THE EVALUATION OF SOIL COVERS USED IN THE REHABILITATION OF COAL MINES

JJG Vermaak · JA Wates · N Bezuidenhout · D Kgwale

WRC Report No. 1002/1/04

Water Research Commission

THE EVALUATION OF SOIL COVERS USED IN THE REHABILITATION OF COAL MINES

Report to the
WATER RESEARCH COMMISSION

by

J.J.G. Vermaak, J.A. Wates, N. Bezuidenhout and D. Kgwale

WATES, MEIRING & BARNARD (PTY) LTD

WRC Report No 1002/1/04
ISBN No 1-77005-114-7

MARCH 2004

EXECUTIVE SUMMARY

1. INTRODUCTION

Environmental impacts related to coal mining have long been recognised. Of particular concern is the impact on water resources where long-term deterioration of water quality may threaten water resources and aquatic ecosystems in particular catchment areas.

Huge surface areas are disturbed during opencast and high extraction mining and large areas are covered by coal discard dumps. The high rainfall infiltration rates into these facilities mean that large leachate volumes are generated. In addition, the high oxygen ingress rate into the spoils and discard results in increased oxidation of sulphide minerals and increased growth of iron-oxidising bacteria populations. For spoils and discards prone to acidification, this accelerates Acid Coal Mine Drainage processes, resulting in reduced pH and increased soluble heavy metal concentrations and salinity loads.

One of the obvious and practical sustainable methods in limiting the generation of leachate from coal discard dumps and opencast mines is the provision of vegetated soil covers. Soil covers are probably the most commonly used mitigation measures to limit the generation of leachate from landfills, tailings facilities and waste rock piles.

The main objectives of soil covers should be to limit water infiltration and impede oxygen ingress into the coal discard or spoils and to inhibit the growth of large iron-oxidising bacteria populations. In this way, the leachate volumes are significantly reduced while the quality of leachate is improved because of lower sulphide oxidation rates.

International literature contains many studies where soil covers have been researched and used for the mitigation of many kinds of mine wastes including tailings, rock dumps and coal discard. The research conducted at the Kilbarchan experimental site is, to the authors' knowledge, the first detailed research on soil covers designed to protect water resources.

This report incorporates the results of an extensive ongoing research project, which was initiated in 1993 with the construction of test cells, simulating cover configurations of coal discard dumps, at the experimental terrain near the old Kilbarchan Collieries. The construction of the test cells formed part of Phase I of the research project, which aimed to evaluate the performance of the different test cells in limiting leachate generation into coal discard.

The main objective of this research project (Phase II) was to understand better the factors that result in the generation of leachate. From this understanding, existing unsaturated flow models could be calibrated and the calibrations used to optimise cover design, given the soils available for cover.

The objectives for this research project according to agreement are:

- To develop a clear understanding of the flow mechanisms in the top unsaturated soil layers of a natural soil cover on a microscale, in order to model recharge accurately. (Existing mathematical models to be used as a basis for the study).

- To obtain continuous soil moisture profile data through the top soil layers in order to be able to calibrate the mathematical model developed in the first objective.

In view of the obvious relationship between leachate quality and oxygen ingress through soil covers, the research team investigated this aspect further. It is believed that the use of soil covers may result in better quality leachate because of the covers' ability to impede oxygen ingress, thereby reducing sulphide oxidation rates.

2. LITERATURE STUDY

The coalmining region is located mainly in the upper regions of three major drainage areas, namely the Vaal and Olifants River and the north eastern escarpment areas. These drainage areas are of considerable environmental and economic importance. Surface water monitoring within these catchment areas showed a deterioration in water quality which could be attributed to coal mining and related activities. The impacts of coal mining are much more pronounced in some river reaches.

Acid drainage has been identified as one of the major environmental problems facing the mining industry today. Acid drainage occurs as a result of the oxidation of sulphide minerals which react with water and oxygen to form iron oxide, sulphate and acidity. The reaction is assisted by the presence of catalysing bacteria such as *Thiobacillus ferrooxidans*. The chemical and biological reactions result in low pH, which has the potential to mobilise heavy metals. Acid drainage processes do occur at most South African coalmines but the acid generated is neutralised by neutralising agents occurring naturally in the rock and in solution in water. Neutralisation reactions contribute to the salt load which is transported to groundwater and surface water regimes. Mitigation strategies are aimed to address one or more of the factors contributing to acid drainage and include: Sulphide removal or isolation, waste segregation and blending, exclusion of water by means of soil covers, exclusion of oxygen and bactericides.

Rehabilitation of opencast coalmines is conducted in accordance with the guidelines published by the Chamber of Mines (1981). These rehabilitation guidelines focus mainly on the restoration of the ground surface and on the vegetation of the rehabilitated area. Few of the recommended operations for rehabilitation apply to limiting sulphide mineral oxidation and preventing contamination of the groundwater resources. The rehabilitation practices in South Africa are similar to those practised in the USA and Australia where the focus of rehabilitation is to redress post-mining land use. In South Africa, however, mining-related salinisation of surface water may threaten water resources and rehabilitation practices should focus on addressing these issues.

Numerous risks are associated with coal mining activities, one of which is the risk associated with the deterioration of water quality during the post-closure phase of opencast coal mining. The degree of risk associated with a particular coalmine should be identified by means of a risk assessment. Once the risks have been identified and the liability associated with the coal mine determined, a number of corrective actions could then be considered.

The final cover system should be designed to reduce risks to the environment to acceptable limits. In the case of the coal mining industry, a simplified cost-effective cover design is preferred because of the large areas that need to be rehabilitated and the consequent large costs associated with the placement and maintenance of the cover system.

Final covers on mine wastes are primarily designed to:

1. Provide a growing medium in order to establish vegetation on the rehabilitated waste/spoils,
2. Minimise infiltration into waste/mine spoils, and
3. Impede acid mine drainage processes within the coal spoils or discard materials, thereby resulting in a better quality leachate from the waste/spoils.

One method of reducing the contamination load is to restrict water from infiltrating the waste material by providing it with a cover. Three classes of cover system are identified, namely, low permeability barriers, store and release systems and capillary barriers. Low permeability barriers typically comprise an infiltration barrier, which limits water infiltration into the wastes. Store and release systems rely on evapotranspiration potential to remove water from the soils before it enters the mine waste. Capillary barriers consist of a capillary layer, an unsaturated drainage layer and a capillary break that are designed to drain water from the UDL before breakthrough occurs in the capillary break.

Final cover systems can also be constructed to impede oxygen ingress into the coal discard or to introduce buffering agents to neutralise acidic water.

- Water covers typically entail flooding the mine wastes by, *inter alia,* constructing an engineered water cover, thereby reducing the rate of sulphide oxidation.
- Wet covers entail the construction of covers which will remain near-saturation for most of the year, implying that oxygen ingress would then be similar to that of water covers.
- Dry covers should be designed to limit infiltration into waste material, rather than to inhibit oxygen ingress.
- Acid drainage can be neutralised by the placement of chemical covers (e.g. a layer of lime placed at the base of the cover). Power station fly ash may also be used as a chemical layer for covering purposes.
- Reactive barriers refer to the provision of a layer on or close to the ground surface which consumes atmospheric oxygen before it enters the mine wastes.

The main objective of vegetation covers is to provide a growth medium for vegetation. The vegetation cover typically comprises an organic-rich topsoil layer and a moisture retention layer overlying the mine waste. The main objective of the topsoil layer is to provide a growth medium and the moisture retention layer should retain soil moisture during the dry season.

The main objective of low permeability barriers is to restrict rainfall water infiltrating into the waste. The low-permeability barrier typically comprises the following components: (1) Topsoil layer, (2) Protection layer, (3) Drainage layer, (4) Infiltration barrier, and (5) Capillary break.

The main functions of the topsoil layer are to promote vegetation growth, to promote evapotranspiration and to act as protection against water and wind erosion. It typically comprises nutrient-rich soil that is not compacted. The main functions of the protection layer are to act as a storage medium for water entering the soil cover, to remove water from storage by means of evapotranspiration processes, to protect underlying layers from intrusion by plant roots, burrowing animals and anthropological impacts, to protect the infiltration barrier against desiccation, to protect the barrier layer against freezing/thawing and to maintain stability. The main functions of the drainage layer are to drain away infiltrating water, to dissipate seepage forces that may have developed along the infiltration barrier/moisture retention layer interface, to protect the infiltration barrier against plant roots and burrowing animals and to reduce pore-water pressures within the soil covers, thereby improving slope stability.

The main functions of the infiltration barrier are to minimise infiltration of water into the waste material, to promote storage in the upper uncompacted soil layers and to minimise oxygen flux into the waste material. The infiltration barrier could comprise compacted clay liners (CCL), geomembrane barriers (GM) or geosynthetic clay liners (GCL). The use of geomembrane barriers and geosynthetic clay liners are considered too costly for mining wastes. CCL's are prone to cracking due to desiccation and freezing and need to be protected. The main function of the capillary break is to ensure high moisture contents within the overlying infiltration barrier.

Store and release covers rely on evapotranspiration potential to remove soil water from the cover before it infiltrates the wastes. These covers have the ability to retain and store rainfall water in the cover and also to promote upward movement of soil water. The store and release cover typically comprises a topsoil layer, a moisture retention layer and a capillary break. The purpose of the moisture retention layer is to retain and store infiltrating rainfall water and to promote upward movement of soil water by evapotranspiration. The purpose of the capillary break is to prevent downward movement and infiltration into the waste. A capillary break refers to a cover system where a fine-grained soil layer (moisture retention layer) overlies a coarse-grained soil layer (capillary break). Soil water is retained at the bottom of the moisture retention layer but cannot infiltrate the capillary break because of differences in pore pressure. Once a particular water content is exceeded, breakthrough will occur when soil water will rapidly drain into the coarse-grained layer.

The capillary barrier is closely related to store and release covers in that a capillary break is used to prevent rainfall water from infiltrating mining waste. However, capillary barriers drain water from the covers before it enters the capillary break and waste. The capillary barrier typically comprises a topsoil layer, a moisture retention layer, an unsaturated drainage layer (UDL) and a capillary break. The purpose of the moisture retention layer is to provide moisture for vegetation and to promote evapotranspiration. The purpose of the UDL is to drain soil water from the cover before it infiltrates the capillary break. Interception drains are provided at particular positions to intercept soil water at the interface between the UDL and capillary break.

Wet cover systems are designed to limit acid generation by ensuring that the cover remains near saturation throughout the year, thereby impeding oxygen ingress. The wet cover typically comprises a topsoil layer, an oxygen barrier and a capillary break. The topsoil layer may also comprise sandy soil with the purpose of limiting upward movement of soil water through evapotranspiration. The effectiveness of oxygen barriers is measured in terms of the layer's ability to impede oxygen ingress into the waste. It has been shown that oxygen diffusion is the dominant mechanism in which oxygen enters mining wastes and soil water content is the dominant factor affecting oxygen ingress and oxygen flux into the waste material.

The performance of soil covers depends on climate, type of soils available for cover construction and cover configuration. The design of soil covers is complicated by environmental factors that include cyclic wetting and drying, temperature extremes, penetration of the covers by plant roots and burrowing animals, erosion and other factors. Construction quality assurance (CQA) is critical during the construction of an engineered cover system to ensure that it will perform satisfactorily. The infiltration barrier requires the most stringent CQA and poor construction of this layer will render the whole soil cover system ineffective.

Soil covers will degrade with time resulting in increased infiltration into the mine wastes. A rehabilitation plan should include a maintenance contract for at least two years to ensure that the vegetation is established and to prevent erosion. Desiccation and/or freezing could cause cracks to develop in the cover. The cover may be penetrated by plant roots and burrowing animals and trees may naturally re-establish on the cover. In the long term, soil cover degradation is likely to be caused by erosion processes and soil loss.

In continental climates, designers focussed on limiting oxygen ingress into mine wastes rather than, or in addition to, limiting rainfall infiltration. The climate's low evaporation potential does not support store and release covers. Infiltration barriers are sometimes used but an adequate, and expensive, protection layer is required to protect the clay layer against freezing effects.

In more temperate climates, low-permeability covers are preferred but wet cover systems are also used to inhibit oxygen ingress into mine waste. Low permeability barriers are covered with a protection layer to prevent desiccation and freezing effects. Low permeability covers are also preferred in tropical regions and the infiltration barrier is sometimes also used as an oxygen barrier. Low-permeability covers require a well-designed drainage layer to remove water accumulating on the infiltration barrier. For regions with distinctive dry seasons, the infiltration barrier could dry out and lead to desiccation.

Low permeability barriers and store and release covers are used in areas with a semi-arid climate or where the climate is characterised by distinctive wet and dry seasons. Significant drying of the infiltration barrier occurs during the dry season, resulting in desiccation, and a thick protection layer is required to prevent desiccation. For arid regions, designers often use simple covers on mine waste and incorporate erosion control measures such as cobbles. However, these erosion control measures promote infiltration and prevent evapotranspiration. Store and release covers and low permeability barriers are used where contamination is problematic.

3. UNSATURATED FLOW MODELLING THEORY

The flow of water through a porous medium is complex and is governed by gravitational and capillary forces and the hydraulic characteristics of the porous material. The important processes governing flow rates through unsaturated soils include soil-atmosphere interactions (infiltration, evaporation, transpiration, surface run-off and preferential infiltration) and unsaturated flow processes (redistribution, soil-water retention, sub-surface drainage, funnelled flow, fingered flow and flow through the bottom boundary).

Soil-atmosphere interactions represent the top boundary of the conceptual model where rainfall water enters the unsaturated system and is released to the atmosphere by means of evapotranspiration. Reference evaporation is the maximum rate at which soil water can be removed from the soil zone. The rate of actual evaporation is restricted by the hydraulic characteristics of the soil at ground surface and decreases rapidly as the soil dries.

Vegetation plays an important role in the evapotranspiration process. Transpiration is a function of the leaf area index (LAI). The depth at which vegetation extracts water from the soil profile is governed by the depth and extent of the root system.

The unique relationship between water content and soil suction is represented by soil-water characteristic curves which are an indication of the soil water retention capabilities of a specific soil. Flow in unsaturated media is complex and is governed by hydraulic conductivity, moisture content and soil suction. Hydraulic conductivity in unsaturated porous media is a non-linear function of volumetric water content and soil suction.

Rainfall events are erratic, not only in frequency but also in duration and intensity. This affects the infiltration and redistribution of water flowing through the unsaturated soils. Since flow in the unsaturated soils is dynamic and transient in nature, numerical modelling by means of computer models offers the best tool to understand, simulate and ultimately predict flow of water and solutes through the soils. Various unsaturated flow models can be used to simulate the flow of water through covers and mine waste and include SoilCover, Unsat-H, HELP and SWACROP.

4. EXPERIMENTAL SET UP

The experimental site is situated close to the old Kilbarchan Colliery, approximately 10 kilometres south-east of the town Newcastle, in KwaZulu-Natal. Ten experimental cells were constructed, each cell having a surface area of $100m^2$. The cells are separated from each other by means of 1 m thick compacted clay walls. Each of the cells is 3 m deep. The cells were filled with fine coal discard on which the respective soil covers were placed. The cells were designed to allow leachate to drain freely. The leachate was collected in tipping buckets to enable measurement of leachate volumes. The configurations of the respective experimental cells are as follows:

Cell 1	No cover, unvegetated, fine coal, uncompacted, 1:50 slope.
Cell 2	No cover, unvegetated, fine coal, compacted, 1:50 slope.
Cell 3	No cover, vegetated, top layer treated with lime, fine coal, uncompacted,1:50 slope.
Cell 4	0.3 m Avalon soil, uncompacted, vegetated, 1:50 slope.
Cell 5	0.5 m Avalon soil, compacted, vegetated, 1:50 slope.
Cell 6	0.3 m Avalon soil, uncompacted, vegetated; 0.7 m Estcourt soil, compacted, 1:50 slope.
Cell 7	0.3 m Avalon soil, uncompacted, vegetated; 0.7 m Avalon soil, compacted, 1:50 slope.
Cell 8	0.7 m Avalon soil, uncompacted, vegetated; 0.3 m Estcourt soil, compacted, 1:50 slope.
Cell 9	0.3 m Avalon soil, uncompacted, vegetated; 0.7 m Estcourt soil, compacted, 1:10 slope.
Cell 10	0.3 m Avalon soil, uncompacted, vegetated; 0.7 m Estcourt soil, compacted, 1:5 slope

The cells were first seeded early in November 1993 with seeding being repeated in October 1994. Vegetation established well, attaining a cover percentage of 90%.

The experimental site was extensively instrumented. Leachate collection systems were installed, comprising tipping buckets to measure leachate volumes. The site was equipped with an automated weather station to measure rainfall, temperature, humidity, net radiation and wind speed. Each cell was provided with two steel canisters from which oxygen and carbon dioxide concentrations could be measured. Each cell was provided with access holes from which density and volumetric water content readings could be taken using a nuclear probe. Two of the cells, cell 5 and cell 6, were provided with water content reflectometers from which continuous volumetric water content readings could be obtained and two of the cells were provided with soil temperature probes.

Field monitoring was conducted weekly to record weekly rainfall and evaporation and outflow from each of the test cells, recorded by the tipping buckets. In addition, oxygen and carbon dioxide were measured and leachate samples obtained for water quality analysis from each of the test cells.

Two soil types were used in the experimental cells, namely, Avalon and Estcourt. The Avalon soil was selected to sustain the vegetation while the Estcourt soil was selected for the infiltration barrier. However, tests revealed little difference between the two soils.

The fine coal discard comprises more than 90% sand and gravel and less than 3% clay. The particle size distributions for the Avalon and Estcourt soils are very similar, with both soils comprising more than 30% clay and equal amounts of silt. Both soils are classified as a clay loam according to the soil textural chart.

The clay fraction mineralogy is quite similar for both soils. However, the Estcourt soils appear to contain more smectite (which, through swelling, can contribute to structural instability and impermeability) and, more significantly, they do not contain goethite (a structural stabilising iron hydroxide),unlike the Avalon soils.

A number of laboratory and field experiments were undertaken to determine the hydraulic properties of the cover and fine coal discard material of the test cells, including falling head permeability tests, double-ring infiltrometer tests, small-diameter double ring infiltrometer tests, laboratory tests to determine water retention characteristics and unsaturated hydraulic conductivity of the soils and *in situ* tension infiltrometer tests.

The fine coal discard has hydraulic conductivities similar to sand and there is little difference between the compacted, uncompacted and treated coal discard. The uncompacted Avalon soils have hydraulic conductivities similar to the fine coal discard while those of the compacted Avalon soils are approximately ten times lower. The hydraulic conductivity of the Estcourt soils is approximately ten times lower than the compacted Avalon soils and approximately 100 times lower than the uncompacted Avalon soils. The Estcourt soils do not meet the requirements of a infiltration barrier.

The water retention characteristics of the coal materials are clearly different to those of the cover soils, with much of the soil water drained at relatively low tension whereas the soils are still close to saturation. The residual water contents for the coal material are much lower than those of the cover soils and the air entry values of the compacted soils are much higher than those of the coal discard. The compacted Estcourt soils exhibit the greatest water holding capacity, followed by the compacted Avalon soils.

The unsaturated hydraulic conductivities of the materials at high tensions are the inverse of the saturated hydraulic conductivities, with compacted Estcourt being the most conductive and the uncompacted coal the least conductive material.

Chemical analysis of the fine coal discard revealed that the discard is characterised by relatively high ash contents and low calorific values while the sulphur content is within the range of coal discard. Acid base accounting tests showed that the fine coal discard has very little neutralising potential and significant acid potential.

5. MONITORING PROGRAMME RESULTS

The study area is situated in a typical summer rainfall area, with rainfall being highly seasonal, mostly falling between October and April. Average rainfall for the Newcastle area is 873mm. The region is characterised by warm summers and mild winters with cold mornings. A-pan evaporation in the Newcastle region is between 2 000 and 2 200 mm/a. The prevailing wind direction for the region for most of the year is from the south-east. The windiest months are from October through to December. During the early spring, hot, dry berg winds blow from the west to north-west and are characterised by high wind speeds.

The average rainfall at the experimental site over the eight years of monitoring was similar to that of the Newcastle region. The rainfall years, 1995/1996 and 1996/1997, were particularly wet and the rainfall years, 1997/1998 and 2000/2001, were particularly dry. The rainfall intensity analyses indicate that high intensity rainfall occurs mostly in the late rainfall season (January to March) but also occurring frequently during other months of the wet season.

Reference evaporation was calculated based on the Penman equation using temperature, humidity, net radiation and wind velocity data. The average reference evaporation at the experimental site is similar to the mean annual reference evaporation for the Newcastle region. Reference evaporation is on average, 2.5 times higher than rainfall. For dry years, evaporation is approximately four times higher and for wet years, it is about 1.5 times higher than rainfall.

The volumetric water content data showed significant drying of the compacted Avalon soils in cell 5 during the dry season. The start of the rainy season resulted in rapid increases of soil water content throughout the cover. The Avalon soils did not remain moist for long, with moisture contents decreasing rapidly after rainfall events.

A large diameter double ring infiltrometer test was conducted on cell 6 to obtain an infiltration and drainage curve to which the SoilCover model could be calibrated. The infiltrometer test resulted in the rapid saturation of the cover profile. The soil water in the Avalon soils rapidly drained or evaporated after the test but the Estcourt soils retained the soil moisture for a much longer period. The top portion of the Estcourt soils dried out fairly rapidly but the bottom portion remained moist.

The soil water content of cell 6 increased rapidly with the commencement of the rainy season. The Avalon soils were characterised by cycles of wetting and drying but the Estcourt soils remained moist throughout the rainy season. The fine coal discard remained dry throughout the rainy season with the exception of three breakthrough events.

Although every effort was made to maintain a reliable outflow database, it is likely that the database contains several outflow measurement errors, but it is believed that the database is a fairly accurate representation of actual outflow.

Outflow rates are related to the thickness of the cover with high outflow rates measured for the 0.3m and 0.5m covers and lower outflow rates for the 1.0m covers. There is also a distinct relationship with rainfall, with high outflow rates corresponding to above-average rainfall seasons and low outflow rates to below-average rainfall seasons.

The highest outflow rates were measured in the uncovered cells 1 to 3 with average outflow rates of between 28.4% and 31.3% of MAP. The outflow varies considerably over the monitoring period with more than six times higher outflow rates measured for the wet 1995/1996 year than for the 2000/2001 rainfall season.

Outflow rates are significantly lower for cells that were provided with a soil cover. Average outflow rates for cell 4 are 20% of MAP while average outflow rates through cell 5 are 14.8% of MAP. The outflow rates are also significantly higher than the target for infiltration-limiting covers of 5% of MAP.

Outflow rates for double layer covers are significantly lower than uncovered cells, with outflow rates being 30% to 40% of those of covered cells. The average outflow rates for cell 6 are 12.0% of MAP and the average outflow rates for cell 8 are 10.3% of MAP. These comparatively high outflow rates suggest that the cover configuration of cells 6 and 8 are ineffective in limiting rainfall infiltration.

Cell 7 is by far the best performing cover with average outflow rates of less than 5% of MAP, thus meeting the target for infiltration-limiting covers. The outflow rates are approximately one tenth of the outflow rate of the uncovered cells. Cell 7 has a typical configuration of store and release cover systems and confirms the effectiveness of store and release covers for the Northern KwaZulu-Natal climate.

The outflow results of the sloped cells are mixed, with cell 9 performing relatively poorly and cell 10 performing satisfactorily. The average outflow rates for cell 9 are 13.6% of MAP and those of cell 10 7.2% of MAP. As breakthrough would be expected to occur more readily in sloped cells, so outflow rates would be expected to be higher than for non-sloped cells. This would explain the high outflow rates for cell 9 but does not explain the low outflow rates for cell 10. The reasons for the difference of outflow rates between the sloped cells remain inconclusive.

Oxygen results indicate high oxygen concentrations, similar to atmospheric concentrations, for the uncovered cells 1, 2 and 3, suggesting that oxygen diffusion into the fine coal discard is almost unrestricted. Carbon dioxide concentrations in uncovered cells are low, suggesting that carbon dioxide, generated by sulphide oxidation processes, are unrestricted in diffusing into the atmosphere.

Oxygen concentrations in cell 4 are high but lower than those of the uncovered cells, indicating that oxygen is slightly restricted in diffusing into the fine coal discard. Carbon dioxide concentrations are slightly higher than those of the uncovered cells. Oxygen concentrations in cell 5 are low, indicating that oxygen is restricted in diffusing into the fine coal discard. Low oxygen concentrations were measured for all 1.0 m thick covers (cells 6, 7, 8, 9 and 10), suggesting that the 1.0 m thick covers are effective in restricting oxygen ingress but they do not completely prevent oxygen ingress into the fine coal discard.

6. UNSATURATED FLOW MODELLING RESULTS

Numerical models can be used to evaluate the effectiveness of hypothetical covers for a particular climate and cover configuration (cover type, cover material properties, layer thickness and compaction state). One of the objectives of the research programme was to understand better the flow of soil water through covers in order to model recharge accurately. The model could then be calibrated to soil moisture data measured in the covers of cells 5 and 6.

The model, SoilCover, was selected to model changes in soil water content and outflow for the respective cells. The finite-element model calculates infiltration, evapotranspiration, liquid and vapour flow and oxygen ingress into the cover.

Eight soil cover models were constructed representing the experimental cells 1 to 8. The sloped covers, experimental cells 9 and 10, were not modelled. The bottom boundary was assigned free drainage for all cells. Eight climatic data files were compiled for the years 1993 to 2001 using climatic data measured at the experimental site and serving as the top boundary condition of the model.

The calibration of the SoilCover model demonstrates that the modelled values are a true reflection of the actual situation. The SoilCover model was calibrated to both soil water content and outflow (bottom flux). The bottom flux was calibrated to the outflow volumes as measured by the tipping buckets.

After initial runs, it was found that the model under-estimated the conductive characteristics and over-estimated the retention characteristics of the compacted Avalon and compacted Estcourt soils. After reducing the air entry values and the retention capabilities of these soils, the model more accurately simulated the soil water contents of cells 5 and 6.

Excellent calibration curves were achieved, suggesting that the SoilCover model is able to simulate unsaturated flow through soil covers accurately, provided that the soil properties are an accurate reflection of the field soils. The large diameter double ring infiltrometer test, rainfall infiltration, drainage and evapotranspiration was all well simulated. In addition, the modelled outflow compares well with the measured outflow as recorded by the tipping buckets.

The model can be used to estimate outflow through soil covers, provided that the soil properties used in the model are an accurate reflection of the field soils. The use of models prior to cover construction should be restricted to comparing the performance of different cover configurations. The performance of these cover configurations should be tested by field trials, after the information from which changes may be made to the model so that the model reflects the properties of the cover soils.

7. LEACHATE QUALITY

Acid base accounting tests showed that the fine coal discard contains significant acid potential and very little neutralisation potential, suggesting a high probability that acid drainage occurs. This was proven accurate when acid breakthrough occurred for the uncovered cell 1.

Acid breakthrough was recorded for all the uncovered cells. The onset of acid drainage for cells 2 and 3 occurred three years later than acid drainage in cell 1. Acid drainage also occurred for cell 4which had a 0.3 m cover.

Although acid drainage has not been observed for cell 5, the increase in sulphate concentrations is indicative of increased sulphide oxidation rates. Acid drainage was not observed for any of the 1.0 m thick cells (excluding the sloped cells) which showed a slight decrease of sulphate concentrations, indicating that sulphide oxidation rates had decreased since placement of the cover.

Acid drainage was observed for the sloped cell 10, even though the discard was provided with a 1.0 m cover. It is believed that soil water flowed laterally downwards along the Estcourt and fine coal discard interface, resulting in the drying out of the soil layer along the top portions of the cover thereby increasing ingress of oxygen into the fine coal discard. The high sulphate concentrations indicate that similar processes also occurred in cell 9.

8. FRAMEWORK FOR THE DEVELOPMENT OF A COVER ASSESSMENT PROGRAM

SoilCover requires considerable and detailed data in order to obtain reliable results. A tool, however, is required to assess cover configurations for planning purposes and it was decided that the research team should aim to develop a framework for such a tool. The objective of the cover assessment program is to compare the effectiveness of different soil covers.

The user would be required to specify the cover type (e.g. low permeability, store and release), the types of soils to be used as cover material, layer thickness and compaction state of the cover materials. The program will then assign input distributions of the hydraulic and retention properties typical of the particular soil types.

The procedures that would be followed in developing the cover assessment program include: (1) obtain climatic data that is representative of the main South African coalfields region (2) identify the soil groups that can be used to construct soil covers (3) estimate the retention and hydraulic characteristics of the different soil groups (4) conduct a number of SoilCover models to obtain modelled outflow rates (5) relate input parameters to modelled outflow rates and (6) compare estimated outflow rates with actual outflow rates.

9. DISCUSSION, CONCLUSION & RECOMMENDATIONS

Rehabilitation practices of the South Africa coalmining industry are similar to those practised in other coal-producing countries, but some coalmines may have major long-term water impacts. Soil covers can be used to limit water infiltration, to impede oxygen ingress and to inhibit the growth of large iron-oxidising bacteria populations. Designers should be cautious when designing covers and covers should perform satisfactorily when correctly designed and constructed. Store and release type covers perform well in climates where evapotranspiration exceeds rainfall by a significant margin. Low permeability barriers and wet covers should be designed with caution in climates characterised by distinct wet and dry seasons as infiltration barriers or oxygen barriers may dry out and desiccate during the dry season.

Soil water became entrapped in the Estcourt soils, was prevented from flowing downward by a capillary break and was prevented from moving upwards by the dry non-conductive Avalon soils, resulting in breakthrough and higher outflow rates during subsequent rainfall events.

The differences in outflow rates between the compacted and uncompacted fine coal discard are small, suggesting that the compaction of coal discard does not affect outflow rates significantly. Covers with thickness of less than 1.0 m seem to be ineffective in reducing infiltration to acceptable limits. Double layer covers (cells 6 and 8) are not effective and store and release covers (cell 7) are effective in limiting rainfall infiltration to acceptable limits. The mixed outflow results observed for the sloped cells (cells 9 and 10) could not be explained and the results remain inconclusive.

Initial model runs showed that the model over-estimated the retention capabilities of the compacted cover soils and under-estimated their saturated hydraulic conductivity, because soil properties were not representative of field soils. Excellent calibration curves were obtained after adjusting soil properties.

1.0m thick covers were able to reduce the oxygen flux rate significantly but exceptionally high oxygen concentrations were measured. Oxygen moves almost unrestricted into uncovered waste while 0.3 m and 0.5 m covers are inadequate to impede oxygen ingress.

Acid breakthrough occurred in all uncovered cells but the onset of acid drainage was prolonged by compaction and treatment of coal discard. The 0.3 m cover is ineffective in significantly prolonging the onset of acid drainage. Although acid drainage has not been observed for cell 5, the increase in sulphate concentrations is indicative of increased sulphide oxidation rates.

Acid drainage was not observed in any of the 1.0m thick cells (excluding the sloped cells) and actually showed a slight decrease in sulphate concentrations, indicating that sulphide oxidation rates decreased. Acid drainage was observed in the sloped cell 10, even though the discard was provided with a 1.0 m cover.

Outflow rates are related to rainfall, with high outflows corresponding to above-average rainfall years and low outflows corresponding to below-average rainfall years. Outflow rates are not only a function of the amount of rainfall but also rainfall intensity and frequency. The reduction in outflow rates by compacting the coal discard is insignificant compared with providing the discard with a cover. Outflow rates are related to the thickness of the cover with lower outflow occurring with a thicker cover. Store and release type covers perform well in climates similar to that of the South African coalmining region and the storage capacity of store and release covers can be increased by compacting the bottom portion of the cover. Gravel-sized coal discard material could act as a capillary break. Topsoils may act as a capillary break, limiting upward movement and removal of soil water through evaporation.

Numerical modelling is the only way to simulate and predict accurately the change in soil water content and outflow rates through soil covers. Existing numerical models are unsuitable for use as planning tool. Accurate predictions of outflow rates are only possible if representative soil properties are obtained. Unsaturated flow models can be used to evaluate different cover configurations but there may be significant uncertainties of soil properties. One therefore needs to test cover configurations by means of field trials.

There is a distinct relationship between oxygen ingress rates and leachate quality. The quality of leachate can be improved by restricting oxygen ingress into sulphide-containing mine wastes. Oxygen is not significantly restricted in diffusing into uncovered coal discard and covers of less than 1.0 m thickness. Covers of 1.0 m thickness or more are able to restrict oxygen ingress. Sloped covers are less effective in limiting oxygen ingress.

ACKNOWLEDGEMENTS

The research in this report emanated from a project funded by the Water Research Commission and entitled:

"UNDERSTANDING AND MODELLING OF WATER FLOW THROUGH SOIL COVERS USED FOR REHABILITATING COAL DISCARD DUMPS AND OPENCAST MINES"

The Steering Committee responsible for this project, consisted of the following persons:

Mr HM du Plessis	WRC (Chairman)
Mr H Maaren	Water Research Commission
Mr JA Wates	Wates, Meiring & Barnard
Dr JJG Vermaak	Wates, Meiring & Barnard
Ms B Postma	Dept. of Water Affairs and Forestry
Dr DG Wymer	Chamber of Mines
Ms M Naidoo	Dept. of Minerals and Energy
Dr SA Lorentz	University of Natal
Prof MV Fey	University of Stellenbosch
Mr AI Kotze	Sasol Mining
Mr AT van Coller	National Department of Agriculture
Mr P du Toit Iscor	Mining Limited
Mr S Mungaroo	Ingwe Coal
Mr R Meyer	Ingwe Coal
Mr B Botha	Sasol Mining
Mrs CM Smit	WRC (Committee Services)

The Water Research Commission financed the project and the contribution of members of the Steering Committee is gratefully acknowledged.

The contribution of Coaltech in financing the monitoring programme during the research period is gratefully acknowledged. Five mining groups, Ingwe, Anglo Coal, Iscor Mining and Sasol Mining, also assisted in financing the project.

The project was only possible with the co-operation of many individuals and institutions. The authors therefore wish to record their sincere thanks to the following person and institutions:

The Department of Water Affairs and Forestry for its contribution in conducting weekly monitoring. In particular, the research team would like to thank Mr. Rothman (Dundee office) who ensured that regular maintenance was carried out on site throughout the monitoring period.

The Institute for Water Quality Studies (Department of Water Affairs and Forestry) which conducted bi-weekly analyses of the leachate samples.

Mr. Yoshan Nero of the Department of Water Affairs and Forestry, Dundee, who took the physical experimental readings on a weekly basis at the experimental site.

Dr. Simon Lorentz of the University of Natal for valuable technical guidance throughout the project.

The many individuals and institutions who were involved in the project from its outset in 1993.

TABLE OF CONTENTS

APPENDICES

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

INTRODUCTION

1.1 PROJECT JUSTIFICATION

Environmental impacts related to coal mining have long been recognised. Of particular concern is the impact on water resources where long-term deterioration of water quality may threaten water resources and aquatic ecosystems, and catchment areas in particular. The South African coal industry has become increasingly aware of its impact on water resources. The promulgation of the new National Water Act (Act No 36 of 1998), the Minerals Act (Act No 50 of 1991) and the National Environmental Management Act (Act No 107 of 1998) and other factors have all increased the awareness of economic and social liabilities associated with coal mining (Salmon, 2000).

Coal mining creates impacts on water resources throughout the life cycle of the mine, including the pre-mining, operational, decommissioning and closure phases. Whereas the operating collieries are held responsible for water impacts during the pre-mining, operational and decommissioning phases, the environmental liabilities are transferred to the new owner at closure. Uncertainties in terms of long-term water quality of closed mines are often too great for the authorities to issue closure certificates with confidence and, as such, very few closure certificates have been issued. This has prompted numerous research projects which have been aimed to quantify impacts on water resources during the closure phase more precisely and to assess the effectiveness of rehabilitation strategies in terms of lessening impacts on water resources to acceptable levels (Hodgson & Krantz, 1998; Hodgson *et al*, in preparation; Wates *et al*, 2000).

Numerous investigations have shown that coal mining related impacts on water resources during the closure phase are the greatest at coal discard dumps, rehabilitated opencast mines and areas undermined by high extraction techniques. The magnitude of these impacts can be explained by the huge surface areas being disturbed during opencast and high extraction mining and the large areas covered by coal discard dumps. These result in increased recharge rates and hence large leachate volumes. In addition, the high oxygen ingress rate into the spoils, discard or mine workings results in increased oxidation of sulphide minerals and increased iron-oxidising bacteria populations. For spoils and discards prone to acidification, the

Acid Coal Mine Drainage processes are accelerated, resulting in low pH, increased soluble heavy metal concentrations and increased salinity loads. For spoils and discard not prone to acidification, the processes result in increased salinity loads. The coal mining related impacts on water resources are described in detail in **Chapter 2**.

One of the obvious and practical sustainable methods to limit the generation of leachate from coal discard dumps and opencast mines is the provision of vegetated soil covers. The use of soil covers is probably the most common mitigation measure used to limit the generation of leachate from landfills, tailings facilities and waste rock piles. The provision of top soils has long been used as part of the rehabilitation of opencast areas (Chamber of Mines, 1981). Traditionally, the purpose of these layers was primarily to provide a growth medium for vegetation. The focus has now shifted towards protecting water resources.

The main objectives of soil covers should be to limit water infiltration into coal discard or spoils, thereby impeding oxygen ingress, and to inhibit the growth of large iron-oxidising bacteria populations. In this way, leachate volumes are significantly reduced and the quality of leachate is improved because of lower sulphide oxidation rates.

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. Rainfall patterns, duration and intensity of rainfall events and their often significant variability are some of the important components to consider in the assessment of recharge. Other factors determining the efficiency of a soil cover are soil type, soil compaction and preconditioning of the soil cover. While the choice of soils used at most sites would usually be limited to those in close proximity to the mine, the thickness and order of compaction in which the available soils are placed can be varied to achieve a cost-effective design addressing most environmental concerns.

There is currently inadequate knowledge and experience to compare the advantages, disadvantages and cost implications of various rehabilitation techniques. There is 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 others argue that recharge can only be limited by placing combined geomembrane / geosynthetic covers on the discard material.

International literature is awash with studies where soil covers have been researched and used for the mitigation of many kinds of mine wastes including tailings, rock dumps and coal discard.

Similar studies are conspicuous by their absence in South African literature. The research conducted at the Kilbarchan experimental site is, according to the authors' knowledge, the first detailed research in South Africa on soil covers designed to protect water resources. This research is long overdue as coal mining is a prominent economic activity which has well-documented long-term water impacts in a country with scarce water resources.

1.2 BACKGROUND

This report incorporates the results of an extensive ongoing research project which was initiated in 1993. Test cells were constructed at the experimental terrain near the Ngagane station at the old Kilbarchan Collieries simulating cover configurations of coal discard dumps. The test cells formed part of a previous WRC-funded research project (Phase I) entitled, "*The performance of natural soil covers in rehabilitating opencast mines and waste dumps in South Africa*" (Wates, Rykaart, Vermaak & Bezuidenhout, 2000). This research project aimed to assess the performance of different soil cover configurations in terms of limiting leachate generation into coal discard. The project entailed the construction of 10 test cells, each with a different soil cover configuration and each provided with an underdrain and leachate collection system to measure the quantity and quality of the leachate. The cells were fully instrumented to obtain the parameters necessary for the construction of the unsaturated flow model. The experimental set-up is described in **Chapter 3** of this report. The results of this project have been incorporated into the results of the current project.

Another WRC-funded project entitled, "*An investigation of the occurrence of bacteria causing acid mine drainage in the outer layers of coal waste dumps*" (Loos *et al*, 1999), was completed, coinciding with the above WRC project. In this study, the occurrence and population sizes of iron-oxidising bacteria in the outer layer of coal discard materials and their resultant effect on leachate quality were investigated for the different soil cover configurations.

In 1999, Wates Meiring & Barnard, members of the coal mining industry and the Department of Water Affairs and Forestry initiated a project to continue the monitoring programme at the experimental site. It was felt that the continuation of monitoring would contribute greatly to a better understanding of the long-term performance of soil covers. The project terminated in December 1999. In 2000, it was decided that the monitoring programme at Kilbarchan should form part of the Mine 20/20 initiative under the guidance of Coaltech. The current monitoring programme, funded by Coaltech and with co-operation from the Department of Water Affairs and Forestry, is due to end by December 2002.

This monitoring programme coincided with Phase II of the WRC research project concerning the performance of soil covers. As mentioned, Phase II of the WRC research project was initiated to develop a better understanding of unsaturated flow through soil covers and to calibrate unsaturated flow models which could assist in the design of soil covers. This research document incorporates the results of both Phase I and Phase II of the WRC research project, as well as the results of the monitoring programme.

The research projects conducted at the Kilbarchan experimental site are summarised in **Table 1.3 (a)**.

Table 1.3(a): Summary of projects undertaken at the Kilbarchan experimental site

Project	Funded by	Period
The performance of natural soil covers in rehabilitating opencast mines and waste dumps in South Africa	Water Research Commission	January 1993 – June 1998
An investigation of the occurrence of bacteria causing acid mine drainage in the outer layers of coal waste dumps	Water Research Commission	January 1993 – June 1998
The design and evaluation of soil covers used in the rehabilitation of coal discard dumps and opencast mines in South Africa	Water Research Commission	January 1999 – December 2000
Monitoring programme	Members of the coal mining industry	January 1999 – December 1999
Monitoring programme	Coaltech	January 2000 – December 2002

1.3 PROJECT OBJECTIVES

The initial research project, which commenced in 1993, was initiated because of the need to understand the performance of soil covers in terms of limiting rain water infiltration. The results of the six-year research project indicate that the outflow rate was significantly reduced for cells provided with soil covers. However, attempts to model outflow rates for the different cells using unsaturated flow models proved unsuccessful.

The main objective of this research project was to understand better the factors that result in the generation of leachate. One could then calibrate existing unsaturated flow models so that the models accurately reflect the effects of the South African climate and the soils used for cover material. The calibrated model could then be used to optimise cover design, using the soils available for cover.

The agreed objectives for this research project are:

1. To develop a clear understanding of the flow mechanisms in the top unsaturated soil layers of a natural soil cover on a microscale, in order to model recharge accurately. (Existing mathematical models will be used as a basis for the study).

2. To obtain continuous soil moisture profile data through the top soil layers in order to be able to calibrate the mathematical model developed in Objective No. 1.

The anticipated research product is:

- **Soil water flow models**: The researchers aimed to refine existing numerical unsaturated flow models. This product can be used by the mining industry, authorities and design engineers to optimise soil cover design on rehabilitated coal discard dumps and opencast mines.

In view of the obvious relationship between leachate quality and oxygen ingress through soil covers, the researchers took it upon themselves – and with the approval of the steering committee - to investigate this aspect further, even though this did not form part of the original project objectives. This decision was based on extensive evidence from the literature that soil covers may result in better quality leachate, because of the reduction in sulphide oxidation rates at low oxygen fluxes. In addition, the investigation was facilitated by assistance with the monitoring programme from the Department of Water Affairs and Forestry. This investigation is discussed in **Chapter 9**.

1.4 REPORT LAYOUT

The report incorporates the results of both Phase I and Phase II of the WRC research project concerning the performance of soil covers as well as the results of the monitoring programme coinciding with the projects. The report is divided into 10 chapters which incorporate the literature survey, experimental procedures, results, discussion and conclusions. **Chapter 1** comprises the introduction explaining project justification, project objectives and background to the project. The extensive literature survey is reported in **Chapter 2** dealing with environmental impacts associated with coal mining and including a review on the soil cover systems used as part of mine rehabilitation strategies. **Chapter 3** discusses the current level of knowledge concerning unsaturated flow theory. **Chapter 4** describes the experimental set-up and describes the physical and hydraulic characteristics of the soils and coal discard used in the experiment. The results of the monitoring programme are found in **Chapter 5**. The construction, calibration and results of the unsaturated flow model are discussed in **Chapter 6**. The leachate quality results and its relationship with acid mine drainage potential and oxygen diffusion are described in **Chapter 7**. **Chapter 8** describes how the results of the research project can be incorporated in a risk-based software application that can be used to compare different soil cover configurations, given local climate characteristics and available cover material. The discussion, conclusions and recommendations for future research are found in **Chapter 9**. The references are listed in **Chapter 10**.

CHAPTER 2

LITERATURE REVIEW

2.1 ENVIRONMENTAL IMPACTS ASSOCIATED WITH COAL MINING IN SOUTH AFRICA

The environmental impacts associated with coal mining in South Africa have long been recognised. The mining industry is responsible for the major part of waste generation in South Africa, contributing approximately 318 million tonnes, or 75%, of waste per annum of the total waste production stream. Low-grade coal discard dumps contribute approximately 44 million tonnes of waste per annum. In 1992, it was estimated that 283 tonnes of accumulated coal wastes had been produced, covering 1 020 ha (Korentajer, 1992). Pulverised fly ash (PVA), associated with electricity production in the coal mining region, contributed approximately 35 million tonnes of waste per annum. Extensive areas have been undermined in the coal mining region. De Villiers (1992) estimated that 1 000 ha per annum were disturbed by surface or high extraction mining. It is estimated that 400 000 ha could, with time, be affected by surface or high extraction mining.

The majority of coal mines are located in the north eastern parts of South Africa (**Figure 2.1(a)**). Coal mining takes place mainly in the Mpumalanga Province, with 82% of total coal production in 1997 (Department of Mineral and Energy Affairs, 1998). The coal mining region is located mainly in the upper regions of three major drainage areas, namely the Vaal River, Olifants River and the north eastern escarpment drainage areas. The four major rivers, Tugela, Mkuzi, Umfolozi and Pongola, flow through the latter area (Salmon, 2000). These drainage areas are of considerable importance as they supply water needs to the Gauteng region (Vaal River basin) and also to numerous medium and small towns in the other drainage areas (in particular, Witbank and Middelburg). They also supply water for irrigation purposes (Loskop Dam) and for electricity generation. In addition, the drainage areas are of international importance as both the Olifants River and the Orange River (of which the Vaal River is a tributary) either flow through or share international boundaries with Mozambique and Namibia respectively. The Olifants River also flows through the Kruger National Park which is of significant national and international importance.

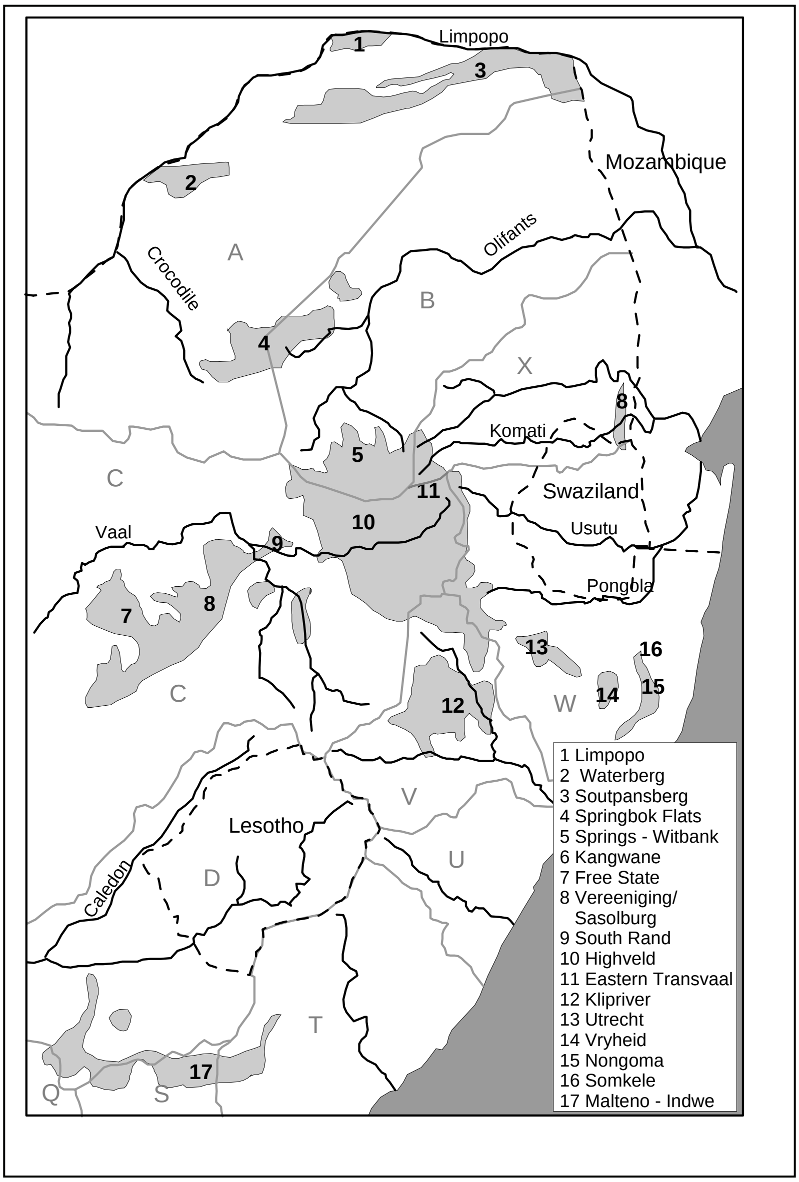


Figure 2.1(a): Distribution of the coalfields in South Africa in relation to the catchment systems (modified after Van der Merwe, 1990)

2.1.1 IMPACTS ON GROUNDWATER RESOURCES

Typically, aquifers in Ecca sediments (which form part of the Karoo Supergroup with which the coal seams are associated) are classified as poor with yields of between 0.05 and 2.0 ℓ/s. Rainfall recharge along the coal fields area is low, typically 15 to 20mm per annum, implying low sustainable borehole yields. The aquifers are typically used for domestic and stock watering purposes and are generally inadequate for irrigation or community water supply. However, in view of the growing population in the coal mining region and government's commitment to supplying water needs, the groundwater resources of the Karoo aquifers may play a more important role in the future.

Coal mining has dramatic impacts on groundwater resources in that the removed coal leaves large underground voids in which groundwater can accumulate. The impacts are even greater for opencast and high extraction mining where much of the strata overlying the coal seams are broken up or shattered, thereby increasing the storage capacity and transmissivity. During the operational phase, opencast and high extraction mining may result in the dewatering of the aquifers adjacent to the mine workings. During the post-closure phase, the mine voids will fill with water, thereby creating new water reserves, albeit of poor quality. Recharge along high extraction areas and rehabilitated opencast mines are also greater compared with undisturbed areas, typically 70-80mm/a (Hodgson & Krantz, 1995).

