mg and SO_4 concentrations is related to the oxidation of pyrite causing acidity which is neutralised by Ca and Mg carbonate minerals, resulting in the dissolution of Ca and Mg ions. However, no significant correlation exists between Ca and SO_4. This is probably because the concentration of Ca ions in solution is controlled by the solubility of Gypsum ($CaSO_4$) which at SO_4 levels of approximately 2000mg/*l* precipitates from solution (Stumm and Morgan, 1981). However, this is not the case with Mg SO_4 mineral phases, which are more soluble than the Ca equivalents. Continued presence of high concentration levels of Ca post acidification is probably due to the dissolution of gypsum.

9.5 CONCLUDING REMARKS

The following key results were obtained from the statistical and comparative analysis conducted on the leachate quality database:

1. The discard material has more acid generating potential than acid neutralising potential, which means that the discard material will turn acid, as was demonstrated at Cell 1.

2. Increasing trends of salinity have been recorded at Cells 1-5 indicating the presence of acid generating and pH buffering processes. The EC, TDS, Mg and SO_4 concentration levels increased over time in these cells.

3. A trend of decreasing salinity was recorded at Cells 6-10 indicating the absence or significant inhibition of acid generating processes. The EC, TDS, Mg and So_4 concentration levels either stayed the same or decreased over time.

From these results it can be concluded that the single layered dump covers (Cells 4 and 5) are less effective in preventing the production of acidity and salinity from the discard material. However, these single layered covers inhibit some of the acid generating processes by inhibiting the ingress of water and oxygen into the discard material. This means that an acid breakthrough in leachate quality will occur but will only take place in a number of years. Multi layered covers on the other hand have the capacity to prevent the production of acidity by establishing permanent anaerobic conditions in the discard material. This is confirmed by the oxygen monitoring results showing that zero oxygen was recorded at cells 6-10 for most of the monitoring period. By restricting the ingress of water to 7% of MAP and completely preventing the migration of oxygen into the discard material, the multi layered covers succeed in preventing acid generating processes and subsequent generation of salinity through pH buffering processes.

The residual high TDS recorded at cells 6-10 seems to be a result of washout of previously deposited oxidation and weathering products, that are not driven by the production of acidity and the buffering of the acidity by dissolution of base minerals.

10.CONCLUSION

10.1 DISCUSSION

Opencast coal mines and discard dumps covers large areas and could contribute significantly to salinity and acidity to the groundwater regime. Increased salinity and acidity are caused mainly by the oxidation of sulphide minerals which are exposed to oxygen and water during the mining process. In addition, the acid formation process can greatly be increased by bacterial activity. The most common mitigation method to limit increased salinity and acidity is to provide the discard dump or back-filled opencast mine with a soil cover, the purpose of which to exclude or limit either or both water and oxygen from entering the discard material.

In order to assess the effectiveness of the soil cover to limit outflow through the discard dump, it is necessary to have a tool whereby outflow can be predicted. However, recharge processes are highly complex, as have been shown by numerous authors, as well as this research. Due to these complexities, a calibrated numerical unsaturated flow model offers the best way to predict outflow for specific climatic scenarios. Various authors have found that recharge are sensitive to certain climatic events, in particular, rainfall patterns. In addition, it has been found that the integrity of the soil covers, insofar hydraulic properties are concerned, are an important aspect to consider in predicting outflow. However, it has been found that many numerical unsaturated flow models do not address these aspects adequately. Notoriously little information could be found regarding long-term outflow monitoring.

The experimental set-up was constructed as such to test various single and double soil cover configurations and to compare this to uncovered cells, as well as to examine the effect of vegetation. In addition, the cells have been constructed with an under-drainage system to intercept all water flowing through the experimental cells. This proved to be advantageous compared to the more traditional lysimeters since water flowing via preferential pathways is not easily intercepted by lysimeters. A large range of weather variables has continuously been monitored and the soil hydraulic properties have been extensively examined.

It has been found that an accurate description of the hydraulic properties of the soil cover is critical in assessing outflow. The most significant aspect, as indicated by the experimental results, is the differences of the hydraulic properties between *in situ* and remoulded samples, differing by up to a factor 18 000. This indicates that laboratory permeability tests are by far inadequate to assess the hydraulic properties of the soil cover material.

The unsaturated hydraulic conductivity results indicate that the hydraulic characteristics can be explained by a two-domain system, whereby a high hydraulic conductivity occurs at near saturated conditions while significantly lower hydraulic conductivity occurs at unsaturated conditions. This is probably because water flows preferentially along large pores and macropores in near saturated conditions and flows via the soil matrix in unsaturated conditions. The situation could be compared to a damwall scenario where, storage is available in the dam, only limited amounts of water will seep through and underneath the damwall while when the dam has reached capacity, overflow will occur which is analogue to preferential flow through large and macropores. Most unsaturated models are not able to handle two-domain systems and as a result, poor predictions of recharge can be expected.

The oxygen and carbon dioxide results indicate significant differences between uncovered, single-layer and double-layer configurations. High oxygen and low carbon dioxide concentrations have been measured in uncovered cells while almost no oxygen and high carbon dioxide concentrations have been measured in the double-layer configurations. (The exceptions being high rainfall events that resulted in a temporary increase in oxygen and decrease in carbon dioxide concentrations) This indicates that double layer systems are particularly effective in limiting oxygen ingress into the soil, probably more so than limiting water ingress. These results indicate that soil covers should be designed as to exclude oxygen ingress, rather than to focus on limiting water ingress, and requires additional research.

The weather results have highlighted the erratic behaviour of rainfall. The importance of rainfall patterns, and its affect on recharge, has also been highlighted. It has shown that high-intensity short duration thundershowers should be adequately addressed by the unsaturated model as to accurately define the top boundary, in particular run-off.

The outflow results have highlighted the sensitivity of unsaturated flow processes to rainfall events. High outflow events have without exception be directly associated with high rainfall events, though more pronounced in the uncovered cells. The high outflow percentages during the winter months are misleading, since much of this outflow is the result of rainfall events occurring during the rainy season.

10.2 CONCLUSIONS

The research project has indicated that prediction of recharge (or outflow) at discard dumps and rehabilitated opencast mines are extremely difficult. The many factors, many of which are time dependant, indicate that traditional empirical and analytical models are far inadequate to predict recharge. Numerical modelling offers the only way to predict and assess recharge adequately. However, these numerical models have to be modified to incorporate site specific climate and soil conditions.

10.2.1. Climatic effects on cover efficiency

The results of the experiment indicate that recharge is sensitive to specific rainfall patterns and that the high variability in seasons had marked effects on the outflow results. In addition, the results indicate that cover efficiency is greatly effected by climatic changes, with very high outflow recorded during high-intensity rain seasons. The experimental results further show that:

- The outflow results mimic the seasonal rainfall pattern almost without exception, with the high outflows being associated with the high rainfall events.
- Summer outflows were found to be generally lower than winter outflows. However, some of the outflow observed during the winter season could actually be a result of summer rainfall, which only resulted in outflow during the winter season.
- Direct relationships between rainfall events and outflows could not be found from the experimental data. However, the results from uncovered cells 1 - 3 indicate that single large outflow events usually follow single large rainfall events. Although high outflow events have been found to occur after high rainfall events for cells 4 – 10, the lag time

between rainfall and outflow and complicated flow processes resulting from two succeeding rainfall events made direct relationships difficult to observe.

- Sporadic winter rainfall events tend to have no effect on the outflow results. It is postulated that all moisture that infiltrated the soil cover and discard material have been removed by evapotranspiration processes

10.2.2. Cover effectiveness as oxygen inhibitor

The literature survey indicated that if oxygen were to be excluded from the coal discard, pyrite oxidation would not occur easily. The oxygen readings taken on the experimental site leads to the following conclusions:

- The oxygen concentrations in the cells follow consistent patterns, which are only deviated from when significant rainfall events occur.
- During rainfall events that exceeded 120mm/week, the oxygen content in cells 1 - 4 dropped significantly, probably as a result of saturation of the soil profile, temporary excluding oxygen from entering the profile.
- In the case of cells 5 – 10 the oxygen concentration increased dramatically as these significant rainfall events occurred. The reason for these increases is not clear, but the saturation could have caused air at the surface to be trapped in the profile, resulting in the higher oxygen concentration.
- The results for cells 1 – 3 indicate that oxygen moved easily into the discard material. The compacted cell no 2 was almost completely ineffective in reducing the oxygen concentration.
- The results for cell 4, with a soil cover of 300mm uncompacted Avalon, indicate that oxygen concentrations have been reduced to 15%, but is still ineffective as oxygen barrier.
- The results for cell no 5, with a 500mm of compacted Avalon soil cover, indicate that oxygen ingress are limited significantly, indicating an effective cover.
- The lowest oxygen concentrations have been measured for the layered cells 6 – 10, which almost completely excluded oxygen ingress, indicating a very effective cover.
- The results indicate that oxygen ingress can be reduced significantly by increasing the cover thickness of the compacted soil cover.
- Although the oxygen concentrations could suggest an impermeable cover, outflow has been measured. This indicates that water filled the pores while flowing through the soil cover, thereby limiting oxygen ingress.

10.2.3. Cover effectiveness to limit outflow

The following conclusions can be made regarding the effectiveness of the covers to limit outflow:

- As expected, outflow recorded from uncovered cells, whether they are compacted, uncompacted, vegetated or not, have been higher than covered cells, indicating that soil covers do reduce outflow.

- The results have shown that outflow through uncovered coal discard can be slightly reduced by compacting the discard.

- The results indicate that vegetation of uncovered spoils has no effect in reducing outflow.

- Simple single layered soil covers did reduce outflow significantly for uncompacted and compacted soils respectively.

- Double layered soil covers also reduced outflow significantly, though by the same order of magnitude than simple single soil covers.

- The double layered cells, which comprised of Estcourt and Avalon soils performed poorer than the single layer compacted Avalon soil cover. The best performance was recorded for a double layered soil cover comprising of both compacted and uncompacted Avalon. This indicates that soils with a stable structure, such as Avalon soils, do perform better than soils with a less stable structure, such as Estcourt soils.

- The steeply sloped cells generally performed better than the gentle sloped cells. However, the sloped cells performed much worse than the double and even single layer cells during high rainfall seasons. The reasons for the poor performance is not clear yet but it is speculated that preferential pathways, caused by desiccating cracking, burrowing animals and root penetration could have resulted in the higher outflow rates, assisted by other preferential flow mechanisms, in particular funnelled flow. However, experimental error cannot be ruled out.

- The effectiveness of the soil covers did not appear to improve with vegetation of the experimental cells. However, increased outflow resulting from the succeeding high rainfall season could have overwhelmed the effect of vegetation.

- In conclusion the results indicate outflow through uncovered cells to be approximately 20%, for simple soil covers outflow have been reduced to approximately 10% and for double layered covers outflow have been reduced to approximately 11% with sloped covers indicating 8% outflow.

10.3 GUIDELINES FOR CONSTRUCTING EFFECTIVE COVERS

Based on the findings of this report, the following recommendations for the design of natural soil covers, to limit oxygen ingress and recharge, can be made:

- The coal discard dump, or opencast spoils should be compacted where possible and this will resulted in reduced outflow.
- The discard dump has to be shaped as such that slopes in excess of 5% are attained. This has been showed to reduce outflow by a significant margin. Steep slopes are obviously more advantageous, but care should be taken to prevent erosion.
- The use of clayey materials, with a poor structure, should be avoided where the moisture profile cannot be kept moist. The severe drying and wetting could cause degradation of the soil cover resulting in an increased permeability. If no other material is present, the clayey material should be protected by a protection layer of adequate thickness.
- Long-term degradation of the soil cover should be expected, and funds have to be made available for general maintenance of the soil cover. The soil cover design should take cognisance of long-term degradation.
- Vegetation of the coal spoils is not effective in reducing the outflow. A compacted soil layer of adequate thickness should be provided to limit outflow through coal spoils.
- Since vegetation do not appear to have a significant effect on outflow, vegetation is not necessitated. However, vegetation, or other erosion protection material should be provided to prevent erosion.
- A combination of tufted and stoloniferous grass types should be used if the soil cover is to be vegetated. The tufted grass types will assist in evapotranspiration while stoloniferous grass types will reduce the erosion potential.
- Outflow collection systems should be sized for at least 23% of MAP in uncovered cells and 12% on covered cells.

10.4 FURTHER RESEARCH NEEDS

This project has provided invaluable insights into the performance of soil covers, but questions regarding the long-term performance of soil covers have not been addressed adequately. The following recommendations are made:

- It is highly recommended that a geochemical study be undertaken, together with the outflow studies so that AMD processes and contaminant loads can be investigated as functions of recharge.
- The results indicate that soil covers are probably more effective in limiting oxygen influx than limiting outflow. Additional research should be undertaken to assess the effectiveness of soil covers to oxygen ingress.
- Although good results have been obtained from this project, the soil covers proved to be not up to standard regarding field permeability is concerned. It is recommended that two or three covers be supplied with different soil configurations as to investigate outflow and oxygen ingress for less permeable soil types.

- Monitoring on this experimental site should continue for at least 5 more years, or until it is proved that the outflow pattern can be predicted accurately.

- Annual tests should be conducted to determine the soil hydraulic properties as to determine the degree the soil cover deteriorates, if any.

- Lysimeters should be installed to determine the actual water quality within the discard material and to determine soil water content/hydraulic head relations for calibration purposes.

- The experimental site should be upgraded to include for the measurement of runoff to determine the exact rainfall threshold event whereby no infiltration takes place.

- On site measurements of rainfall events with associated moisture profile changes before and after the event should be conducted to determine the response time of the moisture profile with the rainfall event.

- A number of actual waste dumps should be identified and instrumented to give additional data on actual cover performance.

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SUMMARY OF MODELS ABLE TO HANDLE UNSATURATED FLOW CONDITIONS

Model Name	Model Description	Model Processes	Author
1. ACRU	It is a multi-purpose model which integrates the various water budgeting and runoff producing components of the terrestrial hydrological system.	evapotranspiration, interception, infiltration	RE Schulze, 1995
2. DRAINMOD	An analytical model for unsteady, one-dimensional, horizontal/vertical, saturated/unsaturated problems; simulates water table position and soil water regime above water table for artificially drained soils	capillary, evapotranspiration	RW Skaggs, 1980
3. FEATSMF	A transient finite-element 2-D soil moisture flow model for homogeneous, isotropic hill slopes where the moisture is supplied by rainfall	capillary, evapotranspiration	JL Neiber, 1979
4. FEMWATER /FECWATER	A two-dimensional finite-element model to simulate transient, cross-sectional flow in saturated-unsaturated anisotropic, heterogenous porous media	capillary, infiltration, ponding	GT Yeh; DS Ward, 1987
5. FLO	FLO simulates the elements of the hydrologic cycle which are directly influenced by soil and surface drainage improvements. Total discharge from a drained plot is estimated. Detailed accounts of unsaturated flow are considered	capillary, evapotranspiration	A Vandenberg, 1985
6. FLOWVEC	A finite difference model which utilises a vector processor for solutions to three dimensional variably saturated flow problems	capillary forces	RM Li, KG Eggert, K Zachmann, 1983
7. FLUMP	A finite-element model for computation of steady and nonsteady pressure head distributions in two-dimensional or asymmetric, heterogeneous, anisotropic, variably saturated porous media with complex geometry	capillary, diffusion, evapotranspiration	TN Narasimhan; SP Neuman, 1981
8. GRWATER	A finite difference model to predict the decline of ground water mounds developed under recharge in an isotropic, heterogeneous aquifer with transient saturated or unsaturated conditions	infiltration, capillarity, evapotranspiration	DK Sunada, 1981
9. HELP	The Hydraulic Evaluation of Landfill Performance model is a quasi-two-dimensional, deterministic, computer based water budget model. Climatologic and design input data in the form of daily rainfall, mean monthly temperatures, mean monthly solar radiation, leaf area indices, soil characteristics and design specification are used to perform a sequential daily analysis to determine runoff, evapotranspiration water budget for a landfill capping	Runoff is calculated by the Soil Conservation runoff curve. Evapotranspiration by the modified Penna method and percolation by a linear Darcy approximation for unsaturated conditions	PR Schroeder; AC Gibson; MD Smolen, 1989
10. HSSWDS	1-D analytical water budget model to estimate the amount of moisture percolation through different typed of landfills	capillary, evapotranspiration, runoff, snowmelt	ER Perrier; AC Gibson
11. HYDRUS	Program designed to simulate one-dimensional flow through variably saturated porous media	Galerkin finite elements, Richards equation, hysteresis	T Vogel; K Huang; R Zhang; M Th van Genuchten, 1996
12. ICE - 1	A one-dimensional analytical solution for the analysis of heat, water and solute transport in unsaturated, partially frozen soils	accounts for heave	

Model Name	Model Description	Model Processes	Author
13. INFGR	1-D vertical model to estimate infiltration rates, using the Green and Ampt equation. The compression method is used to estimate infiltration during low rainfall periods	capillary	PM Graig; EC Davis, 1985
14. INFIL	An analytical solution to calculate infiltration rate and water content profile at different times, using the Philip series solution of a one-dimensional form of the Richard's equation	infiltration	AL El-Kadi, 1987
15. INFIL	The finite-difference model solves for one-dimensional infiltration into a deep homogeneous soil. Output includes water content profile and amount and rate of infiltration at different simulation times	capillary, infiltration, evapotranspiration	M Vauclin, 1983
16. LANDFIL	Model simulates the transport of moisture throughout the unsaturated zone, using a finite-difference solution for the 1-D flow equation	capillary, evapotranspiration	GP Korfiatis, 1984
17. MATTUM	This is a three-dimensional model for simulating moisture and thermal transport in unsaturated porous media. The model solves both the flow equation and the heat equation using the integrated compartment method	capillarity	GT Yeh; RJ Luxmoore, 1983
18. MIKE SHE WM	A comprehensive deterministic, distributed and physically based modelling system for the simulation of all kinds of major hydrological processes, of the land based part of the hydrological cycle	interception, evapotranspiration, Richards equation	
19. MOTRANS	A numerical model for multi phase flow and transport of multi component organic liquids in two dimensional vertical sections through saturated and unsaturated zones	multi-phase transport	
20. MUST	A finite-difference model which simulates one-dimensional vertical, unsaturated, groundwater flow, evapotranspiration, and interception of precipitation by plants	capillary, evapotranspiration, plant uptake	PJM DeLaat, 1985
21. PRZM-2	This is a one-dimensional finite difference model, which predicts pesticide transport and fate through the unsaturated zone.	constitutive relationship between pressure, water content and hydraulic conductivity	JA Mullens, 1994
22. SEEP/W	From a CAD like input, simple steady state problems or sophisticated saturated/unsaturated time dependant problems are solved	infiltration, precipitation, migration of wetting front, dissipation of excess pore-water pressure, Richard's equation	
23. SEEPV	A finite-difference transient flow model to simulate vertical seepage from a tailings impoundment in variably saturated flow systems; considers interactions between a liner and the underlying aquifer	infiltration, capillary, evapotranspiration	LA Davies, 1980
24. SESOIL	A one-dimensional vertical transport model for the unsaturated zone	infiltration, soil water content, evapotranspiration	M Bonazountas; J Wagner, DM Hetric, 1994

Model Name	Model Description	Model Processes	Author
25. SOILCOVER	One-dimensional transient analysis program, that predicts the actual rate of evaporation from both saturated and unsaturated soil surfaces taking account of the soil properties and effects of vegetation	evapotranspiration	M O'Kane, GW Wilson, Barbour, SL, 1993
26. SOILMOP	An analytical model to predict ponding time, infiltration rate and amount, and water content profiles under variable rainfall conditions. The model solves a one-dimensional flow equitation in a homogeneous soil. Air phase is also included	capillary	DL Ross; HJ Morel-Seytox, 1982
27. SOMOF	A finite-difference model for simulation of transient unsaturated soil moisture flow in a vertical profile	precipitation, capillary, evapotranspiration, gravity drainage, plant uptake, ponding	JW Wesseling, 1982
28. SPLASHWATR	Simulation of coupled heat and moisture fields in the unsaturated zone	capillarity, evapotranspiration, convection, conduction, diffusion, change of phase, hysteresis, adsorption	P Christopher; D Milly, 1983
29. ST2D	A program for the stochastic analysis of gravity drainage and the effects of parameter variability	Monte-Carlo technique, generator for hydraulic conductivity realization finite-element simulation and statistical analysis	
30. SUMATRA-1	A one-dimensional Hermitian finite element model for simulation of simultaneous movement of water and solute i a heterogeneous soil profile	saturated and moderately unsaturated soul conditions with fairly abrupt layering can be handled	M Th van Genuchten, 1986
31. SUTRA	Two dimensional simulation of flow and either solute or energy transport in saturated/unsaturated variable density systems		1991
32. SWACROP	A transient one-dimensional finite difference model for simulation of the unsaturated zone, incorporating the process of water uptake by roots	Numerous options for defining unsaturated soil relationships and calculating potential evapotranspiration. The Richard's equation are solved in an implicit tridiagonal algorithm	JG Wesseling; P Kabat; BJ van den Broek; RA Feddes, 1992
33. SWANFLOW	A three-dimensional finite-difference code for simulating the flow of water and an immiscible nonaqueous phase under saturated and unsaturated near-surface conditions		
34. SWATRE, SWATR-CROPR	A finite-difference model for simulation of the water balance of agricultural soil	precipitation, capillary, evapotranspiration	RA Feddes, 1981
35. SWIM	A simulation package to solve the unsaturated soil water flow equations to determine the soil water balance, infiltration and movement	vegetation characteristics, precipitation, evapotranspiration and Richard's equation	PJ Ross, 1990
36. SWMS_2D	Numerical model for simulating water and solute movement in two-dimensional variably saturated media	root water uptake, adsorption, Richards equation	J Simunek; T Vogel; MTh van Genuchten, 1994

Model Name	Model Description	Model Processes	Author
37. TRUST	To compute steady and nonsteady pressure head distributions in multi-dimensional, heterogeneous, variably saturated, deformable porous media, with complex geometry; uses integrated-finite-difference method	capillary, diffusion, consolidation, hysteresis	TN Narasimhan, 1981
38. UNSAT-H	UNSAT-H is a finite-difference one-dimensional, unsaturated flow model. It simulates infiltration, drainage, redistribution, surface evaporation, and plant water uptake from soil. The model is designed for arid zones similar to the Hanford Site (Washington)	capillary, evapotranspiration, infiltration, drainage plant uptake	MJ Fayer, GW Gee, 1985
39. UNSAT1	A finite-element solution to Richard's equation to simulate one-dimensional saturated-unsaturated flow in heterogeneous soils	capillary, evapotranspiration	M Th van Genuchten, 1978
40. UNSAT2	A two-dimensional finite element model for horizontal, vertical or axi-symmetric simulation of transient flow in a variably saturated, non-uniform, anisotropic porous medium	capillary, evapotranspiration, plant uptake	SP Neuman, 1979
41. UNSAT1D	A finite-difference model for one-dimensional simulation of unsteady vertical unsaturated flow	capillary, evapotranspiration, plant uptake	SK Gupta; CS Simmons, 1981
42. VS2D	2-D finite-difference code for the analysis of flow in variably saturated porous media. Model considers recharge, evaporation, and plant root uptake	evaporation, recharge, plant uptake	EG Lappala; Healy, RW; EP Weeks
43. VS2D/T	A program for solving problems of water flow and solute transport in a variably saturated porous media	Relative hydraulic conductivity is evaluated by using full upstream weighting. Characteristics are represented by Van Genuchten, Brooks-Corey, Haverkamp or tabulated data	RW Healy, 1993
44. WATERFLO	A one-dimensional finite-difference solution for the Richard's equation to simulate water movements through soils		DL Nofzinger, 1983

COLOUR PHOTOGRAPHS OF VARIOUS ELEMENTS OF THE EXPERIMENT

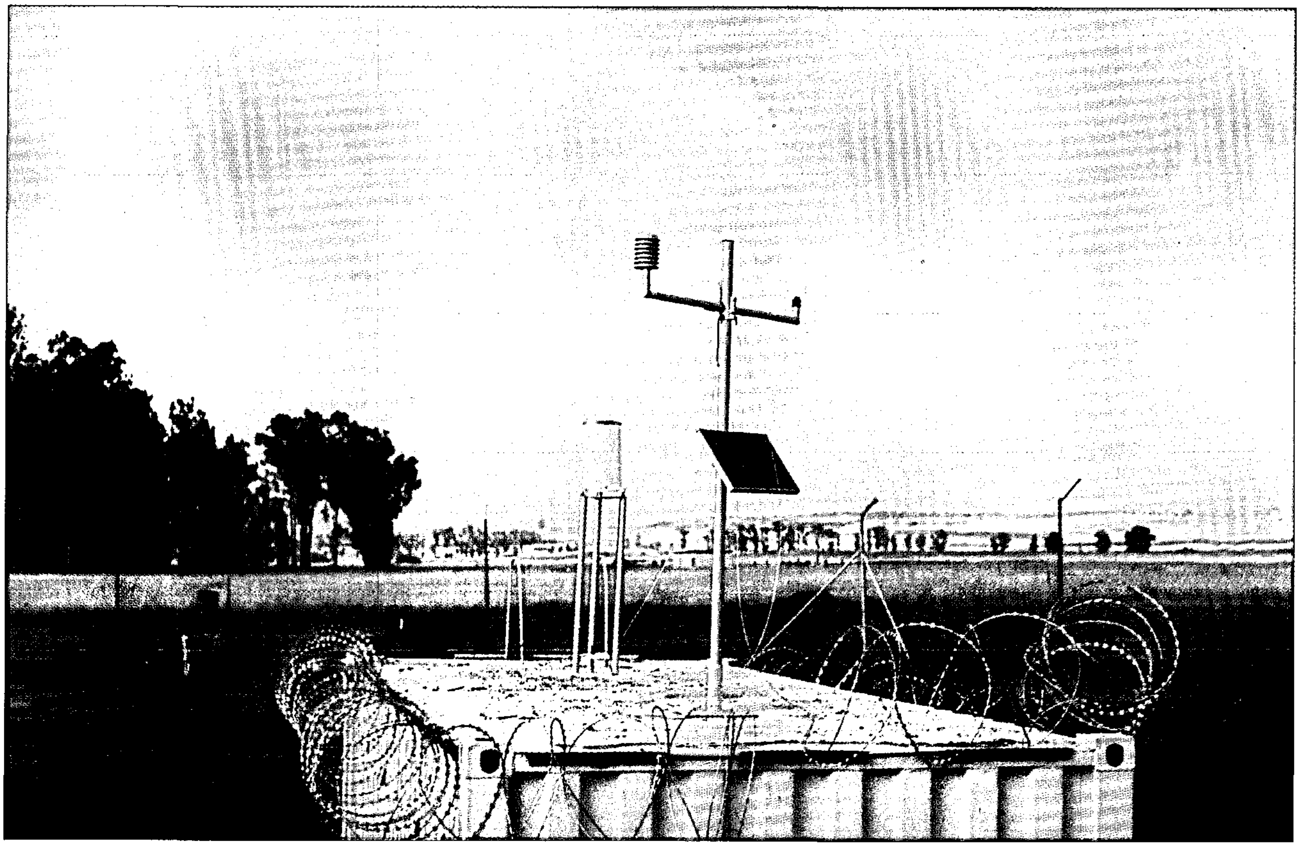


Fig B.1: The weather station at the experimental site.

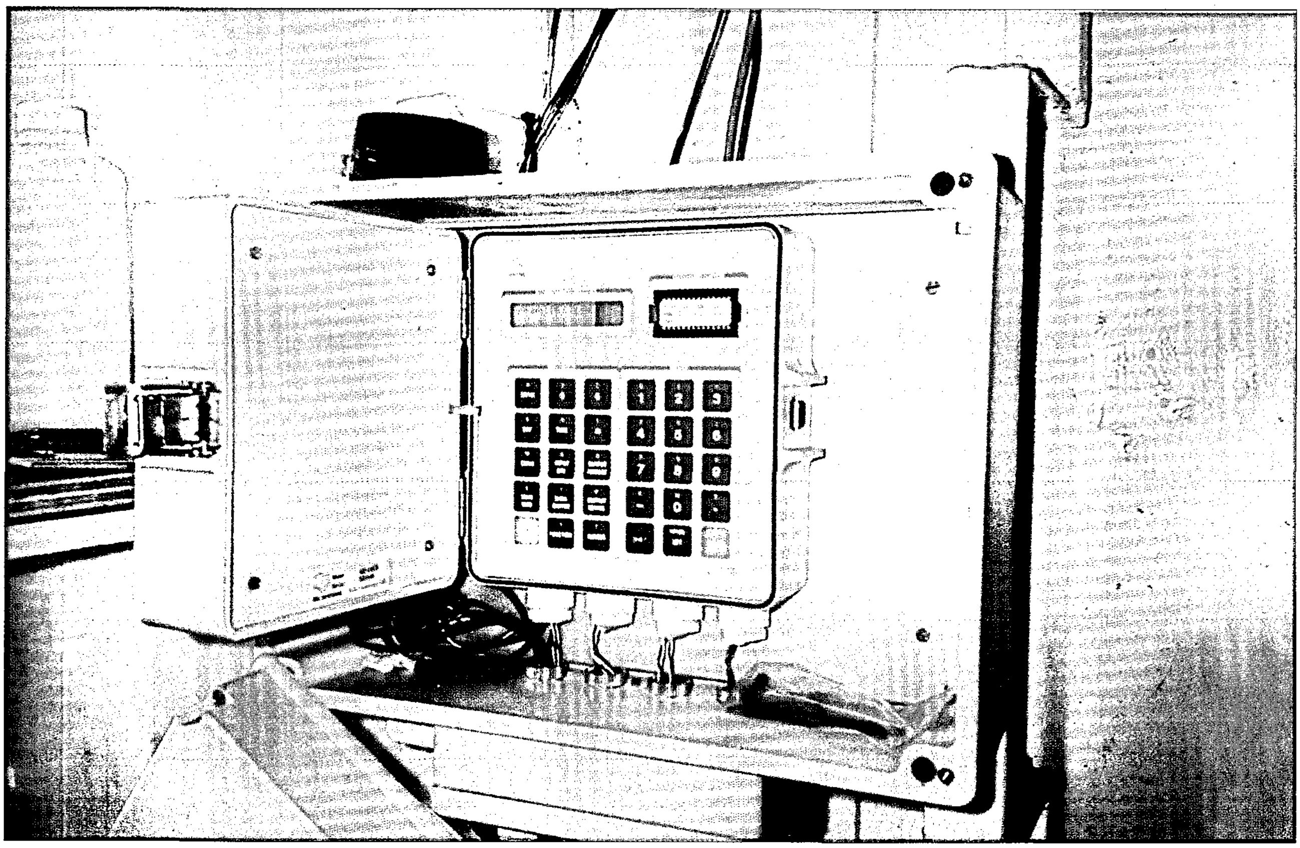


Fig B.2: The data logger used for compiling the weather data.

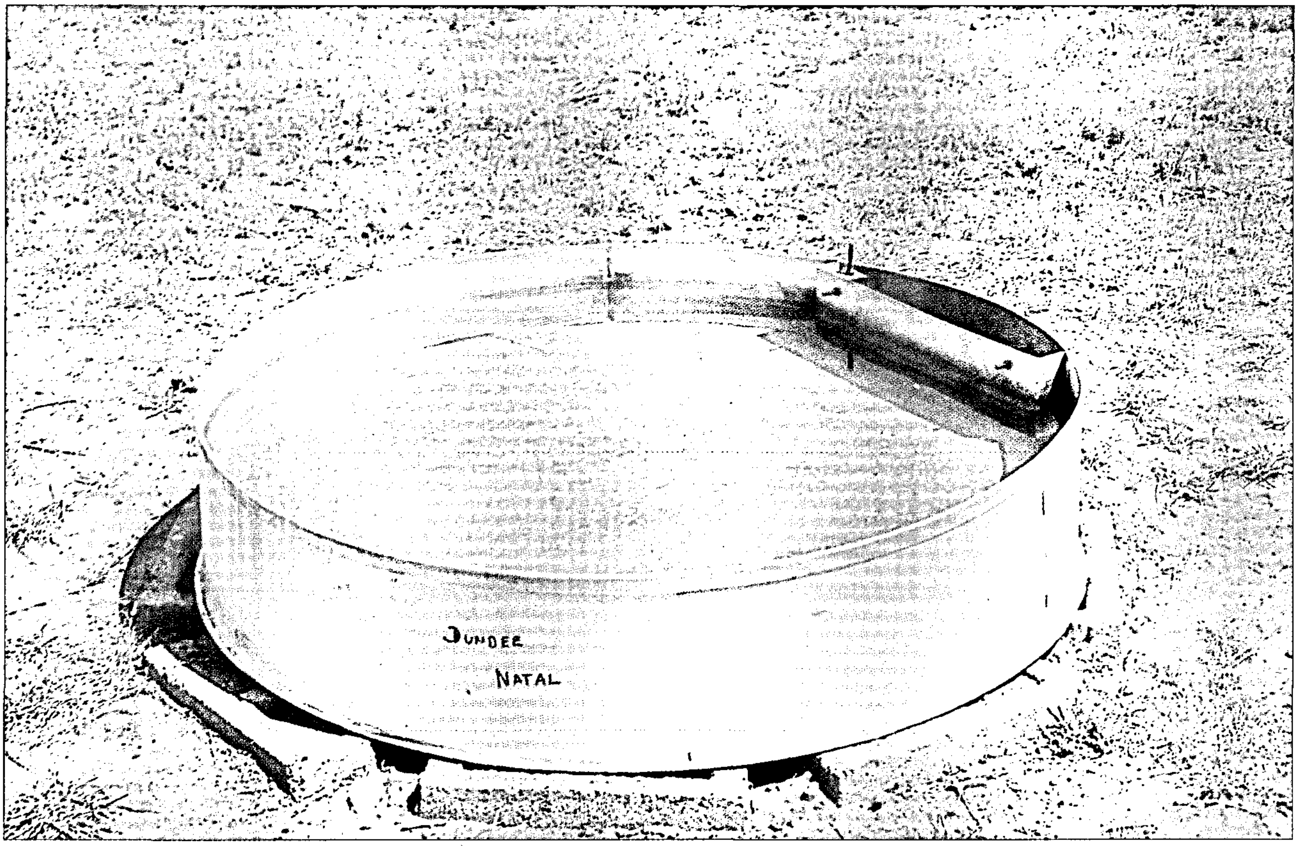


Fig B.3: The evaporation pan installed at the experimental site.

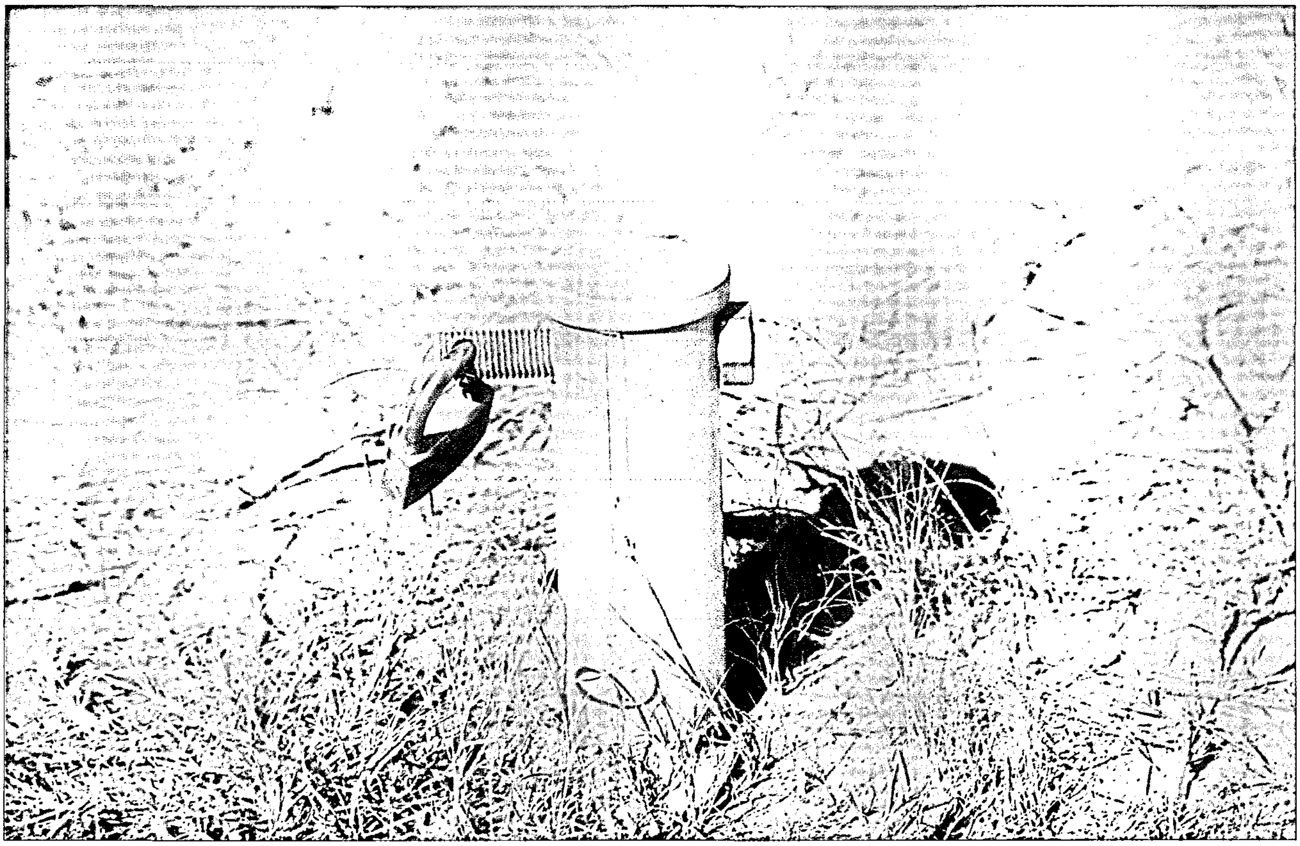


Fig B.4: A sample of one of the access tubes protruding from the soil cover.

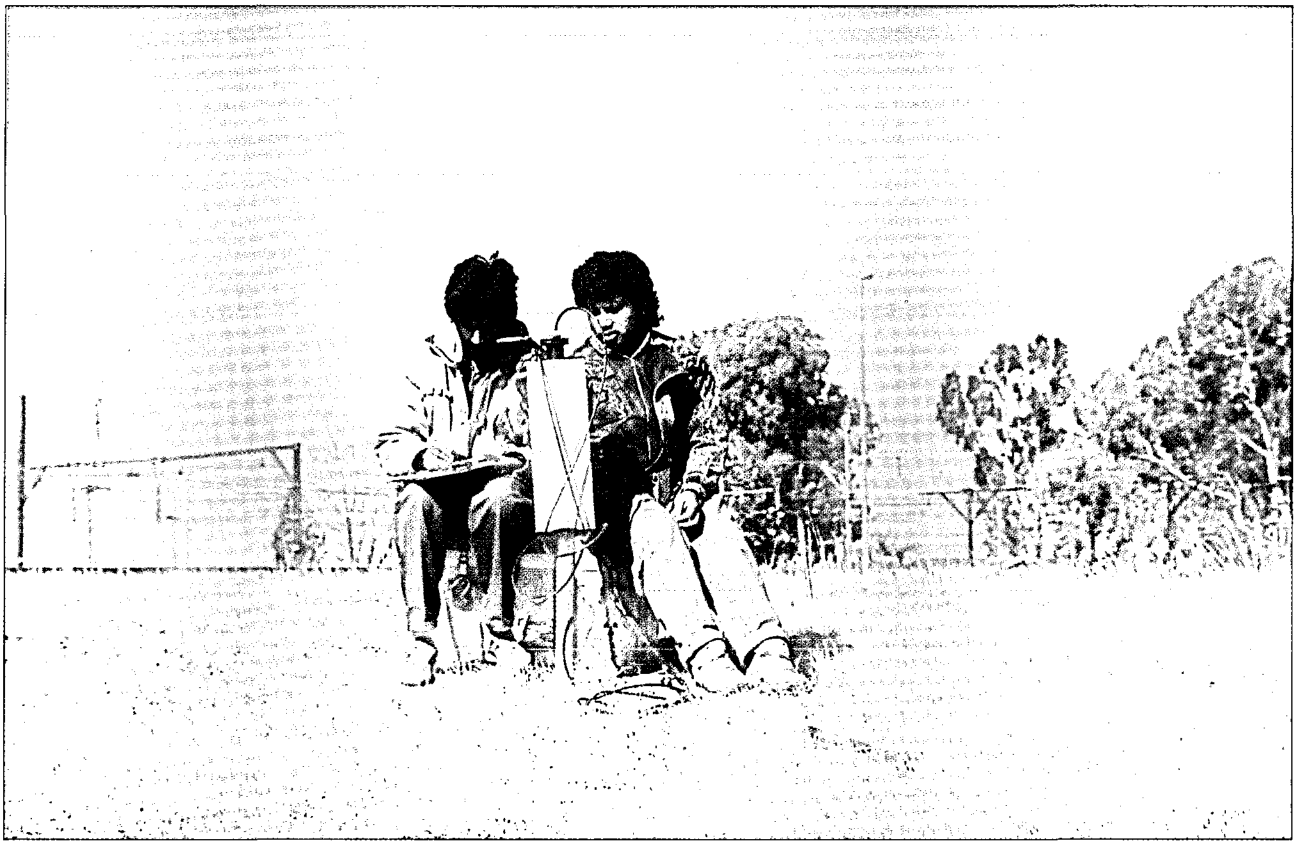


Fig B.5: Nuclear probe used to determine in-situ moisture content and density.

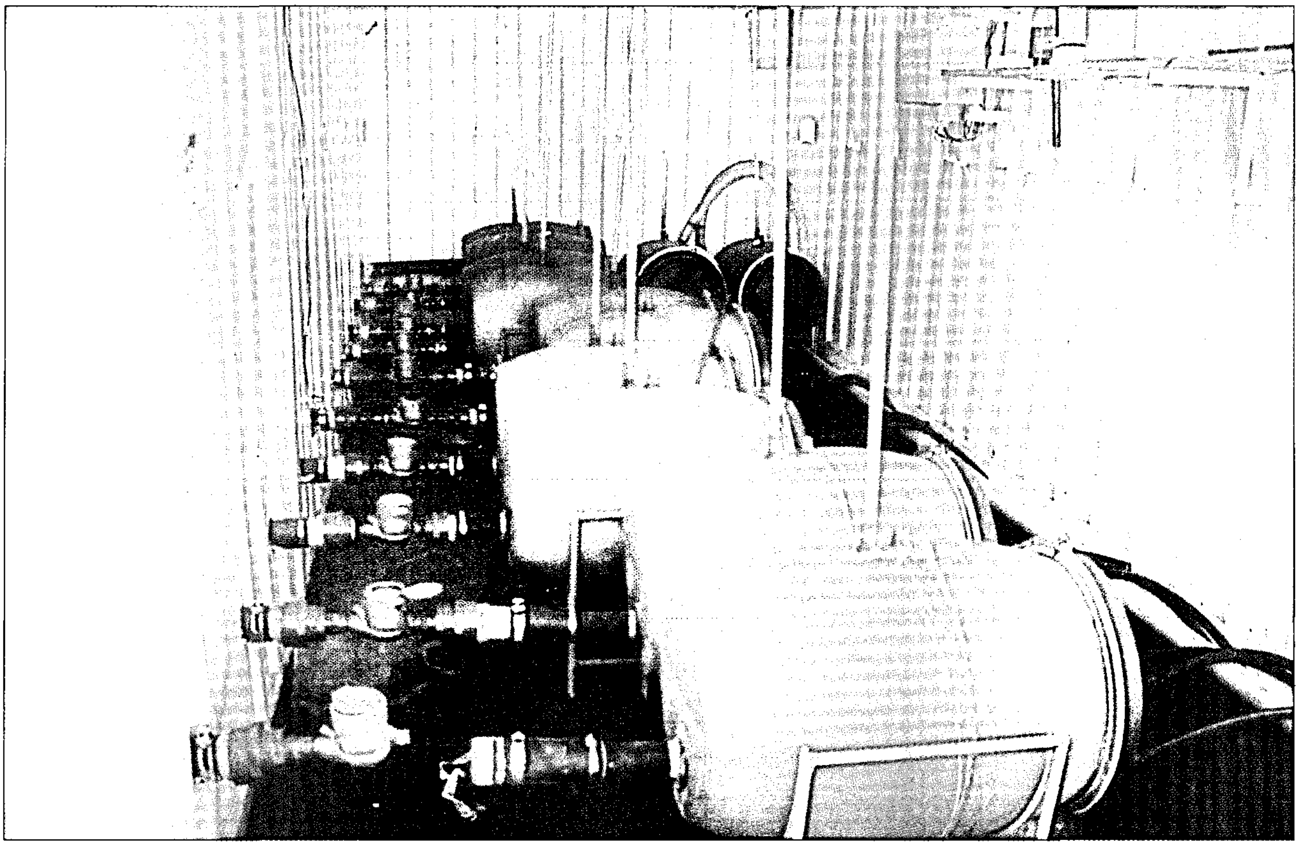


Fig B.6: Leachate collection system prior to February 1995.

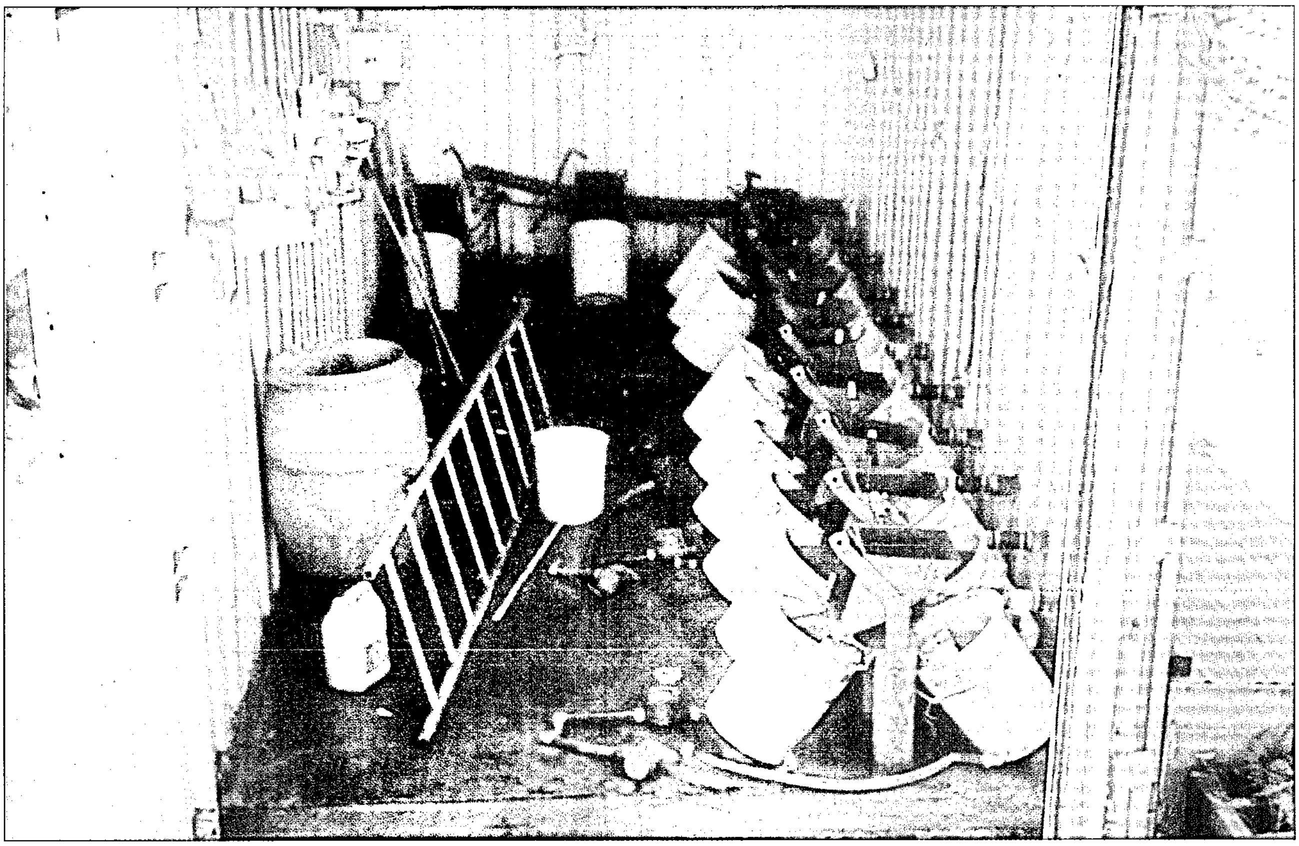


Fig B.7: Leachate collection system after February 1995.

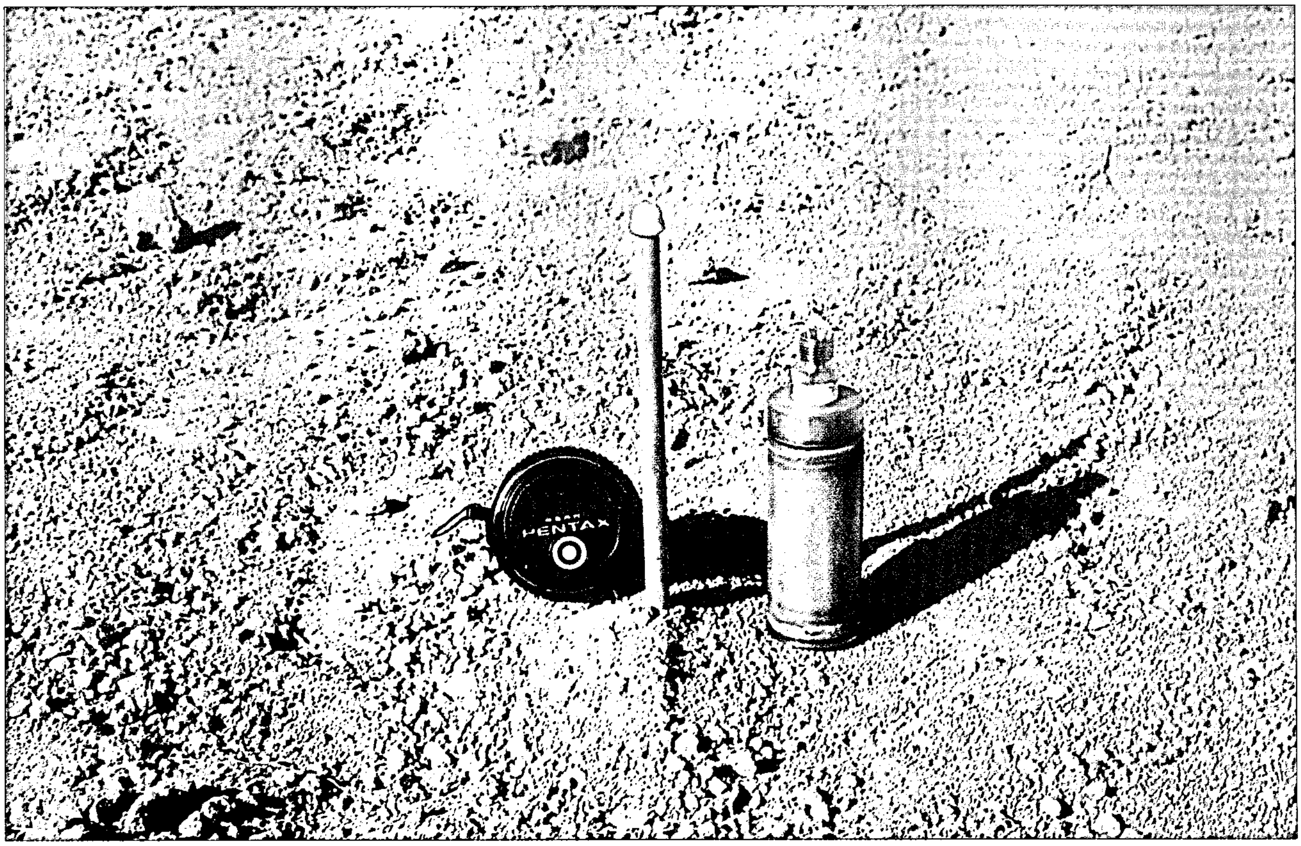


Fig B.8: Sample of the sintered gasmeter probe used to measure the oxygen and carbon dioxide concentrations below surface.

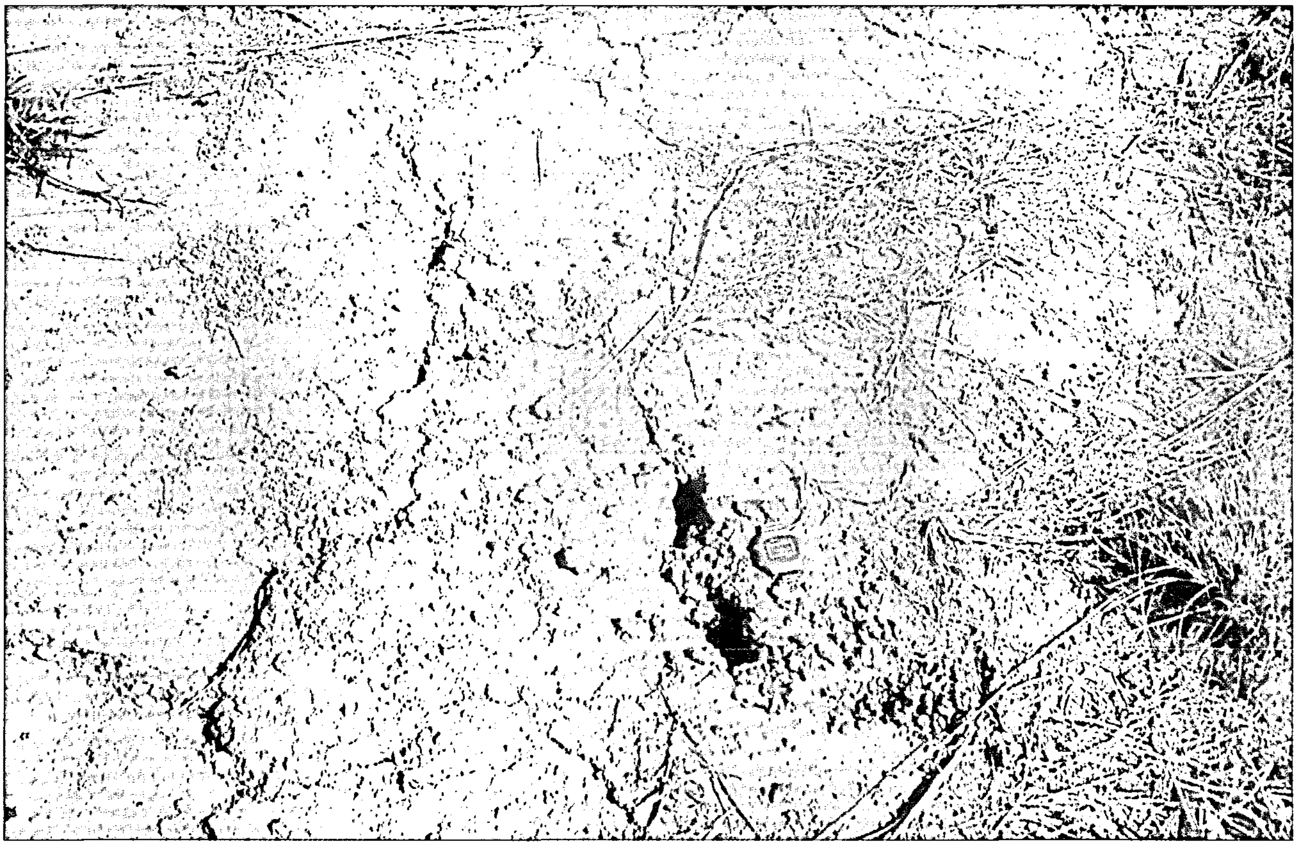


Fig B.9: Desiccation cracks developed on the soil covers prior to the 1995/96 rain season.

Fig B.10: Small samples of the materials used in the cell construction.

TABLES OF MOISTURE RETENTION CURVES OF THE SOIL TYPES USED IN THE EXPERIMENT - MODIFIED FOR USE IN SWACROP

UNCOMPACTED COAL		
Moisture content	*Pressure head (cm)*	*Hydraulic conductivity (cm/day)*
0.02	1.46E+05	1.61E-07
0.03	2.53E+04	1.61E-06
0.04	7.62E+03	1.18E-05
0.05	3.10E+03	5.80E-05
0.06	1.52E+03	2.11E-04
0.07	8.46E+02	6.20E-04
0.08	4.73E+02	1.46E-03
0.09	2.83E+02	3.33E-03
0.10	1.90E+02	7.26E-03
0.11	1.35E+02	1.55E-02
0.12	1.00E+02	3.23E-02
0.13	7.60E+01	6.42E-02
0.14	5.92E+01	1.20E-01
0.15	4.70E+01	2.13E-01
0.16	3.79E+01	3.59E-01
0.17	3.10E+01	5.76E-01
0.18	2.57E+01	8.91E-01
0.19	2.15E+01	1.34E+00
0.20	1.82E+01	1.96E+00
0.21	1.54E+01	2.82E+00
0.22	1.32E+01	4.02E+00
0.23	1.14E+01	5.69E+00
0.24	9.79E+00	8.02E+00
0.25	8.47E+00	1.13E+01
0.26	7.33E+00	1.60E+01
0.27	6.33E+00	2.30E+01
0.28	5.40E+00	3.35E+01
0.29	1.11E+00	5.03E+01
0.30	1.00E+00	5.25E+02

COMPACTED COAL		
Moisture content	*Pressure head (cm)*	*Hydraulic conductivity (cm/day)*
0.03	1.65E+04	3.26E-07
0.04	5.87E+03	1.35E-05
0.05	2.68E+03	1.34E-04
0.06	1.42E+03	6.77E-04
0.07	8.35E+02	2.33E-03
0.08	5.30E+02	6.24E-03
0.09	3.56E+02	1.39E-02
0.10	2.50E+02	2.72E-02
0.11	1.83E+02	4.79E-02
0.12	1.37E+02	7.77E-02
0.13	1.06E+02	1.18E-01
0.14	8.30E+01	1.70E-01
0.15	6.64E+01	2.35E-01
0.16	5.40E+01	3.15E-01
0.17	4.44E+01	4.13E-01
0.18	3.70E+01	5.32E-01
0.19	3.11E+01	6.77E-01
0.20	2.63E+01	8.56E-01
0.21	2.25E+01	1.08E+00
0.22	1.93E+01	1.36E+00
0.23	1.66E+01	1.72E+00
0.24	1.44E+01	2.19E+00
0.25	1.24E+01	2.78E+00
0.26	1.08E+01	3.55E+00
0.27	9.30E+00	4.55E+00
0.28	7.85E+00	5.86E+00
0.29	6.30E+00	7.58E+00
0.30	1.00E+00	3.86E+02

UNCOMPACTED AVALON		
Moisture content	*Pressure head (cm)*	*Hydraulic conductivity (cm/day)*
0.01	3.38E+08	1.97E-09
0.02	7.90E+07	1.00E-08
0.03	2.21E+07	4.23E-08
0.04	7.11E+06	1.53E-07
0.05	2.57E+06	4.89E-07
0.06	1.02E+06	1.41E-06
0.07	4.41E+05	3.76E-06
0.08	2.04E+05	9.28E-06
0.09	1.01E+05	2.15E-05
0.10	5.28E+04	4.73E-05
0.11	2.91E+04	9.92E-05
0.12	1.68E+04	1.99E-04
0.13	1.01E+04	3.86E-04
0.14	6.35E+03	7.24E-04
0.15	4.14E+03	1.32E-03
0.16	2.80E+03	2.33E-03
0.17	1.95E+03	4.02E-03
0.18	1.40E+03	6.79E-03
0.19	1.03E+03	1.12E-02
0.20	7.74E+02	1.83E-02
0.21	5.95E+02	2.93E-02
0.22	4.66E+02	4.62E-02
0.23	3.71E+02	7.21E-02
0.24	2.99E+02	1.11E-01
0.25	2.45E+02	1.70E-01
0.26	2.02E+02	2.57E-01
0.27	1.69E+02	3.87E-01
0.28	2.48E+01	5.88E-01
0.29	1.77E+01	8.95E-01
0.30	1.23E+01	1.36E+00
0.31	8.23E+00	2.10E+00
0.32	4.99E+00	3.35E+00
0.33	1.76E+00	2.75E+02

COMPACTED AVALON		
Moisture content	*Pressure head (cm)*	*Hydraulic conductivity (cm/day)*
0.01	9.36E+13	2.37E-19
0.02	3.66E+11	1.47E-15
0.03	1.43E+10	2.43E-13
0.04	1.43E+09	9.12E-12
0.05	2.41E+08	1.52E-10
0.06	5.62E+07	1.51E-09
0.07	1.65E+07	1.05E-08
0.08	5.71E+06	5.66E-08
0.09	2.25E+06	2.50E-07
0.10	9.82E+05	9.42E-07
0.11	4.65E+05	3.13E-06
0.12	2.37E+05	9.37E-06
0.13	1.28E+05	2.57E-05
0.14	7.25E+04	6.53E-05
0.15	4.30E+04	1.56E-04
0.16	2.66E+04	3.51E-04
0.17	1.70E+04	7.54E-04
0.18	1.12E+04	1.55E-03
0.19	7.61E+03	3.06E-03
0.20	5.30E+03	5.85E-03
0.21	3.77E+03	1.08E-02
0.22	2.74E+03	1.94E-02
0.23	2.03E+03	3.40E-02
0.24	1.53E+03	3.88E-02
0.25	7.11E+02	6.60E-02
0.26	4.08E+02	1.10E-01
0.27	2.73E+02	1.79E-01
0.28	1.94E+02	2.85E-01
0.29	1.43E+02	4.47E-01
0.30	1.06E+02	6.95E-01
0.31	8.04E+01	1.07E+00
0.32	6.12E+01	1.62E+00
0.33	4.43E+01	2.48E+00
0.34	1.76E+01	3.14E+01

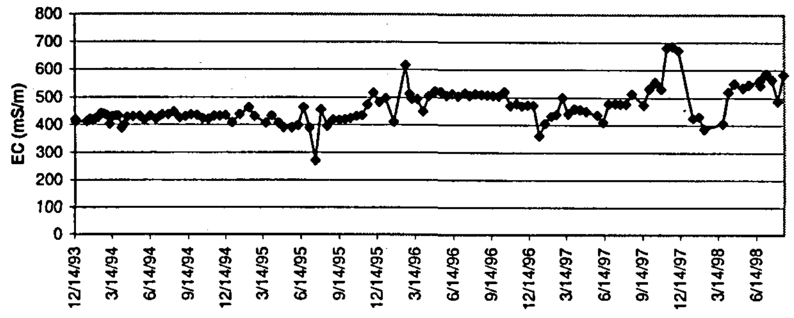
COMPACTED ESTCOURT		
Moisture content	*Pressure head (cm)*	*Hydraulic conductivity (cm/day)*
0.01	3.42E+27	6.13E-17
0.02	2.61E+22	1.26E-13
0.03	2.65E+19	1.09E-11
0.04	1.99E+17	2.57E-10
0.05	4.48E+15	2.99E-09
0.06	2.02E+14	2.23E-08
0.07	1.47E+13	1.21E-07
0.08	1.52E+12	5.27E-07
0.09	2.05E+11	1.92E-06
0.10	3.42E+10	6.13E-06
0.11	6.76E+09	1.75E-05
0.12	1.54E+09	4.56E-05
0.13	3.95E+08	1.10E-04
0.14	1.12E+08	2.48E-04
0.15	3.47E+07	5.31E-04
0.16	1.16E+07	1.08E-03
0.17	4.13E+06	2.10E-03
0.18	1.56E+06	3.94E-03
0.19	6.24E+05	7.14E-03
0.20	1.74E+05	2.10E-02
0.21	7.63E+04	2.70E-02
0.22	3.44E+04	3.66E-02
0.23	1.61E+04	5.29E-02
0.24	7.83E+03	7.79E-02
0.25	3.91E+03	1.15E-01
0.26	2.06E+03	1.65E-01
0.27	1.08E+03	2.47E-01
0.28	5.84E+02	3.67E-01
0.29	3.22E+02	5.49E-01
0.30	1.00E+00	1.05E+01