Coal mining also has impacts on groundwater quality. During the operational phase, groundwater flows into the mine workings and may become contaminated. This groundwater needs to be stored or pumped out so that mining can take place During the closure phase, groundwater levels recover and, with time, will decant on the ground surface and also in the subsurface. Both the underground water and the decant water are typically poor quality, characterised by high TDS loads and, in some cases, low pH and high heavy metal concentrations. Decant water results in contamination of groundwater (subsurface decant) and surface water (ground surface decant and indirectly from subsurface decant).

2.1.2 IMPACTS ON SURFACE WATER RESOURCES

Surface water monitoring conducted by the Department of Water Affairs and Forestry in the Vaal and Olifants River basins showed a deterioration in water quality which could be attributed to coal mining and related activities. In particular, increasing sulphate, sodium, calcium and chloride concentrations were measured at various monitoring points, including the Loskop, Witbank and Middelburg dams (Hodgson & Krantz, 1998). These higher concentrations correlate with the period during which coal mining took place. Sulphate and calcium dominate the water chemistries and these could be attributed to acid rock drainage and processes taking place in coal discard and underground workings. The impacts of coal mining are more pronounced in certain river reaches, such as the Wolwekrans, Spookspruit and Steenkoolspruit, where very high salinity levels have been recorded (Hodgson & Krantz).

The deterioration of surface water resources have been attributed by, *inter alia,* operational coal mines where, in the past, poor water management practices have resulted in contamination of some river reaches. It is also suspected that much of the current surface water contamination results from contaminated baseflow, feeding the rivers. In addition, abandoned mines also contribute to surface water contamination, as do closed mines where decant of poor quality water occurs.

2.2 ACID DRAINAGE AND SALINISATION

2.2.1 ACID DRAINAGE

Acid drainage is a naturally-occurring phenomenon where sulphide minerals enclosed in rock produce sulphuric acid in the presence of water and oxygen. The rate at which acid drainage is produced increases considerably during mining, when the surface area of sulphidic rocks is greatly increased when the ore material is fractured and crushed. Acid drainage typically has two environmental consequences:

- Acid drainage reaches streams where it lowers the pH of the river, thereby damaging or destroying the river ecology.
- Acid drainage may leach metals from the mine waste or rock into the groundwater and surface water resources, thereby contaminating water supplies.

Acid drainage has been identified as one of the major environmental problems facing the mining industry today (Taylor, 1998). Liabilities associated with acid drainage around the world have been estimated at $C2 to $C5 billion in Canada, $US20 billion in the USA, DM13 billion for the uranium mines in East Germany, $US300 million in Sweden and $A60 million in Australia annually (Taylor, 1998). Acid Mine Drainage has been identified as a potentially serious threat to the water quality of South African major water resources (Van der Merwe, 1990).

Acid drainage is associated with most mining activities, including rock dumps, low grade ore, overburden and run-of-mill stockpiles. Acid drainage also occurs at abandoned mines, adits, shafts and open cuts. In the South African coalfields, acid drainage occurs at abandoned mines (Witbank and Vryheid areas), coal discard dumps, opencast and underground mines. Sulphide minerals are typically enclosed in coal and in the under- and overlying geological formations. During mining, sulphide minerals are exposed to air and water, resulting in acid drainage.

Acid drainage occurs as a result of the oxidation of sulphide minerals, mainly pyrite, but also pyrrhotite, marcasite, galena, sphalerite and chalcopyrite. Sulphide minerals, such as pyrite, react with water and oxygen to form iron oxide, sulphate and acidity (Stumm & Morgan, 1981; Steffan, Robertson & Kirsten, 1989). The reaction is assisted by the presence of catalysing bacteria such as *Thiobacillus ferrooxidans* (Walsh *et al*, 1979; Loos et al, 2000).

The reaction for pyrite may be expressed as follows (Appelo & Postma, 1994):

$$4FeS_2 + 15O_2 + 8H_2O \xrightarrow{bacteria} 2Fe_2O_3 + 8SO_4{}^{2-} + 16H^+$$

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 then transported to the receiving environment.

2.2.2 SALINISATION

Acid drainage does not occur with all coal mining activities. At most coal mines, acid drainage processes do occur, but the acid generated is neutralised by neutralising agents occurring naturally in the rock and in solution in water. In the South African coalfields, acid water is typically neutralised by carbonate minerals, occurring in the coal material itself and also within the overlying geological formations. Neutralisation processes have been extensively discussed in literature (Blowes & Jambor, 1980; Glyn, 1991; Liu, 1991; Walter & Norris, 1991). Neutralisation reactions produce salts, most notably gypsum ($CaSO_4 \cdot 8H_20$). These salts are generally in solution, contributing to the salt load, which is transported to groundwater and surface water regimes. The environmental consequences of these increased salt loads include:

- As with acid mine drainage, high salt loads reach waterways and damage the river ecology.
- Very high salt loads may render water supplies (in particular, groundwater supplies) unusable.

Another important consequence of high salt loads is the accumulative effect of coal mining in particular catchments, resulting in increased salt loads being transported to downstream water users.

Static and kinetic tests are conducted to determine the potential for coal discard or spoils to generate acidity. The net neutralisation potential (NNP) is determined by acid-base accounting. The probability for a particular material to generate acid can be determined by kinetic tests such as leaching columns or humidity cells. Chemical equilibrium models, such as MINTEQ, PHREEQC and WATEQ can be used to deal with the chemistry under equilibrium conditions (Felmy *et al*, 1984; Parkhurst *et al*, 1980; Trusdell and Jones, 1974). More advanced geochemical models, such as SATRA-CHEM (Lewis *et al*, 1986) are used to combine equilibrium chemistry with mass transport.

2.2.3 MITIGATION STRATEGIES TO CONTROL ACID DRAINAGE PROCESSES

A number of factors contribute to the rate of sulphide oxidation:

- Presence of iron oxidising bacteria
- Microscopic texture and crystal form of the sulphide mineral
- Presence and availability of oxygen and oxidants such as Fe^{3+}
- Temperature and pH
- Particle size distribution
- Presence of water

Mitigation strategies are aimed to address one or more of the factors contributing to acid drainage and these are discussed.

SULPHIDE REMOVAL OR ISOLATION

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

WASTE SEGREGATION AND BLENDING

Waste segregation involves the removal and separate handling of wastes on the crushing site. The benefits of this process are firstly, minimisation of waste volume that would generate acidic drainage and secondly, waste containing carbonate can be blended with the acid-generating waste, thereby ensuring that neutralisation potential is larger than acid-forming potential. This practice has 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, and possibly enhanced by blending. As collieries do not normally have abundant supplies of carbonate waste, this option could be costly, especially if material has to be imported.

EXCLUSION OF WATER

The main objective of this approach is to prevent any surface water from entering the sulphuric wastes. This can only be achieved by constructing an impermeable seal, such as by using 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 the exclusion of water to the extent that acid generation no longer exists, is not practical (SRK, 1989).

Although it may not be practical to exclude water from waste material totally, water infiltration into waste material can be significantly reduced by means of a final cover, thereby resulting in a much reduced waste load to the groundwater and eventually to the surface water regimes.

EXCLUSION OF OXYGEN

Although it is possible to form acid in anaerobic conditions, it has been shown to occur less easily (SRK, 1989). The exclusion of oxygen to the extent that acid generation is reduced to significantly low levels requires 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.

BACTERICIDES

As bacteriological growth can increase the rate of acid formation, bactericides are used to create a toxic environment for the bacteria, thereby limiting bacteria populations and reducing the rate of acid formation. However, bactericides will not prevent acid formation. Research on bactericides are fairly advanced, all showing 50 – 59%, effectiveness in the short term (SRK, 1988). Bactericides does not remain effective indefinitely as they degrade and are removed by percolating water.

Bactericides are usually applied to the surface of the waste by means of a spray-on hydroseed system, or by spreading time-release rubber pellets, which release the bactericides over time. This approach remains a temporary and costly method of reducing the rate of acid formation.

2.3 CURRENT REHABILITATION PRACTICES

2.3.1 SOUTH AFRICAN GUIDELINES

At present, rehabilitation of opencast coal mines is conducted in accordance with the guidelines published by the Chamber of Mines (1981), entitled: "*The rehabilitation of land disturbed by surface coal mining in South Africa*". The guidelines have been prepared to assist mine management to carry out their national obligation in respect of environmental protection by following the "best practice" approach. More stringent environmental legislation, particularly in respect of water resources, implies that the "best practice" approach should be modified to meet current legislation standards.

The current Chamber of Mines guidelines are divided into 31 sections covering six topics applicable to the rehabilitation of opencast mines. These are:

- Topic 1: Legal requirements
- Topic 2: Guidelines for characterising the pre-mining environment
- Topic 3: Guidelines for managing and protecting water resources
- Topic 4: Guidelines for spoil grading and topsoiling
- Topic 5: Guidelines for re-vegetating disturbed land, and
- Topic 6: Guidelines for planning, monitoring and recording

In essence, the guidelines contain a list of essential operations to be executed before mining commences (Topic 2), during mining operations (Topic 3) and during the rehabilitation period (Topics 4, 5 and 6). In terms of rehabilitation, the following operations should be executed (Chamber of Mines, 1981):

1. The spoil should be levelled in such a way as to approximate original contours, minimise erosion of slopes and provide drainage lines for the discharge of run-off. Suitable soil materials should be applied to levelled spoil in sufficient quantity to achieve the post mining land capability envisaged in the rehabilitation plan. An erosion-minimising surface drainage system should be installed for the safe discharge of run-off into waterways and drainage lines. Excess soil should be stockpiled for repair work.
2. The topsoil materials should be ameliorated as to eliminate, or reduce, conditions such as acidity, nutrient deficiencies, surface crusting or droughtiness, which will limit the growth of vegetation. Suitable plants should be selected to establish an adequate vegetation cover, using

mulches and irrigation if necessary. A management programme should be initiated to maintain the fertility, conduct periodic defoliation, assess the utilisation of the vegetation cover and to monitor the basal cover and species composition. A re-vegetation management system should be developed to accommodate ongoing functions of planning, budgeting, monitoring and recording.

3. Upon cessation of mining, the rehabilitation should comply with all legal requirements regarding demolition of structures and other matters in order to obtain certificates of closure.

The rehabilitation guidelines focus mainly on the restoration of the ground surface and on the vegetation of the rehabilitated area. The guidelines include sections on underground water and pyrite weathering (Sections 13 and 14) in which it confesses that "*water quality degradation has been identified as one of the most significant potential long-term effects of surface mining*" (Chamber of Mines, 1981). Despite this statement, few of the recommended operations for rehabilitation pertain to limiting sulphide mineral oxidation and preventing contamination of the groundwater resources. The prevention of sulphide mineral oxidation involves expensive rehabilitation operations, such as the flooding of potential acid-generating spoils, which are often uneconomical. However, new legislation may force coal mines to include steps to prevent contamination of groundwater (and indirectly, surface water) resources as part of their rehabilitation programmes. Cost-effective ways should thus be found to address these issues.

2.3.2 REHABILITATION PRACTICES IN OTHER COUNTRIES

Opencast coal mining and coal discard disposal is obviously not restricted to South Africa. A large number of coal-producing countries use opencast coal mining techniques while coal discard disposal occurs at most coal mines. The largest coal-producing countries, in order of scale of production, are China, USA, India, former USSR, South Africa and Australia (Department of Mineral and Energy Affairs, 1998). Literature regarding rehabilitation strategies in China, India and the former USSR is rare but suggests that coal mining activities significantly threaten water resources in Western China while large portions of agricultural areas are threatened by mining activities in India.

In the Appalachian coalfields, USA, acid drainage has caused severe pollution of streams and rivers, resulting in significant impacts on the river ecology (http://www.osmre.gov/acsihome.htm). Some of the worst affected areas include Pennsylvania and West Virginia. Most acid drainage is attributed to abandoned underground coal mines, flowing in the surface or groundwater and into nearby streams. The focus in this region is therefore to clean-up polluted surface water by means of active and passive treatment systems.

The effects of mine rehabilitation (termed reclamation in the USA) practices on post-mining water quality and the extent to which acid mine drainage is generated, have long been recognised for the opencast coal mines (termed surface coal mines in the USA) of the Appalachian coalfields (Carruccio, 1968, Erickson *et al*, 1982). Rehabilitation practices may include a number of operations to prevent the contamination of surface and groundwater resources (Gardner, 1999). The most important method described to prevent the contamination of water resources is the limitation of surface water infiltration into the spoils). Gardner noted that acid drainage could be significantly reduced by top soiling and re-vegetation of the mined land. However, for sites with a high potential to produce acid, a low permeability barrier should be constructed below the topsoil. This barrier could comprise clay or fly-ash cement (Sheetz *et al*, 1997). The construction of barriers does not often form part of rehabilitation plans and is used mostly as abatement at sites that already have poor quality discharges. In one case, the construction of a 1m clay cap resulted in a two-thirds decrease of discharge rates (Gardner, 1999).

In the Australian coalfields, in particular the Bowen Basin coalfields in central Queensland, authorities are more concerned with surface water resources than with groundwater, since the groundwater is often highly saline and not used to any extent (Williams, 2001). Groundwater levels are also deep and are characterised by low aquifer yields. The coal and overlying strata have lower sulphur contents compared with the South African coalfields and hence have less potential for acid generation (and spontaneous combustion of coal wastes). The main focus of rehabilitation is therefore to redress post-mining land use, typically grazing for the central Queensland area. Little attention is given to limiting rainfall infiltration and oxygen ingress. However, since many single-layer soil covers are covered by topsoil, designers believe that it could mitigate against these processes.

In summary, the literature survey has revealed that the rehabilitation practices in South Africa are similar to those practised in the USA and Australia in that the focus of rehabilitation is to redress post-mining land use. However, rehabilitation practices should be seen in the context of the water situation in the particular coal mining region. In the USA and Australia, acid drainage remediation actions focus on restoring river ecology and address contamination caused by the leaching of metals into waterways. In neither country are water resources significantly threatened because of significant dilution along their river systems.

In South Africa, the mining-related salinisation of surface water has been identified as one of the major long-term threats to water resources in South Africa. Because of lower rainfall, low recharge and subsequent low baseflow to the rivers, dilution is significantly lower in the upper reaches of the

South African river systems compared with other coal mining countries. Rehabilitation practices in South Africa should therefore focus on addressing the increased salinity of its water resources.

2.4 RISK ASSESSMENT

Probabilistic risk assessment (PRA) is a general term for risk assessments that use probability models to represent the likelihood of different risk levels in a population (i.e. variability) or to characterise uncertainty in risk assessments (US EPA, 1999). In human health risk assessments, the probability distribution for risk reflects the variability or uncertainty in exposure while for ecological risk assessments, it reflects the variability or uncertainty in exposure or toxicity. Economic, legal and social acceptability risks could also be induced during coal mining activities.

Numerous risks are associated with coal mining activities, one of which is the risk associated with the deterioration of water quality during the post-closure phase of opencast coal mining. In order to understand these risks, one needs to identify all the hazards associated with deteriorating water quality, assess the various pathways to the point of exposure and then assess whether the exposure levels are acceptable. Typical examples of risks associated with the deterioration of water quality during the post-closure mining phase include:

- Human health risks when contaminated groundwater may be used for domestic purposes.
- Economic risks when new water supplies may be found, for example, for stock watering or power generation.
- Ecological risks when contaminated groundwater may provides baseflow to a stream or river.
- Long-term human health, ecological and economic risks associated with the cumulative TDS load discharged into streams in a particular catchment.

The degree of risk associated with a particular coal mine should be identified by means of a risk assessment. Once the risks have been identified and the liability associated with the coal mine determined, a number of corrective actions should then be considered. The implications of each corrective action are then subjected to the risk assessment once again. Risk-based corrective actions have gained in popularity for being a consistent decision-making process for the assessment and response to an activity that could impose risks to human health and the environment.

Several guidelines have been developed to streamline the risk-based corrective action approach. Probably the most popular is the RBCA approach, an acronym for “Risk Based Corrective Action” and pronounced “Rebecca” (ASTM, 1996). RBCA refers specifically to the standard Guide for

Risk-Based Corrective Action Applied at Petroleum Sites [E-1739-95] that was published by the American Society for Testing and Materials (ASTM). RBCA is a streamlined approach in which exposure and risk assessment practices are integrated with traditional components of the corrective action process to ensure that appropriate and cost-effective remedies are selected and that limited resources are properly allocated (ASTM, 1996).

The incorporation of risk-based corrective action procedures in the rehabilitation process of coal discard and opencast mines could prove beneficial for both the mining industry and the authorities, especially in terms of the risks associated with long-term deterioration of water quality. On the one hand, mining companies could be assured that more stringent rehabilitation requirements might not be applied for particular coal mining activities if the mining company can prove that its operations will not have significant long-term water impacts. On the other hand, authorities might require stricter rehabilitation measures if evidence exists that a particular coal mining activity could have significant long-term water impacts.

2.5 FINAL COVER SYSTEMS: FUNCTIONS & CLASSIFICATION

Final covers can be used to perform a variety of functions. Aside from the coal mining industry, soil covers are used extensively in the waste disposal industry and they also form part of rehabilitation plans for many other mining developments. Soil covers can thus be used to perform the following functions:

- Minimise infiltration into waste/mine spoils, thereby minimising outflow or recharge of leachate to the groundwater regime
- Separate the waste/mine spoils from plants and animals
- Act as a growing medium in order to establish vegetation on the rehabilitated waste/mine spoils
- Minimise run-off so as to prevent erosion and promote controlled run-off
- Raise ground surface elevations in low-lying areas
- Restore the topography which has been disturbed by underground mining activities (e.g. high extraction coal mining).
- Minimise oxygen flux into the waste material thereby limiting Acid Mine Drainage processes in sulphide-rich waste material
- Minimise oxygen flux into carbon-rich waste material (i.e. coal discard dumps) thereby preventing spontaneous combustion

- Prevent seepage occurring along the side slopes of some waste impoundments (e.g. tailings dams)
- Control the release of gasses emitted from the waste material (e.g. methane gas from landfill sites)
- Prevent emission of radioactive gasses from waste material (e.g. radon gasses from mainly uranium tailings)

Final cover systems are a critical component in the rehabilitation of mined-out areas and discard facilities. The final cover system should be designed to reduce risks to the environment to acceptable limits. In the case of high risk to the environment, a carefully engineered cover system should be constructed, probably incorporating geosynthetic material. A simpler cover could be considered in the case of lower risk to the environment..

For the coal mining industry, a simplified cost-effective cover design is preferred because of the large areas that need to be rehabilitated and the subsequent huge costs associated with the placement and maintenance of the cover system. As a result, soil covers are used by choice as final cover design in the rehabilitation of opencast mines and coal discard dumps. In addition, soil covers provide the opportunity to re-use the land for agricultural purposes.

Notwithstanding these advantages, simple soil covers will not be effective where there are high risks to the environment in the long term (e.g. coal discard that has a high potential for Acid Mine Drainage). In these cases, a more sophisticated cover should be adopted.

Final covers used for mine wastes can be classified in terms of their purpose and their configuration. This is summarised in **Figure 2.5(a)**. Typically, final covers on mine wastes are primarily designed to meet one or more of the following objectives:

1. To provide a growing medium in order to establish vegetation on the rehabilitated waste/spoils.
2. To minimise infiltration into waste/mine spoils, thereby minimising outflow or recharge of leachate to the groundwater regime.
3. To impede acid mine drainage processes within the coal spoils or discard materials, thereby resulting in a better quality leachate from the waste/spoils.

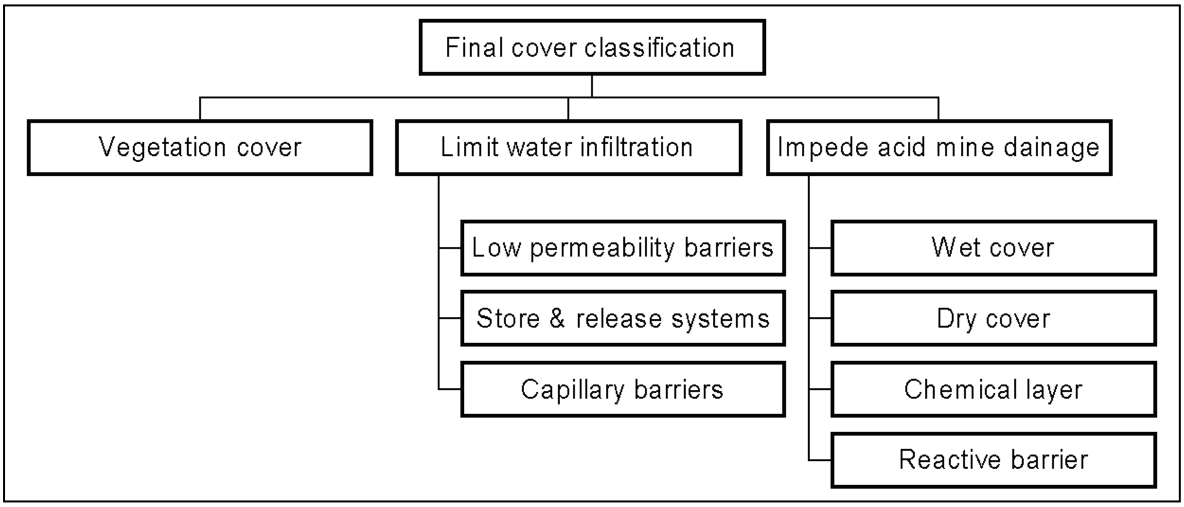


Figure 2.5(a): Classification of final covers

The functions of the respective covers are described below. The covers are described in more detail in Sections 2.6 to 2.10. Water covers and covers incorporating chemical and reactive layers are not discussed in those sections.

2.5.1 PROVIDE GROWTH MEDIUM

A number of researchers (Bell, 1988; La Gory et al, 1988; Environmental Protection Agency, 1995) reported that establishing vegetation direct onto reactive waste neither restricts sulphide oxidation nor limits water infiltration and, most often, does not germinate at all due to the hostile conditions.

Current rehabilitation practices decree that rehabilitated opencast coal mines and coal discard dumps should be provided with topsoil. The purpose of the topsoil is to provide a growth medium for vegetation. The placement of even a thin layer of topsoil material on the surface of graded spoils enhances the germination, survival and biomass production of vegetation (Chamber of Mines, 1981). Topsoiling is regarded as mandatory on all disturbed land.

During mining, the surface layers, comprising mostly the organic rich A horizons, are segregated and stockpiled. The A horizons are generally superior to underlying soils as a medium to establish vegetation. After placement of topsoil, amelioration of the soils is required to establish vegetation. Amelioration typically comprises subsoiling, fertilising and in some cases, liming. The management of soil fertility is discussed by a number of authors (Chamber of Mines, 1981; Strock, 2001).

The configuration of vegetation covers is discussed in **Section 2.6.**

2.5.2 LIMIT WATER INFILTRATION

The mobilisation of contaminants into water regimes occurs mainly by means of water percolating through the waste material. One obvious way to reduce the contamination load from reaching the water regime is to restrict water from infiltrating the waste material. This is achieved by providing the waste material with cover systems of which three classes have been identified:

- Low permeability barriers
- Store and release systems
- Capillary barriers

Low permeability barriers rely mainly on the low hydraulic characteristics of the barrier to limit rainfall infiltration. Store-and-release systems rely mainly on evapotranspiration processes to remove soil water from the cover before it infiltrates the waste. Capillary barriers rely on a capillary break to limit water infiltrating into the wastes and an unsaturated drainage layer to remove excess water infiltrating into the cover. These systems are described in more detail.

LOW PERMEABILITY BARRIERS

Low permeability barriers typically comprise an infiltration barrier which limits water infiltration into wastes. Three types of infiltration barrier used are *compacted clay layers*, *geomembranes* and *geosynthetic* clay liners. Almost without exception, the barriers are provided with a protective soil layer to provide a growth medium for vegetation, protect the barrier against damage and, in some cases, to act as a store and release mechanism to further reduce water percolation through the barrier. A drainage layer often forms part of the low-permeability barrier with the purpose of removing excess water from the infiltration barrier. The various low-permeability barriers are discussed in **Section 2.6**.

The processes associated with flow through low permeability barriers are presented schematically in **Figure 2.5.2(a)**.

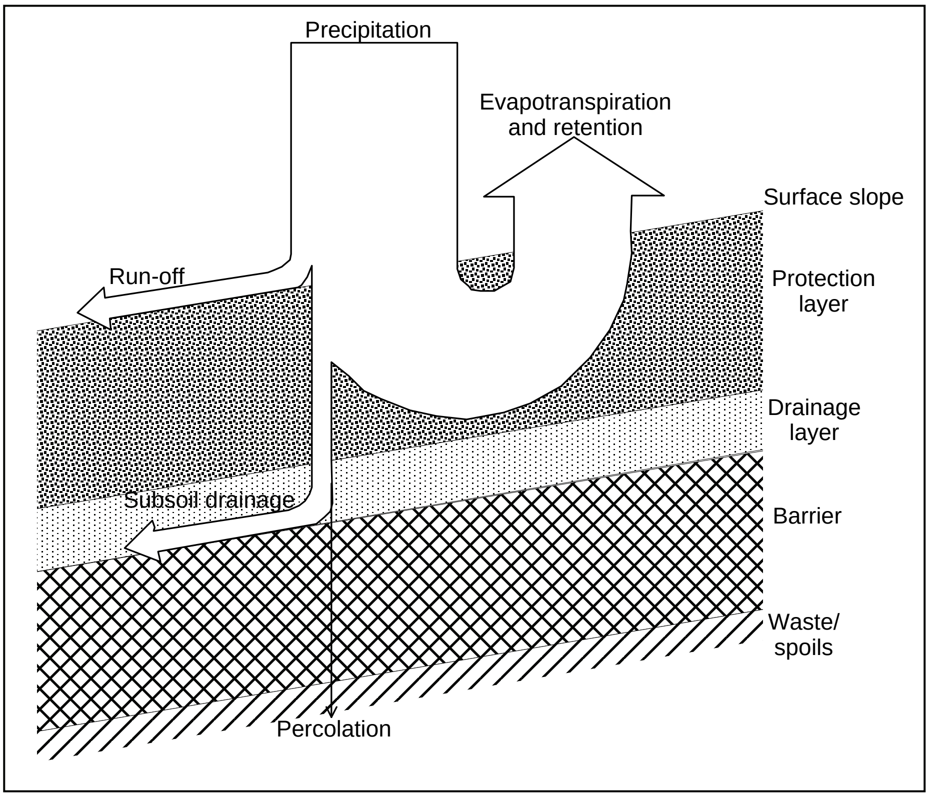


Figure 2.5.2(a): Flow processes associated with low permeability barriers (modified after the Australian & New Zealand Environment and Conservation Council, 1999):

When it rains, a portion of the rainfall water will infiltrate the soil while another portion will flow down the surface slope as run-off. Typically, the protection layer comprises loose medium-permeable soils to accommodate vegetation And this also facilitates infiltration into the protection layer. A major portion of infiltrated water will be retained in the protection layer from where it will be lost to the atmosphere by evapotranspiration processes. A portion of the water will percolate through the protection layer and into the subsoil drainage layer. Once the water reaches the base of the hydraulic barrier, a portion will be drained along the drainage layer while another portion may infiltrate the hydraulic barrier and into the wastes. The amount of water infiltrating the barrier depends on the hydraulic characteristics of both the drainage layer and the barrier. Low permeability barriers are discussed in more detail in **Section 2.6**.

STORE-AND-RELEASE SYTEMS

Historically, low permeability barriers were seen as the only way by which water could be limited from infiltrating wastes. However, there is a growing interest in cover systems that do not rely on hydraulic barriers, as they are expensive and difficult to construct (Benson & Kire, 1991). Store and release systems are a comparatively new technology which does not rely on hydraulic barriers to limit infiltration but rather utilise evapotranspiration potential to remove water from the soils.

Two types of store and release system are generally recognised, *monolayers* and *capillary break* systems (Australian & New Zealand Environment and Conservation Council, 1999). Monolayers simply comprise a thick (1.5 to 3.0m) layer of homogeneous soil characterised by high soil-water retention capabilities. Its function is to store infiltrated water to be later released by means of evapotranspiration. *Capillary break covers* comprise a relatively thick layer of fine soil characterised by high soil-water retention characteristics. This layer is underlain by a layer of poorly-graded coarse sand or fine gravel which, acting as a capillary break, prevents water from infiltrating the waste. Capillary breaks are discusses in **Section 2.6**. The processes associated with store and release systems are presented schematically in **Figure 2.5.2(b)**.

When a precipitation event occurs, a portion of the rainfall water will infiltrate the soil while another portion will flow down the surface slope as run-off. Typically, the capillary layer comprises loose medium-permeable soils to accommodate vegetation and this also facilitates infiltration into the protection layer. A major portion of infiltrated water is retained in the capillary layer from where it will be lost to the atmosphere by evapotranspiration processes. Another portion of infiltrated water percolates through the capillary layer until it reaches its base where it will accumulate along its base and removed by evapotranspiration processes. However, once the critical saturation point has been reached, breakthrough will occur and water will infiltrate the capillary block and the waste. The critical saturation point is similar to the opening of floodgates once a particular water level has been reached. This process is described in more detail in **Section 2.6**.

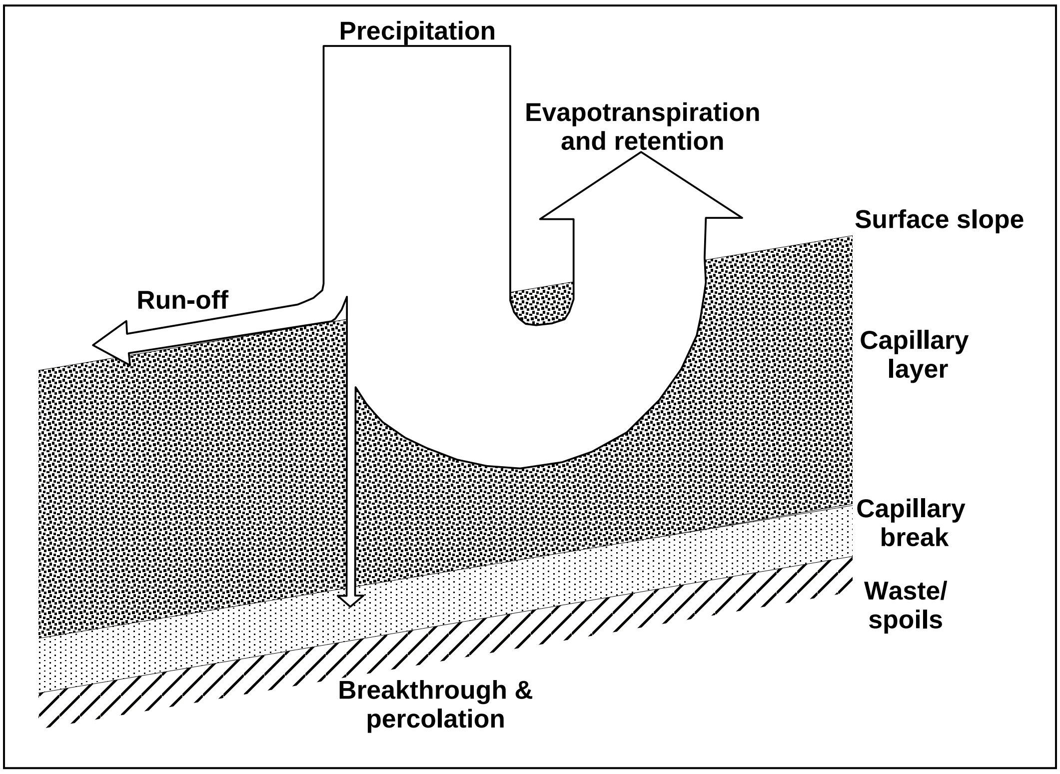


Figure 2.5.2(b): Flow processes associated with store-and-release systems

CAPILLARY BARRIERS

A major drawback of store-and-release systems is that breakthrough occurs once the critical saturation point is reached, resulting in unacceptable infiltration into the waste. In arid and semi-arid climates, the critical saturation point is rarely reached because of evapotranspiration removing soil water from the capillary layer. However, the evapotranspiration potential is not adequate to remove soil water in temperate climates.

The design of capillary barriers is similar to the store-and-release systems, storing water in the capillary layer. However, rather than soil water being removed by evapotranspiration, capillary barriers are designed to drain water from the capillary layer by gravitational forces. A typical capillary barrier consists of topsoil or capillary layer, an unsaturated drainage layer and a capillary break. The purpose of the unsaturated drainage layer is to drain water from the capillary layer and to prevent breakthrough and subsequent infiltration into the waste. Capillary barriers are discussed in **Section 2.6**. The processes associated with store and release systems are schematically presented in **Figure 2.5.2(c)**.

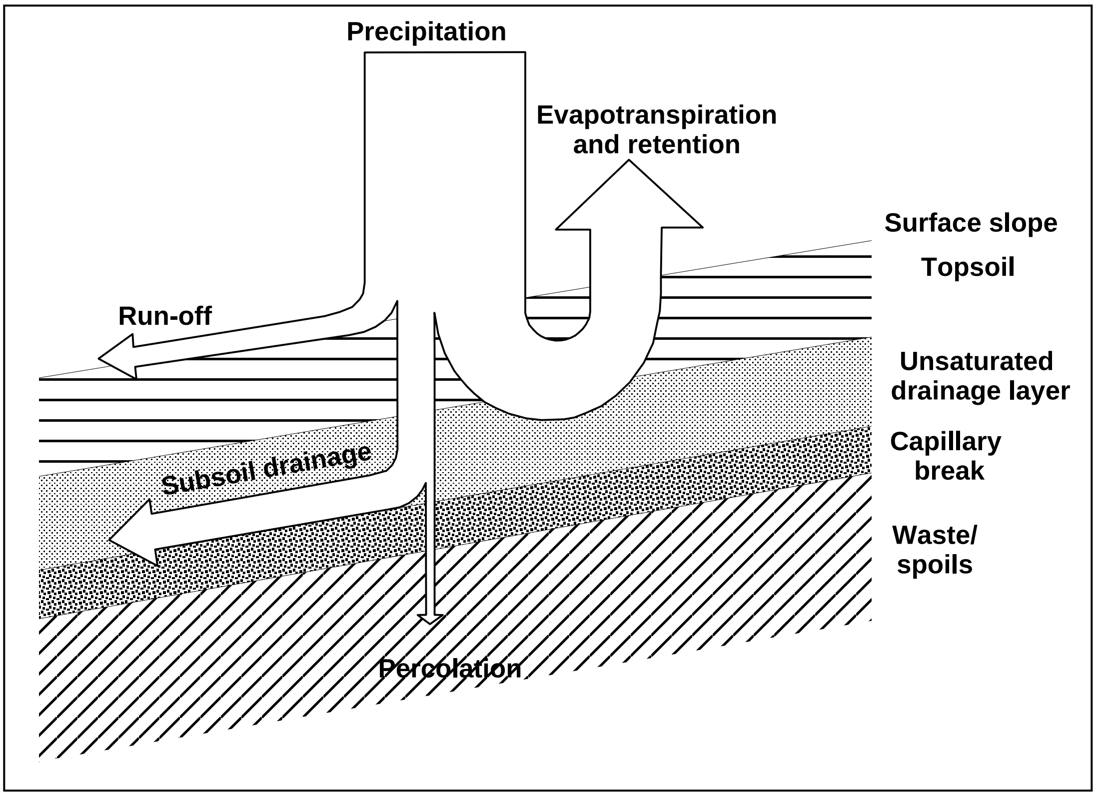


Figure 2.5.2(c): Flow processes associated with capillary barriers

When a precipitation event occurs, a portion of the rainfall water will infiltrate the soil while another portion will flow down the surface slope as run-off. Typically, the topsoil comprises loose medium-permeable soils to accommodate vegetation and this also facilitates infiltration into the topsoil. A major portion of infiltrated water is retained in the topsoil from where it is removed by evapotranspiration. Another portion of infiltrated water percolates through the topsoil and infiltrates the unsaturated drainage layer. Water flows along the interface of the unsaturated drainage layer and capillary break where it is intercepted and drained. The interception points are placed so that breakthrough is prevented. However, breakthrough may occur during periods of high rainfall or where the interface between the unsaturated drainage layer and capillary break is uneven. This process is described in more detail in **Section 2.6**.

2.5.3 IMPEDE ACID DRAINAGE PROCESSES

The deterioration of leachate quality from coal discard or coal spoils can be attributed to sulphide oxidation processes. As previously mentioned, sulphide minerals react in an oxidising environment to form sulphate, iron hydroxide and acidity in the presence of air, water and catalysing bacteria. In terms of acid drainage processes, final cover systems can be constructed to achieve the following:

1. Impede oxygen ingress into the coal discard and spoils.
2. Introduce buffering agents to neutralise acidic water.

Although it is possible to form acid in anaerobic conditions, it has been shown not to occur easily (Robertson *et al*, 1997). The restriction of oxygen from entering coal discard and spoils is seen by many researchers to be the most effective solution for long-term acid prevention (Davis & Ritchie, 1986; Nicholson *et al*, 1989; Steffan Robertson & Kirsten, 1989; Yanful, 1994). By restricting oxygen ingress, the rate of sulphide oxidation can be reduced, thereby reducing the production of oxidation products (acidity, dissolved metals and salt loads) and improving leachate quality.

Where sulphide oxidation does occur, a number of buffering agents may be introduced to neutralise acidic water. A buffering agent may be introduced into the system by placing it as an additive at the base of the soil cover. The agent is then transported in solution by percolating rainwater into the mine waste or spoils where it will react with the acidic water. Although buffering agents can be successful in increasing pH levels and precipitating metals out of percolating water, it increases the salt load that is transported to the water regime.

A number of approaches can be followed to design final covers to impede sulphide oxidation processes. The approach followed will depend on numerous site-specific factors such as climate and materials available. The following types of final cover can be considered:

- Water covers
- Wet covers
- Dry covers
- Chemical layers
- Reactive barriers

WATER COVERS

Water covers entail the flooding of mine wastes so that the whole of the waste material is submerged below water. In some cases, reactive mine wastes are simply dumped into a natural marine or lake environment. In most cases, however, an engineered water cover is constructed to flood the surface of the mine wastes (Li et al, 1997; Dave et al, 1997). The construction of water covers obviously demands particular site-specific requirements, such as an upstream source of water that can be used to flood the mine wastes, low permeable impoundment structures which can contain the water on the waste surface and suitable climatic conditions (i.e., rainfall must exceed evaporation by a significant margin).

The use of water covers is based on work conducted in Canada, which showed that the rate of sulphide oxidation underwater is considerably lower than when the sulphide minerals are exposed to air (David & Nicholson, 1995; Li et al, 1997; Dave et al, 1997). Li et al (2000) point out that the amount of oxygen dissolved in water is about 30 times less than that in air while the diffusion coefficient is approximately 15 000 times less with water compared with air. Both the combined effect of these properties and the effects of wind-induced convection in shallow water bodies, creating an almost continuous saturated dissolved oxygen profile, mean that oxygen flux, and thus sulphide oxidation rates, are 2000 to 5000 times lower when wastes are in water compared with wastes exposed to air.

Numerous examples are cited where water covers has been successfully applied (Li et al, 2000; DeVos *et al*, 2000, Catalan et al, 2000). The flooding of mine wastes is currently common practice in Canada where 50% of all new mines plan to use water covers as part of their rehabilitation strategy (Li *et al*, 2000).

In South Africa, this approach would be impractical due to the country's limited water resources. However, the principle of water covers should be kept in mind when considering the flooding of spoils with high acid generation potential in opencast mines.

WET COVERS

The design of wet covers entails the construction of covers which will remain near-saturated for most of the year. Near-saturated conditions imply that most of the pores in the spoils would be filled with water and oxygen ingress would be restricted in a similar way to the spoils being completely submerged in water. Wet covers are typically applied in climates where precipitation exceeds evaporation for the greater part of the year, thereby ensuring that the layers remain near saturated (Swanson *et al*, 1997).

Wet cover systems comprise a compacted layer, usually of clay, sandwiched between two coarse-grained layers. Cover configurations may differ (**Section 2.6**), with the surface sometimes being covered by a loose layer to provide protection and to support vegetation (Swanson *et al*, 1997; Yanful & Bell, 1993). The cover incorporates a capillary break to prevent drainage into the waste and to ensure near-saturated conditions at the base of the compacted layer. Similarly, the top coarse-grained layer prevents evapotranspiration and drying-out of the compacted clay. The flow processes are schematically shown in **Figure 2.5.3(a)**.

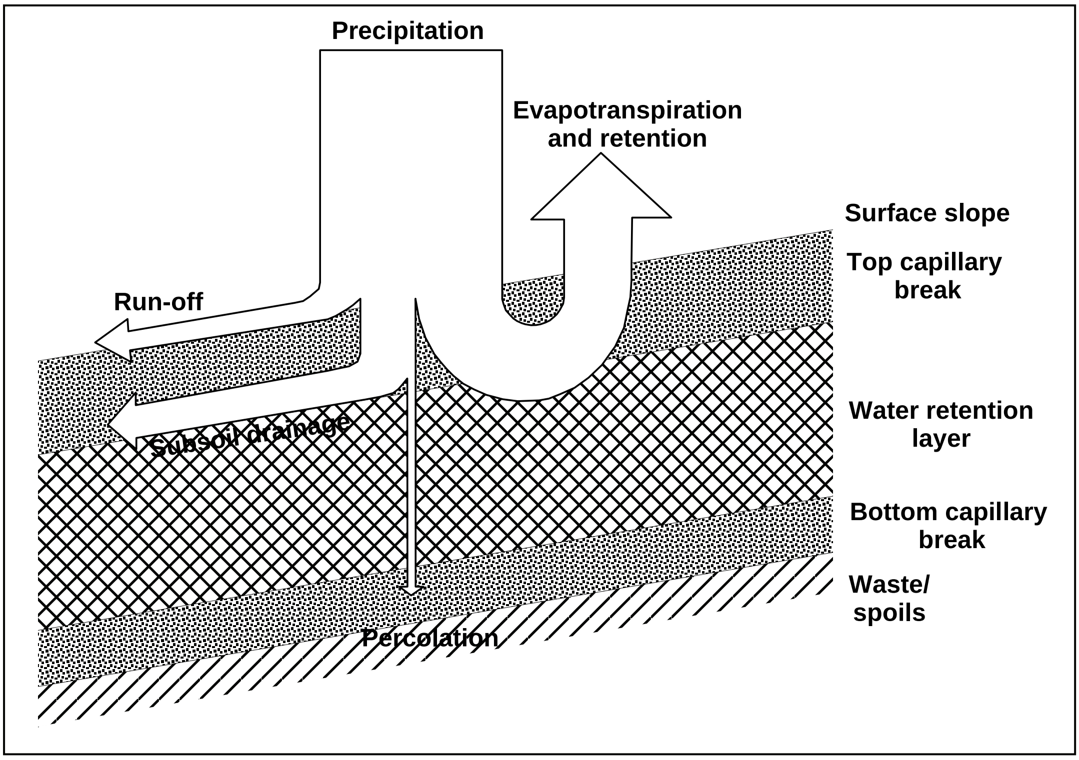


Figure 2.5.3 (a): Flow processes associated with wet cover systems

The effectiveness of this cover system is based on the principle that the diffusion coefficient of near-saturated soils is much smaller than that of unsaturated soils and approximates the diffusion coefficient of water ($2.0 \times 10^{-9} m^2/s$). Yanful (1993) reports that the diffusion coefficient of till soils are reduced by approximately two orders of magnitude when the degree of saturation is increased to approximately 80%, resulting in a significant reduction of oxygen influx. Yanful *et al* (1994) reported a 99.9% reduction of oxygen concentration after construction of such a cover. The reduction in oxygen influx into the wastes results in a significant reduction in sulphide oxidation and a subsequent improvement of leachate quality.

The effectiveness of a wet cover system can only be achieved if a high saturation index can be ensured throughout the year. Swanson *et al* (1997) report that, in general, high saturation indices cannot be ensured in climates where evaporation exceeds precipitation and, in these cases, dry cover designs should be considered. In addition, the drying out of compacted layers could result in desiccation and subsequent compromise of layer integrity. In Australia, Currey (1998) reports that wet covers are only applicable in the southern and northern regions (and also New Zealand) where precipitation exceeds evaporation and that dry covers should be considered for most of the country. In South Africa, where evaporation exceeds precipitation, one should also expect that wet covers would not be an applicable cover design.

DRY COVERS

In many countries, including South Africa, climatic constraints dictate that dry covers be used for rehabilitation purposes. Swanson *et al* (1997) stated that low permeability barriers are not necessarily the most effective covers in arid and semi-arid climates. This is because high saturation cannot be ensured for the compacted layer throughout the year. Unsaturated conditions within the compacted layer will result in increased oxygen diffusion into the waste. Another important aspect is that low permeable barriers in dry climates are prone to desiccation (Swanson *et al*, 1997; Daniel & Wu, 1993; Daniel & Koerner, 1993), resulting in the barrier integrity being compromised.

Swanson *et al* (1997) proposed that dry covers should be designed to limit infiltration into waste material rather than inhibit oxygen ingress, the reason being that a compacted, near-saturated barrier is likely to fail in a dry climate. A number of authors now agree that store and release systems could be an effective cover design in climates where evaporation exceeds rainfall by a significant margin (Swanson *et al*, 1997; Australian & New Zealand Environment and Conservation Council, 1999; Durham *et al*, 2000; Milczarek *et al*, 2000). Store and release systems are discussed in **Section 2.6.2**.

Although primarily designed to limit rainfall infiltration, the design could include a compacted layer at the base of the cover with the purpose of providing a measure of impedance to oxygen ingress. Such a system would not be as effective as wet covers.

Given the climatic characteristics of the South African coalfields, cover design engineers are likely to adopt dry cover systems for rehabilitation purposes.

CHEMICAL LAYERS

As previously mentioned, acid drainage may be neutralised by introducing buffering agents. One method of introducing a buffering agent is through the use of a chemical cover. As water percolates through the cover, the buffering agent in the chemical cover is transported to the waste where it reacts with the acid generated and neutralises it.

A chemical cover comprises a layer of lime which is placed at the base of the mine waste and sometimes mixed with the top mine waste layers. The thickness of the lime layer required depends on the net neutralisation requirement of the discard or spoils. There is also a limit to the solubility of the minerals with rainwater, weakening the buffering capacity of the chemical layer. It may prove more effective to use the lime for treatment purposes rather than to use it in a chemical layer.

Lime addition may be more effective if it is thoroughly mixed with the top layer of the spoil or coal discard. The neutralisation components are then placed in close proximity to the acid-generating material, thereby inhibiting the formation of pockets of acidic environment. This will, in turn, limit bacterial growth which will further inhibit acid formation (Hodgson & Krantz, 1998). The addition of lime will be most effective where used on fine-grained material, such as coal slurry. Much of the lime in coarse-grained material could simply be leached to the groundwater without contributing to acid neutralisation - and could even contribute to increased salinity if the waste is not acid generating. Komnitsas *et al* (2000) describe the use of lime as part of the rehabilitation strategy of acid-generating tailings dams in Greece; this is discussed in more detail in **Section 2.8.4**. Apart from relying on the buffering capacity of the neutralisation material, Komnitsas et al (2000) mentions that a lime crust may develop on the surface of the tailings dam, which may also limit water infiltration into the waste. A lime surface crust is often observed on the surfaces of gold tailings dams. Such crusts will not develop on coarse-grained materials such as coal discard and spoils.

Power station fly ash may also be used as a chemical layer for covering purposes. Large amounts of fly ash are generated by the power industry and it may be economically viable to use it. The capacity of fly ash to neutralise acid drainage is only about 5%-16% of that of lime (Hodgson & Krantz, 1998) and hence, large quantities of fly ash may be needed to neutralise the acidic wastes. Fly ash also contains significant concentrations of heavy metals which may be released if the fly ash proves insufficient to neutralise all the acid. It is therefore recommended that fly ash be used only for spoils and discard with a low acid-generating potential.

Although the use of fly ash has, to the authors' knowledge, not yet been investigated, its physical properties may enable it to be used as an adequate cover material. Although the hydraulic conductivity of fly ash is too high for its use as an hydraulic barrier, the material may prove to be adequate for a store-and-release cover, although a thick layer (more than 0.5m) would be required. Fly ash may also impede oxygen ingress into the spoils or discard.

The effectiveness of fly ash as a cover material and its economic viability as a cover material should be further investigated.

REACTIVE BARRIERS

In addition to physical barriers, such as water and soil covers, the impedance of oxygen influx into mine wastes can be achieved by the provision of reactive barriers. These entail the provision of a layer on, or close to, the ground surface which consumes atmospheric oxygen before it enters the mine wastes. Typically, these barriers comprise organic material where oxygen is consumed by the oxidation of carbon. Several products can be used such as forestry wastes (Tasse *et al*, 1994), pulp and paper mill products (Bromaan et al, 1991) or lime-stabilised sewage sludge (Kardos et al, 1979; Joost *et al*, 1987).

Dick (2001) investigated the use of calcium sulphate based flue gas desulfurisation (FGD) by-products for the treatment of coal discard. This laboratory-scale investigation showed that such by-products are efficient scavengers of oxygen. FGD can be used to cap coal discard, to restrict water infiltration and also to remove oxygen from the cover. In places where significant quantities of FGD by-product are produced (such as sites in Ohio, USA), it may be economically feasible to use this product for covering purposes.

One of the major drawbacks of using reactive barriers is that the reactive layer has only a limited oxygen consumption capacity and therefore, reactive layers have an effective life span after which sulphide oxidation will continue (Tasse, 2000). However, some researchers are of the opinion that the purpose of oxygen-consuming covers to buy sufficient time for vegetation to become established, after which organic matter inputs and decay may (partially) fulfil the role of oxygen consumption (Dick, 2001)

2.6 VEGETATION COVERS

As mentioned in Section 2.5.1, the main objective of vegetation covers is to provide a growth medium for vegetation. The cover configuration, therefore, almost always incorporates an organic-rich topsoil layer to promote vegetation growth. However, in some instances, the cover may also be designed to minimise erosion and may therefore incorporate geosynthetic materials or cobbles in its design. Erosion measures may be necessary, especially in arid and semi-arid climates characterised by sparse vegetation. Erosion measures may also be necessary where steep or long slopes need to be covered.

Typically, topsoil removed from the borrow areas (or in the case of opencast mines, removed from the site prior to mining) is stockpiled separately for use as the surface layer (Chamber of Mines, 1981). The topsoil layer comprises the organic-rich A-horizons of a soil profile which are generally superior to the underlying soils as a medium to establish vegetation. The topsoil generally contains nutrients and organic matter which assist in vegetation establishment. The surface layer should be at least 300 mm thick to sustain vegetation although thicker layers are preferable where there is a risk of soil-water depletion. The surface layer is not compacted in order to allow full development of plant roots.