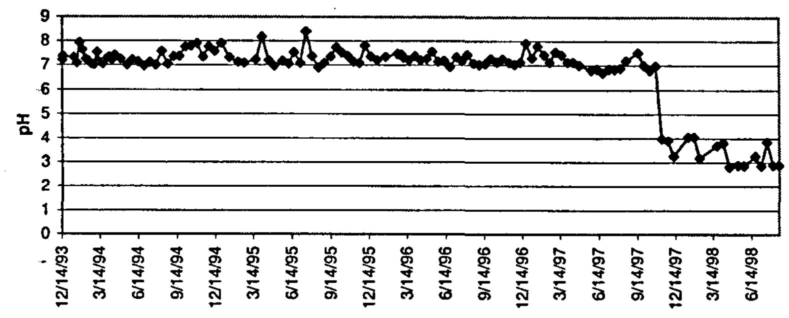
WATER QUALITY ANALYSES RESULTS

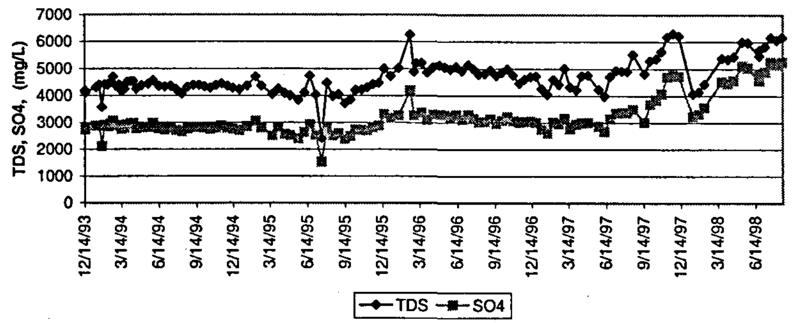
Cell 1

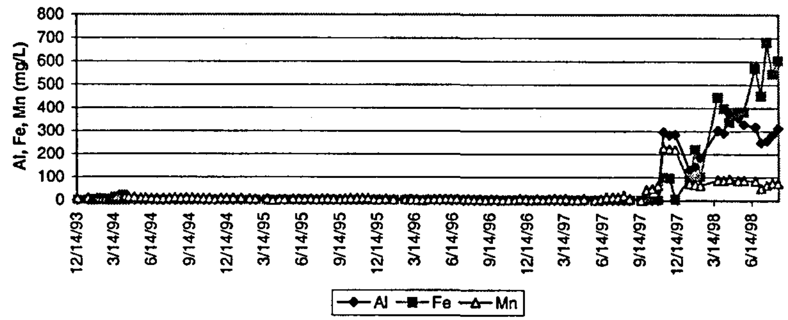
Date	EC	TDS	pH	Na	Mg	Ca	Fl	Cl	NO3	SO4	PO4	ALK	Si	K	NH4	Al	Fe	Mn
12/14/93	419	4178	7.21	76.5	416	530	0.2	18.6	0.012	2803.7	0.005	265.8	4.69	7.95	0.407	0.365	0.035	10.245
12/15/93	411	4115	7.37	72.3	404	539	0.22	19.5	0.013	2740.3	0.006	271	4.49	8.41	0.425	0.471	0.046	6.665
1/10/94	412	4304	7.31	85.3	431.2	548.1	0.29	28.6	0.033	2878.8	0.014	264.3	4.61	9.17	0.394	0.217	0.019	9.36
1/18/94	420	4392	7.09	95	422.9	561.3	0.28	17.5	0.018	2883.1	0.008	329.5	4.74	9.59	0.401	0.313	0.007	4.179
1/24/94	418	3577	7.92	96.2	433.1	475	0.2	30	0.02	2118.6	0.017	339	4.66	9.73	0.332	0	0	4.325
1/31/94	422	4411	7.63	106	422.4	547	0.22	24.5	0.025	2898.6	0.015	328.9	4.69	10.33	0.335	0	0.009	8.82
2/7/94	426	4378	7.25	101.2	424.2	549.7	0.23	24.1	0.026	2857.8	0.007	336.7	5.09	9.68	0.375	0.072	0	8.37
2/14/94	441	4495	7.18	115.5	435.7	541.8	0.26	19.1	0.023	2963.5	0.004	335	5.23	10.06	0.336	0.342	0.032	7.39
2/21/94	439	4707	7.05	121.1	441.8	571.9	0.28	19	0.014	3069.9	0.008	386	4.19	11.71	0.311	0.155	0	7.47
2/28/94	434	4344	7.02	115.8	425.8	493.7	0.28	21.7	0.016	2878.3	0.007	326	4.02	10.12	0.324	0.205	0	5.2
3/7/94	402	4406	7.52	124.6	426.1	535.2	0.3	21.9	0.018	2896.7	0.029	318.4	4.99	14.14	0.536	0.139	0.013	13
3/14/94	430	4163	7.12	114.9	408.1	497.3	0.27	24.8	0.023	2742.5	0.007	292.7	4.68	17.08	0.522	0.302	1.659	13.43
3/21/94	432	4242	7.05	113.1	402.5	512.4	0.21	22.7	0.011	2790.6	0.019	315.3	4.83	14.3	0.852	0.137	0	15.49
3/28/94	432	4502	7.25	153.8	432.7	535.5	0.29	23.3	0.016	2927.8	0.025	338.5	4.79	14.95	0.771	0.108	0.274	12.06
4/5/94	388	4525	7.32	138.8	414	545	0.44	22.8	0.037	2975.5	0.012	338.8	4.61	14.1	0.905	0.116	21.61	13.68
4/11/94	401	4528	7.21	136.9	414.1	545.9	0.29	22.9	0.019	2970.6	0.006	345.8	4.61	14.26	0.953	0.041	0.022	16.04
4/18/94	427	4236	7.41	132.9	397.2	492	0.27	22.5	0.023	2776.5	0.011	326.8	4.55	14.29	0.948	0.127	0	13.42
5/2/94	429	4376	7.24	127	425.1	538.3	0.3	22	0.021	2809.8	0.013	358.8	4.49	14.35	0.959	0	0.169	13.54
5/16/94	430	4435	7.01	126.6	409.5	543.7	0.23	67	0.035	2832.6	0.006	360.6	4.62	14.38	0.879	0.116	0.018	10.42
5/30/94	416	4556	7.22	124.6	433.1	532.8	0.36	19.2	0.03	2970.3	0.007	377.1	4.6	14.4	0.849	0.046	0	10.71
6/13/94	432	4345	7.14	124	432.9	506.4	0.23	23.8	0.028	2771.3	0.007	385.9	4.42	14.4	0.842	0.124	0.331	9.43
6/27/94	420	4326	6.97	120.4	412.9	538.6	0.26	21	0.017	2735.4	0.004	395.5	4.04	13.47	0.806	0.109	0.006	8.66
7/11/94	436	4346	7.13	127.3	374.3	547	0.26	20.2	0.017	2797.6	0.007	379.8	4.35	15.39	0.858	0.133	0.052	8.79
7/25/94	437	4232	7.01	98	424.8	478.1	0.24	77.6	0.094	2712.7	0.009	347	3.68	16.13	0.922	0.117	0.552	10.14
8/8/94	447	4069	7.56	103.4	427	474.1	0.24	85.9	0.026	2670.4	0.021	237.6	3.46	16.63	0.914	0.164	0.058	12.59
8/22/94	424	4313	7.05	132.7	406.1	541.4	0.19	22.3	0.07	2766.7	0.002	349.6	3.53	15.8	1.018	0.416	0.336	9.94
9/5/94	429	4386	7.35	133.5	410.7	508.2	0.17	26.8	0.033	2828.6	0.006	377.7	3.56	15.82	1.089	0.469	0.047	11.43
9/19/94	436	4380	7.37	126	409.1	510.9	0.25	26.8	0.116	2836.4	0.006	372.5	3.79	14.88	0.668	0.145	0	10.54
10/3/94	435	4338	7.75	132.2	399.4	537.5	0.26	24	0.372	2811.8	0.002	340.1	3.51	16.09	0.628	0.126	0.019	9.26
10/17/94	422	4272	7.79	128.7	407.4	508.1	0.21	27.1	0.791	2760.8	0.001	344.8	3.47	15.38	0.106	0.156	0.016	8.215
10/31/94	420	4378	7.9	136.4	400.3	562.5	0.23	13.5	0.623	2809.2	0.012	361.3	3.67	12.6	0.17	0.128	0.025	8.516
11/14/94	432	4439	7.34	127.2	407.9	515.1	0.23	27.5	0.534	2895.5	0.003	366.1	3.88	15.94	0.453	0.133	0.025	3.426
11/28/94	432	4359	7.76	145.2	410	534.9	0.17	30.3	0.383	2792	0.012	350.2	3.9	16.82	0.83	0.132	0	9.302
12/12/94	434	4270	7.58	131.3	398.2	536.4	0.19	33	0.147	2758.9	0.012	347.6	4.13	15.83	1.028	0.139	0.145	9.461
12/28/94	408	4212	7.69	133.1	370.3	514.3	0.16	33	0.146	2716.1	0.017	349.7	4.26	16.44	1.057	0.122	0.404	9.643
1/16/95	438	4355	7.31	96.6	417.7	529.5	0.21	14.9	0.291	2850.7	0.009	349.3	3.92	16.9	0.838	0.109	0	9.229
2/6/95	462	4700	7.12	183.4	478.5	499.4	0.18	22.6	0.006	3054.4	0.002	376.3	4.28	21.46	0.834	0.12	0.008	6.914
2/20/95	430	4356	7.09	154.2	412.7	512.4	0.2	20.5	0.039	2807.9	0.008	353.5	4.42	16.28	0.767	0.129	0.001	5.758
3/20/95	406	4045	7.22	96.3	367.4	541.7	0.22	38.1	0.004	2513.2	0.009	388.5	4.5	15.98	0.499	0.168	0.794	5.334
4/3/95	431	4245	8.16	134.1	408.1	533.1	0.21	18.6	0.06	2817.4	0.01	257.8	4.55	17.92	0.498	0.012	0	0
4/19/95	407	4090	7.19	94.4	373.6	543.8	0.21	21.5	0.012	2566.3	0.007	388.2	4.57	16.27	0.408	0.157	0.053	3.587
5/2/95	389	3999	6.96	90.4	346.6	536	0.19	22.3	0.018	2517.1	0.007	385.4	4.8	16.07	0.365	0.126	1.388	4.56
5/22/95	389	3846	7.18	96.6	354.5	489.2	0.18	17.3	0.017	2409.6	0.003	377.7	4.48	17.49	0.459	0.174	0.317	5.64
6/6/95	398	4112	7.06	104.6	341.5	545	0.45	15.4	0.019	2642.5	0.026	364.7	4.47	17.19	0.473	0.069	0.031	5.033
6/19/95	463	4733	7.53	112.1	426.6	651.3	0.15	108.3	0.042	2931.1	0.01	390.9	4.59	26.42	0.51	0.15	0.045	5.033
7/3/95	388	4026	7.08	98	371.4	527.4	0.33	33.8	0.016	2533.8	0.035	364.6	5.82	17.67	0.623	0.159	0.283	6.747
7/17/95	270	2402	8.39	56.9	205.7	331.7	0.17	15.6	0.248	1523.2	0.002	208.4	4.2	13.61	0.11	0.08	0	2.965
7/31/95	455	4470	7.37	138.7	427.6	535.9	0.69	89.4	0.021	2769.6	0.036	396.6	4.5	22.84	1.185	0.168	0.104	6.661
8/14/95	395	3977	6.9	91.9	349.1	542.9	0.24	28.7	0.027	2505.5	0.001	361	4.27	17.19	0.632	0.103	0.017	6.99
8/28/95	417	4038	7.09	89	366.5	519.2	0.22	16.2	0.011	2605.9	0.005	347.3	4.98	16.99	0.618	0.158	0.496	6.989
9/13/95	416	3718	7.35	85.9	335	459.1	0.23	24.5	0.022	2390.5	0.007	332.4	4.62	16.38	0.596	0.161	0.03	4.05
9/26/95	419	3861	7.74	89.4	359.9	465.9	0.25	25.1	0.049	2501	0.002	329.3	4.76	16.95	0.617	0.197	0.093	6.732
10/9/95	423	4210	7.53	101.5	382.6	533.9	0.19	31.1	0.016	2734.8	0.011	334.1	4.55	17.57	0.758	0.144	0	7.698
10/24/95	432	4217	7.38	101.3	398.1	501.5	0.21	31.6	0.059	2723.8	0.006	361.8	4.85	18.06	0.738	0.166	0	7.99
11/6/95	434	4305	7.15	117.4	412.4	534.6	0.24	25.7	0.056	2700.8	0.011	404.1	4.81	19.39	0.837	0.136	0	9.969
11/20/95	474	4423	7.09	114.9	427.9	575	0.17	47.5	0.009	2819.7	0.005	336.5	4.43	25.99	1.068	0.233	0.094	9.197
12/4/95	516	4467	7.81	163.3	465.2	499.5	0.19	37.5	0.022	2891.4	0.014	311.6	4.32	28.15	0.975	0	0	3.831
12/18/95	482	4993	7.36	259.7	436.6	548.3	0.22	35.8	0.035	3311.5	0.008	311.6	4.23	19.93	0.45	0	0.013	3.309
1/2/96	496	4722	7.2	164	424.9	546.5	0.21	37.6	0.006	3173.5	0.01	282.9	4.85	27.14	0.74	0.098	0	6.721
1/22/96	410	5016	7.34	297.4	436	510.8	0.22	65.6	0.04	3272.1	0.01	343.8	4.58	25.86	0.418	0.11	0.013	2.288
2/19/96	615	6267	7.47	373.8	680.2	499.6	0.35	43.9	2.66	4191.9	0.006	358.5	6.01	27.79	0.213	0.133	0.491	3.624
2/29/96	512	4893	7.45	275.2	456.4	504.9	0.26	36.6	0.89	3263.8	0.01	285	4.64	3.62	0.326	0.113	0.039	2.984
3/5/96	494	5203	7.3	311.4	427.4	534.1	0.26	46.2	0.715		0.005	321.5	4.55	24.9	0.191	0.282	0	2.456
3/18/96	494	5214	7.21	332.8	431.4	518.4	0.25	42.6	0.143	3374.3	0.009	399.1	4.71	26.32	0.212	0.074	0	2.558
4/1/96	449	4862	7.37	342.8	440.5	488.1	0.28	43	0.007	3119.9	0.008	335.6	4.31	17.73	0.345	0.117	0.008	0.186
4/15/96	504	5047	7.2	370.4	446.5	498.3	0.21	50.1	0.019	3295.1	0.004	295.4	4.12	25.43	0.409	0.102	0	4.77
4/30/96	521	5126	7.26	329.6	474	505.4	0.25	37.9	0.012	3309.9	0.006	363.3	4.54	25.28	0.543	0.378	0.071	4.652
5/13/96	521	5058	7.55	318.7	436.1	469.7	0.31	30.2	0.034	3272.5	0.004	400	4.33	21.7	0.554	0.113	0	4.686
5/27/96	507	4980	7.15	328.4	442.7	465.5	0.23	31.1	0.032	3194	0.007	403.6	4.37	25.29	0.577	0.074	0	5.22
6/10/96	512	5073	7.18	326.6	459.5	483.9	0.26	37.7	0.011	3292	0.009	366.8	4.68	24.7	0.668	0.083	0	5.08
6/24/96	504	4917	6.92	334.8	419	520.7	0.3	31	0.016	3116.9	0.018	365.3	5.05	23.09	0.796	0	0	5.32
7/10/96	515	5123	7.33	346.8	394.9	540.4	0.23	38.2	0.027	3294.8	0.01	392.9	4.99	27.66	0.816	0.12	0	5.71
7/22/96	507	4982	7.17	366	399	502.6	0.23	51.2	0.019	3148.2	0.011	401.4	4.83	24.77	0.662	0.138	0	5.22
8/5/96	512	4783	7.43	360.7	439.8	411.8	0.23	38.6	0.022	3023.6	0.003	395.4	4.74	25.24	0.664	0.114	0	4.388
8/19/96	510	4807	7.08	345.9	395.4	480.2	0.24	44.7	0.023	3030.9	0.004	394.9	4.89	27.26	0.557	0	0	3.806
9/2/96	508	4940	7.02	340.6	426.1	495.8	0.21	44.1	0.047	3133	0.02	386.4	4.64	27.57	0.675	0	0	1.295
9/16/96	506	4739	7.06	330.8	438.3	478.5	0.18	41.7	0.019	2974.4	0.013	377.9	4.79	13.13	0.574	0.215	0.039	4.476
9/30/96	504	4860	7.27	335.3	433	494.4	0.21	42.9	0.008	3076.1	0.012	380	4.64	13.43	0.645	0.168	0.055	4.533
10/14/96	521	4992	7.12	355.1	442.7	494	0.21	30.1	0.037	3221.6	0.002	355.1	4.59	14.96	0.544	0	0	1.911
10/28/96	470	4764	7.26	359.4	370.9	462.8	0.16	40.5	0.034	3068.6	0.028	366.9	4.67	13.18	0.327	0.078	0	2.613
11/12/96	477	4457	7.11	292.9	403.3	463.6	0.49	34.6	0.03	3014.4	0.002	192.6	5.01	12.01	0.321	0.342	0	2.27
11/25/96	469	4607	7.03	262.6	377.5	510.9	0.61	37.4	0.012	3044.3	0.008	295.3	4.89	12.87	0.345	0.347	0	6.73
12/9/96	473	4701	7.13	284	389.7	499.9	0.57	30.6	0.02	3061.6	0.009	344.9	5.96	13.4	0.378	0.359	0	5.934
12/23/96	471	4720	7.91	168.5	508.8	463.6	0.1	39.1	0.021	3002.8	0.008	424	5.39	18.48	1.035	0.362	0.015	1.521
1/6/97	361	4250	7.3	250.9	303	542.4	0.37	19.7	0.028	2742.4	0.009	310.9	6.61	11.5	0.225	0.191	0.021	5.766
1/20/97	406	4046	7.79	215.5	275.9	553.3	0.35	18.2	0.05	2618.1	0.003	290	6.43	10.09	0.338	0	0	2.696
2/4/97	432	4598	7.43	251.1	374.4	529.5	0.5	19.6	0.029	3019.3	0.006	320.9	3.9	11.77	0.452	0	0	4.806
2/17/97	439	4422	7.13	222.5	351.6	535.4	0.35	17.5	0.034	2963.6	0.007	262	6.63	10.57	0.417	0	0	7.53
3/3/97	500	5008	7.55	162.6	534.5	519.7	0.14	33.5	0.034	3160.5	0.008	472.6	5.36	18.87	1.257	0.572	0.077	3.828
3/17/97	441	4321	7.43	206.4	370.1	534.4	0.48	15.7	0.014	2785.6	0.039	324.1	6.87	10.85	0.377	0	0	7.36
4/1/97	459	4217	7.13	221.5	410.3	469.4	0.51	17.1	0.036	2932.2	0.01	126.1	6.63	11.11	0.442	0.122	0	1.193
4/14/97	456	4741	7.13	232.6	409.9	546.4	0.51	20.9	0.024	2999.3	0.015	426.6	6.68	10.95	0.469	0.159	0	1.441
4/29/97	449	4767	7	241.2	406.2	554.3	0.65	26.5	0.014	3004.2	0.018	427.5	6.74	11.67	0.45	0.148	0	7
5/26/97	436	4227	6.81	198.1	350.7	532.4	0.56	18.1	0.012	2866.2	0.006	205.3	6.14	10.17	0.37	0.108	0	1.93
6/9/97	410	3987	6.85	187.2	296.5	553	0.48	18.1	0.014	2677.3	0.003	201.4	8.44	8.76	0.316	0.093	0	5.82
6/23/97	477	4710	6.7	207.7	464.1	530.3	0.52	30.3	0.021	3154.3	0.009	256.5	6.56	9.54	0.41	0.092	0	13.31
7/8/97	476	4942	6.84	207.9	503.2	521.8	0.56	29.9	0.032	3359	0.007	253.2	6.36	10.46	0.388	0.055	0	13.41
7/21/97	477	4912	6.63	202.3	468.8	544	0.65	29.7	0.016	3385	0.007	222.6	5.73	9.97	0.416	0.131	0.011	13.42
8/4/97	477	4906	6.89	220.1	476.1	525.5	0.89	30.7	0.021	3373.7	0.004	220.1	6.2	10.03	0.452	0.112	0	20.8
8/18/97	514	5533	7.19	235.7	593.8	518.9	0.16	38.3	0.023	3501.8	0.005	515	4.8	16.52	1.083	0.106	0	6.54
9/15/97	474	4816	7.53	178.1	490.1	502.1	0.19	30.9	0.041	3020.8	0.004	469.5	5.22	19.62	1.186	0	0	0
9/29/97	532	5293	7.01	223.1	584	561.4	1	31.4	0.034	3691.1	0.004	153.9	4.61	12.38	0.518	0	0.057	45
10/13/97	554	5382	6.79	222	613	486	1.26	32.6	0.064	3859.8	0.01	125	4.67	13.84	0.465	0	0.192	49.18
10/27/97	531	5639	6.98	227	616.1	483.7	1.16	26.4	0.047	4083.4	0.017	150.8	4.63	14.41	0.47	0	0.095	64.68
11/10/97	680	6184	3.98	213.9	701.6	512.8	0	28.7	0	4703.4	0.016	0	21.54	23	0.594	296.2	99.96	227.8
11/24/97	684	6307	3.89	214	733.5	516.2	0	59.8	0	4760.2	0.017	0	21.8	22.56	0.607	282	96.56	223.4
12/8/97	670	6217	3.26	208.3	707.5	514.8	0	30.7	0	4731.7	0.013	0	23.59	23.21	0.565	285.6	5.79	219.6
1/12/98	424	4074	4.05	99.4	221.4	494.5	0	13.6	0.004	3233.8	0.012	0	21.4	11.02	0.471	130.9	96.9	72
1/26/98	430	4147	4.06	112.9	185	491.2	0	15.4	0	3330.6	0.017	0	24.4	11.37	0.2	145.42	220.59	67.97
2/8/98	386	4435	3.16	120.7	205	503.9	0	16.6	0	3576.6	0.015	0	29.32	11.62	0.235	185.354	102.218	63.72
3/23/98	406	5386	3.7	118	222.4	490.2	0	13.1	0	4526.3	0.01	0	32.55	15.5	0.202	302.458	447.738	88.258
4/6/98	520	5359	3.8	114	205.3	544.1	0	26.2	0	4452.1	0.012	0	32.87	16.47	0.197	292.4	399.2	86.78
4/20/98	550	5451	2.82	106.8	206.7	519.3	0	30.2	0	4571.3	0.021	0	25.94	16.52	0.217	377.112	339.324	91.928
5/11/98	536	5990	2.88	108.9	228.3	490.7	0	27.2	0	5119.1	0.043	0	19.92	15.18	0.21	357.224	381.766	84.752
5/25/98	546	5974	2.87	113.4	226.9	538.5	0	32.5	0	5047.6	0.023	0	19.43	15.21	0.193	328.366	383.046	86.474
6/22/98	562	5484	3.26	123.7	230.9	511.6	0	27	0	4575.6	0.016	0	29.23	14.5	0.173	317.2	572.4	84.06
6/22/98	545	5687	3.26	120.1	230	509.1	0	27.2	0	4784.9	0.013	0	29.1	15.43	0.201	316	571.8	84.06
7/6/98	586	5831	2.86	124.1	266.3	518.4	0	17.2	0	4890.6	0.016	0	16.31	13.84	0.087	249.96	452.76	52.28
7/20/98	565	6157	3.84	129.6	249.8	483.7	0	19.1	0	5259.5	0.088	0	16.62	14.56	0.134	257.31	681.71	65.1
8/3/98	488	6068	2.89	126.9	249	494.3	0	17.7	0	5165.9	0.11	0	16.71	13.17	0.091	282.55	547.03	75.98
8/17/98	583	6158	2.89	126.7	250.2	495.9	0	18.7	0	5253.5	0.02	0	16.6	12.98	0.088	310.38	604.34	74.11
Min	270	2402	2.82	56.9	185	331.7	0	3.3	0	1523.2	0.001	0	3.46	3.62	0.087	0	0	0
Max	684	6307	8.39	373.8	733.5	651.3	1.26	108.3	2.66	5259.5	0.11	515	32.87	28.15	1.257	377.112	681.71	227.8
Mean	463.2479	4674.446	6.730165	179.1727	404.8273	516.0752	0.269339	30.2314	0.086174	3172.678	0.012165	288.2041	7.405455	16.19149	0.550099	39.09958	49.86803	21.49019
Median	439	4495	7.18	133.5	410.7	518.4	0.23	27.1	0.022	2970.45	0.009	338.5	4.68	15.39	0.498	0.133	0.017	7.36
95-percent	389	3987	3.18	89.4	222.4	465.5	0	15.4	0	2512.815	0.002	0	3.68	9.59	0.17	0	0	1.521

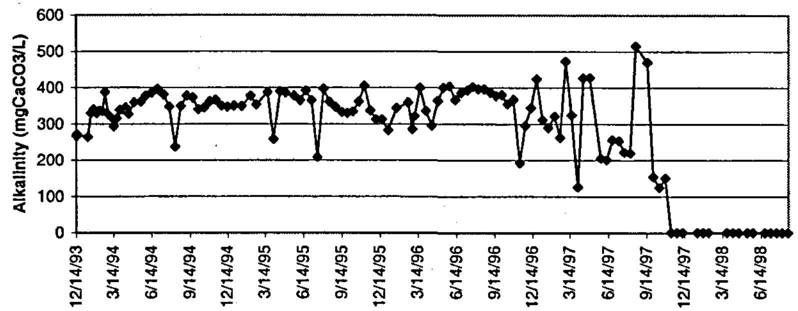
Cell 1

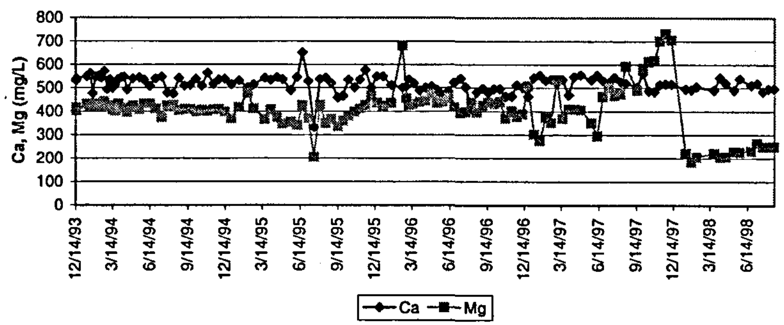

EC (mS/m)


pH


TDS, SO4, (mg/L)
TDS
SO4


Al, Fe, Mn (mg/L)
Al
Fe
Mn

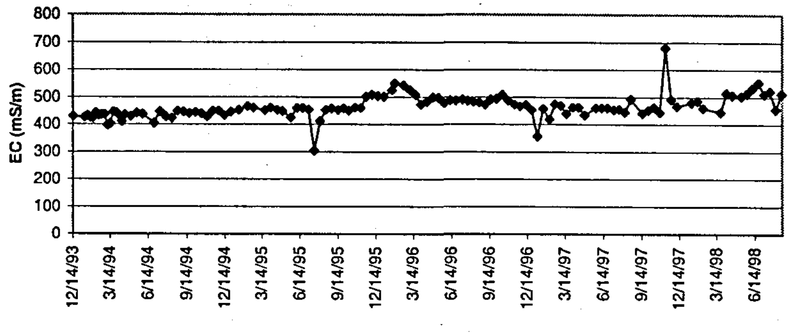

Alkalinity (mgCaCO3/L)

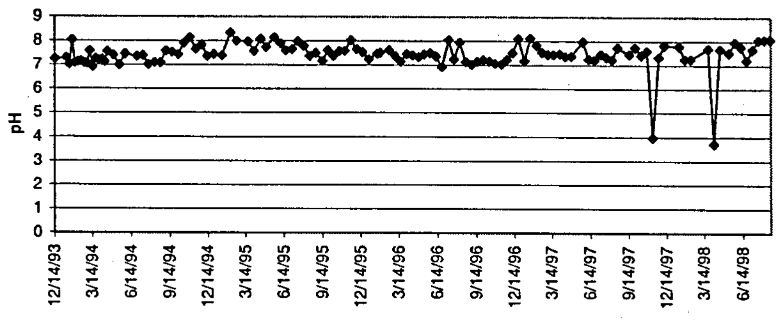

Ca, Mg (mg/L)
Ca
Mg

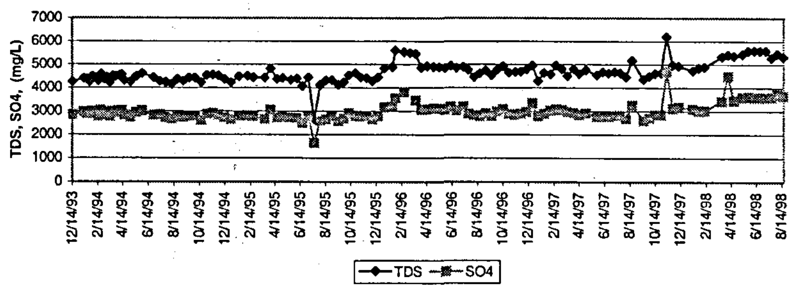
Cell 2

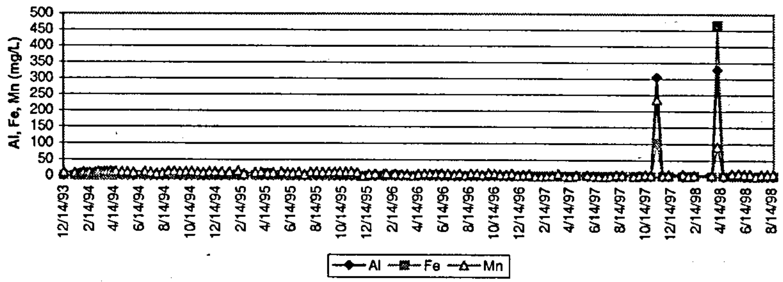
Date	EC	TDS	pH	Na	Mg	Ca	Fl	Cl	NO3	SO4	PO4	ALK	Si	K	NH4	Al	Fe	Mn
12/14/93	428	4242	7.24	78.7	445	522	0.18	31	0.012	2853.7	0.006	247	4.19	9.85	0.376	0.215	0.013	10.855
1/10/94	424	4402	7.29	83.4	447.5	542.6	0.29	50.5	0.026	2974.8	0.015	239.5	4.06	10.52	0.359	0.32	0.02	8.39
1/18/94	431	4372	7.01	95	441.9	555.3	0.21	42	0.032	2889.2	0.006	276	4.15	11.35	0.36	0.116	0	5.56
1/24/94	424	4247	8.03	87.2	447.4	519.6	0.26	30.8	0.013	2931	0.015	179.4	3.96	11.07	0.321	0	0	7.44
1/31/94	422	4494	7.1	93.2	445.3	559	0.22	53.4	0.023	2995.8	0.019	274.2	3.96	12.12	0.349	0	0.017	11.78
2/7/94	442	4413	7.15	89.9	448.6	535.8	0.27	49.9	0.109	2930.5	0.005	283.3	4.52	11.35	0.366	0.202	0	8.39
2/14/94	432	4291	7.16	90.1	434.9	530.1	0.25	92.5	0.028	2778.7	0.007	288.5	4.32	11.66	0.385	0.171	0.012	10.8
2/21/94	435	4592	7.09	95.4	448.7	565.8	0.43	56.6	0.025	3034.4	0.013	309.3	3.61	12.96	0.325	0.127	0	6.69
2/28/94	435	4351	7.07	88.5	426.2	523.2	0.3	57.2	0.014	2865.7	0.01	309.6	3.55	11.53	0.363	0.188	0	10.42
3/7/94	396	4454	7.58	117.7	446.9	528	0.36	49.1	0.02	2949.6	0.025	283.6	4.07	15.9	0.511	0.185	0.001	13.27
3/14/94	402	4224	6.91	123	430.1	506.4	0.4	52.8	0.11	2780.4	0.015	259.9	3.95	13.46	0.396	0.504	1.1	12.06
3/21/94	445	4500	7.27	99.7	461.4	532.8	0.26	46.7	0.016	2969.1	0.017	290.3	4.27	15.09	0.549	0.129	0	12.92
3/28/94	442	4479	7.2	112.2	465.1	533.3	0.3	49.6	0.009	2938.6	0.023	297.8	4.42	16.16	0.594	0.122	0.001	13.08
4/5/94	429	4524	7.24	104.3	447.8	536.9	0.3	43.4	0.024	3015.5	0.005	295	4.26	14.93	0.725	0.104	5.16	15.06
4/11/94	409	4553	7.13	103.5	448	546.4	0.32	51.5	0.029	3020.4	0.009	300.7	4.34	15.17	0.752	0.154	0.565	12.75
4/18/94	434	4295	7.55	99.4	446.4	516.6	0.2	44.5	0.016	2831.7	0.006	279	4.32	14.76	0.751	0.123	0.019	13.91
5/2/94	428	4242	7.4	107.1	443	513	0.27	64.9	0.039	2734.4	0.007	297.5	4.4	15.84	0.728	0.024	0.098	13.05
5/16/94	441	4479	7	108	436.3	548.7	0.27	59.3	0.032	2941.6	0.004	301.8	4.35	15.77	0.729	0.13	0.021	12.14
5/30/94	436	4606	7.45	99.4	473.4	536.7	0.31	56.8	0.031	3028.5	0.007	322.9	4.24	15.57	0.764	0.065	0	11.18
6/27/94	404	4438	7.35	98.5	451.7	537.1	0.35	71.5	0.02	2820.8	0.012	362.3	3.82	14.7	0.873	0.094	0.033	13.86
7/11/94	446	4274	7.39	104.9	438.5	475.5	0.39	90.2	0.03	2852.3	0.011	241.4	3.9	16.81	0.894	0.152	0.068	11.06
7/25/94	427	4238	7.02	114.5	404.6	497.3	0.32	22.4	0.094	2731.8	0.007	370.4	3.78	14.26	0.97	0.134	0.053	8.01
8/8/94	422	4152	7.1	124.8	390.6	506	0.32	24	0.061	2654	0.041	356.9	3.82	15.27	0.956	0.134	0.058	9.27
8/22/94	448	4364	7.1	103.2	441.6	535.1	0.25	80.6	0.064	2745.3	0.003	361.1	3.38	16.43	0.93	0.302	0.058	13.56
9/5/94	446	4290	7.58	100	450	486.5	0.26	86.2	0.149	2754.6	0.007	322.9	3.31	16.39	0.922	0.601	0.088	14.53
9/19/94	440	4425	7.52	100.8	452.7	512.3	0.33	85	0.168	2799.8	0.006	373.8	3.52	16.24	0.806	0.161	0	13.17
10/3/94	443	4417	7.43	100.7	443.7	545.1	0.33	85.5	0.023	2799.3	0.003	347.7	3.23	17.19	0.777	0.121	0.006	13.581
10/17/94	439	4219	7.91	107.4	442.8	512.2	0.28	96.1	0.45	2608.5	0.002	354.5	3.4	16.57	0.381	0.078	0.012	14.345
10/31/94	427	4533	8.13	111.5	443.9	563.4	0.32	73.1	0.504	2870.7	0.008	372.1	3.47	13.61	0.649	0.127	0.028	11.643
11/14/94	448	4553	7.66	105.7	445	520.7	0.3	88.2	0.972	2918.8	0.004	371.1	3.06	16.8	0.297	0.15	0.032	10.575
11/28/94	449	4512	7.83	128.7	448.9	540.5	0.25	96.6	0.761	2833.2	0.003	360.7	3.99	19.29	0.764	0.143	0	13.131
12/12/94	431	4372	7.36	105.3	429.8	538.8	0.27	116.6	0.304	2729.8	0.01	353.8	4.25	17.76	0.978	0.137	1.903	12.609
12/28/94	444	4214	7.44	100.5	370	544	0.23	113.6	0.347	2651.1	0.006	340.3	4.43	17.29	0.853	0.158	0	12.554
1/16/95	452	4474	7.39	113.4	446.3	548	0.27	124.4	0.293	2796.4	0.01	345.9	4.18	19.36	0.824	0.148	0	12.701
2/6/95	466	4506	8.34	124.9	467.7	501.1	0.27	107	0.01	2802.3	0.007	390.7	4.46	24.86	1.084	0.064	0.004	15.463
2/20/95	460	4437	8	124.9	427.7	541.8	0.28	105.8	0.016	2763	0.009	371.8	4.78	19.44	1.05	0.156	0.256	6.343
3/20/95	450	4417	7.96	130.1	414.8	534.9	0.33	144.7	0.003	2664.7	0.011	414.6	4.8	20.63	1.018	0.153	0.539	11.146
4/3/95	460	4812	7.87	137.4	480.7	535.3	0.28	102	0.272	3050	0.01	388.9	5.03	29.15	0.94	0.183	0	11.283
4/19/95	451	4372	8.07	130.7	411	547.5	0.32	99.2	0.009	2716.9	0.006	364	4.88	21.38	1.002	0.184	6.423	8.907
5/2/95	447	4409	7.73	129.5	398.4	537.6	0.29	99	0.006	2739.7	0.005	396	5.05	20.4	1.021	0.098	0.681	10.228
5/22/95	423	4325	8.14	145.6	435.1	470	0.27	84.6	0.041	2709.7	0.003	367	4.92	30.19	1.092	0.218	0.144	12.7
6/6/95	458	4387	7.89	135.2	384.3	514.8	0.42	146.2	0.008	2704.6	0.021	392.1	4.81	21.39	1.056	0.066	0.035	10.6
6/19/95	459	4068	7.6	127.4	395.9	490	0.25	98.6	0.022	2480.4	0.01	371.7	4.44	20.86	1.01	0.135	0.029	9.874
7/3/95	453	4431	7.65	132.7	420.4	527.9	0.45	84.1	0.028	2766.7	0.028	389.7	4.53	21.85	1.157	0.158	0.135	11.335
7/17/95	303	2633	7.97	78.2	246.7	323	0.25	52.2	0.796	1640.7	0.002	223.4	3.35	16.26	0.067	0.119	0	5.264
7/31/95	411	4108	7.79	95.6	374.2	542.1	0.4	45.4	0.023	2583.9	0.024	367.6	4.32	17.62	0.625	0.144	0.075	12.336
8/14/95	452	4304	7.38	127.2	421.8	528.5	0.22	72	0.042	2651.2	0.004	393.7	4.39	21.1	1.241	0.11	0.036	12.835
8/28/95	457	4312	7.5	124.2	405.3	510	0.34	21.8	0.056	2758.5	0.005	384.8	5.08	21.17	1.299	0.142	0.079	11.417
9/13/95	452	4116	7.18	115.6	369.1	527.8	0.28	63.7	1.947	2557.8	0.009	372.6	4.77	19.58	1.248	0.176	0.335	12.818
9/26/95	457	4228	7.6	123	421.8	448.1	0.32	75.4	0.048	2681.8	0.004	373.1	4.99	20.47	1.375	0.221	0.048	12.309
10/9/95	449	4535	7.37	126.9	419.1	533.7	0.19	75	0.011	2910.4	0.013	366.4	4.79	21	1.417	0.171	0	13.365
10/24/95	461	4622	7.57	147.5	442	553.4	0.21	156	0.031	2777.7	0.017	421.3	4.95	30	1.448	0.132	0	13.166
11/6/95	460	4440	7.59	128.8	444.8	499.3	0.2	65.5	0.056	2754.5	0.012	423.5	4.85	28.66	1.497	0.191	0	13.72
11/20/95	501	4411	8.03	128.3	438.3	523.8	0.17	70.8	0.24	2792.8	0.013	349.1	4.4	28.45	1.248	0.209	0.059	11.308
12/4/95	508	4271	7.66	142	417.5	512.6	0.19	97.6	0.031	2648.2	0.012	343.6	4.99	31.1	1.681	0	0	0.373
12/18/95	503	4453	7.54	166.4	429.4	527.8	0.2	93.3	0.124	2776.4	0.012	352.9	4.86	24.89	1.018	0.149	0.013	5.639
1/2/96	501	4834	7.24	154.1	447.8	555.6	0.19	55.8	0.006	3163	0.007	347.6	5.24	31.93	1.087	0	0	6.532
1/22/96	524	4890	7.47	187.5	480.4	513.7	0.22	37.6	0.05	3193.3	0.009	363.6	5.23	31.82	1.04	0.126	0.053	7.26
1/29/96	549	5603	7.51	322.4	536.6	512.2	0.26	48.7	0.029	3572.5	0.014	482.2	4.68	21.66	0.824	0.119	0.119	7.38
2/19/96	542	5533	7.61	242.8	481.3	432.9	0.23	47.6	0.042	3805.5	0.005	403.2	4.66	30.63	0.55	0.135	2.716	6.59
3/5/96	524	5492	7.37	404.8	440.8	531	0.25	57.6	0.014		0.008	411.1	4.49	29.03	0.638	0	0	4.583
3/18/96	508	5456	7.15	334.4	477.7	513.1	0.22	43.8	0.013	3455.1	0.012	492.8	4.93	30.29	0.599	0.084	0	5.76
4/1/96	473	4867	7.45	260.3	455.5	522.3	0.22	51.3	0.024	3069.4	0.007	392.1	4.88	28.32	0.767	0.134	0.011	0.534
4/15/96	482	4919	7.4	260.4	420.2	449.3	0.23	54.7	0.049	3078.3	0.006	395.6	4.39	171.92	0.806	0.126	0.011	5.61
4/30/96	496	4904	7.33	255.7	466.6	511.6	0.2	45.9	0.022	3117.7	0.007	389.7	5.06	30.05	0.851	0.5	0.186	7.68
5/13/96	497	4883	7.44	219.2	480.3	468.4	0.37	30.7	0.057	3107.3	0.008	449.7	4.85	27.44	0.935	0.01	0	7.6
5/27/96	477	4830	7.49	224.1	456.2	471	0.38	31.3	0.041	3068.9	0.005	450	4.9	27.69	0.914	0.195	3.062	8.02
6/10/96	486	4938	7.36	211.4	495.5	502.6	0.24	38.2	0.01	3186.8	0.008	388.6	5.52	28.13	0.903	0.11	0	7.64
6/24/96	487	4847	6.92	208.9	454.6	550.5	0.36	31.3	0.021	3023.4	0.016	450	5.7	27.86	0.971	0.126	0	8.09
7/10/96	490	4890	8.04	189.2	459.2	525.3	0.19	40.4	0.023	3193.6	0.007	370.1	5.41	29.35	0.986	0.135	0	6.31
7/22/96	485	4758	7.24	228.1	456.9	499.2	0.23	53.9	0.03	2893.5	0.011	489.3	5.95	27.99	1.062	0.134	0	7.655
8/5/96	482	4445	7.94	254.4	443.3	367.7	0.18	47.7	0.055	2820.4	0.003	395.9	5.06	27.35	1.002	0	0	3.031
8/19/96	480	4616	7.14	256	414.9	479.2	0.24	53.9	0.017	2766.1	0.011	504.4	5.32	29.32	0.927	0.127	0	7.838
9/2/96	471	4735	7.02	260.7	442.5	462.3	0.21	56.2	0.038	2906.5	0.021	472.8	5.09	28.47	1.011	0	0	7.966
9/16/96	490	4528	7.15	218	451.2	456.2	0.19	51.7	0.019	2777.9	0.004	457	5.43	14.48	1.056	0.153	0.035	3.87
9/30/96	492	4780	7.22	221.8	469.7	484.4	0.21	53.8	0.008	2980.2	0.014	452	5.22	16.91	1.09	0.146	0.077	9.14
10/14/96	508	4912	7.16	236.3	462.8	510.5	0.2	41.5	0.046	3082.7	0.005	458.3	5.24	17.4	1.092	0	0	7.347
10/28/96	486	4653	7.07	237.5	467.1	465	0.15	40.7	0.031	2880.3	0.029	444.1	5.29	19.13	1.023	0.101	0.097	4.907
11/12/96	473	4675	7.03	252.1	416.8	522.2	0.15	51.7	0.032	2830.6	0.011	477	5.2	16.42	0.915	0.331	0	5.335
11/25/96	486	4691	7.23	210	445.7	508.9	0.18	48.3	0.016	2888.6	0.01	469.1	5.02	15.7	0.988	0.252	0.011	7.61
12/9/96	471	4788	7.51	250.7	434.4	522.3	0.16	39.5	0.02	2968.7	0.013	455.3	5.93	16.17	1.024	0.35	0	1.631
12/23/96	452	4952	8.09	223.9	521.2	415.7	0.01	24.6	0.027	3341.5	0.005	331.4	5.36	19.26	1.07	0.268	0.012	3.656
1/6/97	356	4282	7.18	251.6	299	543.3	0.42	18.5	0.024	2776	0.007	312.8	6.65	11.03	0.223	0.484	0.016	5.884
1/20/97	456	4640	8.11	224.1	392.3	522.7	0.18	30.2	0.131	2888.6	0.004	462.1	4.94	16.94	1.14	0	0	0
2/4/97	417	4579	7.81	247.5	374.8	624.8	0.42	19.4	0.049	3019.5	0.004	312	3.05	12.08	0.27	0	0	0.233
2/17/97	474	4952	7.54	204.4	462	574.6	0.18	37.2	0.576	3089.9	0.003	462.1	5	17.1	0.706	0	0	1.299
3/3/97	468	4799	7.44	224.7	416	524.6	0.12	34.3	0.034	3057.2	0.007	430	5.21	15.83	1.233	0.536	0.049	2.415
3/17/97	439	4507	7.44	213.9	369.4	527.1	0.49	18	0.036	2968.2	0.008	326.5	6.91	11.12	0.404	0	0	7.48
4/1/97	462	4799	7.47	239.3	433.2	547.2	0.23	36.6	0.061	2931.1	0.013	485.9	5.3	17.4	1.129	0.135	0	1.186
4/14/97	462	4603	7.36	232.2	446.3	449.1	0.22	36	0.025	2832.4	0.013	481.7	5.45	17.41	1.223	0.162	0	0.284
4/29/97	434	4758	7.38	230.5	437.9	538.3	0.23	25.6	0.047	2916.6	0.014	483.9	5.25	16.64	1.161	0.153	0	2.495
5/26/97	460	4542	7.98	226.4	400.2	507.8	0.21	34.9	0.193	2763.9	0.009	483.9	4.98	16.94	0.991	0.084	0	3.772
6/9/97	460	4680	7.26	271.8	348.9	551	0.19	35.5	0.019	2757.4	0.006	572.9	5.26	15.29	0.842	0.051	0	2.372
6/23/97	460	4631	7.21	243.3	398.1	509.1	0.19	32.2	0.028	2769.4	0.008	543	5.42	15.28	0.935	0.031	0	1.179
7/8/97	453	4676	7.46	244.5	398	530.8	0.2	24.5	0.05	2805.1	0.006	538.6	5.21	14.8	0.958	0.019	0	0.462
7/21/97	455	4638	7.33	242.8	372.5	522	0.19	19.1	0.046	2818.2	0.007	530.9	4.98	14.1	0.936	0.05	0	1.565
8/4/97	445	4460	7.23	240.5	367	487	0.22	29.8	0.063	2683.2	0.004	521.7	5.55	15.04	0.951	0.045	0	4.686
8/18/97	492	5173	7.74	238.5	526.4	518.2	0.18	36.3	0.03	3262.3	0.005	470.1	4.62	15.89	1.074	0.094	0	3.639
9/15/97	440	4358	7.45	223	358.5	516.1	0.21	22.9	0.055	2590.9	0.006	516.7	5.02	14.38	1.044	0	0	0.71
9/29/97	451	4484	7.73	207.9	392.3	536.6	0.21	21.7	0.113	2705.8	0.006	494	4.89	14.93	0.998	0	0	3.564
10/13/97	462	4609	7.41	205.9	412.3	508	0.27	29.5	0.049	2842.7	0.013	486.4	5.16	15.28	1.08	0	0	5.83
10/27/97	443	4627	7.59	206.6	416.2	535.1	0.25	20.3	0.047	2845	0.014	480.4	5.23	15.94	1.126	0	0	3.642
11/10/97	680	6180	3.97	215.2	702.6	507.5	0	30.6	0	4700.9	0.018	0	21.82	22.66	0.615	304.4	103.2	236.2
11/24/97	491	4973	7.34	196.4	516	528.3	0	40.8	0.016	3125.8	0.009	449.8	5.27	15.63	1.011	0	0.011	2.471
12/8/97	467	4936	7.83	199.2	509	532.5	0	35.6	0.851	3168.6	0.008	386.7	4.25	15.99	0.045	0	0	5.54
1/12/98	480	4737	7.79	180.9	489.3	530.3	0	29.3	0.532	3093.8	0.003	324.3	4.9	15.01	0.483	0	0.046	7.24
1/26/98	485	4839	7.26	203.3	449.7	547.2	0	31.1	0.013	3001.6	0.008	483.4	5.01	15.15	0.832	0.687	1.173	1.21
2/9/98	460	4878	7.26	211.2	456	539.6	0.15	31.2	0.04	3023.5	0.015	492.4	4.96	14.74	0.827	1.252	0.541	3.968
3/23/98	445	5332	7.69	224.7	545	540.1	0.21	16.5	0.463	3420.3	0.005	464.9	4.97	15.94	0.44	0	0.132	5.93
4/6/98	515	5415	3.72	108.9	230.7	531.9	0	25.9	0	4501.9	0.012	0	32.99	15.48	0.2	327.716	466.858	92.026
4/20/98	507	5354	7.67	209.6	585.5	515.7	0.16	34.9	0.675	3454.4	0.011	438.9	4.62	14.5	0.569	0	0.15	3.66
5/11/98	503	5445	7.52	203.7	628.8	489.4	0	35.5	0.157	3589.7	0.028	392.7	4.39	17.23	0.957	1.148	1.285	8.46
5/25/98	514	5590	7.96	212.7	631.7	528.1	0	34.9	0.157	3628	0.007	440	4.28	16.7	0.949	1.71	1.888	9.44
6/8/98	533	5601	7.77	202.6	641.8	517.2	0	32.2	0.005	3580.1	0.006	499.5	5.68	16.22	1.215	0.318	0.131	7.46
6/22/98	552	5589	7.21	208.8	624	518	0	31.1	0.011	3595.2	0.01	486.9	5.77	17.17	1.16	0.249	0.143	8.02
7/6/98	511	5585	7.67	194.8	627.1	542.1	0	27.5	0.09	3578.9	0.033	487.1	5.34	18.49	1.322	0.193	0.15	0.992
7/20/98	520	5290	8.05	212.2	598.6	465.3	0	31.7	0.758	3603.2	0.045	293	5.14	18.22	0.318	0.174	0.152	7.32
8/3/98	455	5469	8.07	214.4	646	465.3	0	24	0.754	3744.3	0.046	289.6	4.96	17.86	0.348	0.189	0.126	6.95
8/17/98	512	5338	8.08	210.5	604.5	467.3	0	29.5	0.81	3659.2	0.016	283.2	6.97	17.4	0.303	0.181	0.14	7.51
Min	303	2633	3.72	78.2	230.7	323	0	16.5	0	1640.7	0.002	0	3.05	9.85	0.045	0	0	0
Max	680	6180	8.34	404.8	702.6	574.6	0.49	156	1.947	4700.9	0.046	572.9	32.99	171.92	1.681	327.716	466.858	236.2
Mean	462.6471	4660.513	7.435042	173.7067	449.9076	514.6067	0.226891	54.28403	0.138118	2974.157	0.010731	383.1092	5.10437	20.13454	0.843227	5.482546	5.049059	10.52506
Median	457	4553	7.44	187.5	444.8	522.7	0.23	47.6	0.032	2888.9	0.006	384.8	4.88	16.91	0.93	0.134	0.012	7.68
95-percent	410.8	4218.5	7.019	90.08	368.89	449.28	0	21.56	0.0078	2642.245	0.003	246.44	3.398	11.35	0.3024	0	0	0.6924

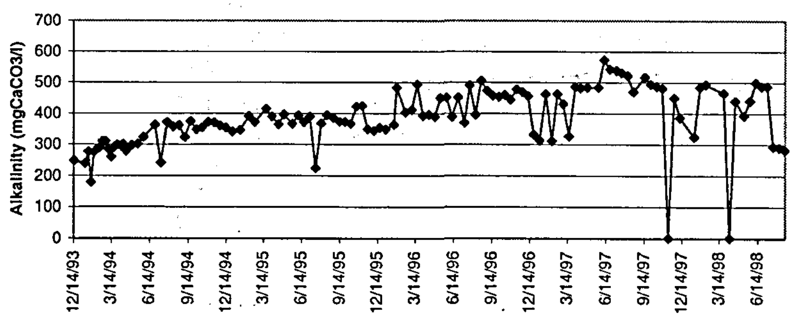
Cell 2

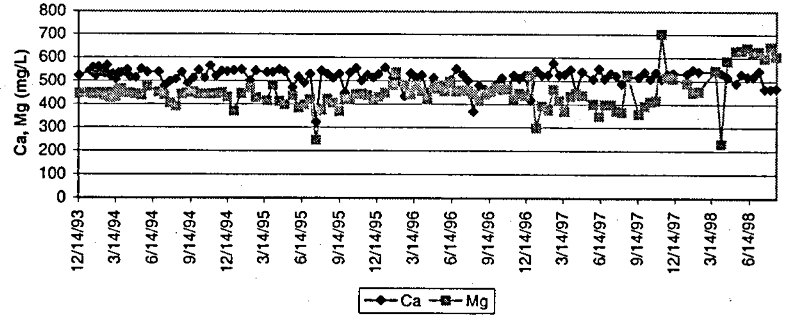

EC (mS/m)


pH


TDS, SO4, (mg/L)
TDS
SO4


Al, Fe, Mn (mg/L)
Al
Fe
Mn

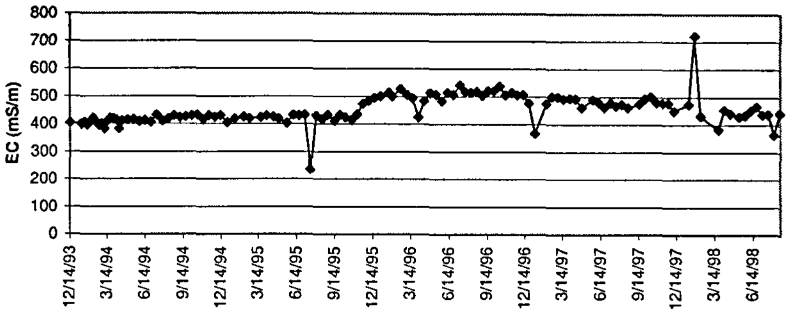

Alkalinity (mgCaCO3/l)

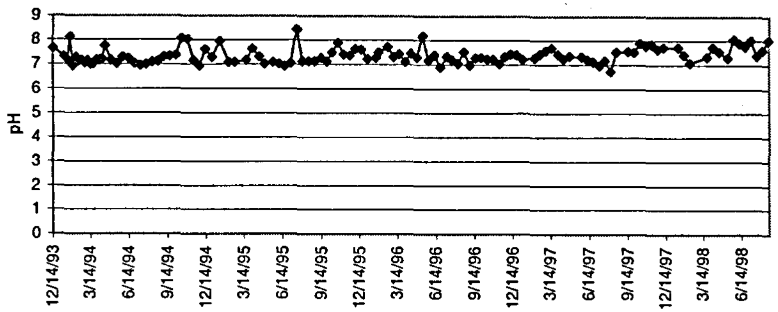

Ca, Mg (mg/L)
Ca
Mg

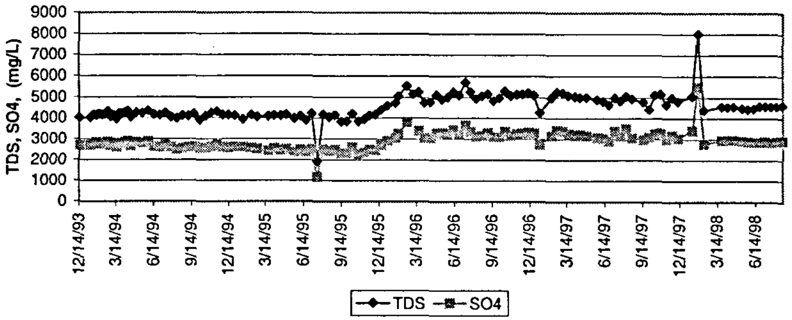
Cell 3

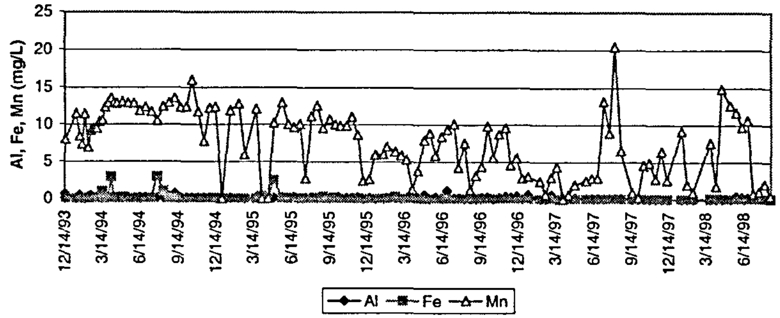
Date	EC	TDS	pH	Na	Mg	Ca	Fl	Cl	NO3	SO4	PO4	ALK	Si	K	NH4	Al	Fe	Mn
12/14/93	403	4002	7.65	67.3	394	532	0.22	34.9	0.017	2696.2	0.006	220.4	4.49	7.64	0.3	0.613	0.068	7.995
1/10/94	399	4004	7.31	81	356.6	546.9	0.29	48.9	0.032	2697	0.012	215.9	4.4	9.17	0.292	0.059	0	11.49
1/18/94	405	4147	7.18	89.1	388.8	554.4	0.27	38.7	0.017	2766.4	0.004	245.6	4.45	9.56	0.306	0.416	0.019	8.45
1/24/94	395	4110	8.11	85.1	400.7	535	0.3	28.3	0.02	2837.3	0.015	174.7	4.29	9.97	0.273	0.026	0	7.35
1/31/94	406	4187	6.93	90.1	390.1	558.6	0.21	48.7	0.021	2785	0.014	249	4.38	10.41	0.301	0	0.027	11.42
2/7/94	420	4149	7.27	89.2	393.3	543	0.3	42.4	0.035	2748	0.009	263.8	4.86	10.29	0.307	0.222	0	6.94
2/14/94	408	4173	7.12	97.1	372.7	543.6	0.28	31.7	0.016	2779.4	0.007	276.7	4.92	10.13	0.306	0.378	0.036	9.2
2/21/94	395	4306	7.15	107.5	378.4	557.5	0.29	36.1	0.016	2863.5	0.01	287.5	4.04	11.92	0.319	0.131	0	9.52
2/28/94	400	4045	7.05	96.7	361	528.6	0.31	37.9	0.016	2678	0.008	271.3	4	10.64	0.312	0.19	0	9.52
3/7/94	382	4120	7.14	102.7	364.6	536.2	0.31	34.6	0.025	2740.5	0.022	267.4	5	14.3	0.446	0.368	0.022	10.4
3/14/94	409	3948	6.99	113.8	377	500.2	0.29	39.8	0.017	2610.4	0.006	239.6	4.81	13.4	0.299	0.51	1	10.63
3/21/94	420	4196	7.02	100.3	395.1	534.5	0.31	34.6	0.005	2787.7	0.025	269.7	4.86	14.12	0.509	0.107	0.037	12.35
3/28/94	419	4206	7.17	109.7	403.7	542	0.32	34.2	0.011	2767.5	0.026	273	4.92	15.09	0.458	0.131	0.003	12.87
4/5/94	414	4259	7.17	100.4	394	542.8	0.3	32.4	0.044	2848.8	0.008	267.4	4.75	13.7	0.594	0.134	2.934	13.59
4/11/94	383	4317	7.21	95.5	399	651.1	0.31	33.8	0.032	2892.7	0.007	271	4.83	13.57	0.602	0.179	0	12.98
4/18/94	411	4028	7.75	95.3	391	517.5	0.29	34.3	0.05	2667.9	0.01	251.7	4.68	13.9	0.549	0.134	0.001	12.86
5/2/94	414	4242	7.16	100.2	393.1	519.9	0.22	36.7	0.017	2848.5	0.008	269.3	4.5	14.34	0.672	0.067	0.199	13.05
5/16/94	415	4222	7.02	99.2	371.7	548.2	0.32	48	0.024	2794.9	0.004	282.6	4.66	14.06	0.693	0.128	0.02	12.88
5/30/94	408	4319	7.28	97.6	362.3	544.6	0.39	45.9	0.037	2881.1	0.005	304.8	4.61	14.29	0.743	0.074	0	12.86
6/13/94	412	4153	7.23	107.5	410.3	517.9	0.34	58	0.025	2640.6	0.008	330.2	4.5	15.02	0.821	0.144	0.042	11.87
6/27/94	406	4121	7.03	102.7	374.4	542.9	0.42	62.8	0.014	2608.9	0.005	339.1	4.12	13.73	0.816	0.124	0.019	12.34
7/11/94	430	4241	6.95	113.5	368.5	584.2	0.43	83.2	0.015	2708.7	0.011	332.2	4.52	15.98	0.885	0.136	0.037	11.72
7/25/94	410	4037	6.99	103.3	360.7	528.6	0.36	31.5	0.092	2606.1	0.007	319.9	4	14.51	0.922	0.144	2.998	10.51
8/8/94	417	3973	7.08	107	367.3	538.2	0.37	72	0.037	2479.6	0.012	321.2	4.09	15.35	0.853	0.118	1.037	12.4
8/22/94	426	4100	7.12	110.6	384.5	542.6	0.31	73.3	0.042	2564.6	0.002	334.1	3.74	15.63	0.919	0.324	0.084	12.92
9/5/94	422	4080	7.3	107.1	370.8	532.9	0.31	63.1	0.039	2604.2	0.008	315.9	3.6	15.48	0.949	0.668	0.089	13.52
9/19/94	424	4182	7.32	110	387.1	525.1	0.36	79.3	0.021	2639	0.007	347.3	4.02	15.93	0.868	0.16	0	12.27
10/3/94	428	3902	7.37	106.7	368	497	0.37	88.1	0.011	2550.9	0.004	224.7	3.74	15.61	0.934	0.134	0.008	12.364
10/17/94	432	4084	8.07	108.1	396.6	467.7	0.27	111.4	0.131	2573.8	0.006	335.9	2.99	14.8	0.859	0.133	0.024	15.958
10/31/94	416	4228	8.01	114.8	382.5	569.6	0.36	70.2	0.038	2641.9	0.008	356.3	4.26	12.78	0.993	0.116	0.023	11.709
11/14/94	429	4291	7.15	108.1	392	533.4	0.35	90.2	0.023	2706.5	0.004	361	3.96	16.35	1.117	0.123	0.041	7.729
11/28/94	423	4149	6.93	105.8	392.7	509.9	0.24	95.2	0.107	2615.4	0.006	336.2	3.99	18	1.108	0.133	0	12.199
12/12/94	429	4144	7.6	108	380.4	536.2	0.3	108.2	0.03	2585.1	0.008	336.2	4.22	14.2	1.03	0.14	0.138	12.353
12/28/94	406	4112	7.29	112.5	367.3	533.1	0.26	37.8	0.074	2637.6	0.012	331.1	4.66	18.39	1.195	0	0.054	0
1/16/95	418	3932	7.94	101.8	383.4	494.5	0.27	28.1	0.016	2621.6	0.007	231.7	4.13	18.31	1.084	0.098	0	11.854
2/6/95	425	4141	7.08	139.8	369.2	508.4	0.3	69.8	0.01	2591.4	0.003	362.2	5.12	19.53	1.096	0.05	0.006	12.74
2/20/95	419	4053	7.08	124.6	338.9	535.8	0.3	69.9	0.025	2533.2	0.01	353	5.18	18.57	1.012	0	0.004	5.961
3/20/95	422	4084	7.17	135.6	355.6	535.7	0.37	110.9	0.013	2441.6	0.008	396.1	5.16	19.93	1.1	0.161	0.022	12.089
4/3/95	428	4116	7.63	148.7	341.9	545.5	0.31	21.4	0.034	2560.4	0.015	389	5.46	21.61	0.97	0.202	0.396	0
4/19/95	424	4117	7.31	133.4	354.9	556.3	0.36	90	0.012	2472.7	0.007	399.1	5.23	20.69	1.093	0.013	0	0.103
5/2/95	418	4153	7.02	135.4	363.1	539	0.31	89.2	0.005	2518.3	0.006	399	5.47	20.24	1.072	0.123	2.519	10.241
5/22/95	402	3979	7.09	139.5	353.2	525	0.3	75.8	0.066	2375.9	0.002	398.8	5.22	21.38	1.148	0.188	0.051	12.94
6/6/95	430	4088	7.02	166	334.8	524.5	0.38	87	0.019	2487.4	0.018	380.3	5.06	22.25	1.138	0.057	0.09	9.998
6/19/95	429	3880	6.93	147.8	336.2	488.2	0.27	61.1	0.053	2378	0.01	366.1	4.8	21.88	1.043	0.178	0.06	9.57
7/3/95	432	4200	7.04	147.4	357.3	543.8	0.4	90.4	0.039	2522.4	0.021	422.5	5.15	21.7	1.186	0.135	0.085	10.123
7/17/95	235	1921	8.44	70.1	164.9	253.6	0.27	37.3	0.142	1193.1	0.003	156.9	4.24	9.65	0.426	0.114	0	2.734
7/31/95	428	4150	7.12	146.2	355	544.5	0.39	85.6	0.019	2512	0.018	395.9	5.04	21.56	1.182	0.229	0.009	11.124
8/14/95	415	4040	7.13	145.3	341.1	550.7	0.24	79.2	0.025	2420.8	0.003	393.5	5.11	21.32	1.2	0.075	0.192	12.551
8/28/95	432	4125	7.12	138.8	338.9	593.6	0.38	78.2	0.029	2486.5	0.007	381.3	5.73	22.23	1.189	0.147	0.343	9.526
9/13/95	411	3822	7.26	133.3	335.3	498.1	0.29	67.2	0.017	2314.5	0.008	370.6	5.1	19.99	1.114	0.155	0.048	10.751
9/26/95	432	3836	7.13	135.7	357.4	457.6	0.32	64.9	0.046	2318.7	0.005	376	5.36	20.37	1.23	0.205	0.223	10.079
10/9/95	423	4193	7.49	139	340.4	536.8	0.19	73.7	0.01	2626.5	0.011	372.6	5.06	20.61	1.194	0.108	0	9.835
10/24/95	414	3838	7.88	138.8	330.4	495	0.24	66.2	0.067	2266	0.019	393.1	5.25	20.07	1.154	0.109	0	9.904
11/6/95	434	3932	7.41	140.2	353.3	464.3	0.22	80.8	0.037	2340.8	0.009	434.8	5.04	21.04	1.248	0.132	0.014	11.061
11/20/95	473	4114	7.36	137.9	348.4	548.2	0.18	78.8	0.021	2501.4	0.007	384.4	4.65	27.96	1.421	0.231	0.082	8.667
12/4/95	483	4161	7.63	159.3	354.3	538.2	0.19	190.7	0.013	2488	0.016	342.5	5.36	31.33	1.16	0	0	2.424
12/18/95	493	4374	7.61	182.3	392.9	540.1	0.21	92.5	0.032	2708.4	0.006	354.1	5.33	24.44	0.988	0.114	0.009	2.641
1/2/96	500	4581	7.22	166.2	419	556.7	0.21	60.7	0.005	2915.7	0.007	351.9	5.81	32.25	0.974	0	0	5.957
1/22/96	512	4722	7.27	192.2	428.9	535.7	0.2	44.9	0.031	3047.8	0.01	360.6	5.73	31.13	0.925	0	0	6.05
1/29/96	500	5037	7.48	268.7	453.9	530.6	0.27	45.7	0.045	3256	0.012	376.8	5.28	20.89	0.859	0.127	0.025	7.04
2/19/96	525	5521	7.71	214.7	484.1	466	0.25	39.9	0.047	3803.7	0.009	393.7	4.99	31.41	0.731	0.137	0.29	6.37
3/5/96	505	5145	7.31	287.2	456.3	523.5	0.24	51.8	0.022		0.006	390.1	4.9	30.34	0.732	0	0	5.87
3/18/96	492	5244	7.42	249.7	484	516.5	0.24	42.1	0.027	3400	0.011	425.4	5.2	31.33	0.683	0.114	0	5.29
4/1/96	423	4714	7.11	211.4	445.2	514	0.26	15.2	0.009	3037.4	0.006	383.5	5.04	21.58	0.768	0.159	0.014	1.299
4/15/96	483	4771	7.45	229.4	486.2	455.7	0.26	42.7	0.049	3065	0.005	377.8	4.57	29.56	0.775	0.172	0.014	3.821
4/30/96	511	5096	7.28	245.4	504.6	523.7	0.25	38	0.023	3287.4	0.006	378.2	5.3	34.38	0.809	0.513	0.066	7.9
5/13/96	506	4888	8.16	210.3	526.3	430.2	0.33	27.4	0.058	3300.9	0.004	296	5.02	30.31	1.023	0.007	0	8.85
5/27/96	483	4993	7.16	212.5	510.7	474.9	0.4	28	0.018	3246.4	0.007	399	5.1	30.61	0.99	0.229	0	5.88
6/10/96	613	6241	7.38	208.1	547	604.3	0.26	36.8	0.015	3442	0.008	386	5.48	31.27	0.996	0.142	0	8.39
6/24/96	607	6104	6.89	211.3	503.5	547	0.41	28.7	0.021	3237.7	0.014	444.8	5.74	31.22	1.082	1.052	0	9.35
7/10/96	640	6699	7.32	208	604.8	584	0.23	38.1	0.027	3665.5	0.01	462.3	5.7	32.84	1.121	0.101	0	10.12
7/22/96	617	6259	7.18	198.8	566.1	484	0.23	44.7	0.005	3387.3	0.01	463.3	6.37	31.78	1.073	0.097	0	4.257
8/5/96	513	4941	7.04	198.8	556.1	416.9	0.23	46.9	0.023	3131.2	0.005	458.5	5.44	30.4	1.162	0	0	7.55
8/19/96	617	5054	7.51	212.9	526.8	505.9	0.23	47.1	0.021	3161	0.011	464.8	5.41	32.27	1.025	0	0	1.219
9/2/96	603	5148	6.98	222.2	549	452.3	0.22	46.4	0.061	3297.8	0.012	447.7	5.23	32.22	1.098	0	0	3.123
9/16/96	519	4829	7.26	208.6	532.6	468.3	0.14	48.4	0.035	3105.2	0.004	367	8.49	19.1	1.07	0.163	0.041	4.375
9/30/96	519	4972	7.29	214.7	644.9	485.1	0.22	47	0.014	3099	0.015	458.2	5.36	20.31	1.183	0.207	0.059	9.81
10/14/96	537	5285	7.22	233	644.5	507.4	0.22	33.6	0.038	3359	0.004	479.6	8.3	21.08	1.174	0	0	5.545
10/28/96	505	5068	7.21	237.3	540.2	479.2	0.16	40.8	0.013	3170.2	0.023	472.7	5.32	21.87	1.153	0.108	0	8.747
11/12/96	514	5133	7.03	203.1	545.5	508.3	0.15	28.8	0.017	3255.1	0	468.8	5.42	18.87	0.953	0.28	0	9.577
11/25/96	505	5140	7.31	176.3	533	514.6	0.19	42.8	0.015	3285.8	0.011	465.8	5.25	18.34	1.039	0.219	0.012	4.56
12/9/96	507	5214	7.42	205.6	557.8	519	0.14	33.1	0.021	3329.1	0.013	451	6.14	18.49	1.071	0.368	0	5.542
12/23/96	476	5103	7.59	174.1	525.8	516.4	0.14	35.1	0.026	3288.1	0.006	444.9	5.59	20.21	1.052	0	0	2.768
1/6/97	367	4248	7.21	253.1	300.2	537.5	0.38	17.8	0.03	2754.9	0.007	306.1	7.65	10.94	0.246	0.563	0.021	3.046
2/4/97	475	4981	7.27	160	537.8	498.6	0.17	30.3	0.029	3174.1	0.004	458.6	5.27	18.55	1.372	0	0	2.352
2/17/97	500	5233	7.43	169.8	564.6	464.9	0.17	31.1	0.037	3423	0.007	457	5.21	20.61	1.472	0	0	0.653
3/3/97	498	5214	7.58	166.4	532.8	523.7	0.17	31.8	0.041	3385.2	0.007	453.3	5.37	19.39	1.29	0.576	0.042	2.928
3/17/97	491	5084	7.69	139.3	556.5	507.4	0.22	30.7	0.019	3260.8	0.007	465.8	6.39	19.73	1.221	0	0	4.349
4/1/97	493	5040	7.42	161.5	554.2	525.6	0.21	35	0.017	3179.5	0.013	461.3	5.53	19.32	1.277	0.113	0	0.008
4/14/97	492	4999	7.23	169.5	562.1	423.4	0.21	33	0.03	3222.1	0.014	464.4	5.6	20.57	1.298	0.183	0	0.614
4/29/97	461	5000	7.35	170.1	597.2	455.4	0.2	31.1	0.028	3166.3	0.015	458	5.42	19.68	1.269	0.172	0	1.928
5/28/97	489	4895	7.32	158	524.2	493	0.2	33.1	0.013	3097.4	0.009	465.2	5.44	19.8	1.203	0.097	0	2.474
6/9/97	480	4819	7.21	168.6	498.1	494.8	0.19	32.8	0.016	3040.7	0.014	462.3	5.64	18.78	1.052	0.073	0	2.626
6/23/97	461	4639	7.13	160.5	471.9	489.6	0.17	30.6	0.027	2904.9	0.006	459.3	5.55	19.86	1.011	0.026	0	2.813
7/8/97	478	4987	6.97	210.6	503.5	516.8	0.6	29.7	0.036	3400.6	0.007	257.2	6.28	11.02	0.396	0.058	0	13.15
7/21/97	467	4829	7.17	192.5	486.9	527.2	0.38	23.5	0.016	3156.6	0.009	348.3	5.29	15.96	0.887	0.069	0	8.92
8/4/97	473	5058	6.73	223.9	476.3	529.4	0.87	30.5	0.027	3513.5	0.006	223.4	6.25	10.83	0.454	0.096	0	20.41
8/18/97	461	4929	7.52	190.8	484	528.8	0.19	32.8	0.08	3081.6	0.004	486.3	5.1	16.43	1.024	0.076	0	6.57
9/15/97	474	4786	7.55	180.2	480.6	513.6	0.19	32	0.045	2982	0.003	473	5.28	18.67	1.165	0	0	0.903
9/29/97	492	4418	7.52	185.2	528	383.7	0.19	32.3	0.054	3114	0.006	126.1	5.29	18.6	1.186	0	0	0.229
10/13/97	501	5115	7.86	155.5	559.4	506.2	0.23	27.3	0.155	3269.5	0.014	471.7	5.24	19.67	1.144	0	0	4.561
10/27/97	480	5165	7.78	162.5	561.9	507.7	0.06	27.3	0.137	3312.3	0.023	468	6.34	20.42	1.118	0	0	4.933
11/10/97	477	4658	7.84	167.5	551.2	405.2	0.13	29.3	0.067	3012.7	0.004	387.7	5.31	18	1.083	0	0.036	2.753
11/24/97	477	4962	7.64	162.1	558.7	477	0	36.8	0.009	3197	0.007	434.9	5.47	18.16	1.112	0	0	6.47
12/8/97	449	4810	7.72	157.9	513.2	519	0.01	19.7	0.067	3051.9	0.04	434.2	5.33	17.36	1.097	0	0	2.57
1/12/98	474	5063	7.72	146.4	502.8	639.9	0.38	28.7	0.087	3426.8	0.003	326.6	5.6	17.92	1.113	0	0.007	9.19
1/26/98	721	7992	7.42	254.9	1104.2	453.8	0.05	49.2	0.049	5497	0.014	500.1	4.53	21.42	1.031	0	0	1.98
2/9/98	430	4386	7.09	133	424	540.2	0.33	15.9	0.014	2793.4	0.009	376.4	5.28	18.63	0.889	0	0	0.959
3/23/98	382	4546	7.32	136.7	427.4	550.9	0.11	14.4	0.184	2954.2	0.002	362.4	5.76	18.65	1.034	0	0.12	7.56
4/6/98	453	4537	7.72	130.7	433.3	555.2	0.27	14.2	0.129	2968.3	0.007	342.6	5.97	17.67	1.037	0	0.109	1.769
4/20/98	440	4550	7.54	124.7	434	533.9	0.29	17.7	0.305	2966	0.02	373.3	5.58	16.18	0.789	0	0.044	14.91
5/11/98	428	4474	7.3	127.7	425.4	492.5	0	19.8	0.025	2916.8	0.015	366.3	5.96	19.09	1.24	0.007	0	12.63
5/25/98	433	4437	8.06	125.4	433.2	487.9	0	17	0.016	2899.8	0.006	371.3	5.81	19.4	1.254	0.391	0	11.68
6/8/98	450	4460	7.9	124.5	448.2	450.6	0.03	17.4	0.033	2859.6	0.006	442	5.8	18.44	1.351	0.274	0.025	9.76
6/22/98	465	4586	7.76	130.7	456.9	533.5	0	30.5	0.016	2867.3	0.01	448.1	5.94	19.33	1.343	0.23	0.028	10.65
7/6/98	436	4587	8.01	110.6	429.6	556.1	0	20.7	0.07	2912.3	0.048	440.4	5.65	18.5	1.273	0.119	0.05	0.758
7/20/98	437	4566	7.38	118	461.5	530	0	17.8	0.022	2862.3	0.044	455.5	6.26	18.9	1.354	0.106	0.044	1.018
8/3/98	364	4570	7.61	119.7	445.9	528	0	17.8	0.066	2892.5	0.057	447.5	5.85	18.66	1.285	0.12	0.028	2.05
8/17/98	440	4616	8.01	118.7	466.4	533.4	0.02	21.7	0.08	2933.8	0.012	427.9	5.79	18.24	1.226	0.135	0.1	0.476
Min	235	1921	6.73	67.3	164.9	253.6	0	14.2	0.005	1193.1	0	126.1	2.99	7.64	0.246	0	0	0
Max	721	7992	8.44	287.2	1104.2	593.6	0.87	190.7	0.305	5497	0.057	500.1	7.85	34.38	1.472	1.052	2.998	20.41
Mean	450.8992	4530.983	7.361429	151.2445	441.7092	513.6798	0.251849	47.45798	0.038655	2902.864	0.010412	368.6261	5.107059	19.38252	0.950731	0.142748	0.120067	7.674311
Median	433	4418	7.29	139.5	424	525.1	0.26	37.8	0.027	2865.4	0.008	376.8	5.23	18.78	1.037	0.119	0.006	8.667
95-percent	393.8	3929	6.968	90.01	338.63	448.56	0	17.67	0.0099	2375.985	0.003	224.57	3.999	10.274	0.3055	0	0	0.6002

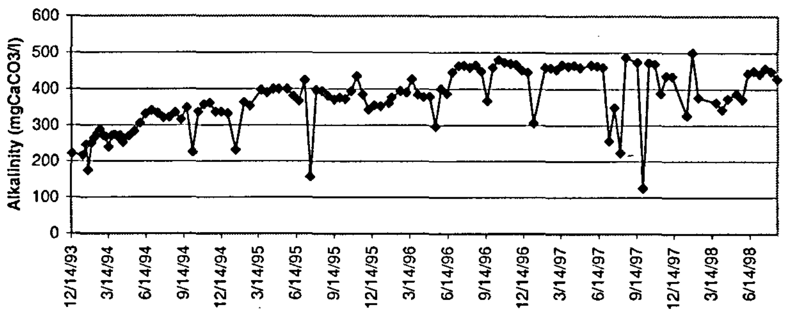
Cell 3

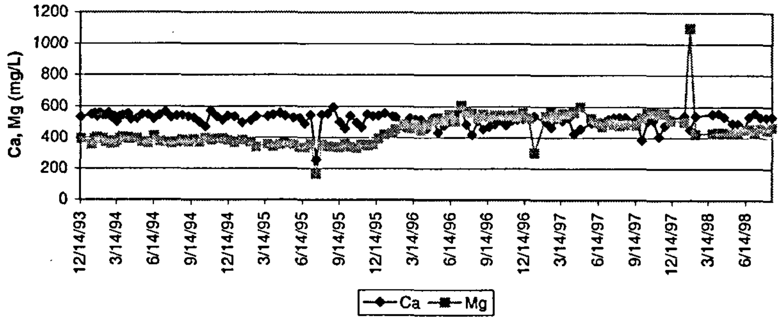

EC (mS/m)


pH


TDS, SO4, (mg/L)
TDS
SO4


Al, Fe, Mn (mg/L)
Al
Fe
Mn

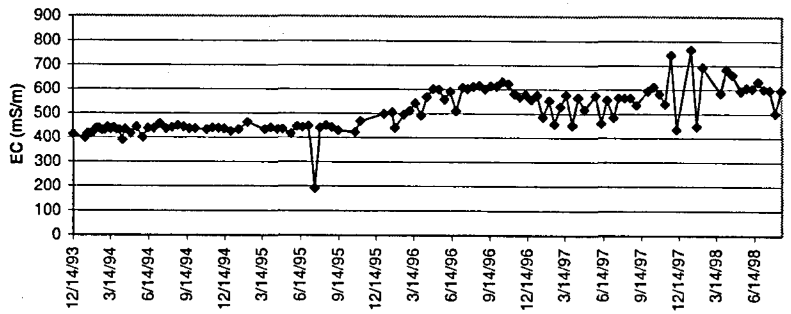

Alkalinity (mgCaCO3/l)

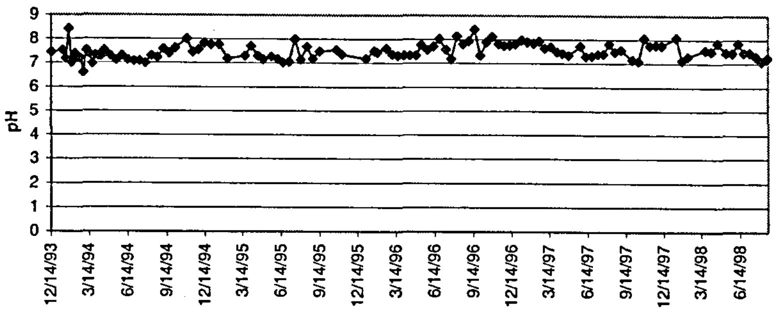

Ca, Mg (mg/L)
Ca
Mg

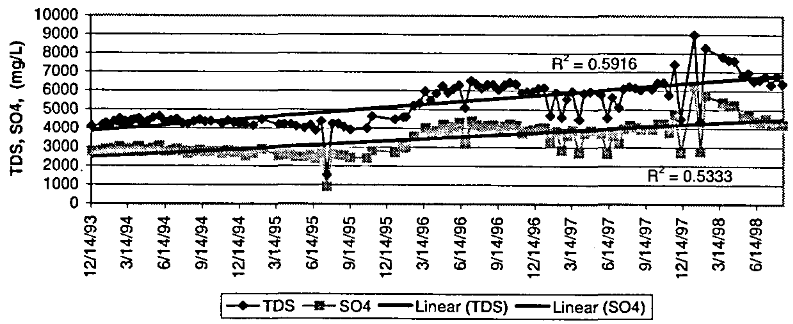
Cell 4

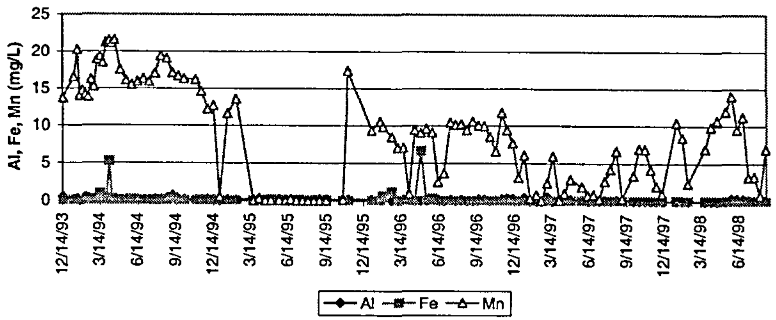
Date	EC	TDS	pH	Na	Mg	Ca	Fl	Cl	NO3	SO4	PO4	ALK	Si	K	NH4	Al	Fe	Mn
12/14/93	412	4099	7.45	72.5	411	524	0.21	39.5	0.02	2779.9	0.006	215.9	4.29	8.43	0.361	0.47	0.053	13.715
1/10/94	397	4154	7.52	80.6	421.2	540	0.28	35.3	0.024	2797	0.011	221.5	4	9.35	0.28	0.134	0.001	16.51
1/18/94	416	4266	7.18	80.9	422.6	545.9	0.25	38.1	0.018	2872.2	0.006	243.3	3.96	8.95	0.344	0.222	0	20.23
1/24/94	415	4066	8.41	78	437.6	466	0.31	56	0.02	2721	0.012	260	3.86	9.59	0.286	0.003	0	13.99
1/31/94	421	4202	7	85.4	425.7	553.1	0.17	59.4	0.026	2761.7	0.015	251.1	3.88	9.82	0.317	0	0.02	14.79
2/7/94	436	4353	7.39	84	434.1	537.7	0.3	59.3	0.03	2903.7	0.013	264.9	4.39	9.96	0.346	0.418	0.021	14.16
2/14/94	437	4337	7.19	86	427.3	540.8	0.27	57.4	0.021	2888.8	0.006	267.5	4.41	9.84	0.326	0.311	0.027	13.86
2/21/94	429	4493	7.19	87.1	437.4	552.8	0.26	63.4	0.014	2993.8	0.008	284.3	3.68	11.18	0.329	0.156	0	16.22
2/28/94	430	4188	6.59	82.1	422.8	486.1	0.3	34.4	0.043	2828	0.009	265.8	3.53	9.62	0.343	0.176	0.003	15.22
3/7/94	441	4367	7.52	108.4	446.9	533.3	0.48	70.2	0.012	2866.8	0.032	266.9	4.47	14.45	0.42	0.331	0.026	18.91
3/14/94	433	4176	7.37	111.7	420.6	508.1	0.26	76.2	0.026	2749.3	0.007	242.7	3.95	13.58	0.31	0.132	0.937	19.36
3/21/94	439	4388	6.97	99.6	441.1	527.7	0.29	67.5	0.007	2904.4	0.021	273.1	4.55	13.71	0.532	0.134	0.027	18.45
3/28/94	431	4416	7.33	112.3	450	542.7	0.3	71.3	0.007	2883.4	0.024	279.3	4.57	14.35	0.501	0.144	0.009	21.25
4/5/94	429	4465	7.29	106.4	437.7	540.7	0.27	61.2	0.022	2970.6	0.007	273.9	4.37	13.6	0.635	0.279	5.28	21.55
4/11/94	390	4499	7.28	105	432.5	545	0.3	50.8	0.02	3014.3	0.005	276.1	4.38	13.62	0.681	0.107	0.276	21.12
4/18/94	433	4206	7.52	102.5	433.2	519.3	0.23	71.7	0.032	2747.4	0.01	259.5	4.45	13.77	0.709	0.111	0.073	21.59
5/2/94	416	4373	7.3	106	435.4	510.9	0.48	71.3	0.031	2875.3	0.016	293.8	4.33	13.92	0.647	0.082	0.014	17.52
5/16/94	442	4551	7.11	106.4	435	544	0.3	157.7	0.019	2928.2	0.004	297.9	4.23	14.82	0.617	0.128	0.023	16.11
5/30/94	400	4626	7.3	108	463.2	532.8	0.62	75.7	0.063	3039.1	0.012	321.1	4.33	14.32	0.667	0.098	0.181	15.48
6/13/94	437	4310	7.12	108.3	458.1	494	0.34	87.1	0.03	2750	0.007	325.6	4.07	14.35	0.718	0.137	0.053	15.91
6/27/94	437	4414	7.07	109	436.7	533.8	0.42	86.5	0.035	2810.5	0.008	346.9	3.67	13.67	0.76	0.131	0.03	16.31
7/11/94	456	4492	7.09	115.8	442.2	526.9	0.42	89.8	0.019	2889.9	0.01	336.8	4.03	15.33	0.834	0.145	0.033	15.91
7/25/94	436	4255	6.99	110.6	431.8	498.7	0.36	28.3	0.092	2786.8	0.009	313.9	3.41	14.19	0.885	0.151	0.073	17.03
8/8/94	441	4209	7.3	111.8	409.8	533	0.35	93.4	0.03	2657.2	0.01	317.6	3.35	14.97	0.858	0.156	0.136	19.39
8/22/94	449	4354	7.23	113.5	441.1	529.8	0.28	99.2	0.082	2756.3	0.002	326.1	3.12	15.21	0.943	0.332	0.035	19.04
9/5/94	443	4457	7.59	108.5	444.6	505.7	0.29	133.7	0.043	2821.1	0.007	350	3.01	14.63	0.972	0.677	0.441	17.06
9/19/94	435	4333	7.4	109	434.5	510.4	0.33	97.1	0.022	2741.7	0.008	347.8	3.09	14.7	0.793	0.164	0	16.69
10/3/94	436	4359	7.63	109.8	421.8	542.3	0.37	100.2	0.082	2771.7	0.001	324.9	2.89	15.56	0.896	0.16	0.015	16.3
10/31/94	431	4235	8	117.5	416.1	509	0.35	94.5	0.238	2679.3	0.009	332.1	3.03	11.28	0.733	0.106	0.017	16.199
11/14/94	440	4407	7.46	114.5	419.4	510.1	0.32	106.3	0.604	2810	0.002	350.3	2.68	15.57	0.507	0.122	0.04	14.655
11/28/94	438	4298	7.56	111.1	429.8	527.3	0.26	108.8	0.818	2703	0.003	325.6	2.54	17	0.293	0.155	0	12.23
12/12/94	436	4230	7.83	113.3	410.7	516.9	0.3	6.4	0.962	2748	0.007	340.2	2.74	15.19	0.221	0.14	0.026	12.703
12/28/94	425	4196	7.77	114.2	413.1	504.4	0.27	225.4	0.905	2542.3	0.008	308.6	2.91	15.75	0.173	0	0	0.493
1/16/95	433	4143	7.78	90.5	421.8	500.6	0.28	32	0.979	2674.5	0.008	329.9	2.74	16.26	0.1	0.112	0	11.635
2/6/95	463	4471	7.18	127.5	445.1	531.1	0.31	111	0.005	2891.6	0.002	277	4.41	25.37	1.064	0.065	0.016	13.589
3/20/95	433	4200	7.3	119.2	399.8	511.4	0.38	137.4	1.838	2549.6	0.013	375.1	3.69	16.43	0.164	0.155	0	0
4/3/95	441	4219	7.71	116.5	404.2	498	0.31	104.2	0.9	2608.8	0.007	381.7	3.98	16.18	0.783	0.176	0.058	0.286
4/19/95	434	4208	7.3	121	404.8	518.8	0.36	109.9	1.843	2565.1	0.012	379.8	3.76	17.11	0.094	0	0	0
5/2/95	434	4100	7.15	121.2	399.1	503.1	0.32	112.6	1.8	2466.9	0.01	387.4	3.74	16.32	0.072	0.094	0.16	0.027
5/22/95	416	4008	7.26	126.1	374.9	436.2	0.3	111.4	2.016	2477.2	0.003	372.7	3.51	17.95	0.229	0.217	0.016	0.032
6/6/95	445	4165	7.16	139.7	385.2	475	0.35	110.5	2.252	2591.1	0.016	356.2	3.61	18.03	0.257	0.089	0.03	0.02
6/19/95	442	3873	7.02	118	393	449	0.27	105.2	2.144	2375	0.009	333.1	3.32	16.52	0.145	0.126	0.022	0.226
7/3/95	448	4373	7.04	127.3	424	525	0.38	143.3	2.367	2680.4	0.019	363.6	3.65	17.96	0.173	0.009	0.07	0
7/17/95	191	1531	7.99	67.3	133.5	171.5	0.28	50.6	0.877	915.2	0.008	149.3	3.18	6.52	0.086	0.075	0	0
7/31/95	439	4230	7.14	125.9	374.7	524.8	0.38	106.3	2.32	2659	0.018	337.2	3.58	17.57	0.121	0.015	0	0
8/14/95	450	4238	7.69	128.7	414.3	527	0.25	111.5	2.411	2591.2	0.007	357.7	3.79	17.78	0.349	0.069	0.001	0.013
8/28/95	442	4069	7.18	120.2	392.2	490.4	0.38	106.3	2.681	2548.3	0.007	312.4	3.89	18.25	0.401	0.151	0.027	0.01
9/13/95	429	3914	7.49	111.1	363.5	487.2	0.28	95.4	2.257	2430.8	0.011	327.5	3.68	16.24	0.145	0.147	0.044	0.007
10/24/95	423	3985	7.55	116	399.5	462.9	0.22	112.2	3.165	2399.5	0.017	380.5	3.83	16.7	0.179	0.108	0	0.14
11/6/95	468	4644	7.35	184.2	443.8	535.8	0.19	152.7	2.505	2814.3	0.01	389.3	3.96	27.25	0.192	0.157	0	17.382
1/2/96	498	4468	7.18	172.8	425.8	560.9	0.18	90.3	0.017	2726.5	0.009	376.2	5.25	30.8	1.536	0.122	0	9.384
1/22/96	504	4562	7.5	176.4	414.6	530.2	0.2	70.5	0.007	2953	0.009	331.7	5.11	30.36	1.606	0.139	0.037	10.54
1/29/96	440	4601	7.45	171.9	422.9	527	0.24	45.9	0.069	3005.2	0.01	334.8	4.78	18.45	0.887	0.181	0.634	9.86
2/19/96	495	5187	7.62	175.4	451.9	473.7	0.23	32.9	0.115	3572.3	0.01	367.1	4.69	31.47	0.663	0	1.194	8.54
3/5/96	512	5314	7.36	246.1	501.8	517.7	0.23	48.6	0.009		0.004	375.6	4.39	30.9	0.637	0.057	0	7.05
3/18/96	542	5964	7.31	237.8	633.5	507.8	0.22	38.2	0.056	4005.7	0.017	415.3	4.72	33.09	0.649	0.11	0	7.08
4/1/96	492	5497	7.33	198	509.2	542.7	0.23	43.6	0.07	3710.7	0.007	377.5	4.45	30.91	0.759	0.173	0.019	0.955
4/15/96	569	5855	7.32	248	656.2	541.6	0.23	48.7	0.019	3866.7	0.006	378.9	4.13	30.82	0.861	0	0	9.44
4/30/96	600	6221	7.33	248.5	733.6	503.5	0.22	29.7	0.023	4199.2	0.004	387.5	4.71	32.5	0.793	0.009	6.68	9.07
5/13/96	599	5889	7.76	217.9	729.2	466.9	0.21	38.9	0.069	3864.2	0.006	442.9	4.32	29.82	0.805	0.035	0	9.59
5/27/96	558	6092	7.56	219.7	733.4	459.3	0.41	29.8	0.025	4076.8	0.005	442	4.49	30.3	0.859	0.289	0.285	9.12
6/10/96	589	6282	7.71	220.2	722.4	510.2	0.24	37.1	0.025	4289.8	0.01	386.1	4.63	30.5	0.826	0.111	0	2.544
6/24/96	510	5099	8.01	369.1	406.7	534.6	0.34	33.3	0.023	3193.3	0.015	435.4	3.87	29.49	0.737	0	0	3.683
7/10/96	606	6522	7.58	210.4	789.2	516.3	0.2	41.5	0.029	4387.9	0.016	446.3	4.94	31.48	0.876	0.12	0	10.43
7/22/96	601	6351	7.18	224	791.5	488	0.2	50	0.01	4180.6	0.011	479.3	4.79	30.69	0.807	0	0	10.163
8/5/96	610	6120	8.12	225.3	814.9	385	0.2	44.2	0.016	4054.3	0.006	464	4.85	29.56	0.791	0.07	0	10.23
8/19/96	615	6304	7.81	234.1	780.5	478.5	0.17	47.6	0.017	4142	0.016	482.5	4.85	31.4	0.741	0	0	9.442
9/2/96	600	6303	7.94	237.8	739.9	490.7	0.18	50.7	0.041	4173.3	0.011	474	4.58	31.03	0.793	0	0	10.58
9/16/96	613	6046	8.42	223.7	797.2	437.7	0.16	45.3	0.028	3948.1	0.006	472.2	4.79	16.62	0.843	0.217	0.046	10.071
9/30/96	612	6295	7.32	243	804.2	480.1	0.19	48	0.003	4127.4	0.018	469.1	4.62	19.09	0.918	0.177	0.049	9.96
10/14/96	630	6434	7.88	233.4	809.9	493.9	0.19	42.7	0.025	4237.5	0.003	488.8	4.57	19.04	0.927	0.057	0	8.562
10/28/96	622	6346	8.11	251.3	824.8	467.6	0.13	43.2	0.068	4166.5	0.065	470.3	4.74	18.29	0.606	0.102	0	6.626
11/12/96	582	5891	7.82	235.9	731.4	500	0.13	52.4	0.013	3761	0.005	484.1	4.81	18.38	0.945	0.238	0	11.753
11/25/96	569	5944	7.74	212.9	692.7	520.9	0.16	57	0.019	3852.4	0.009	482.1	4.74	18.68	1.052	0.327	0	9.47
12/9/96	578	5945	7.77	225.2	698.8	468.3	0.13	40.7	0.015	3919.3	0.013	468.7	5.57	19.22	1.04	0.306	0	7.718
12/23/96	556	6102	7.82	246.4	732.1	487.7	0.12	47	0.026	4006.2	0.006	459.2	4.57	20.5	1.164	0.055	0.004	3.146
1/6/97	575	6146	7.96	227.6	721.6	602.7	0.13	42.7	0.019	4052.2	0.007	472.2	5.34	21.31	1.162	0.422	0.021	6.095
1/20/97	486	4692	7.89	175.3	522.2	423.3	0.16	28.3	0.032	3302.9	0.005	180.2	5.14	18.11	1.279	0	0	0.34
2/4/97	552	5891	7.84	220.2	691.9	494.3	0.13	44.5	0.033	3827.5	0.005	483.2	4.77	21.01	1.661	0	0	0.804
2/17/97	456	4587	7.92	199.3	387.2	551.1	0.15	69.7	0.049	2845.1	0.005	424	4.19	16.36	0.826	0	0	0.098
3/3/97	529	5564	7.64	231.2	581.2	511.1	0.18	38	0.043	3618.9	0.009	461.9	5.09	18.21	1.296	0.539	0.032	2.414
3/17/97	576	5951	7.7	205.1	725.3	498.5	0.21	39.2	0.034	3688.9	0.009	469	5.66	20.07	1.318	0	0	5.94
4/1/97	451	4473	7.49	221.9	384.6	563.6	0.17	70.6	0.015	2714.2	0.013	410	4.67	16.63	0.878	0.113	0	0.078
4/14/97	566	5857	7.42	225.1	692	524.8	0.18	44.3	0.049	3752.7	0.016	488.4	4.97	20.35	1.353	0.204	0	1.008
4/29/97	517	5936	7.34	231.1	706.6	464.4	0.18	38.8	0.048	3882.7	0.013	484	4.94	20.55	1.339	0.172	0	2.88
5/26/97	574	5779	7.73	217.4	690.2	479.2	0.17	37.1	0.025	3740.3	0.008	485.6	4.85	20.36	1.32	0.112	0	1.875
6/9/97	460	4545	7.29	273.6	354.5	517.3	0.2	34.7	0.035	2653.2	0.006	570.9	5.18	14.43	0.892	0.06	0	0.79
6/23/97	556	5653	7.3	201.4	676.3	505.9	0.14	34.7	0.03	3628.6	0.01	477.9	5.21	21.75	1.118	0.023	0	0.845
7/8/97	484	5118	7.38	228.3	511	509.4	0.2	33.9	0.046	3194.4	0.008	511.3	5.11	16.28	1.021	0.032	0	0.284
7/21/97	566	6083	7.39	219.8	734.4	509.4	0.14	26.9	0.035	3982.8	0.005	483.2	4.8	19.06	1.084	0.083	0	2.672
8/4/97	565	6209	7.62	225.2	734	455.3	0.2	36.8	0.349	4157.9	0.003	474.2	4.82	18.67	0.906	0.056	0	4.247
8/18/97	566	6147	7.48	229.3	714.8	500.1	0.16	37.7	0.036	4039.3	0.007	496.4	4.64	18.39	1.223	0.109	0	6.69
9/1/97	535	6045	7.57	227.9	721.4	504.2	0.17	35.5	0.053	3934.5	0.004	492.7	4.54	19.06	1.133	0.152	0	0.329
9/29/97	594	6087	7.15	239	767	448.1	0.16	35.1	0.026	3962.3	0.009	504.1	4.92	19.48	1.184	0	0	3.429
10/13/97	610	6396	7.08	212.6	799.3	483	0.21	30.7	0.015	4237	0.017	501.2	5.4	20.98	1.075	0	0	6.98
10/27/97	581	6431	8.05	245.3	795.2	485.7	0.19	29.9	0.012	4244.9	0.012	498.2	4.96	20.52	1.082	0	0	6.89
11/10/97	541	5778	7.75	217	689.1	462.5	0.04	47.7	0.065	3776.1	0.008	463.8	4.67	18.27	0.939	0	0	4.197
11/24/97	742	7416	7.76	272.3	1214.8	481.1	0	38.8	0.027	4752.4	0.009	519.6	4.7	21.85	1.272	0	0	1.966
12/8/97	434	4484	7.75	277.2	353.2	522.5	0	33.3	0.029	2724.9	0.007	454.5	4.7	17.29	0.936	0	0	0.991
1/12/98	765	8991	8.08	273.6	1286.2	490.7	0.1	30.9	0.489	6266.7	0.008	506.5	4.52	22.53	0.738	0	0.055	10.46
1/26/98	448	4369	7.12	131.7	421.7	540.9	0.29	15.8	0.043	2776.5	0.011	379.2	5.46	18.35	0.924	0	0	8.47
2/9/98	692	8299	7.29	259.8	1165.7	449.9	0.13	34.6	0.041	5754.1	0.009	502.5	4.58	20.68	1.02	0	0	2.37
3/23/98	586	7816	7.56	248.9	1037	497.1	0.07	27.6	0.125	5387	0.005	488.7	4.85	20.48	1.179	0	0.049	6.97
4/6/98	683	7644	7.51	251.3	1032.9	494.5	0.14	27.7	0.108	5228	0.006	481.1	4.9	20.72	1.182	0	0.046	9.9
4/20/98	661	7609	7.86	235.6	998.1	500.9	0.16	34.8	0.025	5240.9	0.012	474.9	4.53	17.7	1.334	0	0.053	10.74
5/11/98	594	6801	7.46	221.2	871.9	467.3	0.01	32.8	0.03	4590.5	0.013	488	4.95	20.19	1.174	0	0	11.93
5/25/98	606	6960	7.44	217.7	880.4	477.5	0.01	31.6	0.024	4740.3	0.012	485	4.86	19.56	1.168	0.312	0	14.02
6/8/98	604	6519	7.84	221.1	838.4	478.1	0.02	31	0.025	4379.3	0.007	452.7	4.99	17.69	1.163	0.293	0.016	9.55
6/22/98	632	6574	7.46	226.4	854.7	487.2	0.05	28.1	0.013	4339.8	0.01	506.7	5.2	18.9	1.113	0.258	0.015	11.23
7/6/98	601	6767	7.46	223.6	831.9	513.1	0.01	34.1	0.021	4515.9	0.031	515.4	5.15	18.08	1.134	0.114	0.024	3.231
7/20/98	597	6334	7.3	231.9	747.2	480.4	0	33.8	0.018	4195.1	0.043	513.5	5.15	17.58	1.07	0.095	0.021	3.298
8/3/98	503	6778	7.08	233.1	829	496.5	0.01	284.7	0.027	4286.7	0.056	515.2	5.52	18.01	1.102	0.114	0.017	0.759
8/17/98	596	6380	7.24	218.4	786.2	482.9	0.03	36.2	0.034	4212.2	0.011	512.1	9.07	18.02	1.107	0.129	0.019	6.92
Min	191	1531	6.59	67.3	133.5	171.5	0	6.4	0.003	915.2	0.001	149.3	2.54	6.52	0.072	0	0	0
Max	765	8991	8.42	369.1	1286.2	563.6	0.62	284.7	3.165	6266.7	0.065	570.9	9.07	33.09	1.661	0.677	6.68	21.59
Mean	506.2301	5238.301	7.492124	174.8027	583.3257	500.7602	0.226726	63.50442	0.351876	3414.998	0.010779	392.3451	4.384513	18.8815	0.775283	0.12446	0.156018	8.584416
Median	484	4626	7.46	198	450	505.7	0.22	47.6	0.031	3009.75	0.009	381.7	4.53	18.02	0.826	0.112	0.001	9.12
95-percent	415.6	4079.2	7.058	83.24	380.72	448.64	0.01	28.22	0.0096	2513.005	0.003	247.98	2.97	9.74	0.145	0	0	0.0088

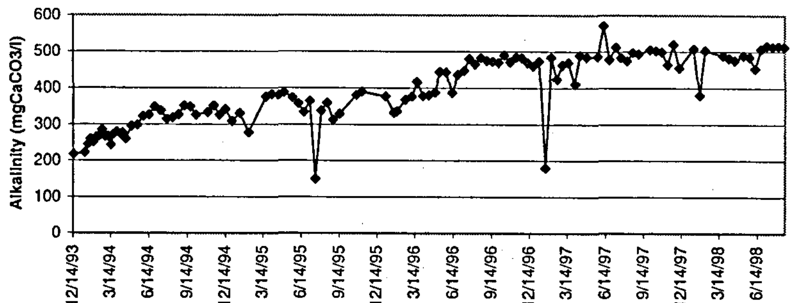
Cell 4

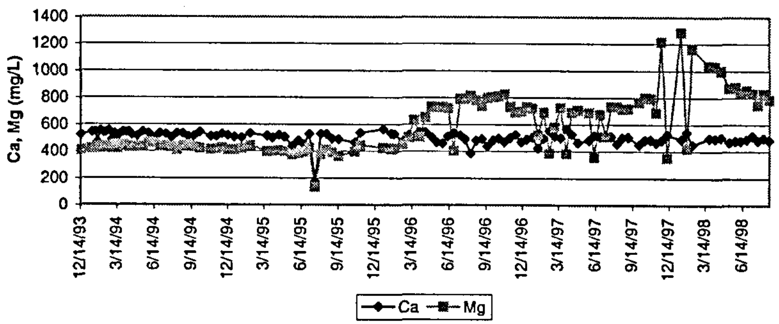

EC (mS/m)


pH


TDS, SO4, (mg/L)
R^2 = 0.5916
R^2 = 0.5333
TDS
SO4
Linear (TDS)
Linear (SO4)


Al, Fe, Mn (mg/L)
Al
Fe
Mn

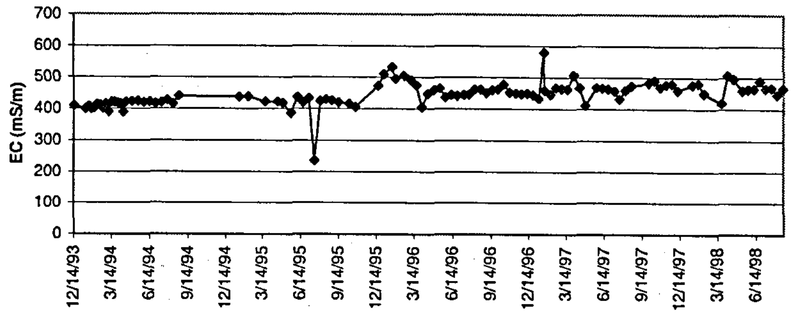

Alkalinity (mgCaCO3/l)

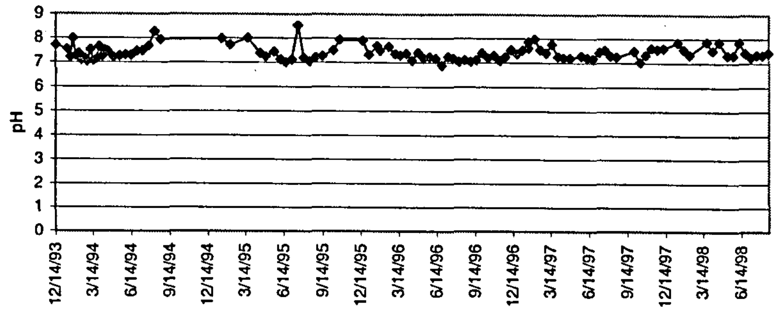

Ca, Mg (mg/L)
Ca
Mg

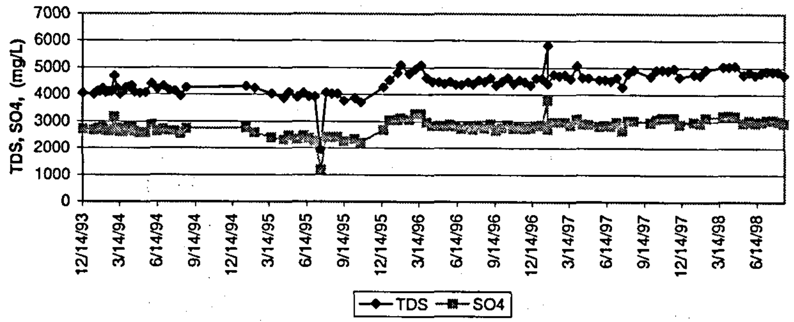
Cell 5

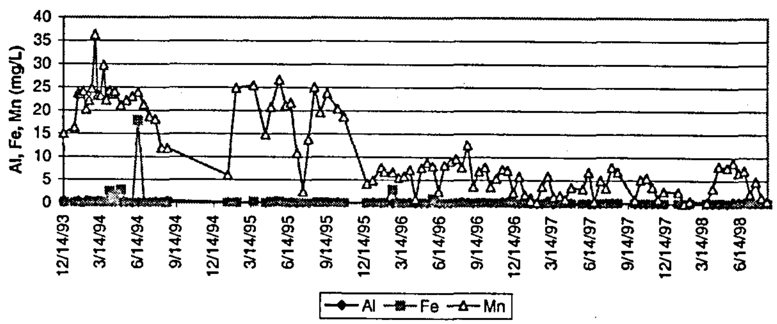
Date	EC	TDS	pH	Na	Mg	Ca	Fl	Cl	NO3	SO4	PO4	ALK	Si	K	NH4	Al	Fe	Mn
12/14/93	409	4037	7.7	69.6	393	538	0.21	45	0.017	2716.6	0.007	218	4.44	7.7	0.439	0.42	0.05	14.975
1/10/94	399	4007	7.54	69.7	368.8	547.6	0.28	54.9	0.015	2674.3	0.012	231.8	4.44	8.36	0.476	0.114	0.006	16.37
1/18/94	407	4114	7.21	81	388.5	554.2	0.26	45.3	0.018	2714.1	0.003	263.3	4.46	9	0.645	0.366	0.026	23.71
1/24/94	399	4106	7.97	85	400.7	549.6	0.3	33.4	0.02	2740.8	0.012	234.3	4.12	9.07	0.677	0.023	0	23.47
1/31/94	402	4213	7.27	95.6	392.3	561.3	0.22	63.3	0.025	2765.4	0.015	259	4.17	17.95	0.769	0	0.024	24.1
2/7/94	413	4072	7.36	83.8	387.3	535.4	0.3	55.9	0.02	2667.5	0.005	271.3	4.45	9.52	0.806	0.397	0.018	20.3
2/14/94	411	4114	7.1	83.3	393	535.1	0.28	101.9	0.014	2640.1	0.011	286.5	4.57	9.72	0.937	0.369	0.042	22.16
2/21/94	401	4100	7.18	84.7	377.8	521	0.28	64.8	0.034	2697.4	0.01	281.6	3.74	8.96	0.957	0.173	0	24.75
2/28/94	414	4691	7.03	111.5	479.7	528.1	0.27	73.8	0.009	3165.1	0.009	264	3.42	10.46	0.472	0.108	0.011	36.27
3/7/94	390	4228	7.51	98.5	410.3	535.5	0.31	68.6	0.017	2759.6	0.024	279.5	4.39	12.82	1.095	0.313	0.027	23.26
3/14/94	421	4016	7.07	101.4	389.5	509.1	0.28	72.6	0.022	2618.5	0.007	254.1	3.61	13.9	0.823	0.258	0.018	23.16
3/21/94	421	4094	7.14	104.2	403.4	539.3	0.3	68.2	0.009	2606.1	0.02	293.1	4.3	13.23	1.061	0.129	0	29.71
3/28/94	418	4251	7.64	114.7	417.3	540.8	0.31	74.1	0.018	2728.1	0.014	296	4.31	13.57	1.004	0.227	0.018	22.27
4/5/94	415	4271	7.24	100.4	403	540.5	0.28	61.3	0.023	2792.4	0.007	294.7	4.32	12.46	1.361	0.369	2.447	24.32
4/11/94	389	4326	7.5	93.2	404.6	554.5	0.27	65.1	0.025	2824.3	0.007	302.9	4.57	12.96	1.37	0.159	1.579	23.47
4/18/94	421	4083	7.44	95.6	391.4	516.8	0.26	69.7	0.018	2645.3	0.011	285.9	4.42	13.02	1.418	0.127	0.319	24.01
5/2/94	423	4048	7.21	92	365	546.3	0.28	67.7	0.022	2583	0.009	310	4.51	14.04	1.39	0.097	2.824	21.13
5/16/94	424	4074	7.26	97.4	360.7	549.3	0.31	84.9	0.03	2595.5	0.004	302.7	4.41	14.37	1.454	0.146	0.025	22.09
5/30/94	420	4412	7.3	91.8	419.5	533.3	0.34	83.4	0.049	2875.5	0.003	321.6	4.61	13.55	1.49	0.055	0	23.04
6/13/94	422	4194	7.29	89.8	428.3	498.3	0.34	93.2	0.045	2640.5	0.01	351.1	4.82	13.82	1.383	0.126	17.9	23.87
6/27/94	416	4315	7.46	90.3	412	552.8	0.38	94.4	0.043	2715.9	0.008	355.5	3.97	13.45	1.47	0.14	0	21.29
7/11/94	420	4158	7.47	89.3	365.5	538.1	0.4	87.2	0.025	2647.9	0.01	336.9	4.78	14.71	1.378	0.154	0.042	18.73
7/25/94	427	4135	7.67	89	413.4	520.1	0.36	32.6	0.116	2658.2	0.014	331.6	3.98	14.58	1.268	0.177	0.021	18.17
8/8/94	415	3949	8.27	88.9	386	503	0.33	97.9	0.412	2543.7	0.029	254.4	2.25	15.4	1.118	0.164	0.035	11.95
8/22/94	440	4257	7.93	100.2	427.9	537.7	0.28	106.9	1.056	2735.6	0.005	267.9	2.15	16.1	0.823	0.393	0.111	11.86
1/16/95	437	4302	7.98	96.4	431.7	525	0.26	115.1	1.148	2763.4	0.008	285.6	2.55	16.97	0.123	0.104	0	5.966
2/6/95	438	4229	7.73	140.2	391.3	510.5	0.29	108.6	1.188	2578.1	0.005	390	4.9	17	1.441	0.064	0.017	24.86
3/20/95	422	4032	8	152.3	353	505.9	0.34	108.1	0.022	2391	0.01	410	5.1	16.09	4.385	0.176	0.258	25.44
4/19/95	422	3866	7.38	151.7	330.3	482.6	0.32	97.4	0.028	2314.6	0.01	382.6	5.21	16.07	4.399	0	0	14.81
5/2/95	418	4080	7.24	152	361.9	510	0.27	90.5	0.044	2467.9	0.007	390	5.36	15.23	4.795	0.15	0.174	20.784
5/22/95	386	3891	7.43	158.9	356.2	427.9	0.27	93.3	0.031	2338.2	0.065	405	5.05	16.75	4.489	0.304	0.34	26.67
6/6/95	436	4053	7.13	175.6	337.2	471.1	0.31	95.2	0.024	2468.1	0.013	395.8	5.12	16.55	4.944	0.087	0.026	21.16
6/19/95	419	3924	7.01	152.3	342.6	479.6	0.23	84.2	0.096	2374.6	0.008	384.1	4.72	16.06	4.519	0.171	0.04	21.701
7/3/95	433	3909	7.11	167.3	358.9	468.3	0.34	120.6	0.902	2259.6	0.014	420	5.39	13.25	3.226	0.012	0.063	10.842
7/17/95	235	1939	8.54	99	166.2	224.2	0.27	55.6	0.655	1197.1	0.008	149.1	3.76	7.38	2.571	0.051	0	2.461
7/31/95	424	4064	7.19	162.5	341.9	511.5	0.28	126.8	1.144	2418.3	0.013	392	5.59	16.19	2.87	0	0	13.798
8/14/95	429	4021	7.04	162.4	353.8	519.5	0.22	91.6	1.441	2404.7	0.011	380.5	5.39	15.76	1.867	0.127	0.005	24.98
8/28/95	426	4010	7.21	150.5	326	555.1	0.32	86.2	2.173	2417.8	0.009	367	5.74	15.61	0.807	0.123	0.035	19.563
9/13/95	420	3755	7.26	150.9	316.5	494.5	0.26	95.4	1.096	2245.9	0.01	353	5.28	15.47	0.429	0.141	0.04	23.701
10/9/95	415	3859	7.5	155.4	330.9	495	0.17	96.6	1.89	2335.4	0.018	345.2	5.25	15.76	0.427	0.125	0	20.423
10/24/95	405	3706	7.94	153.7	320.2	437.2	0.18	90.7	1.706	2207	0.014	388.6	5.36	15.47	0.456	0.095	0	18.667
12/18/95	473	4266	7.89	256.9	344.1	496.9	0.18	58.2	3.335	2687.3	0.007	316.6	4.97	18.75	1.967	0.096	0	4.156
1/2/96	510	4536	7.31	213	402.3	569.1	0.19	123.6	0	3038.5	0.017	129	5.39	29.38	1.646	0.11	0	4.682
1/22/96	532	4804	7.69	269.2	417.8	528	0.19	84.9	1.924	3056.2	0.008	334.3	5.12	29.81	1.488	0	0	7.65
1/29/96	495	5086	7.49	364.7	406.8	546.6	0.27	99	11.447	3127.8	0.014	386.1	5	18.1	0.888	0.148	0.072	6.69
2/19/96	505	4770	7.65	276.1	376.3	526	0.25	49.4	1.263	3072.3	0.005	357.9	4.51	26.9	0.456	0	2.918	6.66
3/5/96	491	4942	7.35	337.2	376.5	531.5	0.24	53.5	0.055	3276	0.006	278.5	4.61	26.22	0.48	0.1	0	5.47
3/18/96	475	5080	7.29	302.6	393.2	522.7	0.23	52.6	0	3281	0.011	410	4.89	27.36	0.471	0.05	0	5.8
4/1/96	405	4620	7.36	266.4	389.5	514	0.24	43.7	0.035	2967.3	0.008	344.4	4.6	17.5	0.636	0.188	0.023	7.19
4/15/96	447	4478	7.08	241.1	391	493.8	0.24	63.2	0.017	2841.6	0.005	351.2	4.49	18.04	0.704	0	0	0.901
4/30/96	460	4452	7.4	194	390.7	524.1	0.24	47.7	0.011	2828.1	0.003	360.4	5	27.01	0.677	0.024	0.09	7.64
5/13/96	465	4398	7.18	187.9	398.1	477.7	0.38	33.6	0.022	2815.4	0.006	376.2	4.88	24.88	0.797	0.013	0	8.78
5/27/96	437	4463	7.23	189.9	401.1	491.3	0.36	30.6	0.042	2872.9	0.005	376.1	4.86	17.23	0.8	0.619	0.96	8.02
6/10/96	444	4357	7.17	175.2	371.9	508.6	0.25	17.3	0.017	2823.6	0.006	363.5	5.05	16.33	0.775	0.071	0	2.55
6/24/96	441	4353	6.88	177.9	363.5	572.8	0.36	31.1	0.022	2720.3	0.013	384	5.44	17.13	0.877	0	0	8.21
7/10/96	444	4448	7.25	171.7	396.5	513.1	0.23	42.5	0.023	2809.7	0.005	406.2	5.22	17.97	0.838	0.098	0	9.07
7/22/96	445	4374	7.18	208.4	404.1	503.3	0.21	47.6	0.008	2690.8	0.01	411.5	5.12	17.17	0.798	0.079	0	9.584
8/5/96	462	4522	7.05	193.7	399.2	527.1	0.22	46.2	0.035	2837.4	0.006	410	5.44	17.17	0.776	0.262	0	7.75
8/19/96	462	4460	7.11	205.7	388.6	522.9	0.22	53.2	0.019	2734.6	0.008	431.3	5.41	27.38	0.722	0.11	0	12.578
9/2/96	450	4613	7.04	201.4	403.7	516.9	0.22	53.8	0.042	2894.8	0.009	428.9	5.16	18.16	0.848	0	0	3.599
9/16/96	460	4334	7.11	192	397	501.3	0.18	52.7	0.019	2654.8	0.008	428.2	5.39	12.83	0.892	0.159	0.036	6.837
9/30/96	463	4482	7.39	219.2	399.2	524	0.22	53.9	0.032	2749.8	0.015	427.5	5.22	12.96	0.971	0.118	0.073	7.79
10/14/96	478	4615	7.19	214.9	401.9	536.2	0.21	41.2	0.03	2866.7	0.004	442.4	5.07	13.4	1.079	0.054	0	3.572
10/28/96	452	4400	7.28	208.8	392.7	477.5	0.16	35.7	0.026	2737.2	0.016	436.8	5.16	13.63	1.069	0.042	0	5.333
11/12/96	449	4540	7.09	179	405.6	545	0.16	54.8	0.025	2786.6	0	455.2	5.5	12.54	1.014	0.279	0	7.318
11/25/96	447	4470	7.25	176.7	402.7	552.9	0.19	52.3	0.02	2725.9	0.011	446.5	5.35	13.16	1.073	0.36	0	7.06
12/9/96	449	4343	7.53	183.9	369	495.7	0.15	46.7	0.014	2760.8	0.012	384	6.15	16.9	1.11	0.349	0	2.32
12/23/96	444	4611	7.36	223.1	413.1	536.7	0.14	49.4	0.02	2842.3	0.007	434.3	5.6	14.98	1.088	0	0	5.726
1/6/97	433	4592	7.52	194.6	410	540.4	0.15	50.2	0.023	2861.5	0.007	425.8	5.66	14.89	1.107	0.434	0.017	1.951
1/20/97	579	5823	7.86	243.7	715.7	442.2	0.14	37.8	0.03	3785	0.002	473	4.64	19.6	1.607	0	0	1.271
1/20/97	460	4401	7.6	188.8	422.5	462.4	0.16	45.1	0.033	2730	0.005	439.8	5.11	14.19	1.598	0	0	0.636
2/4/97	446	4745	7.98	189.5	427.8	540.2	0.15	49.3	0.026	2987.7	0.008	437.1	4.98	15.54	1.506	0	0	0.204
2/17/97	468	4700	7.54	174.3	444.8	498.2	0.17	53.6	0.041	2980.6	0.008	435	5.07	16.13	1.589	0	0	3.712
3/3/97	465	4734	7.41	196.2	419.5	544.6	0.2	53	0.03	2979.3	0.006	429.8	5.25	15.17	1.331	0.587	0.065	5.86
3/17/97	464	4598	7.77	173.1	430.6	533.2	0.2	53.9	0.006	2865.5	0.009	430.2	6.31	15	1.313	0	0	1.488
4/1/97	508	5075	7.26	360.3	426.3	529.4	0.18	53.6	0.023	3102.5	0.012	477.5	5.26	19.19	1.169	0.157	0	1.689
4/14/97	468	4634	7.21	202.2	440.8	455.9	0.19	57.8	0.034	2917.6	0.012	444.6	5.52	15.83	1.367	0.18	0	0.962
4/29/97	411	4617	7.19	195.4	459.2	460	0.19	48.6	0.036	2894.9	0.013	443.5	5.55	15.78	1.355	0.18	0	3.527
5/26/97	469	4545	7.29	188.2	430	496.9	0.19	44.4	0.039	2821.3	0.005	447	5.39	16.89	1.296	0.094	0	3.205
6/9/97	467	4547	7.21	195.3	439.6	509.6	0.17	39.5	0.046	2859	0.004	399.6	5.39	14.86	1.121	0.071	0	6.8
6/23/97	464	4502	7.16	191.2	437.4	433.9	0.16	39.1	0.035	2834.3	0.007	449.6	5.47	16.32	1.168	0.006	0	0.448
7/8/97	457	4629	7.45	305.7	382.9	470.2	0.13	37	0.031	2974.8	0.008	365.7	4.35	12.06	0.344	0.02	0	4.959
7/21/97	433	4278	7.53	212.2	354	521.8	0.13	56.3	0.043	2652.9	0.005	380.9	4.29	14.82	0.89	0.045	0	3.39
8/4/97	459	4783	7.28	206.2	430.9	522.1	0.19	32.6	0.056	3028	0.004	446.7	5.53	14.61	1.202	0.052	0	7.84
8/18/97	474	4911	7.25	348.1	393.5	526.8	0.16	45.4	0.045	3034.8	0.004	446.3	4.62	16.73	0.974	0.095	0	6.77
9/29/97	483	4683	7.48	203.7	474.6	424.8	0.18	39.6	0.053	2955.6	0.007	465.5	5.08	15.15	1.275	0	0	0.793
10/13/97	490	4902	7.03	210.3	485.8	512.8	0.22	35.6	0.038	3078.1	0.014	460.4	5.24	16.14	1.15	0	0	5.15
10/27/97	470	4917	7.33	186	487.3	499.1	0.21	34.6	0.041	3133.3	0.013	457.4	5.28	16.58	1.226	0	0	5.48
11/10/97	478	4897	7.6	205.3	471.9	467.5	0.01	43.6	0.062	3131.5	0.005	459.9	5.27	15.03	1.232	0	0	3.595
11/24/97	480	4961	7.56	202.3	472.7	526.5	0.03	48.3	0.026	3139.9	0.009	452.4	5.26	15.59	1.194	0	0	0.933
12/8/97	460	4655	7.6	215.2	477.9	456.1	0.03	42.7	0.005	2886.5	0.011	458.3	5.13	15.86	1.137	0	0	2.584
1/12/98	477	4767	7.64	198.6	473.9	519.8	0.12	32	0.062	2982.4	0.007	444.7	5.28	15.61	1.258	0	0	2.444
1/26/98	481	4714	7.57	200.2	446.2	515.7	0.15	31.5	0.017	2938.8	0.014	461.9	5.1	16.12	1.121	0	0	0
2/9/98	450	4933	7.34	205.9	468.5	518.3	0.16	22.5	0.051	3142.7	0.008	457.8	5.06	15.14	1.08	0	0	0.541
3/23/98	420	5032	7.87	209.1	507.7	533	0.09	18.8	0.066	3199.9	0.005	446.4	5.43	17.46	1.303	0	0.037	0.309
4/6/98	508	5039	7.53	202	495	504.5	0.03	28.3	0.042	3221.9	0.01	467	5.4	15.93	1.386	0	0.038	3.344
4/20/98	496	5061	7.66	226	490.4	538	0.17	38.4	0.05	3194.1	0.014	458.4	4.88	13.42	1.176	0	0.045	8.1
5/11/98	460	4739	7.33	213.4	461.8	496.8	0.07	34.8	0.042	2941.4	0.014	470	5.38	16.38	1.219	0	0	7.83
5/25/98	464	4837	7.32	213.8	467.2	504	0.06	34	0.033	3030.5	0.008	467.4	5.34	16.1	1.194	0.36	0	8.81
6/8/98	466	4723	7.86	217.4	431.7	525.3	0.09	31.9	0.033	2940.9	0.006	458.3	5.42	15.45	1.126	0.275	0	6.63
6/22/98	489	4795	7.43	222.8	444.6	524.4	0.1	32.6	0.013	2984.4	0.008	467.2	5.72	15.13	1.114	0.248	0.021	7.11
7/6/98	467	4871	7.25	217.3	432	556.1	0.08	35.4	0.021	3043.5	0.055	465.6	5.86	17.24	1.176	0.084	0.01	2.113
7/20/98	469	4852	7.34	207.1	427.9	527.8	0.07	30.7	0.03	3067.4	0.023	471	5.86	15.15	1.176	0.093	0.007	4.791
8/3/98	447	4854	7.32	229	459.7	516.2	0.07	31.9	0.043	3022.9	0.06	472.9	5.77	15.49	1.179	0.075	0.006	1.377
8/17/98	467	4723	7.43	219.9	422.3	505.9	0.06	43.8	0.027	2939.4	0.015	472.2	5.77	14.56	1.144	0.105	0.007	0.555
Min	235	1939	6.88	69.6	166.2	224.2	0.01	17.3	0	1197.1	0	129	2.15	7.38	0.123	0	0	0
Max	579	5823	8.54	364.7	715.7	572.6	0.4	126.8	11.447	3785	0.065	477.5	6.31	29.81	4.944	0.619	17.9	36.27
Mean	445.0857	4436.086	7.415714	177.9514	407.2229	511.6343	0.216667	59.3219	0.340257	2797.31	0.010848	380.04	4.928571	15.63219	1.312143	0.125962	0.295105	10.90112
Median	446	4460	7.34	188.8	402.7	520.1	0.22	53	0.031	2821.3	0.008	392	5.1	15.54	1.126	0.098	0	7.64
95-percent	399.4	3894.6	7.042	84.76	332.16	444.94	0.062	30.78	0.009	2335.96	0.004	254.16	3.744	9.16	0.456	0	0	0.5712

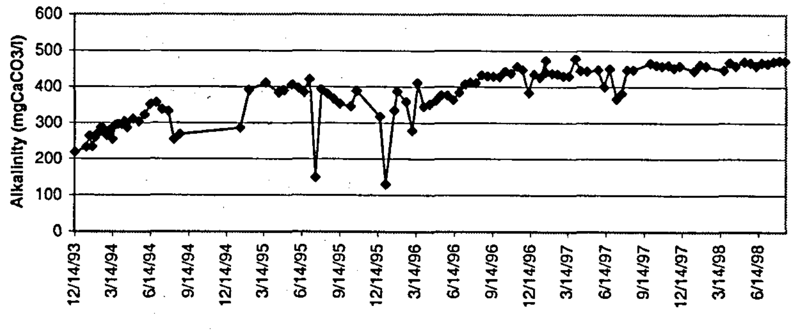
Cell 5

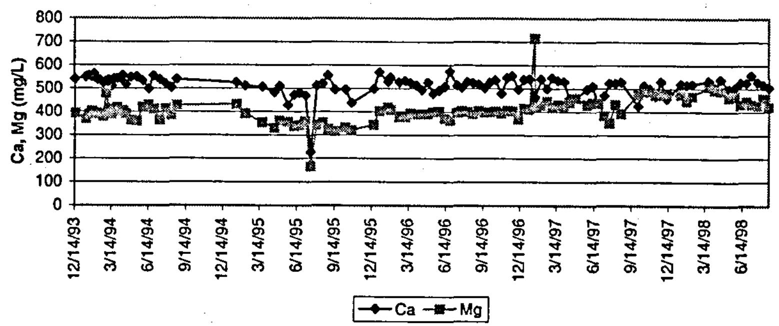

EC (mS/m)


pH


TDS, SO4, (mg/L)
TDS
SO4


Al, Fe, Mn (mg/L)
Al
Fe
Mn

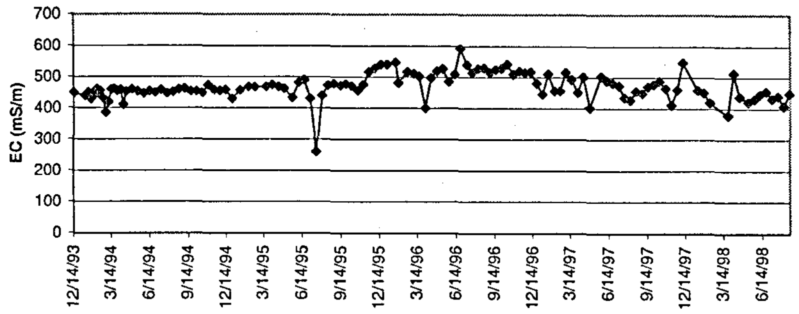

Alkalinity (mgCaCO3/l)

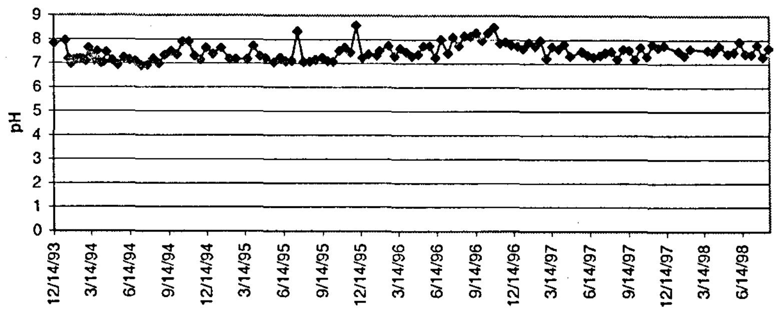

Ca, Mg (mg/L)
Ca
Mg

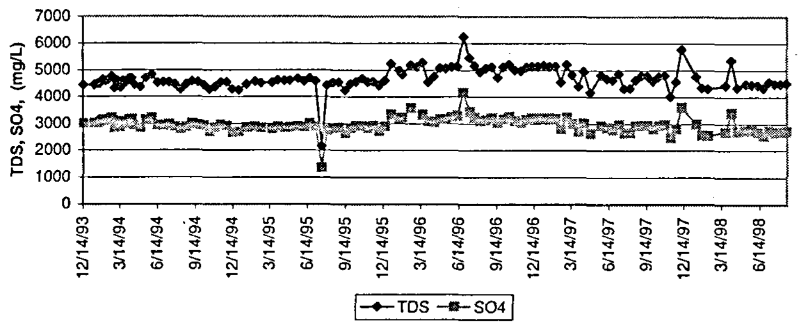
Cell 6

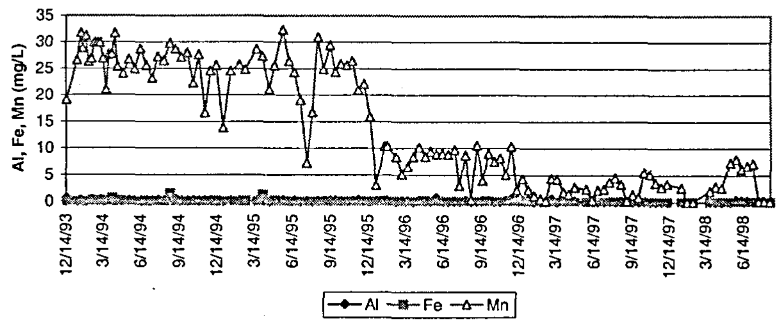
Date	EC	TDS	pH	Na	Mg	Ca	Fl	Cl	NO3	SO4	PO4	ALK	Si	K	NH4	Al	Fe	Mn
12/14/93	448	4443	7.83	91	480	524	0.19	52.9	0.017	3019.2	0.008	218.5	4.25	8.83	0.453	0.59	0.066	19.115
1/10/94	439	4440	7.95	93.7	483.6	529	0.23	61.1	0.013	3016.2	0.018	202.3	3.92	8.93	0.415	0.029	0	26.61
1/18/94	450	4493	7.19	101.2	482	527.2	0.24	59.2	0.018	3023.4	0.004	237	3.92	10.29	0.468	0.226	0.007	31.78
1/24/94	428	4498	6.97	98.6	482.3	537.3	0.28	38.9	0.021	3081.1	0.01	208.1	3.69	9.48	0.409	0.004	0	28.9
1/31/94	439	4643	7.14	109.7	468.5	539.9	0.2	70.4	0.025	3154.1	0.014	237.2	3.61	9.87	0.448	0	0.019	31.24
2/7/94	461	4600	7.16	105.6	486.1	521.5	0.28	66.8	0.032	3108.8	0.01	246.5	4.13	9.17	0.457	0.208	0.004	26.3
2/14/94	455	4639	7.18	117.4	480.5	532.4	0.25	67.1	0.011	3117.5	0.007	257	4.24	9.46	0.499	0.335	0.046	26.93
2/21/94	432	4757	7.18	118.9	482	536	0.27	69.9	0.016	3217.9	0.008	262.7	3.57	10.67	0.477	0.164	0.001	29.97
2/28/94	386	4322	7.1	100.6	394.6	548.3	0.32	67	0.009	2844.1	0.012	291.8	3.57	10.03	0.923	0.112	0.02	29.92
3/7/94	419	4602	7.64	112.3	490.9	512.4	0.28	74.3	0.028	3086.1	0.021	255.9	4.21	13.25	0.587	0.316	0.033	29.93
3/14/94	459	4336	7.38	106.4	460.8	492.4	0.26	80.2	0.021	2878	0.007	231.6	3.54	15.14	0.444	0.153	0	26.91
3/21/94	462	4594	7.12	115.3	479.5	525	0.27	70.6	0.007	3061.1	0.022	266.1	4.03	16.58	0.813	0.131	0.008	21.04
3/28/94	454	4541	7.5	126.4	481.7	520.9	0.29	82.6	0.019	2962.1	0.018	272	4.19	14.03	0.631	0.144	0.009	27.62
4/5/94	458	4674	7.01	121.6	476.6	516	0.27	69.2	0.02	3147.5	0.007	269.5	3.97	13.07	0.898	0.124	0.665	27.74
4/11/94	410	4695	7.04	113.3	475.7	532	0.26	71.5	0.025	3157.1	0.008	271.2	3.87	13.17	0.899	0.095	0.158	31.7
4/18/94	452	4457	7.45	125.7	468.1	502.9	0.23	79.2	0.012	2953.5	0.008	256.2	4.15	13.72	0.875	0.158	0.135	25.35
5/2/94	460	4371	7.14	119	462.8	515	0.28	84.4	0.007	2838.8	0.016	273	4.01	16.21	0.89	0.104	0.012	24.04
5/16/94	453	4700	6.94	125.3	470.3	531.7	0.28	84.2	0.025	3143.2	0.004	270.3	3.73	14.47	0.902	0.127	0.025	26.74
5/30/94	446	4817	7.23	122.9	513.7	495.1	0.37	92.2	0.036	3223.8	0.002	290	3.9	14.05	0.969	0.096	0	24.96
6/13/94	453	4522	7.13	121.3	480.3	483.1	0.32	101.1	0.03	2949.6	0.007	304.4	3.61	13.92	0.991	0.121	0.006	28.69
6/27/94	449	4534	7.1	119.4	477.8	513.1	0.37	98.2	0.037	2921.3	0.002	319.6	3.3	13.05	1.029	0.156	0.1	25.58
7/11/94	456	4542	6.91	122.9	471.1	498.9	0.38	100.9	0.025	2987.4	0.012	282.7	3.51	14.64	1.049	0.147	0.039	23.22
7/25/94	447	4465	6.92	121	476.9	489.6	0.34	103.3	0.099	2895.8	0.009	296.7	2.98	14.23	1.08	0.211	0.031	27.18
8/8/94	451	4259	7.19	92.7	446	495.7	0.32	106.6	0.042	2799	0.016	248.3	3.09	14.59	1.013	0.175	0.056	26.51
8/22/94	459	4468	6.99	118.6	472	521.7	0.27	110.4	0.024	2875.4	0.003	289.3	2.97	15.01	1.079	1.15	1.488	29.76
9/5/94	463	4566	7.33	94.9	462.8	519	0.28	97.5	0.039	3008.7	0.007	298	2.96	18.13	1.118	0.433	0.041	28.71
9/19/94	453	4553	7.51	105.5	476.4	497	0.32	111.6	0.037	2965	0.006	312.9	2.9	14.29	1.171	0.165	0.003	27.15
10/3/94	453	4445	7.36	112.1	455	483.7	0.34	160.8	0.041	2941.1	0.006	229.7	2.92	10.45	1.147	0.139	0.014	28.009
10/17/94	449	4265	7.91	109.3	458	481.4	0.27	123.4	0.005	2705.4	0.01	304.7	2.84	14.28	1.179	0.154	0.032	22.299
10/31/94	474	4367	7.91	116.3	418.1	492.2	0.33	93	0.063	2849.9	0.007	315.3	2.89	10.52	1.198	0.13	0.027	27.617
11/14/94	458	4540	7.31	109.3	459.2	476.4	0.3	113.4	0.022	2965.3	0.005	328.1	2.94	14.48	1.291	0.141	0.047	16.671
11/28/94	455	4534	7.15	143.6	456.5	510.9	0.24	123.3	0.062	2912.2	0.003	302.1	2.76	16.96	1.301	0.178	0	24.56
12/12/94	458	4276	7.64	119.1	444.8	525	0.27	129.9	0.135	2676.5	0.008	297.8	2.95	14.83	1.178	0.125	0.094	25.565
12/28/94	430	4242	7.39	125.1	374.9	522.6	0.25	124.9	0.274	2705.6	0.006	303.7	3.15	15.43	1.085	0	0	13.851
1/16/95	457	4471	7.64	131.3	460.5	503.7	0.27	132.3	0.62	2848.8	0.007	306.9	2.95	15.89	0.749	0.135	0	24.57
2/6/95	469	4577	7.17	163.9	466.2	480.6	0.27	109	0.138	2885.7	0.004	367.7	3.4	20.97	1.433	0.153	0.023	25.703
2/20/95	468	4514	7.18	158.2	429.5	522.8	0.29	106.1	0.026	2843	0.007	353.2	3.99	21.39	1.772	0.03	0.138	24.824
3/20/95	469	4526	7.17	170.5	418.6	532.1	0.34	113.6	0.009	2799	0.011	381.7	4.16	22.88	2.554	0.201	0	28.676
4/3/95	475	4618	7.72	165.6	467.7	503.5	0.29	92.6	0.019	2895.5	0.01	385.2	4.1	20.57	1.779	0.186	1.233	27.301
4/19/95	469	4591	7.3	168.9	445.7	524.7	0.3	99.8	0.011	2847.9	0.006	391.2	4.16	23.71	2.587	0.006	0	21.071
5/2/95	463	4607	7.21	167.3	437.8	527.1	0.29	100.5	0.011	2868.7	0.007	393.1	4.21	22.36	2.674	0.132	0.268	25.599
5/22/95	433	4674	7.04	174.4	465.3	531.9	0.26	100.5	0.064	2905.5	0.041	382.9	3.99	25.17	2.951	0.257	0.049	32.37
6/6/95	482	4582	7.23	199	422.2	502.4	0.28	108.1	0.006	2872.3	0.011	364.7	3.91	29.53	2.521	0.062	0.015	26.408
6/19/95	490	4699	7.08	167.8	463.3	534.9	0.23	80.1	0.051	3003.5	0.009	344.9	3.73	25.43	2.299	0.196	0.021	24.327
7/3/95	430	4587	7.11	157.5	417.7	525.6	0.63	122.6	0.026	2892.2	0.022	366.2	3.89	20.99	2.465	0.025	0.008	18.985
7/17/95	260	2142	8.33	104	194.6	225.7	0.26	62.8	0.163	1362.9	0.004	148.7	3.26	8.01	1.212	0.134	0	7.226
7/31/95	440	4419	7.05	178.1	373.4	523.7	0.38	116.2	0.022	2760.9	0.021	364.5	3.91	18.26	2.424	0.01	0.007	16.753
8/14/95	473	4525	7.07	162.4	390.5	568.6	0.22	104.8	0.057	2830.2	0.015	361	3.95	24.68	2.444	0.118	0.007	31.01
8/28/95	479	4539	7.15	163.1	428.7	530.1	0.31	106.1	0.048	2860.3	0.009	346.4	4.3	24.98	2.436	0.162	0.025	24.862
9/13/95	473	4245	7.23	179.4	394.5	481.2	0.25	98.6	0.077	2647	0.022	341.1	4.03	24.68	2.484	0.172	0.034	29.439
9/26/95	478	4479	7.09	170.8	430.6	502.5	0.27	108.3	0.341	2832.7	0.008	331.4	4.16	25.69	2.092	0.236	0.06	24.417
10/9/95	472	4554	7.07	191.6	418.7	515.6	0.17	114.3	1.283	2923.8	0.013	296.4	4	24.61	0.245	0.116	0	25.87
10/24/95	456	4684	7.52	194.3	443.4	512.5	0.18	110	2.285	2909.8	0.012	396	4.2	20.38	0.039	0.081	0	25.679
11/6/95	476	4549	7.67	165.1	455	478.4	0.18	96.9	2.257	2834.7	0.009	394.2	4.08	25.42	0.075	0.203	0	26.443
11/20/95	517	4559	7.45	163.4	433.6	522.7	0.15	97.8	1.992	2929.5	0.007	309.8	3.64	25.29	0.061	0.271	0.05	21.001
12/4/95	528	4417	8.57	193.7	433.6	528	0.15	128.1	1.981	2725	0.016	304.9	3.76	27.6	0.016	0.148	0.016	22.136
12/18/95	540	4610	7.23	183.2	448.9	511.8	0.17	100.5	0.017	2699.5	0.009	356.4	4.59	29.84	1.48	0.074	0	15.922
1/2/96	540	5225	7.37	229.8	509.2	580.2	0.18	107.1	0	3342.4	0.008	346.9	5.08	31.53	0.91	0.131	0	3.058
1/22/96	546	4981	7.32	221.4	487.3	516.1	0.18	81.2	0.003	3207.6	0.008	357.2	4.73	30.47	1.067	0.158	0.173	10.36
1/29/96	482	4828	7.52	243.5	472.2	474.5	0.13	65.3	2.38	3233.5	0.009	236.8	4.63	18.56	0.805	0.154	0.024	10.42
2/19/96	517	5178	7.73	221.5	417.5	438.9	0.24	57.4	0.045	3677.6	0.008	355.6	4.26	29.98	0.494	0	0.033	8.39
3/5/96	511	5114	7.3	437.1	383.4	511.4	0.22	54.6	0.004		0.005	395.7	4.32	30.27	0.465	0.09	0	5.15
3/18/96	502	5267	7.63	404.2	394.6	514.4	0.21	31.7	0	3344.6	0.008	446.6	4.55	31.78	0.516	0.097	0	6.53
4/1/96	400	4550	7.47	273.1	368.8	506.8	0.2	55.1	0.028	3094.7	0.005	202.1	4.02	4.01	0.533	0	0	8.41
4/15/96	497	4756	7.29	380	410.8	415	0.19	56.4	0.062	3051.3	0.005	340.4	4.19	26.29	0.743	0.241	0	10.17
4/30/96	519	5074	7.37	398	416.3	448.3	0.19	47.4	0.035	3173.2	0.006	458.2	4.67	31.12	0.717	0.089	0.207	8.46
5/13/96	526	5056	7.72	367.2	424	471.9	0.34	33	0.042	3188.3	0.004	443.7	4.29	28.97	0.72	0.01	0	9.42
5/27/96	486	5113	7.73	370.6	410.1	472.1	0.32	34.4	0.042	3262.1	0.004	437.2	4.36	29.22	0.71	0.709	0	8.85
6/10/96	510	5142	7.24	367.8	426.9	489.3	0.22	39.2	0.008	3304.7	0.006	396.1	4.67	30.25	0.695	0.119	0	8.94
6/24/96	592	6258	8	233.2	729.2	516.2	0.42	31.3	0.099	4167.4	0.014	450	5.05	30.1	0.768	0	0	8.81
7/10/96	539	5463	7.43	372	475	552.1	0.2	45.9	0.035	3448	0.02	440	5.03	31.54	0.786	0.085	0	9.7
7/22/96	515	5160	8.09	378.6	442	502.6	0.18	52.9	0.078	3232.9	0.01	425.9	4.87	30.32	0.706	0	0	2.971
8/5/96	527	4929	7.73	362.6	444.7	387.5	0.2	43.3	0.277	3109	0.007	452.3	4.62	28.68	0.459	0.215	0	8.69
8/19/96	529	5075	8.15	363.4	423.4	506.7	0.19	47.6	0.404	3138.5	0.022	461.2	4.79	30.77	0.456	0	0	0.34
9/2/96	515	5116	8.14	358.2	444	468	0.2	51.4	0.451	3216	0.011	448.9	4.8	30.83	0.056	0	0	10.577
9/16/96	524	4724	8.27	354.9	436.7	398.3	0.15	46.8	0.283	3027.6	0.008	361.1	4.76	17.61	0.087	0.173	0.029	3.951
9/30/96	528	5112	7.96	384.3	436.5	502.4	0.2	48.6	0.08	3177	0.019	446.8	4.63	17.85	0.041	0.167	0.037	8.99
10/14/96	541	5211	8.27	395.7	437.7	501	0.18	35.9	0.026	3273.2	0.004	450	4.49	18.19	0.037	0	0	7.504
10/28/96	510	4997	8.5	383	442.6	466.4	0.14	44.4	0.065	3105.3	0.015	440	4.54	18.84	0.06	0	0	8.127
11/12/96	520	4973	7.84	379.5	437.1	454	0.13	63.9	0.014	3041.9	0.016	473.7	4.71	17.89	0.778	0.26	0	5.006
11/25/96	515	5108	7.9	361.9	431.7	513.1	0.18	58.9	0.011	3146.2	0.01	473.1	4.59	18.33	0.999	0.486	0.016	10.28
12/9/96	517	5137	7.77	379.6	449	460.4	0.13	46	0.016	3217.1	0.012	462.5	5.58	19.16	0.954	0.358	0	2.144
12/23/96	481	5141	7.72	377.9	425.7	501.7	0.12	49.8	0.027	3211.8	0.006	453.7	4.75	19.99	0.792	0.305	0	4.33
1/6/97	445	5176	7.63	397.8	433.7	516	0.13	47.8	0.028	3198	0.008	460	4.96	20.08	0.97	0.419	0.014	2.301
1/20/97	511	5130	7.87	351.4	414.9	502.7	0.14	50.3	0.032	3220.4	0.004	466.8	4.47	19.82	0.942	0	0	1.14
2/4/97	456	5144	7.72	356.4	425.6	519.6	0.14	56.4	0.028	3201.3	0.004	461.5	3.22	19.71	1.281	0	0	0.518
2/17/97	456	4554	7.96	200.9	389.4	548.1	0.14	69.7	0.061	2816.2	0.006	420	4.25	15.92	0.855	0	0	0.168
3/3/97	516	5200	7.21	383	411.7	518.1	0.18	53	0.039	3245	0.005	466	4.88	18.78	1.205	0.556	0.055	4.398
3/17/97	493	4822	7.71	263.7	417.1	517.6	0.17	58.4	0.018	3005	0.008	443.9	5.59	17.47	1.056	0	0	4.206
4/1/97	451	4383	7.62	224.3	375.9	464.2	0.16	71.6	0.049	2707.7	0.012	427.6	4.59	16.7	0.867	0.151	0	1.852
4/14/97	501	4947	7.81	354.5	432.2	475.2	0.17	51.4	0.021	3028.2	0.011	478.6	5.17	20.08	1.162	0.166	0	1.425
4/29/97	402	4168	7.31	203.4	376.4	493.6	0.16	66.7	0.031	2639.9	0.013	303	4.68	16.75	0.885	0.177	0	2.703
5/26/97	503	4818	7.49	343	404.6	487.7	0.18	49.4	0.029	2941	0.01	468.6	4.84	19.12	1.134	0.067	0	2.366
6/9/97	489	4674	7.35	342.6	368	497	0.14	44.1	0.03	2658.3	0.01	446.4	4.06	18.54	0.947	0.057	0	0.356
6/23/97	482	4628	7.27	330.4	387.6	470.2	0.14	31.3	0.026	2785.4	0.008	493.9	4.98	19.53	0.905	0.023	0	2.14
7/8/97	474	4873	7.33	343.2	387.5	505.1	0.15	45.8	0.07	2970.2	0.009	493.6	4.89	17.41	0.935	0.031	0	2.347
7/21/97	435	4312	7.48	221.1	365.4	517.1	0.14	51.3	0.051	2659.8	0.006	394.1	4.43	15.06	0.884	0.076	0	3.671
8/4/97	427	4326	7.5	207.2	350.7	501.1	0.16	57	0.041	2675.1	0.002	424.4	4.85	15.57	0.88	0.017	0	4.429
8/18/97	455	4630	7.19	215.1	434.2	516.8	0.17	33.7	0.098	2930.9	0.004	396.7	5.06	13.77	1.155	0.095	0	3.315
9/1/97	449	4801	7.6	326.9	360	514.7	0.16	38.2	0.037	2950.9	0.004	485.4	4.62	16.76	0.994	0.17	0	0.162
9/15/97	471	4782	7.56	292.2	372.4	525.9	0.17	46.3	0.031	2948.3	0.004	474.5	4.61	16.89	0.944	0	0	1.309
9/29/97	478	4599	7.19	316.5	384	431.8	0.16	40.4	0.022	2824.3	0.007	478	4.75	17.76	1.043	0	0	0.811
10/13/97	488	4758	7.68	285.4	395.9	500.5	0.19	39.7	0.071	2931.8	0.011	479.6	4.65	18.05	1.007	0	0	5.44
10/27/97	466	4809	7.3	287.1	407.7	498.3	0.18	35.6	0.072	2975.3	0.012	480.4	4.71	17.84	1.054	0	0.003	5.16
11/10/97	411	4018	7.8	176.1	343.5	474.2	0	49.3	0.141	2483.3	0.004	388.3	4.59	16.1	0.808	0	0	3.517
11/24/97	461	4577	7.68	276.1	391.2	460.7	0.05	52.8	0.098	2820	0.006	457	5.03	17.17	0.995	0	0	2.756
12/8/97	548	5784	7.76	277.7	726.5	516	0.03	44.8	0.004	3619.7	0.005	474	4.74	19.39	1.094	0	0	3.381
1/12/98	460	4758	7.52	272	340.8	641.4	0.09	33.5	0.055	2991.3	0.004	459.1	5.2	17.24	0.994	0	0	2.644
1/26/98	451	4344	7.33	266.7	318.4	553.6	0.13	20.4	0.035	2596.2	0.01	466.7	4.82	18.43	0.885	0	0	0
2/9/98	420	4306	7.61	274.9	320	537.7	0.14	20.6	0.021	2574.5	0.011	458.2	4.77	18.5	0.936	0	0	0
3/23/98	379	4428	7.56	262.7	316	561.8	0.1	24.2	0.2	2694.7	0.004	450.5	5.17	17.34	0.88	0	0.04	2.066
4/6/98	514	5364	7.48	290.5	613.5	542.4	0	29.2	0.052	3407.6	0.006	460.4	5.12	18.01	1.115	0	0.037	2.905
4/20/98	438	4349	7.73	247.9	342.4	520.4	0.15	26.8	0.127	2729.3	0.007	381.3	4.71	14.94	0.964	0	0.038	2.611
5/11/98	421	4476	7.42	275.1	347.7	487.5	0.07	28.2	0.028	2742.4	0.011	472	4.94	18	1.041	0	0	7.35
5/25/98	431	4454	7.48	278.9	347.9	495.7	0.08	27.6	0.023	2771.2	0.02	421.1	4.89	17.64	1.008	0.37	0	8.06
6/8/98	446	4444	7.92	282.1	349.7	492.3	0.1	25	0.036	2691.4	0.008	480.1	5.12	16.48	1.05	0.257	0.01	6.19
6/22/98	455	4338	7.42	277.9	338.6	532.7	0.11	29.8	0.017	2552.8	0.024	481.1	5.23	17.61	0.991	0.207	0.002	6.8
7/6/98	432	4557	7.39	274.7	325.5	563.8	0.09	33.9	0.456	2749.5	0.045	484.4	5.18	16.64	0.437	0.072	0.007	7.19
7/20/98	440	4485	7.77	286.2	319.7	538.4	0.08	34	0.409	2694.4	0.052	486.3	5.08	17.09	0.447	0.108	0.054	0.093
8/3/98	408	4493	7.28	285.2	339.4	520.5	0.09	34.2	0.415	2703.5	0.046	485.2	5.11	16.31	0.446	0.072	0.002	0.15
8/17/98	448	4507	7.64	286.4	326.9	520.2	0.06	35	0.439	2736.3	0.014	477.9	5.07	16.72	0.43	0.09	0.003	0.038
Min	260	2142	6.91	91	194.6	225.7	0	20.4	0	1362.9	0.002	148.7	2.76	4.01	0.016	0	0	0
Max	592	6258	8.57	437.1	729.2	580.2	0.63	160.8	2.38	4167.4	0.052	493.9	5.59	31.78	2.951	1.15	1.488	32.37
Mean	468.7438	4671.686	7.480909	227.8174	427.9901	504.0455	0.212645	69.30909	0.171711	2964.6	0.010521	372.8843	4.255124	18.9381	0.984777	0.138157	0.048959	14.36616
Median	461	4591	7.43	207.2	433.6	512.5	0.2	61.1	0.035	2944.7	0.008	382.9	4.26	17.84	0.935	0.121	0.002	10.17
95-percent	410	4265	7.04	101.2	326.9	448.3	0.08	28.2	0.006	2646.645	0.004	231.6	2.95	9.48	0.061	0	0	0.168