After placement of the topsoil, amelioration of the soils is required to establish vegetation. Amelioration comprises subsoiling, fertilising and, in some cases, liming of the topsoil. Subsoiling entails the breakdown of compacted surface layers by means of tillage. Subsoiling improves problems associated with compaction, which include differential settlement, drainage impedance and root impedance. Management of soil fertility is an important component of the re-vegetation programme and entails the application of fertiliser and, for acidic soils, lime. The topsoil layer should preferably be a mixed soil comprising significant fine-grained material. A silt loam, loam or sandy clay is preferred.

Topsoil layers should be designed to minimise erosion. Vegetation may be used as an erosion control measure by limiting run-off and acting as a soil binding agent. Soil loss as a result of erosion can be calculated from the state of vegetation, type of soils used for the surface layer, slope angle and length of the slope. Soil loss may be calculated using soil loss models such as the US Department of Agriculture's Universal Soil Loss Equation. The USEPA (1991) recommends that erosion be limited to 5.5 t/ha/a. Highly erodible material, such as silt and fine sand, should either not be used as surface material or should be mixed with coarse material (e.g. cobbles, gravel, coarse sand) to withstand erosion.

Dispersive clays are prone to erosion and should be avoided in the surface layer. Where a clay material is used or used in part for the surface layer, the clays should therefore be tested for dispersiveness. Similarly, where concerns are raised regarding dispersive soils, tests should be carried out to determine the degree of dispersiveness. Several dispersiveness tests, such as the double hydrometer, ESP&SAR and pinhole tests, can be considered to assess dispersiveness (Elges, 1985)

In arid areas where the establishment of a vegetation cover is not possible, cobbles may be placed on the soil surface for erosion protection. However, the cobble layer may prevent evaporation of soil moisture from the surface layers, resulting in increased infiltration into the wastes. In some cases, the increased infiltration rates would be of little concern, given the arid conditions. However, where the increased infiltration rates might present a problem, a mixed layer, comprising fine-grained material incorporating cobbles and gravel, should be considered.

A typical soil cover configuration of vegetation cover is shown in **Figure 2.6(a)**. The vegetation cover typically comprises an organic-rich topsoil layer and a moisture retention layer overlying the mine waste. The main objective of the topsoil layer is to provide both growth medium and nutrients. The objective of the moisture retention layer is to retain soil moisture during the dry season. Various alternate configurations are possible and the most common vegetation cover configurations are summarised in **Table 2.6(a).**

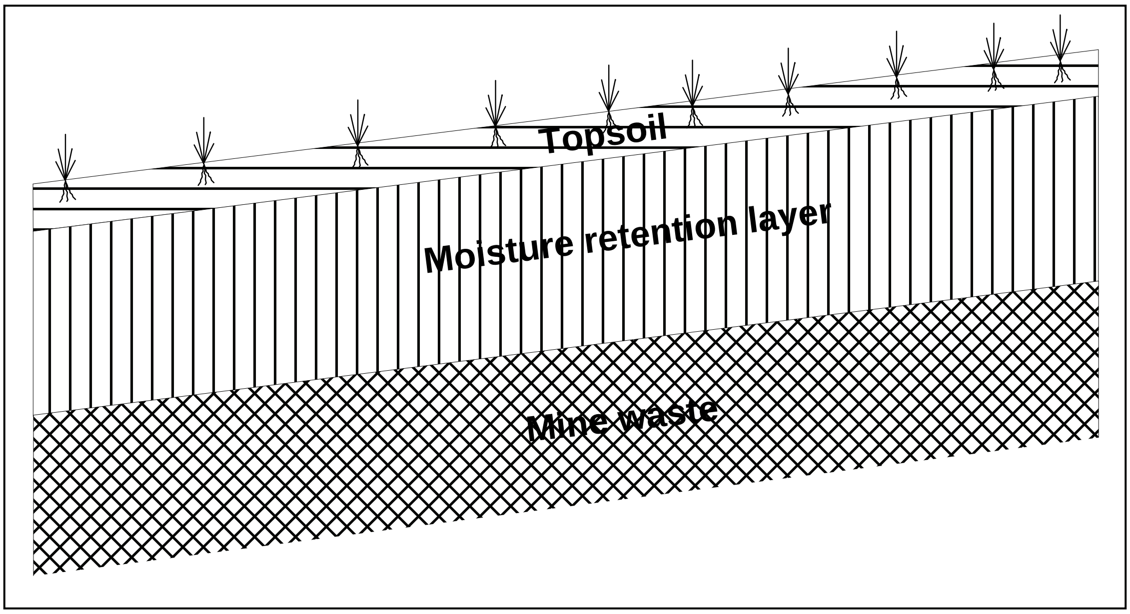


Figure 2.6(a): Typical configuration of a vegetation cover

The type of soils used in the moisture retention layer is typically restricted to the natural soils occurring in the mined-out region. Preferably, soils with high moisture retention capabilities and medium to low hydraulic conductivity characteristics (between 5×10^{-6} to 5×10^{-8} m/s) should be used to allow water to be retained in the layer for use by vegetation and also to allow for evaporation to take place. These include soils with high silt and clay percentages. A sandy material should be avoided.

The required thickness of vegetation cover is governed by the envisaged post-mining land use for the area. The Chamber of Mines rehabilitation guidelines (1981) recommend a minimum of 0.6m topsoil to re-establish arable potential, 0.25m topsoil for grazing and 0.15m for wilderness land.

Table 2.6(a): Alternate cover configurations of vegetation covers (modified after Daniel & Koerner, 1997)

Configuration	Description	Functions/Comments
Type 1	Homogeneous soil and vegetation	Inexpensive but vegetative cover may be difficult to establish because of little nutrition and/or inadequate moisture retention in soils
Type 2	Topsoil and vegetation Moisture retention layer	Topsoil provides nutrition while moisture retention layer retains soil moisture. Most common configuration
Type 3	Topsoil and vegetation Moisture retention layer Biotic layer sometimes with geotextile filter	As with type 2 but biotic layer prevents plant roots and burrowing animals reaching the waste and/or prevents upward migration of contaminants into moisture retention layer. Geotextile filter prevents migration of soil particles in between biotic layer
Type 4	Geosynthetic erosion control Topsoil and vegetation Moisture retention layer	As with type 2 with geosynthetic erosion control layer preventing erosion and gully-forming, thereby reducing maintenance costs
Type 5	Cobbles, paving, asphalt Base soil layer (asphalt & paving)	Used to prevent erosion or where surface water needs to be removed via drainage channels

Experiments were undertaken at an abandoned coal mine in Staunton, Illinois, USA (LaGory *et al*, 1988) where the effects of different soil cover thickness and liming rates on vegetation growth 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 with this soil depth. Plots with only 300mm of soil cover performed better with a higher lime application rate. A 600mm soil 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 create preferential flowpaths, leading to increased leachate production (Knox & Gronow, 1993). The USEPA suggests that a biotic barrier of at least 300mm of cobbles be used (Wallace, 1993). It further requires 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) states 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. Not only do roots penetrate through the clay cover into the waste body but metals are also transported upward into the clay where the roots continue the uptake.

2.7 LOW-PERMEABILITY BARRIERS

The main objective of low-permeability barriers is to restrict the infiltration of rainfall water into the waste by using infiltration barriers of sufficiently low hydraulic characteristics. A typical low-permeability cover configuration is presented in **Figure 2.7(a)**. This cover comprises one or more of the following components.

- Topsoil layer (also known as the surface or erosion protection layer)
- Protection layer (also known as the moisture retention layer)
- Drainage layer (also known as the subsoil drainage layer)
- Infiltration barrier (also known as the hydraulic barrier or resistive barrier)
- Capillary break (also known as the capillary block)

Various alternate configurations of low permeability barriers are possible and the most common configurations are presented on **Table 2.7(a)**.

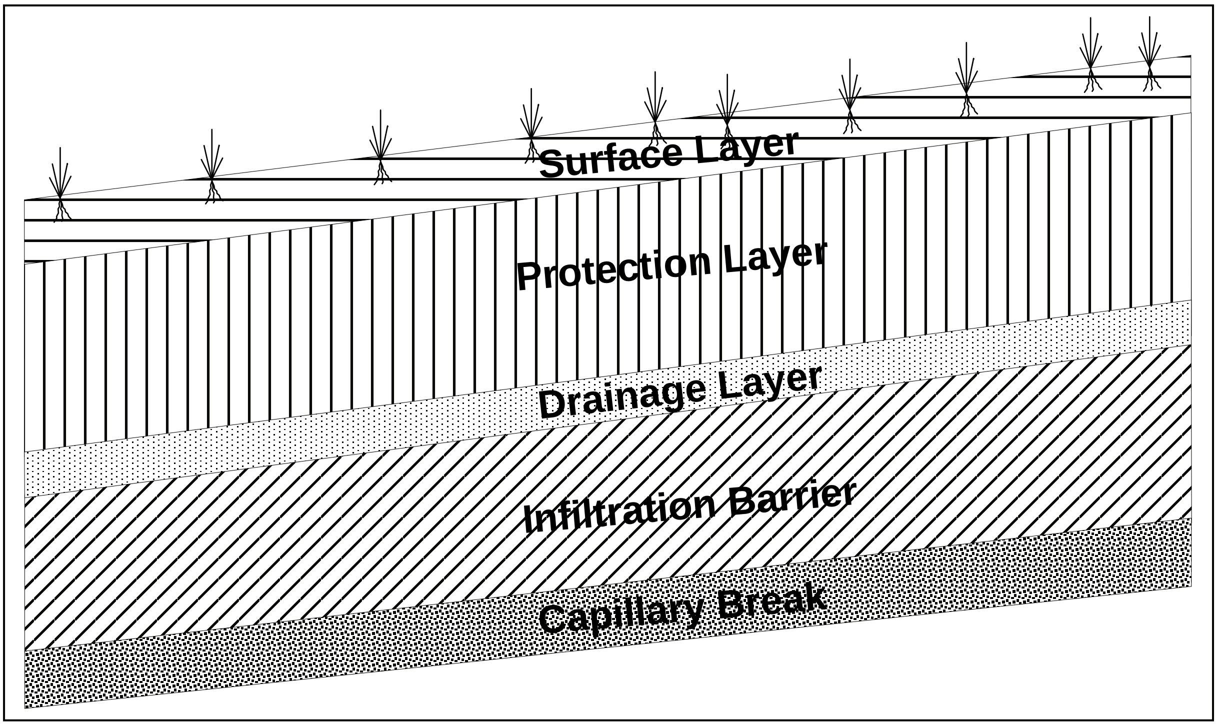


Figure 2.7(a): Components of a typical low-permeability cover configuration

Table 2.7(a): Alternate low-permeability cover configurations (modified after Daniel & Koerner, 1997)

Type	Description	Functions/Comments
Type 1	Topsoil and protection layer[1,2] Compacted clay layer	Protection layer required to store water or to protect underlying layers from desiccation or freezing Conventional design where damage from wetting/drying and freezing is not envisaged.
Type 2	Topsoil and protection layer[1,2] GM or GCL liner	Protection layer required to protect liners from anthropological and natural impacts Small amounts of leakage through the liner and oxygen ingress can be tolerated The area is small enough to warrant the expense
Type 3	Topsoil and protection layer[1,2] Composite liner[3]	Requirement for hazardous wastes. Used where risks to human health and the environment are high. Rarely used to cover large areas of mine wastes because of expense
Type 4	Topsoil and protection layer[1,2] Biotic layer with geotextile or sand filter CCL/GM/GCL/Composite[3]	Biotic layer comprised of cobbles is used to prevent burrowing animals and plant roots from damaging the infiltration barrier
Type 5	Topsoil and protection layer[1,2] Gravel or coarse sand drain with geotextile or sand filter CCL/GM/GCL/Composite[3]	Conventional drainage design to drain water from the infiltration barrier, limiting positive head build-up thereby reducing infiltration
Type 6	Topsoil and protection layer[1,2] Geotextile, Geonet or geocomposite drain CCL/GM/GCL/Composite[3]	Placed directly on infiltration barrier and used if cost-effective compared to sand/gravel drain. Geotextile acts as both drain and filter. Geocomposite drain used where high permeable drainage layer is required
Type 7	Topsoil and protection layer[1,2] Sand or geosynthetic drain[4] CCL/GM/GCL/Composite[3] Sand or gravel capillary break/gas collection	Sand/gravel capillary break used as part of a capillary break system to restrict seepage into the waste layer and to keep the infiltration barrier/protection layer moist, thereby minimising desiccation and impeding oxygen ingress Acts as gas collection layer if gas is generated in waste
Type 8	Topsoil and protection layer[1,2] Sand or geosynthetic drain[4] CCL/GM/GCL/Composite[3] Geotextile	Geotextile used as part of a capillary break system where suitable soil material is not available or not cost beneficial.

[1] Cobbles, asphalt or paving may be considered in place of the topsoil to prevent erosion.
[2] A geosynthetic erosion layer may be considered to prevent erosion of the topsoil.
[3] Two-component GM/CCL, two-component GM/GCL, three-component GM/CCL/GM, three-component GM/GCL/GM.
[4] Sand or gravel with or without geotextile or sand filter, geotextile, geonet or geocomposite drain.

The respective layers are discussed in more detail.

2.7.1 TOPSOIL LAYER

The main functions of the topsoil layer are:

- To promote vegetation growth (for most covers).
- To promote evapotranspiration.
- To act as protection against water and wind erosion.

The surface layer typically comprises nutrient-rich topsoil and could be treated to promote vegetation growth. The topsoil is not compacted. In cases where vegetation cannot be re-established, for instance in arid areas, cobbles may be used for erosion protection. In cases where vegetation needs to be re-established along steep slopes, or where the topsoil is susceptible to erosion, geosynthetic erosion control systems may be established. A surface layer is required for all soil covers to prevent water and wind erosion. The surface layer can be combined with the protection layer into one uniform layer.

2.7.2 PROTECTION LAYER

The main functions of the protection layer or moisture retention layer are:

- To act as a storage medium for water entering the soil cover, thereby providing moisture for vegetation.
- To remove water from the system by means of evapotranspiration processes. This function is the main objective of a store-and-release system, but is often also important in low-permeability cover systems.
- To protect underlying layers from intrusion by plant roots, burrowing animals and anthropological impacts.
- To protect the infiltration barrier against desiccation.
- To protect the barrier layer against freezing/thawing.
- To maintain stability.

The protection layer typically comprises mixed soil and the type of soil is restricted to the local soils available for cover construction. Soils with high water retention characteristics are preferred. A protection layer is required for all soil cover types. Daniel and Koerner (1997) maintain that a low permeability barrier will be rendered ineffective if not protected.

A sandy soil offers the best protection against freezing and desiccation. Because of the high permeability of sandy soils, soil water drains rapidly from the cover. Dry sandy soils are an excellent heat insulator, protecting the infiltration barrier against freezing. Dry sandy soils also act as a capillary break (See **Section 2.8**), preventing upward movement of soil water caused by evapotranspiration and thereby ensuring high moisture contents in the infiltration barrier and preventing desiccation.

In spite of the preferred geotechnical properties of a sandy protection layer, several disadvantages are also associated with sandy soils. Sandy soils greatly reduce the protection layer's ability to store and release soil water by means of evapotranspiration. Rapid percolation through the protection layer will cause a head of water to develop on the infiltration barrier, thereby increasing the infiltration rate. This can be overcome by incorporating a drainage layer between the protection layer and the infiltration layer.

A biotic layer can be included as part of the cover design to prevent damage to the infiltration barrier by plant roots and burrowing animals. The biotic layer will consist of a layer of cobbles or coarse gravel constructed at the base of the protection layer. The biotic layer may also form part of the drainage layer if the latter is included in the cover design.

Where a drainage layer forms part of the cover design, it is possible that so much soil water could be drained from the protection layer that soil water will not be available for the vegetation cover, especially where a thin protection cover is provided. It might then be necessary to construct a layer comprising compacted fine-grained material at the base of the protection layer to retain water within the cover for uptake by vegetation.

2.7.3 DRAINAGE LAYER

The main functions of the drainage layer are:

- To drain away infiltrating water that by-passed the moisture retention layer.
- To dissipate seepage forces that may have developed along the infiltration barrier/moisture retention layer interface.
- To protect the infiltration barrier against plant roots and burrowing animals (in certain cases).
- To reduce pore-water pressures within the soil covers, thereby improving slope stability.

The drainage layer generally comprises coarse sands, gravel or geosynthetic materials. The drainage layer is optional and may be required in cases of excessive by-pass of water through the moisture retention layer. It may also be required in the case of excessive seepage forces.

The construction of an efficient drainage layer in low-permeability cover systems will promote lateral drainage, thereby reducing the head of stored water on the infiltration barrier and minimising percolation through the barrier. A drainage layer does not form part of store-and-release systems.

The construction of effective drainage features in any earthworks structure (i.e. earth dams, tailings dams or soil covers) requires careful engineering. A significant knowledge base has been developed in designing drainage features in the civil engineering community.

The effectiveness of the drainage layer depends on the material used, layer thickness, slope of the layer and drainage path length. Modelling can be conducted to optimise drainage design. Typically, slopes of more than 2% (5% if differential settlement is expected) are required for the drainage layer to be effective (Australian & New Zealand Environment and Conservation Council, 1999). All drainage layers should be designed to allow free drainage to a drainage collection system. Drainage path lengths are usually in the range 25m to 100m.

For sand or gravel drainage layers, the minimum requirements are at least 300 mm thick layer of coarse material with a specified hydraulic conductivity of greater than 1×10^{-4} m/s. The materials selected should not degrade or weather with time. A filter layer may be required to prevent fine material from washing into the drainage layer. The filter layer may comprise soils with particle sizes that cannot be readily washed into the drainage layer. Alternatively, a geofilter may be considered.

Drainage is provided by sand, gravel, geonets and geodrains or thick geotextiles. In some cases, the protection layer is adequate for drainage purposes. The efficiencies of the different drainage materials differ greatly and are given in **Table 2.7.3(a)** which is based on the unconfirmed results of modelling conducted for a site in Queensland (Golder Associates, 1997).

Table 2.7.3(a): Percolation through the infiltration barrier as a percentage of rainfall (Golder Associates, 1997)

	No drainage layer	Sand drainage layer	Geotextile drainage layer	Geonet drainage layer
Compacted clay barrier	15.6%	10.8%	10.5%	1.0%
Poorly constructed geomembrane barrier	19.8%	17.9%	17.4%	1.4%
Well constructed geomembrane barrier	5.0%	1.1%	2.7%	0.0%

Similar results were reported by Mandenville & Tomlin (1997) and are summarised in **Table 2.7.3(b).** Mandenville & Tomlin ascribed these striking differences to the fact that the average head of ponded water above the barrier was 540 mm for the sand drainage layer and 0.4 mm for the geocomposite drain.

Table 2.7.3(b): Percolation through geomembrane liner (mm/a) (Mandenville & Tomlin, 1997)

	Sand drainage layer	Geocomposite drain
4% Slope	112.8	0.204
25% slope	27.6	0.020

The construction of drainage layers on sideslopes should be carefully considered. Apart from the head of water causing increased percolation through the infiltration barrier, seepage forces may also cause slope instability. On slopes steeper than 25%, construction of sand drainage layers is difficult and geodrains are preferred. Geodrains used over geomembranes on slopes should also be carefully considered as friction angles can be as low as 19%, although friction angles of up to 47% can be achieved for some geodrains (Australian & New Zealand Environment and Conservation Council, 1999). The toe drain at the base of the side slope, where the drainage layer the surfaces, should be carefully designed as significant erosion could occur at the toe, resulting in slope instability.

2.7.4 INFILTRATION BARRIER

The main functions of the infiltration barrier are:

- To minimise infiltration of water into the waste material.

- To promote storage in the upper uncompacted soil layers from where water can be removed by evaporation or internal drainage.
- To minimise oxygen flux into the waste material which, if containing sulphide-rich materials, could result in pyrite oxidation and subsequent increased salination and acid generation.

The following types of infiltration barriers can be considered in a cover:

- Compacted clay liners (CCL)
- Geomembrane barriers (GM)
- Geosynthetic clay liners (GCL)

Various complex combinations of infiltration barriers may also be considered. For mining wastes, the use of geomembrane barriers and geosynthetic clay liners are impractical for all but the smallest waste sites. Because mining wastes cover huge areas the placement of synthetic covers is prohibitively expensive. In addition, the risks associated with mining wastes in general do not warrant complex and expensive covers. Only compacted clay liners will therefore be addressed. The advantages and disadvantages of the different infiltration barriers are summarised by Daniel (1995) and are given in **Table:2.7.4(a)**.

Compacted clay liner barriers (CCLs) have the advantage of being relatively cheap, if suitable material is available locally. However, CCLs are prone to cracking from desiccation and freezing and should be protected. CCLs are also prone to cracking where there is differential settlement.

The most important function of the CCL is to provide a hydraulic barrier, limiting water infiltration into the underlying waste. The effectiveness of the CCL is directly proportional to the field hydraulic conductivity (permeability) of the barrier and the field hydraulic conductivity achieved depends to a large extent on the quality assurance of construction.

Golder Associates (1997) has shown that there is little advantage in providing a CCL if a field hydraulic conductivity specification of less than 1×10^{-9} m/s cannot be achieved, as indicated in **Table 2.7.4(b)**.

Table 2.7.4(a): Advantages and disadvantages of the different infiltration barrier materials (based on Daniel, 1995)

Material	Advantages	Disadvantages
Compacted clay barriers	1. Long history of use 2. Regulatory approval is virtually assured 3. Large thickness ensures that the layer will not be punctured 4. Large thickness provides physical separation between wastes and the surface environment 5. Cost is low if the material is locally available	1. Difficult and slow to construct 2. Soil can desiccate and crack 3. Soil can be damaged by freezing 4. Closing of cracks is likely to be slow compared to storm duration 5. Low resistance to cracking from differential settlement 6. It is difficult to compact soils above poorly compacted fill 7. Suitable soils are not always locally available 8. Difficult to repair if damaged 9. May requires a thick thermal or desiccation barrier Note: 2 and 4 may be over-rated in literature
Geomembrane barriers	1. Rapid installation 2. Effective barrier if properly installed 3. Not vulnerable to desiccation 4. Can withstand differential settlement 5. Not dependent on availability of local soils 6. Low weight reduces settlement 7. Easy to repair	1 Can be punctured during or after installation and needs careful protective measures 2 Potential friction problems at interfaces with other materials, but textured versions are less restricting
Geosynthetic clay liner barriers	1 Rapid installation 2 Very low hydraulic conductivity if properly installed 3 Can withstand differential settlement 4 Self healing characteristics 5 Not dependant on the availability of local soils 6 Low weight reduces settlement 7 Easy to repair Note: 4 has been challenged in recent literature	1 Low shear strength of hydrated bentonite but needle punched versions have adequate shear strength 2 Can be punctured during or after installation 3 Potential strength problems at interfaces with other materials 4 Erosion via dispersion of bentonite may occur but not proven 5 GCL may bulge into overlying drainage layer 6 Needle punched GCL requires protective cover e.g. tyres 7 Plants may penetrate GCL's 8 Could desiccate in severe situations 9 Effectiveness could be affected in some chemical environments

Table 2.7.4(b): Effect of CCL hydraulic conductivity on infiltration rate into the waste (After Golder Associates, 1997)

Hydraulic conductivity (m/s) (Coefficient of permeability)	Percolation as a percentage of rainfall (long term average)	
	No drainage layer	**0.15 m sand drainage layer**
No Barrier	22.2%	22.2%
1×10^{-8}	16.7%	8.4%
3×10^{-9}	9.7%	3.4%
1×10^{-9}	3.7%	1.4%

MINIMUM BARRIER THICKNESS

The effect of CCL thickness on percolation rate through the barrier was studied in detail by various authors (Benson & Daniel 1994a and 1994b; Fulheihan & Wissa, 1995). Benson & Daniel (1994a) analysed stochastic models of flow through successive compacted clay lifts and also analysed a large body of case histories in which field hydraulic conductivity tests were carried out. Their main findings are:

- For both poorly built and well-built covers, decreasing hydraulic conductivity with increasing layer thickness was observed. However, little reduction in hydraulic conductivity was observed when the thickness was increased beyond 0.6 to 0.9 metres (four to six lifts).
- The degree of bonding between lifts (i.e. the degree to which zones of high horizontal hydraulic conductivity can be eliminated) is far more important than the number of lifts. Therefore, a well-built CCL containing four lifts will have a much lower hydraulic conductivity compared with a poorly built CCL containing many more lifts. Adding more lifts to a poorly built CCL will not ameliorate the problems caused by poor construction.
- A reasonable minimum thickness for compacted clay barriers is 0.6 to 0.9 m or four to six lifts.

SELECTION AND PLACEMENT OF CLAY USED FOR COMPACTED CLAY LAYERS

Suitable clay material should be well graded with 30% mass material finer than 0.75 mm and more than 15% mass material more than 0.02 mm. The soils should also contain less than 50% gravel (Benson, 1991). The plasticity index of these soils should be between 10% and 30%. Soils which contain high percentages of smectite clay minerals should be avoided. Soils used for the construction of infiltration barriers should also not contain excessive amounts of gravel or too large sized stones and clods as these will complicate effective compaction and may result in higher permeability.

COMPACTION OF COMPACTED CLAY BARRIERS

Compaction tests should be performed to determine the optimum density and water content which will result in the lowest field hydraulic conductivity. Traditionally, modified Proctor and standard Proctor tests were conducted to determine the optimum moisture content and density of the material. Contractors were then required to compact the barrier to within engineering specifications which were usually between 90% and 100% MOD AASHTO. At the same time, the moisture content was specified to be between optimum and optimum +4% (Daniel & Benson, 1990). Compaction with moisture contents lower than optimum could result in clay clods not being effectively moulded, thereby creating preferential pathways for water flowing through voids between the clay clods.

Daniel & Benson (1990) found that the traditional method of compaction could result in the cover not meeting the hydraulic conductivity specifications. Compaction at low compaction efforts may not adequately mould the soil material and break down clay clods, even if the material is at or slightly above optimum moisture content. Benson and Boutwell (1992) reported hydraulic conductivities as much as 100 times higher than that measured in the laboratory. With increased moisture content, however, the soil material is adequately moulded and meets the hydraulic conductivity specifications.

Daniel and Benson (1990) recommended the following procedure to determine whether the hydraulic conductivity specification is met at the specified range of water content and the dry unit weight of soils considered for the hydraulic barrier (**Figure 2.7.4(a)**):

- The soil is compacted using three compactive energies that span the range of compactive effort expected in the field. Daniel and Benson (1990) recommend that the modified Proctor, standard Proctor and reduced Proctor methods be used to achieve the expected compactive effort range.
- The hydraulic conductivity is determined for each soil sample. The tests should appropriately simulate field conditions (i.e. the samples should not be subjected to large confining stresses and hydraulic heads).
- The results of the modified Proctor, standard Proctor and reduced Proctor are plotted on graph and the results of the hydraulic conductivity tests are indicated on the chart (**Figure**

2.7.4(a)). The Acceptable Zone (i.e. the range of water content and dry unit weight values where acceptable hydraulic conductivities will be achieved) is specified.

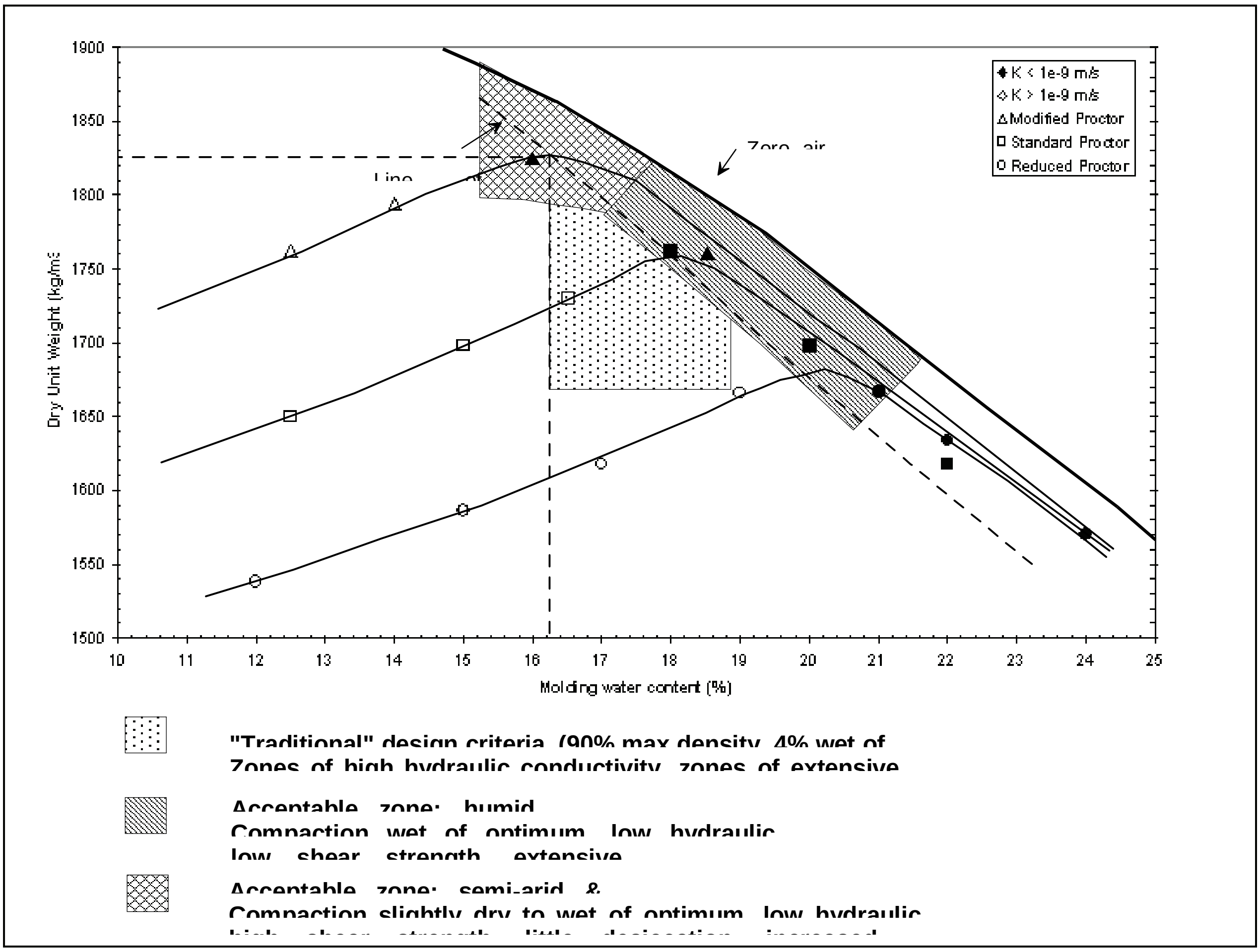


Figure 2.7.4(a): Specification of the Acceptable Zone (modified after EPA, 1991, and Daniel, 1992)

The lower limit of the Acceptable Zone of this example is close to 96% MOD AASHTO and parallel to the line of optima for the lesser-compactive energy curves. In the absence of readily available hydraulic conductivity values, this may be considered the lower boundary of the Acceptable Zone.

Water content strongly influences the geotechnical behaviour of the soils. Compaction of soil at a low water content results in a strong low-compressible soil that is less susceptible to desiccation cracking. However, the soils are brittle and crack easily (e.g. differential settlement of the underlying coal discard or spoils). Compaction of soils at high water content results in a softer compressible and ductile material better able to withstand differential settlement without cracking. These soils are, however, more vulnerable to desiccation cracking.

Engineers and regulators often specify that the moisture content of compacted soils should be wet of optimum because:

1. Soils dry of optimum display a brittle behaviour and require high compaction efforts , and

2. Soils wet of optimum require lower compaction energies to reach hydraulic conductivity specifications.,

Daniel (1992) questioned the validity of this general design guideline for covers constructed in arid climates. Daniel (1992) investigated the performance of cover systems in arid climates and found that desiccation plays an important role in cover performance. Compaction of soils wet of optimum will result in extensive desiccation cracking, thereby compromising cover integrity. Based on this investigation, Daniel recommends that soils in arid regions be compacted to at least 96-98% MOD AASHTO density. Moisture content should not exceed optimum moisture content plus 2% nor should be less than optimum moisture content less 2%. He also made the following recommendations for the design of covers in arid regions:

- Clayey sands are preferred to soils with low sand contents. Clayey sands combine the attributes of low hydraulic conductivity and low shrinkage potential.
- Specify dry unit weight and moisture content that ensure both low hydraulic conductivity and low shrinkage potential.
- Protect the soils from drying by placing a thick protection layer (at least 0.6 m but preferably thicker) on top of the infiltration barrier.

Although not proven, one may assume that the recommendations made by Daniel will also apply to semi-arid climates, especially when characterised by distinct rainfall seasons and high evaporation potential.

2.7.5 CAPILLARY BREAK OR GAS COLLECTION LAYER

The main functions of the capillary break are:

- To ensure a high moisture content within the overlying infiltration barrier, thereby minimising oxygen ingress into the waste material and also preventing desiccation from the bottom of the infiltration barrier.
- Where volatiles are produced, the volatiles could be collected in a gas collection layer which may also acts as a capillary break.

The capillary break is usually constructed from coarse-grained material such as coarse sand and gravel. The capillary break concept is discussed in detail in **Section 2.8**.

2.8 STORE-AND-RELEASE COVERS

The main function of a store-and-release cover is to limit rainfall infiltration into the waste. Whereas low-permeability covers rely on the hydraulic characteristics of the infiltration barrier to limit infiltration, store-and-release covers rely on evapotranspiration potential to remove soil water from the cover before it infiltrates the wastes. Store-and-release covers should have the ability to retain and store rainfall water in the cover and also to promote upward movement of soil water.

A typical configuration for a store and release cover comprises a topsoil layer, a moisture retention layer and a capillary break and is shown in **Figure 2.8(a)**. . The topsoil layer consists of nutrient-rich soils to provide a growth medium for vegetation and to assist in evaporation from the soil surface. The purpose of the moisture retention layer is to retain and store infiltrating rainfall water and to promote upward movement of soil water by evapotranspiration. The capillary break prevents downward movement and infiltration into the waste. These layers are discussed in more detail below. Various alternate configurations are possible and the most common store and release cover configurations are summarised in **Table 2.8(a).**

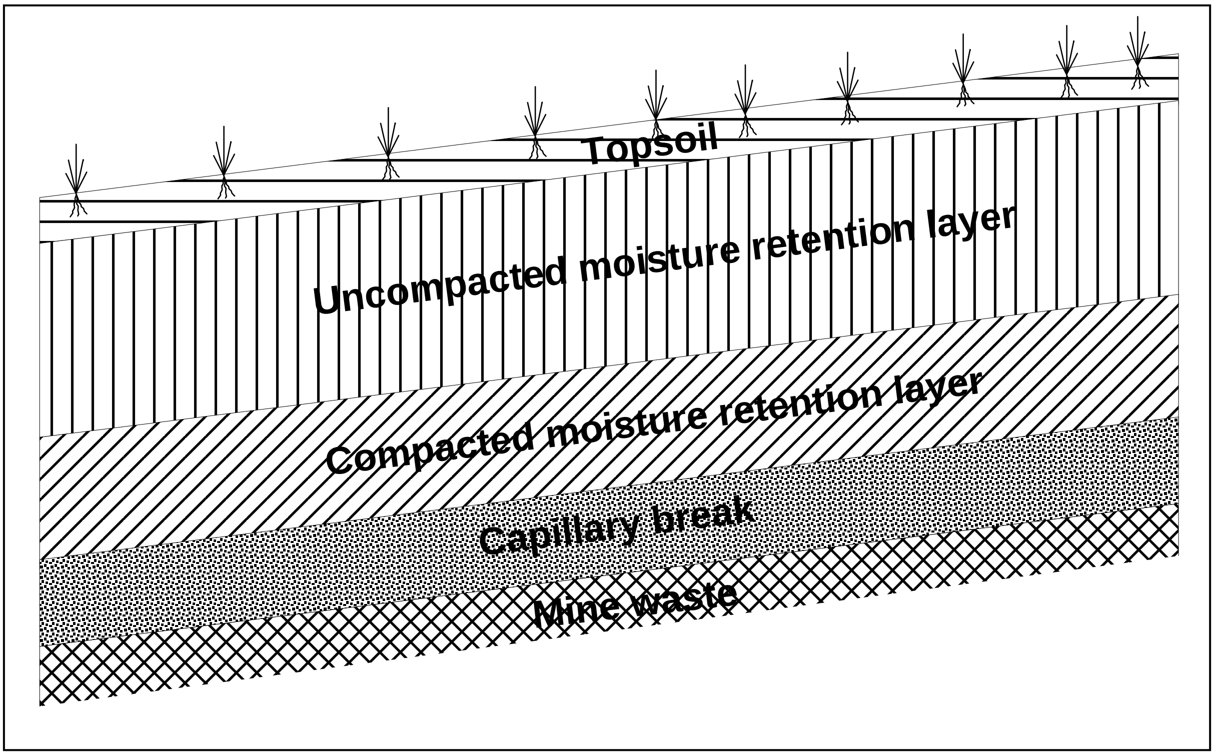


Figure 2.8(a): Typical cover configuration of a store & release cover system

The use of store and release systems on sloped waste facilities should be considered with caution. The retention capabilities of these systems could be reduced by lateral flow and breakthrough along the moisture retention layer and capillary break interface. These aspects are discussed in **Section 2.9**.

Table 2.8(a): Alternate cover configurations of store and release covers (modified after Durham et al, 2000; Milczarec, 2000 and Australian & New Zealand Environment Conservation Council, 1999)

Configuration	Description	Functions/Comments
Type 1	Homogeneous soil and vegetation	Homogenous layer provides storage but establishment of vegetation could be problematic.
Type 2	Topsoil and vegetation Uncompacted moisture retention layer	Uncompacted moisture retention layer provides storage and topsoil provides growth medium for vegetation. Topsoil might hinder upward movement of soil water.
Type 3	Topsoil and vegetation Uncompacted moisture retention layer Coarse sand/fine gravel capillary break	Capillary break limits downward flow of soil water and increases storage capabilities of the cover. Capillary break hinders upward movement of contaminants into cover.
Type 4	Topsoil and vegetation Uncompacted moisture retention layer Compacted moisture retention layer Coarse sand/fine gravel capillary break	Compacted moisture retention layer augments capillary break effect, limiting breakthrough and increasing storage capabilities of the cover

2.8.1 THE CAPILLARY BREAK CONCEPT

A capillary break refers to a cover system where a fine-grained soil layer (moisture retention layer) overlies a coarse-grained soil layer, referred to as the capillary break. The capillary break increases the soil water storage capability of the moisture retention layer. This concept can be demonstrated as follows:

Assume that soils can be represented by a bundle of capillary tubes tied together. The diameter of the respective tubes is equivalent to the average pore size of the soils. In a capillary break set-up, a fine-grained soil layer with smaller pore sizes overlies a coarse-grained layer with larger pore sizes. For the capillary tube model, this is equivalent to smaller diameter capillary tubes overlying larger diameter tubes as illustrated in **Figure 2.8.1(a)**. According to the LaPlace theorem, water will be held within the capillary tubes by capillary forces.

The height to which water can be held in the smaller diameter capillary tube, τ_{max}, can be defined as follows (Kung, 1990):

$$\tau_{\max} = \frac{2\sigma_w}{\rho_w g}\left(\frac{1}{r} - \frac{1}{R}\right) \qquad [2\text{-}1]$$

where σ_w is the surface tension of water, ρ_w is the density of water, g is the constant of gravity and r and R are the diameters of the smaller and larger capillary tubes respectively.

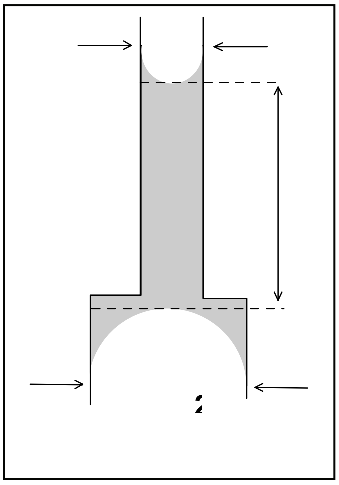


Figure 2.8.1(a): Capillary model of water retention in a thin tube opening into a thick tube (after Miazaki, 1990).

In soils, the capillary break effect can be presented using soil water characteristic curves. The characteristic curves for a fine gravel, uncompacted silt loam and compacted silt loam are shown in **Figure 2.8.1(b)**.

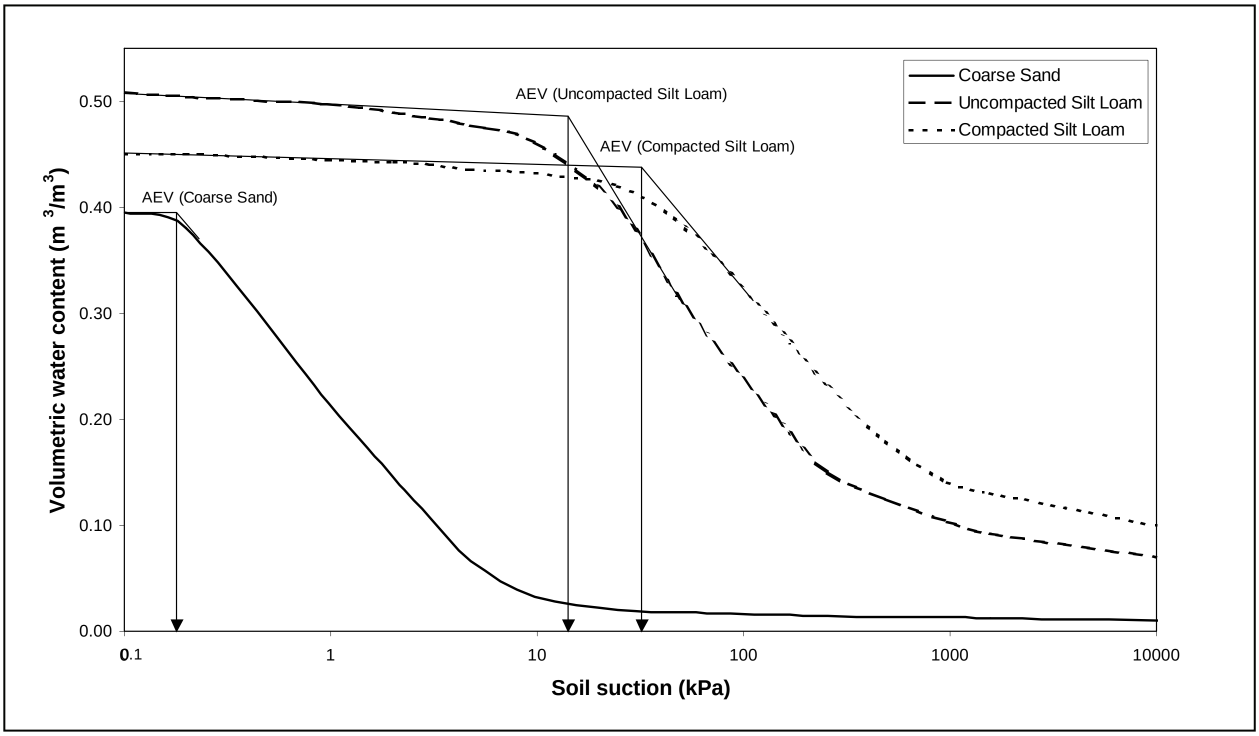


Figure 2.8.1(b): Soil water characteristics of a hypothetical coarse sand and compacted and uncompacted silt loam

The air-entry value (AEV) is the suction value at which water drains from the soil pores and air enters soil pores. The AEV is equivalent to the height to which water will rise in the soil because of capillary forces. The AEV value is also related to the effective pore size of soils according to the following equation (Hillel, 1980):

$$R_{eff} = \frac{2\sigma_w \cos(\alpha_w)}{\psi_{AEV}} \qquad [2\text{-}2]$$

where R_{eff} is the effective pore radius of soils, α_w is the contact angle between water and soil particles and ψ_{AEV} is the soil suction at the air entry value. For a capillary break system, the maximum height at which water can be retained in the fine-grained layer can be estimated by combining equations 2-1 and 2-2:

$$\tau_{\max} = \frac{2\sigma_w}{\rho_w g}\left(\frac{1}{R_{fg}} - \frac{1}{R_{cg}}\right) \qquad [2\text{-}3]$$

where R_{fg} is the effective pore radius of the fine-grained layer and R_{cg} is the effective pore radius of the coarse -rained layer. From equation 2-3, it is evident that the larger the difference of AEV of the coarse-grained and fine-grained soils, the more water can be retained in the fine-grained layer. The capillary break system can also be compared to the water held at the bottom end of a wet hanging towel.

When a soil is compacted, soil particles are rearranged and move between the pores of the soil. This results in a reduction in pore volume and a consequent reduction in effective pore radius. The compaction of soils will thus increase the AEV, thereby increasing the retention capabilities of the fine-grained layer. This is illustrated in **Figure 2.8.1(b)**.

In a capillary break system, rainfall water infiltrates the fine-grained soil layer and will be retained at the bottom end of the layer by capillary forces. Depending on the soil characteristics of both the fine-grained and the coarse-rained layers, rainfall water will accumulate at the bottom end of the fine-grained layer until the optimal height is reached (τ_{max} in Equation 2-3). Once the optimal height is exceeded, water will rapidly drain into the coarse-grained layer, which is termed “breakthrough”.

Because of the lower flux in the coarse-grained layer (the flux cannot exceed that in the less permeable layer on top), the effect of gravity offsets the effect of surface tension of the liquid. This causes wetting front instability in which the wetting front splits into separate “fingers” that move down the coarse-grained layer (Miyazaki, 1994). This is illustrated in **Figure 2.8.1(c)**.

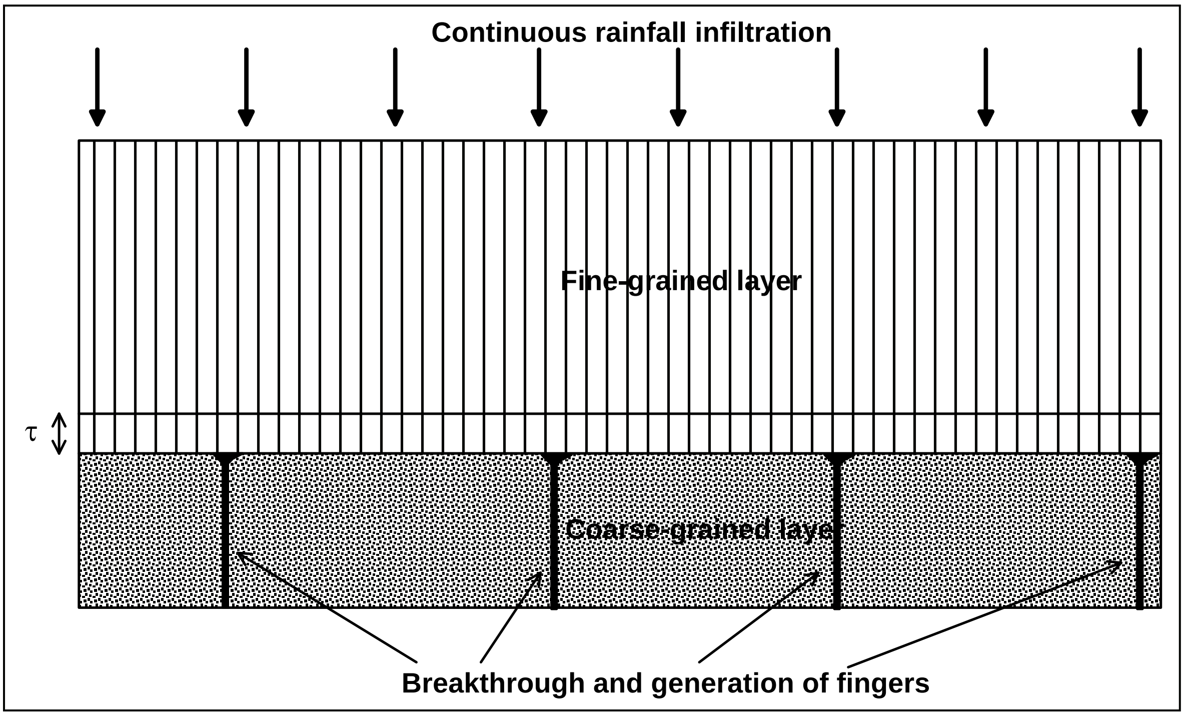


Figure 2.8.1(c): Schematic representation of breakthrough and generation of fingers for a capillary break system.

The capillary break does not prevent soil-water from infiltrating the waste but acts as a floodgate, releasing water into the lower layers in times of high rainfall infiltration into the upper soil layers. However, in times of low rainfall infiltration, soil water is retained in the fine-grained layer from where it is removed by means of evapotranspiration.

Although the retention capabilities of the moisture retention layer are restricted to the optimal height at which water can be retained at the bottom of the layer, storage capabilities can be increased by increasing the thickness of the soil moisture retention layer. By increasing the thickness of this layer, the travel time of water percolating through the moisture retention layer also increases. This provides ample time for the percolating water to be “intercepted” and removed by evapotranspiration processes before it reaches the bottom end of the layer. This process is illustrated in **Figure 2.8.1(d)**.

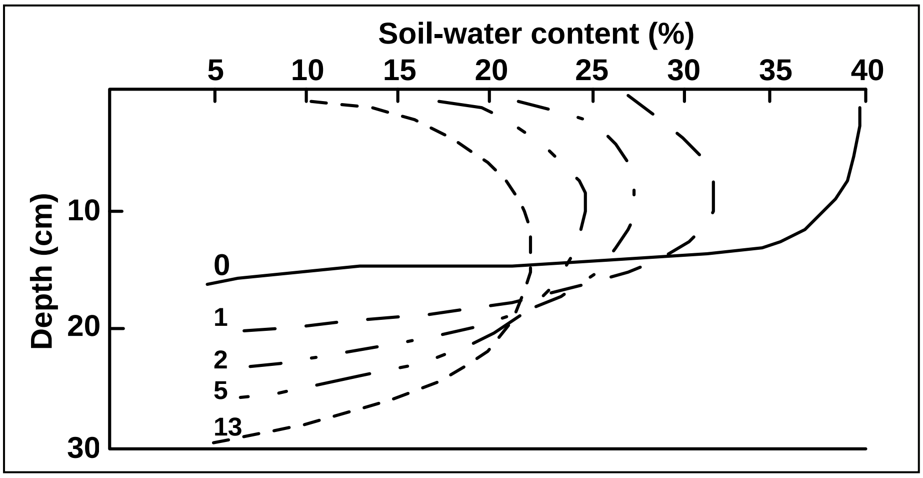


Figure 2.8.1(d): Change in soil water content profiles days after a rainfall event and subsequent evaporation (modified after Ward, 1975)

It is evident that the estimation of breakthrough is complex and depends on the hydraulic characteristics of the moisture retention layer and capillary break as well as climatic characteristics. The soil water characteristics of the moisture retention layer determine to what degree soil water is stored in the layer. The hydraulic conductivity and suction gradient determine the rate at which soil water is removed from the layer. Hydraulic conductivity is a function of soil water content, decreasing with decreasing water content. Soil water content is dynamic, changing with evapotranspiration and rainfall events. Evapotranspiration potential determines the suction gradient for soil-water moving towards the soil surface. Vegetation cover determines the degree of transpiration. The amount, frequency and duration of rainfall events determine the amount of water infiltrating the cover.

Because of these complexities, it is evident that the estimation of breakthrough can only be determined by means of modelling in which movement through the cover profile and atmospheric coupling can be accurately determined on a daily (or shorter) basis. These aspects are discussed in **Chapter 3**.

2.8.2 MATERIAL SELECTION AND DESIGN OF STORE AND RELEASE COVERS

TOPSOIL LAYER

The topsoil layer forms an integral part of a store and release cover system. The importance of the surface layer should not be underestimated as evaporation occurs at or close to the ground surface.

As indicated, the functions of the topsoil layer are to promote evapotranspiration, to provide a growth medium for vegetation and to resist wind and water erosion. The topsoil layer typically comprises the nutrient-rich A horizon soils, which is segregated and stockpiled before mining.

Sandy soils should be avoided. Not only have sandy soils poor water retention characteristics, but they also have very low unsaturated hydraulic conductivities, thereby acting as an evaporation barrier, preventing upward movement and evaporation of soil water. This could prove to be a fatal flaw for store and release cover systems. Similarly, the use of cobbles for erosion protection should be avoided as the cobbled layer also acts as an evaporation barrier. Where erosion control is necessary, a mixture of cobbles and silty soils should be considered.

MOISTURE RETENTION LAYER

The main function of the moisture retention layer is to retain soil-water and to promote upward movement and evaporation of soil-water. The thickness of the moisture retention layer varies typically between 0.5 and 2.0 m and depends on the retention capabilities of the soils and the amount of precipitation that needs to be stored. The optimum thickness of this layer should be determined by unsaturated flow modelling.

The moisture retention layer should have high moisture retention capabilities and medium to low hydraulic conductivity characteristics (between 1×10^{-6} to 1×10^{-8} m/s) to allow water to be retained in the layer. However, unsaturated hydraulic conductivities should not be too low as this will hinder upward movement of soil water. A silt, silt loam, loam or silty clay loam is preferred, although soils with sand fractions of up to 50% can be tolerated. Sandy soils should not be considered as these soils have high conductive and low retention capabilities, resulting in high infiltration rates into the waste material.

It is preferable that the moisture retention layer be compacted to increase the retention capabilities of the soil. Compaction, even at low compaction efforts, could significantly improve the effectiveness of store and release systems.

It is important to establish good hydraulic connectivity between the soil moisture retention layer and surface layer to promote upward movement of soil-water. A break layer between the surface and moisture retention layers could prove fatal for a store and release system. The soils used for the moisture retention and surface layers should, if possible, be of similar origin.

The use of soils with high clay contents could be considered for the moisture retention layer, especially if the purpose of the layer includes impeding oxygen ingress. Sandy clay, clay or silty clay soils could then be considered as these soils have low oxygen diffusion coefficients. In addition, they have high water retention characteristics and the layer will be near saturated for periods of time (depending on the climate, rainfall pattern etc) which further impedes oxygen ingress. However, in order to ensure good hydraulic connectivity with the topsoil layer, the hydraulic properties of the topsoil layer should be similar to those of the moisture retention layer. If this is not the case, the surface layer will act mainly as a one-way gate, allowing water to infiltrate the moisture retention layer but preventing water from moving upwards towards the surface layer. Further, the use of soils with high clay content should be avoided where damage by freezing or desiccation is possible as both effects will result in soil cracking, thereby compromising the integrity of the moisture retention layer. In addition, clayey layers could contribute to slope instability and complicate both placement and establishment of vegetation.

CAPILLARY BREAK

As mentioned, the function of the capillary break is to assist retaining soil water in the moisture retention layer. The capillary break assists in keeping the infiltration barrier moist, thereby restricting oxygen ingress. The capillary break also assists in retaining soil water in the moisture retention layer for later removal by evaporation.

The design of capillary breaks focuses on preventing or limiting the occurrence of breakthrough. Whereas the infiltration barrier or moisture retention layer has high air entry values, capillary barriers should have low air entry values to prevent breakthrough from occurring.

The capillary break typically comprises a layer of poorly graded but uniform coarse sand or fine gravel. The layer is only about 0.2 m thick, as the capillary process occurs at the interface between the capillary break and the layer above. Soil water retention tests should be conducted on both the capillary break and the layer above to assess the likely effectiveness of the capillary break system. The water air values of the capillary break should be significantly lower than those for the overlying layer.

Similar to the drainage layer, fine particles from the layer above may be washed into the capillary break. As the capillary break is a relatively new technology, the effects of this taking place has, to the authors knowledge, not yet been investigated. The use of a filter material to prevent washing in of fine particles should, however, be approached with caution. As the effectiveness of the capillary barrier is based on the difference of material properties between the capillary break and above-lying layer, the use of a filter material may eliminate this contrast with as yet unknown consequences. On the other hand, if the capillary break is effective, washing of fine materials into the capillary break will not occur because water will not readily enter the capillary break.

During preparation of the capillary break, care should be taken not to create depressions in the interface with the layer above as this could result in accumulation and preferential breakthrough of soil water in these depressions.

2.9 CAPILLARY BARRIER SYSTEMS

The capillary barrier is similar to store and release covers in that a capillary break is also used to prevent rainfall water from infiltrating mining waste. However, whereas store and release covers rely on evapotranspiration potential to remove soil water from the cover, capillary barriers drain water from the covers before it enters the capillary break and waste.

Capillary barriers have received widespread interest in recent years as an alternative, low cost cover system compared with traditional low-permeability covers. Unlike store and release covers, capillary barriers do not require high evaporation potentials to remove soil water from the cover. Capillary barriers, especially those incorporating unsaturated drainage layers (UDLs), have been extensively researched (Stormont & Morris, 1998; Morris & Stormont, 1999; Kamfp *et al*, 2001; Jelinek & Amann, 2001; Barth & Wohnlich, 2001 and others).

The typical configuration for a capillary barrier is shown in **Figure 2.9(a)**. The capillary barrier typically comprises a topsoil layer, a moisture retention layer, an unsaturated drainage layer (UDL) and a capillary break. The topsoil layer comprises nutrient-rich soils to provide a growth medium for vegetation. The purpose of the moisture retention layer is to provide moisture for vegetation and to promote evapotranspiration, thereby limiting water infiltrating the UDL. The UDL drains soil water from the cover before it infiltrates the capillary break and waste. Interception drains are provided at intervals to intercept soil water at the interface between the UDL and capillary break. The purpose of the capillary break is to prevent downward movement and infiltration into the waste. These layers are discussed in more detail below. Various alternate configurations are possible and the most common capillary barrier configurations are summarised in **Table 2.9(a).**

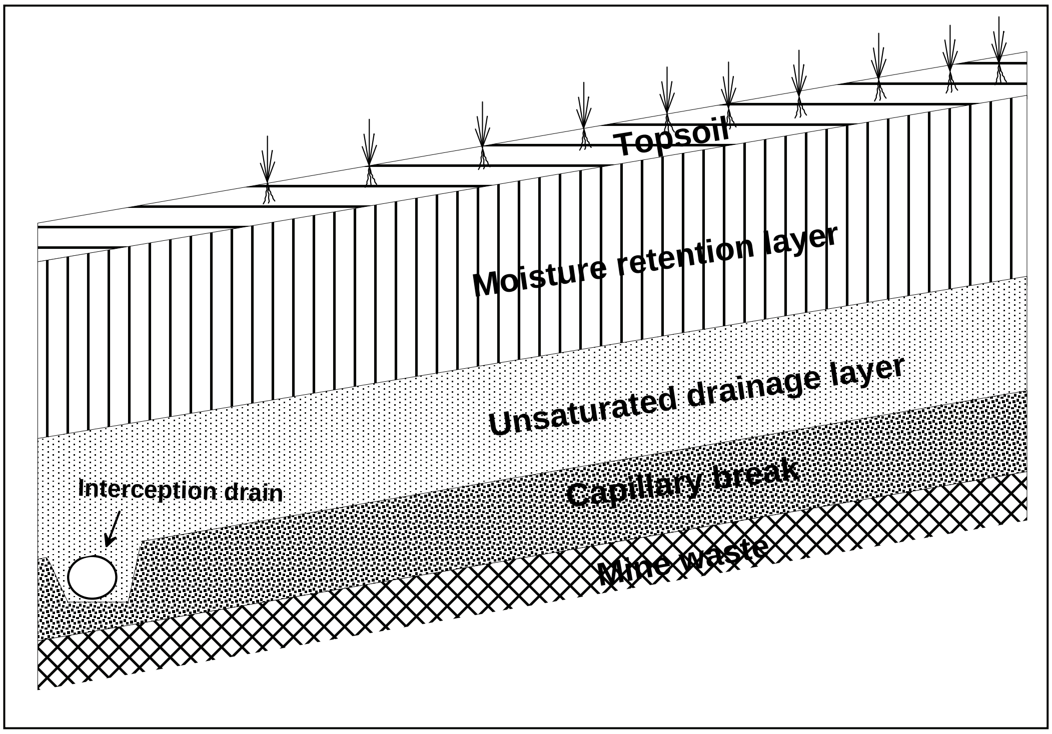


Figure 2.9(a): Typical cover configuration for a capillary barrier system

Table 2.9(a): Alternate cover configurations for capillary barriers (Morris & Stormont, 1999)

Configuration	Description	Functions/Comments
Type 1	Topsoil[1] Moisture retention layer Capillary break	Homogenous layer provides storage but establishment of vegetation could be problematic
Type 2	Topsoil[1] Moisture retention layer UDL Capillary break	Uncompacted moisture retention layer provides storage and topsoil provides growth medium for vegetation. Topsoil might hinder upward movement of soil water

[1] The topsoil and moisture retention layer is often combined in one layer

2.9.1 THE CAPILLARY BARRIER CONCEPT

As mentioned, the capillary barrier is similar to the capillary break system in that a fine-grained soil layer overlies a coarse-grained layer. As with the capillary break system, water is retained in the fine-grained soil layer and will not infiltrate the capillary break because of differences in pore-water pressures. However, where the capillary break system is intended for horizontal layered soils, capillary barriers are constructed on sloped waste facilities. This results in the gravitational flow of soil-water, downward along the interface between the coarse-grained and fine-grained layer. This is schematically presented in **Figure 2.9.1(a).**

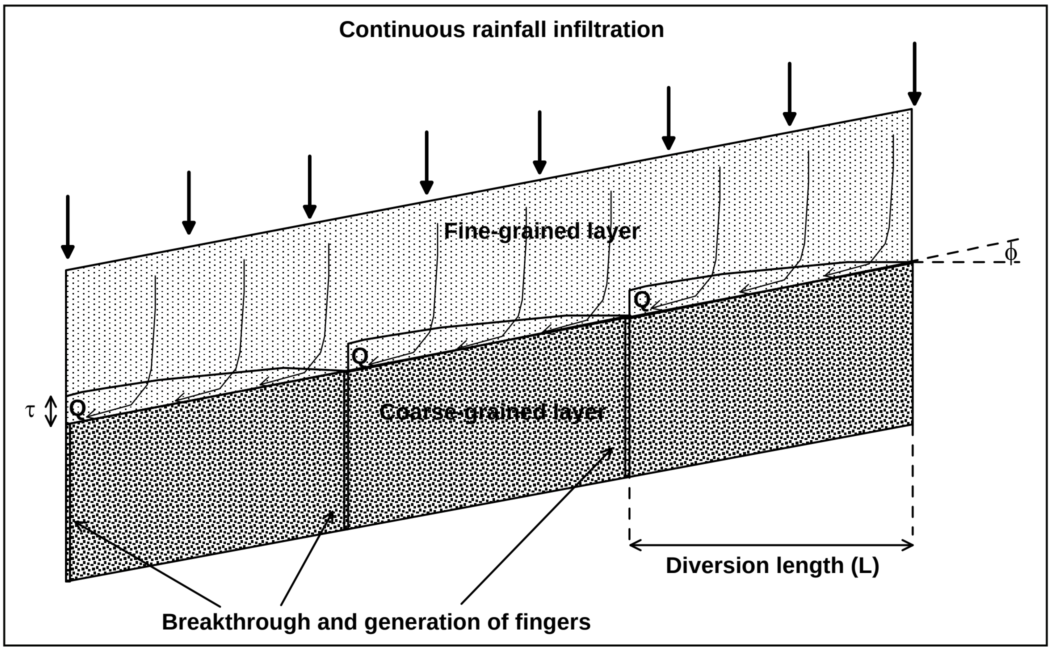


Figure 2.9.1(a): Schematic presentation of unsaturated water flow within a capillary barrier (modified after Miyazaki, 1994)

The down-gradient movement of water along sloped layers of a capillary barrier has two important consequences:

1. In contrast to horizontal layers, soil-water flows down the gradient along sloped layers resulting in breakthrough and reducing the water retention capacity of the cover.
2. Assuming that the fine-grained layer is homogeneous, it is possible to estimate the positions where breakthrough is likely to occur for a particular rainfall intensity.

In the first case, designers should be cautious when designing store and release covers on sloped wastes as the storage capacity of these covers may be less than the storage capacity of the covers on non-sloped wastes.

In the second case, designers have the opportunity to manipulate cover design and to intercept rainfall water before it enters the wastes. In order to intercept infiltrating rainfall water, it is necessary to know the distance between consecutive fingers along the sloped layers – termed the *diversion length* (L) - and also the volume of water that will be intercepted (Q). For a capillary barrier to be cost effective, the diversion length should be as long as possible so as to limit the number of interception drains required along the slope.

Two capillary models, the saturated funnelled flow model (Miyazaki, 1994) and the diversion capacity model (Ross, 1990), are used to estimate the diversion length and volume of water that needs to be intercepted. The saturated funnelled flow model (Miyazaki, 1994) is based on the Laplace theory of capillary flow (section 2.6.3). According to Miyazaki, the maximum flow rate along an inclined soil layer of a capillary barrier system (Q_{max}) occurs just before breakthrough and can be given by:

$$Q_{\max} = \frac{K_s \tau_{\max} \sin 2\phi}{2} \qquad [2\text{-}4]$$

where K_s is the saturated hydraulic conductivity of the fine-grained layer, τ_{max} is the maximum height in which water will be retained in the fine-grained soil and ϕ is the slope inclination. From equation 2-3, it is shown that the maximum height at which water can be retained in the fine grained soil is related to the effective pore radius and the air-entry values of both the fine-grained and coarse-grained soil. The maximum flow rate before breakthrough is therefore expressed as:

$$Q_{\max} = \frac{K_s \sigma_w \sin 2\phi}{\rho_w g}\left(\frac{1}{R_{fg}} - \frac{1}{R_{cg}}\right) \qquad [2\text{-}5]$$

If one assumes that the mass balance equation for fingering flow is given by:

$$Q_{\max} = q_r L \qquad [2\text{-}6]$$

where q_r is constant vertical flux caused by rainfall infiltration and L is the diversion length, the diversion length can be estimated by:

$$L = \frac{K_s \sigma_w \sin 2\phi}{q_v \rho_w g}\left(\frac{1}{R_{fg}} - \frac{1}{R_{cg}}\right) \qquad [2\text{-}7]$$

The diversion capacity model (Ross, 1990) assumes that soil water flow in capillary barriers is also possible for unsaturated conditions. Ross assumed that the horizontal flux at any given point of the cover profile could be given by:

$$q_h = -K \frac{\partial \psi}{\partial z} \sin \phi \qquad [2\text{-}8]$$

where q_h is the horizontal flux at a particular point z, ψ is the soil suction at point z and K is the unsaturated hydraulic conductivity that can be expressed as (Ross, 1990):

$$K = K_s \exp(b\psi) \qquad [2\text{-}9]$$

where b is an experimentally derived parameter. The maximum vertical flux rate is obtained by integrating the soil suction from the fine-grained – coarse-grained interface (z=0) to ground surface (z=∞). Substituting K in equation 2-8 with equation 2-9, the maximum vertical flux is (Q_{max}) obtained by:

$$\begin{aligned} Q_{\max} &= -K_s \tan\phi \int_{\psi(0)}^{\psi(\infty)} \exp(b\psi)\, d\psi \\ &= -\frac{\tan\phi}{b} \{K[\psi(\infty)] - K[\psi(0)]\} \end{aligned} \qquad [2\text{-}10]$$

Since $K[\psi(0)]$ is always less than K_s and $K[\psi(\infty)]$ is regarded to be equal to q_v, the maximum vertical flux can be given by:

$$Q_{\max} < \frac{\tan\phi}{b}(K_s - q_v) \qquad [2\text{-}11]$$

Substituting Q_{max} in equation 2-6, the diversion length can be estimated as:

$$L < \frac{\tan\phi}{b}\left(\frac{K_s}{q_v} - 1\right) \qquad [2\text{-}12]$$

From both equations 2-7 and 2-12, it is evident that the following parameters determine the effectiveness of capillary barriers:

- The rate of infiltration from overlying layers into the capillary layer (the higher the rate of infiltration, the higher the probability of breakthrough);
- Properties of the moisture retention layer/UDL and the capillary break (the higher the saturated conductivity of the UDL and the higher the difference in AEV between the UDL and capillary break, the lower the probability of breakthrough);
- Slope inclination (the steeper the slope, the lower the probability of breakthrough);
- Length of the slope (the longer the slope, the higher the probability that breakthrough will occur);

- Shape of the slope (convex slopes are advantageous as the flow rate increases with increasing gradient).

The diversion length will increase with steeper slope inclination and higher saturated hydraulic conductivity of the fine-grained layer. The diversion length will also increase with larger differences of the air-entry values between the fine-grained and coarse-grained layers. Diversion lengths decrease with increasing vertical flux caused by rainfall infiltration.

Morris and Stormont (1999) observed that experimental studies of capillary barriers showed significant increases of soil water content during periods of high precipitation and low evapotranspiration, some of the experiments resulting in failure of the barrier. They suggested the use of a special layer, termed the unsaturated drainage layer (UDL), placed between the capillary break and the moisture retention layer. The purpose of the UDL is to divert percolating water infiltrating through the moisture retention layer. The purpose of the moisture retention layer is similar to that of store and release covers, which is to limit water infiltration into the underlying UDL. A small portion of rainfall water does, however, infiltrate the UDL.

The UDL typically comprises a highly conductive medium-grained sand layer overlying the capillary break consisting of gravel. The difference in effective pore radius between the UDL and capillary break is adequate to prevent breakthrough. By ensuring that the UDL has a high saturated hydraulic conductivity and limiting the vertical flux through the moisture retention layer, the diversion length is optimised.

The effectiveness of capillary barriers was tested by means of modelling, laboratory-scale and field-scale experiments (Miyazaki, 1994; Morris & Stormont, 1999; Steinert *et al*, 1999; Ursino & Cossu, 2001; Kampf *et al*, 2001 and others). The results were mixed but showed great potential when properly designed. The tests showed that infiltration into waste can be restricted to less than 1% of rainfall and diversion lengths in excess of 10m can be achieved for a well-constructed capillary barrier.

To the author’s knowledge, capillary barriers have not yet been used on mine wastes and tests were mostly aimed at landfill sites and industrial waste facilities.

2.10 WET COVER SYSTEMS

Whereas low-permeability barriers, store and release systems and capillary barriers are designed to limit water infiltration into wastes, wet cover systems are designed to limit acid generation. As mentioned, the main function of wet cover systems is to ensure that the cover remains near saturated throughout the year. A near saturated cover will impede oxygen ingress by means of diffusion, thereby limiting acid generation processes.

The typical configuration for a wet cover comprises a topsoil layer, an oxygen barrier and a capillary break and is shown in **Figure 2.10(a)**. The topsoil layer comprises nutrient-rich uncompacted soils to provide a growth medium for vegetation. In some designs, the topsoil layer may also comprise sandy soil for the purpose of limiting upward movement of soil water through evapotranspiration. The wet cover is sometimes provided with a protection layer to protect the oxygen barrier against freezing effects. The purpose of the oxygen barrier is to retain soil water and ensure that the layer remains near saturated, thereby limiting oxygen ingress into the waste. The capillary break prevents downward movement and infiltration into the waste, thereby ensuring that the oxygen barrier remains near saturated. These layers are discussed in more detail below. Various alternate configurations are possible and most wet cover configurations are summarised in **Table 2.10(a).**

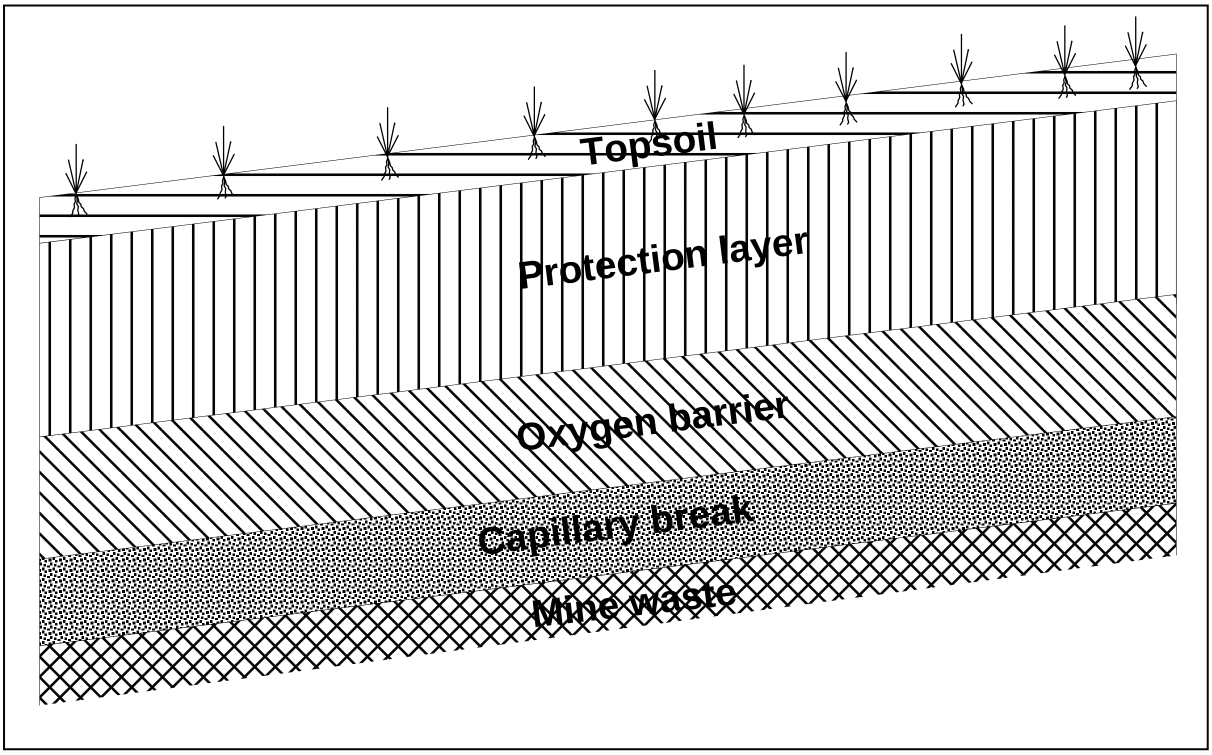


Figure 2.10(a): Typical cover configuration of a wet cover system

The use of wet cover systems on sloped waste facilities should be considered with caution. Bussiere et al (2000) and Golder Associates reported that the soil water content along the upper portions of sloped cells could decrease, caused by the lateral flow along the oxygen barrier and capillary break interface, similar to capillary barriers.

Table 2.10(a): Alternate cover configurations of wet covers (modified after Swanson et al, 1997; Aubertine et al 1997; Timms & Bennett, 2000)

Configuration	Description	Functions/Comments
Type 1	Uncompacted clay Capillary break	Uncompacted clay provides growth medium for vegetation. Capillary break limits downward moisture movement
Type 2	Uncompacted clay Compacted clay Capillary break	Compacted clay ensures near-saturated conditions, impeding oxygen ingress, and limits water infiltration
Type 3	Sandy topsoil Compacted clay Capillary break	Sandy topsoil impedes upward movement of water through evapotranspiration, thereby ensuring high moisture contents in the oxygen barrier
Type 4	Non-reactive tailings	Special case cover where abundant non-reactive tailings are used to cover reactive tailings, impeding oxygen ingress
Type 5	Non-reactive tailings Capillary break	As above, but the effectiveness is enhanced by placement of a sandy capillary break

2.10.1 EFFECTIVENESS OF OXYGEN BARRIERS

The effectiveness of oxygen barriers is measured in terms of the layer's ability to impede oxygen ingress into the waste. Oxygen can enter waste with infiltrating water containing dissolved oxygen, barometric pumping, wind action and volume displacement during infiltration (Nicholson et al, 1989). However, it has been shown that oxygen diffusion is the dominant mechanism by which oxygen enters mining wastes. The diffusion of oxygen can be described by Fick's law:

$$F = -D_e \frac{\partial C}{\partial z} \qquad [2\text{-}13]$$

where F is the diffusive flux of oxygen in the gas phase, D_e is the effective diffusion coefficient, C is the concentration of oxygen in the gas phase and z is depth.. The diffusion coefficient is a function of soil water content and the characteristics of the soil material and its value can vary by up to four orders of magnitude depending on the degree of saturation. It can be measured in the laboratory and can be estimated from empirical models (e.g. Millington & Shearer, 1974; Troeh *et al*, 1982; Collin & Rasmuson, 1988 and Eberling *et al*, 1994). The empirical model proposed by Eberling *et al* (1994) is defined as follows:

$$D_e = \varsigma D_a{}^0 (1-S)^\kappa + \frac{\varsigma S D_w{}^0}{H} \qquad [2\text{-}14]$$

where $D_a{}^0$ is the diffusion coefficient for pure air phase (1.8 × 10^{-5} m^2/s), $D_w{}^0$ is the diffusion coefficient for pure water phase (2.2 × 10^{-9} m^2/s), S is the degree of saturation, H is the dimensionless modified Henry's law constant (33.9 at 25°C) and ς and κ are fitting parameters (ς=0.273 ± 0.08 and κ=3.28 ± 0.4 as proposed by Eberling & Nicholson, 1996). From equation 2-14, it is evident that the degree of saturation is the dominant factor affecting oxygen ingress.

Assuming steady state conditions, the oxygen concentration at a particular depth in the waste can be estimated by the following equation (Nicholson, 1989):

$$C = C_0 \exp\left(-z(\Gamma / D_e)^{0.5}\right) \qquad [2\text{-}15]$$

where C_0 is the oxygen concentration at ground surface and Γ is the reaction rate constant for pyrite oxidation. Where a cover is provided, the oxygen concentration at ground surface is substituted by the oxygen concentration at the interface between the cover and waste, C_L, which can be calculated as follows:

$$C_L = \frac{C_0}{\left[\left(\frac{L}{D_c}\right)(\Gamma D_e)^{0.5} + 1\right]} \qquad [2\text{-}16]$$

where L is the thickness of the cover and D_c is the diffusion coefficient of the cover material. From equations 2-14, 2-15 and 2-16, the oxygen profile through mine waste can be calculated. The oxygen profile through a hypothetical mine waste provided with a 0.3m cover and with different degrees of saturations is shown in **Figure 2.10.1(a)**. It has been assumed that the reaction rate constant for pyrite oxidation is 85.8 a^{-1} for the hypothetical mine waste.

The oxygen flux through the ground surface of uncovered sulphidic waste, F_0, and through the cover interface of covered sulphidic waste, F_L, can be expressed as:

$$F_0 = C_0 (\Gamma D_e)^{0.5}$$
$$F_L = C_L (\Gamma D_e)^{0.5} \qquad [2\text{-}17]$$

The oxygen concentration and oxygen flux at the cover interface of a hypothetical sulphidic waste profile are summarised in **Table 2.10.1(a)**.

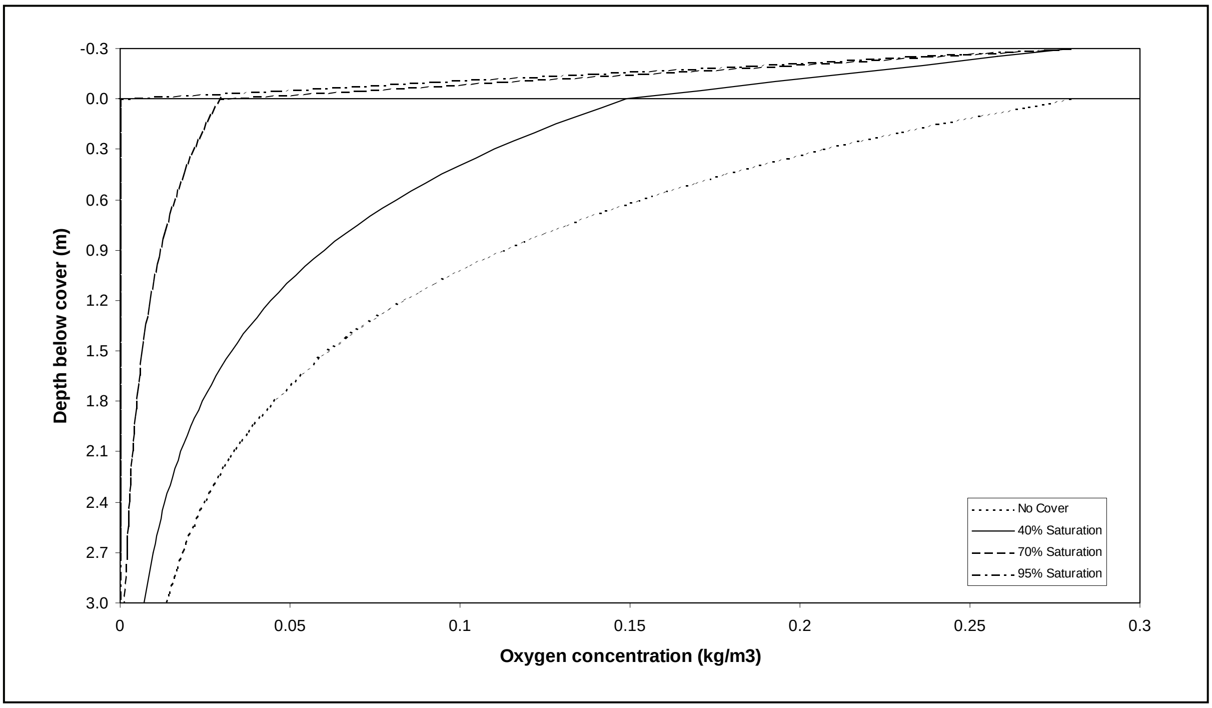


Figure 2.10.1(a): Hypothetical oxygen concentration profiles of sulphidic mining waste for covers with different degrees of saturation.

Table 2.10.1(a): Hypothetical oxygen flux and mass in a hypothetical sulphidic mine waste for covers with different degrees of saturation.

	Oxygen flux (kg/m^2s)	**Oxygen concentration (kg/m^3)**	**Reduction of oxygen flux (%)**
Uncovered waste	7.5×10^{-7}	0.28	-
0.3 m cover at 40% saturation	4.0×10^{-7}	0.15	46.8%
0.3 m cover at 70% saturation	7.9×10^{-8}	0.029	89.5%
0.3 m cover at 95% saturation	2.6×10^{-10}	9.8×10^{-5}	99.97%

Figure 2.10.1(a) indicates high oxygen concentrations for the uncovered waste, decreasing exponentially with depth as oxygen is consumed. **Figure 2.10.1(a)** and **Table 2.10.1(a)** show that the oxygen flux into the waste material is significantly reduced with increasing soil water content in the cover. At 70% saturation, oxygen flux is approximately 10% compared with that of uncovered waste. At 95% saturation (the value many designers aim to achieve for wet cover systems) oxygen flux is negligible.

2.10.2 MATERIAL SELECTION AND WET COVER DESIGN

To achieve near-saturated conditions, materials with high moisture retention characteristics should be selected for use in the oxygen barrier. Clayey and silty soils are suitable materials. In Canada, abundant sources of clayey till are often available and are suitable for use in wet cover systems (Yanful *et al*, 1994; O'Kane *et al*, 1995; Swanson, 1997). The moisture retention capacity of soils can be significantly increased by compaction, as was discussed in **Section 2.8**.

At many gold and base metal mining operations, oxide tailings are produced from the mining of oxidised ore. These tailings are often non-reactive, do not generate acid and often have high soil-water retention characteristics due to the ore being weathered to clayey materials. These tailings can be used as oxygen barriers on tailings dams and waste rock (Aubertin *et al*, 1997; Bussiere *et al*, 1997).

The design of wet cover systems should be aimed to ensure near-saturated conditions in the oxygen barrier and the design should therefore aim to prevent downward flow of soil water into the waste. A capillary barrier can be considered to ensure high soil water contents in the oxygen barrier. The wet cover design should also aim to prevent upward movement of soil water by means of evapotranspiration. The designer should consider the use of a sandy soil layer overlying the oxygen barrier. This layer will act as a capillary break, preventing upward movement of soil water. The wet cover design in which the oxygen barrier is sandwiched between two sandy layer has been tested in field and laboratory experiments (e.g. Yanful, 1993; Woyshner and Yanful, 1995) and has also been successfully applied at a number of mining sites (Yanful *et al*, 1993; Bell *et al*, 1995; Yanful *et al*; 1994).

In addition to the upward and downward movement of soil moisture from the oxygen barrier, it is also likely that soil water may flow laterally along sloped wastes (Golder Associates, 1999; Bussiere *et al*, 2000). This process is synonymous to capillary barriers in that soil-water moves along the interface of the underlying capillary break and oxygen barrier. This lateral flow causes a reduction of soil-water content along the upper portions of the sloped waste, thereby decreasing the effectiveness of the wet cover system.

To the author's knowledge, wet cover systems have not yet been used in coal mining related covers. However, it is likely that fly ash, produced from coal-based power stations, could prove beneficial for use in oxygen barriers.

2.11 SOIL COVER DESIGN AND CONSTRUCTION

A thorough understanding of the basic principles involved in cover design is critical for final cover design. Due to site-specific factors which the design engineer needs to consider site-by-site and cannot alter without incurring great cost, soil cover design cannot be generalised for all sites and for all wastes. These factors include climate, soils available for cover construction, the geometry of the dump and the risk the waste is likely to induce on the environment. The design of a final cover should therefore strike a balance between factors the design engineer cannot alter and factors that the engineer can modify, such as the thickness of the cover, cover configuration, the degree of compaction and the use of geosynthetics. Each cover has to be designed to the site-specific requirements of each site.

The design of soil covers is complicated by environmental factors, including:

- Cyclic wetting and drying, dominant in many semi-arid and arid environments.
- Temperature extremes, possibly including freeze/thaw cycles to significant depths.
- Penetration of the covers by plant roots and burrowing animals.
- Erosion of the cover systems by water and wind.
- Total and differential settlement caused by compression of the underlying waste.
- Down-slope slippage or creep.
- Vehicular movements on haul roads traversing the cover.

Because of these site-specific environmental stresses and conditions, the design of soil cover systems can be very challenging. In practice, it is difficult to provide an effective soil cover system, especially a low-permeable infiltration barrier, because of the many unknown and non-quantifiable environmental stresses acting on the cover.

2.11.1 CONSTRUCTION QUALITY ASSURANCE

Construction quality assurance (CQA) is critical for the construction of an engineered cover system that will perform satisfactory. Details regarding the development of CQA programmes for the construction of soil covers fall outside the scope of this project. The general principles that should be considered when developing a CQA programme are discussed by Daniel (EPA, 1991).

In general, the purpose of CQA is to provide observations and tests that assist in evaluating whether construction of the soil cover has been performed in accordance with specifications. Each CQA programme must be tailored to the specific construction details of a given project.

The factors important in CQA for soils (EPA, 1991) are:

- Control of soil material used to build the respective components of the soil cover system.
- Control of subgrade preparation.
- Control of the placement and compaction of soils.
- Protection and maintenance of the soils during and after construction.
- Construction of test pads, if required.

Of all the components present in a typical soil cover configuration, the infiltration barrier requires the most stringent CQA. Poor construction of this layer will render the whole soil cover system ineffective.

Important quality control tests for soils used in soil cover systems include Atterberg limits, percentage of fines, percentage of gravel and the maximum size of stones and clods found in clay soils. For the construction of infiltration barriers, the soil must have adequate plasticity and a high percentage of fine material.

Water content and dry unit weight greatly affect the permeability, and hence effectiveness, of the infiltration barrier. Quality control of infiltration barrier materials therefore focuses heavily on water content and dry unit weight. Quality control for infiltration barrier layers comprises *in situ* measurement of water content and density for each lift. Values are usually measured by the nuclear method and calibrated by conducting laboratory tests.

Occasionally, test pads are constructed in order to verify that the materials and methods used in compaction will achieve the desired results, that is, low permeability. The CQA team should verify that the specified procedure has been followed.

Tests to be conducted on the test pads should include one or more *in situ* hydraulic conductivity tests for which several methods (e.g. the Double Ring Infiltrometer test (DRI)) are available In addition, a range of other tests (e.g. water content, dry unit weight, Atterberg limits and percentage fines) forms part of the testing protocol.

2.11.2 SOIL COVER DEGRADATION

Any engineering structure, including engineered soil covers, has a specific design life. Soil covers will degrade with time resulting in increased infiltration into the mine wastes. The design life of soil covers has not yet been determined, as covers have only started to be used for rehabilitation purposes relatively recently.

A rehabilitation plan should include a maintenance contract for at least two years after the soil cover has been constructed. During this period, a vegetation cover should be used to prevent extensive erosion from taking place, assist in the re-establishment of the natural eco-system and be aesthetically acceptable. During this maintenance period, allowance should be made for the repair of damage to the soil cover caused by erosion. The two-year maintenance contract should be followed by addressing specific issues, such as localised erosion problems, cutting down of trees that may damage the cover and enforcing the particular land use specified by the rehabilitation plan.

Numerous processes are responsible for soil covers degrading with time. In the short term, desiccation and/or freezing could cause cracks to develop, especially in the infiltration barrier, resulting in that the compromise of the integrity of the cover (Daniel & Koerner 1997). This could occur quite soon after construction, even while the cover is being constructed. The cover design should allow for desiccation and freezing, especially in arid and semi-arid climates (desiccation) and continental climates (freezing). It is probably correct to say that if desiccation has not occurred within the first few years after construction of the cover, desiccation is unlikely to be a problem. However, periods of drought may induce severe desiccation that may have otherwise not occurred. Even then, clay soils have self-healing characteristics and it is likely that desiccation cracks would close with the next rainy season, thereby restoring the integrity of the cover.

Erosion could also be a significant problem in the short term, especially in cases of poorly constructed covers, inadequate surface drainage features or where vegetation has not been re-established. However, erosion is unlikely to be a problem in the short term if adequate steps have been taken during the rehabilitation processes to prevent erosion.

In the short to medium term (two to ten years), soil cover degradation is likely to be caused by plant roots and burrowing animals. As a plant establishes itself on the newly rehabilitated land, its root system may develop well within the soil cover. This root system development is desirable as plants assist in removing water from the soil cover. However, various authors have shown that dead plant roots create macropores and increase the potential for preferential flow (Jury & Fluhler, 1992; Perret *et al*, 1999). Plant roots will naturally develop in zones where sufficient soil-water is available and the infiltration barrier may provide this soil water source, resulting in drying and cracking of the barrier. Plant roots may also develop to below the infiltration barrier, thereby creating potential preferential pathways through the cover. Plant roots may develop to significant depths, often exceeding the cover thickness. This is especially true for arid and semi-arid regions where plants develop deep rooting systems naturally.

As the natural ecosystem re-establishes on the rehabilitated land, a multitude of burrowing animals may be re-inhabit the land. These animals create holes, providing preferential flow paths through the cover. Similar to plants, some animal species may seek moist conditions in the ground and may therefore damage the infiltration barrier. However, few species are known to burrow to depths greater than approximately 1 m.

Trees may naturally re-establish on the soil cover some time after rehabilitation and the degree to which they re-establish will depend on the type of natural vegetation in the area. In the case of natural grasslands, like the South African coalfields, few trees will re-establish and trees will need to be removed only occasionally. However, if the natural vegetation is bush, trees should be removed regularly. Timms & Benett (2000) report that trees need to be regularly removed from the rehabilitated Rum Jungle mine dumps, situated in a tropical climate.

After mining has ceased, there is a possibility that anthropological influences may affect rehabilitated land. For example, humans may construct structures or otherwise disturb the rehabilitated land and it is therefore necessary to have regulations in place to limit anthropological actions from disturbing rehabilitated land.

In the long term (fifty years and onwards), soil cover degradation is likely to be caused by erosion processes. Short-term erosion is likely to be prevented with best practice erosion measures but long term erosion is more difficult to address. Soil loss will occur during the post-rehabilitation phase, albeit at a very low rate. The rate at which soil loss occurs should be determined and, where applicable, the surface layer should be armoured with cobbles and gravel, mixed with sandy silt to provide resistance against erosion.

2.12 SOIL COVER DESIGNS AND PERFORMANCES OVERVIEW

Final covers have been extensively used in many countries for the rehabilitation of mine wastes and opencast mines. In many cases, mine wastes have been provided with soil covers to impede acid generation processes and to reduce waste loads to the groundwater and surface water regimes. Research of final covers often forms part of research organisations such as MEND (Canada), AMIRA (Australia) and INAP, which investigate preventative measures to acid generation processes. The design of soil covers and their performance are therefore well documented.

Soil cover design as used in the rehabilitation of mine wastes is a relatively new branch of engineering. Research on soil covers for mine wastes was initiated in the early 1980's when it was recognised that acid drainage could have extensive environmental liabilities for mining companies (Tremblay, 2000). Initially, soil cover designs used in the rehabilitation of mine wastes were based on final cover designs used in the industrial and waste industry. During the last decade, however, alternative and cheaper cover designs, such as water covers (Li *et al*, 1997; Yanful & Simms, 1997; Li *et al*, 2000), covers incorporating the capillary break concept (Bews *et al*, 1997; Swanson *et al*, 1997; Durham *et al*, 2000) and covers using desulphurised tailings (Aubertin *et al*, 1997; Ricard *et al*, 1997), have been researched and implemented at many mine sites.

The approach in soil cover design varies from mining area to mining area and is largely dictated by the prevailing climate. Design is also dictated by cost, regulatory requirements and the risks that the mine waste impose on the environment.

Table 2.12(a) summarises the cover types that were considered or used for reclamation purposes for the different climates and mining areas. From the literature, it is evident that water covers and wet covers are preferred in continental climates and, to a lesser degree, temperate climates. Infiltration barriers are often considered in all climate zones but are preferred in temperate and tropical climates. Store and release covers are most often considered in arid and semi-arid areas while simple covers are considered in arid climates. In the last few years, capillary barriers have been considered as an alternative to the more expensive infiltration barriers.

In contrast to the extensive research conducted in the developed world, very little research has been conducted in developing mining countries including China, India and Russia; these were not included in **Table 2.12(a).** The approaches to soil cover designs for the different climate zones are discussed in more detail.

Table 2.12(a) Summary of cover types used in different climates and mining areas

Climate	Mining areas	Typical cover types	Characteristics
Continent al	Canada, Scandinavia	Water cover, wet cover, infiltration barrier	Freezing effects, low evaporation, snowmelt
Temperat e	Northern & Central Europe, Appalachian, Central USA, Tasmania and New Zealand	Infiltration barrier, water cover, wet cover, store and release, capillary barrier	Rainfall exceeds evaporation, freezing effects
Tropical	Indonesia, Northern Australia	Infiltration barrier	High rainfall, high evaporation, seasonal rainfall
Semi arid and savannah	South Africa, Australia, Southern Europe	Store and release, infiltration barrier	Medium to low rainfall, high evaporation, seasonal rainfall
Arid	Australia interior, South-western USA	Store and release, simple cover, infiltration barrier	Low rainfall, high evaporation, poor vegetation

2.12.1 CONTINENTAL CLIMATES

For continental climates (mostly Canada and Scandinavia), designers have focused on limiting oxygen ingress into mine wastes rather than on, and sometimes in addition to, limiting rainfall infiltration. The low evaporation potential does not support store and release covers. Infiltration barriers are sometimes used but an adequate (and expensive) protection layer is required to protect the clay layer against freezing effects. It is therefore often more feasible to use soil covers to improve leachate quality by limiting oxygen ingress rather than to limit leachate quantities.

The continental climate is characterised by very low temperatures (less than 0°C) during the winter months and warm during the summer months. In many mining regions of Canada, precipitation is approximately 500 to 600 mm/a of which more than 50% of precipitation occurs as snowfall. The snowfall accumulates during the winter months to form a snow pack which melts during spring. Despite the low precipitation, regions in continental climates can be described as wet because of the low evapotranspiration potential (some 300mm in the mining regions of Canada).

Most of the water infiltration occurs during spring when the snow pack melts and the evaporation potential is low (Gardiner *et al*, 1997). In summer, evaporation often exceeds precipitation and little infiltration occurs. No infiltration occurs during the winter months. The freezing zone can penetrate soil covers to significant depths, damaging the compacted soil layer and resulting in loss of cover integrity. This is particularly harmful to infiltration barriers, which rely on the integrity of the barrier to limit infiltration.

Water covers are often used in the reclamation of mine sites with the purpose of limiting oxygen ingress into the mine wastes and inhibiting acid drainage. Circumstances at these mine sites often lend themselves to the placement of comparatively inexpensive water covers. The effectiveness of water covers in limiting oxygen ingress has been proven in the laboratory as well as in the field (Payant *et al*, 1995; Li *et al*, 1997; Catalan 2000).

Wet cover systems proved to be almost as effective as water covers in limiting oxygen ingress into mine wastes (Yanful *et al*, 1993; O'Kane, 1995). The near-saturated soil layer is, in effect, a water cover. Infiltration barriers are sometimes used in the reclamation of mining areas in continental climates and often form part of a wet cover system to limit both water infiltration and oxygen ingress into mine wastes (Lewis *et al*, 2000). A protection layer should be provided to protect the infiltration barrier from freezing effects.

Table 2.12.1(a) is a summary of documented mine sites where covers were used as part of the rehabilitation plan. In most cases, these case studies formed part of the MEND research plan, which are based in Canada.

Table 2.12.1(a): Mine site in continental climates where covers were used as part of the rehabilitation plan

No.	Mine site	Location	Cover type	Reference
1	Black Angel Mine	Greenland	Water	Asmund, 1992
2	Elliot Lake Uranium District	Canada	Water	Dave & Vivyurka, 1994
3	Louvicourt Mine	Quebec, Canada	Water	Li *et al*, 1997
4	Heath Steele	New Bruswick, Canada	Water Wet	Catalan *et al*, 2000 Germain *et al*. 1997
5	Falconbridge	Ontario, Canada	Water	DeVos *et al*, 2000
6	Equity Silver Mine	British Columbia, Canada	Wet	Kane *et al*, 1995 Aziz & Ferguson, 1997 Wilson *et al*, 1997
7	Les Terrains Auriferes	Quebec, Canada	Wet	Ricard *et al*, 1997
8	Sullivan	British Columbia, Canada	Wet Infiltration barrier	Gardiner *et al*, 1997
9	Millenbach	Quebec, Canada	Wet	Woyshner *et al*, 1997
10	Poirier	Quebec, Canada	Infiltration barrier	Lewis *et al*, 2000
11	Bersbo	Sweden	Wet	Lundgren, 1997
12	Brenda	British Columbia, Canada	Water	Germain *et al*, 1997
13	Kidd Creek	Ontario, Canada	Store and release	Woyshner & Swarbrick, 1997

*In literature (especially Canadian literature), the term "wet cover" is sometimes used to describe water covers while the term "dry cover" is sometimes used to describe wet covers.

Table 2.12.1(b) summarises the results of field trials and modelling runs conducted for various mine sites characterised by continental climates. The table includes the climate, cover configuration, infiltration and oxygen concentration results for the respective mine sites.

Table 2.12.1(b): Effectiveness of covers for continental climates (excluding water covers)

Location	MAP (mm)	MAE (mm)	Cover configuration	Outflow		O_2 conc (%)
				mm	%MAP	
Equity Silver	560	400	0.3m uncompacted till 0.5m compacted till	28	5	3
Sullivan Mine	409	300	0.45m uncompacted tailings 0.2m float rock	112	18	17
			0.3m uncompacted till 0.25m compacted till 0.2m float rock	25	4	17
Les Terrains Auriferes	NA	NA	0.5m coarse grained layer 0.8m compacted tailings 0.3m coarse grained layer	NA	NA	5
Heath Steele	NA	NA	0.1m gravel 0.3m compacted till 0.3m compacted coarse sand	Low	Low	<1
Kidd Creek	NA	NA	0.6m thickened tailings	Low	Low	17-20

Wilson *et al* (1997) reported on the reclamation at Equity Silver Mine (B.C., Canada) in which waste rock was covered to prevent acid generation. The cover was constructed from locally available till. The lower 0.5m till was compacted while the upper 0.3m till was left uncompacted. The upper uncompacted till allows rapid infiltration and storage of precipitation while the lower compacted till is a barrier to infiltration and also ensures near-saturated conditions. The effectiveness of the soil cover was tested by means of modelling using SoilCover which showed that the lower compacted layer would remain near saturated. This was confirmed over five years of field monitoring. Wilson *et al* (1997) expected that the cover would perform satisfactorily in the long term, resulting in the reduction of flow rates and improvement of leachate quality.

Gardiner *et al* (1997) reported on the reclamation of the tailings dam at Sullivan Mine (BC, Canada) which entailed the construction of a soil cover to prevent acid generation. Four test plots were constructed in which the performance of soil cover was evaluated. The soil cover on Plot 3 comprised 0.45m of uncompacted till overlying 0.2 to 0.6m of float rock. The soil cover on Plot 2 comprised 0.3m uncompacted till overlying 0.25 m compacted till and float rock. The function of the compacted till was to reduce the infiltration to less than 5% MAP and to ensure near-saturated conditions. The effectiveness of the covers was tested by means of modelling using SoilCover and two years of field monitoring. The modelled covers predicted a seasonal pattern in which the covers would become saturated in spring from melting snow and would then dry out during summer and autumn. As a result, the covers were not very effective as oxygen barriers. In addition, both the modelling and field monitoring indicated that infiltration rates would exceed 5% MAP in wet years. Gardiner *et al* concluded that treatment of ARD was the only acceptable abatement technology available.