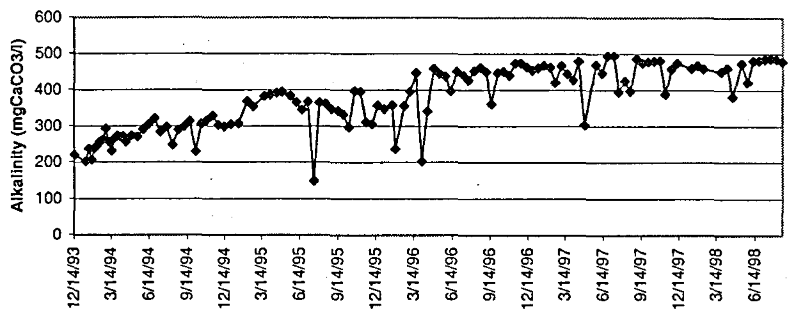
Cell 6

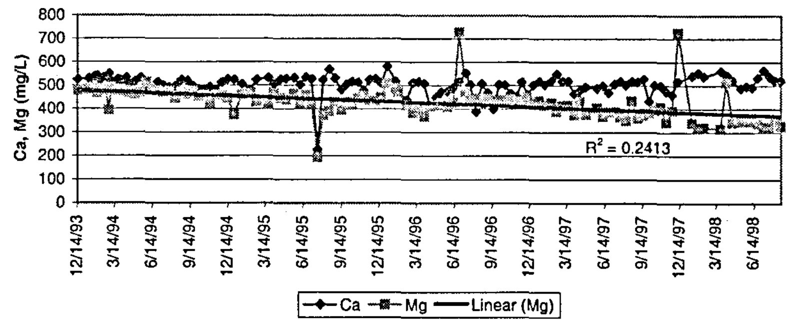

EC (mS/m)


pH


TDS, SO4, (mg/L)
TDS
SO4


Al, Fe, Mn (mg/L)
Al
Fe
Mn

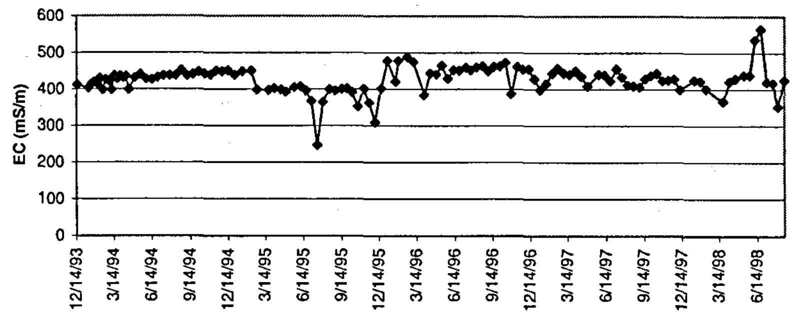

Alkalinity (mgCaCO3/l)

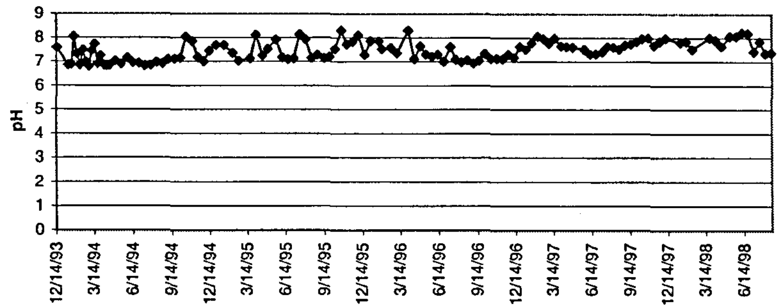

Ca, Mg (mg/L)
R² = 0.2413
Ca
Mg
Linear (Mg)

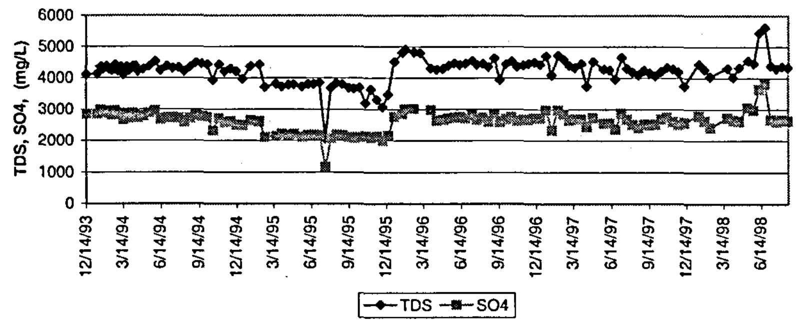
Cell 7

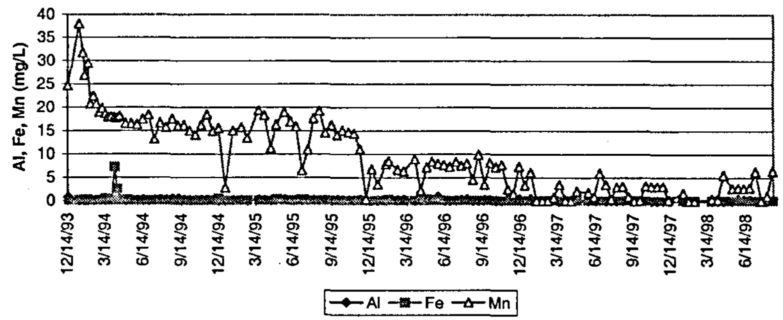
Date	EC	TDS	pH	Na	Mg	Ca	Fl	Cl	NO3	SO4	PO4	ALK	Si	K	NH4	Al	Fe	Mn
12/14/93	411	4106	7.58	68.6	417	528	0.18	50.7	0.016	2841.2	0.007	156.4	3.71	7.73	1.027	0.662	0.081	24.645
1/10/94	403	4124	6.86	70.1	427.2	541.9	0.15	56.8	0.013	2840.9	0.016	146.1	3.46	8.04	0.842	0	0.107	37.93
1/18/94	414	4357	6.88	81.1	437.8	539.3	0.23	50.9	0.02	2976.9	0.004	213.9	3.48	8.71	1.21	0.212	0.002	31.73
1/24/94	419	4272	8.04	73.9	451.1	536.4	0.28	36.5	0.042	2913.8	0.104	204.2	3.4	8.66	1.092	0	0.206	26.83
1/31/94	414	4365	7.31	76.9	433.4	542	0.2	64	0.031	2948.5	0.018	237.1	3.33	9.22	1.045	0	0.031	29.46
2/7/94	430	4274	6.86	72.7	422.3	531	0.3	61.8	0.023	2670.7	0.008	250.7	3.6	8.11	1.029	0.226	0.001	20.77
2/14/94	398	4227	7.48	77.8	418.5	529.3	0.18	66	0.019	2827.4	0.006	244.3	3.79	8.25	0.969	0.028	0.001	22.46
2/21/94	426	4414	6.99	77.2	433	543.9	0.3	72.6	0.018	2953.2	0.011	264.3	3.11	9.87	0.956	0.148	0.003	20.78
2/28/94	422	4210	6.8	77.3	426.5	489.6	0.27	78.2	0.018	2821.1	0.012	251.6	3.14	9.42	0.936	0.151	0.007	18.89
3/7/94	398	4352	7.44	86	456.8	520.3	0.3	74.1	0.011	2872.3	0.021	269.5	3.46	12.96	0.615	0.267	0.029	19.61
3/14/94	437	4097	7.72	104.9	438.4	490	0.19	81.7	0.028	2675.1	0.005	240.8	3.26	11.49	0.888	0.136	0.511	18.66
3/21/94	428	4354	6.91	84.4	450.9	523.2	0.28	78.4	0.016	2851.2	0.019	287.8	3.84	13.12	1.207	0.118	0.018	17.95
3/28/94	436	4221	7.24	82.2	434	521.8	0.29	86.1	0.018	2720.5	0.014	296.2	3.8	13.23	1.132	0.15	0.055	17.96
4/5/94	431	4366	6.86	80.7	437.9	529.9	0.27	71.5	0.016	2665.4	0.004	284.1	3.79	12.43	1.506	0.15	7.24	17.87
4/11/94	435	4380	6.65	83.8	442.1	549	0.48	80.1	0.03	2646.3	0.01	297.7	3.87	12.72	1.561	0.197	2.543	17.73
4/18/94	399	4199	6.85	81	430.2	515	0.41	89.2	0.013	2738.3	0.018	270.5	4.02	12.82	1.518	0.15	0.184	16.15
5/2/94	431	4274	7.03	84.4	419.8	515.2	0.26	95.2	0.017	2791.4	0.007	289.4	3.83	13.2	1.507	0.089	0.216	16.6
5/16/94	440	4365	6.9	87.8	424.9	499	0.28	102.7	0.024	2880.4	0.006	289.8	3.76	14.1	1.512	0.121	0.029	16.54
5/30/94	427	4518	7.15	82.5	474.7	485.7	0.32	109.1	0.035	2961.8	0.003	316.7	3.84	13.23	1.596	0.071	0	16.34
6/13/94	426	4234	6.95	88.6	447.2	489.1	0.32	107.4	0.031	2686.2	0.006	327.7	3.87	13.75	1.491	0.133	0	17.44
6/27/94	432	4363	6.93	89.2	452	529.6	0.37	117	0.034	2732.8	0.002	350.2	3.58	12.94	1.558	0.102	0.035	16.35
7/11/94	437	4308	6.82	90.5	398.5	539.4	0.39	117.9	0.021	2746.1	0.008	327.4	3.68	14.49	1.542	0.149	0.066	13.12
7/25/94	438	4322	6.84	87.8	447.3	506.7	0.35	122.9	0.106	2718.9	0.01	343.1	3.35	14.65	1.624	0.237	0.028	16.62
8/8/94	438	4201	6.97	94.9	418	535.1	0.33	123.8	0.017	2596	0.027	341.2	3.33	14.97	1.473	0.16	0.074	15.69
8/22/94	452	4345	6.91	86.1	444.4	507.1	0.28	130.9	0.022	2720.1	0.002	360.8	3.12	14.27	1.619	0.438	0.046	17.52
9/5/94	437	4473	7.09	91.5	446.5	502	0.28	130.9	0.051	2833.7	0.006	370	3.17	14.68	1.679	0.451	0.046	16.13
9/19/94	440	4446	7.11	90.6	456.3	515.4	0.32	129.2	0.009	2782.3	0.009	373.3	3.55	14.65	1.368	0.177	0	16.19
10/3/94	447	4422	7.15	90.6	436.6	547	0.35	128.6	0.012	2759.1	0.006	362	3.43	15.56	1.647	0.132	0.005	14.973
10/17/94	442	3931	8.03	90	430	478	0.26	140	0.029	2328	0.015	367	3.56	15.1	1.837	0.163	0.022	14.102
10/31/94	439	4420	7.64	97.5	437.9	569.5	0.33	117.1	0.042	2709	0.008	388.5	3.81	12.76	1.919	0.116	0.044	16.25
11/14/94	450	4191	7.16	97.8	406	510	0.3	131	0.049	2592	0.007	359.4	3.62	11.94	2.407	0.146	0.037	18.447
11/28/94	448	4284	7.01	99.5	423.1	517.9	0.24	138.8	0.019	2613	0.007	350.3	3.7	61.31	2.378	0.153	0	14.899
12/12/94	451	4202	7.44	93.7	427.2	541.7	0.27	151.3	0.035	2508.1	0.01	377.6	4	16.38	2.345	0.17	0.479	15.58
12/28/94	439	3956	7.69	97.5	374.8	533.6	0.26	110.3	0.07	2501	0.009	261.3	3.74	16.55	2.519	0	0.011	2.82
1/16/95	448	4364	7.68	100.5	445.6	528.1	0.28	150.6	0.553	2645.9	0.008	385.7	3.56	17.17	1.975	0.109	0.002	14.98
2/6/95	450	4418	7.35	114.7	443.7	489.3	0.28	139.2	0.542	2613.5	0.007	486.9	4.18	17.98	2.256	0.15	0.013	15.739
2/20/95	398	3708	7.03	140.2	327.9	435.9	0.3	91.4	0.022	2115.7	0.009	472.9	4.75	16.43	2.75	0	0.037	13.397
3/20/95	397	3808	7.12	151.7	349.2	445.7	0.37	91.9	0.015	2138.1	0.013	499.2	4.61	17.17	3.97	0.187	0.019	19.34
4/3/95	402	3716	8.11	148.5	339	429.3	0.3	41.3	0.022	2226.6	0.015	418.5	4.78	16.76	2.67	0.157	0	18.268
4/19/95	398	3779	7.24	150.6	348	430.7	0.34	81.6	0.003	2165.3	0.006	477.2	4.44	17.49	3.938	0	0	11.267
5/2/95	392	3791	7.52	149.7	344.9	430	0.31	82.8	0.053	2209.9	0.007	451.8	4.62	16.71	3.975	0.122	0.336	16.279
5/22/95	404	3720	7.91	154.5	351.6	436.4	0.28	82.9	0.011	2120	0.027	451.3	4.4	18.41	4.168	0.243	0.088	18.92
6/6/95	407	3799	7.16	174.8	332.1	407.5	0.3	82.9	0.003	2180.9	0.01	489	4.28	18.88	3.949	0.06	0.044	16.914
6/19/95	396	3801	7.1	147	372	400.6	0.25	78.4	0.037	2189	0.008	485.1	3.99	17.91	3.621	0.152	0.029	15.882
7/3/95	367	3833	7.12	159.9	348.9	439.8	0.35	88.9	0.025	2187.5	0.017	478.6	4.42	18.47	3.899	0	0.234	6.504
7/17/95	246	2048	8.14	101	170.9	220.1	0.3	70.3	0.184	1163.2	0.003	254	2.63	8.57	1.977	0.17	0	10.89
7/31/95	364	3672	7.92	155.1	333.7	428	0.33	104.1	0.025	2075.4	0.015	453	4.29	18.21	3.761	0.114	0	17.596
8/14/95	399	3828	7.15	148.7	313.4	487.4	0.22	83.6	0.041	2189.7	0.007	477.2	4.41	17.83	4.081	0.079	0.005	19.184
8/28/95	396	3795	7.27	147.5	337	447.6	0.32	78.4	0.188	2172.4	0.012	482.7	4.81	17.79	3.891	0.13	0.022	14.511
9/13/95	400	3671	7.14	146.3	343.4	424.5	0.28	71.1	0.238	2109.5	0.013	454.7	4.47	16.47	2.673	0.15	0.061	16.23
9/26/95	402	3657	7.22	154.7	358.1	396.7	0.3	92.7	1.71	2082.1	0.008	446.9	4.74	18.42	1.256	0.23	0.053	14.007
10/9/95	391	3689	7.53	150.4	329.1	429.5	0.21	86.9	2.745	2114.9	0.011	449.7	4.35	17.5	0.102	0.121	0	15.052
10/24/95	352	3191	8.3	154	335	314.4	0.16	85	2.65	2139.2	0.01	107.8	4.28	19.52	0.063	0.106	0	14.635
11/6/95	401	3627	7.72	174.7	343.2	355.9	0.23	94.5	2.713	2094.1	0.013	436.8	4.23	19.05	0.065	0.145	0	14.354
11/20/95	362	3300	7.83	166.2	322.9	336.4	0.18	74.1	2.708	2129	0.017	196.4	3.78	19.61	0.082	0.251	0.041	11.061
12/4/95	309	3066	8.09	123.9	254.7	394.2	0.19	81.4	2.778	2002	0.017	148.3	3.86	16.54	0.062	0.125	0	0.352
12/18/95	402	3459	7.29	179.1	287.5	354.4	0.22	68.4	0.035	2164.2	0.01	313.7	5.31	19.59	2.597	0	0.01	6.775
1/2/96	477	4509	7.86	295.9	372.4	512.2	0.19	113.2	0.115	2765.6	0.008	341.2	4.9	30.16	2.396	0.092	0	3.473
1/22/96	420	4805	7.84	345.9	380.8	483	0.18	121.6	7.878	2855.6	0.009	449.1	6.19	30.83	3.783	0.06	0.117	7.91
1/29/96	477	4894	7.53	332.9	394.6	536	0.22	111.1	9.816	3008	0.009	366.4	4.2	18.62	1.83	0.138	0.295	8.5
2/19/96	488	4817	7.58	290.2	383.2	537.5	0.24	78.2	4.218	3016.7	0.006	379.8	4.38	28.13	0.681	0.165	0	6.62
3/5/96	475	4795	7.35	301.5	364.1	529.9	0.23	88.9	0.575		0.007	385.9	4.43	27.79	0.589	0.217	0	6.35
4/1/96	383	4290	8.3	249.6	366.4	480.2	0.14	80.8	0.01	2974	0.007	96.8	3.93	19.36	0.765	0	0	8.97
4/15/96	443	4251	7.11	222.6	373.2	458.2	0.22	83.4	0.021	2634.7	0.003	378.4	4.04	16.47	0.774	0.158	0.012	2.173
4/30/96	440	4281	7.64	232.5	353.7	461.5	0.2	73.9	0.007	2668.4	0.003	386.4	4.18	18.22	0.812	0.207	0.354	7.17
5/13/96	464	4386	7.3	210	361.5	503.1	0.33	48.7	0.015	2711.1	0.007	430	4.02	25.68	0.887	0.241	0	8.45
5/27/96	429	4453	7.2	210.2	356.5	529	0.31	55.6	0.027	2745.6	0.008	440	4.09	17.69	0.687	0.797	0	7.95
6/10/96	452	4403	7.28	211.2	369.7	520.1	0.23	49.7	0.011	2763.3	0.006	385.2	4.11	18.11	0.64	0.125	0.053	7.66
6/24/96	451	4450	7	207.3	352.3	582.2	0.34	50.3	0.021	2712.5	0.012	431.6	4.38	17.82	0.897	0	0	7.301
7/10/96	459	4542	7.62	204.4	378.6	527.2	0.19	65	0.073	2609.5	0.012	439.6	4.26	18.96	0.641	0.081	0	8.36
7/22/96	452	4411	7.09	208	379.1	522.6	0.2	65.3	0.017	2673.6	0.012	445.2	4.09	18.22	0.61	0.176	0	7.554
8/5/96	460	4446	6.98	200.1	376.1	529.2	0.2	60	0.03	2726.4	0.003	432.2	4.22	25.73	0.763	0.302	0	7.98
8/19/96	463	4346	7.06	212.9	356.1	538.2	0.2	63.4	0.019	2613.6	0.013	438.8	4.26	26.11	0.731	0	0	4.427
9/2/96	449	4620	6.92	211.3	371.4	550	0.19	71.4	0.042	2850.8	0.019	446.8	4.06	19.15	0.851	0	0	9.86
9/16/96	461	3944	7.05	207	377	431	0.15	62.7	0.033	2594.7	0.008	210.9	4.29	13.23	0.943	0.168	0.034	3.416
9/30/96	462	4436	7.32	220.8	376.6	541.4	0.2	63.6	0.198	2689	0.019	433.5	4.19	13.55	0.997	0.188	0.051	8.12
10/14/96	473	4528	7.13	221	374.1	552.1	0.2	48.7	0.025	2766	0.008	451.8	4.15	13.49	1.012	0.055	0	7.252
10/28/96	387	4360	7.13	213.4	366	540.4	0.16	47.3	0.016	2635.3	0.017	445.4	4.16	13.02	0.993	0	0	7.748
11/12/96	461	4407	7.11	221.3	366.8	496.1	0.15	77.3	0.027	2667.1	0.01	462.7	4.12	12.72	1.028	0.389	0.006	2.498
11/25/96	454	4456	7.3	211.7	363.7	551.7	0.17	61.4	0.019	2684.7	0.008	465.9	3.94	12.81	1.096	0.489	0.016	1.477
12/9/96	455	4497	7.16	225.4	354.1	563	0.14	59	0.021	2717.9	0.013	460.6	5.02	13.71	1.142	0.431	0	7.366
12/23/96	428	4422	7.63	398.8	284.2	485.5	0.14	59.2	0.023	2717.1	0.006	383	6.95	9.5	0.506	0.045	0	3.378
1/6/97	398	4702	7.51	199.4	407.3	539.7	0.14	45.5	0.03	2973.6	0.005	426.1	5.75	15.32	1.133	0.476	0.02	6.062
1/20/97	415	4092	7.78	168.2	336.8	519.8	0.17	70.6	0.047	2346.8	0.006	520	4.38	13.46	1.696	0	0	0.034
2/4/97	444	4717	8.06	191.4	422.5	544.7	0.16	47.2	0.034	2969.8	0.006	429.1	4.96	15.88	1.138	0	0	0.09
2/17/97	457	4588	7.96	196	389.1	553	0.14	70.9	0.064	2843	0.004	425.4	4.21	15.99	0.811	0	0	0.057
3/3/97	444	4393	7.77	192.1	348.7	552	0.18	90	0.034	2665.9	0.004	433.9	4.72	13.27	1.162	0.497	0.037	0.729
3/17/97	440	4325	7.98	142	391.8	529	0.14	85.3	0.016	2692.9	0.004	384.9	4.56	13.23	1.1	0	0	3.46
4/1/97	450	4442	7.66	215.2	377.4	558.9	0.17	71.8	0.046	2686.2	0.017	422.3	4.58	16.33	0.878	0.136	0	0.036
4/14/97	435	3732	7.63	157.6	357	400.1	0.17	19.1	0.032	2455.9	0.012	267.6	5.29	13.94	1.432	0.166	0	0.029
4/29/97	409	4519	7.6	220	378.7	570.8	0.16	70.9	0.048	2731.4	0.013	434	4.62	16.53	0.87	0.163	0	2.074
5/26/97	440	4272	7.51	153.6	359.2	548.7	0.19	77.3	0.017	2561.5	0.006	455.2	5.25	14.25	1.376	0.079	0	1.695
6/9/97	439	4241	7.31	184	347.8	529.9	0.15	63.6	0.015	2555.5	0.004	446	5.46	13.91	1.336	0.052	0	0.915
6/23/97	423	3956	7.33	158.3	357	515.6	0.14	69.7	0.018	2366.1	0.009	386.9	5.61	15.54	1.339	0.023	0	6.95
7/8/97	455	4647	7.4	272.9	395	486.4	0.15	29.1	0.078	2878.1	0.013	466	4.86	14.11	0.763	0.015	0	3.472
7/21/97	433	4297	7.63	210.3	357.1	511.8	0.12	56.6	0.044	2679.9	0.006	381.2	4.33	14.98	0.866	0.068	0	0.434
8/4/97	411	4181	7.61	184	357	493	0.18	64.1	0.03	2517.8	0.002	450.2	5.46	13.64	1.407	0.011	0	2.921
8/18/97	409	4095	7.52	230.6	316.1	510.1	0.17	64.2	0.055	2417.6	0.004	445	5.02	11.67	1.257	0.092	0	3.1
9/1/97	406	4237	7.7	171.6	359.3	539.5	0.16	70.9	0.03	2527.8	0.004	452.9	5.02	14.12	1.179	0.61	0.042	0.864
9/15/97	428	4146	7.74	163.2	357.5	516.9	0.16	69.1	0.039	2509.9	0.004	421.5	4.99	13.75	1.146	0	0	0.026
9/29/97	437	4056	7.85	163.1	381.8	417.3	0.15	69.6	0.04	2523.6	0.004	397.7	4.27	14.13	1.25	0	0	0.114
10/13/97	443	4197	7.96	170.7	398.8	494.8	0.13	88.7	0.072	2689.4	0.008	277.6	3.76	14.27	1.023	0	0	3.15
10/27/97	424	4326	7.99	157.9	386.1	539.8	0.13	66.7	0.092	2751.6	0.011	333.6	3.59	15.2	1.036	0	0.016	3.102
11/10/97	425	4272	7.69	150.4	354.2	545.9	0	54.9	0.008	2608.8	0.004	444.1	5.15	14.92	1.419	0	0	3.082
11/24/97	428	4183	7.86	132.8	368.6	550	0.06	51.2	0.006	2518.9	0.005	447.3	5.28	14.1	1.385	0	0	3.063
12/8/97	399	3738	7.99	150.2	367.6	408.4	0.03	48.8	0.035	2577.5	0.005	138.6	5.09	14.95	1.382	0	0	0.209
1/12/98	425	4432	7.81	135.1	363.7	544.4	0.09	42.8	0.053	2788.2	0.004	443.6	5.53	14.72	1.425	0	0	1.638
1/26/98	422	4265	7.84	139.6	361.1	548.9	0.13	38.4	0.02	2632.1	0.007	432.6	5.27	15.49	1.377	0	0	0
2/9/98	401	4042	7.53	134.8	339.8	554	0.14	30.1	0.026	2424.7	0.007	443.4	5.28	16.27	1.35	0	0	0
3/23/98	367	4308	8	164.5	357.2	547.9	0.09	34.7	1.002	2732.3	0.004	370.3	4.99	15.35	0.385	0	0.03	0.414
4/6/98	421	4017	7.9	167	365	487.9	0.05	34.9	0.979	2654.9	0.003	234.8	4.97	16.48	0.384	0	0.035	0.245
4/20/98	429	4320	7.66	159.8	358.8	560.2	0.15	42.4	0.022	2625.4	0.136	457.5	5.49	13.32	1.437	0	0.065	5.58
5/11/98	439	4547	8.07	176.5	413.4	531.7	0.03	43.6	1.2	3059.6	0.032	244.5	4.72	17.93	0.072	0	0	2.663
5/25/98	439	4459	8.07	176.6	410.4	529.1	0.03	43.7	1.162	2977.8	0.033	245.5	4.66	17.14	0.031	0.413	0	2.808
6/8/98	536	5438	8.22	229.8	519.1	640.3	0.03	51.9	1.81	3644	0.081	264.5	4.61	21.63	0.086	0.294	0	2.664
6/22/98	565	5613	8.19	218.7	575.2	624.2	0.03	63.9	1.677	3817.1	0.089	232.1	4.84	22.06	0.096	0.262	0	2.808
7/6/98	419	4387	7.43	149.9	346.8	568	0.09	46.6	0.509	2675.3	0.047	462.2	5.64	14.8	0.069	0.076	0.005	6.33
7/20/98	417	4290	7.84	159.2	345.7	561.3	0.08	50.3	0.512	2612.9	0.047	445	6.04	15.17	0.086	0.08	0.002	0.082
8/3/98	352	4360	7.35	159.7	364.8	546.1	0.09	44.9	0.551	2668	0.049	460.1	5.55	14.98	0.064	0.095	0.004	1.06
8/17/98	425	4324	7.38	157	345.1	553.6	0.08	46.6	0.551	2641.7	0.01	461.8	5.52	14.61	0.054	0.119	0.009	6.43
Min	246	2048	6.8	68.6	170.9	220.1	0	19.1	0.003	1163.2	0.002	96.8	2.63	7.73	0.031	0	0	0
Max	565	5613	8.3	398.8	575.2	640.3	0.48	151.3	9.816	3817.1	0.136	520	6.04	61.31	4.168	0.797	7.24	37.93
Mean	425.9167	4218.467	7.453917	158.6867	382.8567	503.1167	0.214167	76.62833	0.439308	2624.147	0.013567	368.8408	4.325583	16.08592	1.414458	0.138808	0.119608	10.00605
Median	429	4293.5	7.435	154.9	372.8	522.2	0.2	71.45	0.031	2679.9	0.008	386.15	4.26	15.04	1.1705	0.1215	0.0025	7.965
95-percent	366.85	3655.5	6.86	77.295	322.56	396.575	0.049	38.305	0.00995	2114.36	0.003	194.4	3.3265	8.7075	0.0688	0	0	0.05595

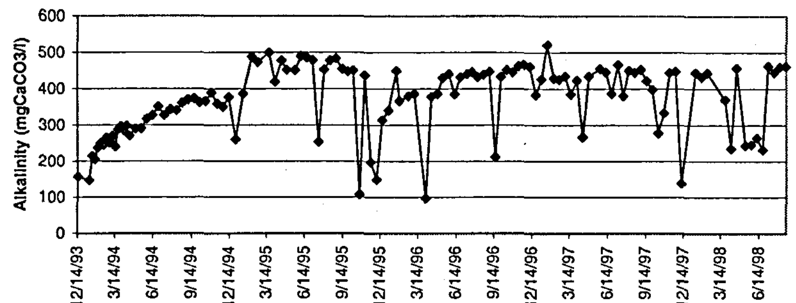
Cell 7

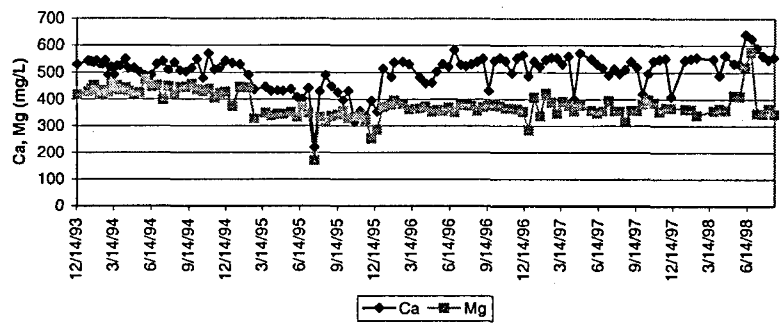

EC (mS/m)


pH


TDS, SO4, (mg/L)
TDS
SO4


Al, Fe, Mn (mg/L)
Al
Fe
Mn

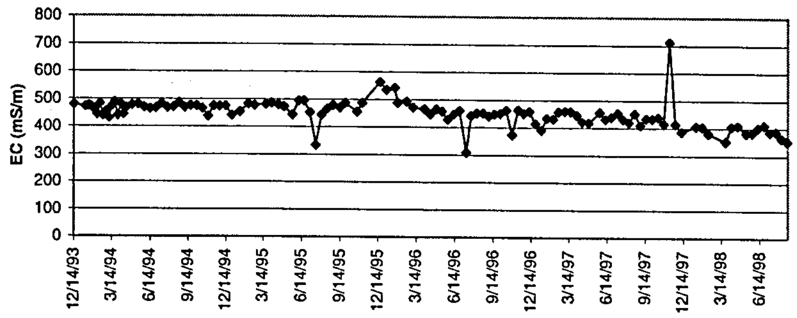

Alkalinity (mgCaCO3/l)


Ca, Mg (mg/L)
Ca
Mg

Cell 8

Date	EC	TDS	pH	Na	Mg	Ca	Fl	Cl	NO3	SO4	PO4	ALK	Si	K	NH4	Al	Fe	Mn
12/14/93	478	4884	7.86	87	555.6	524.5	0.1	50.7	0.017	3390.6	0.004	217.3	3.71	9.38	0.66	0.096	0.004	26.275
1/10/94	471	4909	7.43	89.1	588.9	436.1	0.19	45.5	0.012	3450.4	0.014	236.2	3.53	9.4	0.72	0.003	0	31.15
1/18/94	475	5149	7	88.9	594.6	640.4	0.37	48.7	0.033	3548.8	0.01	260	3.87	9.24	0.769	0.341	0.021	28.8
1/24/94	471	4930	8.17	89.3	572.9	529.9	0.3	34.9	0.02	3416.9	0.013	225.4	3.5	10	0.633	0	0.047	32.18
1/31/94	461	4928	7.01	88.3	561.4	529.3	0.26	76.1	0.027	3363.6	0.018	243.6	3.45	10.53	0.665	0	0.026	28.28
2/7/94	443	4914	7.07	84.7	550.5	518.3	0.42	62.6	0.016	3380.1	0.016	251.2	3.78	9.71	0.68	0.267	0.01	27.39
2/14/94	482	4760	7.14	87.5	556.2	482.4	0.25	69.2	0.019	3316.7	0.006	194.7	3.65	9.11	0.652	0.296	0.028	19.56
2/21/94	440	4972	7.18	94.6	551	534.5	0.26	74.1	0.009	3375.1	0.009	270.9	3.01	11.33	0.661	0.116	0	33.12
2/28/94	454	4979	6.92	94.4	560.4	532.8	0.4	78.5	0.017	3368.4	0.014	272.4	3.03	11.28	0.707	0.126	0	29.68
3/7/94	430	4782	7.64	94.6	551.8	516.2	0.3	78.4	0.016	3202.6	0.027	265	3.72	13.95	0.963	0.375	0.038	25.08
3/14/94	473	5313	6.97	87	586	560	0.26	78	0.023	3693	0.007	243.9	3.16	10.3	0.67	0.216	0.1	23.41
3/21/94	486	4895	6.89	94.8	552.3	533.2	0.28	78.2	0.071	3276.9	0.018	279.3	3.66	17.38	0.836	0.126	0	25.32
3/28/94	440	4865	7.05	106.6	575.4	498.4	0.43	92.2	0.018	3228.6	0.026	283	3.6	15.03	0.838	0.169	0.011	26.76
4/5/94	480	4964	7	96.8	548.4	540.6	0.22	72.3	0.025	3357.4	0.005	270.5	3.58	16.97	1.231	0.218	0.618	25.73
4/11/94	444	5024	7.23	97.2	554.1	533.2	0.29	80.8	0.028	3396	0.006	284.2	3.64	13.78	1.256	0.057	0.396	29.58
4/18/94	468	4689	7.22	93.9	547.5	511.2	0.28	80.1	0.023	3126.9	0.011	254.8	3.72	17.15	1.23	0.141	0.072	25.17
5/2/94	477	4561	7.09	97	535	507.9	0.29	86.3	0.025	2997.9	0.013	260	3.56	18.43	1.202	0.115	0.113	22.8
5/16/94	479	4777	7.07	105.4	514.3	495.6	0.28	91.4	0.025	3228.4	0.006	263	3.28	19.1	1.247	0.131	0.026	25.18
5/30/94	469	4960	7.14	92.1	556.6	505	0.36	79.6	0.118	3360.9	0.003	289.9	3.45	29.28	1.265	0.067	0	24.19
6/13/94	464	4682	6.98	93.1	488.2	506.9	0.33	97.4	0.031	3105.9	0.005	303.7	3.31	15.86	1.278	0.142	0.268	22.55
6/27/94	467	4738	7.04	91.6	545.7	505.2	0.34	100.7	0.026	3080.2	0.016	324.2	3.03	16.63	1.358	0.113	0.011	25.49
7/11/94	482	4949	6.91	91.4	550.5	520.1	0.4	124.5	0.043	3263.3	0.005	309.7	3.19	19.41	1.403	0.186	0.053	16.51
7/25/94	468	4666	6.91	94.1	515.2	506.5	0.36	112.8	0.106	3049.8	0.015	300.5	2.65	18.41	1.388	0.263	0.044	23.64
8/8/94	470	4668	6.99	92.6	515.3	520.1	0.36	213.8	0.024	2944.5	0.029	293.7	2.9	21.46	1.276	0.238	0.074	22.34
8/22/94	485	4576	7.02	93.6	500.3	510.3	0.31	107.8	0.043	3018.7	0.003	266.2	2.78	18.55	1.39	0.448	0.057	25.12
9/5/94	469	4701	7.19	87.3	517.7	510.7	0.3	104.9	0.036	3092.3	0.007	300.9	2.81	19.03	1.453	0.441	0.055	25.19
9/19/94	476	4786	7.16	93	535.1	515.3	0.33	121.5	0.006	3113	0.009	317.5	2.82	19.15	1.304	0.175	0	23.17
10/3/94	475	4732	7.38	89.1	514.7	521.3	0.35	118.9	0.015	3108.6	0.006	292.3	2.74	20.46	1.468	0.157	0.101	20.034
10/17/94	466	4608	7.9	95.1	516.4	498.9	0.27	132.4	0.021	2970.6	0.009	306.1	2.78	19.4	1.53	0.155	0.051	22.217
10/31/94	437	4685	8	103	506.3	540.6	0.35	97.7	0.052	3033.4	0.009	319.3	2.82	11.96	1.543	0.159	0.025	21.394
11/14/94	475	4735	7.16	94.8	504.5	499.7	0.3	135.3	0.012	3125.8	0.009	289.4	2.79	19.62	1.655	0.146	0.105	21.463
11/28/94	474	4715	7.14	97	522	526	0.27	125.7	0.057	3046.9	0.005	306.7	2.64	20.23	1.73	0.145	0	19.312
12/12/94	475	4630	7.42	97.9	506	519	0.27	145.1	0.051	2955.1	0.009	313.7	2.93	21.34	1.681	0.125	0.144	21.28
12/28/94	441	4382	7.57	101	479.1	459.9	0.28	139.8	0.022	2877.9	0.005	242.9	2.89	25.48	1.982	0	0.001	6.804
1/16/95	454	4649	7.4	103.8	520.6	505.5	0.26	145	0.08	2976.3	0.007	309.7	2.77	17	1.867	0.144	0.034	22.658
2/6/95	482	4689	7.73	110.9	544.6	489.5	0.3	127.1	1.632	2977	0.004	335.4	2.41	22.3	0.446	0.122	0.013	19.564
2/20/95	477	4676	7.18	98	508.3	528.6	0.32	125.1	0.021	2958.4	0.008	355.8	3.79	21.85	2.348	0	0.021	17.625
3/20/95	481	4844	7.07	104.1	505.1	522.2	0.36	148.1	0.001	3091.6	0.009	364	4.03	24.17	3.551	0.217	0.075	23.86
4/3/95	485	4758	7.75	107.2	519.9	521.4	0.31	154.8	0.009	2954.1	0.017	388.7	4.12	22.49	2.6	0.191	0.604	20.353
4/19/95	479	4725	7.05	104.8	521.8	518	0.34	144.6	0.009	2921.7	0.007	397	4.05	24.7	3.651	0.014	0	14.788
5/2/95	473	4736	7.1	102.4	507.5	519.5	0.44	126.3	0.014	2976.3	0.006	389.9	4.08	23.28	3.728	0.14	0.547	19.706
5/22/95	443	2247	7.15	531.8	40.6	86	0.29	336.4	0.025	748.4	0.02	390.1	3.81	22.2	3.955	0.258	0.077	25.23
6/6/95	494	4614	7.05	122.4	489.4	491.8	0.31	122.2	0.001	2906.6	0.009	369.2	3.88	26.12	3.78	0.076	0.046	19.536
6/19/95	495	4752	7.38	109	567	425.2	0.28	122.4	0.043	3061	0.008	358	3.74	25.32	3.687	0.2	0.057	19.917
7/3/95	452	4039	7.11	109.4	371.6	543.4	0.32	148	0.023	2391.6	0.011	369	3.97	19.28	4.014	0.172	0.013	21.902
7/17/95	333	2971	8.77	78.5	305.2	314.5	0.32	103	0.151	1857.3	0.004	240.1	3.19	15.54	2.452	0.175	0	8.419
7/31/95	443	3820	7.47	124.1	373.8	406.8	0.31	143.8	0.019	2298.5	0.022	368.3	3.88	18.08	3.85	0.16	0	23.939
8/14/95	465	4776	7.08	96.8	514.9	526.8	0.29	124.5	0.041	3037.6	0.007	362.8	3.86	24.78	4.251	0.146	0.044	20.34
8/28/95	478	4677	7.22	98.1	493.3	517.1	0.33	140.3	0.044	2973.9	0.009	347.2	4.17	25.16	4.211	0.16	0.422	16.804
9/13/95	469	4421	7.26	99.2	492.1	465.8	0.27	109.6	0.372	2808.6	0.009	339.8	3.91	24.71	3.661	0.24	0.043	16.465
9/26/95	487	4393	7.19	100.9	455.3	478.8	0.3	55.4	1.207	2877.9	0.008	319.4	4.1	25.64	2.782	0.266	0.051	12.376
10/24/95	455	4678	7.79	112.9	503.4	481.3	0.2	137.9	3.969	2943.2	0.016	379.1	3.98	19.32	0.066	0.094	0	14.162
11/6/95	486	4712	7.68	119.9	519	492.2	0.2	95.9	3.755	2982	0.009	376.1	3.78	27.42	0.259	0.188	0	12.991
12/18/95	562	4977	7.2	168.5	542.7	507.1	0.17	76.2	0.017	3207.9	0.008	357.8	4.25	36.25	1.698	0.066	0	11.108
1/2/96	535	5036	7.14	158.4	488.4	532	0.16	111.7	0	3351.9	0.008	296.9	4.56	30.25	1.228	0.122	0	11.674
1/22/96	542	4931	7.26	192.5	500.2	509.3	0.18	81.9	0.03	3201.3	0.008	338.8	4.54	30.63	1.057	0	0.011	10.44
1/29/96	488	5100	7.48	274.2	467	627.5	0.21	98.2	2.9	3268.5	0.01	352.6	4.1	20.18	0.731	0.148	0.114	8.36
2/19/96	492	5024	7.63	200.3	379.9	532.6	0.23	59.6	0.015	3357.6	0.008	379.5	4.03	30.06	0.392	0.146	3.821	6.44
3/5/96	471	5002	7.28	389.5	373.6	519.4	0.22	64	0	3164	0.012	378.4	4.08	29.27	0.346	0	0	5.51
4/1/96	466	4034	7.58	237.1	353.6	454.1	0.23	64.3	0.044	2703.4	0.01	169.5	4.06	14.03	0.611	0.261	0.027	1.37
4/15/96	447	4556	7.53	243.2	378.2	520.3	0.2	60.8	0.063	2694.9	0.005	359	3.98	20.07	0.581	0.161	0.015	1.831
4/30/96	466	4653	7.69	238.1	400.5	519.5	0.19	59.1	0.028	2964.3	0.003	363.1	4.37	28.3	0.451	0.242	0.248	7.01
5/13/96	457	4431	7.67	190	371.1	514.4	0.31	37.3	0.023	2819.9	0.005	394	4.11	17.15	0.458	0.044	0	2.672
5/27/96	426	4328	7.55	199.7	369.8	491.1	0.28	41.9	0.022	2755.7	0.004	369.4	4.22	16.26	0.454	0.998	0.581	6.72
6/10/96	447	4408	7.2	199.5	361.6	510.7	0.23	39.5	0.011	2834.5	0.036	363.2	4.61	18.63	0.459	0.114	7.02	7.7
6/24/96	460	4566	7.4	196.8	376.3	593.5	0.31	63.4	0.029	2844.1	0.012	380.1	4.79	26.9	0.475	0	0	7.21
7/10/96	309	2778	7.6	252	194.6	279	0.92	33.8	0.024	1436.6	0.014	462.9	8.39	15.99	0.637	0.047	0	3.632
7/22/96	442	4260	7.4	179.9	401.1	498.5	0.19	54.5	0.016	2619.2	0.011	399.9	4.65	18.29	0.439	0.062	0	7.586
8/5/96	451	4351	7.01	171.2	403.8	523.4	0.16	46	0.049	2692.9	0.003	405.8	4.87	17.72	0.414	0.535	0	6.4
8/19/96	452	4339	7.03	172.6	382.6	490.8	0.19	49	0.099	2732.9	0.015	402.7	4.88	18.76	0.279	0	0	3.781
9/2/96	441	4444	7.02	185.5	383.9	533.6	0.18	56.7	0.141	2789.3	0.009	388.7	4.65	19.43	0.178	0	0	8.98
9/16/96	448	4148	7.12	161.3	370.6	486.2	0.13	47.6	0.197	2584.5	0.011	397.3	4.68	12.28	0.094	0.173	0.034	6.625
9/30/96	450	4299	7.32	179.4	355	550.6	0.18	45.5	0.134	2673.8	0.021	393.5	4.85	14.12	0.062	0.216	0	6.84
10/14/96	462	4393	7.26	163.4	381.8	538.3	0.17	46.6	0.079	2759.1	0.002	385.2	6.29	14.04	0.07	0	0	6.283
10/28/96	373	4079	7.27	184	368.7	489.8	0.14	49.9	0.065	2470	0.012	411.9	4.7	13.58	0.064	0.064	0	7.881
11/12/96	463	4409	7.13	212.8	391.5	459.4	0.13	72.9	0.013	2731.4	0.011	431	4.52	14.47	0.701	0.351	0	1.772
11/25/96	452	4430	7.31	194.3	396.7	537.5	0.15	58.2	0.013	2747.5	0.007	394.7	4.35	13.67	0.584	0.608	0.026	8.32
12/9/96	459	4648	7.33	223.4	409	553.3	0.13	56.1	0.021	2922.6	0.012	384.3	6.35	14.3	0.639	0.407	0	3.917
12/23/96	414	4455	7.73	238.2	384.5	492.1	0.11	57.6	0.029	2782.3	0.006	394.9	4.75	17.42	0.76	0.33	0	2.862
1/6/97	391	4524	7.65	216.3	388.3	542.2	0.12	64.5	0.024	2792.2	0.005	410	4.79	17.12	0.752	0.462	0.017	1.995
1/20/97	434	4434	7.83	212.7	358.3	499.2	0.18	63.4	0.054	2775.3	0.009	415.8	4.4	16.15	0.832	0	0	0.571
2/4/97	431	4535	7.84	201	370.6	541.4	0.13	65.9	0.028	2808.4	0.005	434	4.3	18.56	1.032	0	0	0.002
2/17/97	457	4583	7.9	195.6	396.1	555.3	0.14	70	0.053	2829.4	0.008	423.5	4.2	16.62	0.822	0	0	1.314
3/3/97	460	4540	7.68	230.8	358.4	548.4	0.17	73.2	0.032	2604.9	0.008	417.1	4.57	14.66	0.755	0.652	0.061	2.654
3/17/97	458	4473	7.79	191.1	385.6	532.8	0.16	74	0.021	2766.5	0.005	414.5	5.32	15.97	0.855	0	0	2.327
4/1/97	446	4326	7.62	216.5	379.6	463.9	0.16	81.5	0.049	2644.7	0.013	427.6	4.56	16.57	0.885	0.153	0	1.67
4/14/97	421	4452	7.44	208.4	359.1	566.4	0.19	59.5	0.06	2699.5	0.02	445.1	4.85	15.12	0.925	0.147	0	0
4/29/97	417	4310	7.36	222.9	377.3	434.5	0.16	73.2	0.034	2657.1	0.015	432.5	5.2	16.53	0.865	0.167	0	0.089
5/26/97	456	4343	7.65	214.1	358.8	534.6	0.17	71.3	0.02	2663.2	0.008	395.4	4.61	16.78	1.05	0.055	0	2.152
6/9/97	432	4189	7.4	204.2	327.1	537	0.14	53.7	0.013	2580.8	0.002	384.2	5.75	16	0.967	0.093	0	0.055
6/23/97	439	4147	7.5	223.6	348.5	515.5	0.12	58.2	0.02	2509	0.006	388.6	4.87	17.08	0.902	0.015	0	0.061
7/8/97	454	4617	7.37	290.5	390.1	472.9	0.14	33.7	0.033	2913.3	0.013	411.8	4.61	12.99	0.559	0.066	0	9.593
7/21/97	431	4283	7.48	216.2	354.5	507.9	0.12	55.9	0.045	2665.6	0.006	382.7	4.33	14.93	0.896	0.05	0	3.963
8/4/97	420	4272	7.53	210.2	343.7	516.8	0.15	57.8	0.045	2606.9	0.003	426.6	4.84	15.31	0.9	0.036	0	4.045
8/18/97	451	4740	7.26	211.7	423.1	531.8	0.16	40.1	0.042	2979	0.005	441.9	4.93	13.72	1.112	0.108	0	7.28
9/1/97	409	4265	7.56	199.9	346.2	546.7	0.15	60.4	0.063	2568.4	0.004	432	4.46	15.28	0.865	0.98	0.079	1.583
9/15/97	434	4214	7.51	200.6	345.3	527.6	0.14	54.6	0.037	2560.2	0.006	417.1	4.42	15.59	0.86	0	0	0.07
9/29/97	433	4163	7.63	190	343.7	547	0.13	55.6	0.064	2477.8	0.005	436	4.45	15.54	0.899	0	0	0.043
10/13/97	439	4233	7.53	192.3	349.2	495.6	0.18	75.2	0.069	2579.6	0.018	429	4.66	16.19	0.942	0	0	4.671
10/27/97	415	4253	7.5	173.6	351.6	567.9	0.16	57.9	0.142	2560.4	0.011	429.1	6.47	16.21	0.939	0	0	4.702
11/10/97	711	7129	7.61	275.1	1065.3	403.1	0.04	41.5	0.024	4683	0.012	522.8	4.82	22.01	1.356	0	0	7.04
11/24/97	414	3954	7.73	174.1	309.4	548	0.07	46.1	0.155	2344	0.008	422.3	4.76	15.3	0.838	0	0	0.905
12/8/97	386	3804	7.86	176.2	333.1	528	0.05	62.5	0.901	2264.1	0.009	345	4.78	15.48	0.025	0	0	0.629
1/12/98	436	4124	7.84	176.7	293.6	549.1	0.09	34	0.113	2581.5	0.002	386.3	4.63	16.01	0.94	0	0	2.913
1/26/98	403	3870	7.29	173.8	265.4	570.3	0.13	39.3	0.013	2290	0.007	421.6	4.84	15.37	0.91	0	0	0
2/9/98	380	3647	7.35	177.8	264.3	457.7	0.14	31.9	0.017	2183.4	0.007	422.5	4.77	15.43	0.927	0.062	0	0
3/23/98	352	4060	7.69	196.3	275.2	581	0.1	32.8	0.558	2480.1	0.003	390.2	5.01	15.6	0.33	0	0.042	0.548
4/6/98	405	3980	7.85	200.3	274.9	579.7	0.08	32.6	0.542	2408.3	0.009	382.1	5.03	15.6	0.338	0	0.029	0.166
4/20/98	408	3757	7.79	190.1	261.3	552.8	0.14	32.8	0.023	2296	0.011	333.3	4.92	16.12	0.877	0	0.051	7.49
5/11/98	381	3941	7.94	170.9	281.6	558.7	0.08	21.7	0.053	2428.5	0.013	379.6	4.81	15.67	0.763	0	0	6.77
5/25/98	384	3893	6.46	165.3	271.1	564.9	0.23	39.2	0.046	2704.9	0.038	107.4	5.25	15.67	0.685	0.57	4.026	16.31
6/8/98	401	3939	7.64	168.5	283.7	533.8	0.1	37.8	0.05	2377.7	0.013	427.4	5.22	15.08	0.783	0.271	0	6.22
6/22/98	410	3992	7.4	173.6	276.9	589.9	0.11	34.1	0.038	2378.2	0.013	427.5	5.36	16.26	0.785	0.253	0	6.38
7/6/98	386	3779	7.25	164.1	276	526.5	0.1	46.9	0.288	2233.8	0.039	420.5	5.25	16.64	0.353	0.071	0.004	2.363
7/20/98	387	3868	7.27	169.7	257.7	566.1	0.08	47.6	0.292	2294.2	0.044	421.1	5.3	16.77	0.377	0.103	0.007	3.606
8/3/98	365	3812	7.35	171.1	268.3	555.9	0.09	48.6	0.299	2238.2	0.051	419.7	5.35	16.13	0.373	0.096	0.003	0.13
8/17/98	353	3826	7.23	174.4	266.1	555.9	0.16	50.5	0.298	2247.4	0.017	421	5.45	16.54	0.354	0.122	0.008	3.469
Min	309	2247	6.46	78.5	40.6	86	0.04	21.7	0	748.4	0.002	107.4	2.41	9.11	0.025	0	0	0
Max	711	7129	8.77	531.8	1065.3	593.5	0.92	336.4	3.969	4683	0.051	522.8	8.39	36.25	4.251	0.998	7.02	33.12
Mean	449.6838	4479.103	7.384872	158.7214	431.2103	510.2342	0.226974	79.98547	0.18141	2847.785	0.011034	353.0906	4.197179	18.02026	1.179769	0.156949	0.177556	12.42468
Median	454	4561	7.35	169.7	400.5	520.1	0.21	69.2	0.031	2877.9	0.009	369.4	4.17	16.64	0.877	0.126	0.004	8.36
95-percent	378.6	3799	6.978	88.14	265.96	432.64	0.088	33.78	0.009	2245.56	0.003	239.32	2.788	10.24	0.1612	0	0	0.0596

Cell 8



EC (mS/m)
800
700
600
500
400
300
200
100
0
12/14/93
3/14/94
6/14/94
9/14/94
12/14/94
3/14/95
6/14/95
9/14/95
12/14/95
3/14/96
6/14/96
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3/14/97
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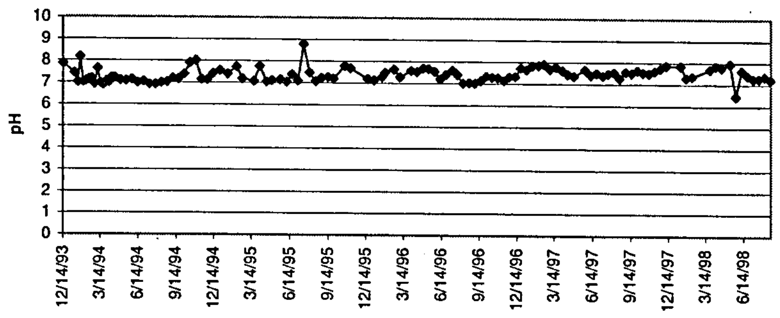
12/14/97
3/14/98
6/14/98



pH
10
9
8
7
6
5
4
3
2
1
0
12/14/93
3/14/94
6/14/94
9/14/94
12/14/94
3/14/95
6/14/95
9/14/95
12/14/95
3/14/96
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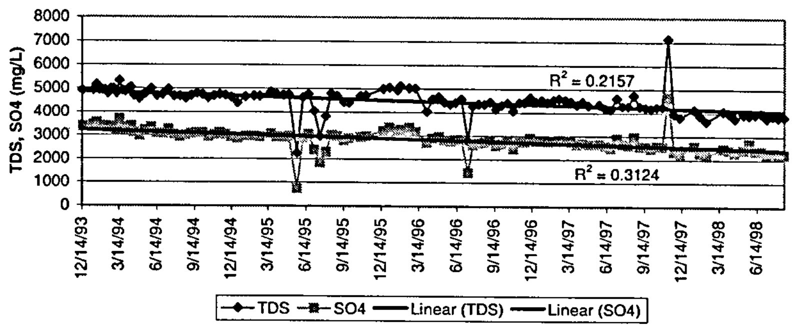
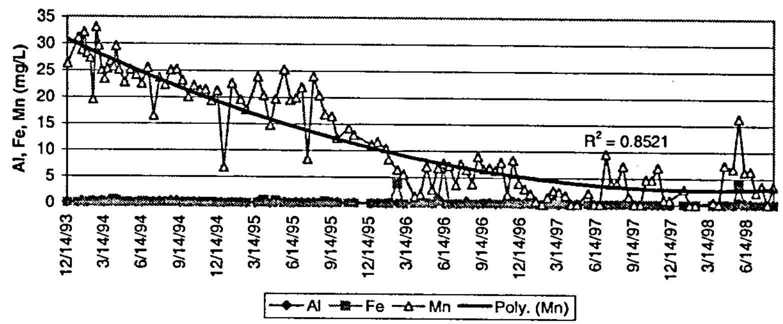
3/14/98
6/14/98



TDS, SO4 (mg/L)
8000
7000
6000
5000
4000
3000
2000
1000
0
R^2 = 0.2157
R^2 = 0.3124
12/14/93
3/14/94
6/14/94
9/14/94
12/14/94
3/14/95
6/14/95
9/14/95
12/14/95
3/14/96
6/14/96
9/14/96
12/14/96
3/14/97
6/14/97
9/14/97
12/14/97
3/14/98
6/14/98
TDS
SO4
Linear (TDS)
Linear (SO4)



Al, Fe, Mn (mg/L)
35
30
25
20
15
10
5
0
R^2 = 0.8521
12/14/93
3/14/94
6/14/94
9/14/94
12/14/94
3/14/95
6/14/95
9/14/95
12/14/95
3/14/96
6/14/96
9/14/96
12/14/96
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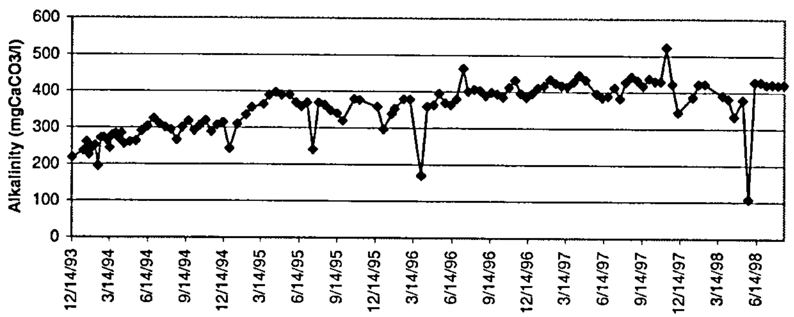
3/14/98
6/14/98
Al
Fe
Mn
Poly. (Mn)



Alkalinity (mgCaCO3/l)
600
500
400
300
200
100
0
12/14/93
3/14/94
6/14/94
9/14/94
12/14/94
3/14/95
6/14/95
9/14/95
12/14/95
3/14/96
6/14/96
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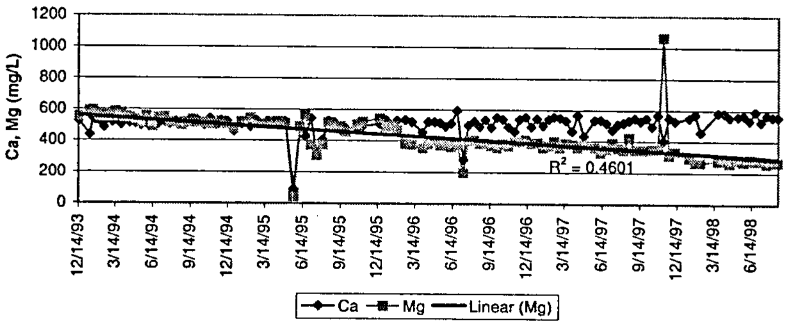
3/14/98
6/14/98



Ca, Mg (mg/L)
1200
1000
800
600
400
200
0
R^2 = 0.4601
12/14/93
3/14/94
6/14/94
9/14/94
12/14/94
3/14/95
6/14/95
9/14/95
12/14/95
3/14/96
6/14/96
9/14/96
12/14/96
3/14/97
6/14/97
9/14/97
12/14/97
3/14/98
6/14/98
Ca
Mg
Linear (Mg)

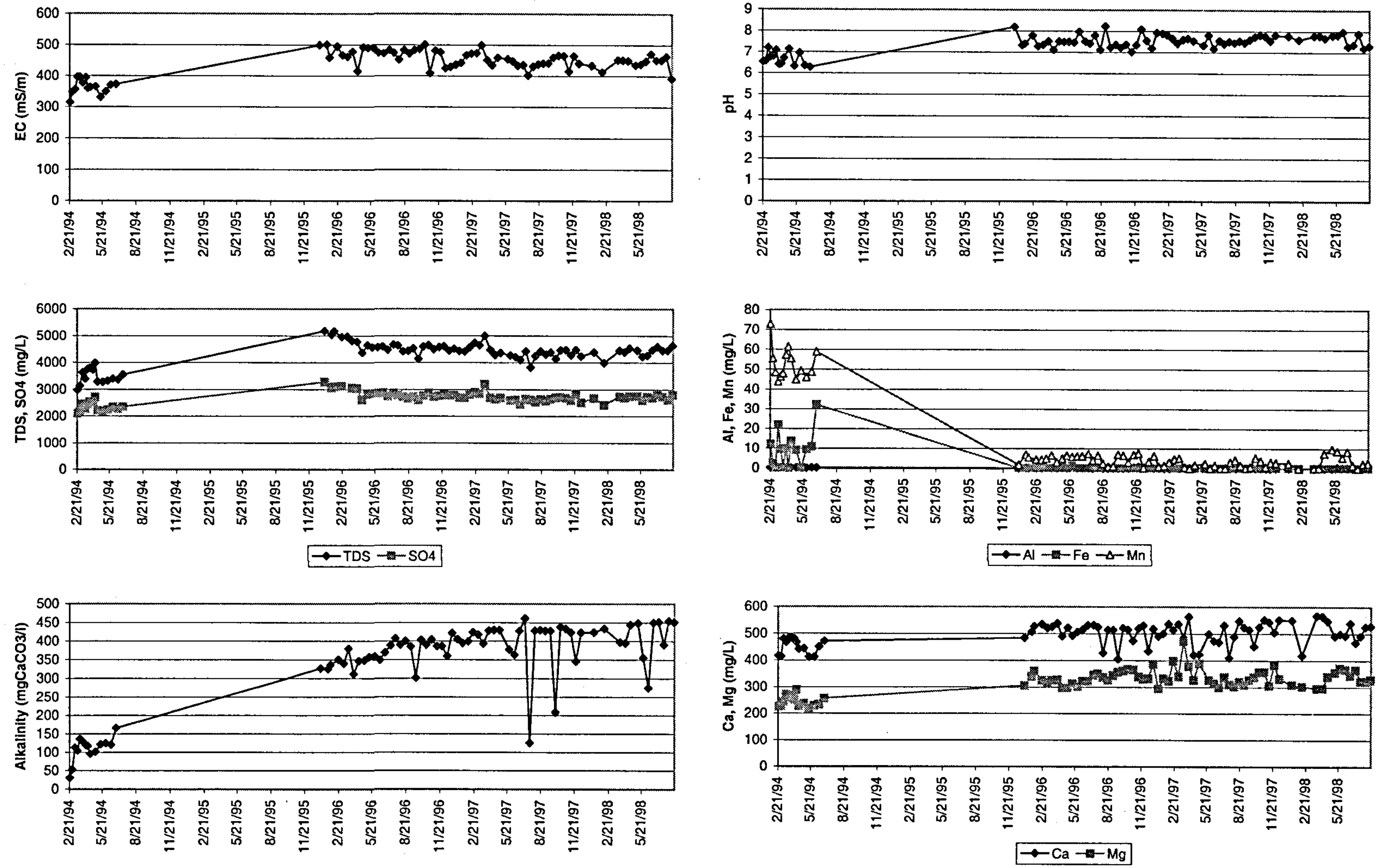
Cell 9A

Date	EC	TDS	pH	Na	Mg	Ca	Fl	Cl	NO3	SO4	PO4	ALK	Si	K	NH4	Al	Fe	Mn
2/28/94	90.3	652	4.35	14.2	40	115.3	0.72	2.1	4.286	456.2	0.007	1	6.55	2.41	0.494	12.5	0.067	3.938
1/22/96	41	254	7.74	22.1	12.2	28	0.18	9.8	0.02	125	0.009	44.2	5.07	2.53	0.053	0	0	0
1/29/96	34.8	242	7.42	20.6	11.4	28.5	0.21	8.2	0.036	117.5	0.014	43.3	5.16	2.88	0.071	0.034	0.004	0
12/9/96	17.9	127	6.91	5.2	5.8	17.2	0.11	3.1	0.017	26.5	0.007	56.3	4.5	0.7	0.035	0.073	0	0.138
Min	17.9	127	4.35	5.2	5.8	17.2	0.11	2.1	0.017	26.5	0.007	1	4.5	0.7	0.035	0	0	0
Max	90.3	652	7.74	22.1	40	115.3	0.72	9.8	4.286	456.2	0.014	56.3	6.55	2.88	0.494	12.5	0.067	3.938
Mean	46	318.75	6.605	15.525	17.35	47.25	0.305	5.8	1.08975	181.3	0.00925	36.2	5.32	2.13	0.16325	3.15175	0.01775	1.019
Median	37.9	248	7.165	17.4	11.8	28.25	0.195	5.65	0.028	121.25	0.008	43.75	5.115	2.47	0.062	0.0535	0.002	0.069
95-percent	20.435	144.25	4.734	6.55	6.64	18.82	0.1205	2.25	0.01745	40.15	0.007	7.345	4.5855	0.9565	0.0377	0.0051	0	0

Cell 9B

Date	EC	TDS	pH	Na	Mg	Ca	FI	Cl	NO3	SO4	PO4	ALK	SI	K	NH4	Al	Fe	Mn
2/21/94	314	2964	6.53	117.7	225.1	416	0.27	54	0.291	2102.9	0.044	30.4	3.85	8.65	1.05	0.118	12.33	72.9
2/28/94	348	3131	6.57	163.4	227.4	414.4	0.24	64.3	0.114	2186.5	0.062	52.6	3.83	8.54	1.098	0.154	2.325	55.4
3/7/94	356	3622	7.19	220.7	243.2	479.8	0.25	78.9	0.041	2446.1	0.022	112.3	4.05	13.71	1.704	0.113	0.011	48.41
3/14/94	396	3387	6.77	113.2	272	467.8	0.22	86.2	0.04	2288.7	0.022	104.2	3.44	30.41	1.317	0.162	22.02	43.79
3/21/94	396	3746	6.8	273.4	258.4	483	0.26	93.3	0.023	2453.7	0.044	136.1	3.76	15.35	2.105	0.123	9.44	46.18
3/28/94	377	3798	7.08	249.7	267.2	483.8	0.27	89.6	0.016	2533.7	0.02	128.6	3.78	14.3	1.955	0.153	0.031	47.88
4/5/94	394	3727	6.42	218.9	252.1	480.7	0.16	72	0.028	2541	0.005	119	3.75	13.27	2.72	0.15	10	57.2
4/11/94	360	3984	6.44	262.7	289.3	467.1	0.22	92.1	0.023	2709.6	0.016	117	3.59	16.41	2.842	0.141	0.115	61.3
4/18/94	363	3278	6.71	182.7	226.8	441.4	0.21	69.1	0.013	2226.2	0.006	95	3.54	12.77	2.629	0.128	13.88	55.4
5/2/94	365	3266	7.13	196.7	236.8	444.1	0.25	67.3	0.025	2180.1	0.008	101.3	3.43	13.66	2.72	0.116	9.25	44.85
5/16/94	331	3309	6.32	193	219.4	412.1	0.26	73.7	0.003	2244.7	0.03	121.4	3.38	13.52	3.456	0.122	0.07	49.26
5/30/94	349	3391	6.95	161.8	229.5	412	0.34	73.6	0.04	2345.5	0.006	124.4	3.15	12.54	2.96	0.041	9.43	45.91
6/13/94	370	3361	6.35	164.1	234.6	450.8	0.28	78.6	0.02	2269.1	0.029	120.3	3.14	12.48	3.024	0.148	10.99	48.77
6/27/94	373	3546	6.27	164.1	256.4	471.6	0.29	83.8	0.02	2351.8	0.012	165.4	2.82	11.29	3.523	0.113	32.3	58.9
1/2/96	499	5175	8.19	551.8	306.5	484.4	0.19	122.1	0	3282.2	0.008	326.7	5.3	28.04	0.942	0.066	0	1.7
1/22/96	501	5035	7.34	483.3	340.2	506	0.19	127.3	19.323	3065.3	0.016	324.8	4.95	29.53	1.147	0.154	0	6.81
1/29/96	459	5168	7.4	508.1	359.3	527.2	0.23	133.7	22.99	3111.6	0.016	336.3	4.59	15.18	0.62	0.181	0.019	5.37
2/19/96	495	4954	7.79	422.1	325.6	534.9	0.25	76.8	3.085	3129.2	0.008	350	4.99	24.71	0.141	0.126	0.22	4.409
3/5/96	467	4963	7.29	473.1	318.8	520.7	0.24	83.8	0.508		0.007	339.8	4.99	23.99	0.293	0	0	4.235
3/18/96	461	4803	7.35	367.4	325.3	525	0.21	44.3	0	3052.8	0.008	379.5	5.25	24.79	0.272	0.301	0	4.868
4/1/96	478	4770	7.51	375.7	327.1	538.3	0.22	88.9	0.018	3037.4	0.006	310.7	4.51	23.08	0.418	0.111	0.016	6.48
4/15/96	415	4361	7.12	410.9	296.9	490.1	0.29	95.1	0.026	2630.2	0.01	346.7	4.47	13.8	0.386	0.13	0.007	2.955
4/30/96	492	4635	7.52	434.5	297.2	522.1	0.23	107.3	0.019	2825.8	0.004	347.7	4.85	23.8	0.304	0.278	0.795	4.811
5/13/96	490	4555	7.49	370.9	313.3	492.1	0.34	68.2	0.032	2849.6	0.004	357.2	4.75	24.53	0.386	0.036	0.032	6.5
5/27/96	490	4555	7.5	353.6	302	506.8	0.39	72.6	0.036	2865.2	0.01	359.3	4.84	15.82	0.367	1.056	1.167	5.76
6/10/96	475	4587	7.47	356.3	323.1	514.7	0.24	70.5	0.024	2870.3	0.011	349.5	4.95	24.69	0.367	0.083	0	6.07
6/24/96	473	4470	7.97	343	322.8	531	0.33	58.5	0.023	2747.3	0.012	369.1	5.39	16.17	0.393	0.08	0	6.026
7/10/96	483	4660	7.51	327.2	345.4	532.2	0.23	92.4	0.035	2862.6	0.008	388.5	5.21	25.42	0.39	0.083	0	7.22
7/22/96	475	4630	7.42	345.8	350.6	523.6	0.22	98.5	0.02	2790.1	0.01	407.3	5.12	23.56	0.403	0	0	3.941
8/5/96	453	4404	7.8	323.5	337.5	427.1	0.21	85.6	0.018	2729.9	0.003	390	5.3	23.65	0.412	0.546	0	6.39
8/19/96	483	4428	7.12	325	326.9	513.7	0.2	84.2	0.015	2671.9	0.009	400	5.27	17.93	0.377	0	0	2.351
9/2/96	472	4513	8.23	340.8	343.9	514.1	0.2	100.1	0.037	2729.6	0.008	385.5	5.05	13.5	0.385	0	0	0.757
9/16/96	483	4134	7.23	314.6	357	405	0.14	68.8	0.02	2611.5	0.007	301.2	5.17	8.69	0.391	0.178	0.026	1.057
9/30/96	487	4587	7.36	344.2	362	520.6	0.2	84.6	0.022	2772.8	0.02	403.6	4.98	9.27	0.456	0.173	0	7.066
10/14/96	501	4639	7.22	338.8	367.8	514.5	0.2	70.7	0.046	2860.6	0.003	390.1	4.84	9.68	0.498	0.05	0	6.475
10/28/96	409	4483	7.37	318.8	364.6	473.6	0.17	89.4	0.016	2734.3	0.008	403.9	4.77	8.72	0.476	0	0	3.078
11/12/96	482	4573	7.03	382	339.5	520.2	0.16	88.4	0.019	2761	0.009	385.9	5.35	10.73	0.422	0.399	0.012	6.92
11/25/96	476	4594	7.35	353.1	331	529.7	0.17	81.6	0.023	2816.5	0.011	386.1	5.12	10.79	0.459	0.781	0.043	7.53
12/9/96	425	4438	8.09	349	332.4	434.6	0.19	89.3	0.029	2782.3	0.018	359.7	5.69	10.92	0.444	0.348	0	0.147
12/23/96	429	4510	7.55	225.2	386.5	518	0.11	56.2	0.027	2791.4	0.006	421.9	4.68	16.78	0.865	0.43	0.014	3.259
1/6/97	436	4429	7.2	367.3	294.5	490.5	0.17	68.5	0.026	2703.2	0.008	405.6	6.16	9.44	0.541	0.197	0.018	6.238
1/20/97	442	4407	7.93	317.2	332.9	499.9	0.16	67.5	0.043	2694.6	0.008	395.2	5.1	11.62	0.841	0	0	0.921
2/4/97	467	4556	7.89	318.8	323.5	536.3	0.21	72.2	0.038	2804	0.006	399.8	5.11	12.34	0.756	0	0	1.175
2/17/97	472	4731	7.82	313	398.9	513.8	0.15	82	0.029	2891.5	0.005	423.7	5.06	14.19	0.663	0	0	2.958
3/3/97	474	4643	7.66	319.7	340.3	535.4	0.18	83.4	0.032	2842.4	0.004	417.3	5.2	11.88	0.678	0.687	0.05	4.732
3/17/97	499	4993	7.42	288	472.4	484.9	0.17	59	0.028	3193.3	0.009	393.5	5.47	14.17	0.493	0	0	5.1
4/1/97	451	4466	7.61	223.8	378.1	563.4	0.16	72.6	0.062	2687.4	0.039	428.1	4.58	16.56	0.887	0.141	0	0.591
4/14/97	434	4283	7.66	341.2	326.8	419.8	0.17	20.5	0.029	2638	0.014	430	5.48	11.08	0.605	0.154	0	0.008
4/29/97	459	4351	7.54	250.4	389.7	422.7	0.19	58.5	0.047	2690.1	0.019	429.5	4.66	14.83	0.722	0.161	0	1.643
5/26/97	454	4269	7.34	298.8	326.5	499.5	0.18	67.3	0.02	2603.5	0.009	377.6	5.26	11.78	0.855	0.077	0	2.314
6/9/97	447	4206	7.81	293.4	314.5	474	0.15	51.3	0.027	2616.5	0.004	363.7	5.06	11.88	0.821	0.103	0	0.003
6/23/97	433	4101	7.18	292.2	300.5	468.2	0.13	52.4	0.02	2453.8	0.01	427.7	5.41	11.05	0.669	0	0	1.558
7/8/97	435	4414	7.55	274.9	338.1	530.8	0.16	47.9	0.031	2647.8	0.009	461.1	5.19	11.42	0.74	0.017	0	0.051
7/21/97	403	3818	7.41	261.7	310.6	410.4	0.13	54.2	0.08	2615.1	0.004	125.8	4.62	11.28	0.73	0.009	0	0.113
8/4/97	431	4242	7.52	306.6	303.5	489.3	0.16	56.8	0.017	2553.1	0.014	428	5.41	9.78	0.709	0.016	0	3.101
8/18/97	438	4421	7.45	307.4	321.3	548.1	0.15	64	0.051	2643.9	0.004	430.2	4.94	10.4	0.838	0.098	0	4.157
9/1/97	440	4293	7.54	282.4	309	523.6	0.2	64.1	0.044	2581.3	0.008	427.7	5.13	9.7	0.671	0.519	0.033	1.498
9/15/97	441	4372	7.46	285.1	326.7	515.1	0.16	64.9	0.034	2647.3	0.005	427.7	5.05	10.17	0.679	0.067	0	0.098
9/29/97	460	4141	7.61	284.3	338.2	453.2	0.15	85.4	0.039	2713.4	0.005	208.3	5.08	11.47	0.65	0	0	0.642
10/13/97	466	4458	7.75	239.6	356.1	524.5	0.2	68.8	0.055	2721.7	0.021	437.7	5.66	12.3	0.66	0	0	5.15
10/27/97	465	4463	7.82	253	357.3	552	0.22	66.9	0.053	2690.7	0.01	433.6	5.66	12.69	0.649	0	0	3.77
11/10/97	415	4277	7.77	247.9	306.4	544	0.08	51.3	0.025	2598.3	0.008	424	5.11	10.86	0.721	0	0	0.727
11/24/97	464	4470	7.55	271.8	383.7	505.7	0.09	29	0.033	2844.8	0.007	345.4	5.34	13.27	0.452	0	0	3.033
12/8/97	440	4230	7.82	237.8	332.1	552	0.11	56.9	0.62	2520.7	0.009	423.4	5.17	10.9	0.075	0	0	2.812
1/12/98	433	4386	7.78	267.3	308.9	549.3	0.11	45.1	0.067	2684.6	0.007	423.8	5.56	12.34	0.754	0	0	2.423
2/9/98	412	3987	7.61	252.2	303.4	417.9	0.15	41.7	0.023	2428.3	0.007	434.6	5.21	11.83	0.769	0	0	0
3/23/98	452	4450	7.78	311.7	295.6	567.4	0.17	40.7	0.37	2738.5	0.013	397.2	5.62	9.49	0.296	0	0.048	0.142
4/6/98	451	4386	7.8	300.1	296.4	565.1	0.11	41.1	0.352	2688.5	0.005	395.3	5.6	10.38	0.302	0	0.028	0.217
4/20/98	449	4526	7.68	277.6	339.9	547.1	0.17	53.3	0.091	2756.2	0.009	443.9	5.48	9.3	0.718	0	0.058	7.54
5/11/98	435	4452	7.81	234.6	355.9	491.4	0.11	51	0.06	2759.6	0.017	448	5.08	12.19	0.803	0	0	9.75
5/25/98	438	4223	7.83	245.6	372.3	499.2	0.13	55.2	0.07	2605.3	0.006	354.9	5.07	11.43	0.821	0.511	0	8.72
6/8/98	448	4262	7.97	271	366.3	492.8	0.11	50.4	0.029	2734.7	0.009	274.4	5.34	10.76	0.909	0.297	0	5.49
6/22/98	471	4466	7.28	274.2	344.7	539.6	0.14	49	0.023	2696.9	0.008	449.9	5.49	11.2	0.835	0.258	0.004	8.51
7/6/98	451	4592	7.37	314.7	365.3	467.8	0.11	76.6	0.026	2803.6	0.05	451.5	5.43	11.84	0.632	0.089	0.003	1.709
7/20/98	451	4450	7.88	320.5	322.7	490.8	0.09	81	0.148	2745.7	0.05	390.5	4.95	11.4	0.658	0.087	0	0.047
8/3/98	463	4448	7.21	315.4	321.3	525.6	0.18	88	0.039	2631.4	0.015	454.4	5.52	11.33	0.647	0.088	0.004	2.295
8/17/98	392	4625	7.31	326.7	328.5	527.9	0.14	79.6	0.037	2798.3	0.011	451.4	5.5	12.28	0.629	0.105	0.007	2.646
Min	314	2964	6.27	113.2	219.4	405	0.08	20.5	0	2102.9	0.003	30.4	2.82	8.54	0.075	0	0	0
Max	501	5175	8.23	551.8	472.4	567.4	0.39	133.7	22.99	3282.2	0.062	461.1	6.16	30.41	3.523	1.056	32.3	72.9
Mean	439.7013	4304.169	7.407403	298.8143	320.0545	495.8935	0.192468	71.86364	0.64839	2683.276	0.013143	336.1481	4.866104	14.35714	0.909026	0.143545	1.750597	12.47035
Median	451	4429	7.47	300.1	325.6	505.7	0.19	70.7	0.029	2700.05	0.009	386.1	5.08	12.3	0.669	0.103	0	4.409
95-percent	354.6	3302.8	6.436	163.96	229.08	413.94	0.11	41.58	0.0146	2240.075	0.004	103.62	3.42	9.16	0.2954	0	0	0.0502

Cell 9B



EC (mS/m)
pH
TDS, SO4 (mg/L)
TDS
SO4
Al, Fe, Mn (mg/L)
Al
Fe
Mn
Alkalinity (mgCaCO3/l)
Ca, Mg (mg/L)
Ca
Mg
2/21/94
5/21/94
8/21/94
11/21/94
2/21/95
5/21/95
8/21/95
11/21/95
2/21/96
5/21/96
8/21/96
11/21/96
2/21/97
5/21/97
8/21/97
11/21/97
2/21/98
5/21/98

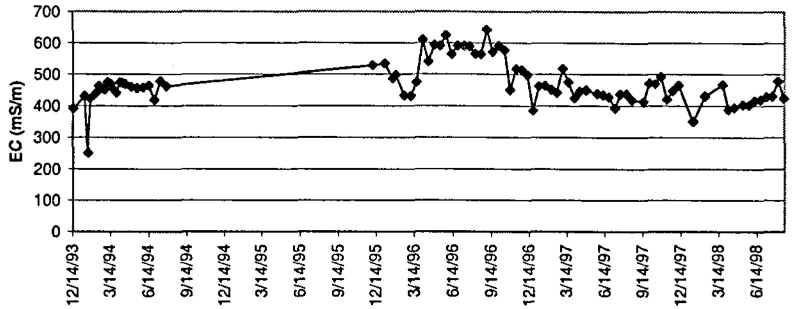
Cell 10A

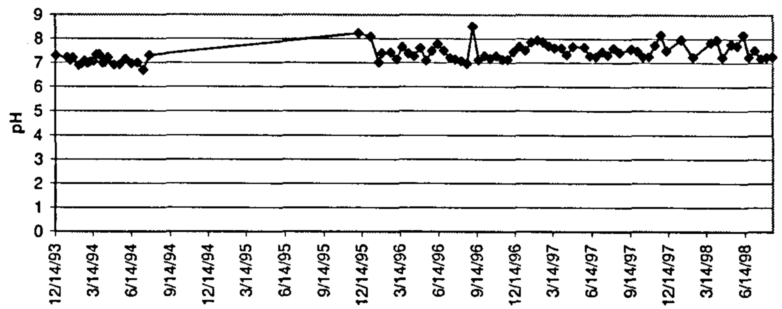
Date	EC	TDS	pH	Na	Mg	Ca	Fl	Cl	NO3	SO4	PO4	ALK	Si	K	NH4	Al	Fe	Mn
1/18/94	426	4363	6.98	216.5	380.3	507.6	0.18	61.1	0.018	2968.4	0.004	179.3	3.23	8.84	0.943	0.264	0.02	40.26
1/24/94	246	1761	7.54	296.1	102.4	134	0.3	118	28.307	938	0.01	35	7.58	3.59	0.224	0	0	0.664
1/31/94	429	4084	7.06	231	342	518	0.13	82.5	0.031	2654.6	0.014	200.8	3.07	9	1.157	0	0.028	36.4
2/7/94	207	1674	6.9	262.8	88.3	126.2	0.18	122.9	24.188	926.7	0.005	30.2	6.4	2.95	0.098	0.211	0	0.432
2/21/94	368	3769	7.18	138.8	393.1	377.9	0.26	84.1	7.808	2506.1	0.012	184	3.38	7.32	0.511	0.145	0	19.18
2/28/94	468	4904	6.82	85.5	567.9	528	0.26	81	0.014	3321.9	0.008	252.9	3	9.92	0.7	0.169	0	24.37
11/20/95	506	4424	7.71	155.7	436.9	498.6	0.13	87	2.841	2944.7	0.016	217.4	1.78	22.62	0.194	0.233	0.05	29.332
12/9/98	56.6	390	7.61	72.7	17.2	23.5	0.09	19.2	0.126	225.1	0.012	25.3	3.04	0.5	0.064	0.094	0	0.057
Min	56.6	390	6.82	72.7	17.2	23.5	0.09	19.2	0.014	225.1	0.004	25.3	1.78	0.5	0.064	0	0	0.057
Max	506	4904	7.71	296.1	567.9	528	0.3	122.9	28.307	3321.9	0.016	252.9	7.58	22.62	1.157	0.264	0.05	40.26
Mean	338.325	3171.125	7.225	182.3875	291.0125	339.225	0.19125	81.975	7.916625	2060.938	0.010125	140.6125	3.935	8.0925	0.486375	0.1395	0.01225	18.83688
Median	397	3926.5	7.12	186.1	361.15	438.25	0.18	83.3	1.4835	2581.35	0.011	181.65	3.15	8.08	0.3675	0.157	0	21.775
95-percent	109.24	839.4	6.848	77.18	42.085	59.445	0.104	33.865	0.0154	470.66	0.00435	27.015	2.207	1.3575	0.0759	0	0	0.18825

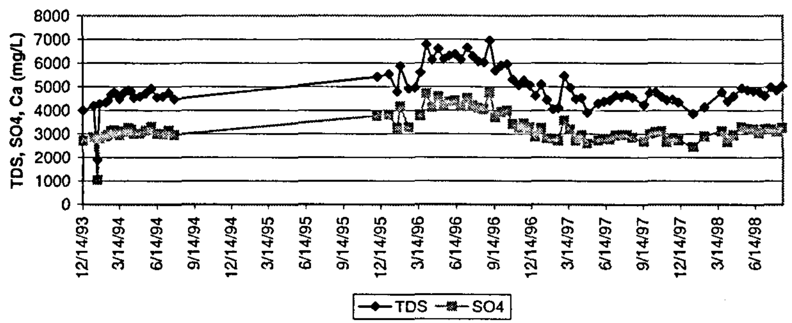
Cell 10B

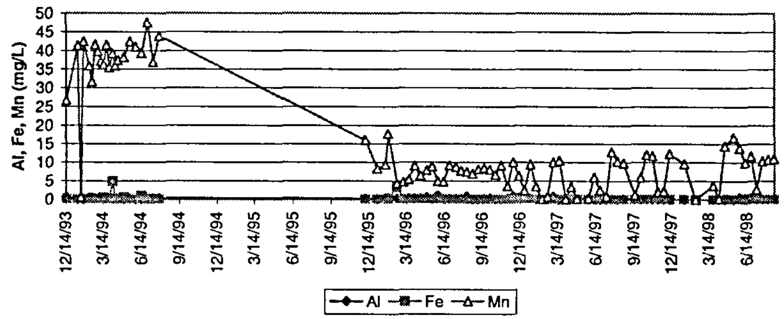
Date	EC	TDS	pH	Na	Mg	Ca	Fl	Cl	NO3	SO4	PO4	ALK	Si	K	NH4	Al	Fe	Mn
12/14/93	391	3984	7.29	161	338.3	497.1	0.32	59	0.024	2726	0.012	158.2	3.49	7.92	0.811	0.593	0.073	26.705
1/10/94	430	4165	7.22	198.3	405.8	430.1	0.15	56.2	0.027	2863.4	0.016	164.9	3.14	9.1	0.736	0	0	41.33
1/18/94	251	1889	7.09	300.5	96.2	154.5	0.23	126.8	29.583	1036.1	0.002	32.3	8	3.65	0.184	0.328	0.003	0.602
1/24/94	422	4244	7.2	213.9	374.7	519.6	0.41	116.2	0.15	2807.7	0.017	164.3	3.1	9.1	0.978	0	0.069	42.42
2/7/94	440	4308	6.9	194	386.9	499.2	0.22	73.5	0.017	2893.5	0.008	205.6	3.27	8.69	0.951	0.468	0.032	35.84
2/14/94	463	4403	6.96	173.5	406.4	501.6	0.18	75.5	0.589	2970	0.009	216.9	3.37	7.38	0.852	0.436	0.045	31.62
2/21/94	454	4661	7.07	205.7	407.3	541.1	0.2	82.7	0.024	3116	0.017	244.1	2.89	9.42	0.836	0.157	0.004	41.57
2/28/94	450	4733	6.96	233.8	409.2	541.1	0.22	85.3	0.023	3150.7	0.017	247.6	2.74	9.66	0.885	0.159	0.012	39.79
3/7/94	475	4665	7.04	219.7	438.8	533.9	0.27	85.5	0.006	3064.3	0.026	248.9	3.46	17.13	1.246	0.348	0.051	37.05
3/14/94	470	4462	7.06	120.3	453	538.9	0.25	95.7	0.025	2965	0.008	229	3.05	8.2	0.753	0.509	0.552	36.22
3/21/94	451	4679	7.33	183.4	456.7	529.4	0.36	92.4	0.024	3092.6	0.031	254.6	3.25	12.37	1.035	0.179	0.008	41.65
3/28/94	441	4770	7.34	217.8	460.2	533	0.2	96.4	0.013	3118.6	0.016	267.8	3.36	13.1	1.248	0.179	0.137	35.43
4/5/94	474	4831	6.99	183.7	450.2	539.5	0.11	76.4	0.079	3246.5	0.002	260.2	3.23	14.97	1.606	0.135	4.863	39.18
4/11/94	472	4797	7.01	173.9	471.1	542.7	0.24	81.5	0.038	3186.1	0.008	265.7	3.31	15.18	1.624	0.188	0.297	35.95
4/18/94	469	4527	7.21	155.8	449.9	513.2	0.19	80.3	0.013	3008.1	0.012	249.4	3.25	12.81	1.536	0.15	0.172	37.39
5/2/94	460	4580	6.91	154.8	470.6	514.9	0.22	83.7	0.027	3024.1	0.008	259.3	2.97	13.87	1.499	0.106	0.641	38.18
5/16/94	455	4713	6.92	151.5	457.3	542	0.43	92	0.117	3138.4	0.016	259.1	2.67	12.79	1.5	0.143	0.03	42.4
5/30/94	457	4897	7.15	151.1	494.5	495.7	0.18	98.2	0.031	3307.3	0.006	275.3	2.78	12.51	1.616	0.027	0	41
6/13/94	464	4550	6.96	135.2	439.1	506.4	0.24	95.7	0.054	3020.4	0.012	282.5	2.79	6.65	1.521	0.179	1.024	39.29
6/27/94	419	4580	6.99	139.4	465.3	520.6	0.2	100.7	0.032	2986.8	0.008	289.9	2.53	11.05	1.521	0.132	0.209	47.55
7/11/94	478	4725	6.7	142	470.7	522.8	0.35	93.2	0.034	3134.7	0.008	281.1	2.57	16.31	1.586	0.188	0.045	36.92
7/25/94	462	4466	7.31	143.2	440.9	501	0.31	96.2	0.099	2970.3	0.01	243	1.71	15.18	1.554	0.263	0.033	43.87
12/4/95	526	5405	8.23	421.6	418.9	536.2	0.08	84.4	0.257	3763.7	0.014	121.6	4.83	30.2	0.063	0.15	0.014	16.073
1/2/96	534	5519	8.08	543.9	335.5	561.9	0.12	84.5	0.005	3813.4	0.026	125.9	3.57	26.23	0.12	0.107	0	8.278
1/22/96	486	4782	7.02	421.5	334.1	477.9	0.14	73.1	0.031	3266.8	0.013	149.7	4.36	25.74	0.229	0.227	0.033	9.44
1/29/96	497	5865	7.4	429.6	566.9	500	0.3	95.3	1.509	4164	0.01	72.1	6.54	14.3	0.168	0.323	0.122	17.73
2/19/96	432	4903	7.43	453.8	356.3	482.8	0.25	53.5	0.802	3284.7	0.009	207.6	4.68	14.61	0.193	0.365	3.329	4.356
3/5/96	431	4941	7.16	400.8	401	461.1	0.23	59.9	0.193		0.01	156.4	4.77	14.47	0.206	0.121	0	4.683
3/18/96	475	5588	7.66	412.8	495.7	485.6	0.27	37.3	0	3773.4	0.015	294.2	4.43	23.41	0.244	0.3	0.009	5.44
4/1/96	609	6772	7.39	374.9	700.9	548.5	0.18	64.7	0.015	4715.6	0.007	281.8	4.69	23.48	0.309	0.163	0	9.11
4/15/96	540	6127	7.27	335.8	725.2	484.9	0.19	69	0.015	4128.8	0.008	296.7	4.44	21.07	0.345	0.15	0.017	6.43
4/30/96	593	6591	7.61	350.1	724.6	482.7	0.22	57.4	0.006	4589.4	0.009	301.2	4.29	19.35	0.342	0.535	0.035	7.67
5/13/96	591	6157	7.09	308.9	744.1	452	0.21	43.1	0.014	4203.5	0.008	323.7	3.84	9.86	0.312	0.066	0.058	8.94
5/27/96	623	6291	7.5	307.5	730.5	452	0.35	43.4	0.025	4353.4	0.007	322.3	3.77	10.02	0.31	1.049	0	4.923
6/10/96	564	6364	7.77	298.6	742.6	478	0.22	46.9	0.016	4402.2	0.012	315.6	3.6	10.33	0.291	0.113	0	4.686
6/24/96	590	6149	7.51	292.4	700.7	519.4	0.19	42.9	0.034	4175	0.022	331.6	3.8	13.28	0.261	0.086	0	9.2
7/10/96	590	6650	7.2	294.8	784.1	526.2	0.18	63.6	0.037	4506.3	0.015	377.2	3.71	14	0.267	0.15	0	6.72
7/22/96	588	6296	7.13	297.4	743.2	501.1	0.17	69	0.019	4210.8	0.014	379.2	3.64	11.76	0.411	0.167	0	7.823
8/5/96	565	6069	7.07	282.1	711.1	476.1	0.18	33.3	0.031	4107.2	0.009	376.1	3.44	0	0.218	0.778	0	7.5
8/19/96	*564*	*6018*	*8.96*	*281.8*	*685.8*	*485.5*	*0.16*	*61.8*	*0.023*	*4046.1*	*0.014*	*370*	*3.33*	*5.71*	*0.2*	*0*	*0*	*6.95*
9/2/96	642	6940	8.51	360.8	833.8	492.8	0.17	86.7	0.063	4751	0.014	325.4	2.7	16.88	0.269	0	0	8.118
9/16/96	571	5667	7.12	277.5	680.4	457.6	0.18	62.1	0.069	3705.1	0.014	392.2	3.13	5.76	0.286	0.163	0.039	8.479
9/30/96	590	5894	7.28	309.4	682	481.3	0.22	61.1	0.146	3921	0.026	353.9	2.93	6.06	0.28	0.276	0	8.03
10/14/96	577	5937	7.18	306.6	672.6	482.4	0.19	49.1	0.189	3997.1	0.01	346.4	2.71	6.12	0.107	0.046	0	6.676
10/28/96	450	5289	7.28	303	589.6	410.5	0.16	76.6	0.016	3429.6	0.009	388.2	3.91	6.03	0.238	0	0	9.171
11/12/96	517	5061	7.13	330	520	445.8	0.14	83.6	0.02	3278.6	0.011	322.5	4.64	8.8	0.308	0.348	0.011	3.61
11/25/96	514	5252	7.13	292	528	495.3	0.17	75.6	0.015	3447.8	0.017	328.5	4.11	11.8	0.349	0.908	0.074	10.14
12/9/96	497	5052	7.47	342.6	458.8	486.8	0.15	58.1	0.03	3276.2	0.019	343.2	5.07	10.81	0.27	0.389	0	6.243
12/23/96	385	4608	7.68	235.7	374.9	527.9	0.12	61.5	0.032	2902.1	0.01	400	4.79	16.51	0.921	0.419	0.012	2.407
1/6/97	462	5080	7.52	332.1	459.4	479.5	0.13	64.1	0.031	3250.5	0.007	392.7	4.65	14.58	0.348	0.217	0.021	9.437
1/20/97	464	4430	7.85	295.1	400.8	446.8	0.15	41.9	0.034	2813.3	0.009	342.2	4.37	13.99	0.495	0	0	3.39
2/4/97	451	4034	7.94	219.4	387.7	434.3	0.15	64.5	0.044	2808.7	0.006	83.4	4.33	16.34	0.82	0	0	0.041
2/17/97	442	4086	7.87	200.8	371.2	458.1	0.18	62.9	0.084	2726.6	0.007	205.2	4.23	14.86	0.719	0	0	0.692
3/3/97	518	5439	7.7	347.1	488.4	506.5	0.2	64.9	0.044	3570.4	0.011	366	4.2	14.15	0.47	0.745	0.089	10.05
3/17/97	475	4959	7.62	292.9	450.6	469.7	0.19	57.1	0.018	3196.3	0.016	391.4	5.43	14.44	0.46	0	0	10.47
4/1/97	425	4471	7.61	205	364.5	563.2	0.19	72.2	0.057	2720	0.017	433.8	4.6	15.28	0.858	0.132	0	0.003
4/14/97	445	4501	7.34	314.7	405.1	452.1	0.16	52.3	0.058	2947.8	0.015	258	4.8	13.34	0.428	0.175	0	3.317
4/29/97	449	3904	7.68	222.8	361.7	436.4	0.16	63.8	0.063	2616.8	0.013	137.3	5.09	13.77	0.883	0.159	0	0.157
5/26/97	438	4277	7.65	288.3	361.1	442.6	0.18	43.5	0.033	2738.6	0.006	319.8	4.27	12.44	0.488	0.043	0	0.238
6/9/97	434	4357	7.28	313	349.8	460.2	0.15	38.4	0.031	2795.9	0.008	316.7	4.39	13	0.394	0.106	0	6.01
6/23/97	428	4414	7.25	302.6	372.3	475.8	0.15	15.8	0.024	2793.6	0.007	361.1	4.53	12.57	0.379	0.002	0	2.565
7/8/97	393	4610	7.45	311.2	381.8	474.5	0.15	38.4	0.036	2937.8	0.009	371.5	4.4	12.32	0.424	0.028	0	0.848
7/21/97	437	4567	7.32	316.8	366	469.5	0.14	32.9	0.03	2981.7	0.008	318.8	4.13	11.06	0.385	0.049	0	12.88
8/4/97	437	4662	7.62	321.1	364.8	498.8	0.18	45.2	0.035	2967.3	0.006	370.9	4.38	11.85	0.508	0.032	0	10.25
8/18/97	419	4534	7.43	297.5	368.5	507.8	0.17	42.4	0.067	2850.9	0.004	373.2	4.26	10.43	0.485	0.097	0	9.84
9/15/97	413	4228	7.57	252.8	341.4	469.4	0.18	35.4	0.034	2690.2	0.006	349.8	4.16	11.18	0.419	0.136	0	1.2
9/29/97	472	4738	7.48	329.3	407.7	527.6	0.17	43.1	0.027	3005.1	0.009	338	4.18	12.42	0.433	0	0	5.96
10/13/97	470	4751	7.24	270.1	409.5	499.6	0.21	38.7	0.045	3069.2	0.024	369.8	4.53	12	0.373	0	0	12.06
10/27/97	491	4562	7.26	282.6	422.9	461	0.18	42.5	0.041	3108	0.004	190.1	4.55	12.25	0.374	0	0	11.73
11/10/97	421	4412	7.73	256.8	348.1	548	0.01	60.7	0.075	2664.8	0.008	427.2	5.09	11.34	0.641	0	0	2.036
11/24/97	447	4445	8.15	268.4	388.8	493.7	0.11	33.9	0.023	2828.4	0.015	342.6	5.18	13.07	0.412	0	0	2.188
12/8/97	465	4321	7.51	276.9	383.1	449	0.11	45.8	0.013	2728.5	0.009	347.3	5.16	13.44	0.362	0	0	12.37
1/12/98	350	3849	7.96	238.6	305.1	418	0.2	24.1	0.069	2467.9	0.02	313.9	5.43	11.35	0.373	0	0	9.62
2/9/98	431	4125	7.24	255.4	392.5	408	0.17	28.6	0.048	2905.8	0.006	99.2	5.21	13.09	0.429	0	0	0
3/23/98	467	4752	7.84	284	390.4	524.3	0.16	32.1	0.082	3123.9	0.007	314.8	5.29	11.92	0.434	0	0.039	3.742
4/6/98	388	4373	7.95	305.8	299.9	568.3	0.15	41.4	0.354	2680.4	0.01	381.4	5.6	9.92	0.313	0	0.025	0.199
4/20/98	394	4593	7.23	281.6	387.5	519.3	0.19	31.8	0.095	2967.8	0.025	323.2	5.07	9.98	0.415	0	0.066	14.5
5/11/98	403	4932	7.77	300.1	423.9	484.8	0.17	29.8	0.341	3298.9	0.137	312.7	4.47	10.65	0.043	0	0	16.75
5/25/98	402	4847	7.72	299.4	412.6	486.2	0.16	30.3	0.328	3230.9	0.018	307.5	4.18	10.68	0.056	0.531	0	13.92
6/8/98	417	4602	8.16	315	421.8	510.4	0.18	26.2	0.027	3208.1	0.022	254.6	4.68	8.75	0.415	0.344	0.135	9.95
6/22/98	420	4779	7.24	299.9	424.1	521.3	0.17	31.2	0.033	3063.9	0.016	350.7	4.77	9.81	0.396	0.309	0.112	11.64
7/6/98	429	4605	7.52	304.3	400.8	466.5	0.21	36.7	0.394	3227.2	0.001	129.4	4.58	9.31	0.057	0.09	0.005	2.751
7/20/98	431	4971	7.18	307.1	436.8	534.4	0.17	38.8	0.399	3192.7	0.046	368.7	4.65	9.36	0.071	0.102	0.006	10.39
8/3/98	478	4839	7.23	303.8	392.9	525.6	0.14	42.4	0.414	3116.1	0.009	366.9	4.66	9.14	0.072	0.122	0.008	10.82
8/17/98	425	5022	7.25	311.4	428.8	518.4	0.14	38.2	0.437	3267.2	0.01	366.4	4.63	9.57	0.057	0.143	0.012	10.94
Min	251	1889	6.7	120.3	96.2	154.5	0.01	15.8	0	1036.1	0.001	32.3	1.71	0	0.043	0	0	0
Max	642	6940	8.51	543.9	833.8	568.3	0.43	126.8	29.583	4751	0.137	433.8	8	30.2	1.624	1.049	4.863	47.55
Mean	470.8471	4918.671	7.391176	276.9635	465.6082	490.8259	0.193294	60.87765	0.454247	3257.15	0.013788	287.0506	4.103294	12.43859	0.568024	0.186212	0.147894	14.89222
Median	460	4738	7.29	292.9	422.9	495.7	0.18	60.7	0.034	3117.35	0.01	313.9	4.26	12.25	0.411	0.136	0.003	9.437
95-pement	391.4	4044.4	6.96	144.78	336.06	430.94	0.112	29.9	0.013	2681.87	0.0044	122.46	2.702	6.036	0.0646	0	0	0.2068

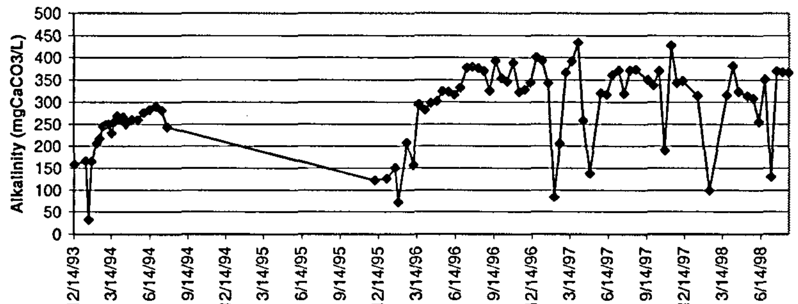
Cell 10B

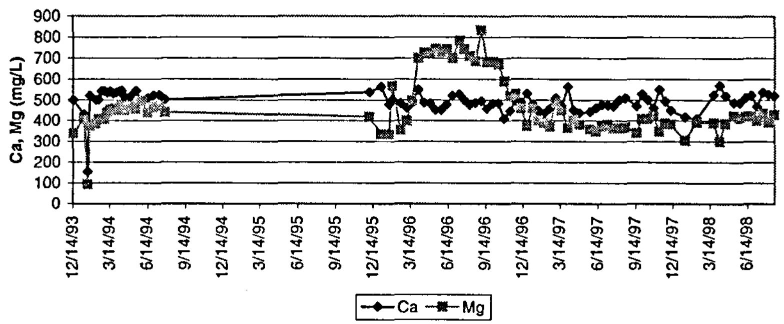

EC (mS/m)


pH

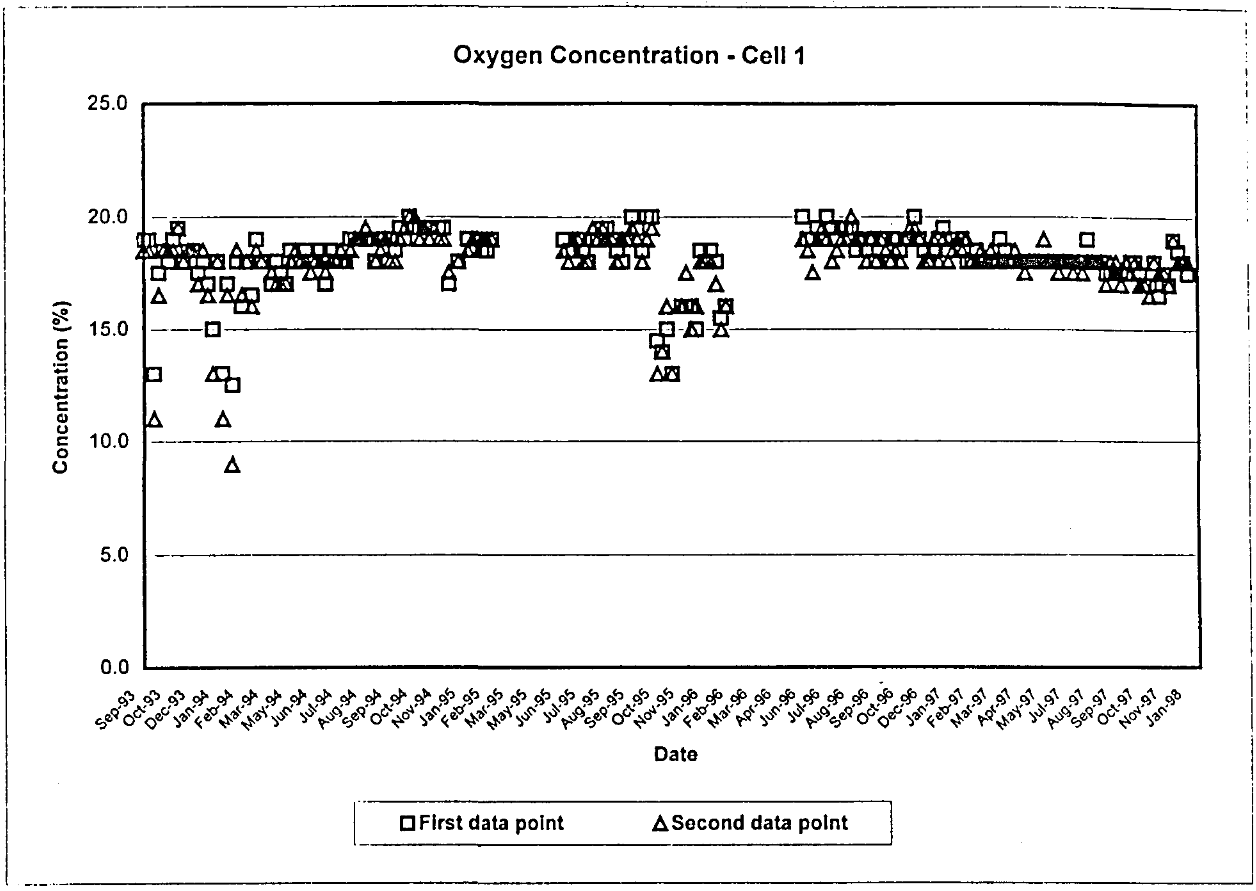

TDS, SO4, Ca (mg/L)
TDS
SO4

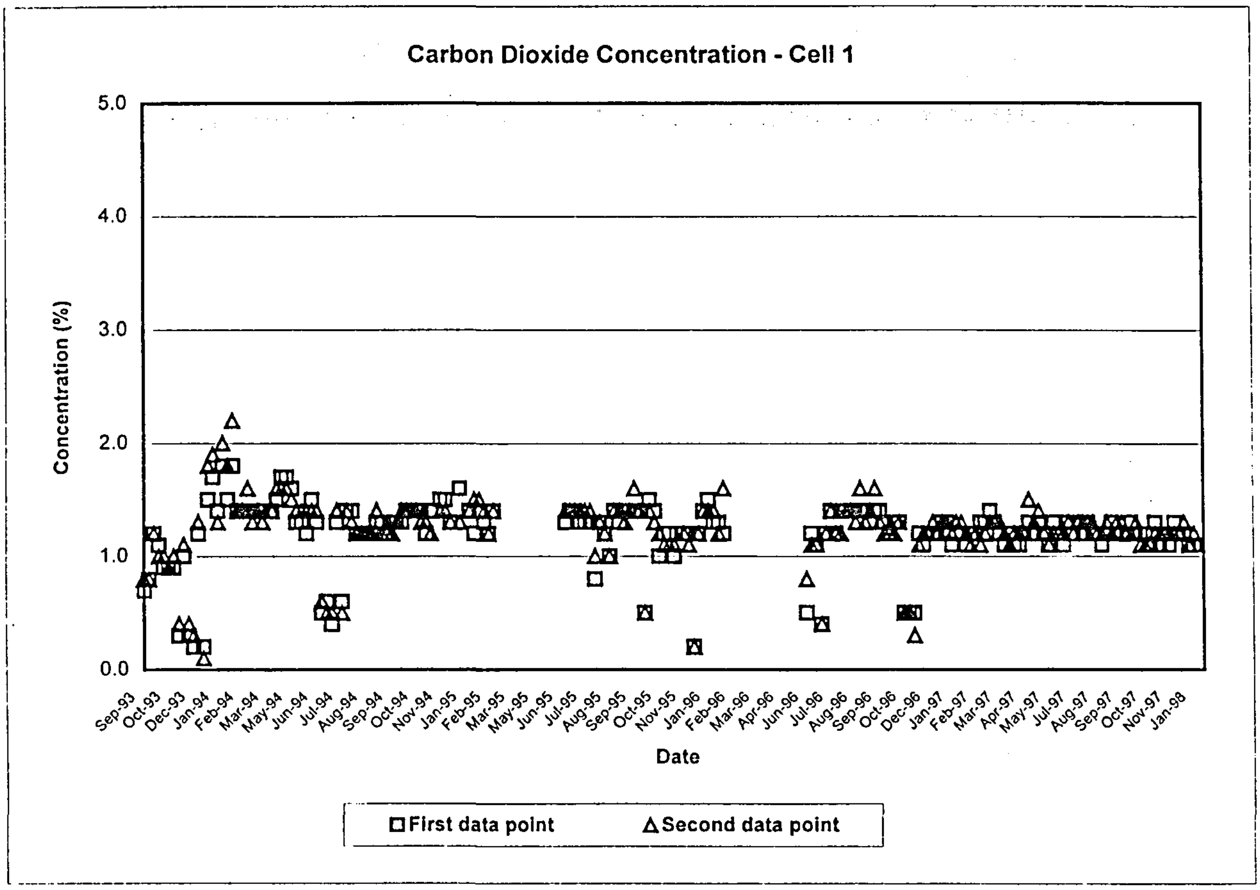

Al, Fe, Mn (mg/L)
Al
Fe
Mn

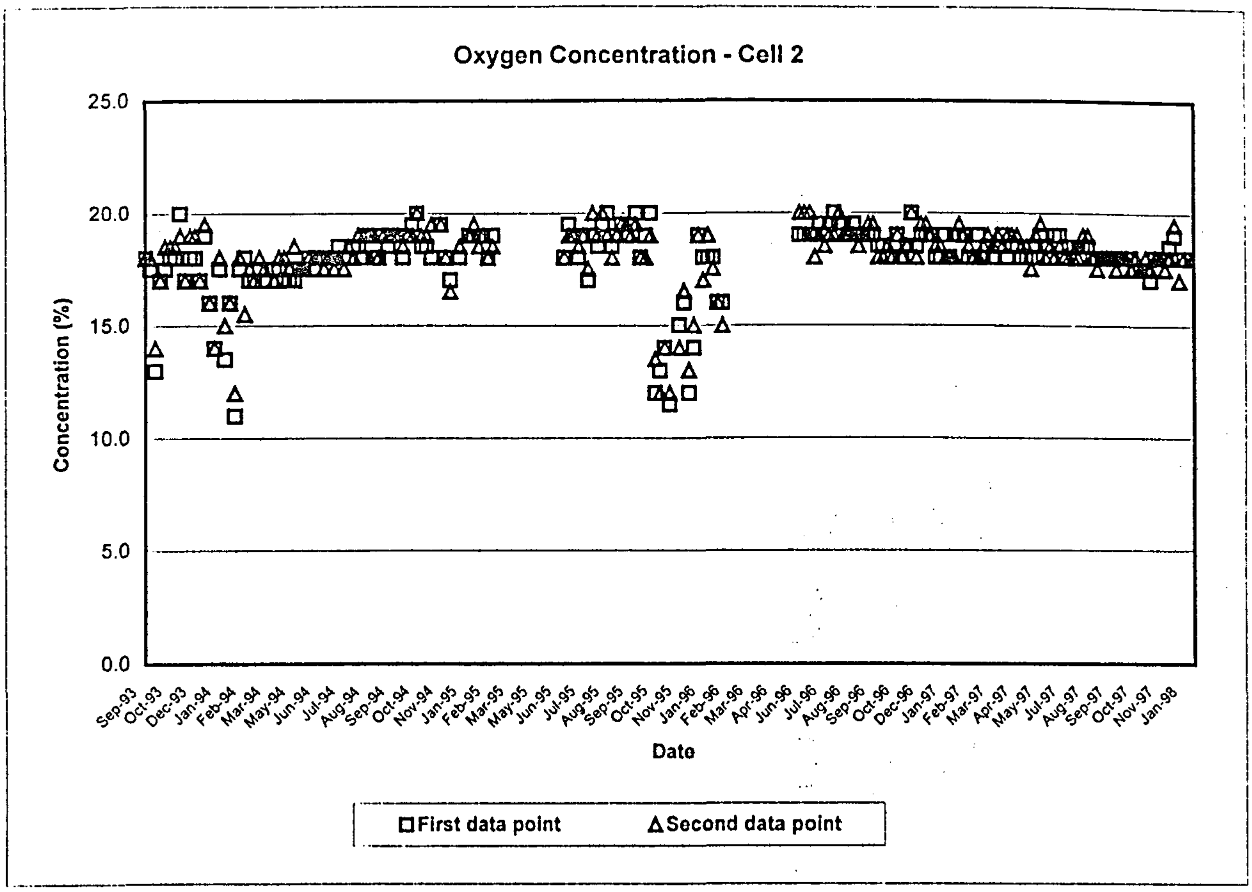

Alkalinity (mgCaCO3/L)


Ca, Mg (mg/L)
Ca
Mg

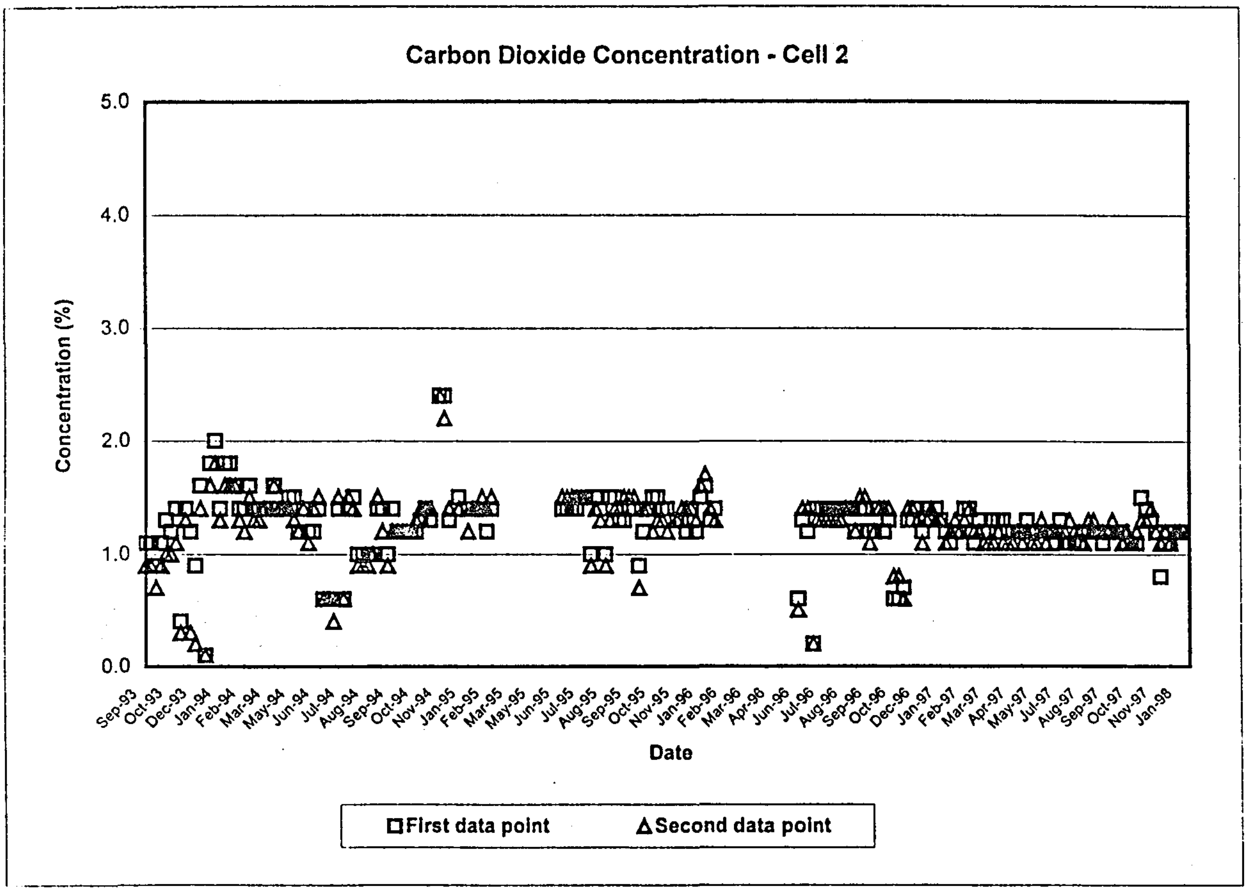
CARBON DIOXIDE ($C0_2$) AND OXYGEN (0_2) RESULTS


Oxygen Concentration - Cell 1
25.0
20.0
15.0
10.0
5.0
0.0
Concentration (%)
Sep-93 Oct-93 Dec-93 Jan-94 Feb-94 Mar-94 May-94 Jun-94 Jul-94 Aug-94 Sep-94 Oct-94 Nov-94 Jan-95 Feb-95 Mar-95 May-95 Jun-95 Jul-95 Aug-95 Sep-95 Oct-95 Nov-95 Jan-96 Feb-96 Mar-96 Apr-96 Jun-96 Jul-96 Aug-96 Sep-96 Oct-96 Dec-96 Jan-97 Feb-97 Mar-97 Apr-97 May-97 Jul-97 Aug-97 Sep-97 Oct-97 Nov-97 Jan-98
Date
□First data point
△Second data point

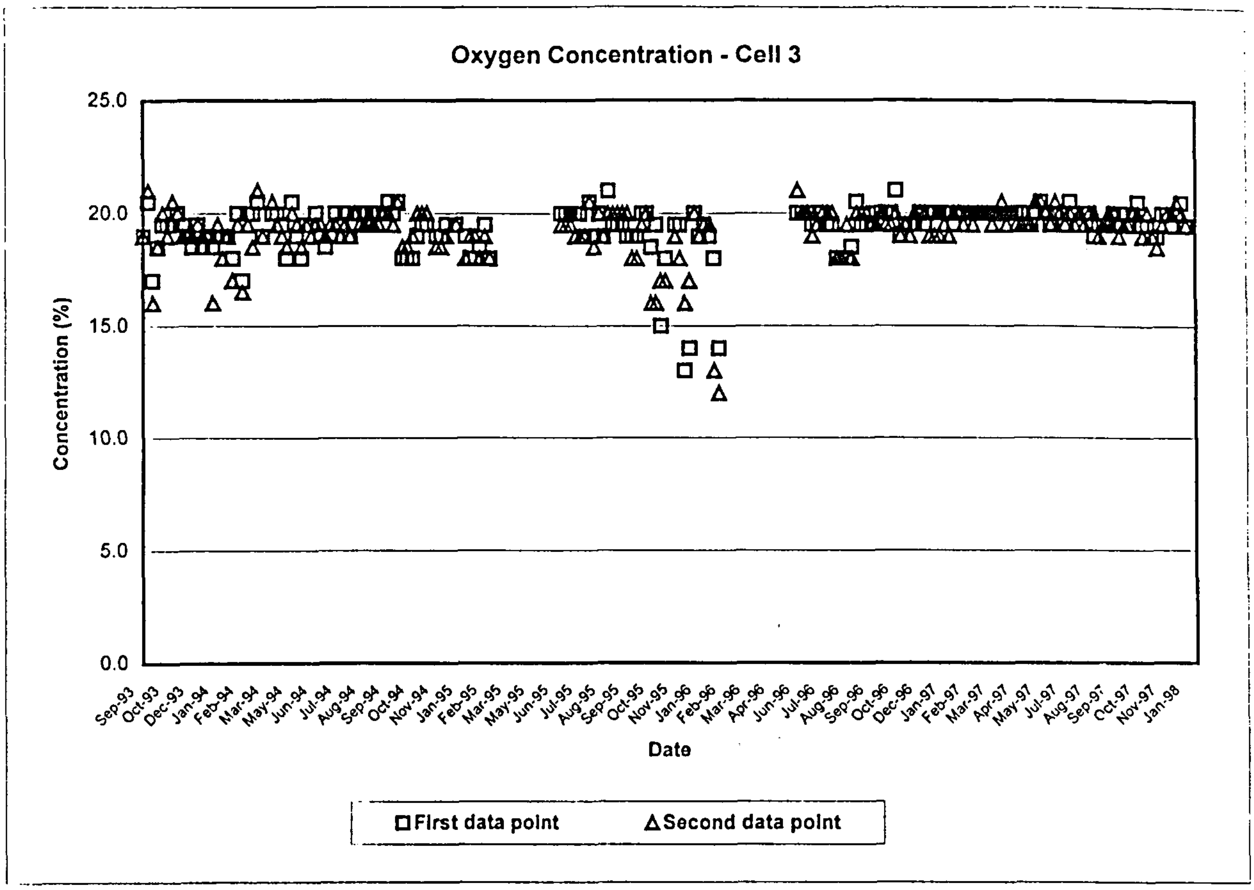

Carbon Dioxide Concentration - Cell 1
5.0
4.0
3.0
2.0
1.0
0.0
Concentration (%)
Sep-93 Oct-93 Dec-93 Jan-94 Feb-94 Mar-94 May-94 Jun-94 Jul-94 Aug-94 Sep-94 Oct-94 Nov-94 Jan-95 Feb-95 Mar-95 May-95 Jun-95 Jul-95 Aug-95 Sep-95 Oct-95 Nov-95 Jan-96 Feb-96 Mar-96 Apr-96 Jun-96 Jul-96 Aug-96 Sep-96 Oct-96 Dec-96 Jan-97 Feb-97 Mar-97 Apr-97 May-97 Jul-97 Aug-97 Sep-97 Oct-97 Nov-97 Jan-98
Date
□First data point
△Second data point



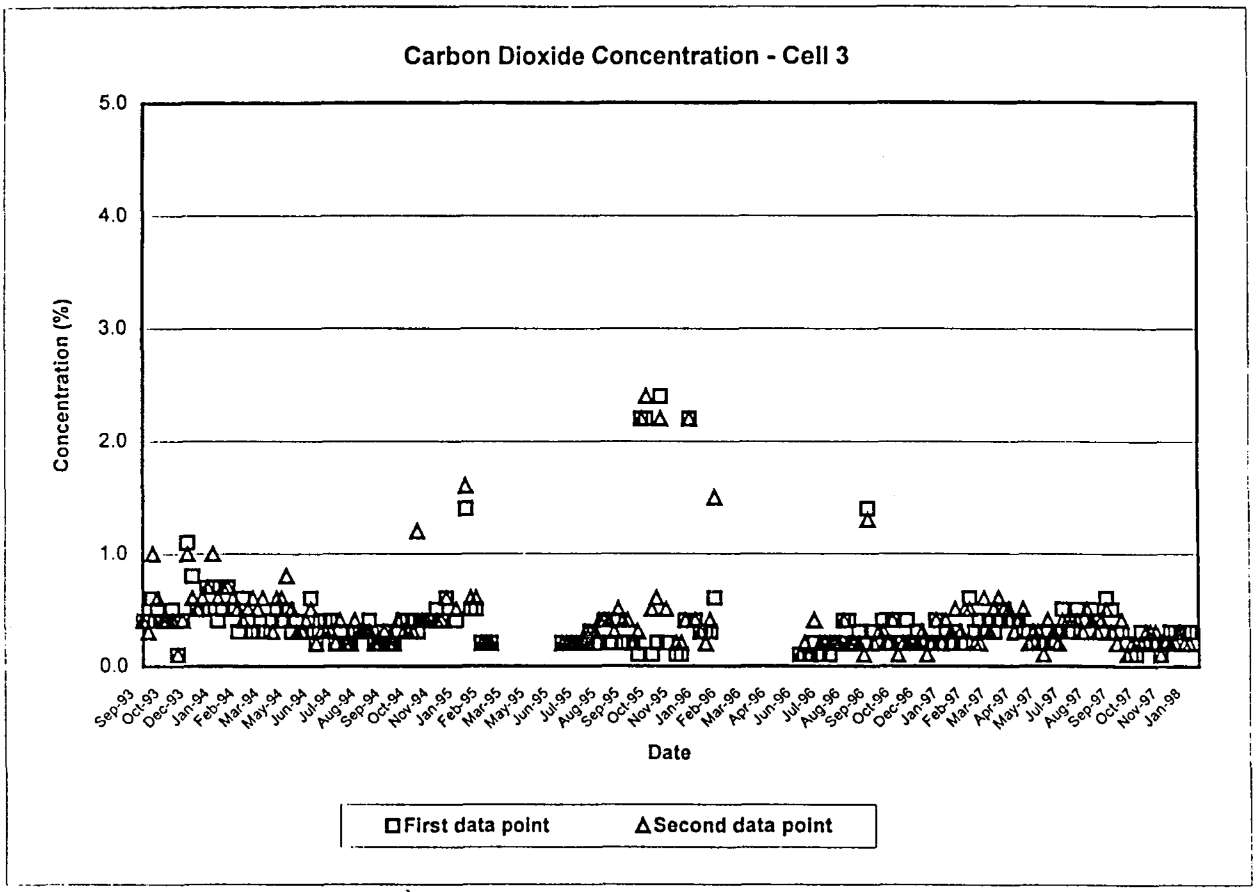
Oxygen Concentration - Cell 2
25.0
20.0
15.0
10.0
5.0
0.0
Concentration (%)
Sep-93 Oct-93 Dec-93 Jan-94 Feb-94 Mar-94 May-94 Jun-94 Jul-94 Aug-94 Sep-94 Oct-94 Nov-94 Jan-95 Feb-95 Mar-95 May-95 Jun-95 Jul-95 Aug-95 Sep-95 Oct-95 Nov-95 Jan-96 Feb-96 Mar-96 Apr-96 Jun-96 Jul-96 Aug-96 Sep-96 Oct-96 Dec-96 Jan-97 Feb-97 Mar-97 Apr-97 May-97 Jul-97 Aug-97 Sep-97 Oct-97 Nov-97 Jan-98
Date
First data point
Second data point



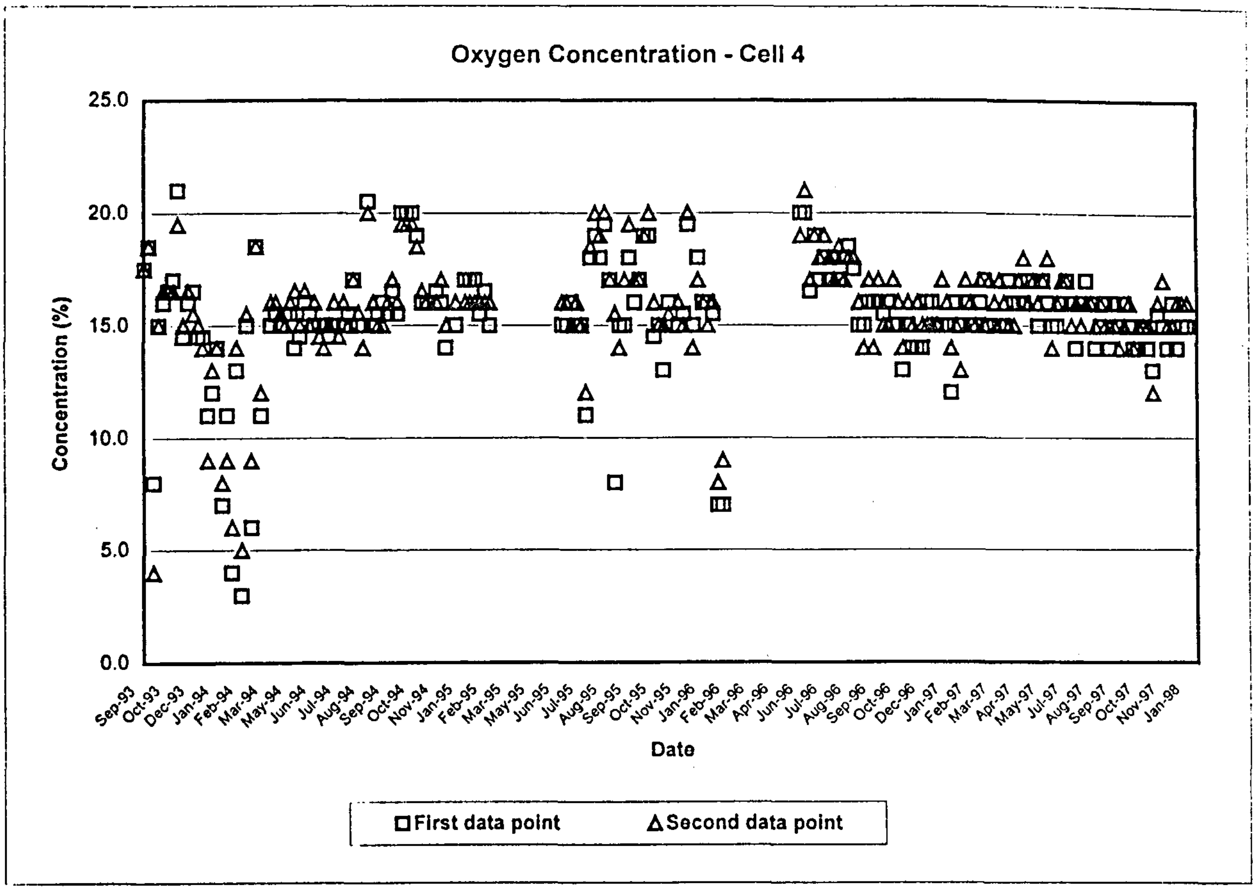
Carbon Dioxide Concentration - Cell 2
5.0
4.0
3.0
2.0
1.0
0.0
Concentration (%)
Sep-93 Oct-93 Dec-93 Jan-94 Feb-94 Mar-94 May-94 Jun-94 Jul-94 Aug-94 Sep-94 Oct-94 Nov-94 Jan-95 Feb-95 Mar-95 May-95 Jun-95 Jul-95 Aug-95 Sep-95 Oct-95 Nov-95 Jan-96 Feb-96 Mar-96 Apr-96 Jun-96 Jul-96 Aug-96 Sep-96 Oct-96 Dec-96 Jan-97 Feb-97 Mar-97 Apr-97 May-97 Jul-97 Aug-97 Sep-97 Oct-97 Nov-97 Jan-98
Date
First data point
Second data point

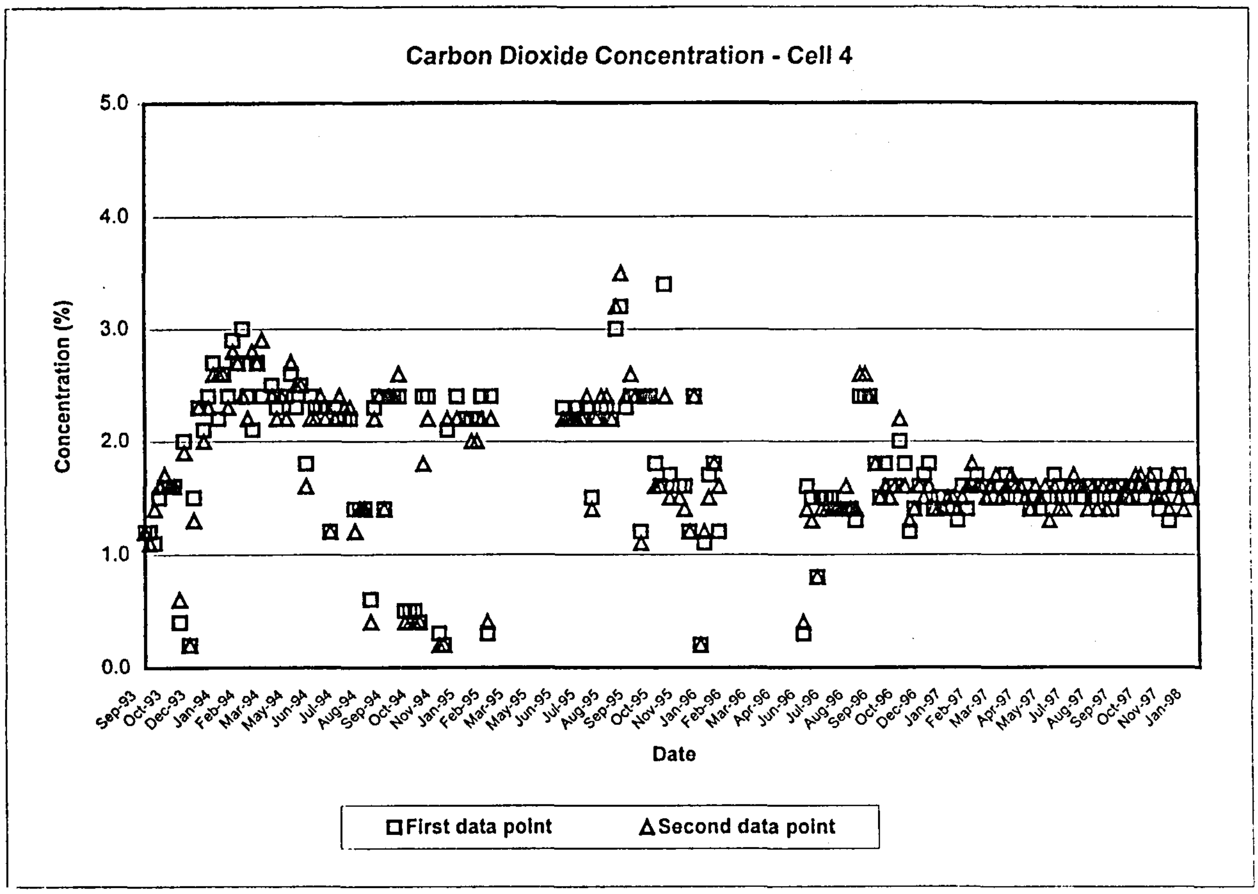


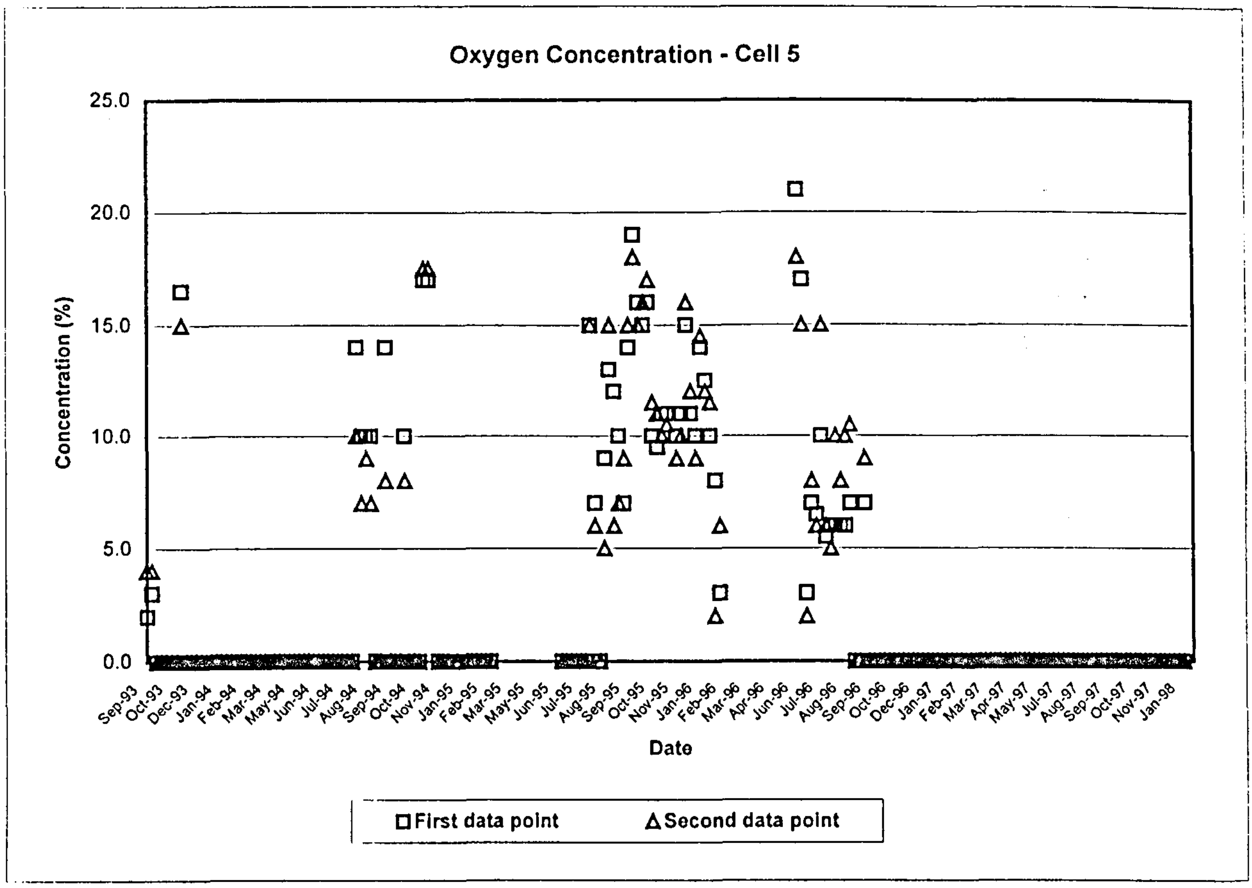
Oxygen Concentration - Cell 3
Concentration (%)
25.0
20.0
15.0
10.0
5.0
0.0
Sep-93 Oct-93 Dec-93 Jan-94 Feb-94 Mar-94 May-94 Jun-94 Jul-94 Aug-94 Sep-94 Oct-94 Nov-94 Jan-95 Feb-95 Mar-95 May-95 Jun-95 Jul-95 Aug-95 Sep-95 Oct-95 Nov-95 Jan-96 Feb-96 Mar-96 Apr-96 Jun-96 Jul-96 Aug-96 Sep-96 Oct-96 Dec-96 Jan-97 Feb-97 Mar-97 Apr-97 May-97 Jul-97 Aug-97 Sep-97 Oct-97 Nov-97 Jan-98
Date
First data point
Second data point