Bell *et al* (1995) reported on the construction of a composite cover at the Heath Steele Mine (New Brunswick, Canada). The cover comprised 0.6 m compacted till cover sandwiched between a lower 0.3m sand base and an upper 0.3m sand and gravel layer. The purpose of the cover was to ensure near-saturated conditions in the compacted till, thereby impeding oxygen ingress. The waste and covers were evaluated and monitored during the period 1988 to 1995. Oxygen concentrations close to the surface varied between 3.2 and 20.8%. After placement of the cover, oxygen concentrations decreased to between 8.2 and 14.5%, with a further decreased to between 0.2 and 0.7%. A decrease in temperature inside the pile was also observed and a slight increase in pH, from 2.4 to 3.1, was measured during the three years of monitoring.

2.12.2 TEMPERATE CLIMATES

In more temperate climates, such as the Appalachian region of the United States of America, the northern and central European countries, Tasmania and New Zealand, low-permeability covers are preferred to limit rainfall infiltration into mine waste (Daniel & Koerner, 1997). However, wet cover systems are also frequently used to inhibit oxygen ingress into mine waste (Brodie, 1998).

Temperate climates are characterised by medium to high annual rainfall which exceeds annual potential evapotranspiration. The climate can therefore be described as wet. Rainfall occurs typically throughout the year. Temperatures are moderate and sometimes drop to below freezing during winter. However, in contrast to continental climates, snow does not accumulate during the winter months and infiltration related to snowmelt is of lesser significance.

Low permeability barriers are the cover system of choice in the temperate regions. The low permeability layers are often covered with a protection layer to prevent drying of and freezing damage to the low-permeability barrier (Daniel & Koerner, 1997). The infiltration barrier often comprises compacted clay layers, geomembrane, geosynthetic clay layers or combinations of these. Documented poor performances of compacted clay layers (Daniel & Koerner, 1997), high costs associated with quality assurance of the compacted clay layers (Daniel, 1995) and stringent regulatory requirements, especially in European countries, have encouraged designers to use geomembranes and geosynthetic clay layers for covering proposes.

There are few documented case studies in which low-permeability barriers were used for mine reclamation. Because of the high cost associated with low-permeability barriers and stringent environmental regulations, many engineers and scientists opted for alternative prevention strategies. In the Wismut uranium mining districts in East Germany, it was decided to relocate acid generating and radioactive wastes to pits where the acid-generating material is placed below the groundwater level (Helm & Heinrich, 1997; Jakubick *et al*, 1997; Hockley *et al*, 1997). In the Appalachian coalfields in the USA, the focus is on active and passive treatment of mine water (Skousen, 1997; Phipps *et al*, 1997; Brown *et al*, 1997; Skousen *et al*, 1997; Faulkner & Skousen, 1997). Where preventative measures are considered, the focus is on alkali addition (Ziemkiewics & Skousen, 1997), selective handling (Phipps *et al*, 1997), grout barriers (Ziemkiwics & Skousen, 1997) and barriers (Ziemkiwics & Skousen, 1997).

In contrast to the few documented cases of cover performance for mining purposes, the performance of covers for landfill purposes are well documented (Knox & Gronow, 1993). For landfill sites, low-permeability barriers incorporating geomembranes or geosynthetic clay liners are standard covering procedures.

Table 2.12.2(a) contains a summary of documented mine sites where covers were used as part of the rehabilitation plan for temperate climates. The effectiveness of some of these covers are summarised in **Table 2.12.2(b)**.

Table 2.12.2(a): Mine sites in temperate climates where covers were used as part of the rehabilitation plan

No.	Mine site	Location	Cover type	Reference
1	Richmond Hill	South Dakota, USA	Infiltration barrier	Duex, 2000
2	Summitville	Colorado, USA	Infiltration barrier	Campbell & Gobla, 2000
3	Martha Mine	Waihi, New Zealand	Wet	Brodie, 1998
4	Clinton County	Pennsylvania, USA	Chemical barrier Infiltration barrier	Ziemkiewicz, 2000
5	KUC Bingham Canyon	Utah, USA	Wet	Schafer *et al*, 1997
6	Upshur Mining Complex	West Virginia, USA	Infiltration barrier	Meek, 1994

Table 2.12.2(b): Effectiveness of covers for temperate climates

Location	MAP (mm)	MAE (mm)	Cover configuration	Outflow		O_2 conc (%)
				mm	%MAP	
Richmond Hill, South Dakota	NA	NA	0.15m topsoil 1.38m thermal barrier 0.46m compacted clay layer 0.15m crushed limestone	0.1	NA	3.7
Summitvale, Colorado	140	NA	Topsoil 1.2m thermal barrier Geosynthetic liner	0	0	NA

Duex (2000) presented the reclamation plan of the Richmond Mine Hill (South Dakota, USA). The reclamation strategy entailed relocating acid generating materials into the former open pit and the construction of a multi-layer capping system on the remainder of the waste rock. The multi-layer capping system was designed to minimise infiltration into this backfilled waste rock. The capping system comprised 0.15 m limestone at the base, 0.46 m low permeability clay liner, 1.2 and 0.46 m thermal barrier/drain layer and 0.15 m topsoil. No water was detected in the lysimeters for the whole of the monitoring period. Pore gas monitoring from the nested drill sites indicated success in limiting oxygen to the backfilled waste. Data from temperature readings in the backfill material indicated that no rapid oxidation of sulphides was occurring in the engineered structure. Ground water quality monitoring indicated that water quality trends were improving and that metal values generally remained below groundwater standards.

Knox & Gronow (1993) reviewed the performance of engineered landfill caps in 12 experimental sites, mostly in the UK but including Holland, Germany, Denmark, USA and Hong Kong. All of the caps were made of natural material, mostly clays. The study indicated that many caps would allow some percolation, and that the amount may increase significantly if extensive desiccation cracking was allowed to occur. The results of this review are summarised in **Table 2.12.2(c)**.

Table 2.12.2(c): Results of low permeability landfill caps in Europe and USA (after Knox & Gronow (1993)

Site	Cover details	Rainfall (mm/a)	Percolation (mm/a)
Calvert, UK	1m clay	670	33
Pitsea, UK	0.3m clay 0.6m clay	592	6-36 0-0.3
Stangate, UK	1-4m hassock	670	100-170
Marchington, UK	Keuper Marl	670	43-86
Milton, UK	0.9m soil 0.6m clay	592	84+
Omega Hills, USA	0.46m soil 0.15m clay	Moderate	50
Bryn Posteg, UK	0.75m soil 0.5m clay	850	11-66+
Denmark	1m soil	Moderate	200
Milton, UK	0.9m soil 0.6m clay	592	<20
Waterford, UK	1.0m soil 1.0m clay	592	43-121
Wijster, Netherlands	1m soil, 0.2m cap 1m soil, 0.1m cap	Moderate	0 94
Georgeswerder, Germany	0.75 m soil, o.3m drainage, 0.5m clay	Moderate	1-7
Denmark	0.7m soil, 0.3m drainage, 0.5m clay	Moderate	56-89

2.12.3 TROPICAL CLIMATES

Tropical climates are characterised by very high rainfall and high evaporation. In most tropical regions, there are distinctive wet and dry seasons with little precipitation in the dry season. Rainfall occurs throughout the year in other tropical regions. Temperatures are high and remain constant throughout the year.

There are few documented cases of covers used in tropical regions. It is evident that low permeability covers are preferred. The low permeability covers are sometimes used as oxygen barriers. The high rainfall requires large storage volumes which make store and release covers impractical. Low-permeability covers require a well-designed drainage layer to remove water accumulating on the infiltration barrier (Timms & Bennet, 2000). In regions with distinctive dry seasons, the infiltration barrier could dry out, resulting in desiccation, compromising the integrity of the infiltration barrier and resulting in increased oxygen ingress to the mine wastes.

In one case, a water cover has been constructed on a tailings dam to prevent acid generation (Firth & van der Linden, 1997). **Table 2.12.3(a)** provides a summary of the effectiveness of covers used in tropical climates.

Table 2.12.3(a): Types and effectiveness of covers in tropical climates (After Timms & Bennett, 2000 and Firth & van der Linden, 1997)

Location	MAP (mm)	MAE (mm)	Cover configuration	Outflow		O_2 conc (%)
				mm	%MAP	
Rum Jungle, NT, Australia	1400		0.15m gravelly sand 0.3m sandy clay loam 0.3m compacted clay	64	4.6	NA
Kelian Equatorial, Indonesia	4000		1m topsoil and clay 1m compacted siltstone 1m compacted clay	NA	NA	NA
			HDPE geomembrane	NA	NA	NA
			Water cover	NA	NA	NA

The Rum Jungle ore bodies are situated approximately 100 km south of Darwin in the Northern Territory, Australia. Being close to the equator, the area has a tropical climate with year round temperatures of 30°C. Mean annual rainfall is 1500 mm, most of which occurs between December and April. The rehabilitation process entailed the provision of soil covers to the overburden heaps, tailings dam and copper heap leach material. The soil covers comprised three-layer cover systems with a compacted clay seal, overlain by a sandy moisture retention zone and overlain by an erosion protection cover. Some engineers have expressed concern that trees establishing on the overburden heap will penetrate the clay seal, permitting the passage of oxygen and water to pyretic overburden. Monitoring of overburden heap temperatures and moisture and oxygen content has indicated the success of the cover system in reducing the rate of pyretic oxidation by reducing the ingress of oxygen and water into the heaps.

2.12.4 SEMI ARID CLIMATES

Probably the greatest challenge in cover design is for areas with a semi-arid climate or where the climate is characterised by distinctive wet and dry seasons. These areas include the immediate Australian interior, portions of southern Europe and most parts of South Africa, including the South African coalfields. Both low-permeability covers and store and release covers are used.

The semi-arid climates are characterised by moderate to low rainfall which is highly seasonal with distinctive wet and dry seasons. Potential evapotranspiration exceeds rainfall by a significant margin and is typically 2 to 3 times higher than rainfall. Temperatures are generally moderate to high throughout the year.

Problems associated with the low-permeability covers are that significant drying of the covers occurs during the dry season, resulting in desiccation of the clay barrier and compromise of the integrity of the infiltration barrier (Benson & Koerner, 1997). A thick protection layer is required to prevent desiccation.

In recent times, store and release covers have gained in popularity as an alternative cover system for mine wastes. Unlike low-permeability covers, store and release covers are not prone to desiccation. These systems should have adequate moisture storage capacity to accommodate the rainfall of the wet season (Durham *et al*, 2000; Bews *et al*, 1997). The soil characteristics of the moisture-retention layer should also promote upward movement and evaporation of soil-water.

Table 2.12.4(a) is a summary of documented case studies in which soil covers were used in semi-arid regions and their effectiveness.

Table 2.12.4(a): Types and effectiveness of covers used in semi-arid climates (after Durham et al, 2000, Garner et al, 2001 and Komnitsas, 2000);

Location	MAP (mm)	MAE (mm)	Cover configuration	Outflow		O_2 conc (%)
				mm	%MAP	
Kidston, Queensland, Australia	720	2300	1.5m oxidised waste rock 0.5m compacted oxidised waste rock	0	0	NA
Springbok Valley, South Africa	NA	NA	0.3m topsoil 0.25m compacted subsoil Lime layer	NA	NA	NA
Lavrion, Greece	NA	NA	0.2m topsoil 0.3m protection layer 0.1m limestone gravel	NA	NA	NA

The Kidston Gold Mine (Queensland, Australia) is located in a semi-arid climate with distinctive wet and dry seasons. The purpose of the cover design was to prevent rainfall infiltration into the sulphidic waste rock (Bews *et al*, 1997; Durham *et al*, 2000). The design of a zero flux cover system requires that precipitation be stored within the cover profile for later release through evapotranspiration, thus limiting the movement of water to the underlying waste material.

The cover comprised a 0.5 m of compacted, oxidized waste rock material overlain with 1.5 m of non-compacted oxidized material. The effectiveness of the covers was tested by means of numerical modelling (using SoilCover). Lysimetres were installed to measure net infiltration rates and moisture condition in the test cover profiles.

It was estimated that less than 5% of rainfall would percolate through the cover and that slightly more would percolate during an extreme wet season. In the two years of monitoring, insignificant through-flow was measured in the lysimetres.

Garner *et al* (2001) reported on the rehabilitation strategies of burning coal discard dumps in the Springbok Valley, South Africa. The main purpose of rehabilitation was to extinguish the fires and to prevent spontaneous combustion. In addition, the rehabilitation aimed to reduce rainfall infiltration and to improve seepage qualities. The cover was therefore designed to impede oxygen ingress. The top layers of the coal discard were compacted and lime was placed on the waste surface. The dump was then covered by a 0.25 m thick compacted subsoil and 0.3 m uncompacted subsoil. Spontaneous combustion was successfully averted and the cover resulted in an improvement of water quality in a nearby stream, possibly because of reduced seepage although no monitoring data is available.

Komnitsas *et al* (2000) reported on the rehabilitation of sulphidic mine wastes at the Lavrion Technological Park (Athens, Greece). Rehabilitation was aimed to halt the autocatalytic chemical and bacterial oxidation mechanism within the sulphide tailings mass and thus to prevent the generation of acid mine drainage and to reduce the environmental risk for the wider Lavrion area. The objective was therefore to adjust the acid generation potential in the upper layers of the tailings by inhibiting oxygen and water infiltration into the tailings through the addition of alkaline minerals to create a hard pan.

Rehabilitation entailed mixing lime sand to the top 0.8 m of tailings. A 0.1 m thick layer of limestone gravel was placed on top of the mixed tailings and compacted to act as a capillary break and to add alkalinity to the tailings by means of percolating rainfall water. A 0.3 m thick protective layer was placed on top of the limestone gravel followed by a 0.4 m thick surface layer. After construction of the cover, a marked improvement of water quality was noticed.

2.12.5 ARID CLIMATES

Many people have commented that contamination of water resources in arid climates should not be problematic due to the limited rainfall. Little attention has thus been given to covering mine waste in arid climates which include much of the south-western states of the USA and Australian arid interior. However, high percolation rates have been recorded at many sites situated in arid regions (Milczarec *et al*, 2000) and more attention is thus now given to cover design.

Arid climates are characterised by low rainfall and high potential evapotranspiration which usually exceeds rainfall by a significant margin. In some arid climates, rainfall occurs mainly in the form of high intensity rainfall events. It is during these events, especially where rainfall events follow in close succession, that most infiltration occurs. Temperatures are high.

Traditionally, cover designers have opted for a simple cover on mine waste and typically incorporate erosion control measures as arid climates do not support vegetation. However, these erosion control measures, usually comprising a cobble layer, promote infiltration and prevent evapotranspiration.

Recently, designers in arid regions have opted for store and release covers which are designed to store rainfall water and then to release it by means of evaporation (Milczarec *et al*, 2000; Wilson *et al*, 1999). Because of the low rainfall, relatively thin and inexpensive covers are required.

The documented effectiveness of some covers in arid climates are summarised in **Table 2.12.5**.

Table 2.12.5: Effectiveness of covers in arid climates (after Milczarec, 2000)

Location	MAP (mm)	MAE (mm)	Cover configuration	Outflow		O_2 conc (%)
				mm	%MAP	
Hanford, Washington	160		1.5m silt loam, 0.2m sand gravel base	0	0	NA
			0.3m topsoil with sand base 0.22m gravel 0.45m natural soil 0.3m sand	0	0	NA
			Gravel surface 1.5m silt loam sand & gravel base	0	0	NA
Ogden, Utah	436		0.9m sandy loam	410	94	NA
			1.5m sandy loam 0.3m gravel	270	62	NA
			1.2m sandy loam 0.3m sand 0.6m clay	0.1	0.02	NA
Los Alamos, New Mexico	471		0.2m topsoil 1.1m crushed tuff	170	36.1	NA
			0.7m topsoil 0.5m gravel 0.9m cobble 0.4m crushed tuff	57	12.1	NA
Mt Whaleback Western Australia	320	3300	2m shale	0	0	NA
			4m shale	0	0	NA
Mercury, Nevada	100		2m single layer	0	0	NA

CHAPTER 3

UNSATURATED FLOW MODELLING THEORY

3.1 INTRODUCTION

Contamination of groundwater and surface water bodies occurs when rainfall water infiltrates and percolates through mine wastes. Contaminants become soluble and are transported with percolating rainfall water through the wastes and into the groundwater. In most cases, flow through mine wastes occurs under unsaturated conditions, which implies that the porous material is partly filled with water and partly filled with air. The flow of water through a porous medium is complex and is governed by gravitational and capillary forces and the hydraulic characteristics of the porous material. A thorough understanding of these processes is crucial to understand and simulate flow of water through mine wastes.

The purpose of a soil cover is to limit water infiltration and/or oxygen ingress into mine wastes. Flow through cover systems may occur under unsaturated conditions and a number of layers are incorporated to restrict flow through the covers, such as infiltration barriers, capillary breaks and drainage layers. These layers complicate flow considerably and the modifying effects of these layers need to be understood in order to model water flow through covers.

Some of the processes that occur in soil covers, namely capillary breaks, capillary barriers and oxygen flow through wet covers, have already been described in **Chapter 2**. In this chapter, the basic principles of unsaturated flow and soil-atmosphere coupling are discussed. Readers are referred to **Chapter 2** for detailed discussion of special covers.

3.2 CONCEPTUAL UNSATURATED FLOW MODEL

A conceptual presentation of unsaturated flow of water through a soil cover and mine waste is given in **Figure 3.2(a)**. Two processes are identified, classified as:

1. Soil-atmosphere interactions (i.e. infiltration, evaporation, transpiration, surface run-off and preferential infiltration).

2. Unsaturated flow (i.e. redistribution and soil-water retention, sub-surface drainage, funnelled flow (as occurs in capillary breaks), fingered flow and flow through the bottom boundary).

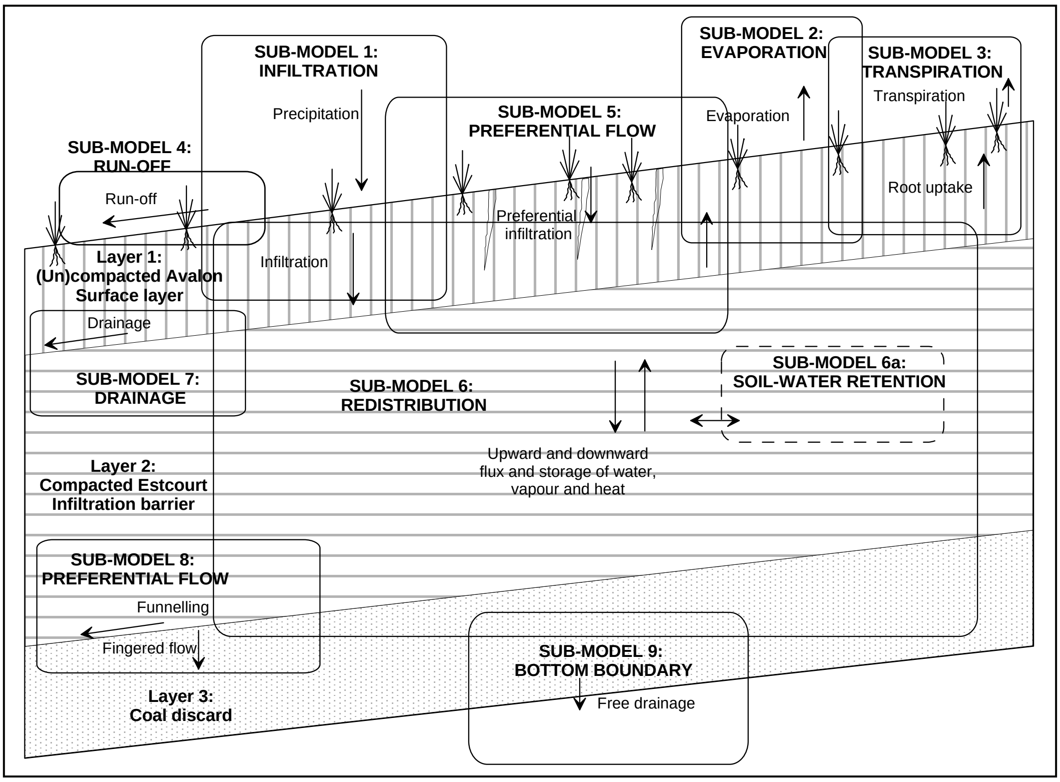


Figure 3.2(a): Conceptual unsaturated flow model through a soil cover and mine waste

The soil-atmosphere interactions represent the top boundary of the conceptual model where rainfall water enters the unsaturated system and is released to the atmosphere by means of evapotranspiration. The rates of infiltration and evapotranspiration are mainly governed by the hydraulic characteristics of the cover or waste. Hydraulic characteristics also determine the redistribution and retention of soil water, subsoil drainage and percolation rate through the mine waste. Percolation rate through mine waste can be expressed as:

$$\begin{aligned} R_e &= I - D - F - \Delta S \qquad where \\ I &= P - P_v - R - T - E \end{aligned} \qquad [3\text{-}1]$$

where R_e is the percolation rate, I is net infiltration, P is precipitation, P_v is interception by vegetation, R is surface runoff, T is transpiration, E is evaporation, D is subsoil drainage, F is funnelled drainage and ΔS is change in storage. The soil surface interactions and unsaturated flow are discussed in more detail.

3.3 ATMOSPHERIC COUPLING

3.3.1 INFILTRATION

During a precipitation event, water will infiltrate the soil surface. The rate at which rainfall water will infiltrate the soil is governed by the hydraulic characteristics of the soil surface. The flux through the ground surface for a given precipitation event can be expressed by the following equations:

$$\begin{aligned} q_i &= q_p - P_v - ET \quad for\, q_p < q_s \\ q_i &= q_s \quad for\;\; q_p \geq q_s \end{aligned} \qquad \text{where} \qquad q_s = K(\theta)\frac{\partial h}{\partial l} \qquad [3\text{-}2]$$

where q_i is the flux through the ground surface during an infiltration event, q_p is the rainfall intensity for the precipitation event, *ET* is evapotranspiration, q_s is the Darcy flux, $K(\theta)$ is the hydraulic conductivity, which is a function of soil water content, θ, $\frac{\partial h}{\partial l}$ is the suction gradient which exist across the soil surface. It is evident that the rate of infiltration will change with time as the soil water content increases and the suction gradient decreases with time. Surface runoff can be expressed simply as:

$$\begin{aligned} R &= 0 \quad for\;\; q_i \leq q_s \\ R &= q_p - q_i \quad for\;\; q_i > q_s \end{aligned} \qquad [3\text{-}3]$$

The change in infiltration rate during a precipitation event is shown schematically in **Figure 3.3.1(a).**

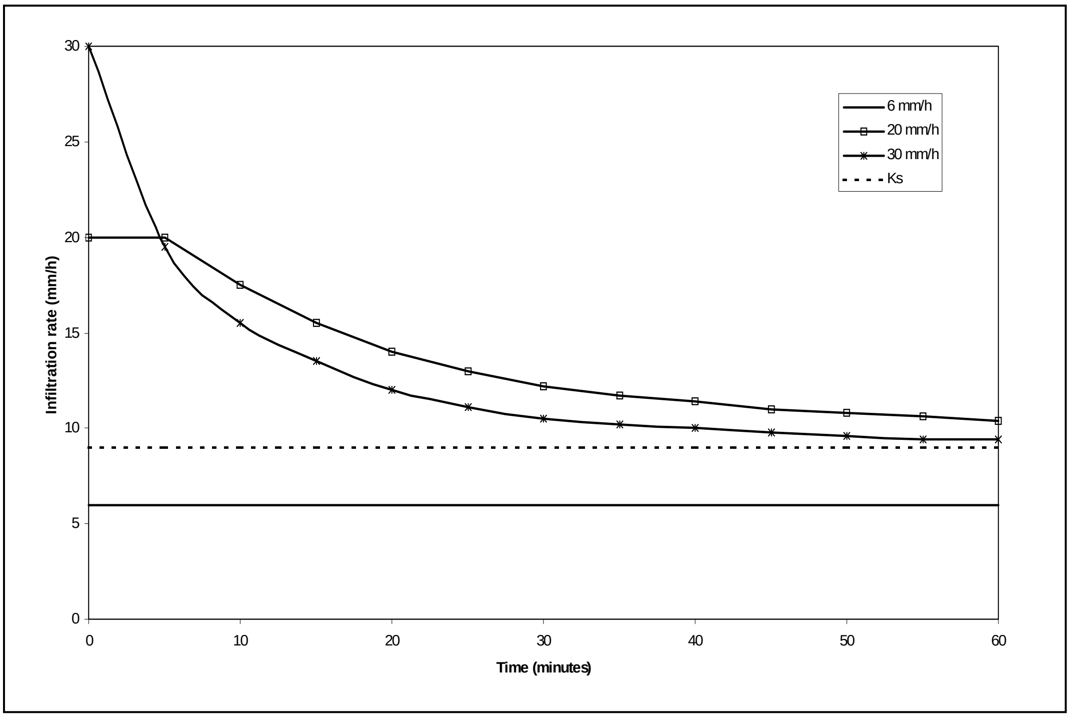


Figure 3.3.1(a): Infiltration rates into a hypothetical soil during rainfall events with constant intensities of 6mm/h, 20mm/h and 30mm/h (modified after Mein & Larson, 1973)

The following can be deduced from **Figure 3.3.1(a)**

- In the case of a constant rainfall intensity of 6mm/h, which is well below the saturated hydraulic conductivity of 2.5×10^{-6} m/s, the infiltration rate remains constant throughout the rainfall event.
- In the case of a constant rainfall intensity of 20mm/h, the infiltration rate remains constant as long as an adequate high suction gradient exists. As the suction gradient decreases upon wetting the infiltration rate then decreases with time.
- In the case of a constant rainfall intensity of 30mm/h, the infiltration rate decreases rapidly with time as the suction gradient decreases with wetting. The infiltration rate tends to approximate the saturated hydraulic conductivity value with time.

A number of functions have been developed to calculate the interception loss due to vegetation. Von Hoyningen-Huene (1983) proposed that the interception loss could be expressed by the following empirical equation:

$$I_I = 0.30 + 0.27P + 0.13LAI - 0.13P \cdot LAI - 0.007LAI^2 \text{ for } P < 18 \qquad [3\text{-}8]$$

where

I_I = interception loss (mm·day^{-1})

P = precipitation for that particular day ($mm \cdot day^{-1}$) and

LAI = leaf area index (discussed in more detail in **Section 3.3.4)**.

3.3.2 REFERENCE EVAPORATION

Reference evaporation is the maximum rate at which soil water can be removed from the soil zone. The rate of actual evaporation is restricted by the hydraulic characteristics of the soil at ground surface. It decreases rapidly as the soil dries but can never be higher than the reference evaporation. The determination of reference evaporation is of great importance in the water balance of soil covers and mine waste. As evaporation typically removes 90% or more of all rainfall infiltration in temperate, semi-arid and arid climates, a small error in evaporation estimation will therefore result in a significant error in the calculation of the percolation rate.

Reference evaporation is governed by climatic conditions including wind speed, net radiation, temperature and relative humidity. Surface temperature, vapour pressure at ground level, altitude and water quality also affect evaporation rate.

Several models have been developed to estimate reference evaporation from soil surfaces. These include:

1. Penman model (Penman, 1948): The most popular and most cited technique to estimate reference evaporation. The model incorporates mass transfer and energy components that are combined to estimate reference evaporation for a vegetated surface.
2. Modified Penman model (Wilson, 1990): A modified version of the Penman model which is used by the unsaturated soil model, SoilCover to estimate reference evaporation.
3. Penman-Monteith method (FAO, 1992): This model, which also incorporates mass transfer and energy components, was used by Schulze (1997) to produce reference evapotranspiration maps for South Africa.
4. Priestly and Taylor method (1972): The evaporation model used by the research team to model unsaturated flow during the first WRC research project.
5. Linacre model (1991): A simplified evaporation model which does not require exhaustive data to estimate reference evaporation.

The models incorporate the parameters summarised in **Table 3.3.2(a).**

Table 3.3.2(a): Parameters considered by the respective reference evaporation models

Model	Required input parameters	Parameters estimated or considered	Parameters not considered
Thornthwaite (1955)	Temperature		Humidity, net radiation, wind speed, vapour pressure, altitude
Penman (1948)	Temperature, humidity, net radiation, wind speed, altitude	Vapour pressure (assume saturated conditions)	Surface temperature
Modified Penman (Wilson, 1990)	Temperature, humidity, net radiation, wind speed, altitude	Vapour pressure, surface temperature	
Penman-Monteith (FAO, 1992)	Temperature, humidity, net radiation, wind speed, altitude	Vapour pressure (assume saturated conditions)	Surface temperature
Priestly & Taylor (1972)	Temperature, humidity, net radiation, altitude	Vapour pressure (assume saturated conditions)	Wind speed, surface temperature
Linacre (1991)	Temperature, wind speed, altitude	Vapour pressure, humidity, net radiation	Surface temperature

Most of these models are based on the Dalton-type equation that can be expressed as follows (Gray, 1970):

$$E_r = f(u)(e_s - e_a) \qquad [3\text{-}4]$$

where E_r is the evaporation rate of a saturated soil surface, $f(u)$ is the turbulent exchange function which depends on the mixing characteristics of the air above the evaporating surface, e_s is the saturation vapour pressure at the ground surface temperature and e_a is the vapour pressure of the air above the saturated surface.

Equation [3-4] is a direct estimation of evaporation and is difficult to determine in the field due to the difficulty of establishing temperature and vapour pressure at ground surface.

This equation forms the basis of the widely-used Penman equation (1948). The Penman equation resolved difficulties associated with ground surface temperature by combining it with another equation for sensible heat flux at ground surface. Penman also provided a simple equation to determine the turbulent exchange function. The modified Penman equation as proposed by Wilson *et al* (1993) can be expressed as follows:

$$E = \frac{\Gamma Q + \nu E_a}{\Gamma + \nu A} \qquad [3\text{-}5]$$

where

E = Vertical evaporative flux (mm·day^{-1})

Γ = Slope of the saturation vapour pressure versus temperature curve at the mean temperature of the air and can be expressed as:

$\Gamma = \dfrac{4098 \cdot e_a}{(273.2 + T)^2}$ where

$$e_a = 610.78 \times \exp\left(\frac{17.2694 \times T}{237.3 + T}\right)$$

T=air temperature (°C)

Q = Net radiant energy available at the surface (mm·day^{-1})

ν = Psychrometric constant and can be expressed as:

$\nu = \dfrac{C_p \times P_a}{L_v \times M_r}$ where

C_p is the specific heat of dry air (1004 J/kg°C)

P_a is the vapour pressure in the air above the evaporating surface (Pa) expressed as:

$P_0 - \left(1.292 \cdot g \cdot H \cdot \left(\dfrac{273.2}{(273.2 + T)}\right)\right)$ where

P_o is the atmospheric pressure at sea level (97,400 Pa),

g is the gravitational force and (9.80665 m^2/s)

H is the altitude (masl)

L_v is the latent heat of vaporisation (J/kg) which can be expressed as:

$$L_v = 1 \times 10^5 \cdot (2.50177 - 0.00241 \times T)$$

M_r is the molar ratio of air (11.208 g/mol) and water (18.020 g/mol)

E_a = $f(u) P_a (B - A)$

f(u) = Function dependant on wind speed, surface roughness and eddy diffusion = $0.35 \times (1 + 0.15 \cdot U_a)$ where

U_a = Wind speed (km·h^{-1})

B = Inverse of the relative humidity of the air = 1/RH

A = Inverse of the relative humidity at the soil surface = 1/h_r

The value of A is equal to 1 for saturated soils and equation [3-5] then conforms to the conventional Penman equation and the vertical evaporative flux is synonymous with the reference evaporation, E_r. The Penman equation has been successfully applied in a wide range of climates (Penman, 1963).

Reference evaporation can be estimated from readily available climatic data (i.e. air temperature, net radiation - estimated from sunshine hours if not available -, relative humidity and wind speed.

3.3.3 ACTUAL EVAPORATION

As previously mentioned, actual evaporation rate is governed by the hydraulic characteristics of the soil material. Evaporation rate will decrease as the soil dries out. In terms of the Dalton-type equation (equation [3-4]), the saturation vapour pressure at ground surface temperature, e_s, is substituted by the vapour pressure at the soil surface, P_v, for unsaturated soils. It is difficult to determine the vapour pressure of unsaturated soils as it is governed by the moisture potential and temperature of the soil surface which, in turn, are functions of soil water content and unsaturated hydraulic conductivity. Vapour pressure at the soil surface is related to relative humidity at the soil surface, h_r, by means of the following equation (relative humidity at soil surface is the inverse of the term A in equation [3-5]) (Edlefsen & Anderson, 1943):

$$P_v = e_s h_r \qquad [3\text{-}6]$$

and the relative humidity at soil surface can be expressed as:

$$h_r = \exp\left(\frac{h\,gW_v}{R\left(T_s + 273.2\right)}\right) \qquad [3\text{-}7]$$

where h is the total potential in the liquid water phase at ground surface, W_v is the molecular weight of water (0.018 kg/mol), R is the gas constant (8.314 J/mol K) and T_s is the soil surface temperature. Both total potential and surface temperature are unknown and vary with changes in moisture content and air temperature.

Wilson *et al* (1993) suggested that actual evaporation could be calculated by the simultaneous solution of the transfer equations of liquid water, water vapour and heat through the cover or waste. These equations are discussed in more detail in **Section 3.4**.

Apart from the hydraulic constraints, actual evaporation is also affected by vegetation. The presence of a canopy cover implies that a portion of the soil is shaded, resulting in a reduction of actual evaporation. The effects of transpiration are discussed in **Section 3.3.4**.

3.3.4 ACTUAL TRANSPIRATION

Vegetation plays an important role in the evapotranspiration process (Tratch *et al*, 1995). The transpiration model should incorporate canopy cover, root density and depth, the effects of water stress and the transpiration characteristics of different plant species. In order to calculate actual transpiration, it is necessary first to calculate reference evaporation, as discussed in **Section 3.3.2**. Reference evaporation then needs to be split into its evaporation and transpiration components.

Ritchie (1972) observed that the transpiration component is a function of leaf area index (LAI). LAI is defined as the planimetric area of the plant leaves relative to the soil surface area (Shulze *et al*, 1995):

$$LAI = \left(\frac{surface\,area_{leaf}}{surface\,area_{soil}} \right) \qquad [3\text{-}8]$$

LAI is used to estimate consumptive water use by plants, reduction of net radiation intercepted by the soil surface due to shade (resulting in reduced evaporation from the soil surface) and canopy interception. In general, soils with a good vegetation cover will have a LAI of approximately 3.0 while soils with a poor vegetation cover will have a LAI of approximately 1.0.

Potential transpiration, E_{pt} , is a fraction of reference evaporation, E_r, and can be estimated as follows:

$$\begin{aligned} E_{pt} &= 0 && for \;\; LAI < 0.1 \\ E_{pt} &= E_r\left(0.70LAI^{0.5} - 0.21\right) && for \;\; 0.1 < LAI < 2.7 \\ E_{pt} &= E_r && for \;\; LAI > 2.7 \end{aligned} \qquad [3\text{-}9]$$

The uptake of soil water from plant roots can be expressed as a soil water sink, *S.* It is a function of soil suction, ψ, and can be expressed as:

$$S(\psi) = \alpha(\psi)E_{pt} \qquad [3\text{-}10]$$

where $\alpha(\psi)$ is the sink variable describing water uptake as a function of pore water tension, ψ. The sink variable is a function which indicates whether vegetation is experiencing stress, resulting in a reduction of water uptake. It can be defined as follows:

$$\begin{aligned}
&\alpha(\psi) = 0 && \textit{for}\ \ \psi < \psi_1 \\
&\alpha(\psi) = \frac{\log(\psi)}{\log(\psi_2) - \log(\psi_1)} - \frac{\log(\psi_1)}{\log(\psi_2) - \log(\psi_1)} && \textit{for}\ \ \psi_1 < \psi < \psi_2 \\
&\alpha(\psi) = 1 && \textit{for}\ \ \psi_2 < \psi < \psi_3 \\
&\alpha(\psi) = \frac{-\log(\psi)}{\log(\psi_4) - \log(\psi_3)} + \frac{\log(\psi_3)}{\log(\psi_4) - \log(\psi_3)} + 1 && \textit{for}\ \ \psi_3 < \psi < \psi_4 \\
&\alpha(\psi) = 0 && \textit{for}\ \ \psi > \psi_4
\end{aligned} \qquad [3\text{-}11]$$

The meaning of the limiting suction values is described below:

In the absence of available plant water or high evaporative demands, most plants will react by closing stomata, reducing transpiration and reducing metabolic actions (Saxton, 1982). The point at which plants begin to experience stress is known as the stress limiting point (ψ_3). This value varies depending on the type of vegetation and ranges between 50 and 100 kPa. Under increased stress, the wilting point will be eventually reached, resulting in tissue death and leaf drop. The wilting point (ψ_4) of most plants is often assumed to be between 1 500 and 2 000 kPa, at which point transpiration will contribute nothing to the evapotranspiration process (Kabat, 1989).

Just as plants are under stress because of a lack of water, so they can also be under stress if the soils are too wet, resulting in an oxygen deficiency. The point at which no transpiration occurs due to too wet soils is termed the anaerobiosis point (ψ_1). The point at which plants experience stress because of oxygen deficiency is the oxygen limiting point (ψ_2), the value of which is approximately 0.1 kPa.

These transpiration effects are presented schematically in **Figure 3.3.4(a)**.

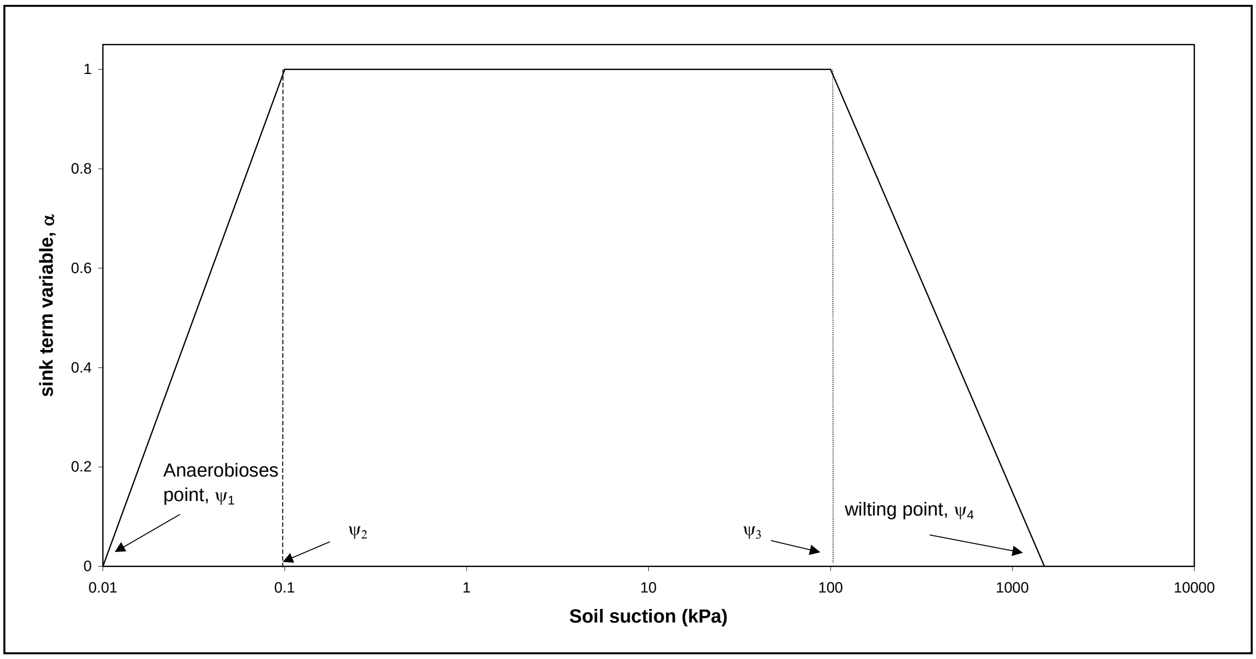


Figure 3.3.4(a): Sink term variable as a function of soil suction (modified after Feddes, 1978)

The sink term, as presented in equation [3-10], applies to the whole soil profile that is occupied by the root structure. The mass water flux due to transpiration is distributed throughout the soil profile. Most of the transpiration water will be extracted from the denser root structure close to the ground surface while only small amounts of water will be extracted from the lower root depths. The uptake of water by roots is presented schematically in **Figure 3.3.4(b)**.

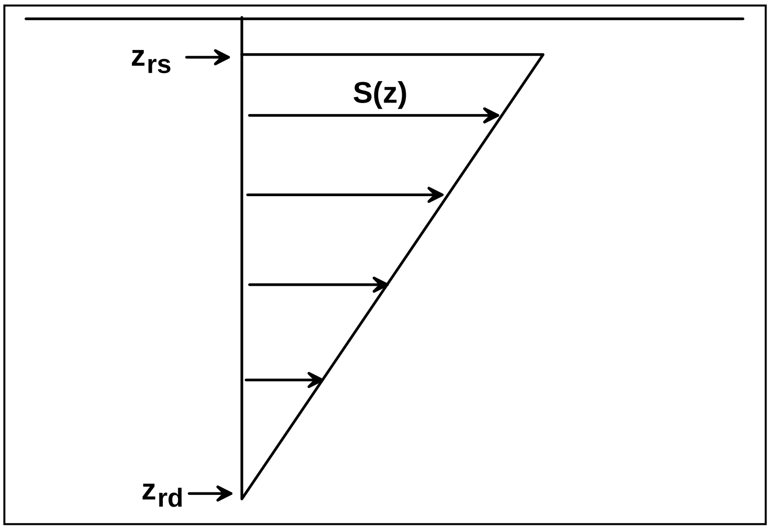


Figure 3.3.4(b): Potential transpiration flux through the active root zone (modified after Prasad, 1988).

The uptake of water through roots is the highest at the upper boundary of the root zone, z_{rs} and is zero at the maximum root depth, z_{rd}. Water uptake, $S(\psi,z)$, at any point between the upper and lower boundary of the root zone, z, can be expressed as:

$$S(\psi, z) = \frac{S(\psi)}{0.5(z_{rd} - z_{rs})}\left(\frac{z}{z_{rd} + z_{rs}} - 1\right) \qquad [3\text{-}12]$$

Total water uptake throughout the active root zone is equal to the soil water sink as expressed in equation [3-10].

The depth to which vegetation extracts water from the soil profile is governed by the depth and extent of the root system. The maximum depth that roots penetrate the soil profile vary with the different vegetation types. Typical root depths of different vegetation types are listed in **Table 3.3.4(a)**.

Table 3.3.4(a): Typical root depths for different vegetation types

Vegetation type	Root depth (cm)	Reference
Grass	30	De Laat, 1985
Potato	40	De Laat, 1985
Sugar beet	40	De Laat, 1985
Maize	70 – 100	Gerwitz & Page,1974
Wheat	600 – 680	Gerwitz & Page,1974
Cotton	1500	Gerwitz & Page,1974

The reliability of the transpiration model as expressed in the above equation has been tested by Tratch et al (1995).

3.4 UNSATURATED FLOW

When water infiltrates soil cover or mine waste, soil water will move downwards or upwards through the soil as governed by the different gravitational and matrix forces. In a liquid, these forces are generally expressed in terms of a difference in pore water pressure and therefore a difference in hydraulic head. Hydraulic gradient represents the loss of hydraulic head between two points and can be expressed as:

$$\frac{dh}{dz} \text{ or } \frac{d\psi}{dz} \qquad [3\text{-}13]$$

where *h* is the hydraulic head, ψ is soil suction (in unsaturated soils) and *z* is soil depth. In this context, the equation represents a one-dimensional vertical situation in which *z* is measured positive downwards. If, in a continuous volume of liquid, there are different energy levels at two points, the flow of liquid will be in the direction of lesser energy (Bell, 1993). The velocity of flow between the two points will be directly proportional to the difference in hydraulic head between them (Das, 1990).

3.4.1 SOIL-WATER CHARACTERISTIC CURVES

When soil pore water tension is slowly increased in a fully saturated non-shrinking soil, the water will begin to retreat below the soil surface. At higher tensions, only the large pores are partially filled with gas, while the smaller pores are filled with water. With increasing pore water tension, the radius of the curved liquid surface becomes smaller in accordance with Laplace's equation and the liquid retreats into the smaller pores.

The unique relationship between water content and soil suction for a specific soil is presented by soil-water characteristic curves. **Figure 3.4.1(a)** shows typical adsorption and desorption soil-water characteristic curves for silty sand. A number of parameters can be defined from these curves, namely the saturated water content, θ_s, residual water content, θ_r, the air-entry or bubbling pressure, ψ_a, and the residual air content, θ_a.

The difference between adsorption (wetting) and desorption (drying) cycles may be attributed to hysteresis. This phenomenon is caused by the 'ink bottle' effect where many pores have narrow connections or entry channels to adjacent pores. This means that, when drying, pores will not drain until suctions are large enough to drain water from the entry channel. Likewise, when wetting, water will not enter a pore until equal suctions are reached. The difference between wetting and drying cycles at saturation can be attributed to air entrapment during the wetting cycle. With time, air bubbles trapped in pores will be released and the water content will be equal to the saturated water content. **Figure 3.4.1(b)** indicates typical drying soil-water retention curves for sand, silt and clay respectively.

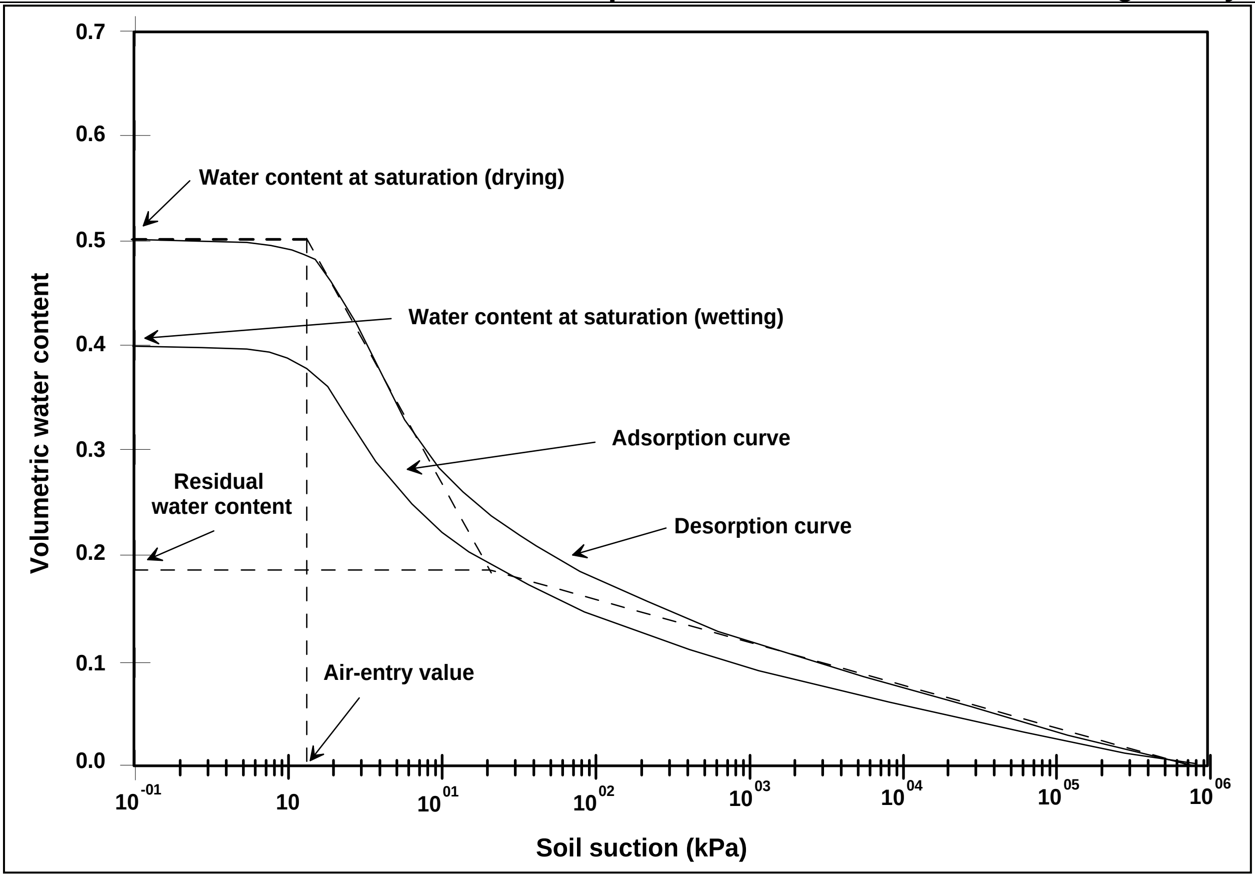


Figure 3.4.1(a): Typical soil-water characteristic curve for a silty sand (after Fredlund & Xing, 1994)

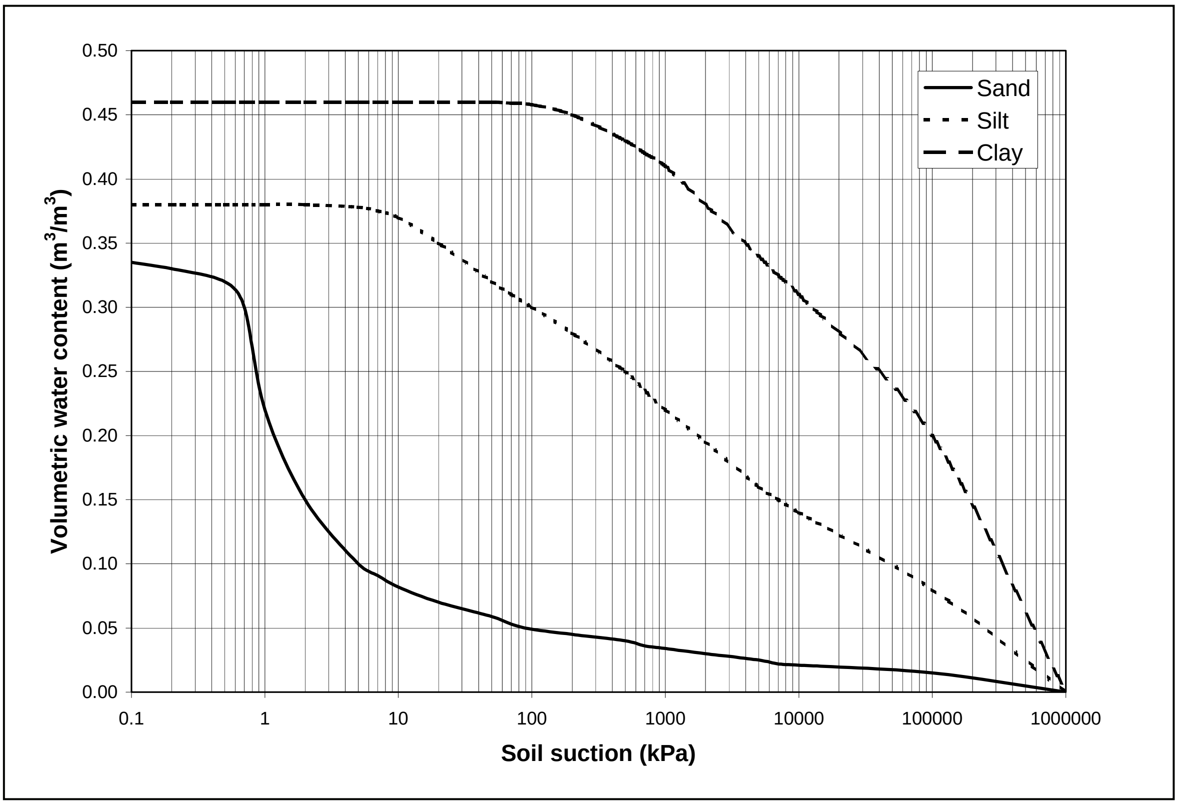


Figure 3.4.1(b): Typical soil-water characteristic curves for a sand silt and clay (Modified after Brady, 1974)

Soil-water characteristic curves are frequently used by the agricultural, soil science and geotechnical communities in unsaturated flow studies (Martin & Koerner, 1984a; Everett *et al*., 1984; Fredlund & Xing, 1994, Leong & Rahardjo, 1997). Many soil laboratories are equipped to determine soil-water retention characteristics.