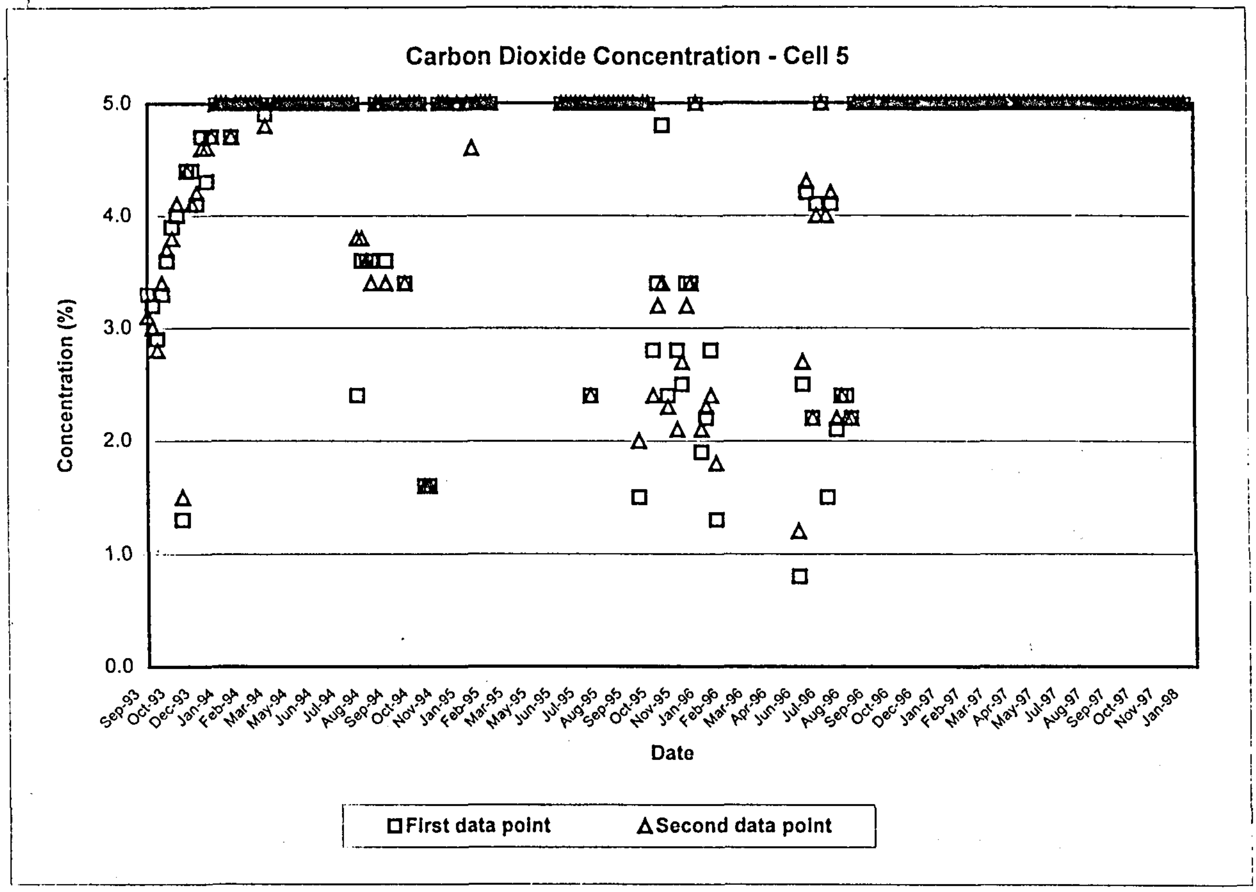
Carbon Dioxide Concentration - Cell 3
Concentration (%)
5.0
4.0
3.0
2.0
1.0
0.0
Sep-93 Oct-93 Dec-93 Jan-94 Feb-94 Mar-94 May-94 Jun-94 Jul-94 Aug-94 Sep-94 Oct-94 Nov-94 Jan-95 Feb-95 Mar-95 May-95 Jun-95 Jul-95 Aug-95 Sep-95 Oct-95 Nov-95 Jan-96 Feb-96 Mar-96 Apr-96 Jun-96 Jul-96 Aug-96 Sep-96 Oct-96 Dec-96 Jan-97 Feb-97 Mar-97 Apr-97 May-97 Jul-97 Aug-97 Sep-97 Oct-97 Nov-97 Jan-98
Date
First data point
Second data point


Oxygen Concentration - Cell 4
Concentration (%)
25.0
20.0
15.0
10.0
5.0
0.0
Sep-93 Oct-93 Dec-93 Jan-94 Feb-94 Mar-94 May-94 Jun-94 Jul-94 Aug-94 Sep-94 Oct-94 Nov-94 Jan-95 Feb-95 Mar-95 May-95 Jun-95 Jul-95 Aug-95 Sep-95 Oct-95 Nov-95 Jan-96 Feb-96 Mar-96 Apr-96 Jun-96 Jul-96 Aug-96 Sep-96 Oct-96 Dec-96 Jan-97 Feb-97 Mar-97 Apr-97 May-97 Jul-97 Aug-97 Sep-97 Oct-97 Nov-97 Jan-98
Date
First data point
Second data point

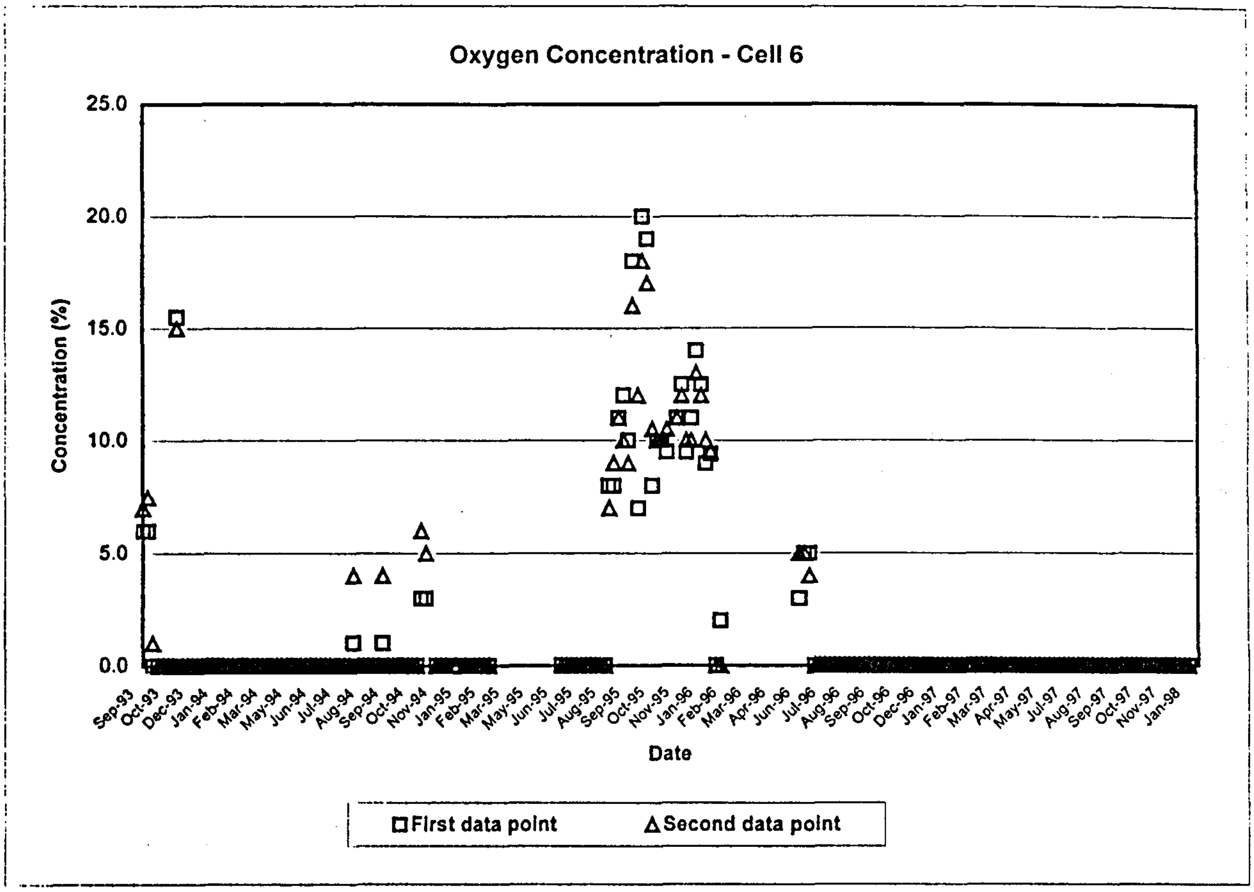

Carbon Dioxide Concentration - Cell 4
Concentration (%)
5.0
4.0
3.0
2.0
1.0
0.0
Sep-93 Oct-93 Dec-93 Jan-94 Feb-94 Mar-94 May-94 Jun-94 Jul-94 Aug-94 Sep-94 Oct-94 Nov-94 Jan-95 Feb-95 Mar-95 May-95 Jun-95 Jul-95 Aug-95 Sep-95 Oct-95 Nov-95 Jan-96 Feb-96 Mar-96 Apr-96 Jun-96 Jul-96 Aug-96 Sep-96 Oct-96 Dec-96 Jan-97 Feb-97 Mar-97 Apr-97 May-97 Jul-97 Aug-97 Sep-97 Oct-97 Nov-97 Jan-98
Date
First data point
Second data point

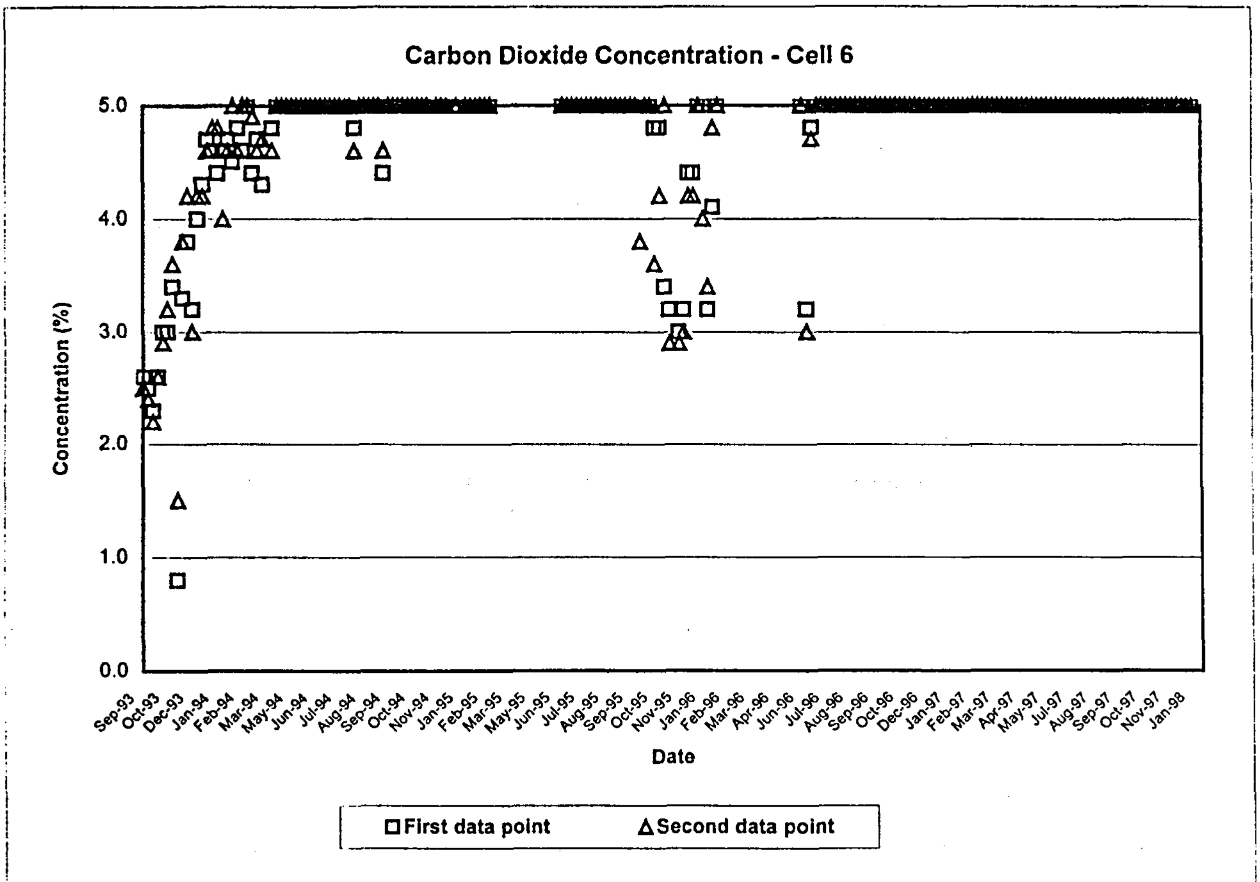


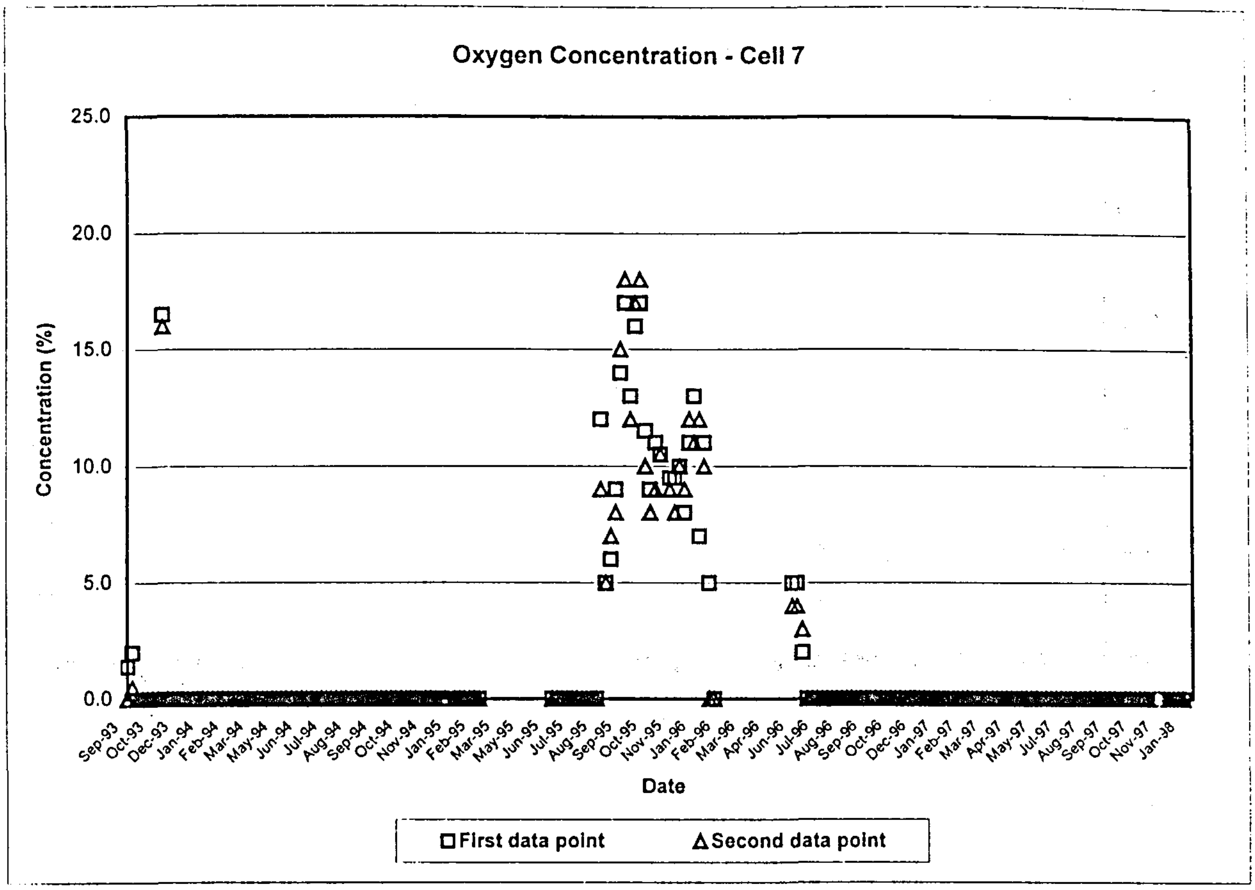
Oxygen Concentration - Cell 5
Concentration (%)
25.0
20.0
15.0
10.0
5.0
0.0
Sep-93 Oct-93 Dec-93 Jan-94 Feb-94 Mar-94 May-94 Jun-94 Jul-94 Aug-94 Sep-94 Oct-94 Nov-94 Jan-95 Feb-95 Mar-95 May-95 Jun-95 Jul-95 Aug-95 Sep-95 Oct-95 Nov-95 Jan-96 Feb-96 Mar-96 Apr-96 Jun-96 Jul-96 Aug-96 Sep-96 Oct-96 Dec-96 Jan-97 Feb-97 Mar-97 Apr-97 May-97 Jul-97 Aug-97 Sep-97 Oct-97 Nov-97 Jan-98
Date
First data point
Second data point



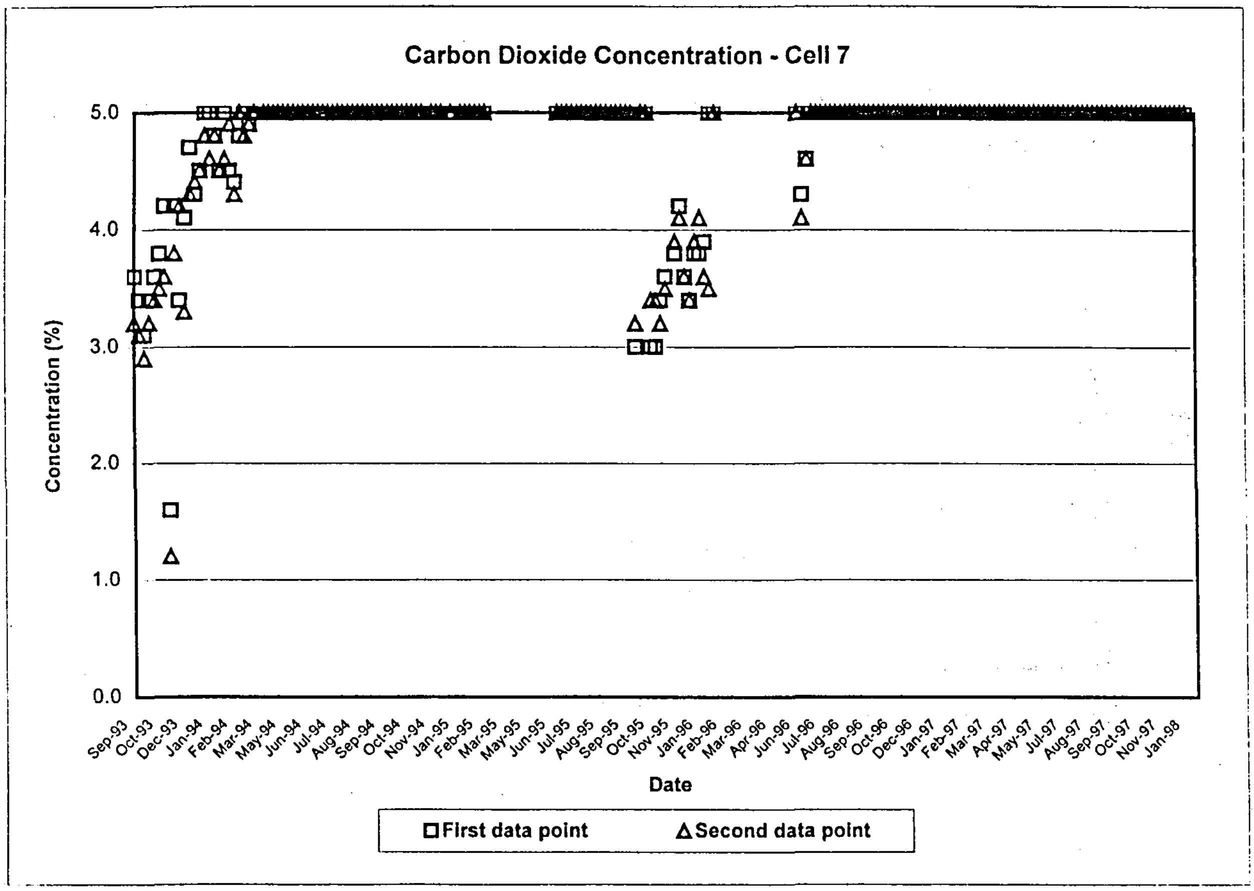
Carbon Dioxide Concentration - Cell 5
Concentration (%)
5.0
4.0
3.0
2.0
1.0
0.0
Sep-93 Oct-93 Dec-93 Jan-94 Feb-94 Mar-94 May-94 Jun-94 Jul-94 Aug-94 Sep-94 Oct-94 Nov-94 Jan-95 Feb-95 Mar-95 May-95 Jun-95 Jul-95 Aug-95 Sep-95 Oct-95 Nov-95 Jan-96 Feb-96 Mar-96 Apr-96 Jun-96 Jul-96 Aug-96 Sep-96 Oct-96 Dec-96 Jan-97 Feb-97 Mar-97 Apr-97 May-97 Jul-97 Aug-97 Sep-97 Oct-97 Nov-97 Jan-98
Date
First data point
Second data point


Oxygen Concentration - Cell 6
Concentration (%)
25.0
20.0
15.0
10.0
5.0
0.0
Sep-93 Oct-93 Dec-93 Jan-94 Feb-94 Mar-94 May-94 Jun-94 Jul-94 Aug-94 Sep-94 Oct-94 Nov-94 Jan-95 Feb-95 Mar-95 May-95 Jun-95 Jul-95 Aug-95 Sep-95 Oct-95 Nov-95 Jan-96 Feb-96 Mar-96 Apr-96 Jun-96 Jul-96 Aug-96 Sep-96 Oct-96 Dec-96 Jan-97 Feb-97 Mar-97 Apr-97 May-97 Jul-97 Aug-97 Sep-97 Oct-97 Nov-97 Jan-98
Date
First data point
Second data point

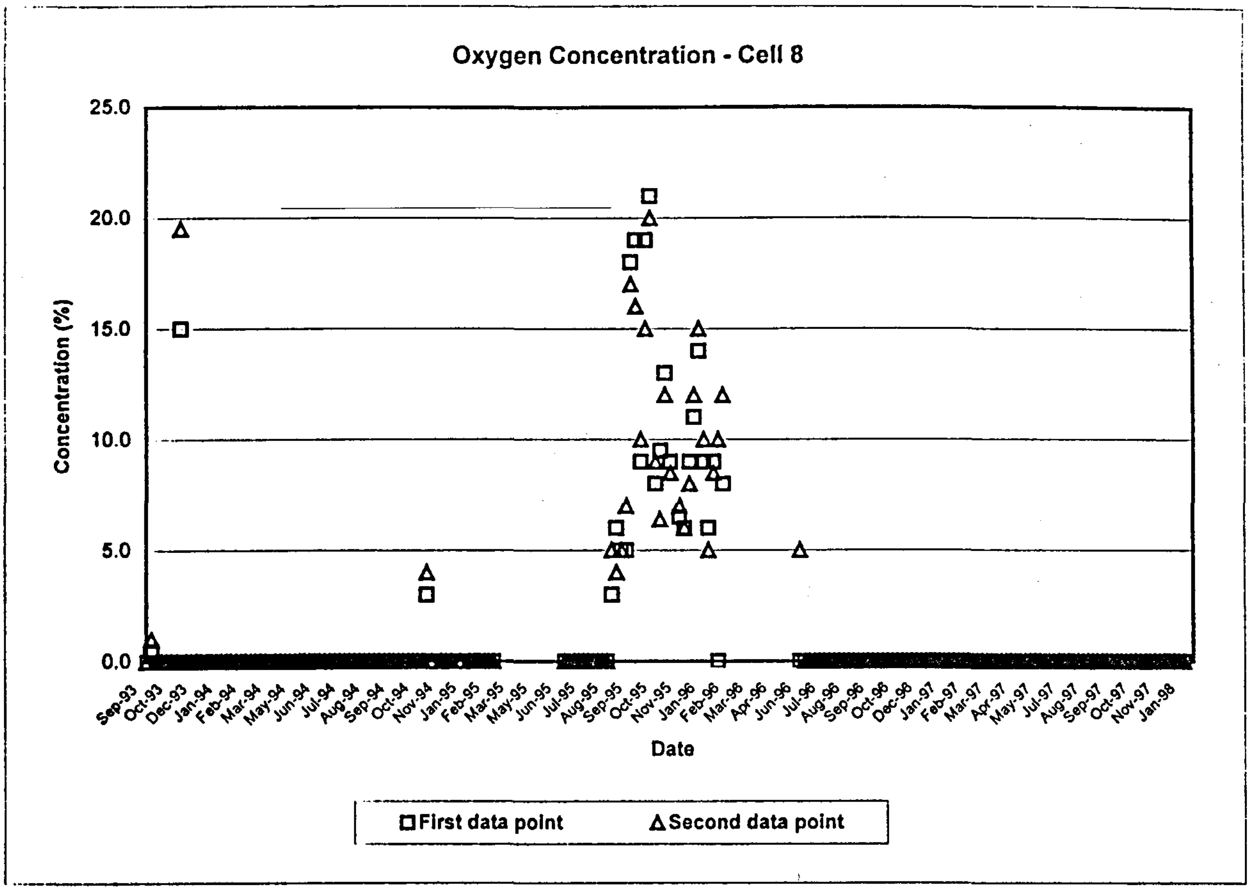

Carbon Dioxide Concentration - Cell 6
Concentration (%)
5.0
4.0
3.0
2.0
1.0
0.0
Sep-93 Oct-93 Dec-93 Jan-94 Feb-94 Mar-94 May-94 Jun-94 Jul-94 Aug-94 Sep-94 Oct-94 Nov-94 Jan-95 Feb-95 Mar-95 May-95 Jun-95 Jul-95 Aug-95 Sep-95 Oct-95 Nov-95 Jan-96 Feb-96 Mar-96 Apr-96 Jun-96 Jul-96 Aug-96 Sep-96 Oct-96 Dec-96 Jan-97 Feb-97 Mar-97 Apr-97 May-97 Jul-97 Aug-97 Sep-97 Oct-97 Nov-97 Jan-98
Date
First data point
Second data point

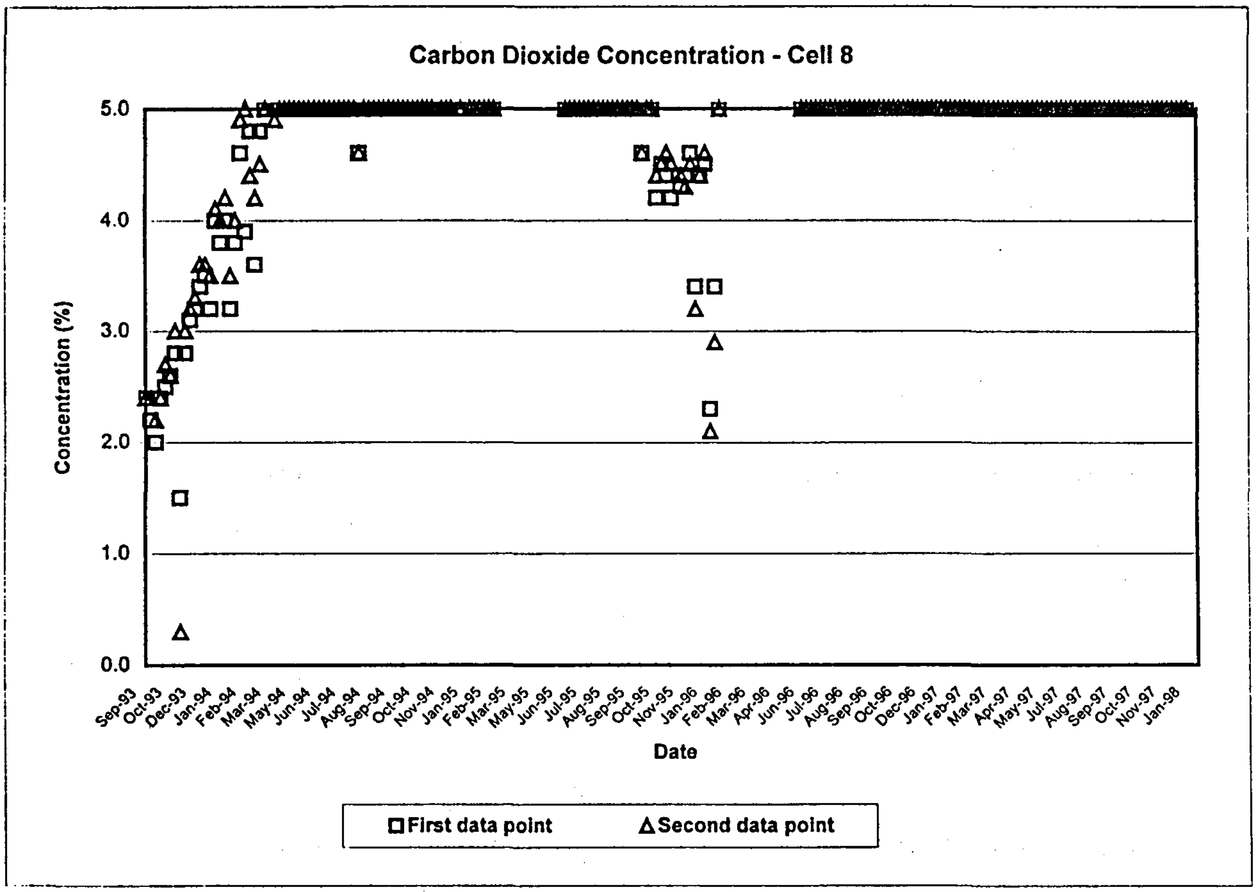


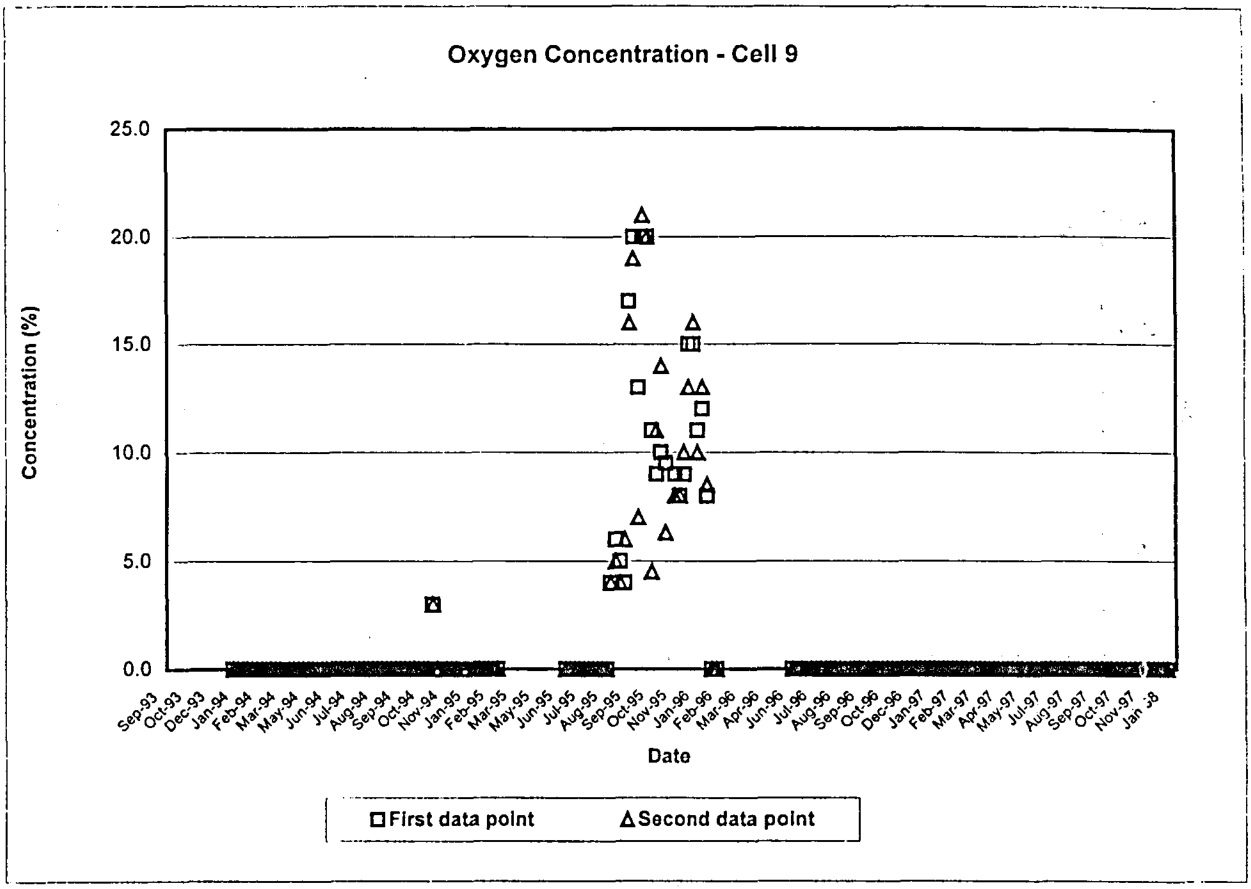
Oxygen Concentration - Cell 7
Concentration (%)
25.0
20.0
15.0
10.0
5.0
0.0
Sep-93 Oct-93 Dec-93 Jan-94 Feb-94 Mar-94 May-94 Jun-94 Jul-94 Aug-94 Sep-94 Oct-94 Nov-94 Jan-95 Feb-95 Mar-95 May-95 Jun-95 Jul-95 Aug-95 Sep-95 Oct-95 Nov-95 Jan-96 Feb-96 Mar-96 Apr-96 Jun-96 Jul-96 Aug-96 Sep-96 Oct-96 Dec-96 Jan-97 Feb-97 Mar-97 Apr-97 May-97 Jul-97 Aug-97 Sep-97 Oct-97 Nov-97 Jan-98
Date
First data point
Second data point

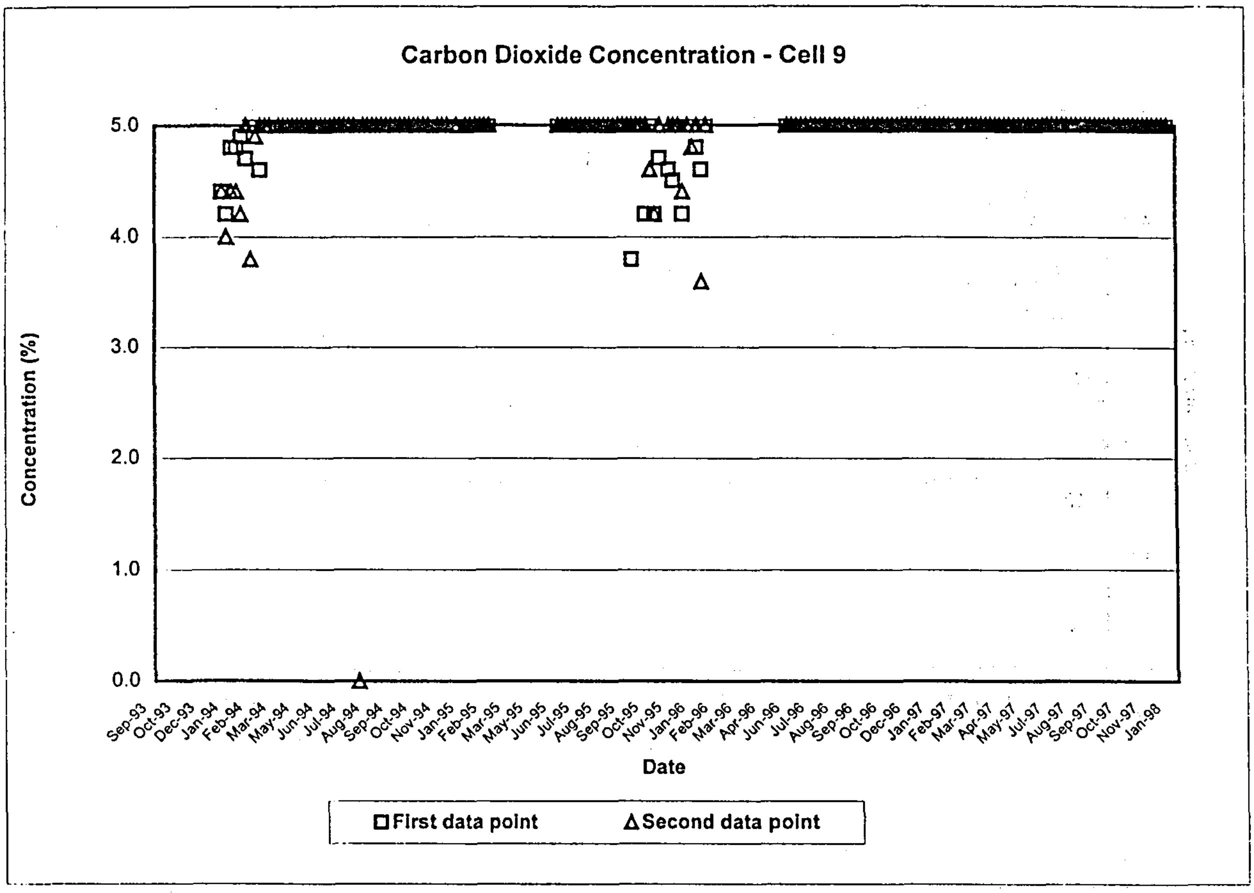


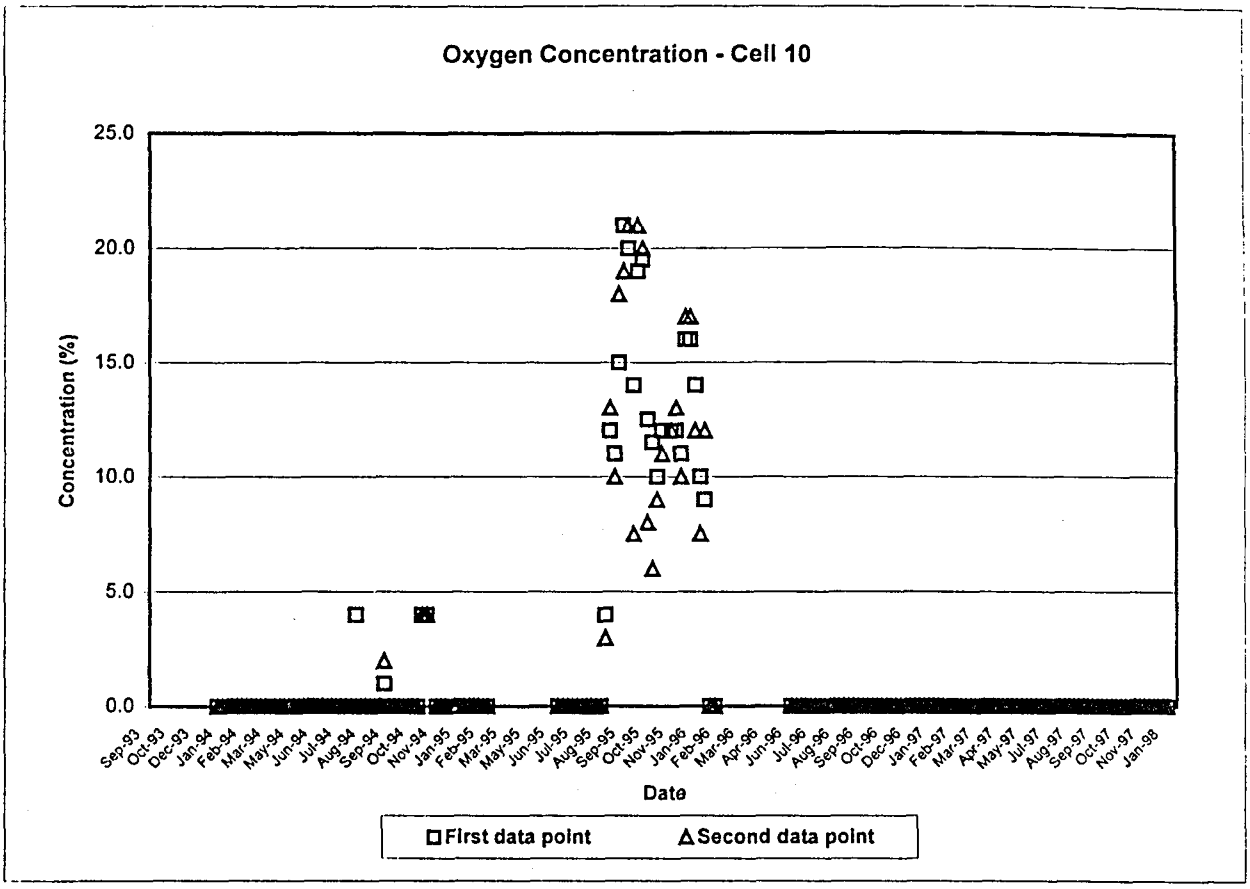
Carbon Dioxide Concentration - Cell 7
Concentration (%)
5.0
4.0
3.0
2.0
1.0
0.0
Sep-93 Oct-93 Dec-93 Jan-94 Feb-94 Mar-94 May-94 Jun-94 Jul-94 Aug-94 Sep-94 Oct-94 Nov-94 Jan-95 Feb-95 Mar-95 May-95 Jun-95 Jul-95 Aug-95 Sep-95 Oct-95 Nov-95 Jan-96 Feb-96 Mar-96 Apr-96 Jun-96 Jul-96 Aug-96 Sep-96 Oct-96 Dec-96 Jan-97 Feb-97 Mar-97 Apr-97 May-97 Jul-97 Aug-97 Sep-97 Oct-97 Nov-97 Jan-98
Date
First data point
Second data point


Oxygen Concentration - Cell 8
Concentration (%)
25.0
20.0
15.0
10.0
5.0
0.0
Date
First data point
Second data point

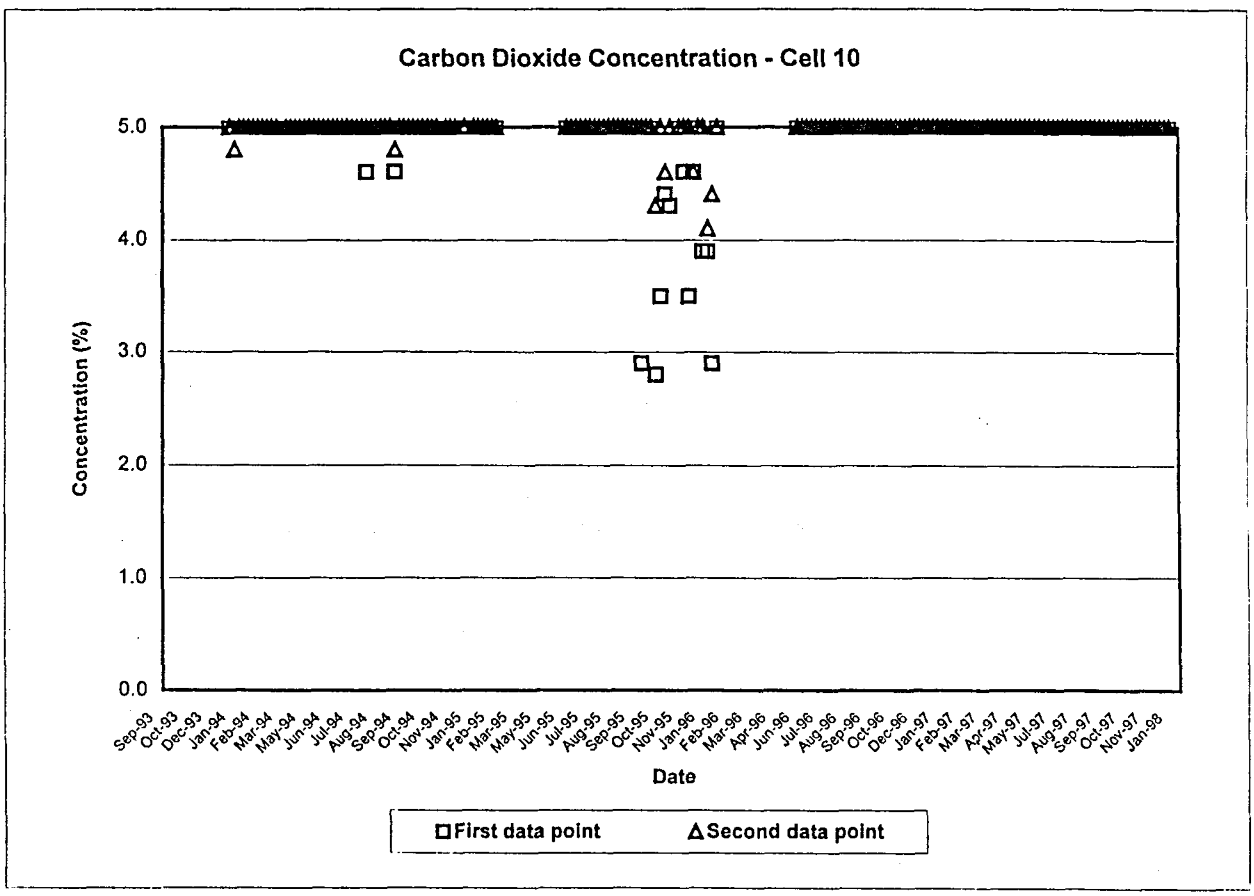

Carbon Dioxide Concentration - Cell 8
Concentration (%)
5.0
4.0
3.0
2.0
1.0
0.0
Date
First data point
Second data point


Oxygen Concentration - Cell 9
Concentration (%)
25.0
20.0
15.0
10.0
5.0
0.0
Sep-93 Oct-93 Dec-93 Jan-94 Feb-94 Mar-94 May-94 Jun-94 Jul-94 Aug-94 Sep-94 Oct-94 Nov-94 Jan-95 Feb-95 Mar-95 May-95 Jun-95 Jul-95 Aug-95 Sep-95 Oct-95 Nov-95 Jan-96 Feb-96 Mar-96 Apr-96 Jun-96 Jul-96 Aug-96 Sep-96 Oct-96 Dec-96 Jan-97 Feb-97 Mar-97 Apr-97 May-97 Jul-97 Aug-97 Sep-97 Oct-97 Nov-97 Jan-98
Date
First data point
Second data point

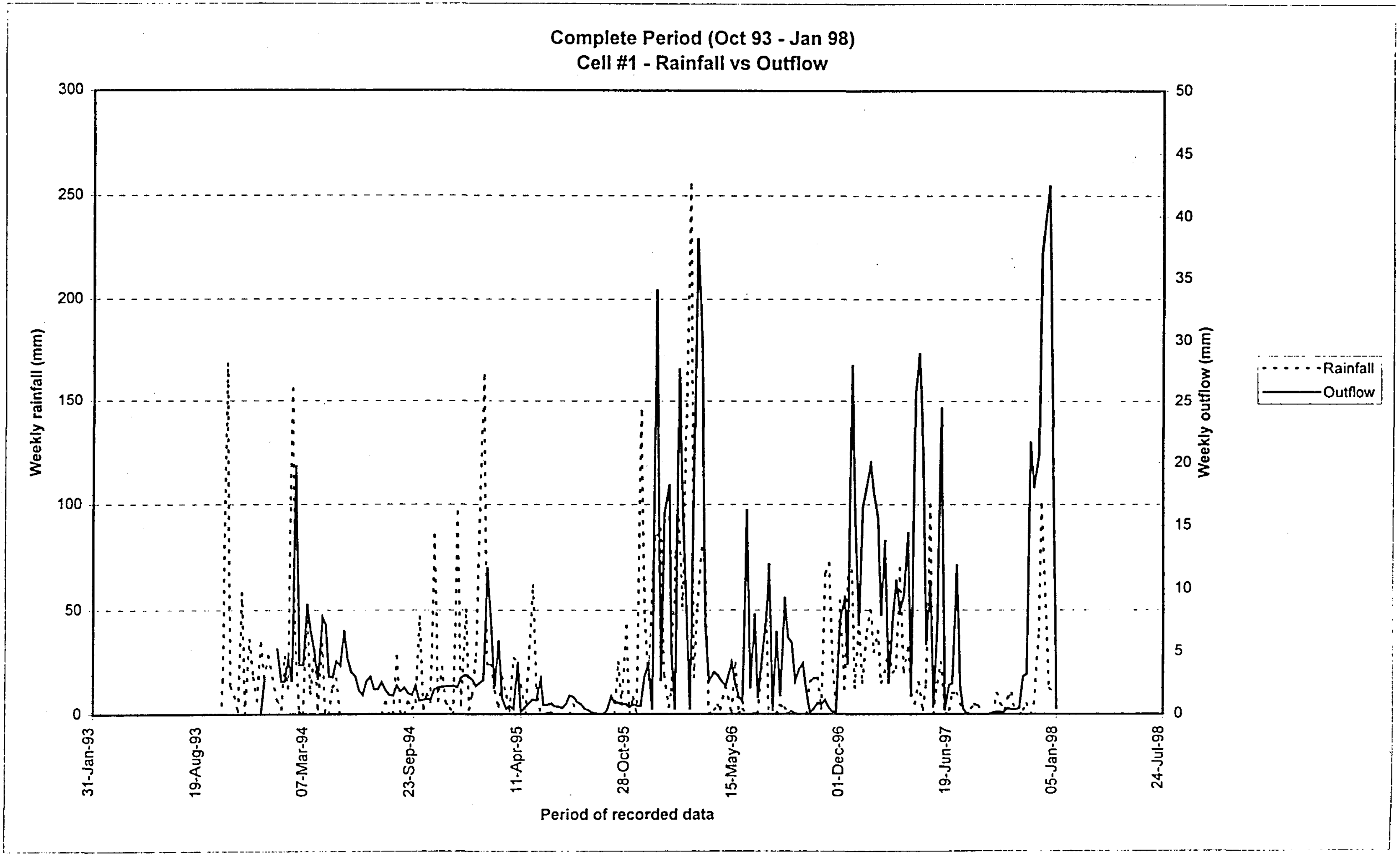

Carbon Dioxide Concentration - Cell 9
Concentration (%)
5.0
4.0
3.0
2.0
1.0
0.0
Sep-93 Oct-93 Dec-93 Jan-94 Feb-94 Mar-94 May-94 Jun-94 Jul-94 Aug-94 Sep-94 Oct-94 Nov-94 Jan-95 Feb-95 Mar-95 May-95 Jun-95 Jul-95 Aug-95 Sep-95 Oct-95 Nov-95 Jan-96 Feb-96 Mar-96 Apr-96 Jun-96 Jul-96 Aug-96 Sep-96 Oct-96 Dec-96 Jan-97 Feb-97 Mar-97 Apr-97 May-97 Jul-97 Aug-97 Sep-97 Oct-97 Nov-97 Jan-98
Date
First data point
Second data point

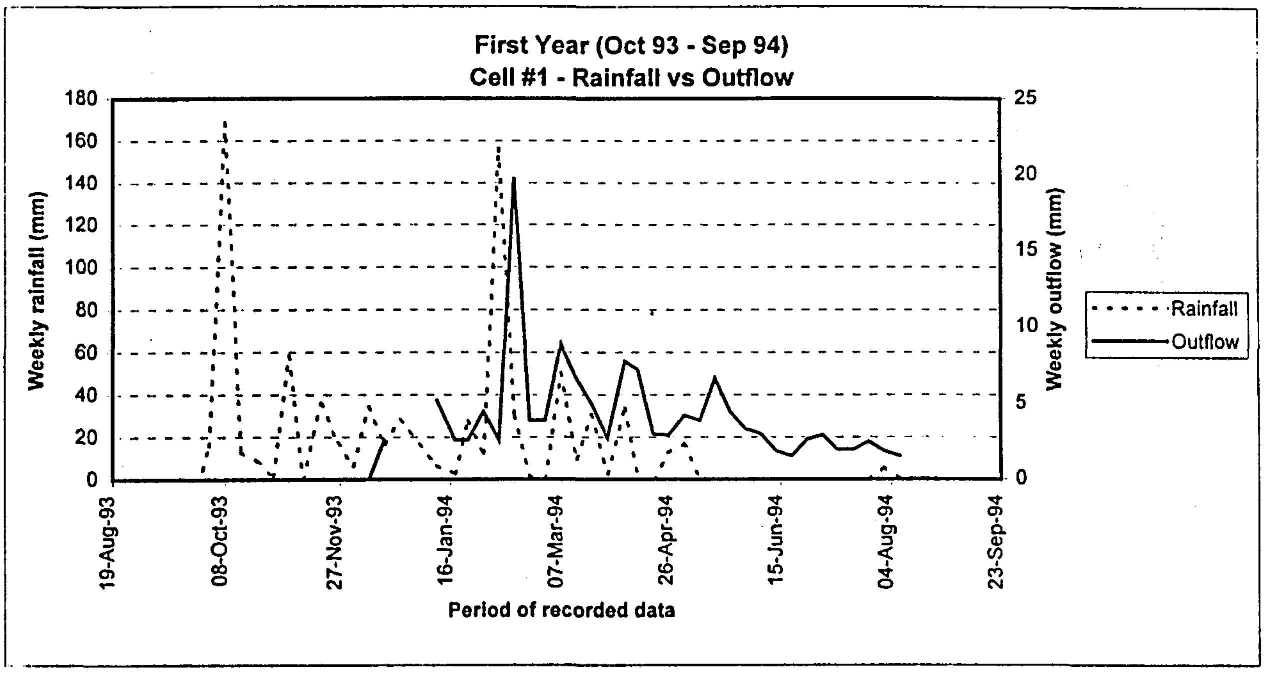


Oxygen Concentration - Cell 10
Concentration (%)
25.0
20.0
15.0
10.0
5.0
0.0
Sep-93 Oct-93 Dec-93 Jan-94 Feb-94 Mar-94 May-94 Jun-94 Jul-94 Aug-94 Sep-94 Oct-94 Nov-94 Jan-95 Feb-95 Mar-95 May-95 Jun-95 Jul-95 Aug-95 Sep-95 Oct-95 Nov-95 Jan-96 Feb-96 Mar-96 Apr-96 Jun-96 Jul-96 Aug-96 Sep-96 Oct-96 Dec-96 Jan-97 Feb-97 Mar-97 Apr-97 May-97 Jul-97 Aug-97 Sep-97 Oct-97 Nov-97 Jan-98
Date
First data point
Second data point

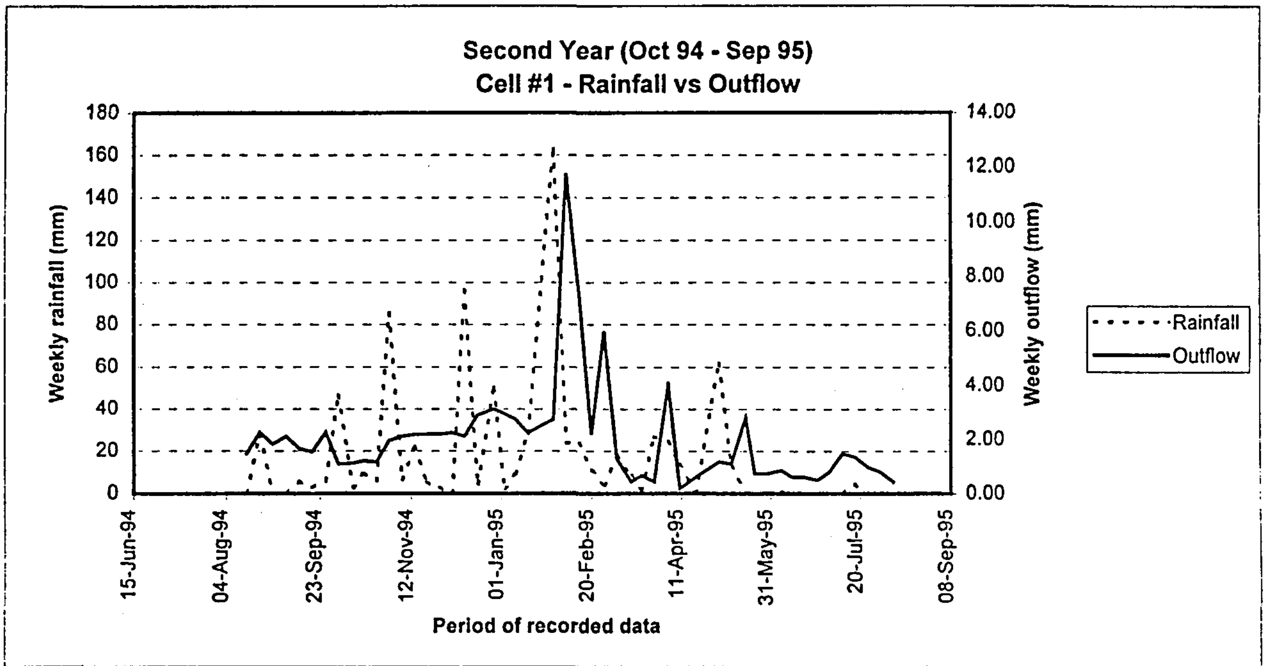


Carbon Dioxide Concentration - Cell 10
Concentration (%)
5.0
4.0
3.0
2.0
1.0
0.0
Sep-93 Oct-93 Dec-93 Jan-94 Feb-94 Mar-94 May-94 Jun-94 Jul-94 Aug-94 Sep-94 Oct-94 Nov-94 Jan-95 Feb-95 Mar-95 May-95 Jun-95 Jul-95 Aug-95 Sep-95 Oct-95 Nov-95 Jan-96 Feb-96 Mar-96 Apr-96 Jun-96 Jul-96 Aug-96 Sep-96 Oct-96 Dec-96 Jan-97 Feb-97 Mar-97 Apr-97 May-97 Jul-97 Aug-97 Sep-97 Oct-97 Nov-97 Jan-98
Date
First data point
Second data point

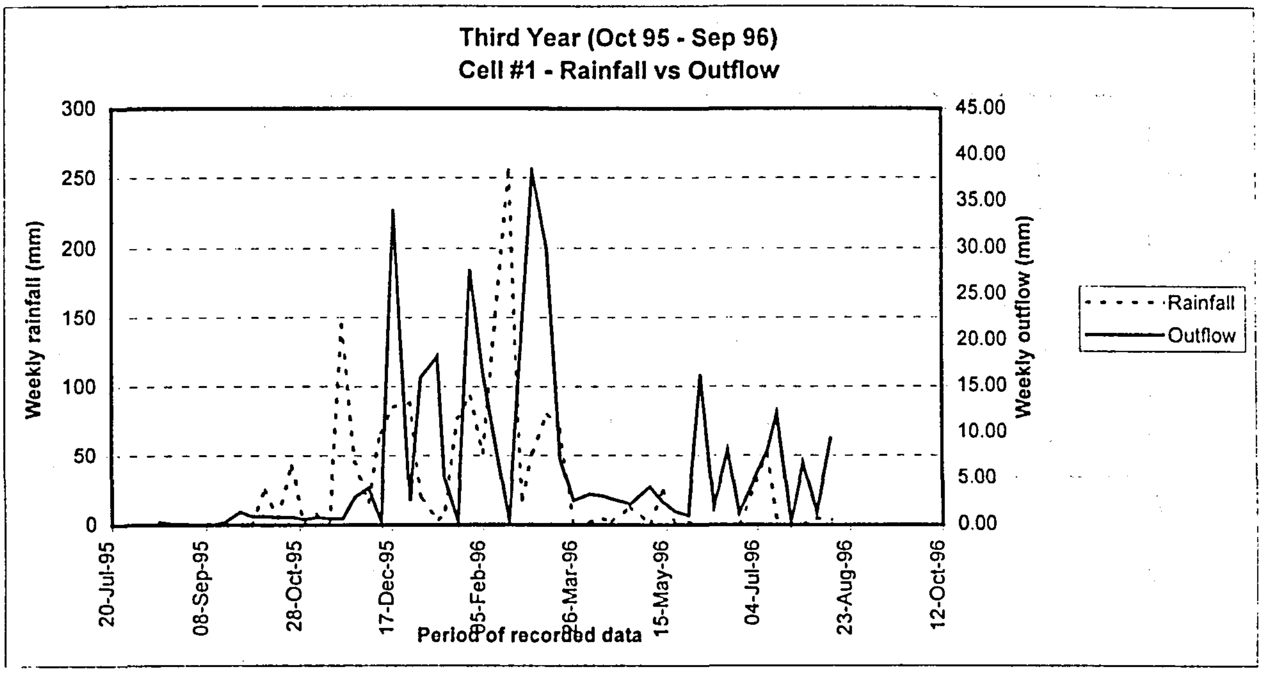

Complete Period (Oct 93 - Jan 98)
Cell #1 - Rainfall vs Outflow
Weekly rainfall (mm)
Weekly outflow (mm)
Period of recorded data
Rainfall
Outflow
0
50
100
150
200
250
300
5
10
15
20
25
30
35
40
45
31-Jan-93
19-Aug-93
07-Mar-94
23-Sep-94
11-Apr-95
28-Oct-95
15-May-96
01-Dec-96
19-Jun-97
05-Jan-98
24-Jul-98

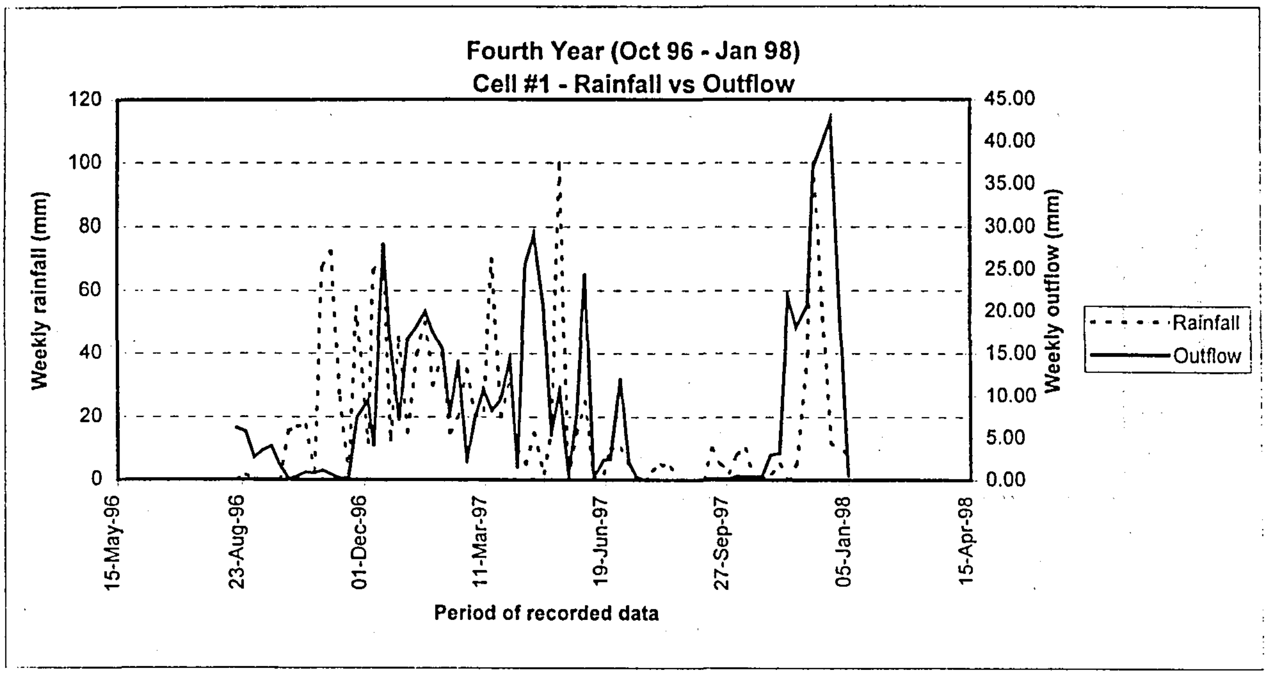


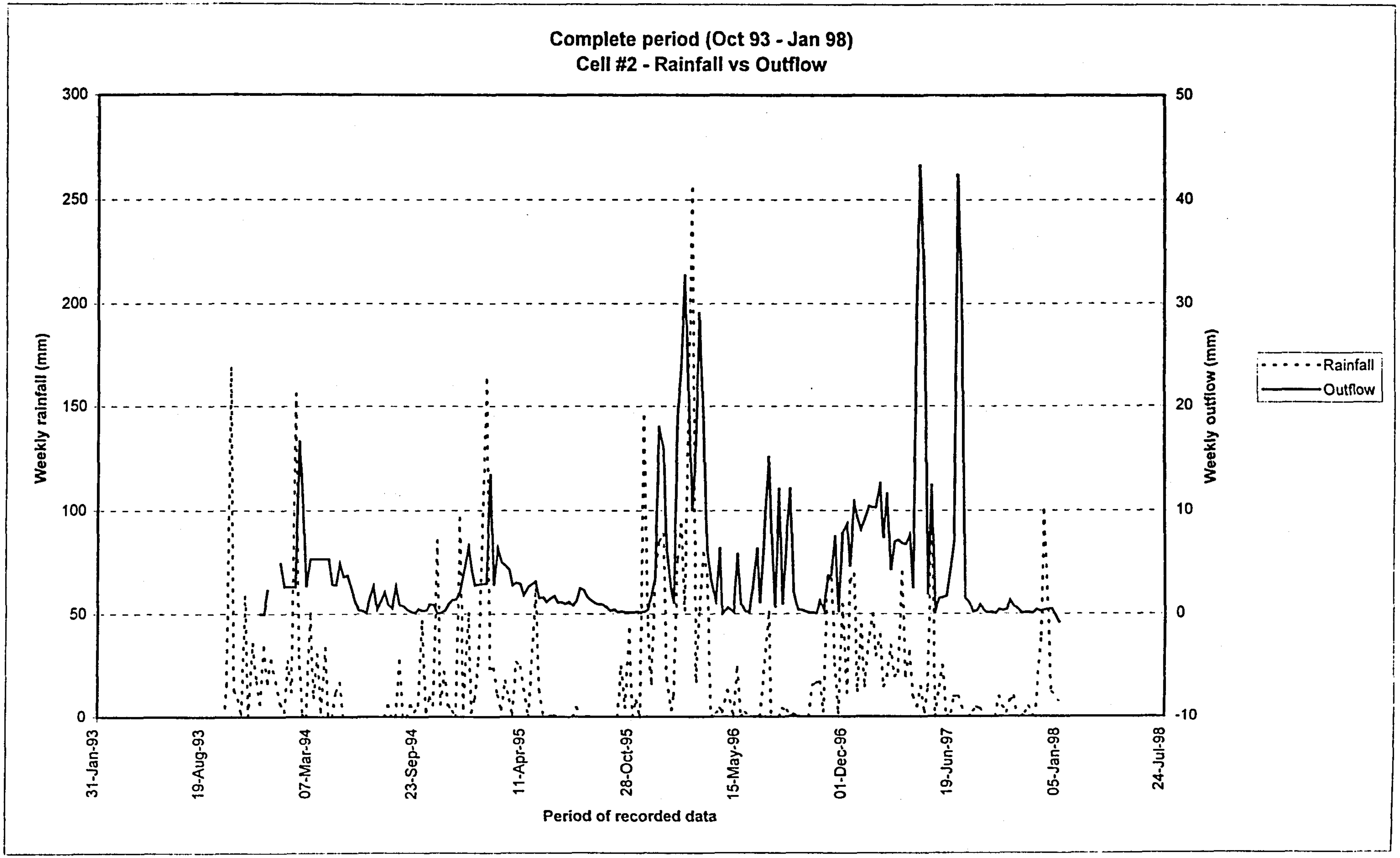
First Year (Oct 93 - Sep 94)
Cell #1 - Rainfall vs Outflow
Weekly rainfall (mm)
Weekly outflow (mm)
180
160
140
120
100
80
60
40
20
0
25
20
15
10
5
0
19-Aug-93
08-Oct-93
27-Nov-93
16-Jan-94
07-Mar-94
26-Apr-94
15-Jun-94
04-Aug-94
23-Sep-94
Period of recorded data
Rainfall
Outflow

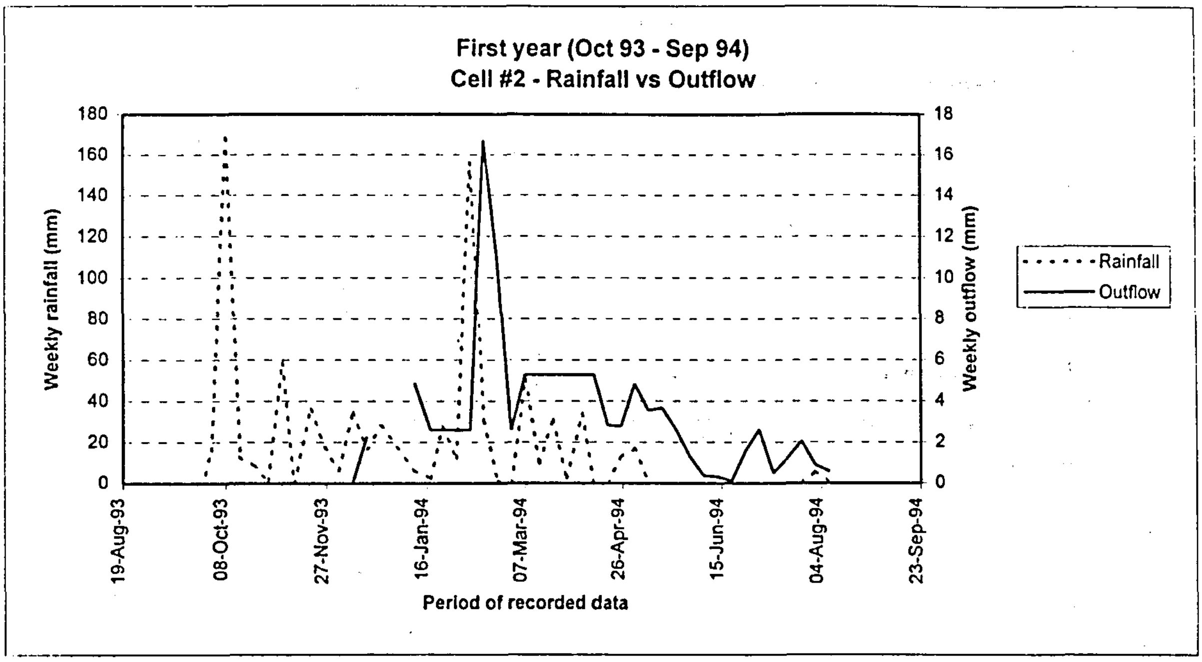


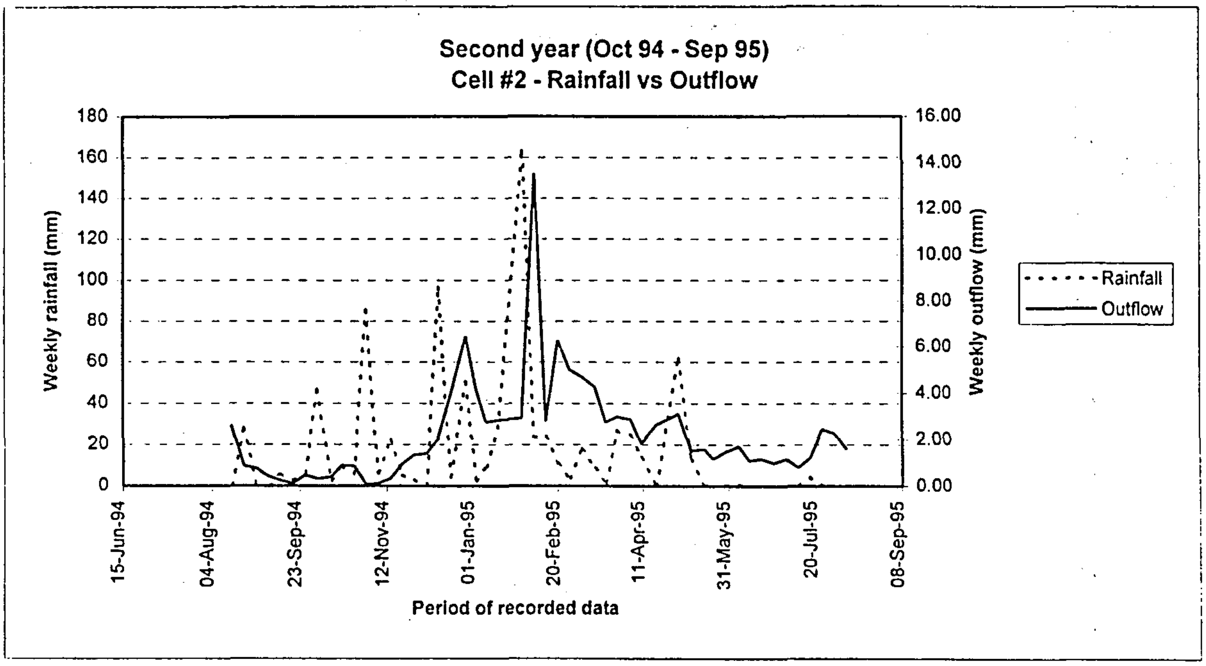
Second Year (Oct 94 - Sep 95)
Cell #1 - Rainfall vs Outflow
Weekly rainfall (mm)
Weekly outflow (mm)
180
160
140
120
100
80
60
40
20
0
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
15-Jun-94
04-Aug-94
23-Sep-94
12-Nov-94
01-Jan-95
20-Feb-95
11-Apr-95
31-May-95
20-Jul-95
08-Sep-95
Period of recorded data
Rainfall
Outflow

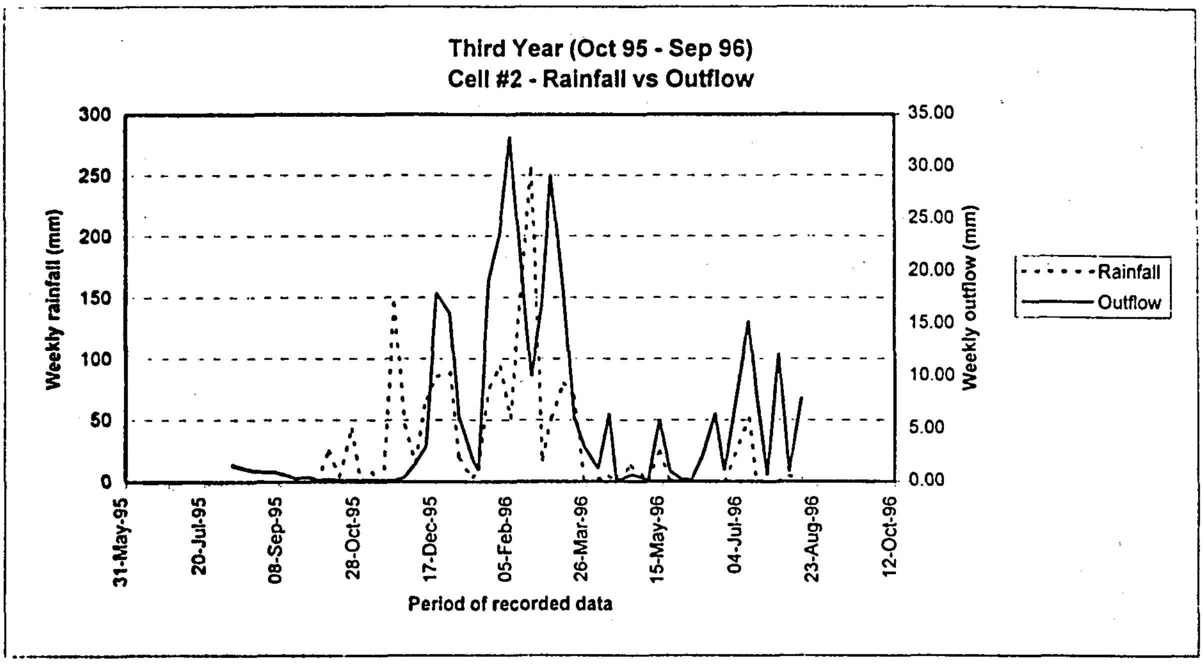

Third Year (Oct 95 - Sep 96)
Cell #1 - Rainfall vs Outflow
Weekly rainfall (mm)
Weekly outflow (mm)
Rainfall
Outflow
300
250
200
150
100
50
0
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
20-Jul-95
08-Sep-95
28-Oct-95
17-Dec-95
05-Feb-96
26-Mar-96
15-May-96
04-Jul-96
23-Aug-96
12-Oct-96
Period of recorded data

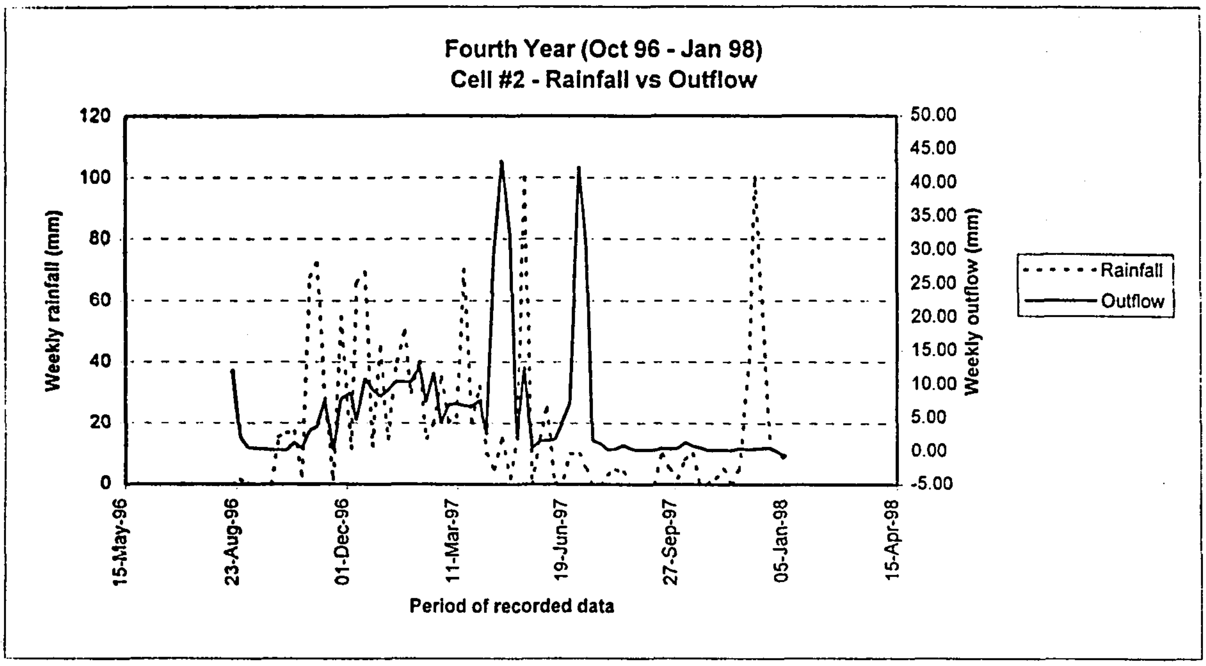

Fourth Year (Oct 96 - Jan 98)
Cell #1 - Rainfall vs Outflow
Weekly rainfall (mm)
Weekly outflow (mm)
Rainfall
Outflow
120
100
80
60
40
20
0
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
15-May-96
23-Aug-96
01-Dec-96
11-Mar-97
19-Jun-97
27-Sep-97
05-Jan-98
15-Apr-98
Period of recorded data

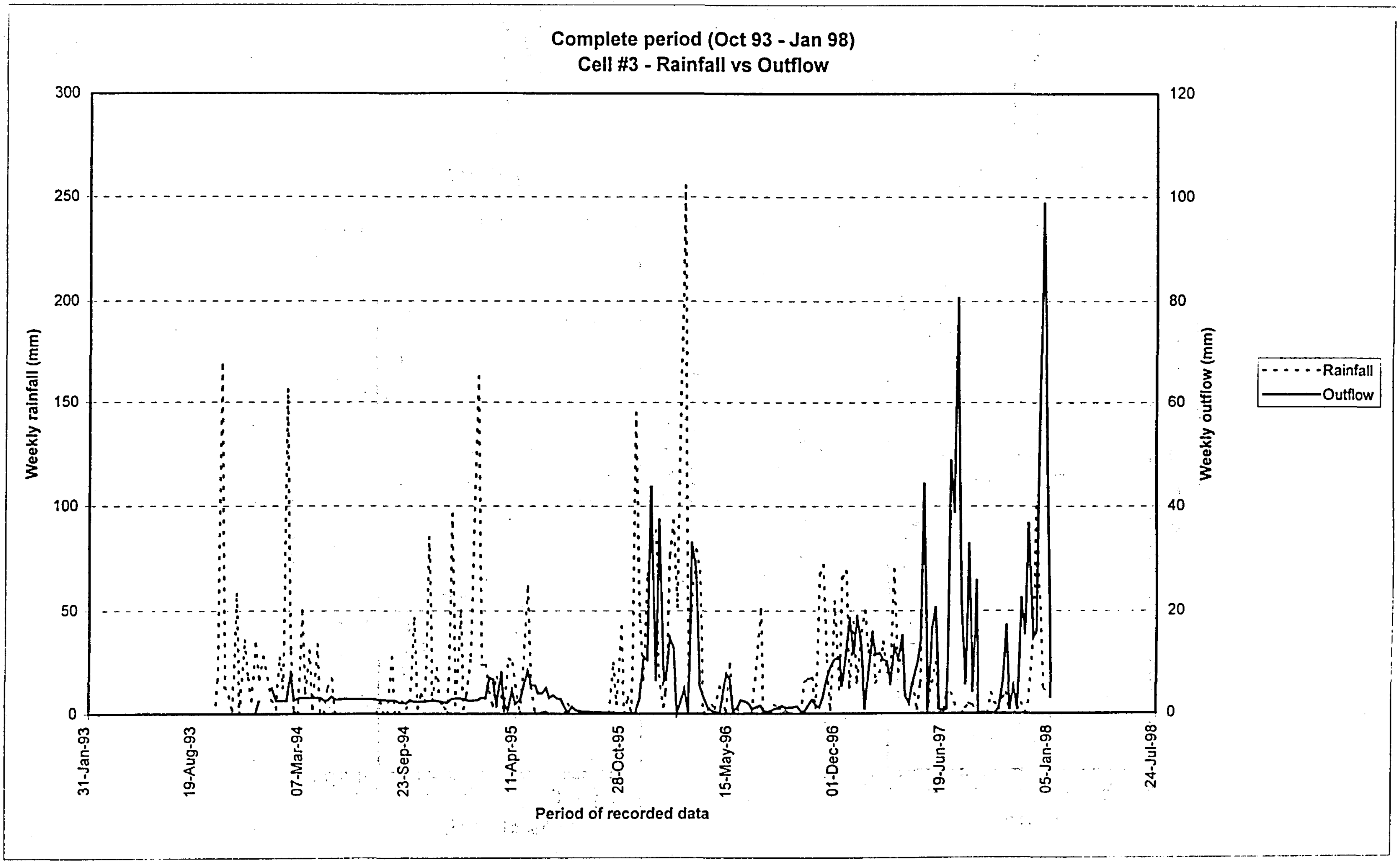

Complete period (Oct 93 - Jan 98)
Cell #2 - Rainfall vs Outflow
Weekly rainfall (mm)
Weekly outflow (mm)
300
250
200
150
100
50
0
50
40
30
20
10
0
-10
31-Jan-93
19-Aug-93
07-Mar-94
23-Sep-94
11-Apr-95
28-Oct-95
15-May-96
01-Dec-96
19-Jun-97
05-Jan-98
24-Jul-98
Period of recorded data
Rainfall
Outflow


First year (Oct 93 - Sep 94)
Cell #2 - Rainfall vs Outflow
Weekly rainfall (mm)
Weekly outflow (mm)
Rainfall
Outflow
19-Aug-93
08-Oct-93
27-Nov-93
16-Jan-94
07-Mar-94
26-Apr-94
15-Jun-94
04-Aug-94
23-Sep-94
Period of recorded data

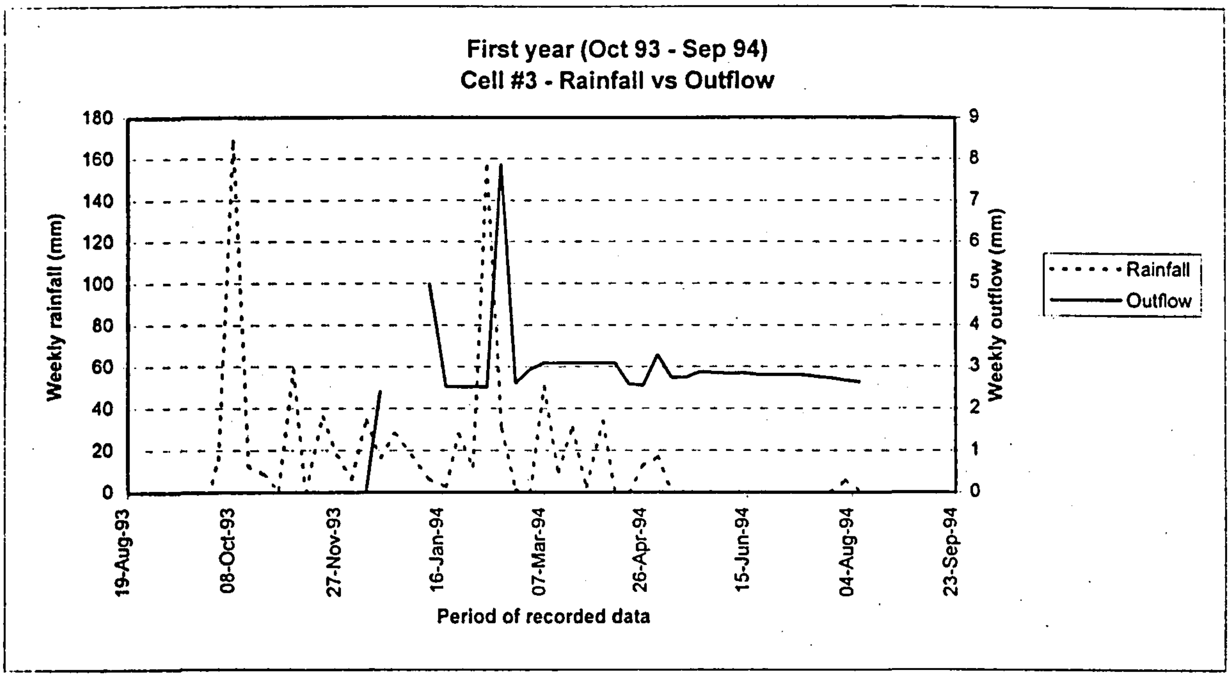

Second year (Oct 94 - Sep 95)
Cell #2 - Rainfall vs Outflow
Weekly rainfall (mm)
Weekly outflow (mm)
Rainfall
Outflow
15-Jun-94
04-Aug-94
23-Sep-94
12-Nov-94
01-Jan-95
20-Feb-95
11-Apr-95
31-May-95
20-Jul-95
08-Sep-95
Period of recorded data

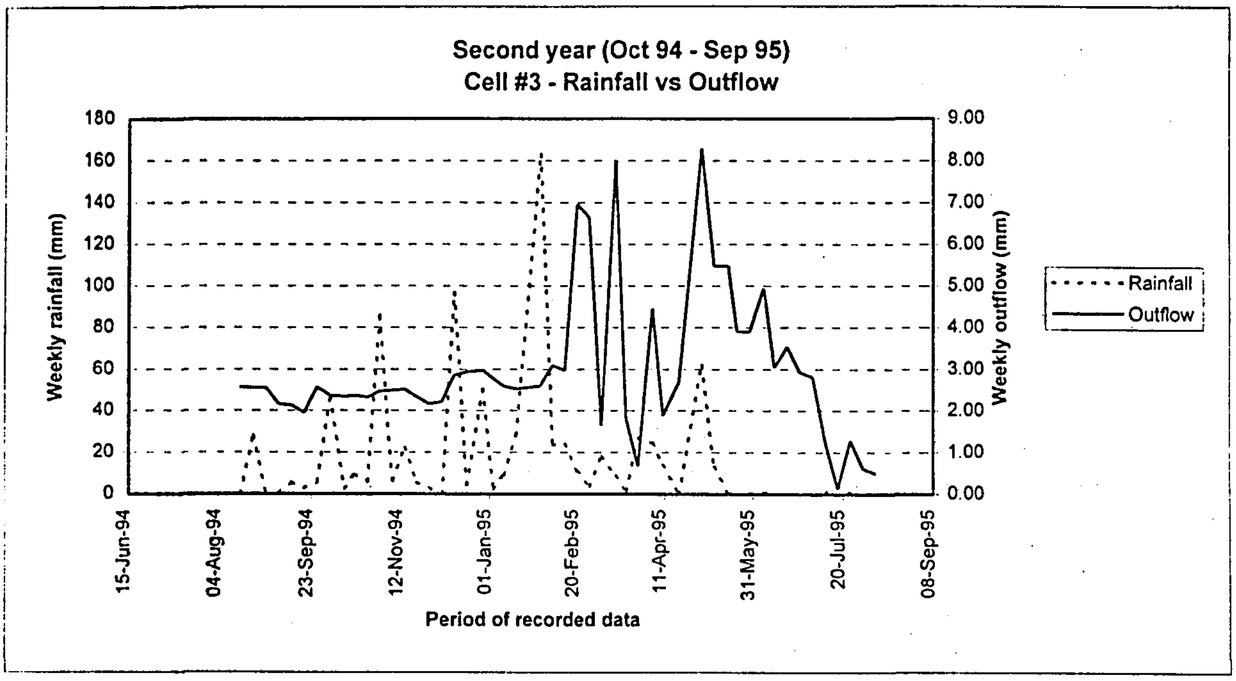

Third Year (Oct 95 - Sep 96)
Cell #2 - Rainfall vs Outflow
Weekly rainfall (mm)
Weekly outflow (mm)
Period of recorded data
Rainfall
Outflow
300
250
200
150
100
50
0
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
31-May-95
20-Jul-95
08-Sep-95
28-Oct-95
17-Dec-95
05-Feb-96
26-Mar-96
15-May-96
04-Jul-96
23-Aug-96
12-Oct-96

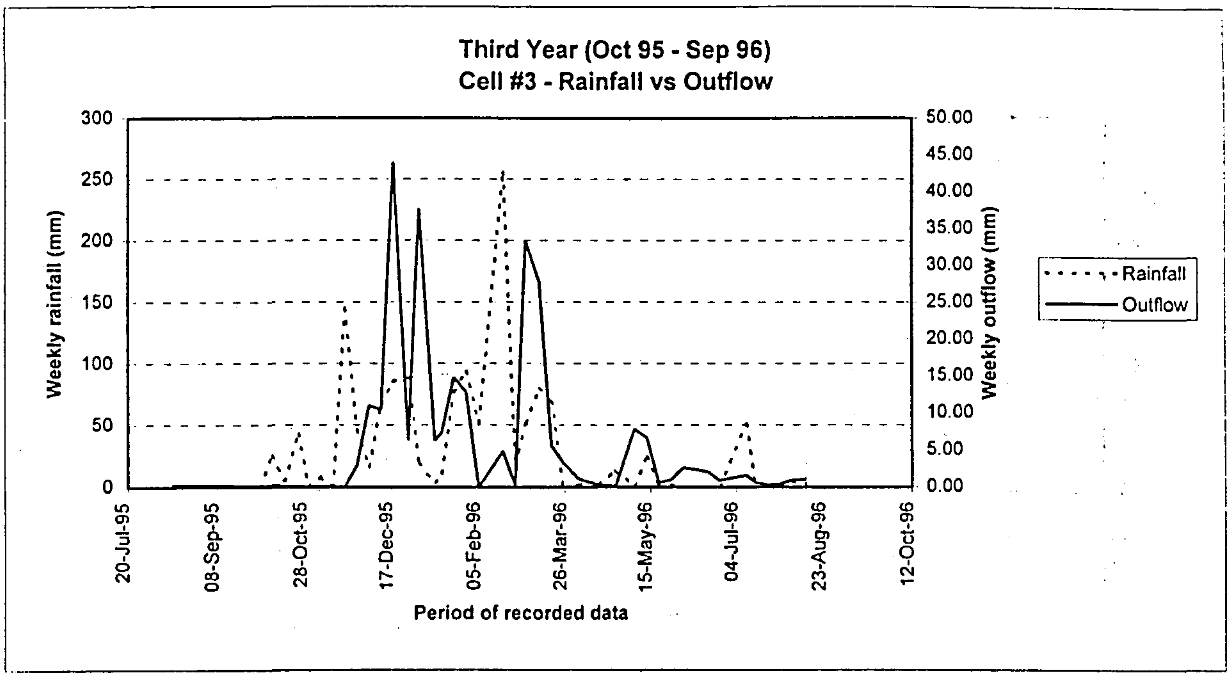

Fourth Year (Oct 96 - Jan 98)
Cell #2 - Rainfall vs Outflow
Weekly rainfall (mm)
Weekly outflow (mm)
Period of recorded data
Rainfall
Outflow
120
100
80
60
40
20
0
50.00
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
-5.00
15-May-96
23-Aug-96
01-Dec-96
11-Mar-97
19-Jun-97
27-Sep-97
05-Jan-98
15-Apr-98



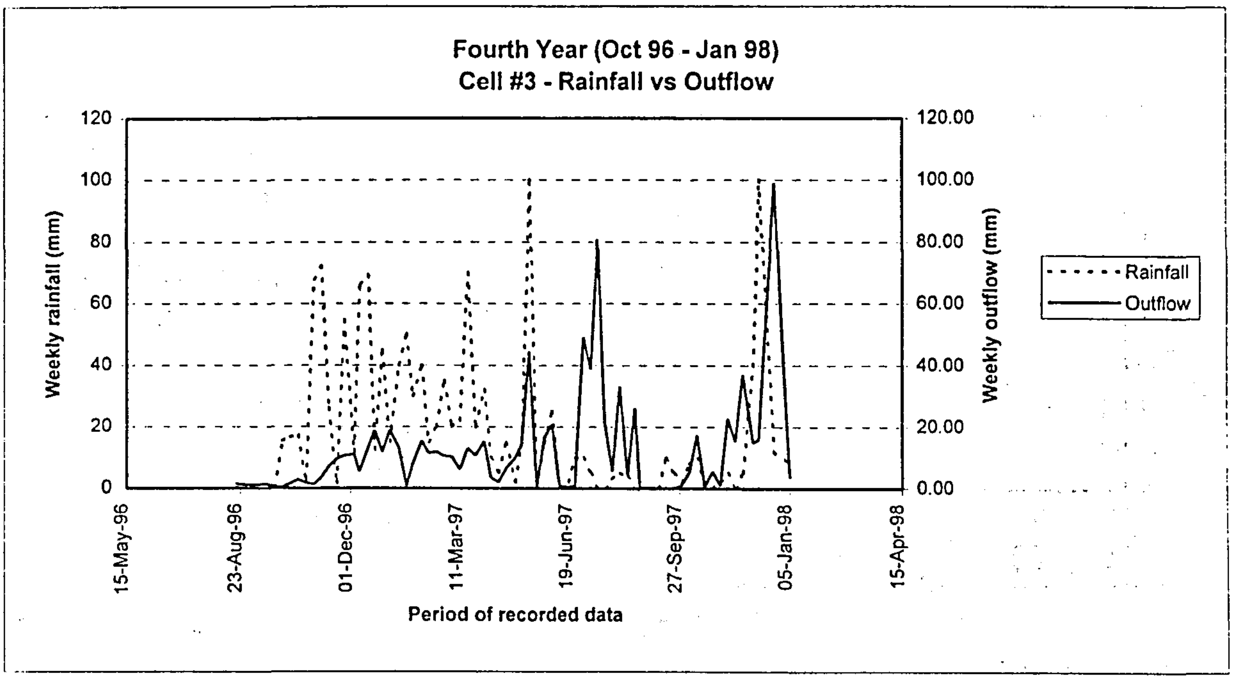
Complete period (Oct 93 - Jan 98)
Cell #3 - Rainfall vs Outflow
Weekly rainfall (mm)
Weekly outflow (mm)
300
250
200
150
100
50
0
120
100
80
60
40
20
0
31-Jan-93
19-Aug-93
07-Mar-94
23-Sep-94
11-Apr-95
28-Oct-95
15-May-96
01-Dec-96
19-Jun-97
05-Jan-98
24-Jul-98
Period of recorded data
Rainfall
Outflow


First year (Oct 93 - Sep 94)
Cell #3 - Rainfall vs Outflow
Weekly rainfall (mm)
Weekly outflow (mm)
180
160
140
120
100
80
60
40
20
0
9
8
7
6
5
4
3
2
1
0
19-Aug-93
08-Oct-93
27-Nov-93
16-Jan-94
07-Mar-94
26-Apr-94
15-Jun-94
04-Aug-94
23-Sep-94
Period of recorded data
Rainfall
Outflow

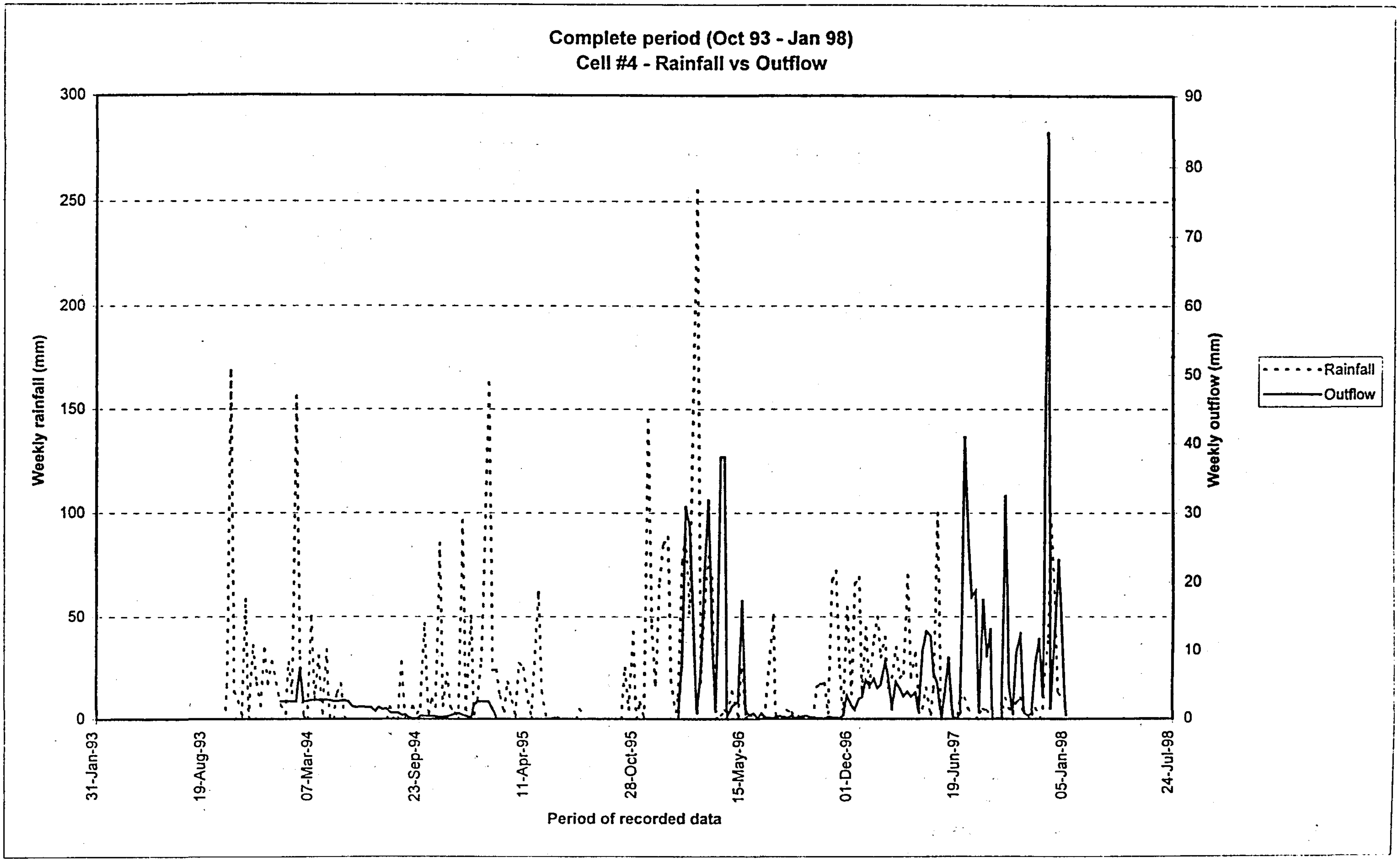

Second year (Oct 94 - Sep 95)
Cell #3 - Rainfall vs Outflow
Weekly rainfall (mm)
Weekly outflow (mm)
180
160
140
120
100
80
60
40
20
0
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
15-Jun-94
04-Aug-94
23-Sep-94
12-Nov-94
01-Jan-95
20-Feb-95
11-Apr-95
31-May-95
20-Jul-95
08-Sep-95
Period of recorded data
Rainfall
Outflow

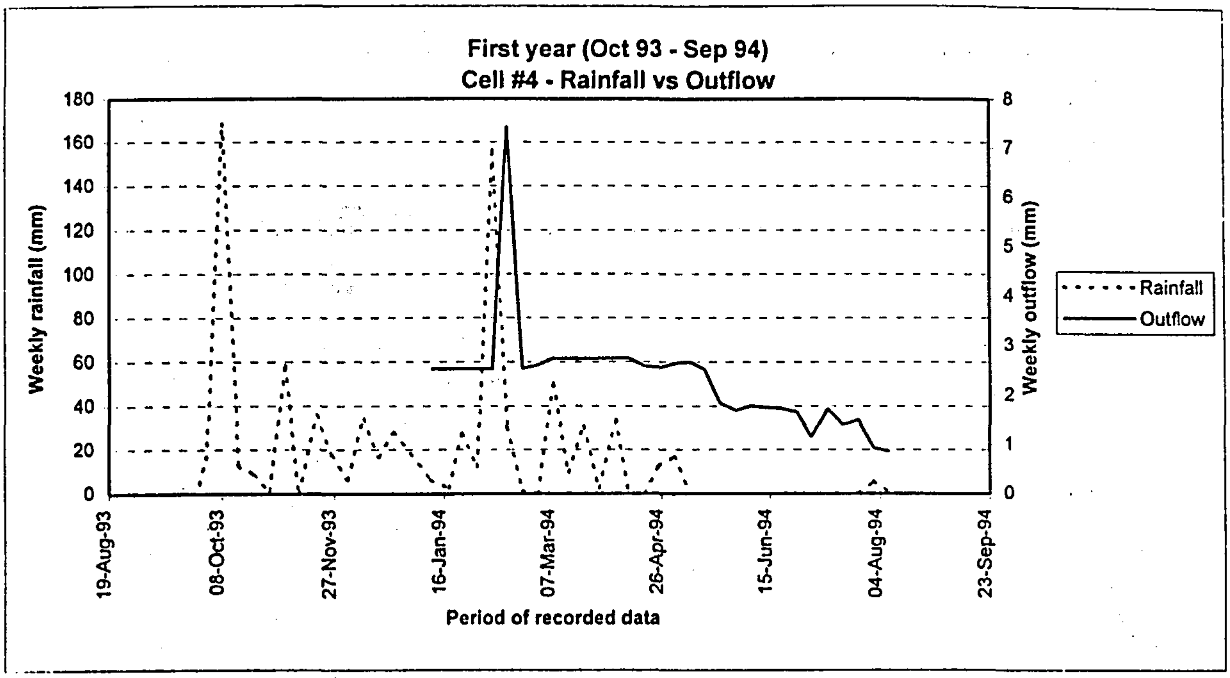


Third Year (Oct 95 - Sep 96)
Cell #3 - Rainfall vs Outflow
Weekly rainfall (mm)
Weekly outflow (mm)
300
250
200
150
100
50
0
50.00
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
Rainfall
Outflow
20-Jul-95
08-Sep-95
28-Oct-95
17-Dec-95
05-Feb-96
26-Mar-96
15-May-96
04-Jul-96
23-Aug-96
12-Oct-96
Period of recorded data

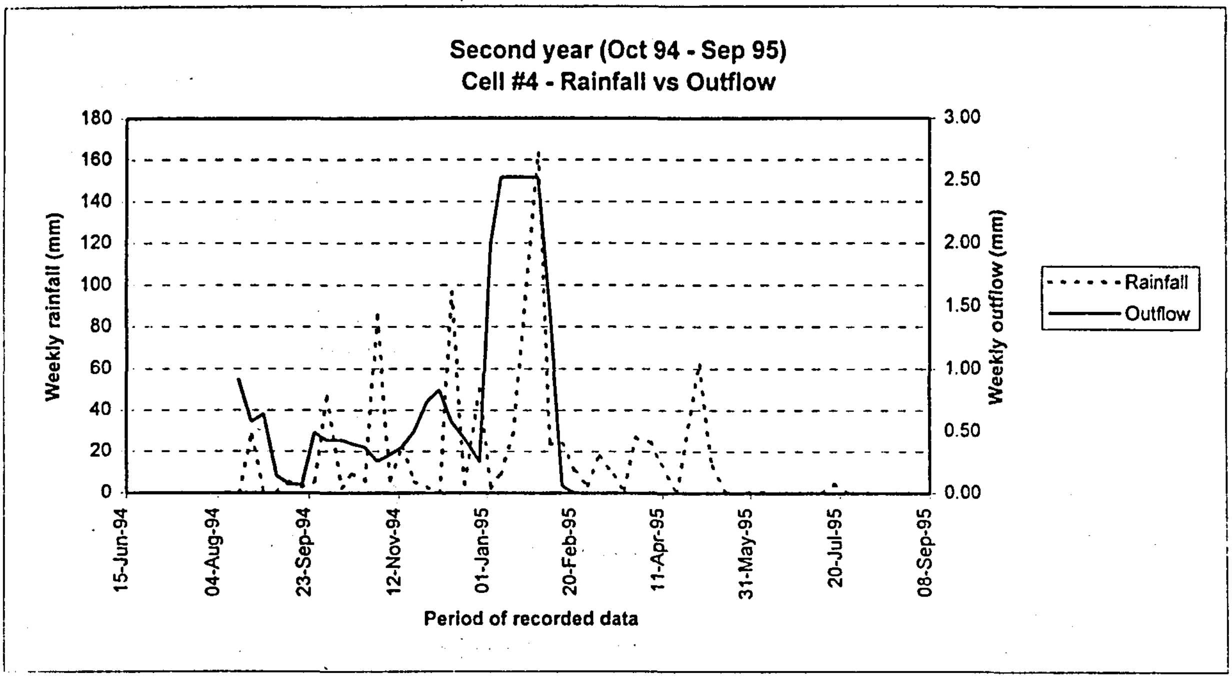


Fourth Year (Oct 96 - Jan 98)
Cell #3 - Rainfall vs Outflow
Weekly rainfall (mm)
Weekly outflow (mm)
120
100
80
60
40
20
0
120.00
100.00
80.00
60.00
40.00
20.00
0.00
Rainfall
Outflow
15-May-96
23-Aug-96
01-Dec-96
11-Mar-97
19-Jun-97
27-Sep-97
05-Jan-98
15-Apr-98
Period of recorded data

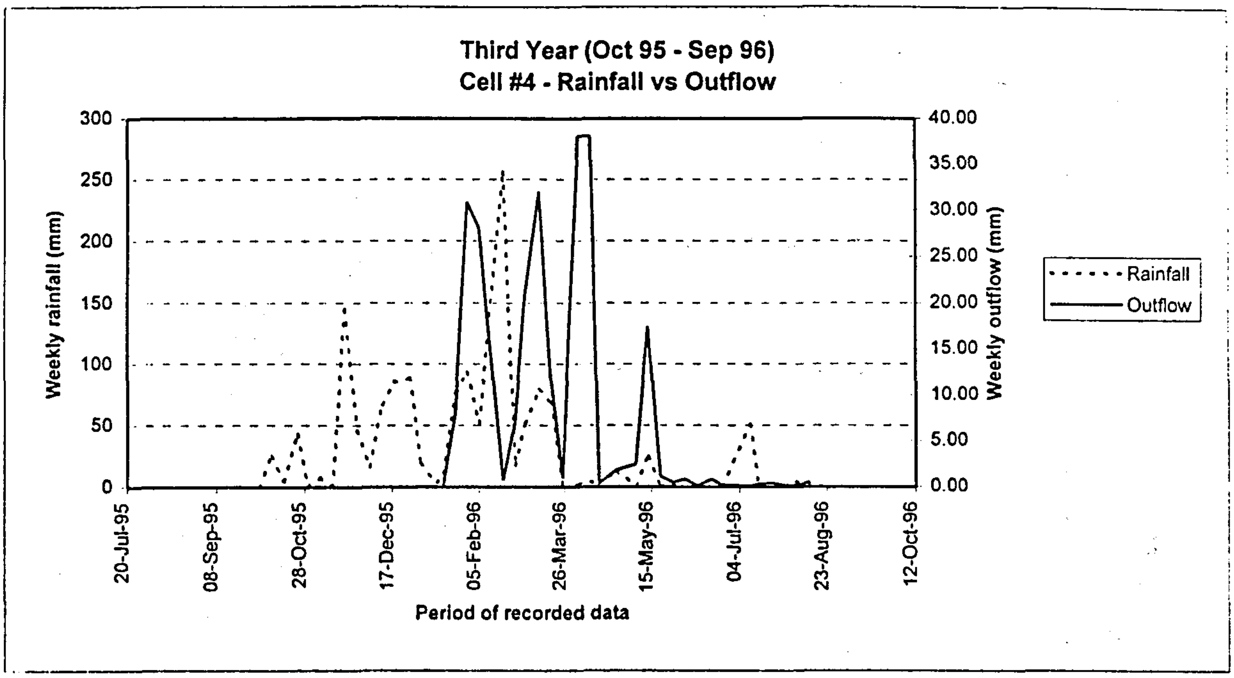

Complete period (Oct 93 - Jan 98)
Cell #4 - Rainfall vs Outflow
Weekly rainfall (mm)
Weekly outflow (mm)
300
250
200
150
100
50
0
90
80
70
60
50
40
30
20
10
0
Rainfall
Outflow
31-Jan-93
19-Aug-93
07-Mar-94
23-Sep-94
11-Apr-95
28-Oct-95
15-May-96
01-Dec-96
19-Jun-97
05-Jan-98
24-Jul-98
Period of recorded data



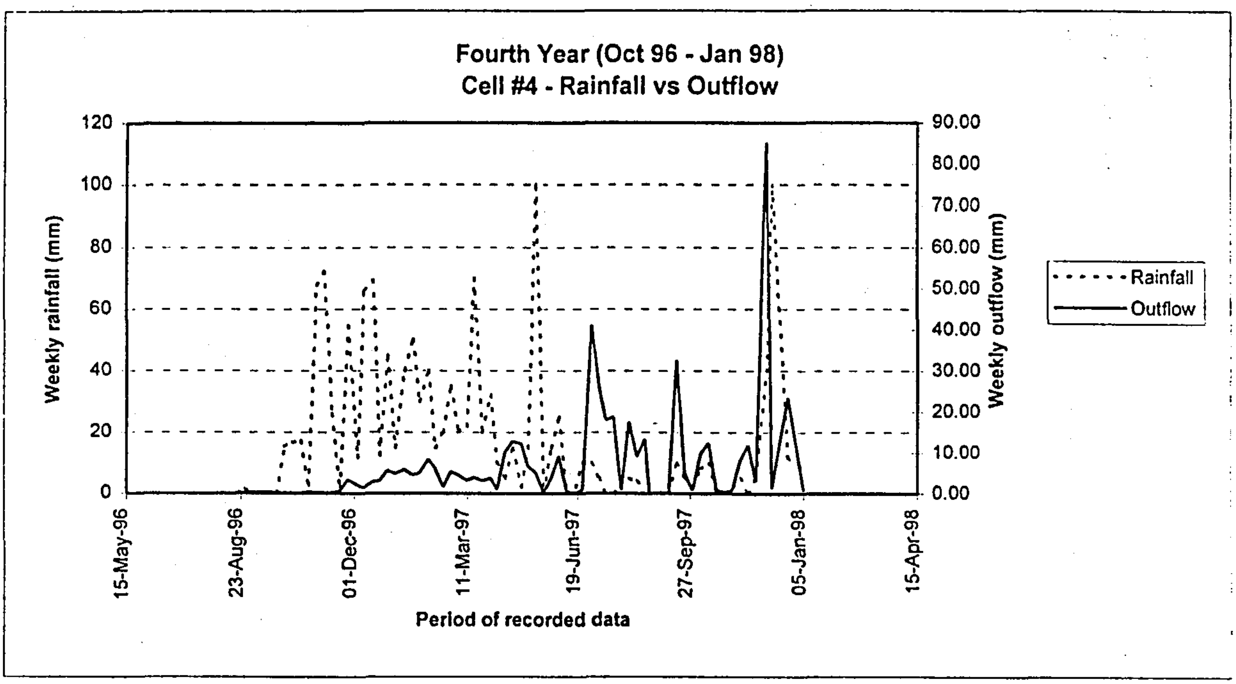
First year (Oct 93 - Sep 94)
Cell #4 - Rainfall vs Outflow
Weekly rainfall (mm)
Weekly outflow (mm)
180
160
140
120
100
80
60
40
20
0
8
7
6
5
4
3
2
1
0
19-Aug-93
08-Oct-93
27-Nov-93
16-Jan-94
07-Mar-94
26-Apr-94
15-Jun-94
04-Aug-94
23-Sep-94
Period of recorded data
Rainfall
Outflow



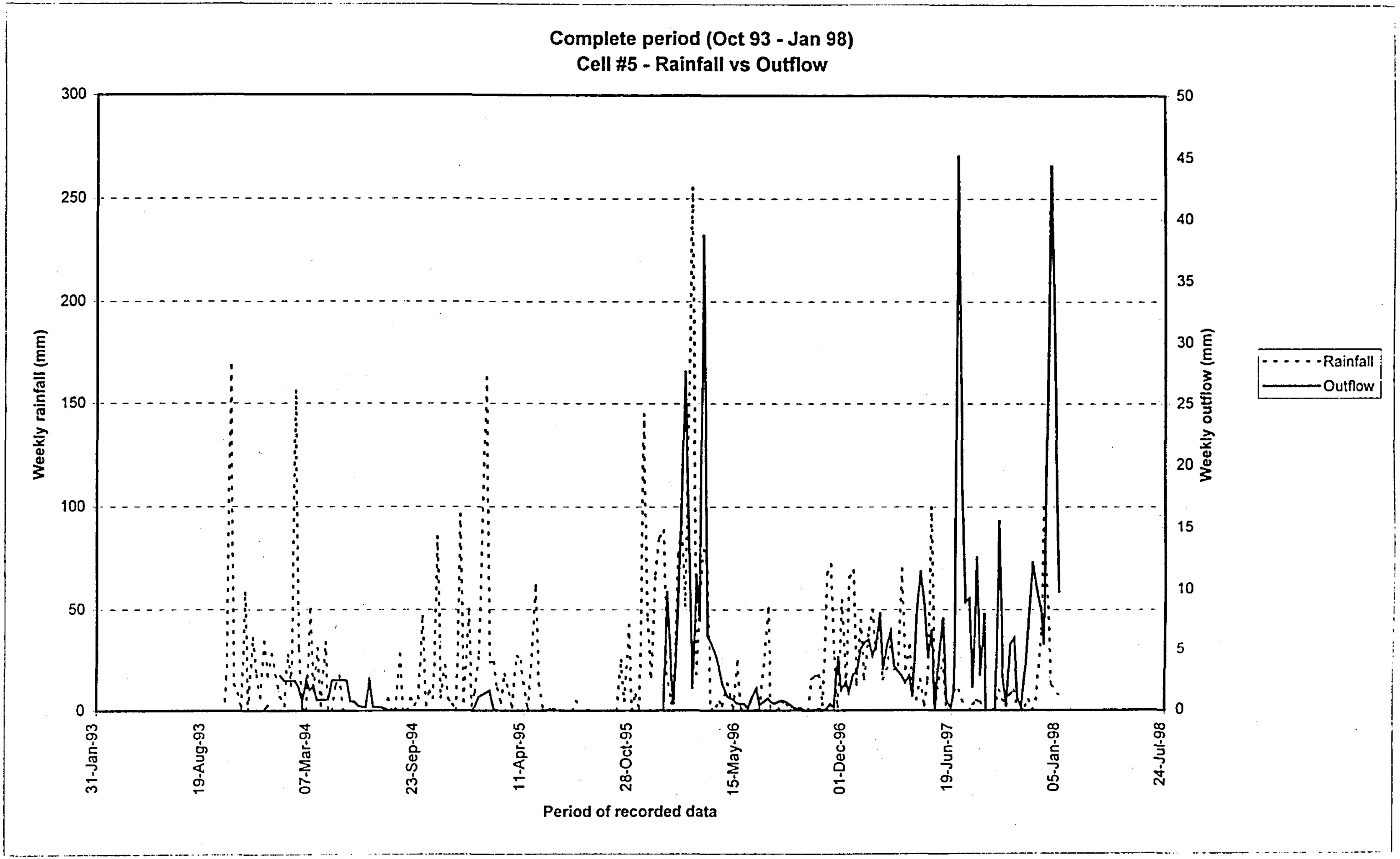
Second year (Oct 94 - Sep 95)
Cell #4 - Rainfall vs Outflow
Weekly rainfall (mm)
Weekly outflow (mm)
180
160
140
120
100
80
60
40
20
0
3.00
2.50
2.00
1.50
1.00
0.50
0.00
15-Jun-94
04-Aug-94
23-Sep-94
12-Nov-94
01-Jan-95
20-Feb-95
11-Apr-95
31-May-95
20-Jul-95
08-Sep-95
Period of recorded data
Rainfall
Outflow



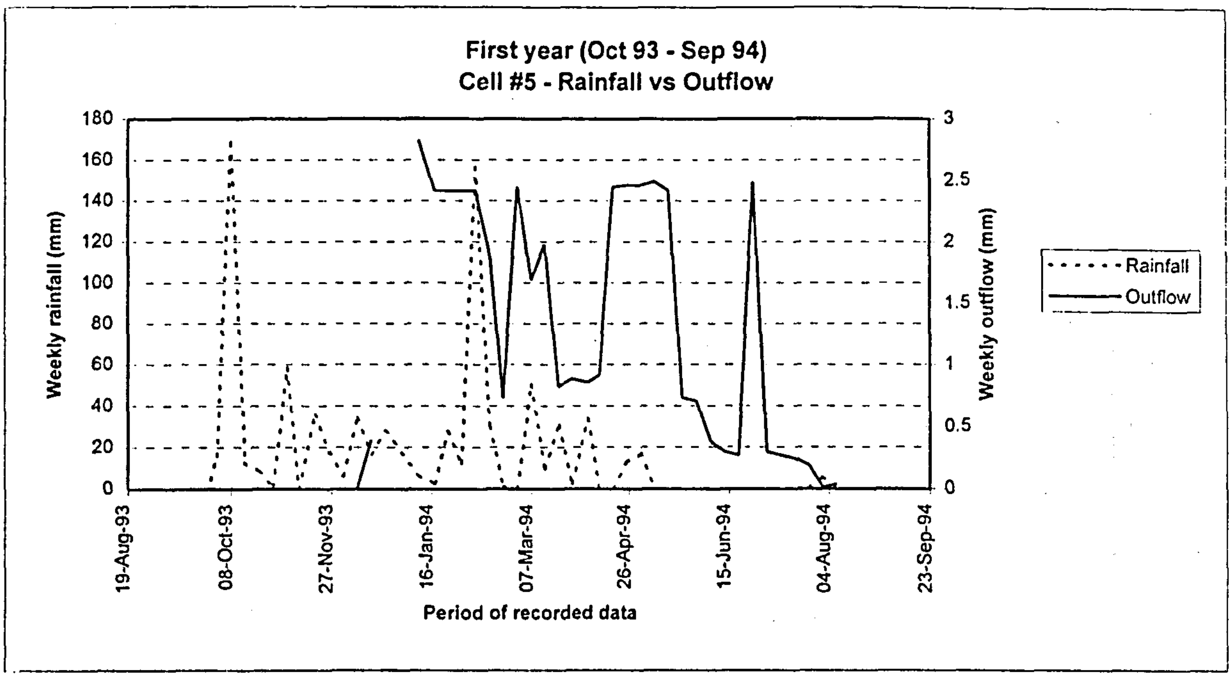
Third Year (Oct 95 - Sep 96)
Cell #4 - Rainfall vs Outflow
Weekly rainfall (mm)
300
250
200
150
100
50
0
Weekly outflow (mm)
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
20-Jul-95
08-Sep-95
28-Oct-95
17-Dec-95
05-Feb-96
26-Mar-96
15-May-96
04-Jul-96
23-Aug-96
12-Oct-96
Period of recorded data
Rainfall
Outflow

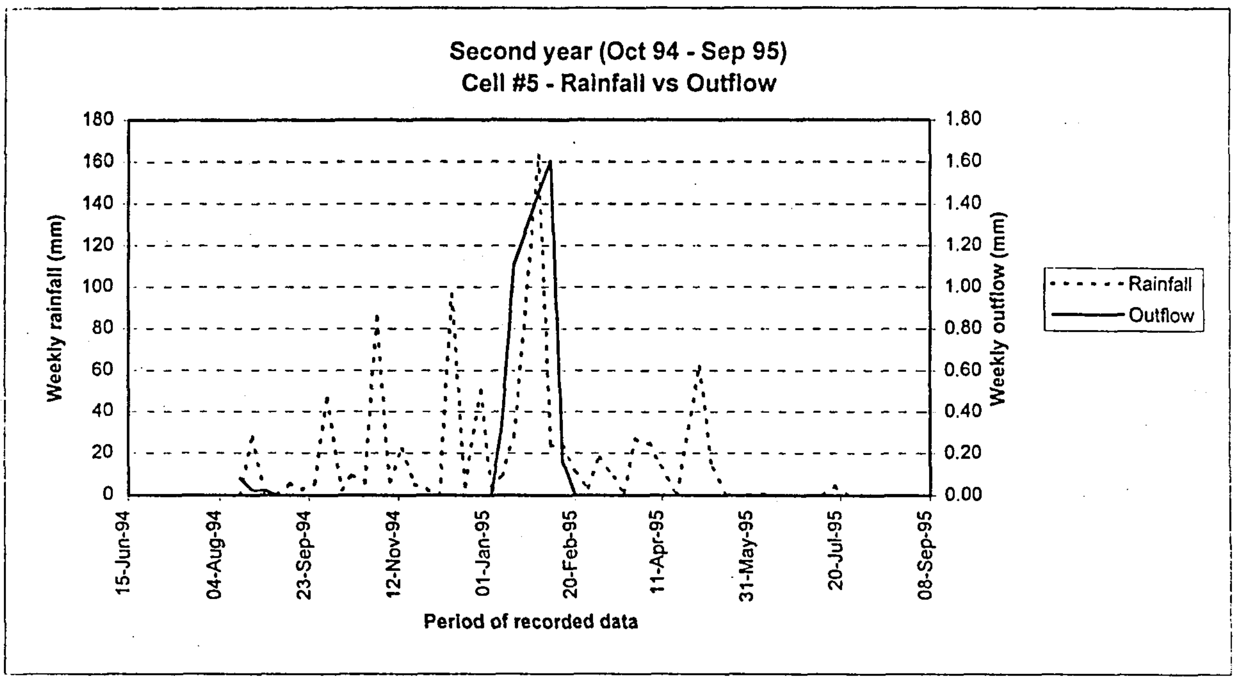


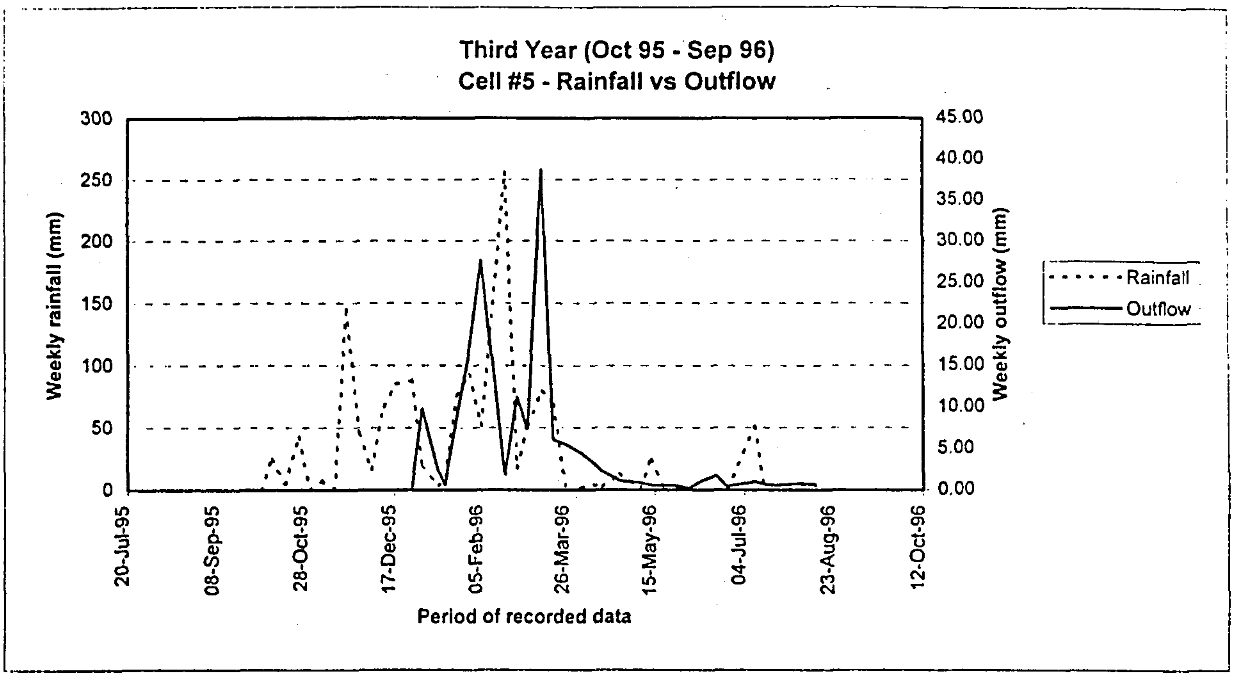
Fourth Year (Oct 96 - Jan 98)
Cell #4 - Rainfall vs Outflow
Weekly rainfall (mm)
120
100
80
60
40
20
0
Weekly outflow (mm)
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
15-May-96
23-Aug-96
01-Dec-96
11-Mar-97
19-Jun-97
27-Sep-97
05-Jan-98
15-Apr-98
Period of recorded data
Rainfall
Outflow



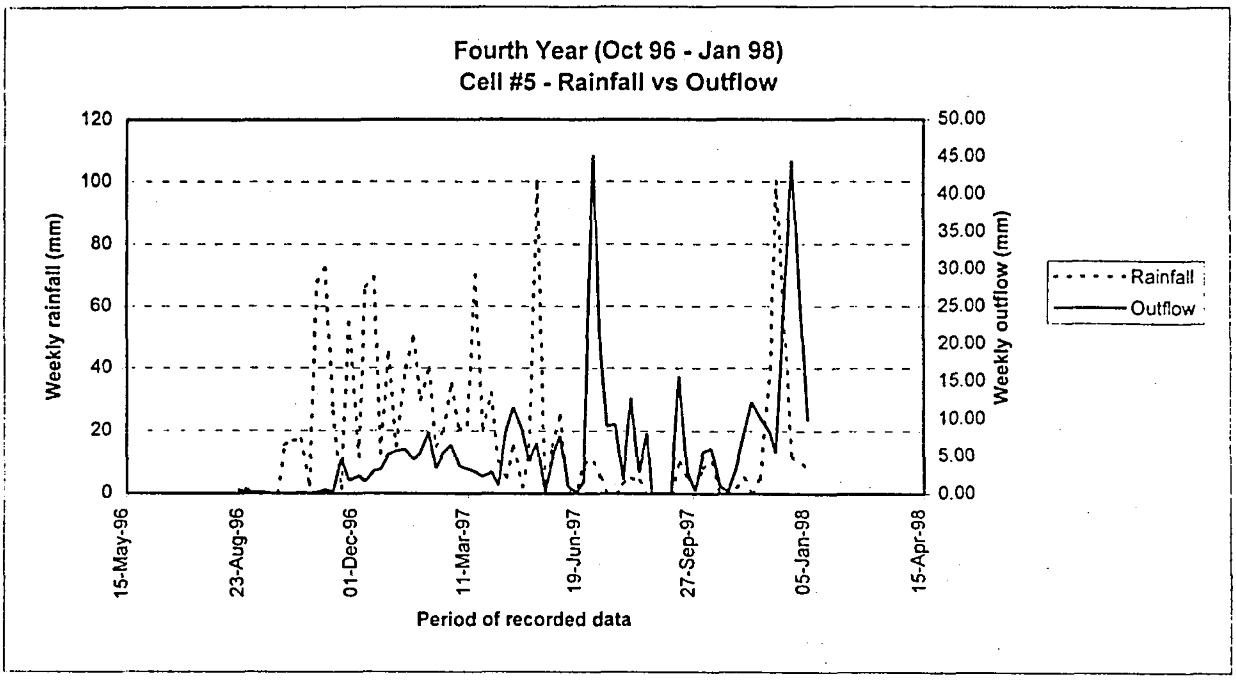
Complete period (Oct 93 - Jan 98)
Cell #5 - Rainfall vs Outflow
Weekly rainfall (mm)
Weekly outflow (mm)
300
250
200
150
100
50
0
50
45
40
35
30
25
20
15
10
5
0
Rainfall
Outflow
31-Jan-93
19-Aug-93
07-Mar-94
23-Sep-94
11-Apr-95
28-Oct-95
15-May-96
01-Dec-96
19-Jun-97
05-Jan-98
24-Jul-98
Period of recorded data


First year (Oct 93 - Sep 94)
Cell #5 - Rainfall vs Outflow
Weekly rainfall (mm)
180
160
140
120
100
80
60
40
20
0
3
2.5
2
1.5
1
0.5
0
Weekly outflow (mm)
19-Aug-93
08-Oct-93
27-Nov-93
16-Jan-94
07-Mar-94
26-Apr-94
15-Jun-94
04-Aug-94
23-Sep-94
Period of recorded data
Rainfall
Outflow

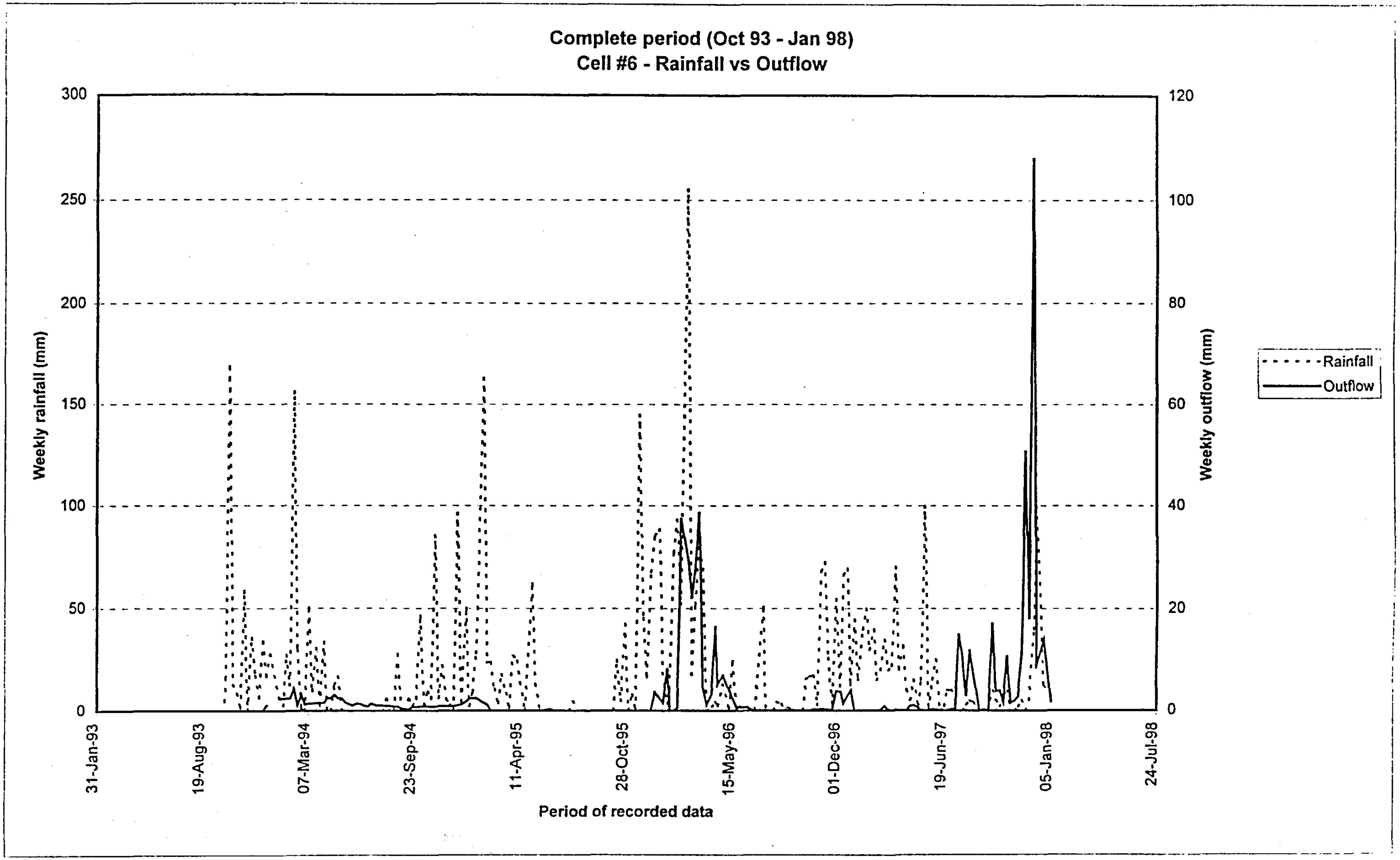

Second year (Oct 94 - Sep 95)
Cell #5 - Rainfall vs Outflow
Weekly rainfall (mm)
180
160
140
120
100
80
60
40
20
0
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
Weekly outflow (mm)
15-Jun-94
04-Aug-94
23-Sep-94
12-Nov-94
01-Jan-95
20-Feb-95
11-Apr-95
31-May-95
20-Jul-95
08-Sep-95
Period of recorded data
Rainfall
Outflow



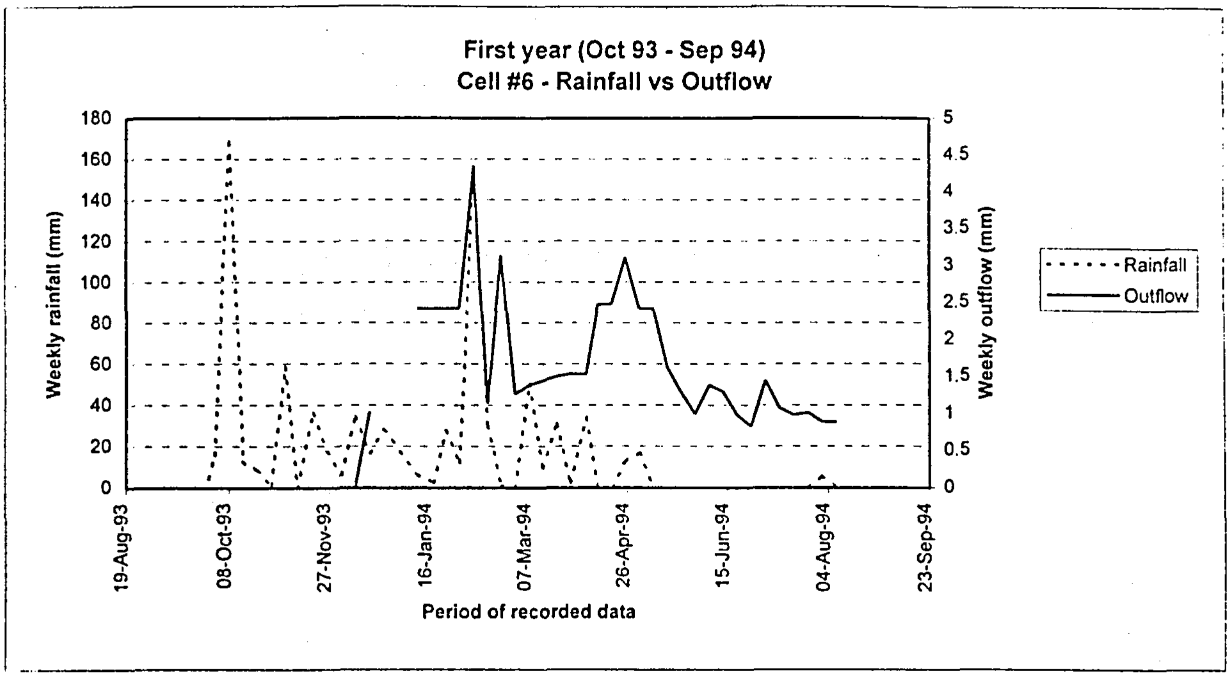
Third Year (Oct 95 - Sep 96)
Cell #5 - Rainfall vs Outflow
Weekly rainfall (mm)
300
250
200
150
100
50
0
Weekly outflow (mm)
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
20-Jul-95
08-Sep-95
28-Oct-95
17-Dec-95
05-Feb-96
26-Mar-96
15-May-96
04-Jul-96
23-Aug-96
12-Oct-96
Period of recorded data
Rainfall
Outflow

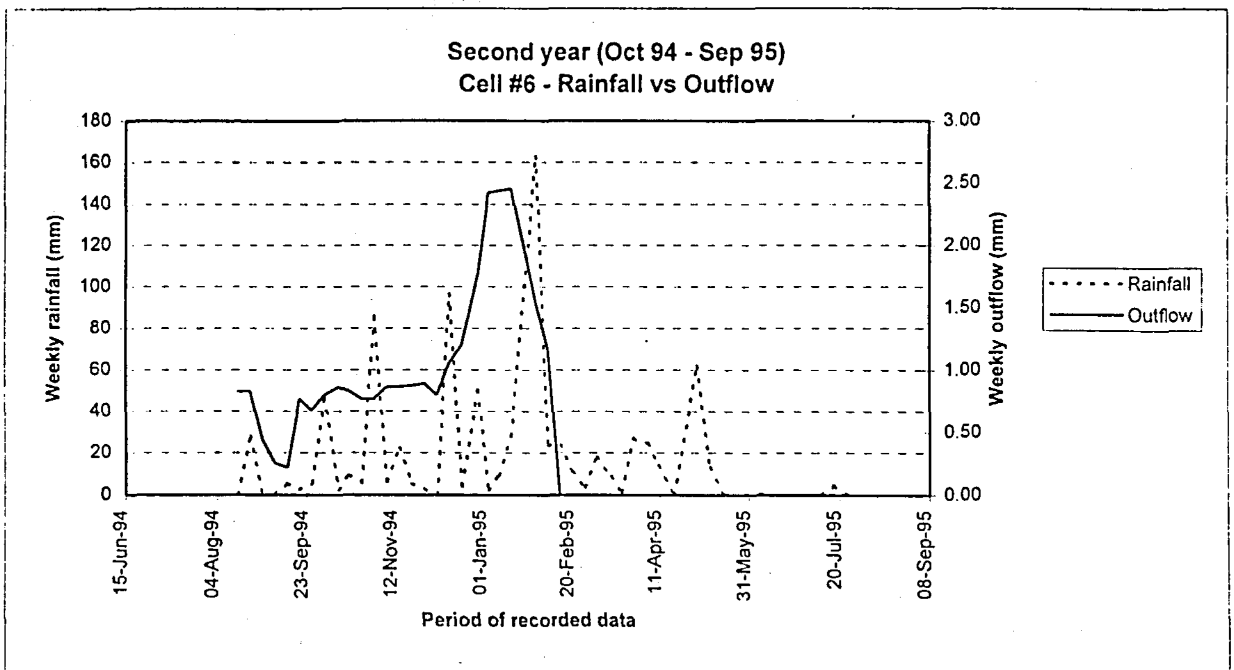


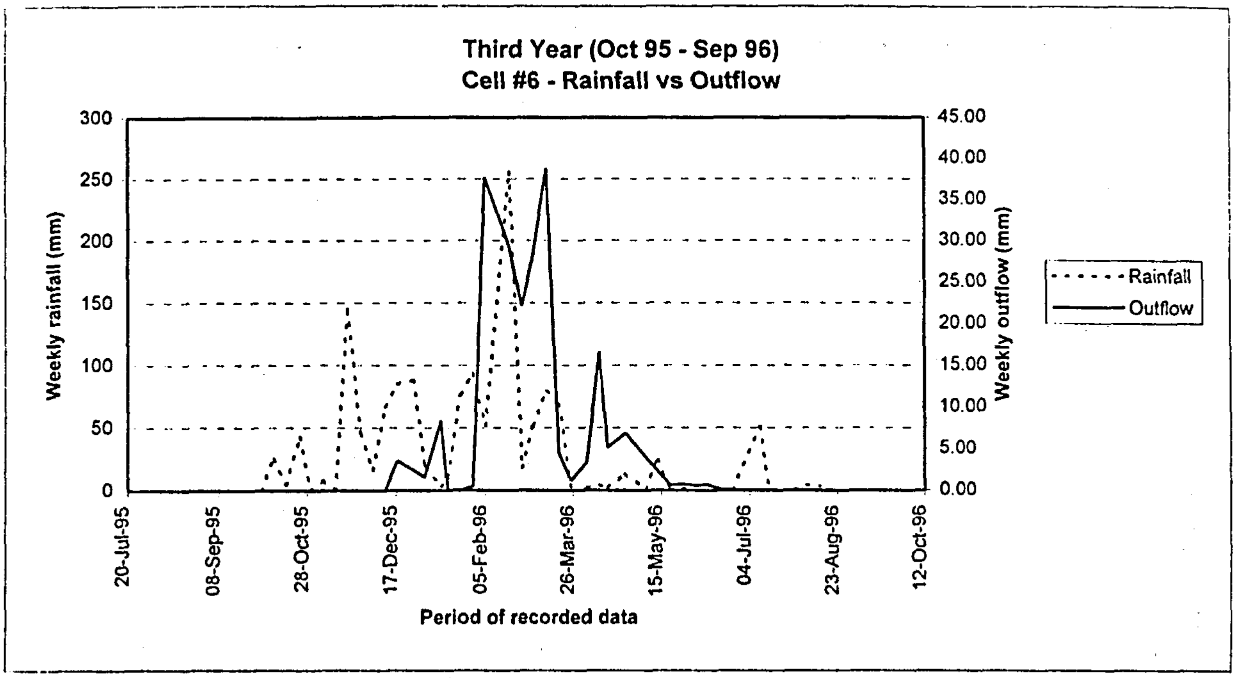
Fourth Year (Oct 96 - Jan 98)
Cell #5 - Rainfall vs Outflow
Weekly rainfall (mm)
120
100
80
60
40
20
0
Weekly outflow (mm)
50.00
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
15-May-96
23-Aug-96
01-Dec-96
11-Mar-97
19-Jun-97
27-Sep-97
05-Jan-98
15-Apr-98
Period of recorded data
Rainfall
Outflow