3.4.2 STEADY-STATE SATURATED FLOW

Flow through soil is a complicated process, inhibited by numerous restrictions, bottlenecks and occasional “dead end” spaces. It is considered too complex to describe in microscopic detail and is rather described in terms of a macroscopic flow vector. Detailed flow pattern is ignored and the conducting body is treated as though it were a uniform medium, with the flow spread over the entire cross-section, solids and pore space alike (Hillel, 1980).

Darcy's empirical expressions describe steady-state macroscopic flow of fluids through a porous medium. While observing the flow of water through sand filters, Darcy (1856) related macroscopic velocity (also known as Darcian velocity), *v*, to hydraulic gradient (Hazen, 1930).

$$v = -K_s \frac{dh}{dz} \qquad [3\text{-}14]$$

where K_s is the saturated hydraulic conductivity. The flow of liquid is therefore directly proportional to the driving force acting on the liquid (i.e. the hydraulic gradient) and also to the ability of the conducting medium to transmit the liquid (i.e. the hydraulic conductivity) (Hillel, 1980). The negative symbol is used by convention and indicates that flow occurs in the direction of decreasing hydraulic head. The steady-state rate of flow, *Q*, through an area can be expressed as:

$$Q = -K_s \frac{dh}{dz} A \qquad [3\text{-}15]$$

Darcian expressions have been validated in both sandy soils and clayey soils by laboratory and *in situ* experiments (Tavenas, Jean, LeBlond & Leroueil, 1983b; Daniel, 1989), indicating that, although not all the assumed criteria are met, a reasonably accurate value of hydraulic conductivity can be obtained.

3.4.3 UNSATURATED FLOW

Flow in unsaturated media is more complex than in saturated media. Complex relationships exist between hydraulic conductivity, moisture content and soil suction and these are further complicated by hysteresis. The basic Darcian principles also apply to unsaturated conditions, that is, flow takes place in the direction of decreasing potential, the rate of flow is proportional to the hydraulic gradient and is affected by the geometric properties of the pore channels. However, soil moisture in unsaturated soil is subject to pressures lower than atmospheric pressure and the flow is governed by both matrix and gravitational forces.

An important difference between the flow of liquid in saturated and in unsaturated conditions is reflected by hydraulic conductivity values. Under saturated conditions, almost all the pores are filled with liquid, except for approximately 5 per cent of the pore volume occupied by entrapped air (Hillel, 1980), and are therefore conductive. As the soil desaturates, some pores are filled with air and the soil thus becomes less conductive.

Hydraulic conductivity in unsaturated porous media is a non-linear function of volumetric water content, $K(\theta)$. Since the volumetric water content is a function of soil suction, $\theta(\psi)$, (as shown in soil-water characteristic curves), the unsaturated hydraulic conductivity is also a function of hydraulic head.

3.4.4 TRANSIENT FLOW OF WATER THROUGH UNSATURATED SOILS

Rainfall events are erratic not only in frequency but also in duration and intensity. These factors have a significant effect on the infiltration and redistribution of water flowing through unsaturated soils. Evaporation and transpiration, however, are less erratic, especially in areas where the climate is characterised by relatively small climatic variations. While rainfall events are time-specific, evaporation and transpiration take place continuously.

SOIL-WATER MOVEMENT DURING INFILTRATION

When precipitation or irrigation events take place, water infiltrates the soil. Soil layers close to ground surface will become saturated and downward movement of a zone with higher volumetric water content will occur. This downward movement is caused by both gravitational forces and a suction gradient between the top saturated soil layers and the lower drier soil layers. Bodman & Colman (1943) identified a number of zones that can be distinguished during infiltration.

The saturated zone at ground surface is approximately one centimetre thick. Immediately below this is the transition zone of a few centimetres thickness and characterised by a fairly sharp decrease of volumetric water content with depth. The transmission zone is situated below the transition zone and is characterised by little variation in moisture content with depth. As the name implies, the transmission zone transmits water from the transition zone to the underlying wetting zone. The wetting zone is characterised by a sharp decrease in volumetric water content with depth. The wetting front marks the limit between the wetted soil profile and the underlying dry soil (Ward, 1975). The sharp decrease in volumetric water content implies that a high suction gradient exists in the wetting zone.

With continuing infiltration, the length of the transmission zone increases and small changes in water content take place in the saturated, transition and transmission zones. However, within the wetting zone, the high suction gradient causes an initial rapid movement of water. With time, implying deeper soil profiles, the suction gradient decreases and the sharp boundary between the wetted and dry soils of the wetting zone becomes less well defined.

SOIL-WATER MOVEMENT DURING REDISTRIBUTION

After the infiltration process has ended, infiltrated water continues to move downwards through the soil profile. The downward flow is termed the redistribution or drainage stage. Water, and therefore also the wetting front, continues to move downwards through the soil profile under gravitational and suction forces. However, as water moves downwards, water in the upper zones begins to drain and the transmission zone subsequently becomes a drainage zone (Ward, 1975). Hydraulic conductivity decreases with lower volumetric water content and subsequently, the water,and therefore also the wetting front, moves downwards at a lower rate. The hydraulic gradient in this zone is slightly higher than one (1) while, at the wetting front, it is much higher (Miyazaki, 1993). A large quantity of downward flow thus takes place around the wetting front, while less downward flow occurs in the wetted front. At volumetric water content values close to field capacity, very little downward movement of water takes place.

SOIL WATER MOVEMENT DURING EVAPOTRANSPIRATION

After infiltration has ended, evaporation starts and results in the removal of water from the surface layers. Evaporation and redistribution processes occur simultaneously and while redistribution will result in a lower rate of downward movement of water, evaporation causes an upward movement due to the suction gradient between the drier surface layers and the wetter deeper soil layers. Evaporation is affected by temperature, relative humidity and wind velocity, as well as by hydrogeological properties such as unsaturated hydraulic conductivity and hydraulic gradient. Three distinct patterns of rate of evaporation can be identified, depending on the evaporation potential of the soil.

It is difficult to estimate rates of evaporation and transpiration in unsaturated soils due to the many factors affecting evaporation rate and the difficulties in measuring these factors. Water movement during redistribution and evapotranspiration is represented graphically in **Figure 3.4.4(a)**.

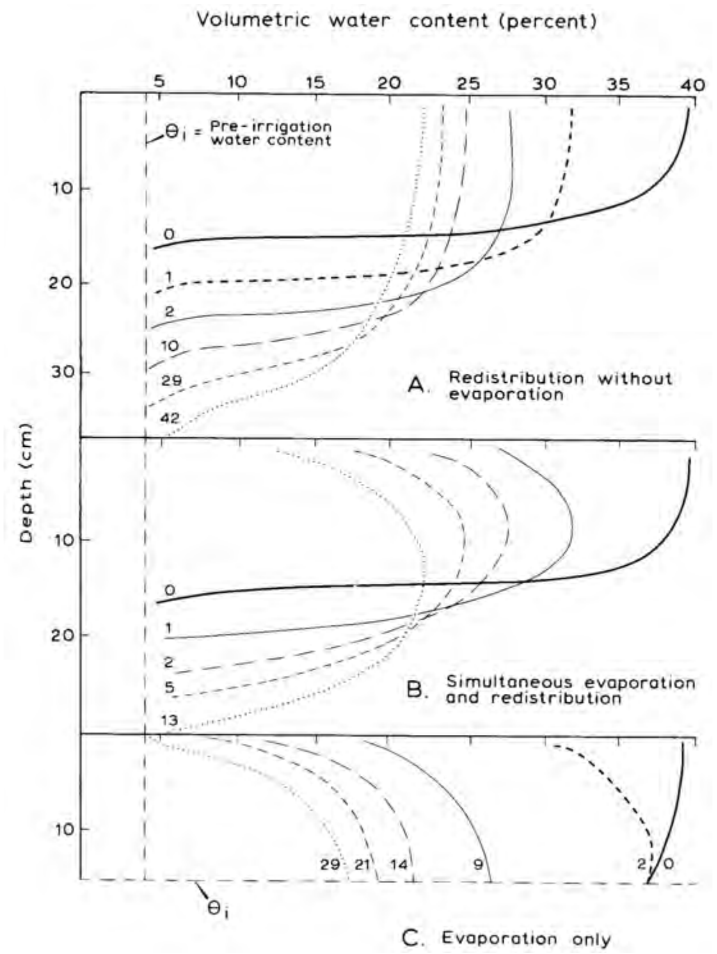


Figure 3.4.4(a): Soil-water content profiles during redistribution and evapotranspiration (numbers indicate days after wetting) (after Ward, 1975)

UPWARD MOVEMENT OF SOIL-WATER

The effects of evaporation and transpiration cause a suction gradient to develop between the lower wetter zones and the upper dried zones. The suction forces cause upward movement of soil-water into the root zone from where it is released to the atmosphere by evaporation and transpiration processes. The rate at which upward movement of soil-water occurs is controlled by various factors, the most important being the permeability of the soil, the rate of drying of the surface layers, the density of the plant root system and the soil depth to the groundwater level. Penman (1948) showed that, in the case of slowly drying soil surfaces, the rate of upward movement of soil-water will keep pace with the rate at which soil-water is removed from soil surfaces by evaporation processes. However, in the case where drying occurs rapidly, upward movement of soil-water will be constrained by the reduced hydraulic conductivity at the dry (hence less permeable) surface layers.

In summary, in humid areas where rainfall exceeds evaporation, downward movement of soil-water will dominate. This results in the leaching of soluble minerals from the topsoil layers and the accumulation of these minerals in lower soil profiles. These processes can eventually result in the development of iron and aluminium-rich horizons and even the development of hardpan ferricrete.

In dry areas, where evaporation exceeds rainfall, upward movement of water will dominate. This can cause upward transport of soluble minerals and the eventual development of typically lime-rich soil horizons. These processes can lead to the accumulation of salts on the surface layers.

3.5 DEVELOPMENTS OF UNSATURATED FLOW THEORY

Since flow in the unsaturated soils is dynamic and transient in nature, numerical modelling by means of computer models offers the best tool to understand, simulate and ultimately predict flow of water and solutes through the soils. Since flow in unsaturated soils is predominantly downward or upward, it can be presented by a one-dimensional model.

3.5.1 UNSATURATED FLOW MODELLING

Unsaturated flow theory, as used by the SWACROP unsaturated flow model, has been described in the first WRC report. Since the introduction of SWACROP, further developments have been made in unsaturated flow theory, applicable to soil cover design, and these have been incorporated in recent unsaturated flow models, in particular SoilCover, Unsat-H and HELP. The most notable development is the description of water vapour flow through unsaturated soils (Wilson, 1990) which has subsequently been incorporated into the SoilCover model. The flow of water liquid and water vapour through unsaturated soils can be described on the basis of Fick's law and Darcy's law (Wilson, 1990):

$$\frac{\delta h}{\delta t} = C^{liquid} \frac{\delta}{\delta z}\left(K(\psi) \frac{\delta h}{\delta z} \right) + C^{vapour} \frac{\delta}{\delta z}\left(D_v \frac{\delta P_v}{\delta z} \right) \qquad [3\text{-}16]$$

where:

h = Total head (m)

t = Time (s)

C^{liquid} = Coefficient of consolidation with respect to liquid water phase

$$= \frac{1}{\rho_w g}$$

ρ_w = Mass density of water (kg·m^{-3})

g = Acceleration due to gravity (m·s^{-2})

z = Position (m)

$K(h)$ = Hydraulic conductivity (m·s-1) as a function of total head in the soil, h (m)

C^{vapour} = Coefficient of consolidation with respect to the water vapour phase

$$= \frac{P + P_v}{P\, \rho_w{}^2 g\, m}$$

P = Total gas pressure in the air phase (kPa)

P_v = Partial pressure due to water vapour (kPa)

$$= P_{sv} \cdot h_r$$

P_{sv} = Saturation vapour pressure (kPa) of the soil at its temperature, T (°K)

h_r =Relative humidity of the soil surface as a function of total suction and temperature

$$= \exp\left(\frac{\psi W_v}{RT}\right)$$

W_v = Molecular weight of water (0.18 kg·mole^{-1})

R = Universal gas constant (8.314 J°K·mole^{-1})

m = Slope of the soil-water characteristic curve (kPa^{-1})

D_v = Diffusion coefficient of water vapour through soil (kg·m·kg^{-1}·s^{-1})

$$= \alpha\beta\left(D_{vap}\frac{Wv}{RT}\right)$$

α = Totuosity factor of soil

$=\beta^{0.667}$

β = Cross sectional area available for vapour flow

$= (1 - S)n$ where

S = degree of saturation

n = porosity

D_{vap} = Molecular diffusivity of water vapour in air (m2·s^{-1})

$$= 2.229 \times 10^{-3} \cdot \left[1.75 \cdot \left(1 + \frac{T}{273.15}\right)\right]$$

This equation can only be solved if the temperature is known for a given time within the soil at a given position. The temperature can be calculated on the basis of conductive and latent heat transfer as follows (Wilson, 1990):

$$C_h \frac{\delta T}{\delta t} = \frac{\delta}{\delta z}\left(\lambda \frac{\delta T}{\delta z} \right) \cdot L_v \left(\frac{P + P_v}{P} \right) \frac{\delta}{\delta z}\left(D_v \frac{\delta P_v}{\delta z} \right) \qquad [3\text{-}17]$$

where:

C_h = Volumetric specific heat of the soil as a function of water content (J°C·m^{-3})

= $C_v \rho_s$

C_v = Specific heat of the soil (J°C·kg^{-1})

ρ_s = Mass density of the soil (kg·m^{-3})

λ = Thermal conductivity of the soil (W°C·m^{-1})

L_v = Latent heat of vaporisation of water (J·kg^{-1})

Wilson *et al* (1994) suggested that equations [3-16], [3-17] and [3-6] be solved simultaneously in order to calculate liquid, heat and vapour flow respectively. They suggested that the equations could be solved by means of Gelarkin-type finite element solutions.

Both the heat and mass transfer equations have been validated by comparing the results to commercially available mass transfer and heat transfer finite element packages, namely SEEP/W and TEMP/W (developed by GeoSlope Ltd.) (SoilCover Manual, 1997).

CHAPTER 4

EXPERIMENTAL SET-UP

4.1 INTRODUCTION

The experimental set-up has been summarised in the WRC report entitled, "*The performance of natural soil covers in rehabilitating opencast mines and waste dumps in South Africa*" (Wates *et al*, 2001). However, in order to provide continuity, the experimental set-up has been repeated in this section.

The experiment was constructed in 1993, close to the old Kilbarchan Colliery, approximately 10 kilometres south-east of the town Newcastle, in KwaZulu-Natal. The site is located adjacent to the Ngagane railway station. The Kilbarchan Colliery forms part of the Kliprivier coalfields, which extends from Newcastle to Ladysmith in KwaZulu-Natal. At the time of construction, a number of mines in this area faced closure and the site was selected to be representative of the climate and soils and was targeted for rehabilitation purposes. Construction was conducted by the Department of Water Affairs and Forestry based on design plans provided by Wates Meiring & Barnard.

The experimental set-up was designed to obtain continuous climate, outflow and water quality data for a long-term period. The experimental cells were constructed to simulate actual waste dumps, rather than 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 so that all the necessary instrumentation could be installed. The design of the experiment had to incorporate the following factors:

- The experiment should be of large enough scale to be representative, so that the results could be readily extrapolated to practical situations.
- The boundary conditions of the experimental cells had to be well defined.
- The experiment had to be sufficiently instrumented to ensure correct data interpretation.
- The experiment had to include different soil cover scenarios and the effect of vegetation.
- The soil properties of the respective covers had to be well defined.

4.2 PHYSICAL CELL CONSTRUCTION

The cells were designed to include the following features:

- All the leachate generated through the cover material must be allowed to drain freely.
- The leachate would be collected in tipping buckets to facilitate measurement of leachate volumes.
- The cells would be isolated from each other so that they could act as individual entities.
- The cells must have varying slopes to test the effect of run-off. Run-off would however not be measured directly.
- The cells must be capable of sustaining vegetation.
- The experiment must be self-sustainable to ensure long term monitoring.

The layout of the experimental site is shown in **Figure 4.2(a)**. Ten experimental cells were constructed with each cell having a surface area of $100m^2$ ($10m \times 10m$). The cells were separated from each other by means of 1 m thick compacted clay walls which were compacted to 93% of Mod AASHTO at optimum moisture content. Each of the cells had a depth of 3 m. The cells were filled with fine coal discard on which the respective soil covers were placed.

The fine coal discard used in the experiment was 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, for the purpose of the experiment, only the finer fraction of coal discard was used as large discard could have significant boundary effects.

The cells were constructed to drain freely as shown in **Figures 4.2(b)** and **4.2(c)**. The base of the cells was constructed from compacted clay shaped to ensure drainage of each cell 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. A 150mm thick leachate collection layer of river sand was placed on top of the liner. This sand layer would collect the leachate which would drain into a perforated geopipe and eventually to the leachate collection system.

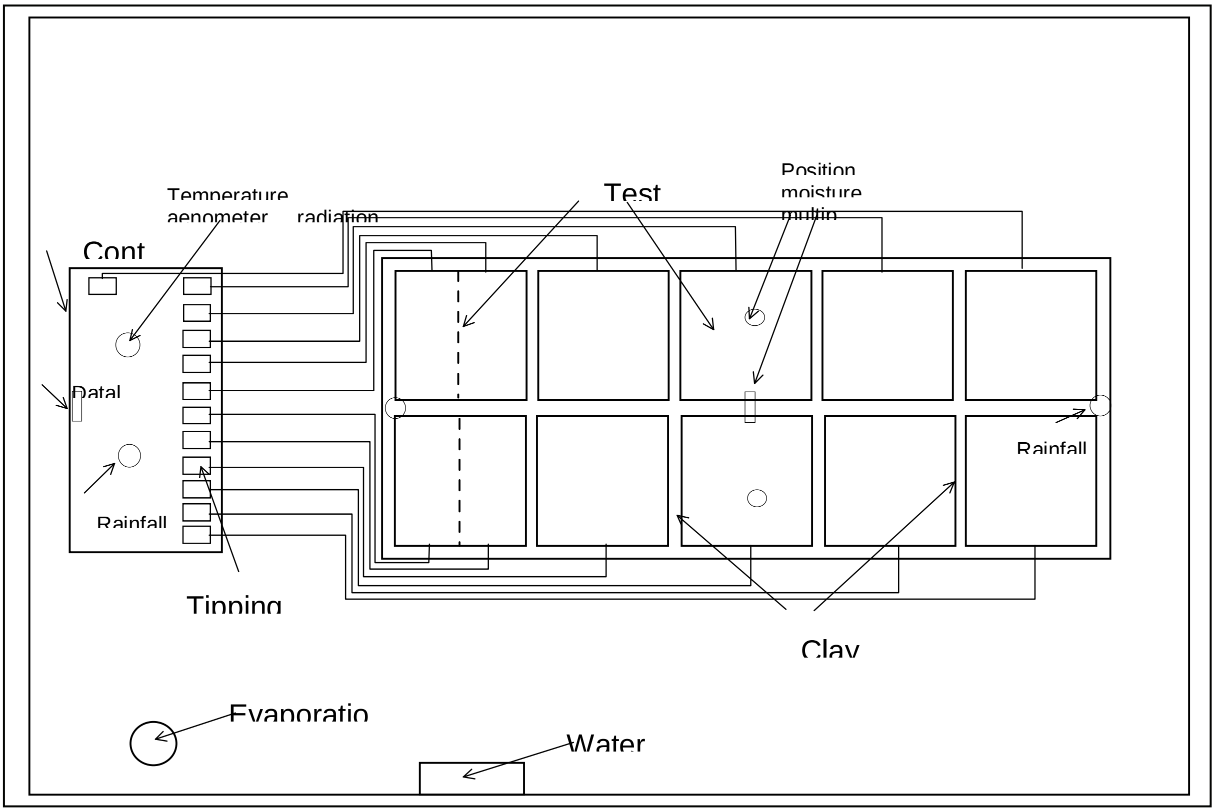


Figure 4.2(a): Layout of the experimental site

Eight of the cells (1 to 8), represented the top section of a rehabilitated discard dump, with a slope of 1% (1:100) which is the smallest slope that would ever be used in discard dump rehabilitation. Cell 9 was constructed with a side slope of 10% (1:10), whilst cell 10 had a slope of 20% (1:5). The compacted layers were compacted at 90% MOD AASHTO.

The configuration of the respective cells are shown in **Figures 4.2(b)** and **4.2(c)** and summarised in **Table 4.2(a)**. In all cases, the cells were 3 m thick and comprised the soil cover overlying coal fines. The material properties of the cover material and coal fines are discussed in **Section 4.5**.

Photographs of the construction of the cells, and the general layout of the experiment are shown in **Appendix A**.

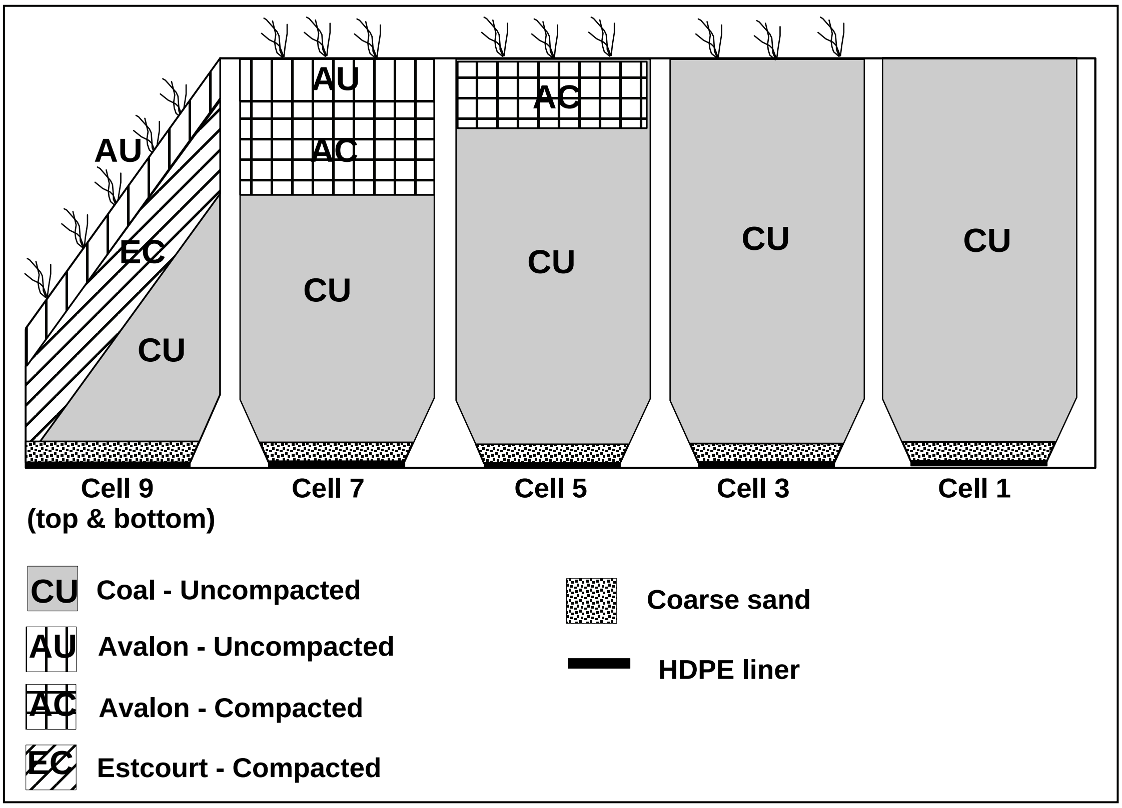


Figure 4.2(b): Cross-sections through cells 1, 3, 5, 7 and 9.

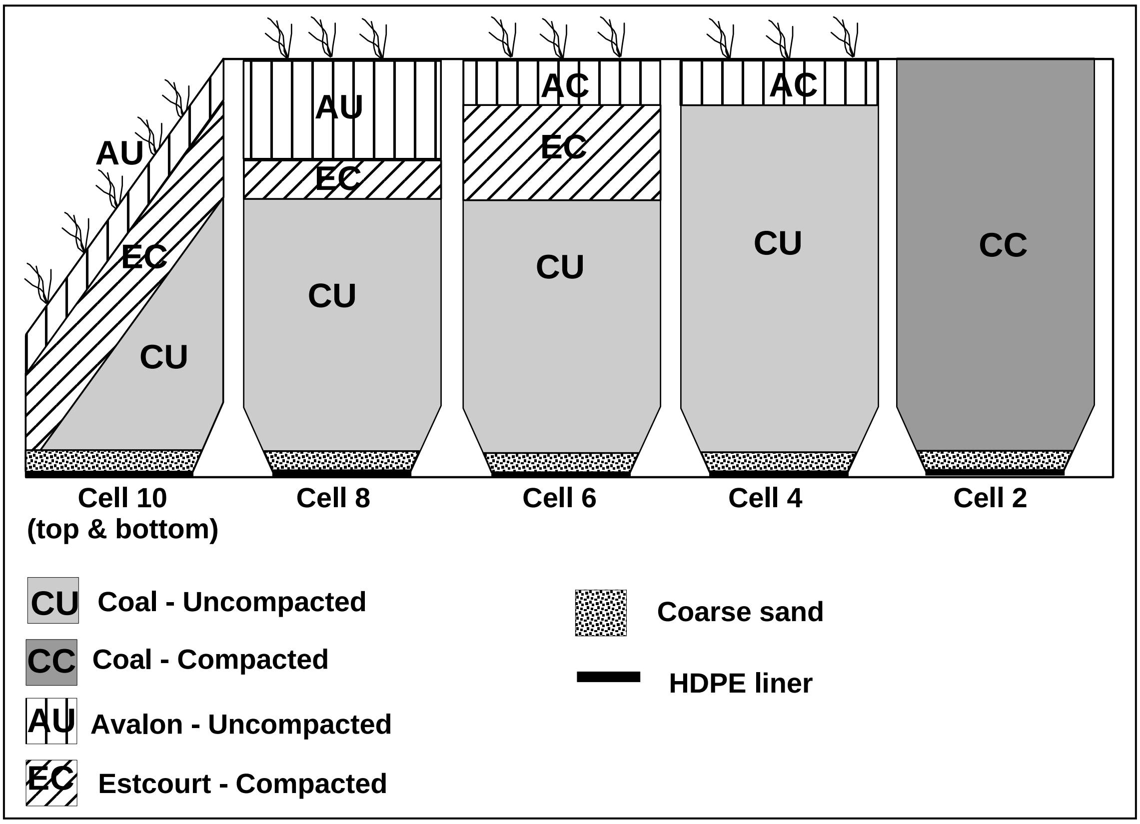


Figure 4.2(c): Cross-sections through cells 2, 4, 6, 8 and 10.

Table 4.2(a): Cell configurations.

Cell No.	Layers (top to bottom)	Slope
1	No cover, unvegetated, fine coal, uncompacted	2% (1:50)
2	No cover, unvegetated, fine coal, compacted	2% (1:50)
3	No cover, vegetated, top coal layer treated with lime, fine coal, 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)

4.2.1 VEGETATION OF THE CELLS

The objective of establishing vegetation is firstly to act as erosion protection and secondly to increase evapotranspiration, thereby reducing infiltration. As erosion protection, the ideal plant type would be a perennial stoloniferous type such as Kikuyu (*Pennisetum clandestinum*), since it provides a good basal cover which would prevent soil erosion during winter seasons and after burning. Stoloniferous grasses, however, are not conducive to high evapotranspiration rates as they have a relatively low biomass. Tufted grasses, such as Blue buffalo grass (*Cenchus cilioris*) do have a high biomass and are conducive to high evapotranspiration rates. The plants have typically large broad leaves which constitutes their large biomass.

The seed cocktail used on experimental cells 4 - 10 comprised five tufted grass types, two stoloniferous types and one combination tufted/stolon type. Cell 3 was eventually planted with only one tufted grass type with some stoloniferous properties.

The cells were first seeded early in November 1993. The seeds were broadcast on the surface by hand and lightly raked in. The seed cocktail used is presented in **Table 4.2.1(a)**.

Table 4.2.1(a): Seed cocktail used at the experimental site.

Common name	Scientific name	Application rate (kg/ha)	Type
Oulandsgras	*Eragrostis curvula*	5	Tufted
Smuts finger	*Digitaria eriantha*	5	Tufted
Rhodes grass	*Chloris gayana*	5	Tufted/stolon
Teff	*Eragrostis teff*	5	Tufted
Kweek	*Cynodon dactylon*	5	Stolon
Paspalum	*Paspalum notatum*	5	Tufted
Kikuyu	*Pennisetum clandestinum*	5	Stolon
Blue buffalo grass	*Cenchus ciliarus*	5	Tufted
Total seed mix		**40**	

The vegetation from this seeding never established well and seeding was therefore repeated in October 1994. On cells 4 to 9, the vegetation established well and attained a cover of 90% with an average grass height of 50cm. However, the vegetation on cell 10 was unevenly distributed, caused by erosion of seed to the bottom of the slope, with highest (95%) and lowest (5%) vegetation cover at the top and bottom of the slope respectively, Cell 3, which was constructed without a soil cover, should have been treated with 20kg of lime before seeding but this was not done during the first seeding period and the grass was never established.

In November 1995, the Chamber of Mines Vegetation Unit re-treated the cells. All vegetated cells were fertilised with 500kg/ha 2:3:2 fertiliser and bare areas 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 (30 tonne/ha of dolomitic lime) and planted with stargrass (*Cynodon ethiopicus*). The plants were placed in shallow holes prepared on a grid of approximately 0.3m by 0.3m and watered in. The 1995/1996 rainy season was particularly wet and the grass covers on the cells became well established.

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

Throughout the experiment, the tufted grasses seemed to perform best. At the peak of the rainfall season, top covers on all the cells were in excess of 98%, except for cell 3. Cover was reduced to between 60 and 70% during the winter season. The main reason for this large seasonal difference was that the stoloniferous grasses never established well. The maximum cover achieved on cell 3 was some 70%, decreasing to 50% during the dry season.

Photographs of the vegetation cover for the wet and dry seasons are shown in **Appendix A.**

4.3 INSTRUMENTATION

The experimental site was extensively instrumented in order to record the parameters governing unsaturated flow and leachate quality. The following systems were installed at the experimental site:

- Leachate collection system comprising tipping buckets from which the volume leachate could be directly measured. The collection systems also facilitated sampling for water quality analysis.
- Fully automated weather system to measure rainfall and to estimate potential evapotranspiration. These parameters were necessary to understand the climatic effects on outflow better and to define the top boundary condition of the unsaturated flow model. The weather station comprised a tipping rainfall bucket, temperature probe, humidity probe, net radiation probe and a wind sentry set. In addition, two rainfall meters and an evaporation pan (A pan) were installed.
- Each cell was provided with two steel canisters, installed at the base of the respective soil covers, from which oxygen and carbon dioxide concentrations could be measured by means of a gas analyser. The oxygen and carbon dioxide concentrations provided an understanding on the effectiveness of soil covers to impede oxygen ingress.
- Each cell was provided with two aluminium tubes from which density and volumetric water content readings could be taken using a nuclear probe. These readings assisted in the understanding of water content changes and density variations within the soil cover profile.
- Two of the cells, cell 5 and cell 6, were provided with five water content reflectometers installed at different depths in the soil cover profile. Soil moisture probes were used to obtain continuous volumetric water content readings. These continuous records assisted in the understanding of unsaturated flow within the soil covers and were also used to calibrate the unsaturated flow model.

- Two of the cells were provided with soil temperature probes. Variations in soil temperature are good indicators of sulphide oxidation processes as these processes are highly exothermic.

The instruments installed at the experimental site are summarised in **Table 4.3(a)**.

Table 4.3(a): Summary of instruments installed at the experimental site

Instrument	Installation date	Function
Outflow tipping buckets	1993	Measurement of outflow
Rainfall meter	September 1993	Measurement of rainfall
Evaporation pan	September 1993	Measurement of surface water evaporation
Datalogger & multiplexer	September 1993	Electronic logging of meteorological, soil temperature and soil moisture data
Rainfall tipping bucket	September 1993	Electronic measurement of rainfall
Temperature and humidity probe	September 1993	Electronic measurement of temperature and humidity
Radiation probe	September 1993	Electronic measurement of net radiation
Wind sentry set	May 1999	Electronic measurement of wind velocity and direction
Neutron probe and access holes	September 1993	Measurement of volumetric water content
Gas analyser and canisters	September 1993	Measurement of oxygen and carbon dioxide concentrations
Soil temperature probes	January 1995	Electronic measurement of soil temperature
Soil moisture probes	July 1999	Electronic measurement of volumetric water content

4.3.1 TIPPING BUCKETS

Tipping buckets were installed in order to measure continuously outflow from the respective tests cells using mechanical counters. Each 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 weekly. The difference between consecutive weekly readings multiplied by two times the bucket volume gave the actual volume of water that flowed through the cell for that specific week. Photographs of the tipping buckets are shown in **Appendix A**.

The use of flowmeters as backup to the tipping buckets was discontinued in 1999 due to the unreliability of results. The high suspended solids content of the leachate led to rapid clogging of the flowmeters and high acidity and salinity caused extensive corrosion.

4.3.2 WEATHER STATION

Climate is a critical aspect in understanding the behaviour of soil water flowing through soil covers. Climate is also critical in the set-up of the unsaturated flow model as it partially dictates how water enters and leaves the soil profile. To ensure that sufficient continuous data was measured, a self-logging weather station was installed. Rainfall, relative humidity, temperature, wind velocity, wind direction and solar radiation were logged hourly. This data was then transformed electronically to facilitate its analysis.

These instruments were installed on top of the container in which the tipping buckets were located, at a height similar to the top of the cells. The data was logged continuously and hourly maximum, minimum, average and, for 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.

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 monitored weekly. An A-pan evaporation pan was installed on site. Evaporation was measured weekly after which the pan was refilled to the required level. Because of high rainfall during particularly wet weeks, the A-pan often overflowed and evaporation could therefore not be measured.

Photographs of the weather station are shown in **Appendix A**.

DATA LOGGER & MULTIPLEXER

The MC Systems 120-02EX electronic data logger was replaced at the beginning of 1999 when it was discovered that it had been damaged by lightning. It was replaced by the Campbell Scientific CR10X datalogger which had 3 pulse channels and was able to measure, *inter alia,* rainfall, wind velocity, tipping bucket events, six differential analogue channels or 12 single-ended analogue channels used for measuring temperature, relative humidity, net radiation and wind direction. In addition, the datalogger was provided with eight digital ports that could be used to prepare the multiplexer for readings. The CR10X datalogger had a microprocessor and a port channel that could be connected to the COM port of a laptop computer, enabling the uploading of programmed instructions to the datalogger and the downloading of measured data from the datalogger. The CR10X datalogger had a final non-volatile storage, which was able to store 62 000 data points. Power was provided by a set of batteries which were replaced and recharged weekly. The use of a solar panel was not considered for security reasons.

A Campbell Scientific AM416 16-Channel 4-Wire Input multiplexer was purchased to measure the ten water content reflectometers as the datalogger did not have adequate input channels. The multiplexer could measure up to 64 additional measuring devices. It could conduct sequential measurements of analogue measuring devices which were then recorded by the datalogger on a single input channel but stored in separate storage locations. The multiplexer was installed separately in a stainless steel meter box in proximity to the soil moisture sensors, thus requiring short signal wires from the soil water meters to the multiplexer and only two signal wires to the datalogger.

METEOROLOGICAL EQUIPMENT

Temperature and relative humidity were recorded using an MCS 174 relative humidity and temperature probe. Measurements were taken every minute and average readings for the hour were recorded and stored by the datalogger.

Solar radiation was measured using an MCS 155 Pyrometer. Measurements were taken every minute and cumulative readings for the hour were recorded and stored by the datalogger. Solar radiation was transformed to net radiation using the Reid (1981) equation:

$$R_n = 0.76R_s - 2.71 \qquad [4\text{-}1]$$

where R_n is the net radiation ($MJ \cdot m^{-2} \cdot day^{-1}$) and R_s is the solar radiation ($mm \cdot day^{-1}$).

Rainfall was measured using an MCS 160 0.2mm tipping bucket rain gauge. Measurements were taken every time a tipping event occurred and cumulative readings for the hour were recorded and stored by the datalogger.

Wind velocity and direction were measured using a Young sentry set, purchased from Campbell Scientific. Measurements were taken every minute and average measurements were recorded and stored by the datalogger.

4.3.3 NEUTRON PROBE

During the previous WRC research project, density and volumetric water content profiles through each of the cells were recorded weekly using a CPN 501DR Depthprobe. Two, 3m deep, aluminium access tubes were installed in each test cell. The nuclear probe was lowered into these tubes in order to measure dry density, wet density and volumetric water content in profile for each of the cells. Readings were taken weekly. It was found, however, that weekly records of volumetric water content contributed little to the understanding of water flow through soil covers, as responses to rainfall events occurred in a matter of hours. For this reason, soil moisture probes were permanently installed in two of the cells to obtain a continuous volumetric water content profile. The nuclear probe was thus used only occasionally during the second WRC project but was used to calibrate the soil moisture probes.

4.3.4 GAS ANALYSER

Oxygen and carbon dioxide concentrations within the fine coal discard were measured by means of a gas analyser. The gas analyser used in the first WRC project was replaced by a Dwyer 1203 combustion analyser, purchased from Gossair, after the former broke down and could not be repaired.

Two stainless steel canisters with perforated sides were installed in each of the cells. They were placed at the base of the respective covers and at a depth of 10 cm in the uncovered cells. The gas analyser was connected to the canisters by means of small diameter (5mm) stainless steel tubes, protruding on the top of each cell.

The gas analyser's internal pump sucked gas from the canister and the concentrations of oxygen and carbon dioxide were measured. The tubes were sealed when readings were not taken to prevent oxygen ingress through the tubes.

4.3.5 SOIL MOISTURE PROBES

Ten Water Content Reflectometers (Model CS615) were obtained from Campbell Scientific to measure electronically volumetric water content on a continuous basis. The Water Content Reflectometer is similar to the well-known, but expensive, Time Domain Reflectometry (TDR) technology. TDR technology has been shown to be accurate and reliable in the determination of soil water contents and material/water relationships over the whole range of water contents.

The Water Content Reflectometer consists of two stainless steel rods connected to a circuit board. High-speed electronic components on the circuit board are configured as a bistable multivibrator which, in turn, is connected to the stainless steel rods which act as a wave guide. When the multivibrator switches states, the transition travels the length of the rods and are reflected by the rod ends. The travel time to the end of the rods and back is dependent on the dielectric constant of the materials surrounding the rods. Since water has a much higher dielectric constant compared with other soil constituents, water content can be accurately measured.

The Water Content Reflectometer is influenced by high Electrical Conductivities in the soil water. One should therefore be cautious in interpreting soil water contents of reflectometers installed in mine waste material though this should not be problematic where reflectometers are installed in the soil cover.

Volumetric water contents were sequentially measured hourly by means of the multiplexer. The data was then recorded and stored by the datalogger.

The moisture probes were installed in cells 5 and 6. Cell 5 represented a typical single-cover configuration with a surface vegetation medium overlying fine coal discard. Cell 6 represented a typical double soil cover configuration with an uncompacted surface layer and a deeper infiltration barrier, which also doubled as an oxygen ingress barrier. The installation depths of the probes are summarised in **Table 4.3.5(a)**.

Table 4.3.5(a): Installation depths of the moisture content reflectometers

Probe no.	Depth	Material
Cell 5		
C5P1	0.25	Compacted Avalon
C5P2	0.45	Compacted Avalon
C5P3	0.65	Uncompacted coal
C5P4	1.00	Uncompacted coal
C5P5	1.50	Uncompacted coal
Cell 6		
C6P1	0.25	Uncompacted Avalon
C6P2	0.35	Compacted Estcourt
C6P3	0.50	Compacted Estcourt
C6P4	0.95	Compacted Estcourt
C6P5	1.20	Uncompacted coal

Approximately one month after the reflectometers were installed, a double ring infiltration test was conducted on cell 6. The test was conducted so that both the moisture content reflectometers and the neutron probe access hole were wetted. Water content readings were taken during infiltration until it was found that a substantial portion of the profile was wetted. The soils were then allowed to drain and water content readings taken during drainage. These tests enabled the research team to obtain a continues water content profile during wetting and drying which could be used to calibrate the reflectometers and to back-calculate soil hydraulic parameters.

The data revealed that reflectometer C5P3 was not in working order. Data loss associated with this probe was deemed not significant as probes set deeper in the fine coal discard could be used to provide representative water content values for the fine coal discard material.

4.3.6 SOIL TEMPERATURE PROBES

Three MC151 temperature sensors were installed in cell 6 during the first WRC project. The probes were installed in different soil types at the following depths:

STP1	1.65 m
STP2	0.72m
STP3	0.30m.

Unfortunately, the temperature sensors could not be connected to the Campbell Scientific datalogger and the soil temperature results presented reflect the work undertaken during the first WRC project.

4.4 MONITORING PROGRAMME

Three monitoring periods can be distinguished since the commissioning of the project in 1993:

- February 1994 – September 1997

  Monitoring that formed part of the first WRC project. Meteorological data was captured by datalogger and outflow, water quality and gas readings were measured weekly.

- October 1997 – April 1999

  Monitoring conducted after the conclusion of the first WRC project. The monitoring team continued weekly monitoring but the meteorological equipment was not maintained and resulted in data loss.

- May 1999 – December 2000

  Monitoring that formed part of this WRC project and funded by some members of the coal mining industry. All equipment was repaired and additional equipment installed.

The data collected for the respective monitoring periods is presented in **Table 4.4(a)**:

Table 4.4(a): Data collected during the respective monitoring periods.

Monitoring period	Data collected	Data not collected
February 1994 – September 1997	Outflow, water quality, rainfall (weekly), evaporation, gas readings, water content (weekly), rainfall (hourly), temperature, humidity, net radiation, soil temperature	Wind speed, wind direction, water content (hourly)
October 1997 – April 1999	Outflow, water quality, rainfall (weekly), evaporation	Gas readings, rainfall (hourly), temperature, humidity, net radiation, wind speed, wind direction, water content, soil temperature
May 1999 – December 2001	Outflow, water quality, rainfall (weekly), evaporation, gas readings, water content (weekly), rainfall (hourly), temperature, humidity, net radiation, wind speed, wind direction, water content (hourly)	Soil temperature

Field monitoring was conducted weekly by Messrs. Yoshan Nehro and Carphas Mndaweni of the Department of Water Affairs and Forestry (DWAF), Dundee office. Field monitoring was similar to that conducted from commissioning of the project in 1993. The monitoring team was requested to undertake the following tasks:

- Record weekly accumulated rainfall measured by two rainfall meters.
- Record weekly accumulated evaporation from an A-pan evaporation pan.
- Record weekly accumulated outflow from each of the test cells via the tipping buckets.
- Record both oxygen and carbon-dioxide concentrations for each of the test cells.
- Obtain water samples from each of the cells on a bi-weekly basis for water quality analysis.
- Replace and recharge two electronic storage cells used for powering the datalogger.

- Perform general maintenance, such as filling holes on the test cell surfaces made by burrowing animals.

DWAF also contributed to the maintenance of the site by regularly cutting grass and supplying water to the experimental site as required.

4.4.1 PROBLEMS ENCOUNTERED DURING THE MONITORING PERIOD

Several problems were encountered during the monitoring period that affected the data collected.

- The mechanical counters used for measuring outflow were subject to wear and tear and were also affected by the corrosive environment. At the start of the second WRC project, several mechanical counters were found to be out of order, which affected the continuity of data from the first to the second WRC project. The mechanical counters were replaced on a regular basis during the second WRC project.
- The mechanical counters frequently showed unreliable readings due to wear. These unreliable results were easily identified as they showed huge increases in outflow over the other cells. The unreliable results were filtered from the outflow database.
- It was observed that “double-tipping” frequently occurred, caused by the bucket bouncing off the mechanical counter during tipping. Outflows may thus have been over-estimated but the frequency of “double-tipping” meant that they could not be filtered from the database. Preliminary observations on “double-tippling” suggest that outflow may have been over-estimated by approximately 10%[1]
- Some of the equipment had to be replaced during the second WRC project. These included the datalogger (damaged by lightning), gas analyser (broke down) and the wind sentry-set (theft). The solar panel, also stolen, was not replaced. The temperature and humidity sensors required repair after they were first damaged by lightning and then by vandalism.
- There was a veld fire at the experimental site during August 2000. The PVC pipes, in which the leachate flowed to the tipping buckets, and the signal wire between the datalogger and multiplexer were severely damaged. This resulted in data loss of outflow, water quality and volumetric water content, measured by the soil moisture probes. The equipment was subsequently repaired.

[1] Funds were obtained to install electronic sensors with anti-bounce circuits, which would eliminate “double-tipping” problems. The database will be updated and reported on by January 2002 as part of the Coaltech research report.

- Site visits revealed that several of the test cell surfaces had been damaged by burrowing animals. The burrowing holes were mainly in the uncovered cells 1, 2 and 3 and could have resulted in increased outflow. The animals have since been controlled and the holes refilled and compacted.

In spite of these problems, which were corrected with a minimum of data loss, an excellent database was established for the experimental site. Where data loss did occur, it was either patched from past records or it proved to be of little significance.

4.4.2 DATA ANALYSIS

From the commissioning of the project in 1993, more than 48 000 hourly entries were recorded by the datalogger and more than 330 000 data points were registered. This translates into more than 24 million measurements by the respective sensors of which more than 14 million were made during the last two years.

Meteorological data was downloaded by means of a PC laptop on a bi-monthly basis, coinciding with experimental site visits. During the initial stages of monitoring, data losses were experienced because of the high power requirements on the 12VDC electric storage cells. A second cell was therefore purchased and the datalogger was re-programmed to reduce the workload of the sensors which reduced the power requirements on the electric storage cells.

Data analysis comprised the following actions:

- Downloading monitoring data (measurements made for the period 1999 and 2000) to PC, screening of data to identify obviously erroneous measurements, validating the data, converting data to required units and saving the data to a database. Some measurements also required calibration before saving it to the database.
- Extracting historical data (measurements made for the period 1993 to 1997), converting the historical data to required units and saving the data to a database.
- Filtering of data to erase obvious anomalies and "patching" of data for periods where data loss occurred. This was necessary so that the data could be used as input for the unsaturated flow model.
- Obtaining meteorological data from the South African Weather Bureau for the period 1998 when no meteorological data was collected.

The resulting data set could be used as input for the unsaturated flow model and also for calibration of the unsaturated model. The results of the monitoring programme are discussed in **Chapter 5**.

4.5 PROPERTIES OF THE FINE COAL DISCARD AND COVER SOILS

Two soil types were used in the experimental cells, namely, Avalon and Estcourt soil types. These soils occur naturally in the area and are commonly used for rehabilitation purposes. Avalon soils consist of an orthic A-horizon, yellow-brown apedal B-horizon grading into a soft plinthic B-horizon. Estcourt soils consist of an orthic A-horizon, E-horizon and prismacutanic B-horizon (SCSSA, 1981). The Avalon soil was selected for the drainage layer and the layer that would sustain the vegetation. The Estcourt soil was selected for the barrier layer. However, subsequent geotechnical tests revealed little difference between the Avalon and Estcourt soils and differences were ascribed to their chemical characteristics.

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 used. The physical, hydraulic and chemical properties of the soils were therefore tested by means of laboratory and in-situ techniques. Similar tests undertaken on the coal material used in the experiment.

4.5.1 PHYSICAL PROPERTIES

A number of laboratory experiments were conducted on the different soil covers and coal material to determine their physical soil properties. The laboratory tests included foundation indicator tests, dry density and specific gravity.

Eight particle size distribution tests were conducted on the fine coal discard and the Avalon and Estcourt soils. The particle size distributions of these materials are summarised in **Table 4.5.1(a)** and presented in **Figure 4.5.1(a).** Details of particle size distribution are presented by Lorentz *et al* (1995).