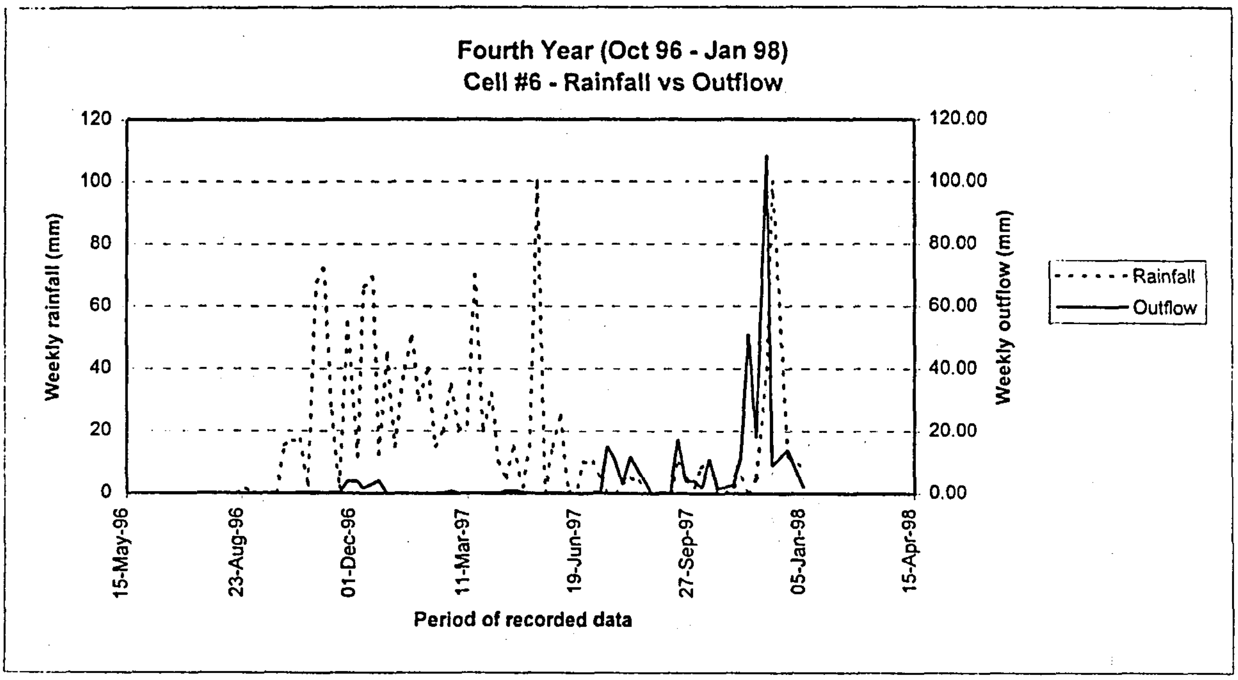
Complete period (Oct 93 - Jan 98)
Cell #6 - Rainfall vs Outflow
Weekly rainfall (mm)
300
250
200
150
100
50
0
Weekly outflow (mm)
120
100
80
60
40
20
0
31-Jan-93
19-Aug-93
07-Mar-94
23-Sep-94
11-Apr-95
28-Oct-95
15-May-96
01-Dec-96
19-Jun-97
05-Jan-98
24-Jul-98
Period of recorded data
Rainfall
Outflow


First year (Oct 93 - Sep 94)
Cell #6 - Rainfall vs Outflow
Weekly rainfall (mm)
Weekly outflow (mm)
Period of recorded data
19-Aug-93
08-Oct-93
27-Nov-93
16-Jan-94
07-Mar-94
26-Apr-94
15-Jun-94
04-Aug-94
23-Sep-94
Rainfall
Outflow

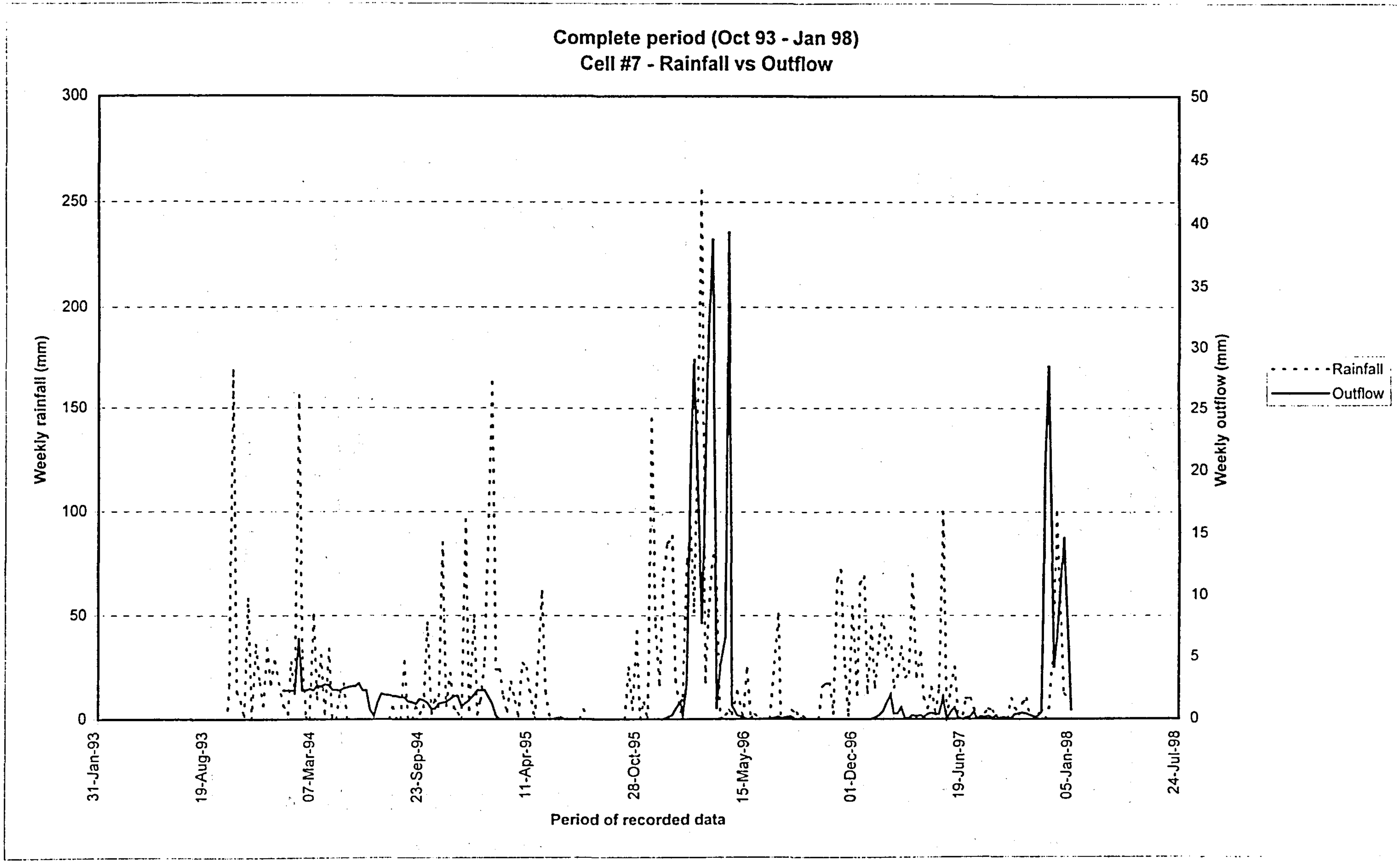

Second year (Oct 94 - Sep 95)
Cell #6 - Rainfall vs Outflow
Weekly rainfall (mm)
Weekly outflow (mm)
Period of recorded data
15-Jun-94
04-Aug-94
23-Sep-94
12-Nov-94
01-Jan-95
20-Feb-95
11-Apr-95
31-May-95
20-Jul-95
08-Sep-95
Rainfall
Outflow

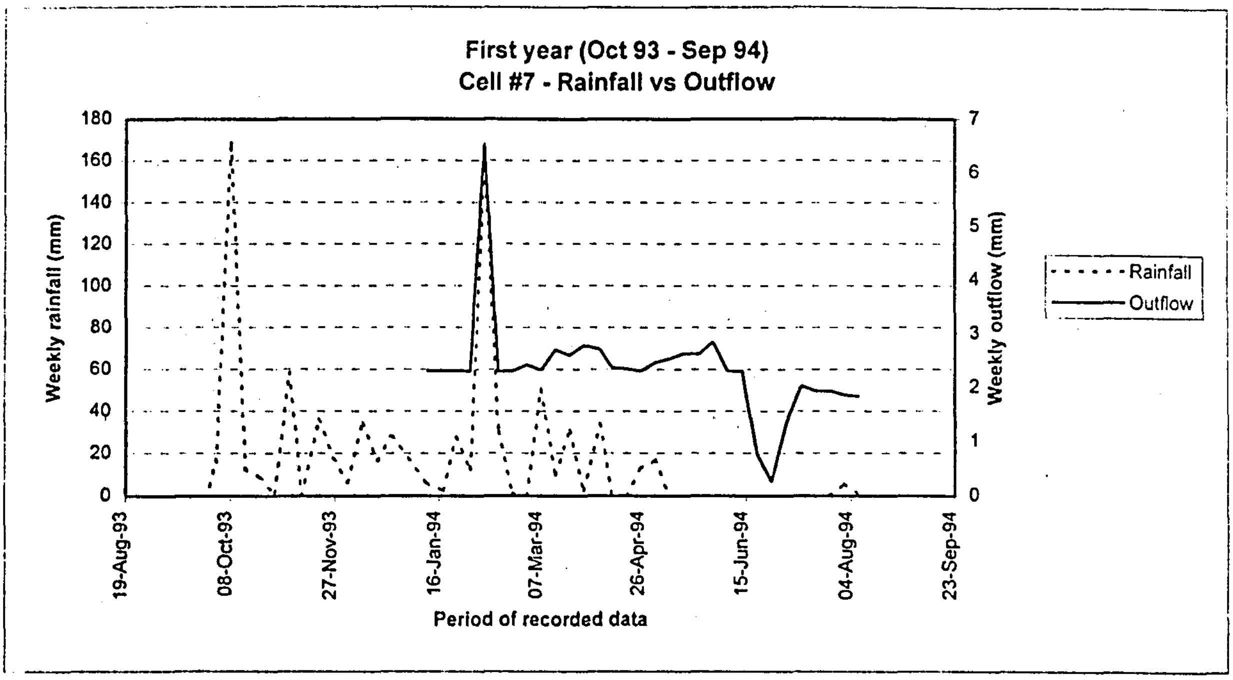


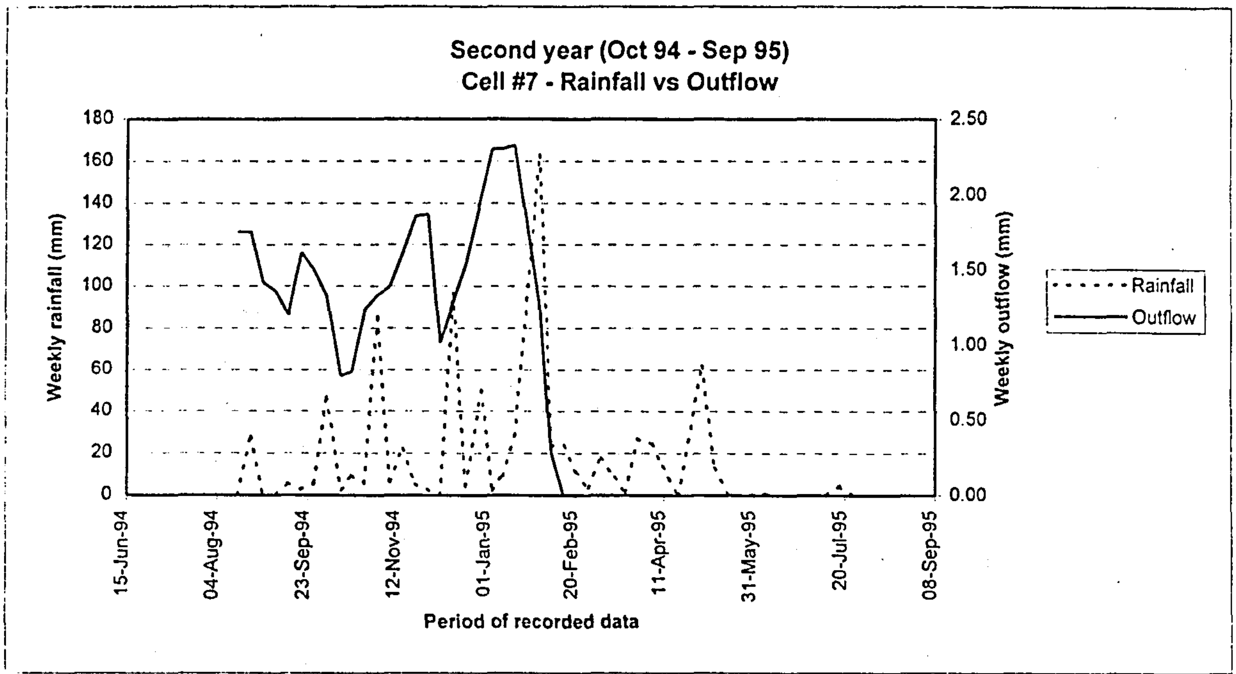
Third Year (Oct 95 - Sep 96)
Cell #6 - Rainfall vs Outflow
Weekly rainfall (mm)
300
250
200
150
100
50
0
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
Weekly outflow (mm)
Rainfall
Outflow
20-Jul-95
08-Sep-95
28-Oct-95
17-Dec-95
05-Feb-96
26-Mar-96
15-May-96
04-Jul-96
23-Aug-96
12-Oct-96
Period of recorded data

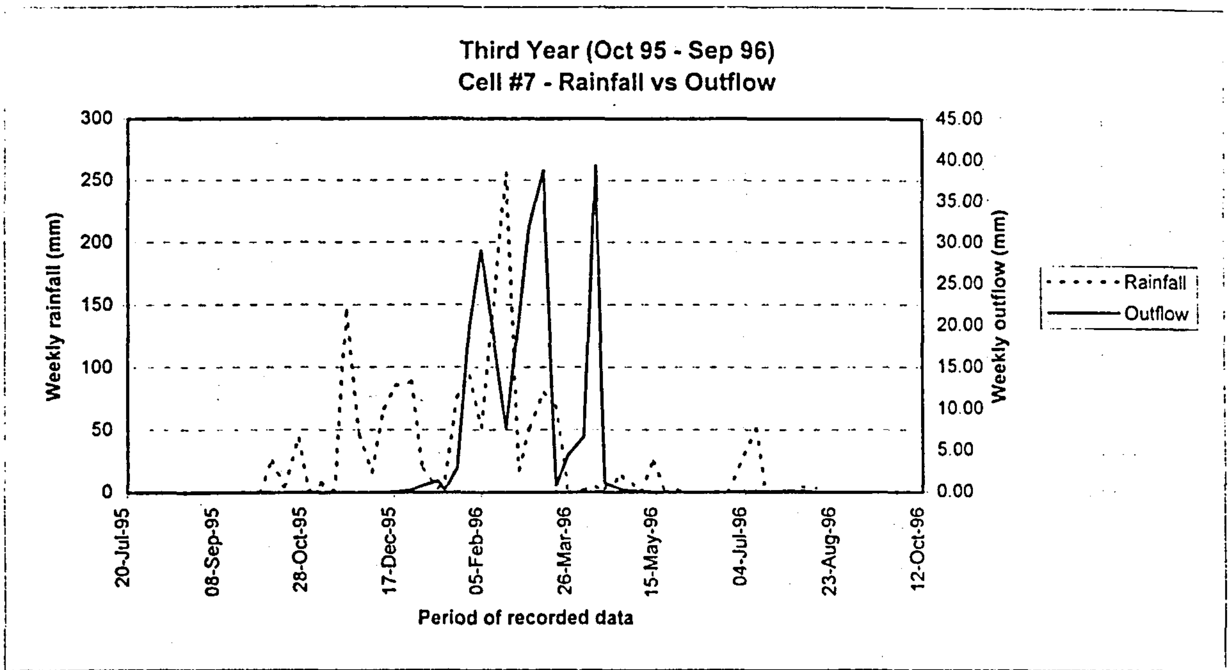


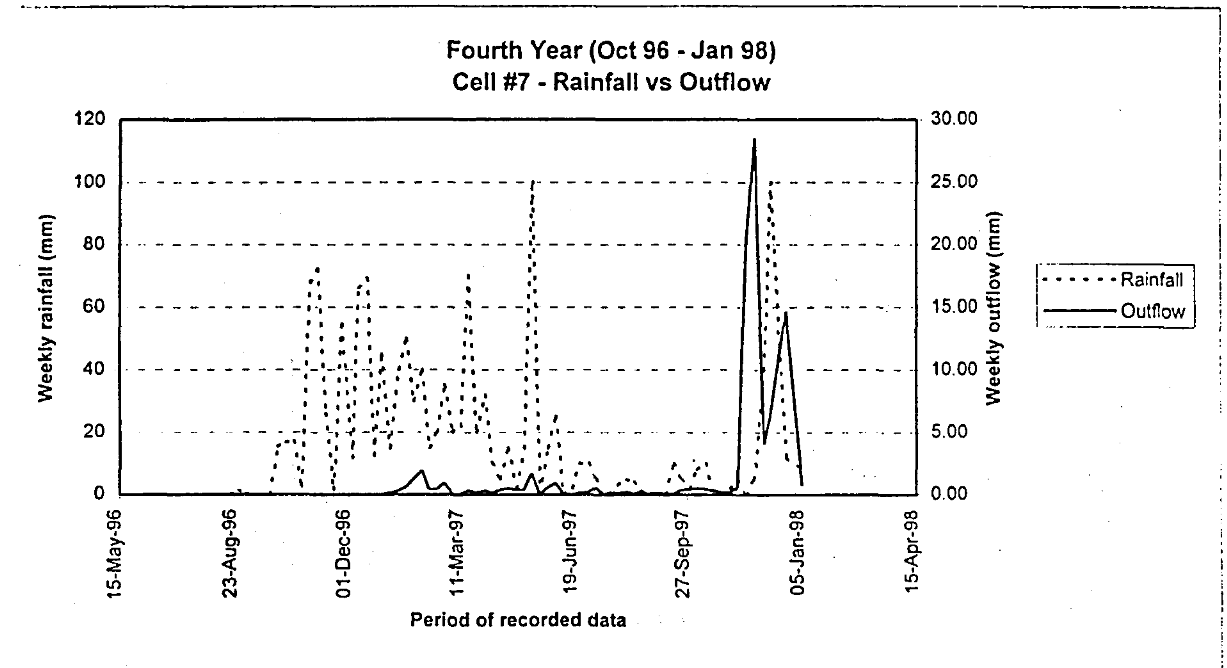
Fourth Year (Oct 96 - Jan 98)
Cell #6 - Rainfall vs Outflow
Weekly rainfall (mm)
120
100
80
60
40
20
0
120.00
100.00
80.00
60.00
40.00
20.00
0.00
Weekly outflow (mm)
Rainfall
Outflow
15-May-96
23-Aug-96
01-Dec-96
11-Mar-97
19-Jun-97
27-Sep-97
05-Jan-98
15-Apr-98
Period of recorded data

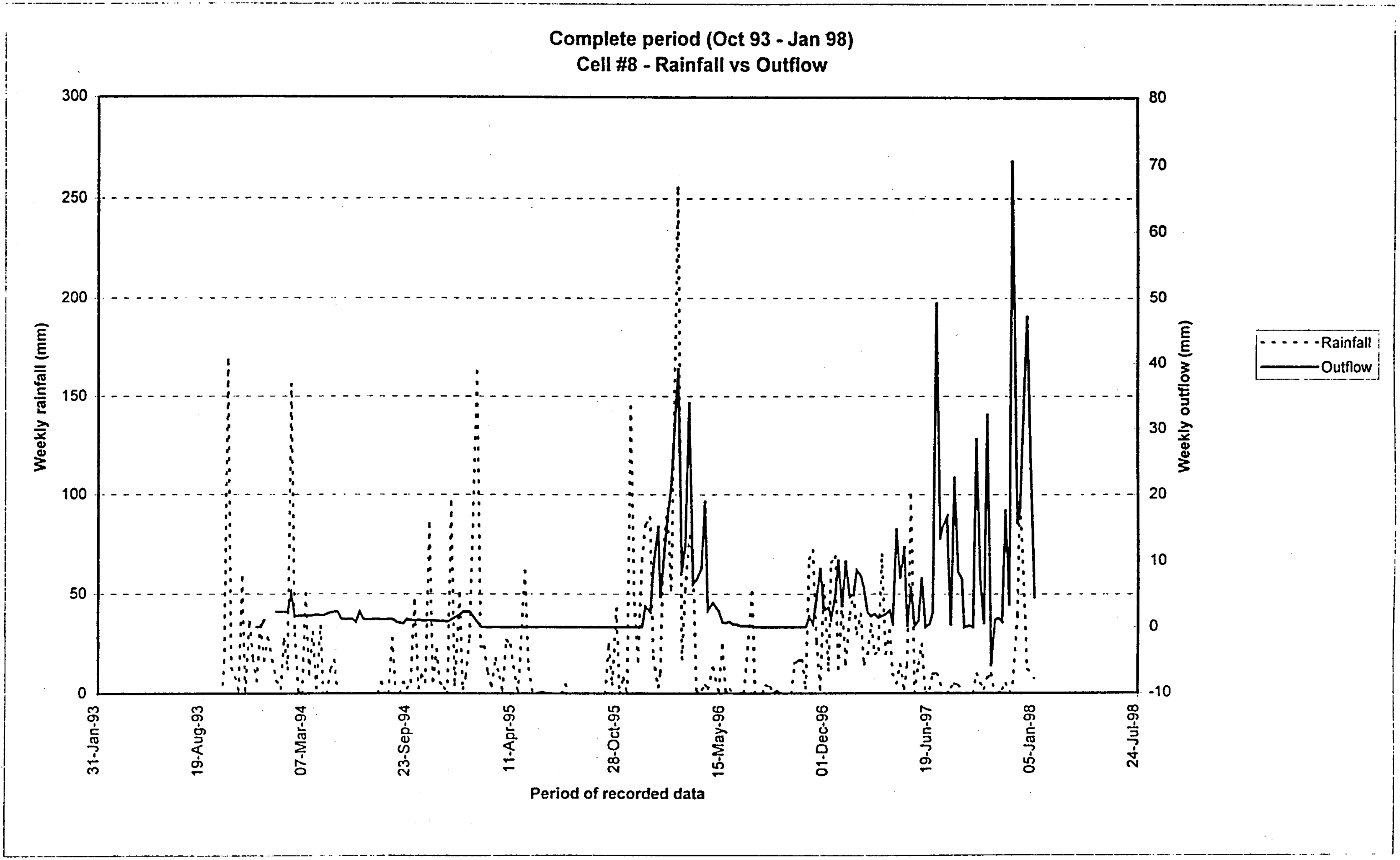

Complete period (Oct 93 - Jan 98)
Cell #7 - Rainfall vs Outflow
Weekly rainfall (mm)
300
250
200
150
100
50
0
Weekly outflow (mm)
50
45
40
35
30
25
20
15
10
5
0
31-Jan-93
19-Aug-93
07-Mar-94
23-Sep-94
11-Apr-95
28-Oct-95
15-May-96
01-Dec-96
19-Jun-97
05-Jan-98
24-Jul-98
Period of recorded data
Rainfall
Outflow


First year (Oct 93 - Sep 94)
Cell #7 - Rainfall vs Outflow
Weekly rainfall (mm)
0
20
40
60
80
100
120
140
160
180
Weekly outflow (mm)
0
1
2
3
4
5
6
7
19-Aug-93
08-Oct-93
27-Nov-93
16-Jan-94
07-Mar-94
26-Apr-94
15-Jun-94
04-Aug-94
23-Sep-94
Period of recorded data
Rainfall
Outflow

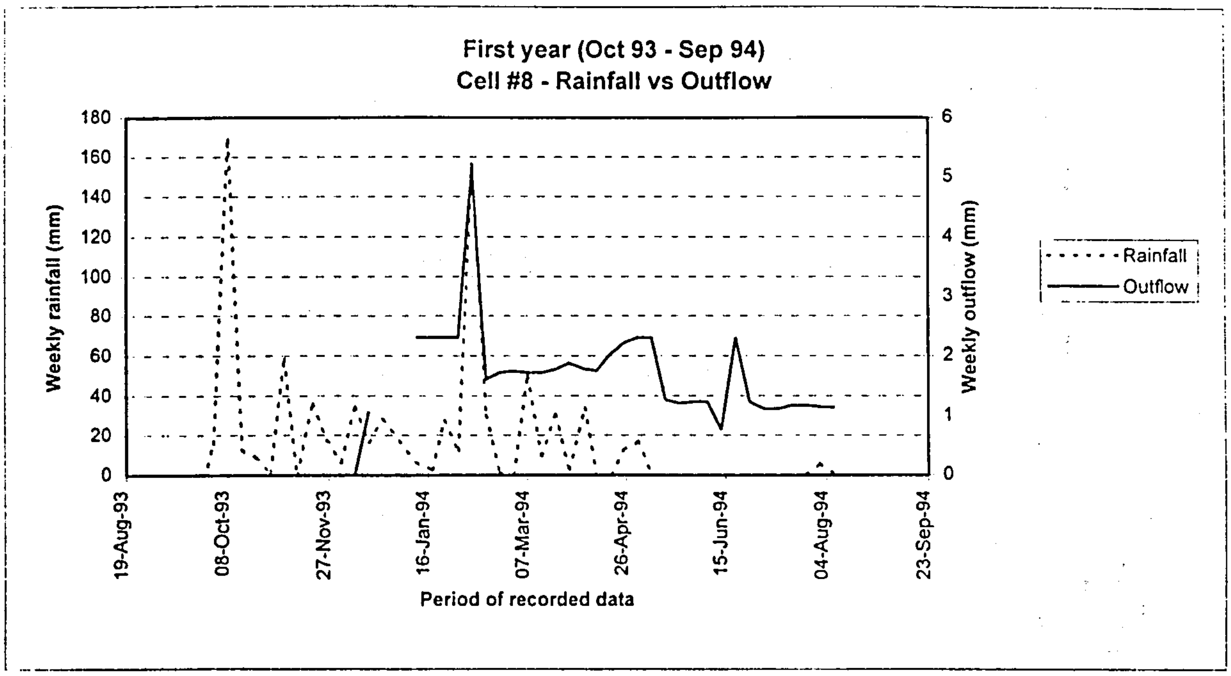

Second year (Oct 94 - Sep 95)
Cell #7 - Rainfall vs Outflow
Weekly rainfall (mm)
0
20
40
60
80
100
120
140
160
180
Weekly outflow (mm)
0.00
0.50
1.00
1.50
2.00
2.50
15-Jun-94
04-Aug-94
23-Sep-94
12-Nov-94
01-Jan-95
20-Feb-95
11-Apr-95
31-May-95
20-Jul-95
08-Sep-95
Period of recorded data
Rainfall
Outflow

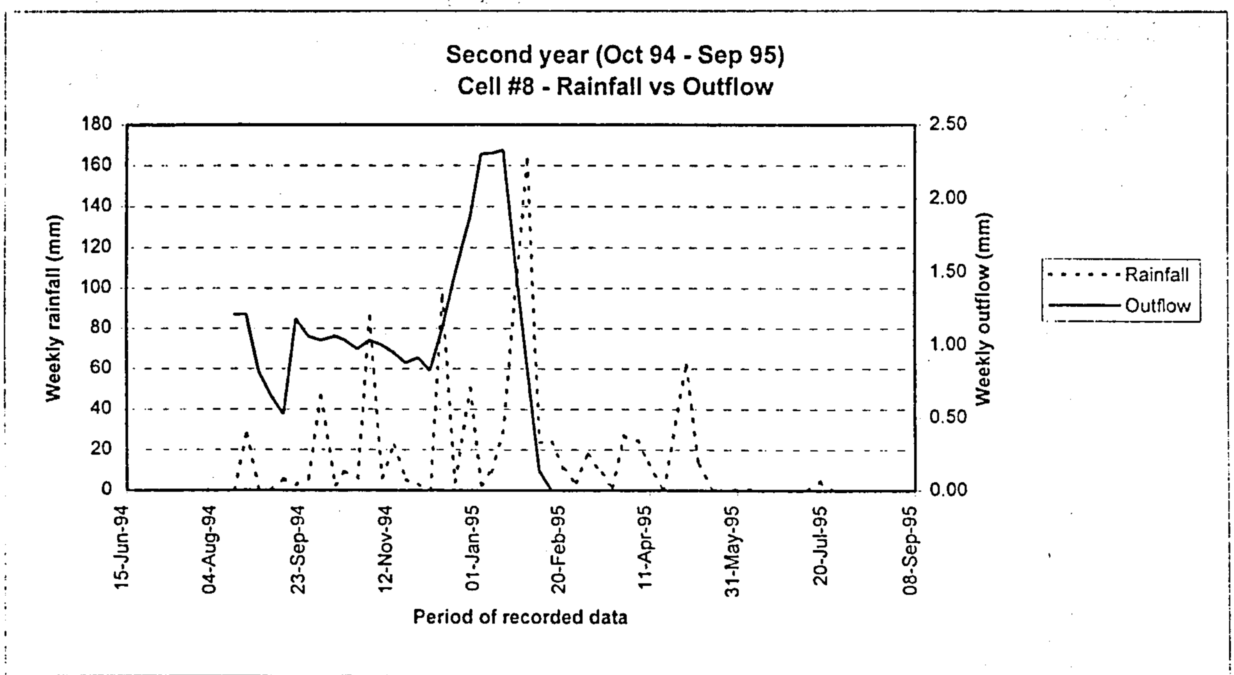

Third Year (Oct 95 - Sep 96)
Cell #7 - Rainfall vs Outflow
Weekly rainfall (mm)
300
250
200
150
100
50
0
Weekly outflow (mm)
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
Rainfall
Outflow
20-Jul-95
08-Sep-95
28-Oct-95
17-Dec-95
05-Feb-96
26-Mar-96
15-May-96
04-Jul-96
23-Aug-96
12-Oct-96
Period of recorded data

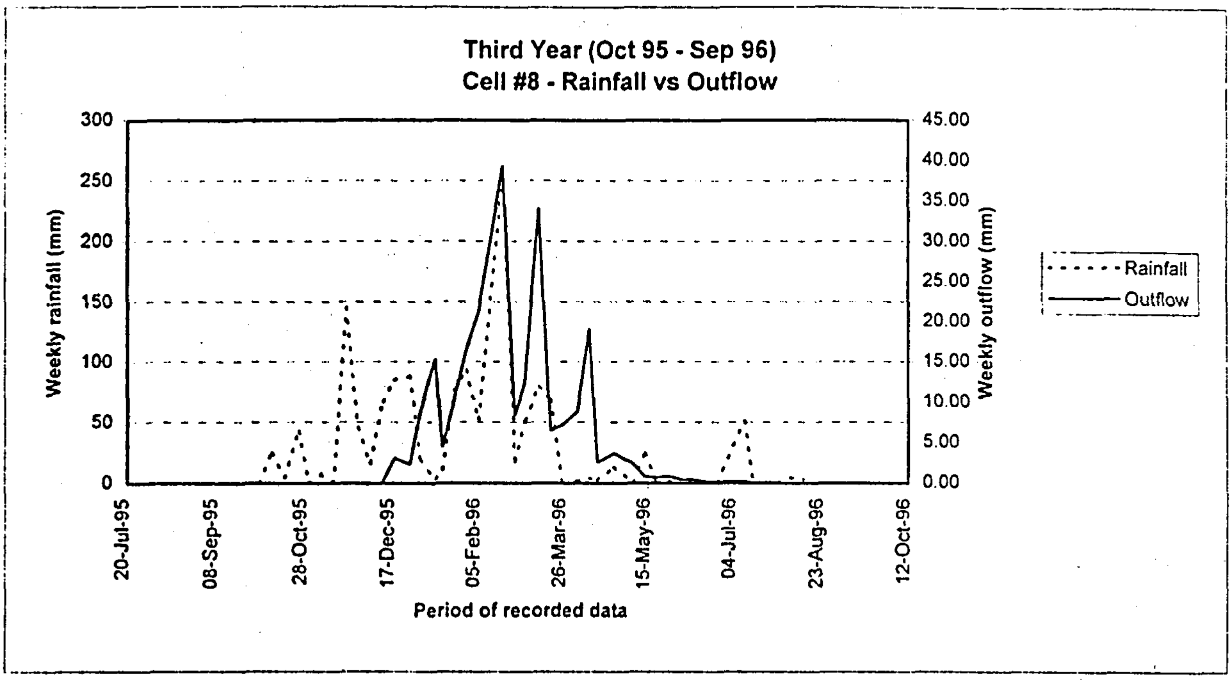

Fourth Year (Oct 96 - Jan 98)
Cell #7 - Rainfall vs Outflow
Weekly rainfall (mm)
120
100
80
60
40
20
0
Weekly outflow (mm)
30.00
25.00
20.00
15.00
10.00
5.00
0.00
Rainfall
Outflow
15-May-96
23-Aug-96
01-Dec-96
11-Mar-97
19-Jun-97
27-Sep-97
05-Jan-98
15-Apr-98
Period of recorded data

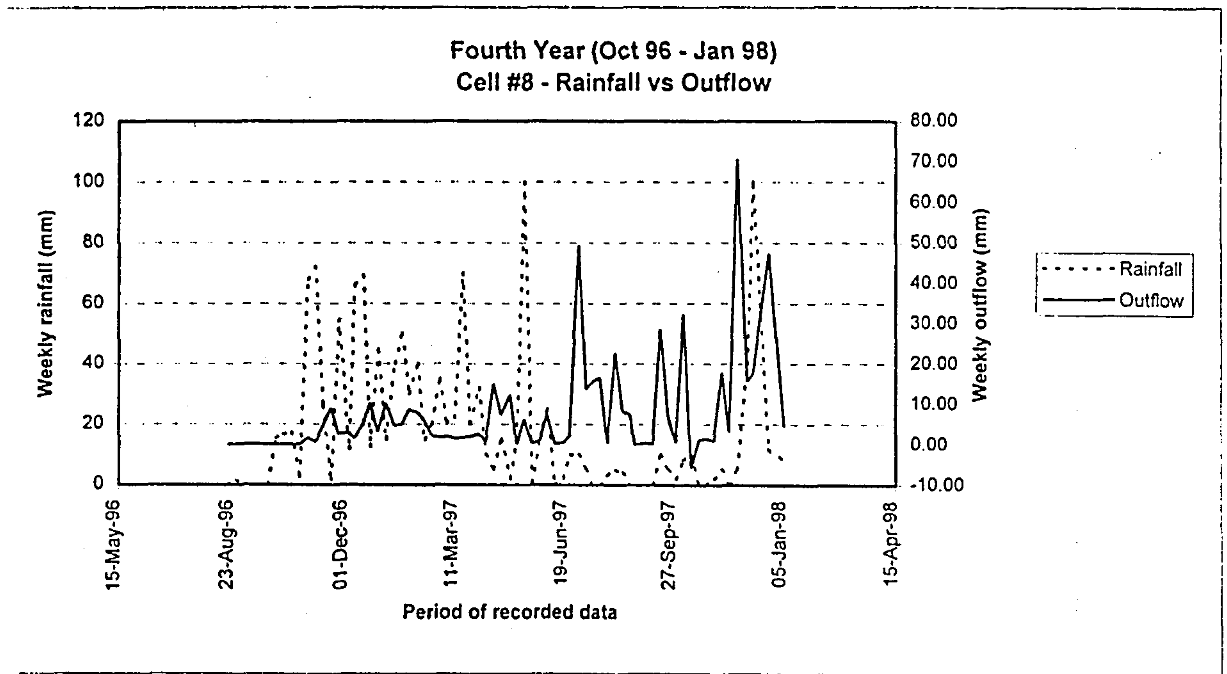


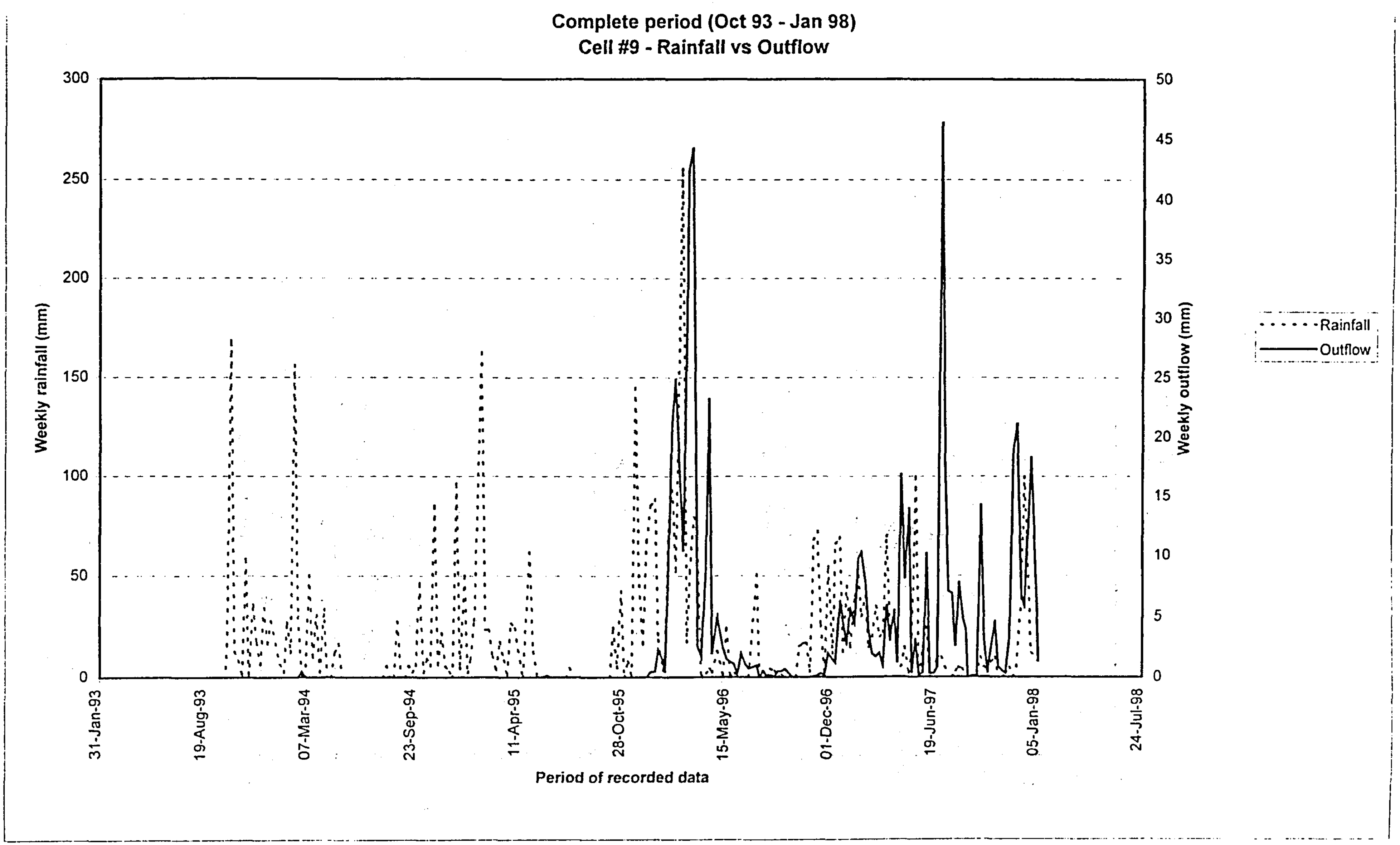
Complete period (Oct 93 - Jan 98)
Cell #8 - Rainfall vs Outflow
Weekly rainfall (mm)
Weekly outflow (mm)
Period of recorded data
Rainfall
Outflow
0
50
100
150
200
250
300
-10
0
10
20
30
40
50
60
70
80
31-Jan-93
19-Aug-93
07-Mar-94
23-Sep-94
11-Apr-95
28-Oct-95
15-May-96
01-Dec-96
19-Jun-97
05-Jan-98
24-Jul-98


First year (Oct 93 - Sep 94)
Cell #8 - Rainfall vs Outflow
Weekly rainfall (mm)
Weekly outflow (mm)
Rainfall
Outflow
180
160
140
120
100
80
60
40
20
0
6
5
4
3
2
1
0
19-Aug-93
08-Oct-93
27-Nov-93
16-Jan-94
07-Mar-94
26-Apr-94
15-Jun-94
04-Aug-94
23-Sep-94
Period of recorded data

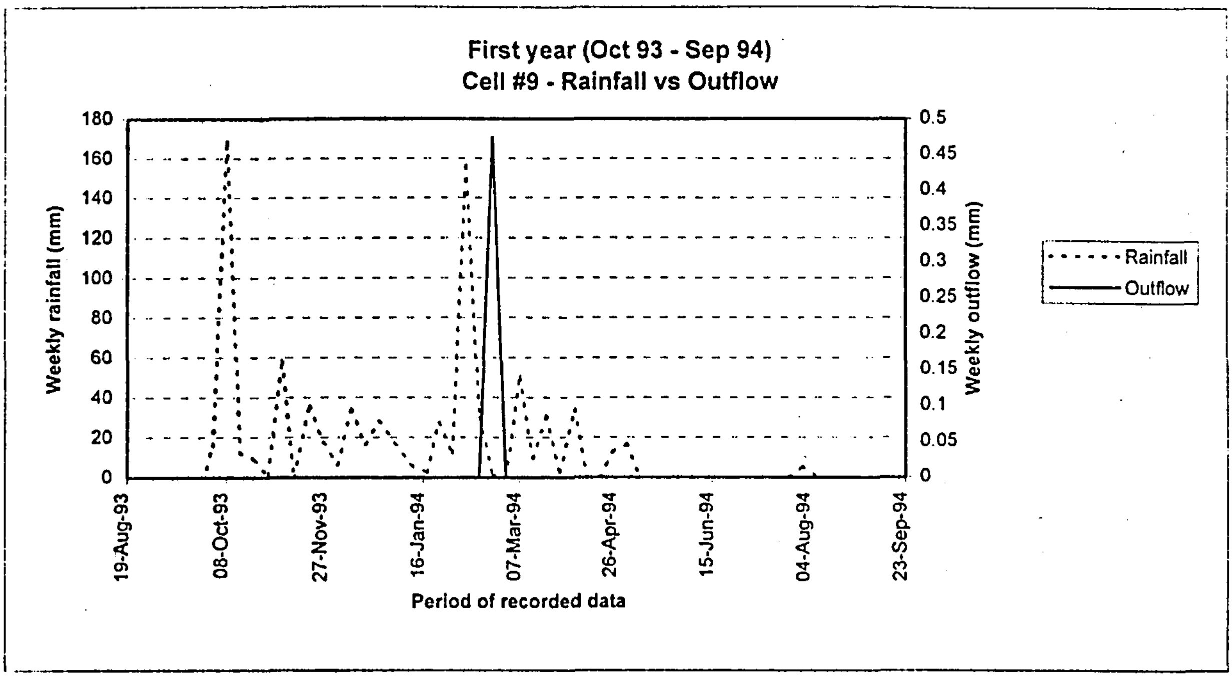

Second year (Oct 94 - Sep 95)
Cell #8 - Rainfall vs Outflow
Weekly rainfall (mm)
Weekly outflow (mm)
Rainfall
Outflow
180
160
140
120
100
80
60
40
20
0
2.50
2.00
1.50
1.00
0.50
0.00
15-Jun-94
04-Aug-94
23-Sep-94
12-Nov-94
01-Jan-95
20-Feb-95
11-Apr-95
31-May-95
20-Jul-95
08-Sep-95
Period of recorded data

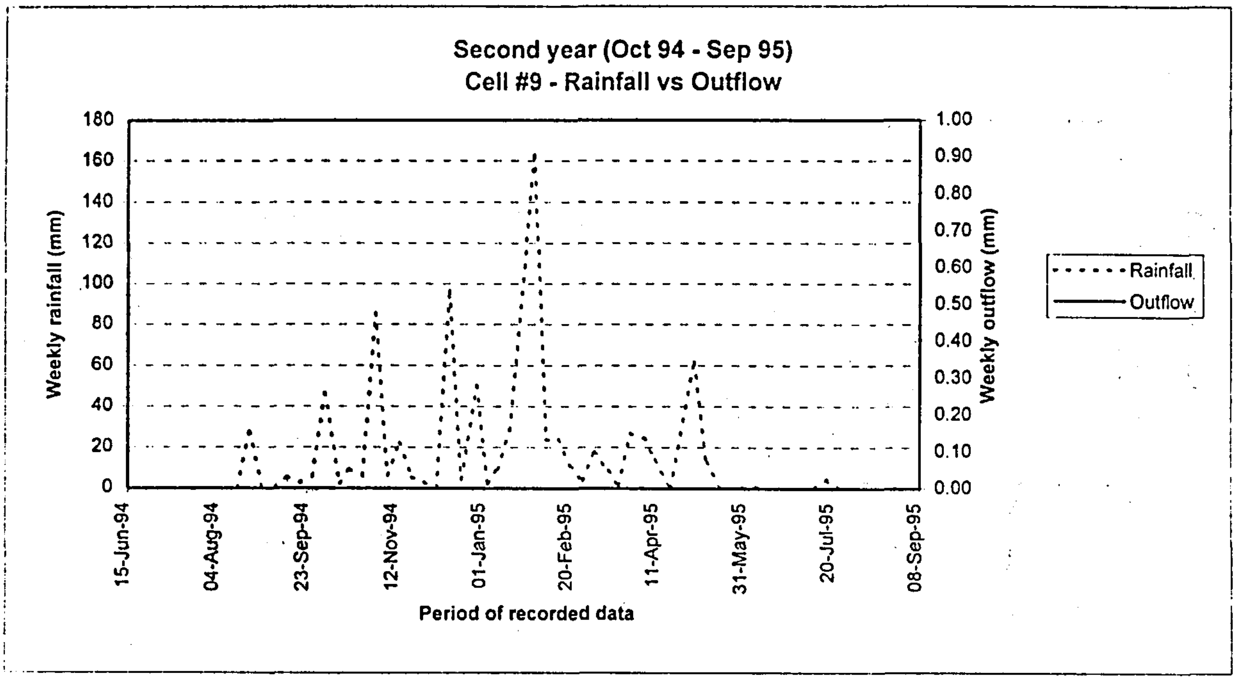

Third Year (Oct 95 - Sep 96)
Cell #8 - Rainfall vs Outflow
Weekly rainfall (mm)
300
250
200
150
100
50
0
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
Weekly outflow (mm)
20-Jul-95
08-Sep-95
28-Oct-95
17-Dec-95
05-Feb-96
26-Mar-96
15-May-96
04-Jul-96
23-Aug-96
12-Oct-96
Period of recorded data
Rainfall
Outflow

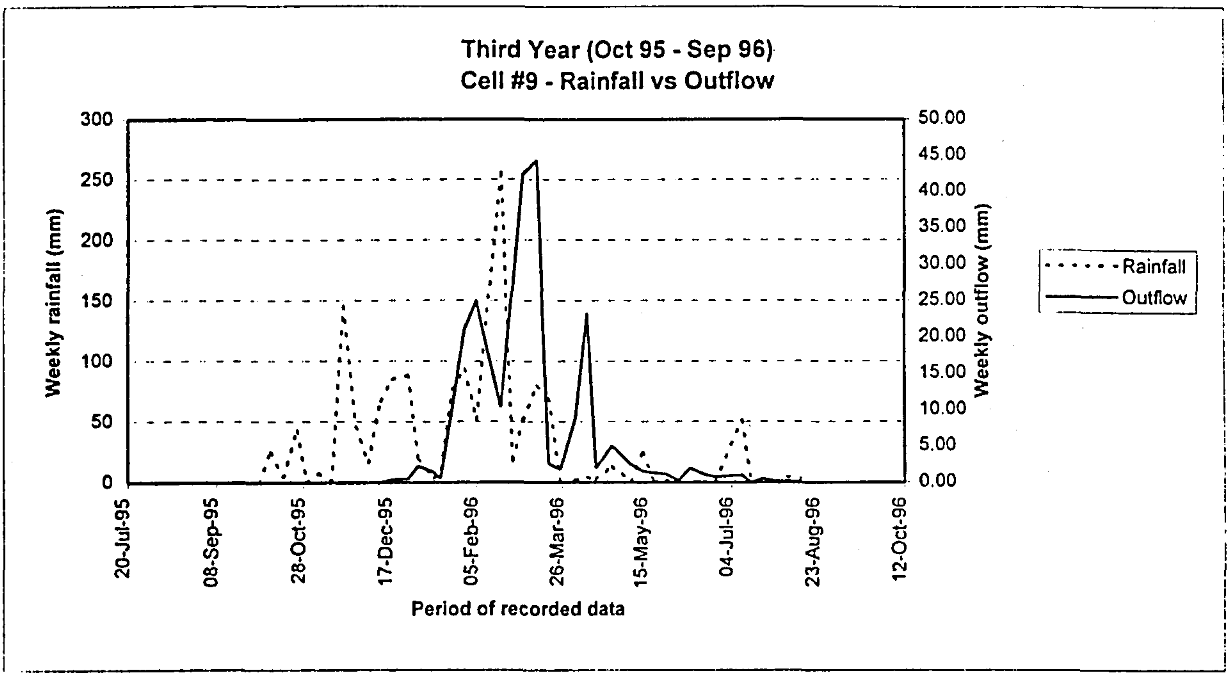

Fourth Year (Oct 96 - Jan 98)
Cell #8 - Rainfall vs Outflow
Weekly rainfall (mm)
120
100
80
60
40
20
0
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
-10.00
Weekly outflow (mm)
15-May-96
23-Aug-96
01-Dec-96
11-Mar-97
19-Jun-97
27-Sep-97
05-Jan-98
15-Apr-98
Period of recorded data
Rainfall
Outflow



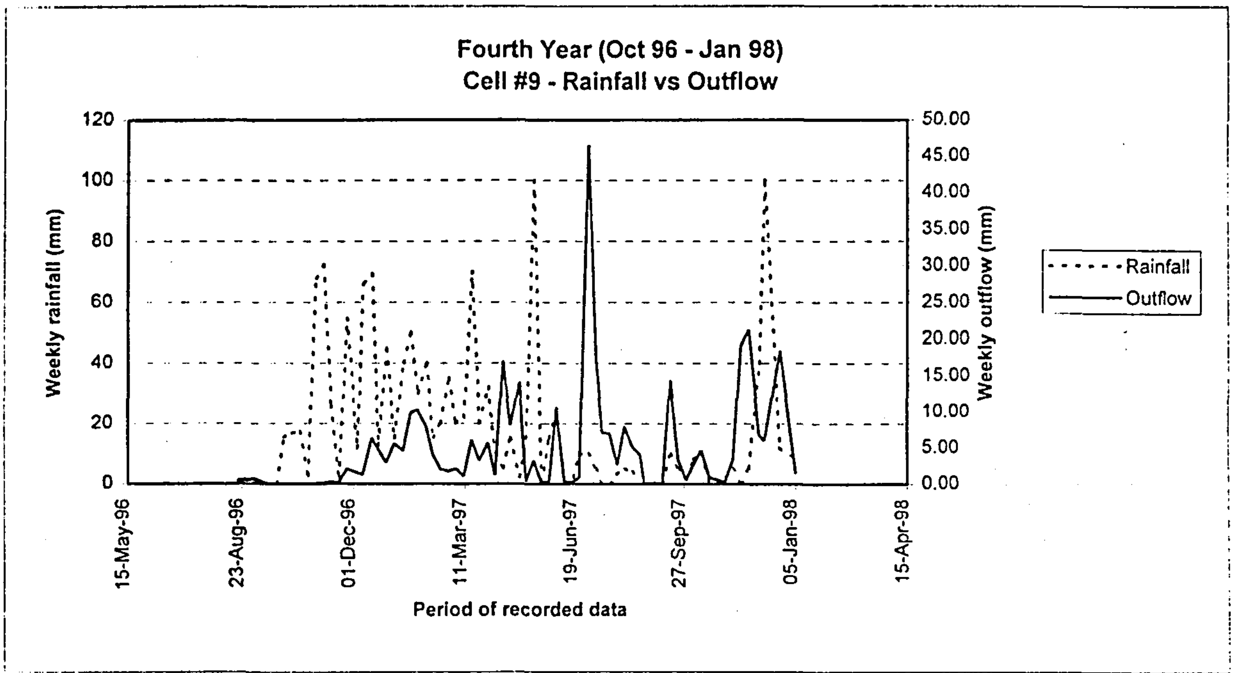
Complete period (Oct 93 - Jan 98)
Cell #9 - Rainfall vs Outflow
Weekly rainfall (mm)
Weekly outflow (mm)
300
250
200
150
100
50
0
45
40
35
30
25
20
15
10
5
Rainfall
Outflow
31-Jan-93
19-Aug-93
07-Mar-94
23-Sep-94
11-Apr-95
28-Oct-95
15-May-96
01-Dec-96
19-Jun-97
05-Jan-98
24-Jul-98
Period of recorded data


First year (Oct 93 - Sep 94)
Cell #9 - Rainfall vs Outflow
Weekly rainfall (mm)
Weekly outflow (mm)
Period of recorded data
19-Aug-93
08-Oct-93
27-Nov-93
16-Jan-94
07-Mar-94
26-Apr-94
15-Jun-94
04-Aug-94
23-Sep-94
Rainfall
Outflow

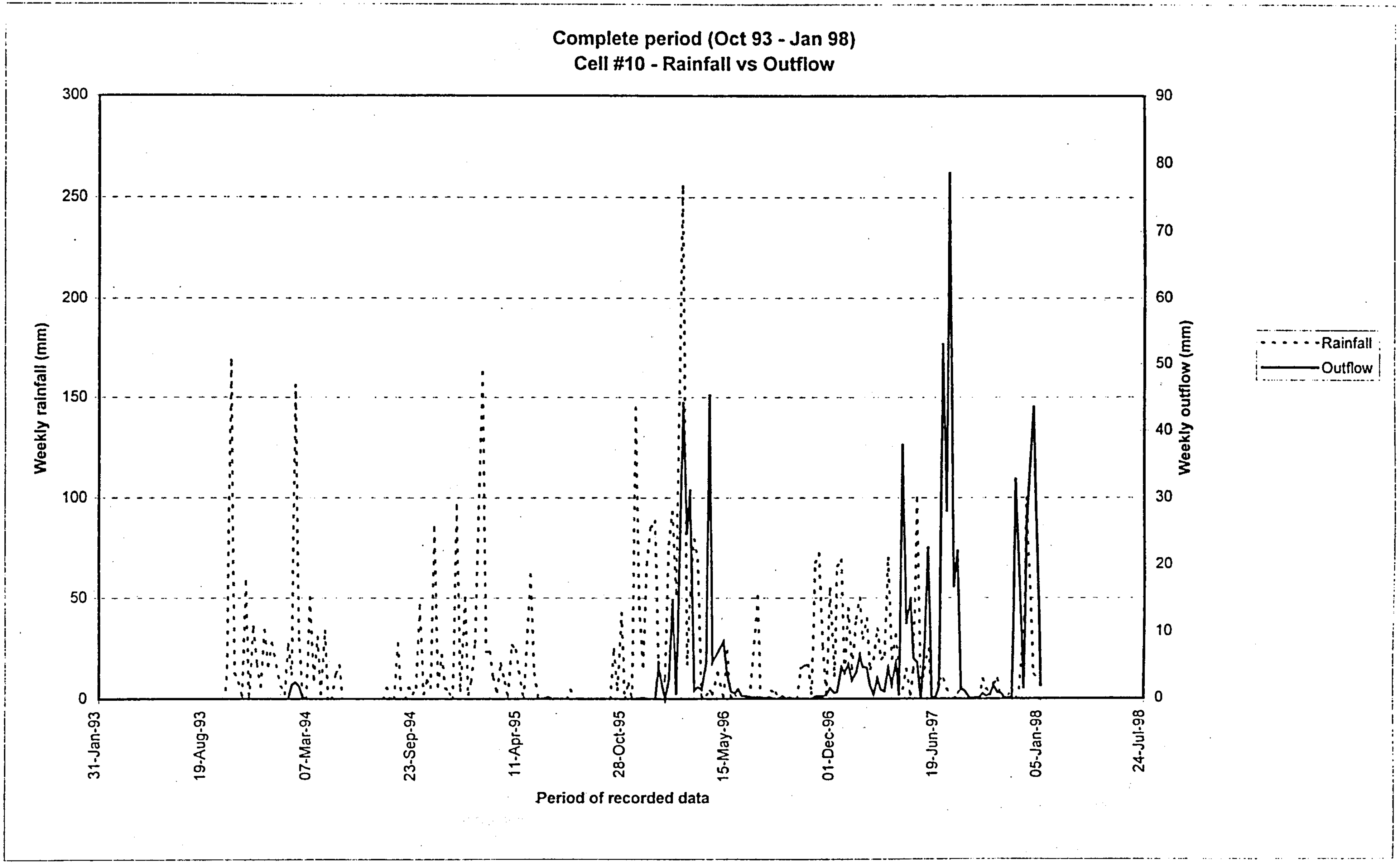

Second year (Oct 94 - Sep 95)
Cell #9 - Rainfall vs Outflow
Weekly rainfall (mm)
Weekly outflow (mm)
Period of recorded data
15-Jun-94
04-Aug-94
23-Sep-94
12-Nov-94
01-Jan-95
20-Feb-95
11-Apr-95
31-May-95
20-Jul-95
08-Sep-95
Rainfall
Outflow

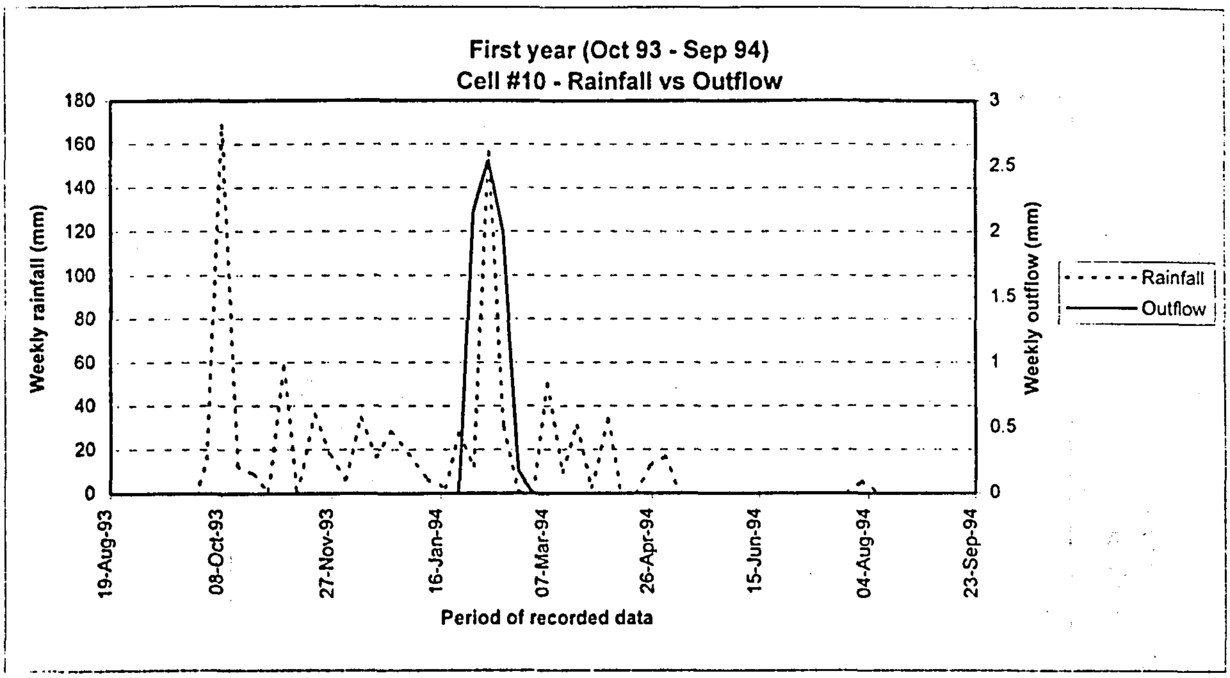


Third Year (Oct 95 - Sep 96)
Cell #9 - Rainfall vs Outflow
Weekly rainfall (mm)
Weekly outflow (mm)
300
250
200
150
100
50
0
50.00
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
20-Jul-95
08-Sep-95
28-Oct-95
17-Dec-95
05-Feb-96
26-Mar-96
15-May-96
04-Jul-96
23-Aug-96
12-Oct-96
Period of recorded data
Rainfall
Outflow

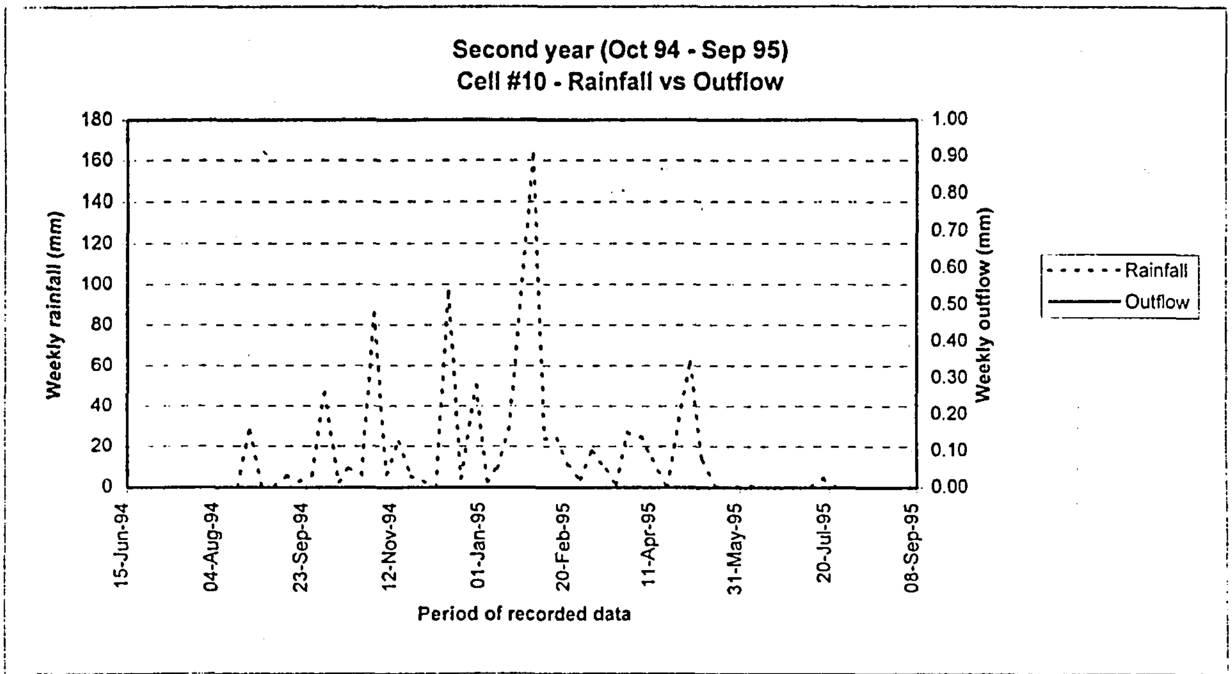


Fourth Year (Oct 96 - Jan 98)
Cell #9 - Rainfall vs Outflow
Weekly rainfall (mm)
Weekly outflow (mm)
120
100
80
60
40
20
0
50.00
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
15-May-96
23-Aug-96
01-Dec-96
11-Mar-97
19-Jun-97
27-Sep-97
05-Jan-98
15-Apr-98
Period of recorded data
Rainfall
Outflow

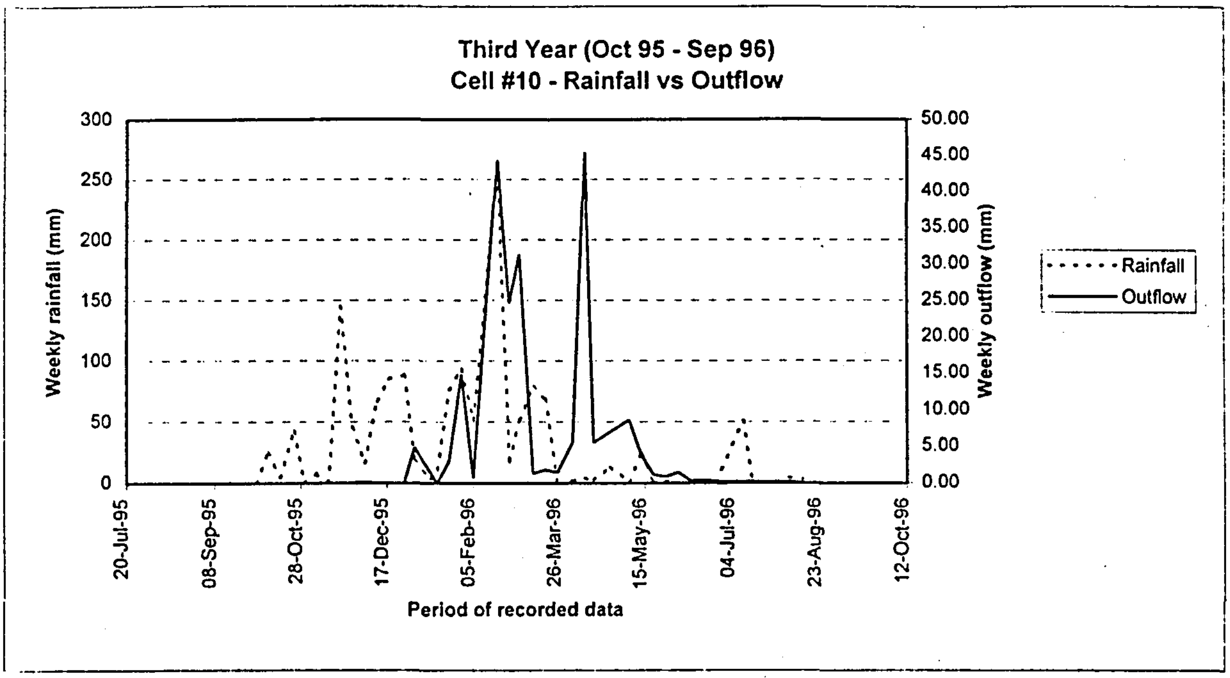

Complete period (Oct 93 - Jan 98)
Cell #10 - Rainfall vs Outflow
Weekly rainfall (mm)
Weekly outflow (mm)
300
250
200
150
100
50
0
90
80
70
60
50
40
30
20
10
0
31-Jan-93
19-Aug-93
07-Mar-94
23-Sep-94
11-Apr-95
28-Oct-95
15-May-96
01-Dec-96
19-Jun-97
05-Jan-98
24-Jul-98
Period of recorded data
Rainfall
Outflow



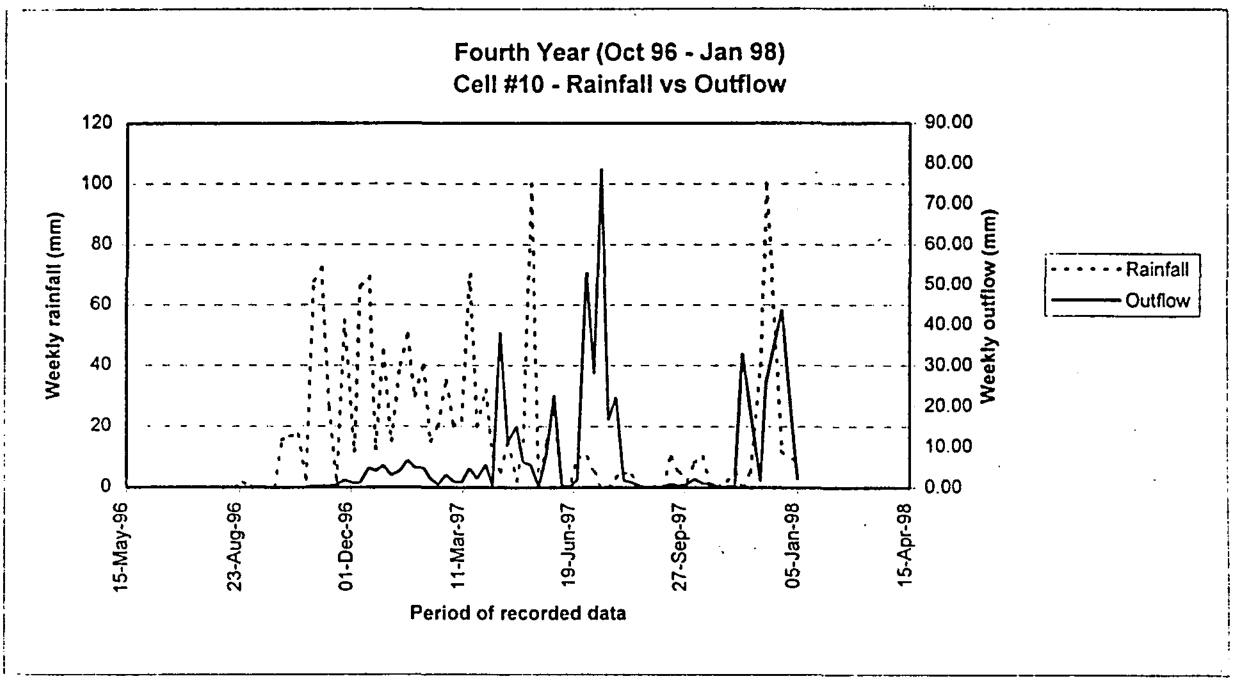
First year (Oct 93 - Sep 94)
Cell #10 - Rainfall vs Outflow
Weekly rainfall (mm)
Weekly outflow (mm)
0
20
40
60
80
100
120
140
160
180
0
0.5
1
1.5
2
2.5
3
19-Aug-93
08-Oct-93
27-Nov-93
16-Jan-94
07-Mar-94
26-Apr-94
15-Jun-94
04-Aug-94
23-Sep-94
Period of recorded data
Rainfall
Outflow



Second year (Oct 94 - Sep 95)
Cell #10 - Rainfall vs Outflow
Weekly rainfall (mm)
Weekly outflow (mm)
0
20
40
60
80
100
120
140
160
180
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
15-Jun-94
04-Aug-94
23-Sep-94
12-Nov-94
01-Jan-95
20-Feb-95
11-Apr-95
31-May-95
20-Jul-95
08-Sep-95
Period of recorded data
Rainfall
Outflow



Third Year (Oct 95 - Sep 96)
Cell #10 - Rainfall vs Outflow
Weekly rainfall (mm)
300
250
200
150
100
50
0
50.00
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
Weekly outflow (mm)
Rainfall
Outflow
20-Jul-95
08-Sep-95
28-Oct-95
17-Dec-95
05-Feb-96
26-Mar-96
15-May-96
04-Jul-96
23-Aug-96
12-Oct-96
Period of recorded data



Fourth Year (Oct 96 - Jan 98)
Cell #10 - Rainfall vs Outflow
Weekly rainfall (mm)
120
100
80
60
40
20
0
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
Weekly outflow (mm)
Rainfall
Outflow
15-May-96
23-Aug-96
01-Dec-96
11-Mar-97
19-Jun-97
27-Sep-97
05-Jan-98
15-Apr-98
Period of recorded data