Table 4.5.1(a): Summary of the foundation indicator test results

Description	Fine coal discard	Avalon	Estcourt
Gravel (%)	10	0	0
Sand (%)	80	37	40
Silt (%)	7	31	28
Clay (%)	3	32	32
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
PI of total sample	3.5	16.4	18.6
Textural Chart Classification	Sand	Clay loam	Clay loam
USCS	SW	CL	CL

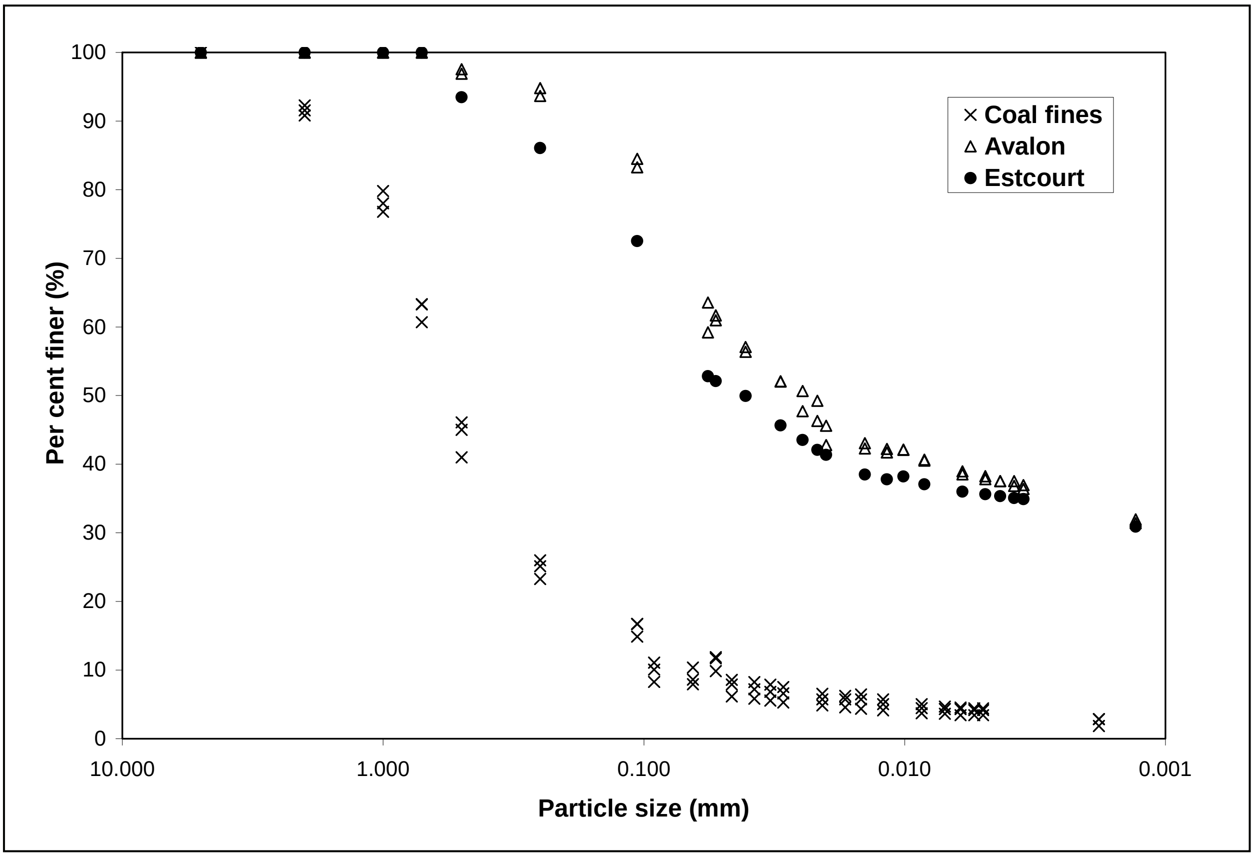


Figure 4.5.1(a): Particle size distribution of fine coal discard, Avalon and Estcourt soils

The fine coal discard is comprised of more than 90% sand and gravel and less than 3% clay. The particle size distributions for the Avalon and Estcourt soils are very similar, implying that these soils are physically the same. Both soils comprise more than 30% clay and equal amounts of silt, suggesting that the soils are a favourable growth medium for vegetation. However, larger clay contents would be required for the soils to be used as infiltration barriers. Both soils have comparatively low liquid limits and plasticity indices, suggesting inactive clay minerals. Both soils are classified as a clay loam according to the soil textural chart.

Eight dry density tests were conducted on the *in situ* soils and covers. The results of the dry density tests are summarised in **Table 4.5.1(b)**. Detailed results are presented by Lorentz *et al* (1995)

Table 4.5.1(b): Summary of the dry density test results

Description	**Fine coal discard**		**Avalon**		**Estcourt**
	Uncompacted	**Compacted**	**Uncompacted**	**Compacted**	**Compacted**
Dry density (kg/m^3)	1 026	1 063	1 601	1 669	1 776
Specific gravity	1.69	1.68	2.52	2.55	2.55
Porosity (%)	29.0	30.0	36.6	34.4	30.1
Void ratio	0.408	0.429	0.577	0.524	0.431

The specific gravity of the fine coal discard (1.69) is much lower than that of the soils (2.5), indicative of its high carbon content. As a result of its low specific gravity, the dry density of the fine coal discard is also much lower than that of the soils. Surprisingly, there is little difference between the dry densities of the compacted and uncompacted Avalon soils, suggesting probable inadequate compaction. Better compaction was achieved with the Estcourt soils, indicative of their higher dry density and low porosity.

4.5.2 HYDRAULIC PROPERTIES

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

- Falling head permeability tests on disturbed remoulded samples compacted to 90% MOD AASHTO.
- Large-diameter double-ring (1 000mm) tests to determine *in-situ* permeability (saturated hydraulic conductivity).
- Small-diameter (300mm) double ring infiltrometer tests to determine *in-situ* permeability.

- Laboratory tests to determine the water retention characteristics and unsaturated hydraulic conductivity of the soils using undisturbed samples in a controlled outflow cell.
- *In situ* tension infiltrometer tests, with a minimum of three tensions, to determine unsaturated hydraulic conductivity as a function of hydraulic head.

SATURATED HYDRAULIC CONDUCTIVITY

The results of the saturated hydraulic conductivity tests are summarised in **Table 4.5.2(a)** and presented in **Figure 4.5.2(a)**.

Table 4.5.2(a): Summary of the permeability test results

Soil Type	***In situ* permeability tests (m/s)**			**Falling head permeability tests (m/s)**	**Median hydraulic conductivity (m/s)**
	Geulph permeameter	**1 000mm double ring Infiltrometer**	**300mm double ring infiltrometer**		
Uncompacted coal	7.30×10^{-5}	1.00×10^{-4}	3.16×10^{-5}	3.20×10^{-5}	5.25×10^{-5}
Compacted coal	5.00×10^{-5}	2.78×10^{-5}	5.64×10^{-5}	4.70×10^{-5}	4.85×10^{-5}
Treated coal	4.00×10^{-5}	1.00×10^{-4}	2.01×10^{-5}	No test	4.00×10^{-5}
Uncompacted Avalon	2.28×10^{-5}	3.33×10^{-5}	3.20×10^{-5}	No test	3.20×10^{-5}
Compacted Avalon	No test	4.15×10^{-6}	3.07×10^{-6}	2.35×10^{-8}	3.07×10^{-6}
Compacted Estcourt	2.00×10^{-7}	3.33×10^{-6}	1.46×10^{-7}	6.15×10^{-8}	1.73×10^{-7}

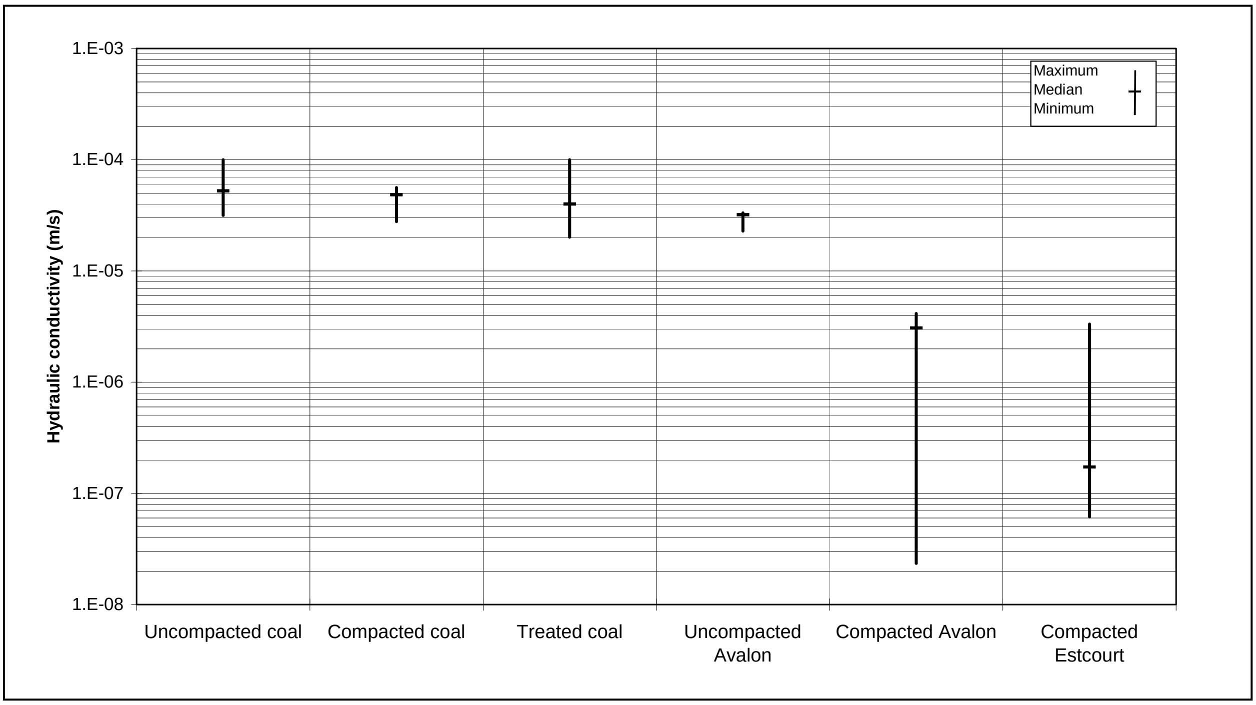


Figure 4.5.2(a): Saturated hydraulic conductivities for the coal, Avalon and Estcourt material.

The following observations are made pertaining to the results of the saturated hydraulic conductivity tests:

- The fine coal discard has a hydraulic conductivity similar to that of sand. This is expected as the discard comprises 90% sand and gravel. There is little difference between the hydraulic conductivities of the compacted, uncompacted and treated coal, suggesting that treatment and compaction have little effect on the hydraulic properties of the coal discard.
- The uncompacted Avalon soils have a hydraulic conductivity similar to that of fine coal discard, which is surprising in view of the comparatively high clay content of the Avalon soils.
- The hydraulic conductivity of compacted Avalon soils is approximately 10 times lower than that of the uncompacted Avalon soils. A large variability in the hydraulic conductivity of compacted Avalon soils is evident in that the lowest hydraulic conductivity value corresponds to the laboratory value, which is approximately 100 times lower that of the *in situ* soils. This could possibly be ascribed to inadequate compaction, as is also evident in the comparatively low dry density of the Avalon soils.
- The hydraulic conductivity of the Estcourt soils is approximately 10 times lower than that of the compacted Avalon soils and approximately 100 times lower than that of the uncompacted Avalon soils. The hydraulic conductivity of the Estcourt soils is comparative to a silt and does not meet the requirements of an infiltration barrier.

- A large variability in the hydraulic conductivity of compacted Estcourt soils is also evident. Hydraulic conductivity as measured by the large-diameter double ring infiltrometer test is approximately 10 times higher that those of other *in situ* tests. This suggests experimental error. However, the higher value may also be ascribed to the larger soil surface area being tested, allowing for preferential flow along cracks and providing values more representative of *in situ* hydraulic conductivity test values.
- Some variability has also been noted between the different *in situ* tests, suggesting caution when interpreting *in situ* test results.

SOIL WATER RETENTION CHARACTERISTICS

The determination of soil water retention characteristics is important in order to understand the unsaturated flow properties of the cover material. Soil water retention characteristics of the fine coal discard, Avalon and Estcourt soils were determined using the controlled outflow cell and was conducted by the University of Natal (Lorentz et al, 1995).

For unsaturated hydraulic conductivity to be determined, the soil water retention data points need to be represented by a mathematical equation. The data points for the fine coal discard and the soils were therefore fitted to the Van Genuchten (1980) and Fredlund & Xing (1994) equations respectively. The mathematical equations used are discussed by Van Schalkwyk and Vermaak (2000).

The results of the soil water retention tests are presented in **Figure 4.5.2(b)**. The points on the graph represent measured data while the lines represent the best-fit curves, applying the Van Genuchten and Fredlund & Xing equations. Detailed results of the soil water characteristic tests are presented by Lorentz *et al* (1995).

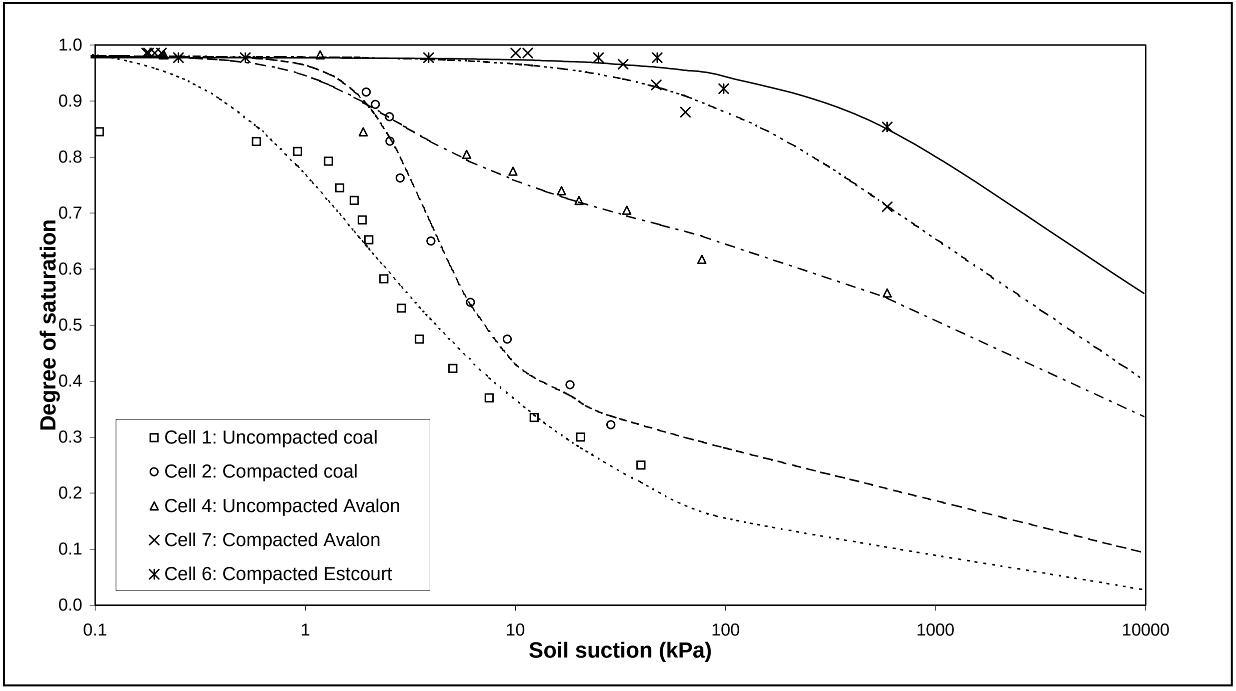


Figure 4.5.2(b): Soil water retention characteristics of fine coal discard, Avalon and Estcourt soils. The points represent measured data and the lines are best-fit curves.

The following observations are made pertaining to the soil water characteristic curves of the fine coal discard, the Avalon and Estcourt soils:

- The water retention characteristics of the coal materials are clearly different to those of the soils. Approximately 60% of the pore water has drained from the coal at a tension of 10 kPa, whereas the soils are still close to saturation, especially the compacted ones.
- The residual water contents for the coal material are approximately 0.09 and 0.12 cm^3/cm^3 for the compacted and uncompacted coal material respectively and occur at a tension of approximately 100 kPa. The residual water contents of the soils are much higher, with values of approximately 0.22, 0.24 and 0.26 cm^3/cm^3 for the uncompacted Avalon, compacted Avalon and compacted Estcourt soils respectively. These residual water contents occur at a tension value of approximately 1 000 kPa.
- The air entry values of the compacted soils are much higher (due to lower pressures) (between 60 and 200 kPa) compared with those of the coal discard (between 0.3 and 2.1 kPa). The air entry value of the uncompacted Avalon is similar to that of the fine coal discard.
- Compaction has a marked effect on air entry values. For the fine coal discard, the air entry value increases from 0.3 kPa to 2.1 kPa with compaction. The effects on the Avalon soils are more noticeable with air entry values increasing from 1 kPa to 60 kPa with compaction.

- The compacted Estcourt soil exhibits the greatest water holding capacity. At 600 kPa tension, the Estcourt soils are still 85% saturated whereas the compacted Avalon soils are 71% saturated and the uncompacted Avalon soils 55% saturated. In contrast, the uncompacted and compacted fine coal discard are only 10% and 20% and saturated.

UNSATURATED HYDRAULIC CONDUCTIVITY

As previously mentioned, unsaturated hydraulic conductivity is not constant but is a function of volumetric water content. Since volumetric water content is a function of soil tension, it follows that unsaturated hydraulic conductivity is also a function of soil tension.

Unsaturated hydraulic conductivity was measured by means of a laboratory-controlled outflow cell. The tests were conducted at the University of Natal and are discussed by Lorentz *et al* (1995). In addition to the controlled outflow cells, unsaturated hydraulic conductivity was also measured *in situ* using a tension infiltrometer. These tests were also conducted by the University of Natal.

Unsaturated hydraulic conductivity can calculated from soil water retention characteristics and saturated hydraulic conductivity (See Van Schalkwyk & Vermaak, 2001, for a review). For the purpose of this study, unsaturated hydraulic conductivity was calculated using the Fredlund *et al* model (1994) and the UNSAT.K software (Crucis Digital, 1998). It is important to know whether or not indirect estimations of unsaturated hydraulic conductivity are reliable, as the direct determination of unsaturated hydraulic conductivity is time-consuming and expensive, and not often conducted in cover design.

The results of the controlled outflow and tension infiltrometer tests and the calculated unsaturated hydraulic conductivity curves are presented in **Figure 4.5.2(c)**.

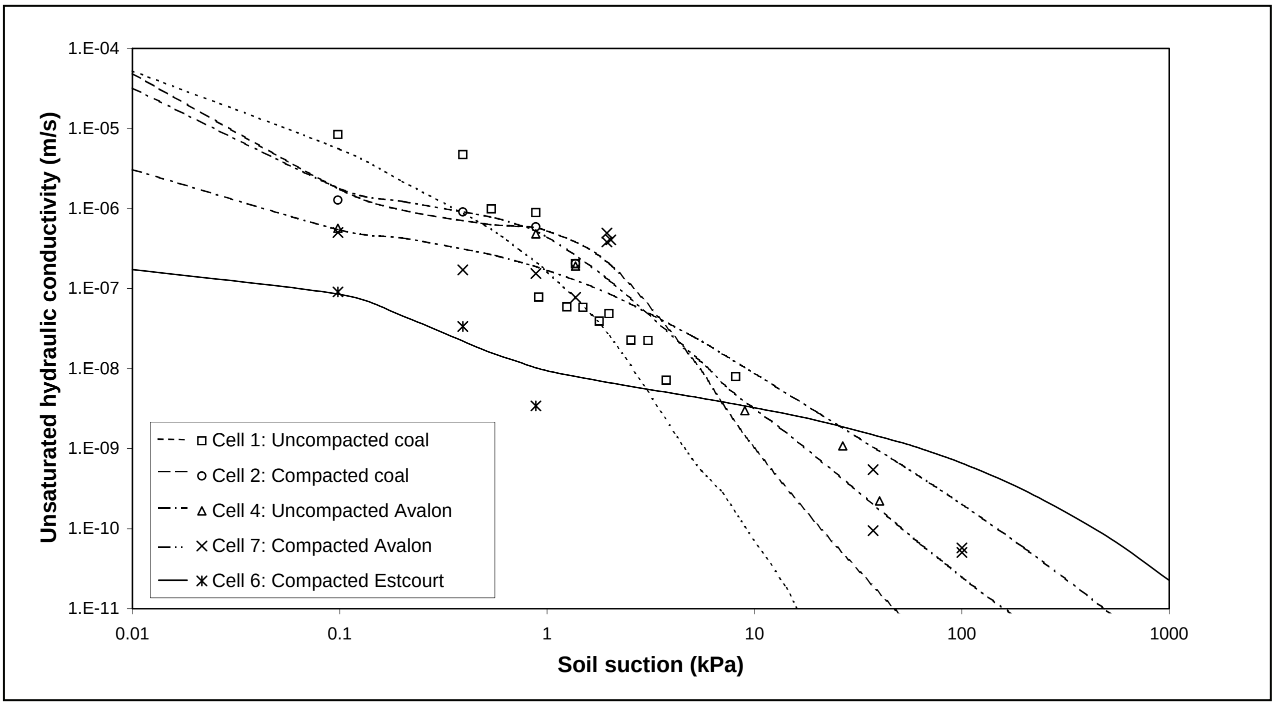


Figure 4.5.2(c): Unsaturated hydraulic conductivity of the fine coal discard, Avalon and Estcourt soils. The points represent measured data and the curves represent calculated hydraulic conductivity.

The following observations are made pertaining to the unsaturated hydraulic conductivities of the fine coal discard, the Avalon and Estcourt soils:

- The unsaturated hydraulic conductivities of the materials at tensions greater than 50kPa are the inverse of the saturated hydraulic conductivities, with compacted Estcourt being the most conductive and the uncompacted coal the least conductive material. This is expected, as soils with comparatively high clay contents are generally more conductive under tension.
- The unsaturated hydraulic conductivity of uncompacted coal discard at 10 kPa is estimated to be 200 000 times lower than its saturated hydraulic conductivity. In contrast, the unsaturated hydraulic conductivity of compacted Estcourt soil is estimated to be 48 times lower than its saturated hydraulic conductivity.
- The unsaturated hydraulic conductivity of uncompacted Avalon soil is similar to the compacted fine coal discard at tensions lower than 10 kPa. At higher tensions, the uncompacted Avalon is similar to the compacted Avalon. This is indicative of the large pores that govern the unsaturated hydraulic characteristics of uncompacted Avalon at low tensions, while the unsaturated hydraulic characteristics are governed by particle size distribution at higher tensions.
- Despite the scatter of measured data, indirect estimations of unsaturated hydraulic conductivity proved to be fairly accurate. However, the unsaturated hydraulic conductivity

curves proved to be accurate only after modifications of the parameters describing the soil water characteristic curve. Caution should be exercised if no unsaturated hydraulic conductivity points have been measured.

- Hydraulic conductivities measured in the controlled outflow cell fit the tension infiltrometer data, confirming the reliability of the *in situ* method. However, it is only applicable at the lower tension ranges.

4.5.3 CHEMICAL PROPERTIES

FINE COAL DISCARD

The fine coal discard was chemically analysed to determine whether it could be regarded as representative of discard material. Two samples taken on site were analysed by Trans-Natal Laboratories for their calorific value, proximate analysis and sulphur content. The results are summarised in **Table 4.5.3(a)**.

Table 4.5.3(a): Calorific value, proximate analyses and sulphur content of the fine coal discard.

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 the two samples of the fine coal discard, undertaken by the Department of Metallurgical Engineering, University of Stellenbosch, showed between 4.15% and 0.81% sulphur. The analyses were performed using a Leco Sulphur Analyser.

The discard is characterised by relatively high ash content and this is higher than typical discard. This is due to only the fine fraction of coal discard, including ash, being selected for this experiment. Its calorific value is low and is typical of coal discard while the sulphur content is also within the range of coal discard.

ACID BASE ACCOUNTING

Acid Base Accounting tests were conducted on the fine coal discard by the Institute for Ground Water Studies at the University of Free State. The results are shown in **Table 4.5.3(b)**. The ABA tests show that the fine coal discard has very little neutralising potential and significant acid potential. These results indicate that the fine coal discard has a significant potential to generate acid if exposed to water, oxygen and catalysing bacteria. Aspects pertaining water quality is discussed in **Chapter 9**.

Table 4.5.3(b): Results of the Acid Base Accounting tests

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)	10989.6	24500.4
Base potential as $CaCO_3$ (mg/g)	540.0	240.4
PH	7.20	1.90

CLAY MINEROLOGY AND CHEMICAL ANALYSES OF THE COVER SOILS

In view of the similar physical properties observed and in order to determine whether there would be any difference between the characteristics of the Avalon and Estcourt soils as a cover material, a detailed clay mineralogical analysis was conducted. These analyses were conducted by the Institute for Soil Climate and Water and the results are presented in **Table 4.5.3(c)**.

The clay fraction mineralogy is quite similar in both soils, although the Estcourt soils appear to contain more smectite (which, through swelling, can contribute to structural instability and impermeability) and, more significantly and unlike the Avalon soils, they do not contain goethite (a structural stabilising iron hydroxide).

The difference between the Avalon and the Estcourt soils is that one might expect the Avalon soils to be more resistant to dispersion and more permeable than the Estcourt soils. Beyond these features, chemical differences between the two soils are minor. The Avalon soils have a slightly higher ESP and SAR than the Estcourt soils. They also have a high EC which favours the maintenance of a more flocculated condition during rainwater impact on the soil surface. Overall, the iron oxide content of the Avalon soils is probably the main reason for its physically different character to Estcourt soils of similar clay content. The other properties are sufficiently similar as not to be implicated in the differences in physical behaviour between the two soils.

Table 4.5.3(c): Clay mineralogy and chemical analysis of Avalon and Estcourt soils.

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 cations [me/100g soil] (Water soluble extraction)		
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%

CHAPTER 5

MONITORING PROGRAMME RESULTS

5.1 CLIMATIC CHARACTERISTICS

The study area is situated in a typical summer rainfall area. Rainfall is highly seasonal with approximately 85% of rainfall occurring between October and April. Most rain occurs in November up to February where approximately 12 rain days per month can be expected compared to June to July where 12 mm can be expected on 2 to 3 rain days per month. Rainfall occurs mainly in the form of high-intensity thundershowers and between 60 to 90 thundershowers can be expected per year. Average rainfall for the nearby Newcastle area is 873mm (1942-1971). Hail occurs three to four times a year and snowfalls can be expected infrequently.

The region is characterised by warm summers and mild winters with cold mornings. The average midday temperature for the summer months exceeds 25°C. In winter, temperatures are frequently below freezing in the mornings but reach 20°C by midday. Large diurnal temperature fluctuations, sometimes more than 30°C is common during the winter months.

According to Shulze et al (1997), A-pan evaporation in the Newcastle region is between 2 000 and 2 200 mm/a. This is significantly higher than the average annual precipitation. However, actual evapotranspiration from vegetated soil covers will be less than measured evaporation since little evapotranspiration will occur during the winter months when the soils are dry and the vegetation has died off.

The prevailing wind direction for the region for most of the year is from the south-east. The average wind speed is 19 km/h. The windiest months are from October through to December. During the early spring, hot, dry berg winds blow from the west to north-west and is characterised by high wind speeds.

Compared to other coal mining regions, the climate of the northern KwaZulu-Natal region is similar to that of the Highveld, Witbank and Eastern Transvaal coal fields. Mean annual rainfall is slightly higher compared to the other Mpumalanga coal fields, where Mean Annual Precipitation is typically between 600 and 800mm. A notable difference is perhaps that the Kilbarchan area is much windier compared to the Mpumalanga coal fields, owing to the effect of the nearby mountain ranges, which results in higher evaporation rates during the windy months.

5.2 METEOROLOGICAL RESULTS

The meteorological results for the respective monitoring periods, as recorded by the datalogger are summarised in **Table 5.1(a)**. The results indicate data loss for all of the monitoring periods. The data loss generally occurred because of power supply problems to the datalogger. No records were obtained for the period September 1997 to May 1999 (before the second WRC project), when the data logger was out of order.

An anemometer has not been installed for the first WRC project and as such, wind velocity data were not collected for the period February 1993 to May 1999. Wind velocity data were collected for the period May 1999 to October 2000. Wind velocity is an important aspect in estimating reference evapotranspiration and as such, data loss during the first WRC project could be significant. Wind velocity data were collected from the South African Weather Bureau and the database were "patched" based on the SAWB data and the 1999 – 2000 wind velocity data.

Infiltration is mainly governed by rainfall events, and as such, the loss of rainfall data is significant. The rainfall record were "patched" from the weekly rainfall measurements monitored manually at the experimental site and from the CCWR rainfall record at the nearby Newcastle rainfall station. Data loss of temperature, net radiation and relative humidity is not significant, as these parameters are not as erratic compared to rainfall and can be estimated by averaging.

Table 5.1(a): Summary of the meteorological data set

	Rainfall (mm)	Temperature (°C)	Humidity (dec.)	Net radiation (MJday/m^2)	Wind speed (km/h)	Wind direction (deg. N)
28 February 1994 to 31 December 1994						
Average/Total	353.2 (T)	15.6	0.55	3 364 (T)	-	-
Minimum	-	-7.9	0.01	-	-	-
Maximum	74.6	37.0	1.00	2.79	-	-
Data loss	37.8%	10.6%	10.6%	10.6%	100%	100%
01 January 1995 to 31 December 1995						
Average/Total	776.0 (T)	17.4	0.54	3 365 (T)	-	-
Minimum	-	-6.3	0.01	-	-	-
Maximum	78.4	39.1	1.00	2.72	-	-
Data loss	16.1%	16.1%	16.1%	16.1%	100%	100%
01 January 1996 to 31 December 1996						
Average/Total	1 023.6 (T)	16.5	0.52	3 251.4 (T)	-	-
Minimum	-	-6.4	0.01	-	-	-
Maximum	53.4	36.6	1.00	2.73	-	-
Data loss	22.6%	22.6%	22.6%	22.6%	100%	100%
01 January 1997 to 22 September 1997						
Average/Total	886.3 (T)	16.5	0.52	2 366.6 (T)	-	-
Minimum	-	-5.1	0.01	-	-	-
Maximum	19.4	35.8	1.00	2.79	-	-
Data loss	17.0%	17.0%	17.0%	17.0%	100%	100%
23 September 1997 to 25 May 1999						
Data logger out of order						
26 May 1999 to 31 December 1999						
Average/Total	230.0	16.5	0.52	4 679.3 (T)	21.7	169
Minimum	-	-7.2	0.07	-	-	-
Maximum	63.0	36.8	1.00	3.78	163.6	-
Data loss	15.3%	15.3%	15.3%	36.9%	15.3%	15.3%
01 January 2000 to 11 December 2000						
Average/Total	864.7	16.0	0.71	4 080.2 (T)	13.0	165
Minimum	-	-6.2	0.05	-	-	-
Maximum	60.2	35.3	1.00	3.97	104.0	-
Data loss	16.5	16.5	16.5	16.5	16.5	16.5

5.2.1 RAINFALL

Monthly precipitation records at the experimental site are summarised in **Table 5.2.1(a).** The rainfall season generally starts in late September or early October and ends in early April. The wet season is defined as October to March and the dry season as April to September.

Table 5.2.1 (a): Monthly precipitation at the Kilbarchan experimental site.

	1993/ 1994	**1994/ 1995**	**1995/ 1996**	**1996/ 1997**	**1997/ 1998**	**1998/ 1999**	**1999/ 2000**	**2000/ 2001**	**Average**
October	191.2	103.4	72.2	153.8	71.7	74.0	34.8	87.0	*98.5*
November	118.0	36.1	213.5	84.8	120.9	80.9	64.2	38.4	*94.6*
December	79.0	153.0	261.0	256.6	161.1	329.4	154.0	114.4	*188.6*
January	67.7	216.8	232.6	160.8	55.4	115.3	252.5	25.0	*140.8*
February	168.7	55.8	328.0	98.8	0.0	27.0	162.5	46.4	*110.9*
March	127.0	68.4	151.4	142.0	38.6	13.6	74.0	61.4	*84.6*
April	29.6	75.8	20.0	37.0	20.4	53.9	32.2	63.8	*41.6*
May	0.2	13.8	27.4	174.0	10.2	7.8	34.0	15.0	*35.3*
June	0.0	1.2	0.4	26.0	0.0	1.5	3.0	1.0	*4.1*
July	5.8	4.6	52.5	11.0	4.5	0.0	0.0	7.0	*10.7*
August	28.0	0.2	8.2	11.0	0.0	0.0	0.0	0.4	*6.0*
September	60.8	0.0	15.4	17.0	68.0	5.9	12.0	7.0	*23.3*
Total	876.0	729.1	1382.6	1172.8	550.8	709.3	823.2	466.8	*838.8*

A total of 6 710.6 mm of rainfall were measured for the eight rainfall seasons. This translates to an average rainfall of 839.8 mm/a, which is higher than the mean annual precipitation of the region of 873 mm/a. The rainfall years 1995/1996 and 1996/1997 was particularly wet with rainfall being 58% and 34% higher than the mean annual precipitation. The rainfall years 1993/1994 and 1999/2000 were normal while the years 1994/1995 and 1998/1999 were drier than normal. The rainfall years 1997/1998 and 2000/2001 were very dry representing 66% and 56% of average rainfall respectively.

Rainfall is highly seasonal with 84% of the rainfall occur during the wet season, but this varies from 91% (1995/1996 rainfall year) to 75% (1997/1998 rainfall year). Notable variation of annual precipitation is evident, as indicated by coefficient of variation, which is 34.6% for the monitoring period. The variation is higher than expected for the area (25 to 30 according to Shulze *et al*, 1997). The variation during the dry seasons is much higher compared to the wet seasons.

Weekly rainfall measurements and cumulative rainfall are shown in **Figure 5.2.1(a).** The high rainfall season of 1995/1996 is notable where in one case, 255mm has been recorded in one week. It is also evident that most rainfall for the 1995/1996 rainfall season was concentrated in a few months whereas for the 1996/1997 rainfall season, rainfall was spread over a number of months.

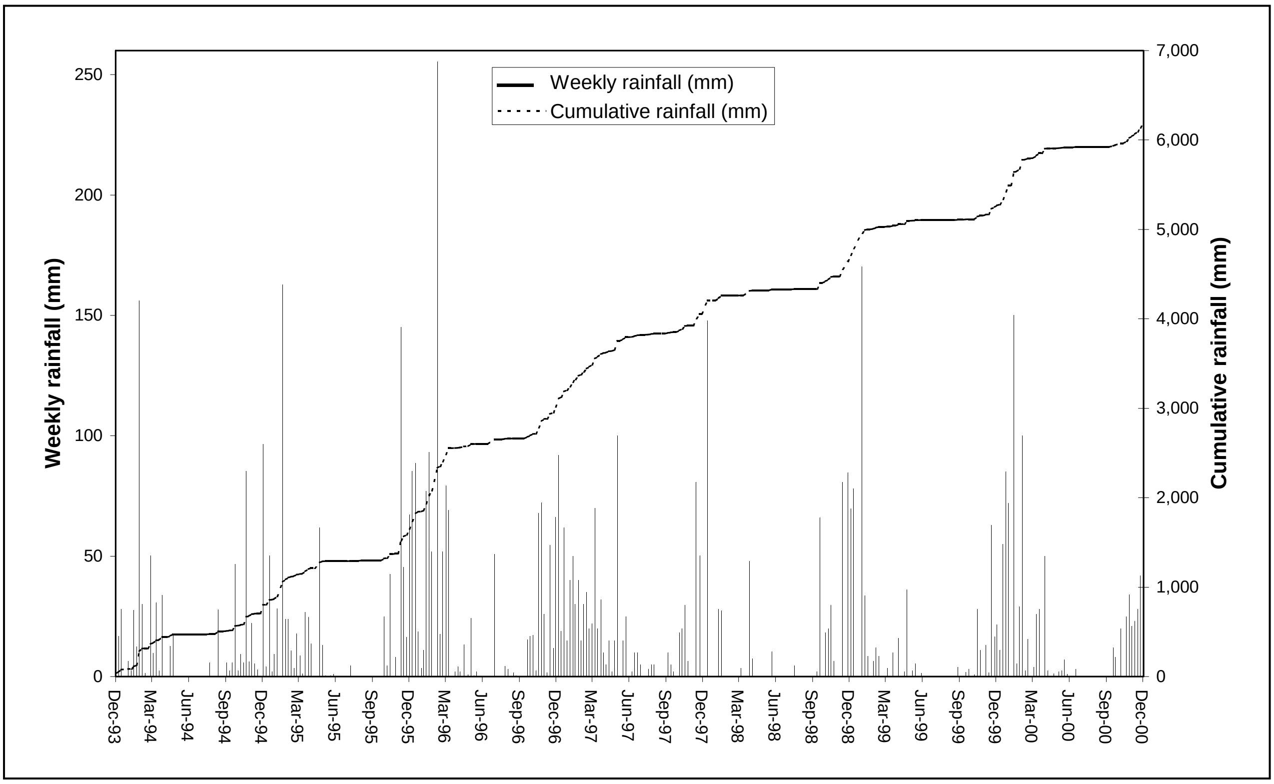


Figure 5.2.1(a): Measured weekly rainfall for the monitoring period.

The rainfall data have been analysed to determine rainfall intensities for the monitoring period. These are summarised in **Table 5.2.1(b)**:

The rainfall intensity analyses indicate that high intensity rainfall occur mostly in the late rainfall season (January to March) but also occurring frequently during other months of the wet season. Rainfall with intensities lower than 5mm/h accounts for approximately 62% of all precipitation. Rainfall with intensities between 5 and 20mm/h accounts for 22% of all precipitation while rainfall with intensities more than 20mm/h accounts for 16%. High intensity rainfall events have the potential to generate significant run-off, especially from compacted Avalon and Estcourt soils. The period in which rainfall occurred at the experimental site represents 4.1% of the monitoring period.

Table 5.2.1(b): Measured rainfall intensities at the experimental site

Rainfall intensities	Rainfall events					Average Events
	1993/1994	1994/1995	1995/1996	1999/2000	2000/2001	
Rainfall hours	170	372	493	335	296	333.2
< 1 mm/h	128	233	302	214	215	218.4
1 - 5 mm/h	36	110	140	95	64	89.0
5 – 10 mm/h	1	16	31	18	7	14.6
10 – 15 mm/h	0	6	10	6	5	5.4
15 – 20 mm/h	1	4	6	2	1	2.8
20 – 30 mm/h	1	2	2	0	2	1.4
30 – 40 mm/h	1	0	1	0	2	0.8
40 – 50 mm/h	1	0	0	0	0	0.2
50 – 75 mm/h	1	0	1	0	0	0.4
> 75 mm/h	0	1	0	0	0	0.2

*Incomplete data sets for the 1997 to 1999

5.2.2 EVAPORATION

Significant data losses (33.6%) have been recorded at the experimental site during the monitoring period because of overflow of the evaporation A-pan during rainy periods. Since May 1999, the monitoring team has been requested to lower the filling height of the evaporation pan, which resulted in a reduction of data loss. However, it appeared that wild animals entered the fenced area and drank water from the evaporation pan, resulting in inaccurate measurements.

Though no reliable A-pan evaporation data could be obtained, the reference evaporation was calculated based on the temperature, humidity, net radiation and wind velocity data and using the Penman equation (1948). The reference evaporation is shown in **Table 5.2.2(a)**.

Table 5.2.2(a): Reference Evaporation Potential calculated for the experimental site

	1993/ 1994	1994/ 1995	1995/ 1996	1996/ 1997	1997/ 1998	1998/ 1999	1999/ 2000	2000/ 2001	Average
October	190.6	251.6	326.6	270.9	282.5	295.6	178.0	242.0	*254.7*
November	223.2	279.8	313.8	291.1	299.8	302.7	240.5	252.1	*275.4*
December	203.4	237.9	244.8	225.3	229.9	230.8	153.9	205.4	*216.4*
January	206.7	209.4	190.5	161.1	184.1	176.2	122.2	169.0	*177.4*
February	129.2	187.8	154.4	156.1	161.9	157.2	100.5	137.1	*148.0*
March	150.7	142.8	148.3	147.7	143.9	145.3	109.7	135.7	*140.5*
April	117.7	114.5	135.4	132.7	125.7	129.2	90.1	119.0	*120.5*
May	140.2	141.9	163.9	155.7	149.9	132.3	110.4	142.2	*142.1*
June	126.1	106.4	110.5	117.1	103.7	73.5	71.9	94.9	*100.5*
July	122.1	138.9	105.7	112.5	110.1	98.7	147.3	106.5	*117.7*
August	115.7	150.5	139.7	123.7	127.7	124.8	99.4	119.6	*125.1*
September	281.8	323.4	339.5	332.7	341.1	247.5	290.4	265.4	*308.1*
TOTAL	**2007.3**	**2284.9**	**2373.1**	**2226.6**	**2260.2**	**2113.6**	**1714.4**	**1988.5**	**2121.0**

The average reference evaporation at the experimental site is 2 121 mm/a, which is on par with the mean annual reference evaporation of the region, which is between 2 000 and 2 200 mm/a (Shultze et al. 1997). Particularly high evaporation was measured for the 1995/1996 and 1999/2000 rainfall years while significantly lower evaporation was measured for the 1996/1997 rainfall year. Evaporation during the winter months is 35% less compared to the summer months, caused by reduced radiation and lower temperatures.

A total of 16 969 mm of evaporation occurred at the experimental site, which is significantly higher than the approximate 6 710.6 mm rainfall that were measured for. Reference evaporation is on average 2.5 times higher than rainfall. For dry years, the evaporation is approximately 4 times higher while for wet years, it is about 1.5 times higher than rainfall (**Table 5.2.2(b)**)

Table 5.2.2 (b): Ratio reference evaporation to rainfall for the monitoring period

	1993/ 1994	1994/ 1995	1995/ 1996	1996/ 1997	1997/ 1998	1998/ 1999	1999/ 2000	2000/ 2001	Average
Rainfall	876.0	729.1	1382.6	1172.8	550.8	709.3	823.2	*459.8*	837.9
Reference Evaporation	2007.3	2284.9	2373.1	2226.6	2260.2	2113.6	1714.4	*1988.5*	2088.0
Ratio RE to rainfall	2.3	3.1	1.7	1.9	4.1	3.0	2.1	*4.3*	2.5

The results of the weekly measurements, converted to indicate daily evaporation rates, are shown in **Figure 5.2.2(a)**. Weekly evaporation measurements vary significantly with average daily evaporation calculated at between 0.7 and 21.4 mm/day. These variations are mainly caused by climatic factors such as wind speed, net radiation, humidity and temperature.

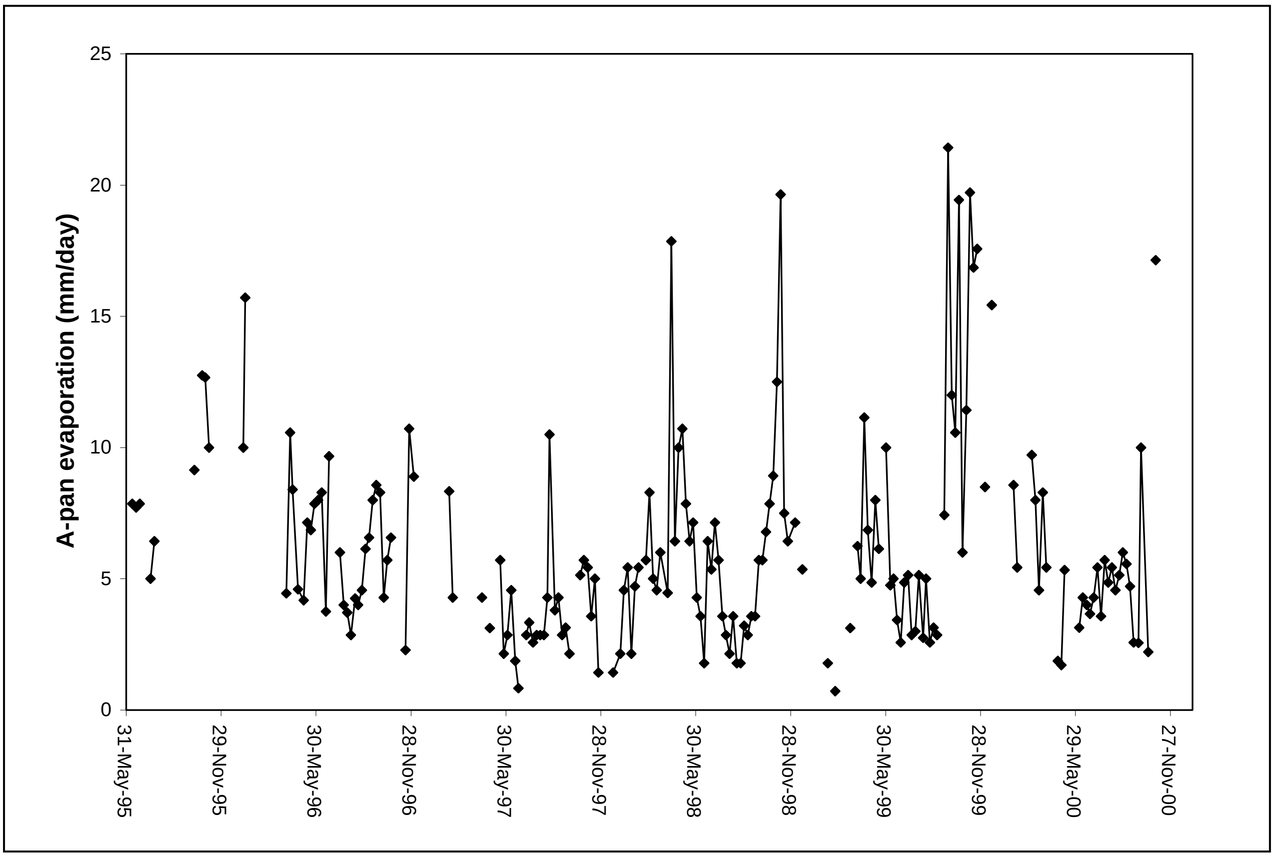


Figure 5.2.2(a): Weekly A-pan evaporation measurements

5.2.3 TEMPERATURE

The data set at the experimental site confirms the typical temperature for the Northern KwaZulu-Natal region. Minimum temperatures in winter mornings is frequently below –5°C and maximum temperatures in summer months is sometimes higher than 35°C. Average yearly temperatures range between 15.6 and 18.0°C. Daily average temperatures for the monitoring period are indicated in **Table 5.2.3(a)** and **Figure 5.2.3(a)**.

Table 5.2.3(a): Average temperatures at the experimental site

	1993/ 1994	1994/ 1995	1995/ 1996	1996/ 1997	1997/ 1998	1998/ 1999	1999/ 2000	2000/ 2001	Average
October	19.3	17.4	19.9	19.9	19.1	19.6	18.3	*18.6*	*19.0*
November	19.5	20.9	20.0	20.3	20.0	20.1	22.6	*17.7*	*20.1*
December	21.5	22.6	20.6	22.2	21.8	21.5	22.9	*20.8*	*21.8*
January	22.4	23.6	23.0	22.2	23.0	22.7	21.2	*21.8*	*22.5*
February	20.7	23.9	22.4	22.4	22.9	22.5	22.2	*19.9*	*22.1*
March	21.4	20.8	19.5	20.9	20.4	20.3	21.7	*20.0*	*20.6*
April	17.9	17.2	17.1	16.6	16.9	16.9	16.7	*17.5*	*17.1*
May	13.6	14.0	13.9	13.1	13.7	14.3	12.8	*14.2*	*13.7*
June	10.1	10.6	11.2	11.6	11.0	11.1	11.5	*11.9*	*11.1*
July	9.3	11.8	9.4	11.3	10.9	11.3	11.8	*10.4*	*10.8*
August	13.0	13.6	13.3	14.6	13.9	13.5	13.9	*14.7*	*13.8*
September	17.8	18.6	17.7	18.5	18.2	16.7	16.7	*17.2*	*17.6*
Average	17.2	17.9	17.3	17.8	17.7	17.6	17.7	*17.0*	*17.5*

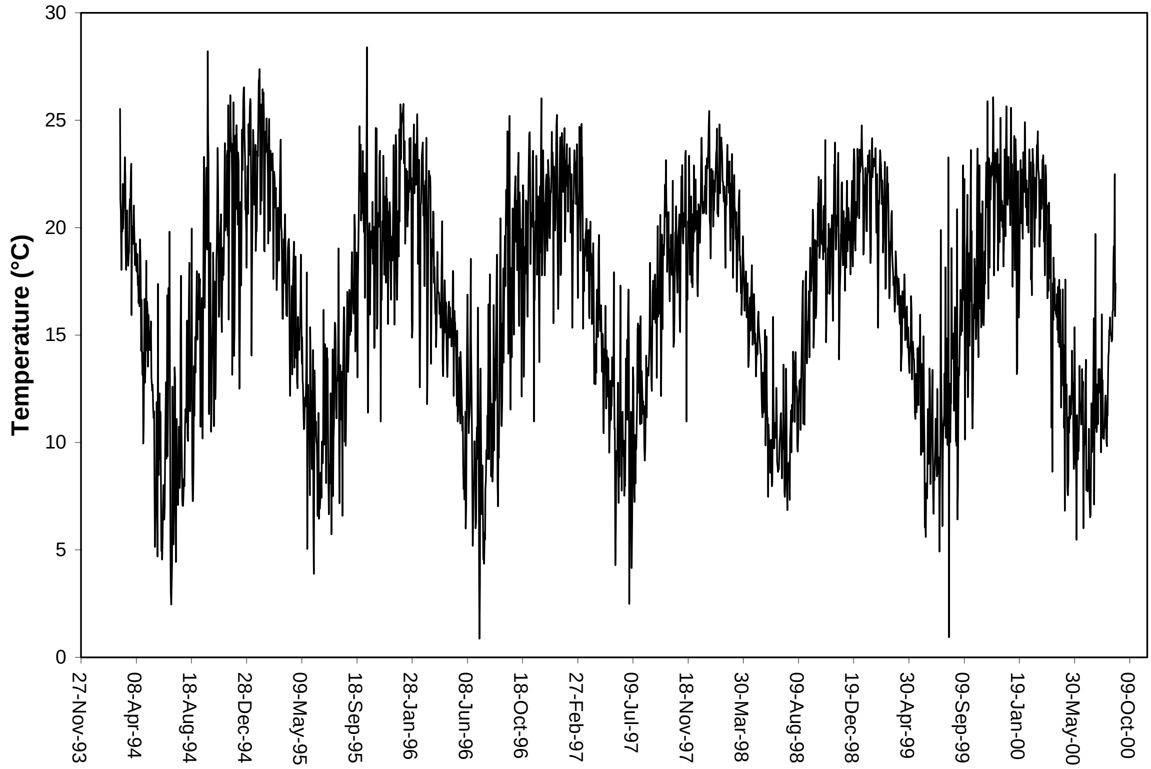


Figure 5.2.3(a): Daily average temperatures for the monitoring period

Temperatures for the 1998 period (where data was not available) were obtained from the SAWB for the Newcastle weather station. Data losses in the remaining data set were "patched" by calculating the average temperatures for the same day for other years of the monitoring period.

5.2.4 RELATIVE HUMIDITY

The data set at the experimental site shows significant diurnal and seasonal variations in relative humidity. During the mornings, the air is frequently near-saturated and relative humidity is close to 100%. During the day, the air is much drier and the relative humidity is approximately 20-30% in winter and 50% in summer. The low relative humidity during the day increases the evaporation potential. Average daily relative humidity is shown in **Table 5.2.4(a)** and **Figure 5.2.4(a)**.

Table 5.2.4(a): Average daily relative humidity at the experimental site.

	1994	1995	1996	1997	1998	1999	2000	2001	Average
October	68.2%	55.3%	47.0%	54.0%	52.1%	51.0%	63.5%	54.7%	55.9%
November	65.1%	56.6%	52.0%	54.7%	53.7%	53.3%	61.8%	55.5%	56.7%
December	64.1%	58.0%	54.0%	57.1%	56.4%	55.9%	67.9%	62.1%	59.1%
January	58.4%	56.6%	58.1%	62.7%	59.1%	60.0%	69.3%	58.4%	60.6%
February	65.8%	57.2%	60.0%	59.8%	59.0%	59.6%	71.3%	60.7%	61.8%
March	61.2%	62.9%	61.1%	61.0%	61.6%	61.2%	69.9%	63.6%	62.7%
April	62.1%	62.9%	56.8%	58.2%	59.4%	58.1%	68.1%	62.9%	60.8%
May	56.4%	57.3%	52.9%	53.0%	54.4%	54.5%	64.2%	52.2%	56.1%
June	46.7%	49.0%	48.0%	48.7%	48.7%	58.1%	62.4%	48.7%	51.7%
July	47.4%	44.6%	50.8%	50.0%	48.4%	56.1%	52.0%	42.0%	49.9%
August	52.6%	47.0%	50.1%	50.6%	49.3%	53.8%	58.7%	53.8%	51.7%
September	49.9%	45.3%	40.6%	45.9%	44.0%	52.9%	50.2%	54.2%	47.0%
Average	58.2%	54.4%	52.6%	54.6%	53.8%	56.2%	63.3%	55.9%	56.3%

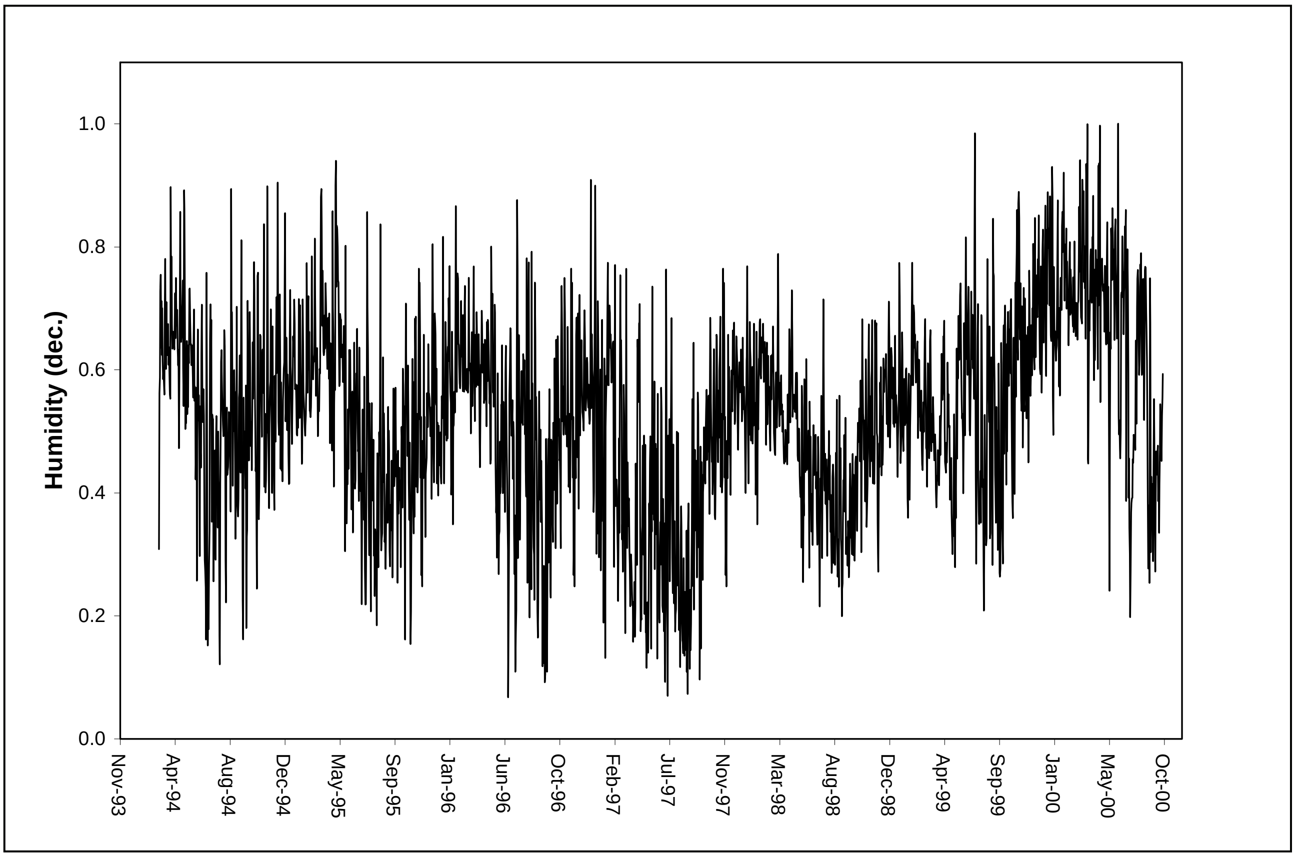


Figure 5.2.4(a): Daily average relative humidity for the monitoring period

Relative humidity for the 1998 period (where data was not available) was obtained from the SAWB for the Newcastle weather station. Data losses in the remaining data set were "patched" by calculating the average relative humidity for the same day for other years of the monitoring period. The relative humidity data set has been calibrated to account for "drift", in which the probe registers higher than actual humidity with time.

5.2.5 NET RADIATION

The data set at the experimental site indicate a yearly net radiation dose of approximately 3 300 MJ/m^2/a. Maximum net radiation occur in midday summer with a net radiation dose of more than 2.5 MJ/m^2/h. Average daily net radiation are shown in **Table 5.2.5 (a)** and **Figure 5.2.5(a)**.

Net radiation for the 1998 period (where data was not available) was obtained by calculating net radiation indirectly from sunshine hours, obtained from SAWB for the Newcastle weather station, using the methods of Ångstrom (1924) and Reid (1981). Data losses in the remaining data set were "patched" by calculating the average net radiation for the same day for other years of the monitoring period.

Table 5.2.5(a): Total monthly net radiation doses at the experimental site (MJ/m^2/a)

	1994	1995	1996	1997	1998	1999	2000	2001	Average
October	630.3	417.7	399.6	377.5	398.3	390.2	341.8	413.2	421.1
November	610.7	449.6	397.3	423.1	413.8	413.8	392.9	418.2	439.9
December	649.6	475.5	442.6	449.5	455.9	453.3	376.9	421.5	465.6
January	421.7	510.1	447.4	473.8	477.1	459.6	374.1	472.3	454.5
February	356.3	443.9	380.4	373.2	393.9	379.9	322.7	382.1	379.0
March	410.4	382.1	371.9	325.0	361.4	353.5	318.5	321.0	355.5
April	349.1	336.0	290.3	331.7	319.2	314.4	259.1	298.2	312.2
May	311.2	304.0	246.3	267.8	273.5	271.3	253.2	285.3	276.6
June	268.6	289.3	253.4	251.2	264.5	265.6	259.1	262.3	264.2
July	276.7	301.3	241.3	272.4	271.7	249.2	256.7	264.5	266.7
August	321.5	337.2	302.3	339.8	324.9	277.9	337.0	335.2	322.0
September	390.8	376.8	392.3	354.4	378.0	320.4	359.3	342.1	367.4
Average	416.4	385.3	347.1	353.3	361.0	345.8	320.9	352.2	360.2

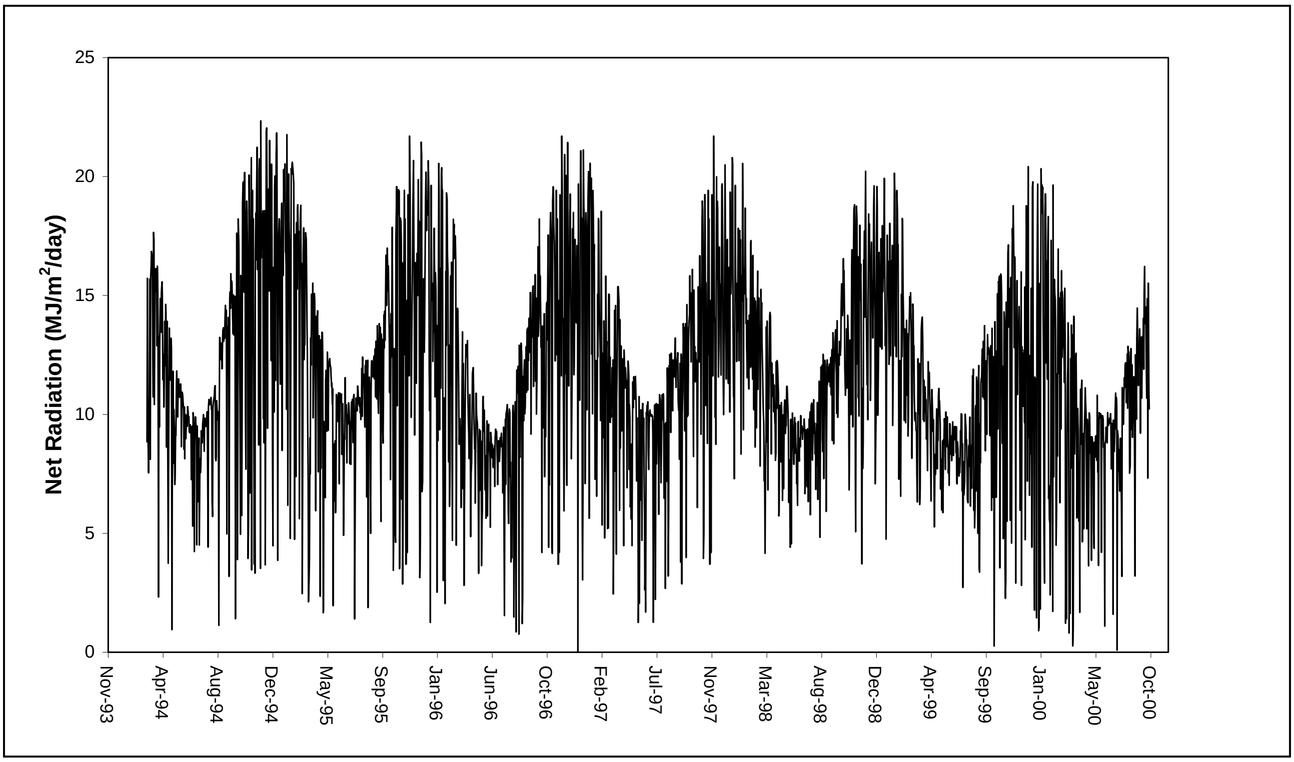


Figure 5.2.5(a): Daily average net radiation over the monitoring period

5.2.6 WIND SPEED AND DIRECTION

Average wind speed at the experimental site is presented in **Table 5.2.6(a)** and **Figure 5.2.6(a)**. The wind speed data shows that the months September, October and November are much windier compared to other months caused by north western berg winds.

Table 5.2.6: Average wind speed at the experimental site

	1998/ 1999	**1999/ 2000**	**2000/ 2001**	**Average**
October	19.3	19.4	17.2	18.6
November	23.7	23.5	16.0	21.1
December	15.9	16.2	16.7	16.3
January	12.3	12.2	15.4	13.3
February	12.2	12.2	13.1	12.5
March	10.6	10.6	14.9	12.0
April	9.3	9.3	10.2	9.6
May	7.9	10.4	12.0	11.8
June	3.1	3.6	4.2	3.7
July	3.7	8.2	7.3	6.4
August	4.5	5.8	19.0	9.8
September	22.4	23.8	18.2	21.5
Average	12.1	12.9	13.3	13.2

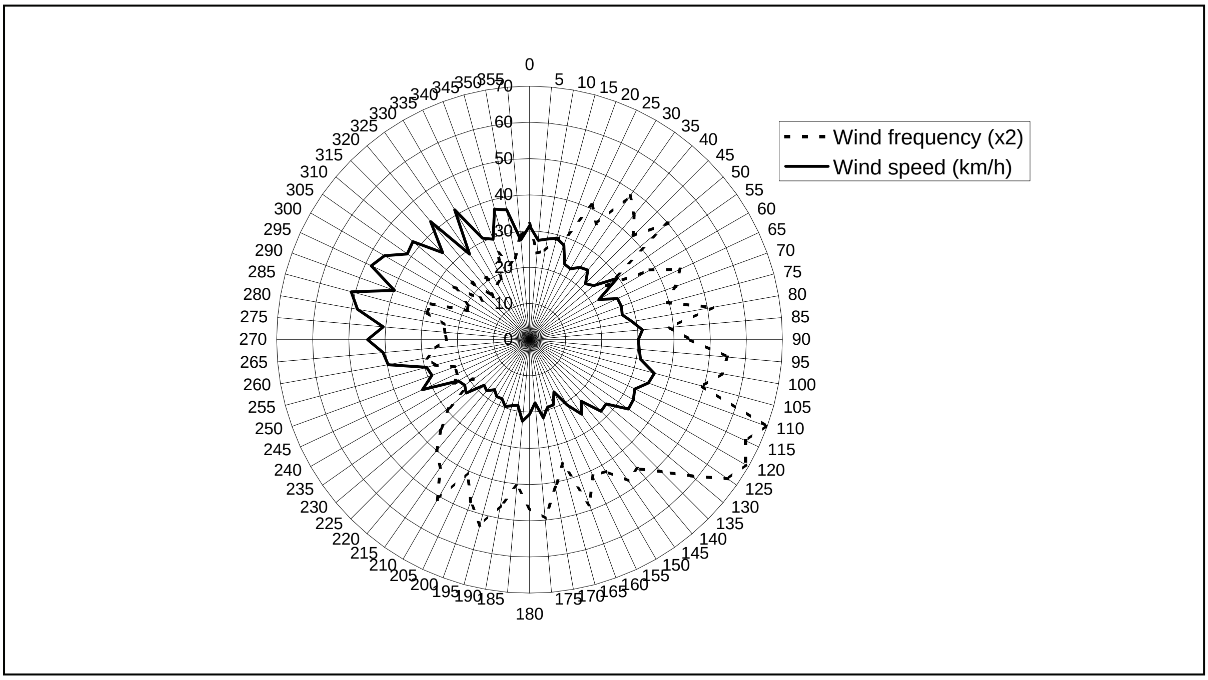


Figure 5.2.6(a): Wind frequencies and velocities

Wind data have only been collected since May 1999, when an anemometer was purchased. Daily wind data could not be obtained from the SAWB. For the unsaturated flow model, wind data for the 1999/2000 period was used as input for the period where no wind data were collected. This could affect the calculation of reference evaporations for these periods.

5.3 VOLUMETRIC WATER CONTENT

As mentioned, continuous time-series volumetric water content profiles were obtained from the reflectometers installed in experimental cells 5 and 6. The data were downloaded exported to a database from where it could be analysed. The measured volumetric water contents were calibrated to values obtained from the neutron probe.

The volumetric water content profile measured over a period of 340 days are presented in **Figures 5.3(a)** and **(b)**. The figures presents measured volumetric water contents measured in the experimental cells 5 and 6 installed at different depths and in different materials. For Cell 5, two of the reflectometres were installed in compacted Avalon and three in uncompacted fine coal discard. For Cell 6, one of the reflectometres was installed in uncompacted Avalon soils, three in compacted Estcourt soils and in uncompacted fine coal discard. One of the reflectometres, the one installed at 0.6m in the fine coal discard in Cell 5, was not functioning and was therefore not considered in this section.

Interpolated volumetric water content contour charts for cells 5 and 6 are presented in **Figures 5.3(c)** and **(d)**. The charts present changes of the volumetric water content profiles with time through the experimental covers of cells 5 and 6. Blue colours represents moist to near saturated soils while red colours represents dry soils.

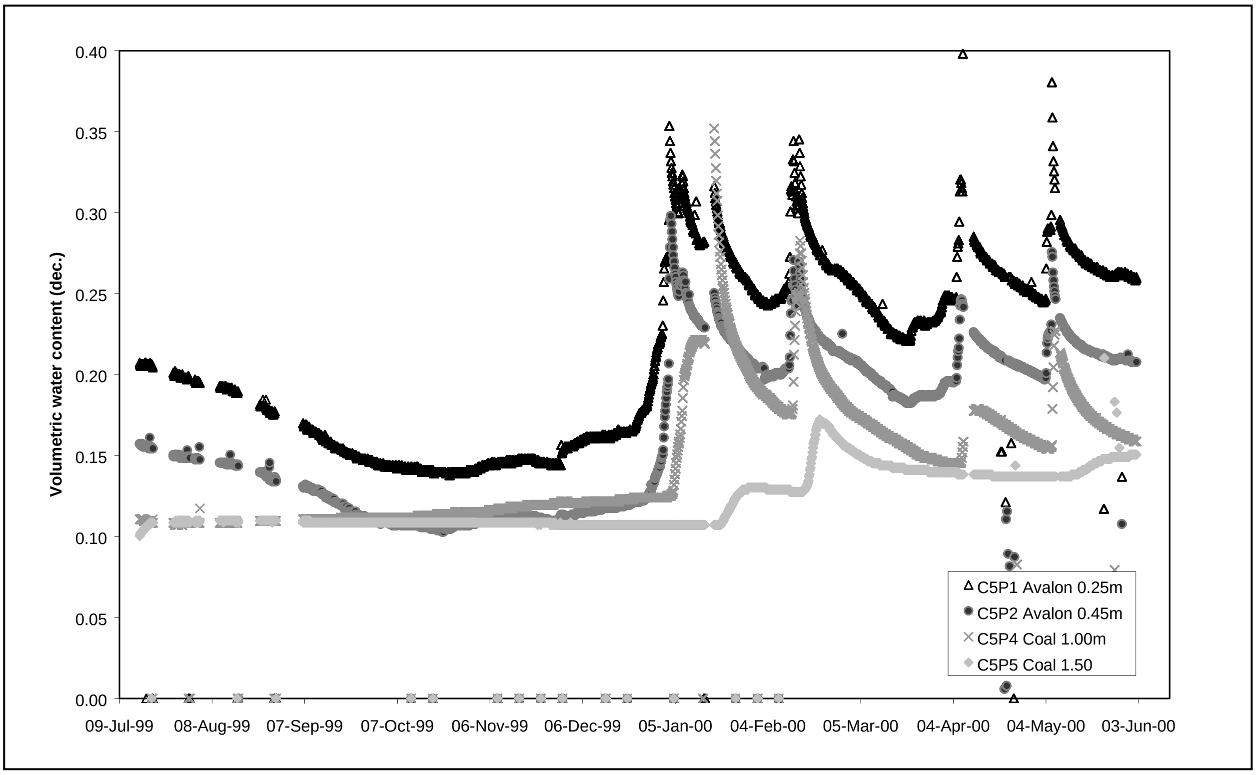


Figure 5.3(a): Time-series volumetric water content profile through experimental cell 5

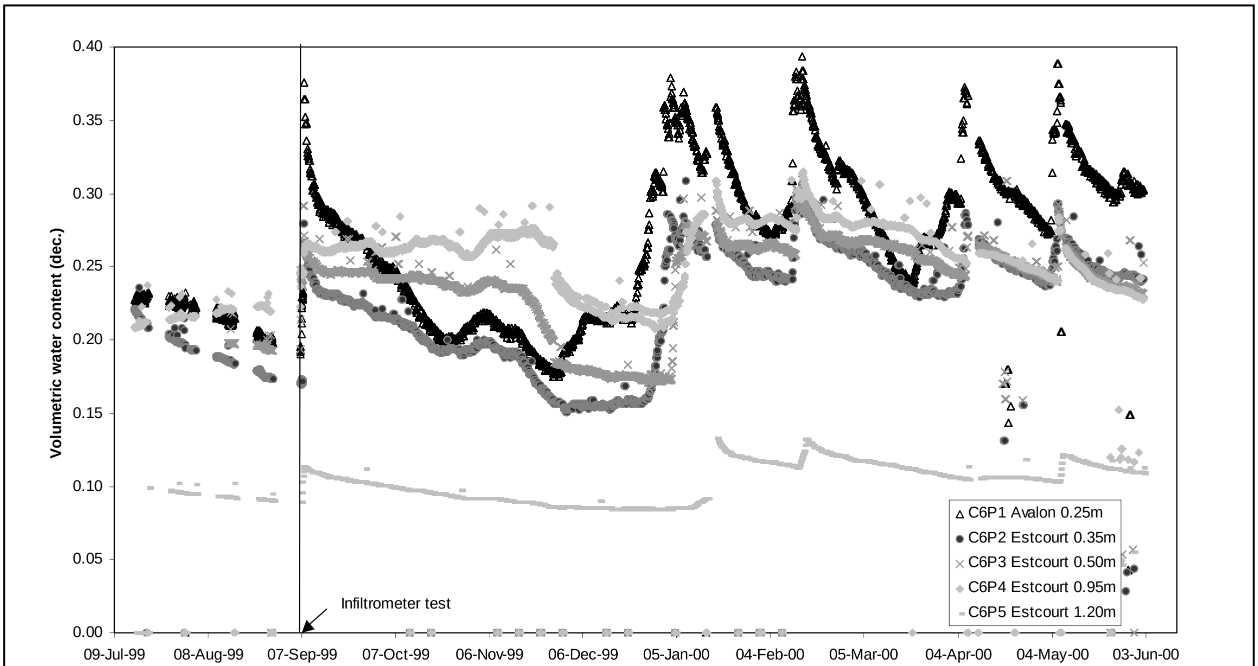


Figure 5.3(b): Time-series volumetric water content profile through experimental cell 6

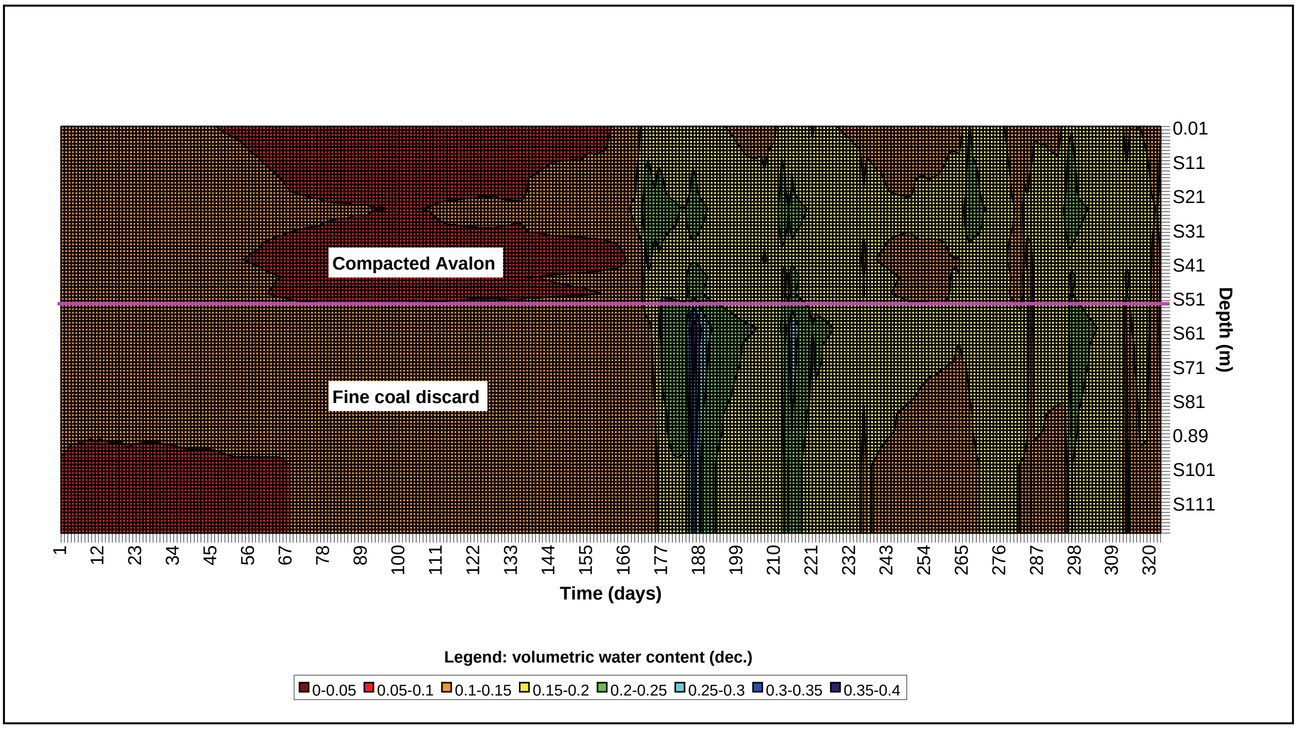


Figure 5.3(c): Volumetric water content contour chart for experimental cell no 5

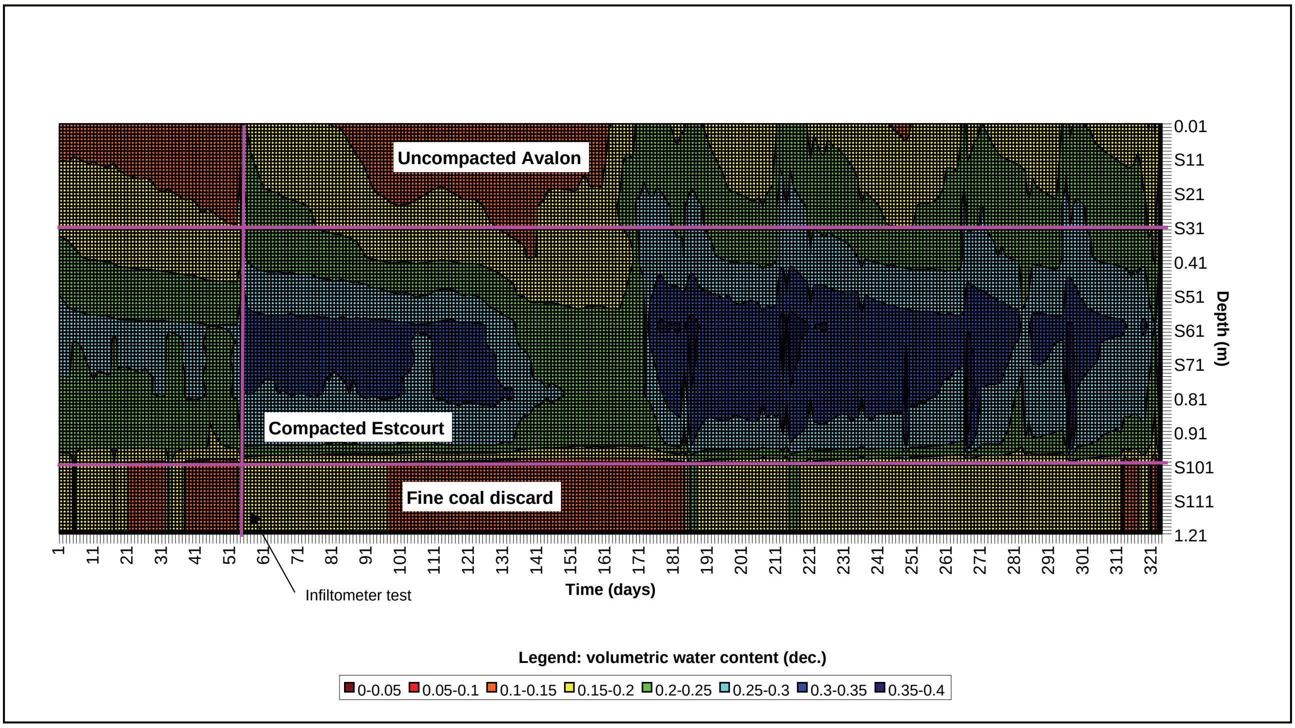


Figure 5.3(d): Volumetric water content contour chart for experimental cell no 6

Figures 5.3(a) and **(c)** indicate significant drying out of the compacted Avalon soils in cell 5 during the dry season. Soil water contents were close to residual water content for both the Avalon soils and fine coal discard. The start of the rainy season resulted in rapid increases of soil water contents throughout the cover. Soil water contents increased from residual water content to near saturation within a few days. The start of the rainy season also resulted in rapid increases of soil water contents of the fine coal discard, suggesting that breakthrough occurred and that a small portion of rainfall has infiltrated the fine coal discard. It is also apparent that the Avalon soils did not remain moist for long with moisture contents decreasing rapidly from the bottom and from the top of the cover, suggesting drainage and also significant removal of soil moisture by means of evapotranspiration.

On 7 September 1999, a large diameter double ring infiltrometer test was conducted on top of the installed reflectometres. The soil was allowed to saturate for a few hours after which the water was allowed to drain. The purpose of the test was to obtain an infiltration and drainage curve to which the SoilCover model could be calibrated. In addition, the working status of the reflectometers was tested.

The infiltrometer test resulted in the rapid saturation of the cover profile at cell 6, as is evident from **Figures 5.3(b)** and **(d)**. It is evident that the Avalon soils quickly saturated during the test after which soil water rapidly drained or evaporated, resulting in a rapid decrease of soil water content. The soil water also rapidly infiltrated the Estcourt soils as is evident from the high soil water contents. However, Estcourt soils retained the soil moisture for a much longer period compared to Avalon soils. The top portion of the Estcourt soils dried out fairly rapidly, but the bottom portion remained moist for approximately 80 days.

Apart from the increase in moisture content for the fine coal discard during or just after the infiltrometer test, the fine coal discard remained fairly dry throughout the drainage period with saturation levels well below that of the Estcourt soils.

Two aspects are highlighted by the infiltrometer test:

- The first aspect is that the fine coal discard acts as a capillary break, preventing soil moisture from infiltrating the fine coal discard. The soil water retention characteristics and particle size distribution of the fine coal discard is typical to that used for a capillary break, i.e. that of a coarse sand or fine gravel with low retention capabilities. The Escourt soil remained moist for a long period, especially along the bottom portion of the cover where soil moisture accumulated, but could not infiltrate the fine coal discard. The soil water retention characteristics and particle size distribution of Estcourt soils is typical of that used for store & release covers, i.e. high retention capabilities and fairly high silt and clay contents.

- The second aspect is that the top uncompacted Avalon soils also acted as a capillary break, preventing upward movement and removal of soil water by means of evapotranspiration processes. The unsaturated hydraulic conductivity of Avalon soils at low soil water contents (high suction values) is extremely low. It is believed that the dry Avalon soils acted as a barrier preventing upward movement of soil moisture.

As with cell 5, the soil water content of cell 6 rapidly increased with the commencement of the rainy season. It is evident that the increase of soil water contents, especially the Avalon soils, is related to rainfall events. The Avalon soils are characterised by cycles of wetting and drying, though the soils does not dry out as much as is the case during the dry season. In contrast, the Estcourt soils remained moist throughout the rainy season. Periods of high saturation can be distinguished coinciding with rainfall events.

It is interesting to note that the fine coal discard remained relatively dry throughout the rainy season with the exception of three breakthrough events. It is apparent that these breakthrough events happened after a series of rainfall events or single considerable rainfall events. It is believed that breakthrough occurred after the storage capacity of the Estcourt soils was exceeded. It is likely that most the outflow occurred after these breakthrough events.

Another interesting aspect is the fact that the moisture contents rapidly decreased at the end of the rainy season in May and June. The Estcourt soils dried out within approximately 30 days, in contrast to around 80 days when the infiltrometer test was conducted. One explanation is that the Avalon soils did not dry out as much compared to when the infiltrometer test was conducted. The Avalon soils were therefore more conductive, which contributed to the upward movement of soil moisture. This is analogous to a slightly moist cloth being more effective to remove moisture than a completely dry cloth.

5.4 OUTFLOW ANALYSES

As discussed in Chapter 4, several problems were encountered with the tipping buckets and mechanical counters, which is used to measure outflow. The outflow database was subsequently reanalysed to eliminate obvious errors. Inaccurate advances of the mechanical counters were corrected by a filtering procedure, which identified and corrected cases where the counters advanced (or regressed) incorrectly by more than 100 in a week. In addition, data losses were corrected by amending counter readings based on the average cumulative recharge rate through the respective covers. Although every effort was made to have a reliable outflow database, it is likely that the database contain several outflow measurement errors. In spite of this, it is believed that the database is a fairly accurate representation of actual outflow. The corrected cumulative outflow rates are summarised in **Tables 5.4(a)** and **(b)** and **Figures 5.4(a), (b)** and **(c)**.

Table 5.4(a): Annual outflow rates at the experimental site

Test cell	Outflow rate (mm)							
	1994/ 1995	1995/ 1996	1996/ 1997	1997/ 1998	1998/ 1999	1999/ 2000	2000/ 2001	1994- 2001
Cell 1	104.3	622.2	390.5	Data not reliable	273.8	319.4	92.8	1803.0
Cell 2	97.7	566.9	316.7		201.4	243.7	71.7	1498.1
Cell 3	97.8	508.8	414.0		218.5	257.7	N.M.	1496.8
Cell 4	16.0	395.4	274.4		144.0	185.2	59.4	1074.4
Cell 5	4.4	284.8	221.7		117.0	145.7	10.5	784.1
Cell 6	21.9	294.5	106.7		87.2	111.1	15.0	636.4
Cell 7	26.2	131.3	15.2		38.3	5.8	0.1	216.9
Cell 8	21.9	243.3	187.6		45.4	40.3	3.2	541.7
Cell 9	0.0	295.9	253.3		17.0	123.5	29.9	719.6
Cell 10	0.0	196.3	110.2		22.7	48.6	3.2	381.0
Rainfall	**729.1**	**1382.6**	**1172.8**		**709.3**	**823.2**	**466.8**	**5283.8**

Table 5.4(b): Outflow rates expressed as percentage of annual rainfall at the experimental site

Test cell	Recharge rate as percentage of rainfall							
	1994/ 1995	1995/ 1996	1996/ 1997	1997/ 1998	1998/ 1999	1999/ 2000	2000/ 2001	1994- 2001
Cell 1	14.3%	45.0%	33.3%	Data not reliable	38.6%	38.8%	20.2%	34.2%
Cell 2	13.4%	41.0%	27.0%		28.4%	29.6%	15.6%	28.4%
Cell 3	13.4%	36.8%	35.3%		30.8%	31.3%	N.M.	31.1%
Cell 4	2.2%	28.6%	23.4%		20.3%	22.5%	12.9%	20.4%
Cell 5	0.6%	20.6%	18.9%		16.5%	17.7%	2.3%	14.9%
Cell 6	3.0%	21.3%	9.1%		12.3%	13.5%	3.3%	12.1%
Cell 7	3.6%	9.5%	1.3%		5.4%	0.7%	0.0%	4.1%
Cell 8	3.0%	17.6%	16.0%		6.4%	4.9%	0.7%	10.3%
Cell 9	0.0%	21.4%	21.6%		2.4%	15.0%	6.5%	13.6%

Cell 10	0.0%	14.2%	9.4%		3.2%	5.9%	0.7%	7.2%

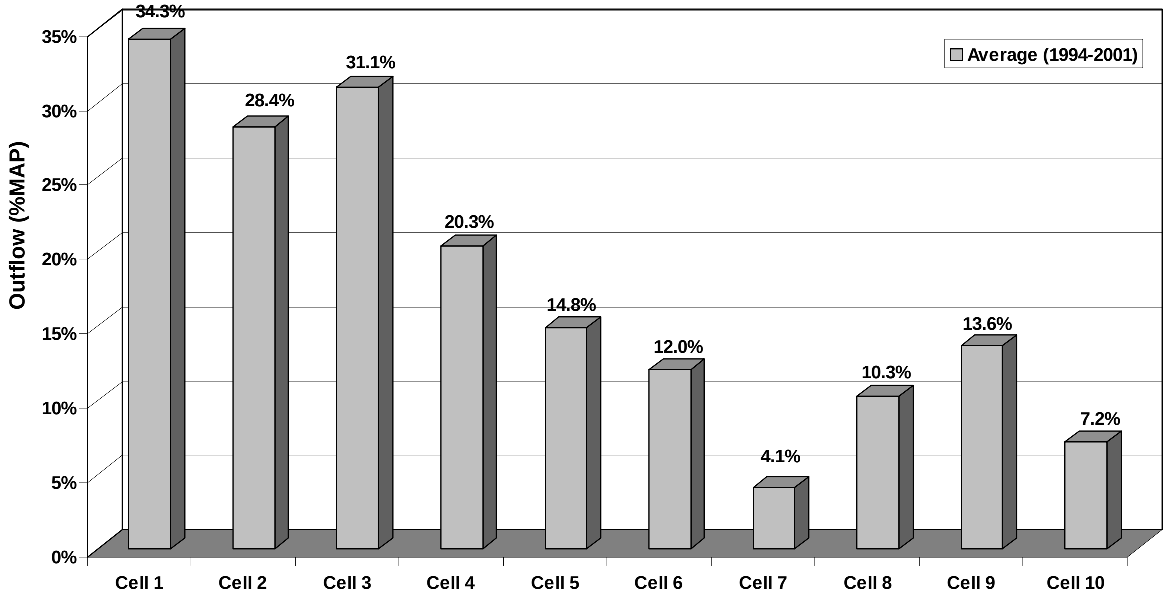


Figure 5.4(a): Summarised outflow rates expressed as percentage of mean annual rainfall

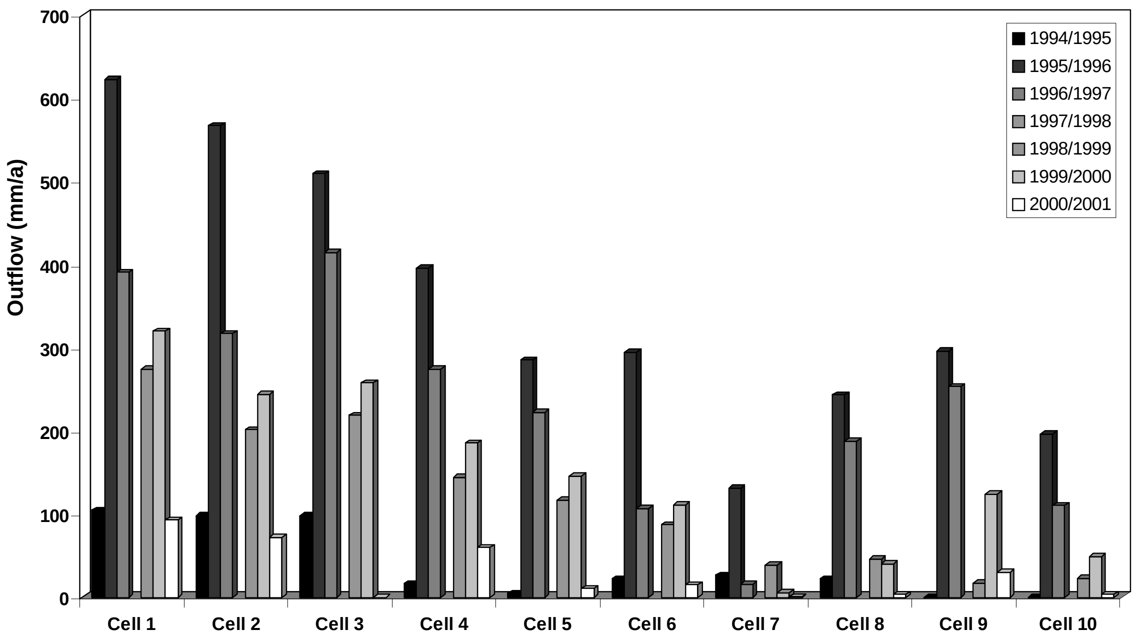


Figure 5.4(b): Annual outflow rates for the respective experimental cells

Tables 5.4(a) and **(b)** clearly shows distinct differences in outflow rates for the different covers. In general, the highest outflow rates were measured for the uncovered cells. Outflow rates are also related to the thickness of the cover with high outflow rates measured for the 0.3m and 0.5m covers and lower outflow rates for the 1.0m covers.

The results also show a distinct relationship with rainfall. High outflow rates correspond to above-average rainfall seasons and low outflow rates with below-average rainfall seasons. However, outflow is not directly related to rainfall and it is evident that other factors, e.g. rainfall intensity and frequency of rainfall events, do influence outflow.

5.4.1 UNCOVERED CELLS (CELLS 1, 2 AND 3)

The highest outflow rates have been measured in the uncovered cells 1 to 3 where average outflow rates of between 28.4% and 31.3% of MAP have been measured. The outflow rates are lower compared to what Anglo American Corporation has found for its uncovered coal discard dumps where between 50 and 60% of MAP percolated through the discard dumps (1986). This can be attributed to the particle size distribution of the fine coal discard used in the experiment, which consist of gravelly sand size particles compared to typical coal discard which consist of a sandy gravel and gravel size particles. The fine coal discard possesses a slightly higher storage capacity and therefore allows more soil water to be removed by evaporation. However, the outflow rates is particularly high compared to natural recharge rates which varies from 3% MAP for the South African coalmining region (Hodgson, 2000) to 10% for areas underlain by dolomite (Bredenkamp, 1999).

The outflow through the uncovered cells varies considerably over the monitoring period. The outflow measured for the 1995/1996 rainfall season is more than 6 times higher compared to the 2000/2001 rainfall season. In fact, the outflow generated during the 1995/1996 rainfall season exceeds the total rainfall which occurred in the 2000/2001 rainfall season. It appears that outflow is not linearly related to rainfall. The outflow during the wet 1995/1996 rainfall season represent 36.8 to 45.0% of MAP whereas the outflow during the dry 2000/2001 rainfall season represent 15.4 to 19.9% MAP. A higher percentage outflow occurs during wet years and lower percentage outflow occurs during dry years.

The highest outflow rates were measured in cell 1, comprising uncompacted fine coal discard, followed by cell 3, comprising treated and vegetated fine coal discard and then cell 2, comprising compacted fine coal discard. The higher outflow rates for cell 1 is expected as the storage capacity of the coal discard is lower compared to compacted fine coal discard and then evapotranspiration is less compared to cell 3, where vegetation assist in removing soil moisture. In addition, it has been observed that a number of holes were made in the cell by burrowing animals. Rainwater could therefore short-circuited the fine coal discard. The burrowing holes were destroyed from time to time to eliminate the effect of burrowing holes.

The outflow rates from cell 3 were lower compared to cell 1 and it is believed that this is largely due to the presence of vegetation that assisted in evapotranspiration. The outflow rates would probably have been higher if the fine coal discard was compacted, thereby increasing the storage capacity of the fine coal discard.

The outflow rates from cell 2 were the lowest of the uncovered cells, largely because of the increased storage capacity of the compacted fine coal discard. Rainfall water is retained in the compacted fine coal discard from where a portion of soil water is evaporated.

5.4.2 SINGLE LAYER COVERS (CELLS 4 AND 5)

The results show that outflow rates are significantly lower for cells that have been provided with a soil cover. The outflow rates for cell 4, which is provided with only a 0.3m soil cover, are on average 20% of MAP compared to the 30% of MAP for uncovered cells. However, the outflow rates are significantly higher compared to other covered cells. When designing infiltration-limiting covers, one would typically aim to reduce rainfall infiltration to typically 5% of MAP. In this respect, the cover fails to meet the infiltration target. The cover is therefore ineffective in limiting infiltration into the fine coal discard.

The outflow rates through cell 5, which is provided with 0.5m compacted Avalon, is less compared to that of cell 4. Outflow rates for cell 5 were on average 14.8% of MAP, which is only slightly more than cells 6 and 8, both of which have been provided with complex cover systems. However, the outflow rates are also significantly higher compared to the target of infiltration-limiting covers, namely 5% of MAP.

With the exception of the rainfall years 1994/1995 and 2000/2001, outflow rates for cell 4 exceeded 20% of MAP. A possible explanation for the low outflow rates for the 1994/1995 rainfall year is that the soils and fine coal discard were placed in a dry state, and that rainfall were soaked up by the soils and coal discard during that year, resulting in minimal outflow. The lower outflow rates for the 2000/2001 rainfall year is due to the low rainfall that occurred for that year and the fact that reference evaporation was 4 times higher than rainfall, which means that a greater portion of soil water could be removed from the cover. However, the outflow rates were relatively high, even in the dry 2000/2001 year, which indicate that the cover is not effective in limiting rainfall infiltration.

The outflow rates for cell 5 are similar to that of cell 4 with relatively high outflow rates of between 16 and 20% MAP for the all the rainfall years except 1994/1995 and 2000/2001. In contrast to cell 4, the soils were compacted for cell 5, thereby increasing the soils air entry value and its soil water retention capabilities. Cell 5 is in effect a store & release cover in which the fine coal discard is a capillary break and the compacted soils are the storage medium. However, the high outflow rates indicate that the storage in the cover is inadequate to store the rainfall volumes, resulting in breakthrough.

It is interesting to note that the outflow rate for the dry 2000/2001 rainfall year represent only 2.2% of MAP. This indicates that for dry years, the storage capacity is adequate to store rainfall water and the cover is effective in limiting rainfall infiltration, but in years of higher rainfall, the storage capacity is exceeded. The results suggest that the cover configuration might be adequate in climates with rainfall less than 500 mm/a. As with cell 4, it is believed that the low outflow rates for the 1994/1995 rainfall year are the result of soils and fine coal discard being placed in a dry state, and that rainfall were soaked up by the soils and coal discard during that year, resulting in minimal outflow.

5.4.3 DOUBLE LAYER COVERS (CELLS 6 AND 8)

Outflow rates for double layer covers are significantly lower compared to uncovered cells with outflow rates being 30% to 40% of that of covered cells. However, outflow rates are mote than twice as high than the target of infiltration limiting covers of approximately 5% of MAP. The outflow rates for cell 6, comprising 0.3m uncompacted Avalon soils overlying 0.7m compacted Estcourt soils were on average 12.0% of MAP. The outflow rates for cell 8, comprising 0.7m uncompacted Avalon soils overlying 0.3m compacted Estcourt soils were on average 10.3% of MAP. The outflow rates are particularly high compared to cell 7, which also has a 1.0m in thick cover, but have outflow rates less than half of that of cells 6 and 8. The outflow rates are also only not significantly lower compared to cell 5, which only have a 0.5m thick cover. The comparatively high outflow rates suggest that the cover configuration of cells 6 and 8 are ineffective in limiting rainfall infiltration and that infiltration rates can be significantly reduced by changing the configuration to that of cell 7.

Cells 6 and 8 were originally designed to be infiltration barriers in which the compacted Estcourt would act as the infiltration barrier and the Avalon be used as topsoil with the functions to provide a growth medium for vegetation and to protect the Estcourt soils against desiccation. Unfortunately, it was found that the properties of the Estcourt soils are not conducive for use as an infiltration barrier. The field saturated hydraulic conductivity (1.73×10^{-7} m/s) is 17 times higher than the typical specified saturated hydraulic conductivity for infiltration barriers (1.0×10^{-8} m/s). A more stringent value of 1.0×10^{-9} m/s is often required for infiltration barriers of capping layers (Benson & Koerner, 1997). The importance of the saturated hydraulic conductivity in the design of infiltration barriers were highlighted in **Chapter 2** where it was shown that infiltration barriers are rendered ineffective if the specified saturated hydraulic conductivity is not achieved.

The actual saturated hydraulic conductivity is significantly higher compared to that measured by laboratory tests, possibly because of inadequate compaction during construction of the cover. This highlights the importance of quality assurance during construction of infiltration barriers.

Cells 6 and 8 were not provided with drainage layers. The importance of the drainage layer was highlighted in **Chapter 2** where it was shown that percolation rates into infiltration barriers are significantly higher for covers that do not have drainage layers. It is believed that rainfall water accumulated and infiltrated the compacted Estcourt soils resulting in higher outflow rates.

Even though the covers on cells 6 and 8 failed as infiltration barriers, the outflow results indicate that the covers act as store & release covers. The fine coal discard acts as a capillary break, limiting infiltration into the fine coal discard. The compacted Estcourt soils act as storage medium in which infiltrating soil water is retained before being released by means of evapotranspiration.

However, as was mentioned in **Section 5.3**, the Avalon soils overlying the Estcourt soils also acts as a capillary break, limiting upward movement of soil water and entrapping soil water in the Estcourt soils. With subsequent rainfall events, the soil water content increases in the Estcourt soils resulting in breakthrough and infiltration into the fine coal discard. The covers therefore not only failed as infiltration barriers, but are also shown to be less effective as store & release covers.

The outflow results show significant differences of outflow between cells 6 and 8. It is evident that higher outflows occurred in cell 8 during the wet 1995/1996 and 1996/1997 seasons. For the average and dry rainfall seasons higher outflow rates were measured in cell 6.

It is believed that the 0.7m uncompacted Avalon soils in cell 8 provided storage for infiltrating rainfall water for average and dry years, which were then removed by evapotranspiration. However, the hydraulic characteristics of uncompacted Avalon soils are not conducive for soil water storage during wet periods and soil water percolates through the Avalon and Estcourt soils and infiltrates the fine coal discard before evapotranspiration can remove water from the cover.

The outflow results show that the outflow rate for cell 8 during average and dry seasons represents 4.4% of MAP and for wet seasons, the outflow rate is 16.9% of MAP.

The outflow rates for cell 6, comprising 0.3m uncompacted Avalon overlying 0.7m compacted Estcourt soils, are more difficult to interpret. High outflow rates were measured for the wet 1995/1996 season but relatively low outflow rates were measured for the almost equally wet 1996/1997 season. The outflow rates for the average rainfall years were higher compared to cell 8 at 12% MAP and outflow rates exceeded that of Cell 5 for the dry 2000/2001 season. The outflow rates highlight the complexity in predicting outflow rates for a particular cover and its dependence on specific climatic characteristics.

It is believed that the high outflow measured during the wet 1995/1996 season can be attributed to the fact that most of the rainfall occurred during the months of December and January. Soils remained near saturated resulting in rapid infiltration into the fine coal discard. Little rainfall occurred in February and March, resulting in drying out of the overlying Avalon soils and entrapment of soil moisture in the compacted Estcourt.

In contrast to the 1995/1996 rainfall season, rainfall in the wet 1996/1997 season was spread throughout the wet season. There was adequate time for much of the infiltrating water to be removed by evapotranspiration processes. In addition, the continuous rainfall prevented the Avalon soils from drying out thereby ensuring that the soils are not a barrier to upward movement of soil water. The cover was therefore more effective in releasing water via evapotranspiration compared to the 1995/1996 rainfall season.

In contrast to cell 8, which has 0.7m thick Avalon soils to provide storage for infiltrating rainfall water, cell 6 only has 0.3m of Avalon soils after which it infiltrated the compacted Estcourt. For average and dry rainfall years, rainfall water infiltrates the Estcourt soils but is prevented from being evaporated because of the dry, less conductive Avalon soils. Outflow rates for dry and average rainfall years are therefore higher compared to cell 8.

5.4.4 STORE & RELEASE COVER (CELL 7)

Cell 7 is by far the best performing cover with average outflow rates of less than 5% of MAP, therefore meeting the target of infiltration limiting covers. The outflow rates are approximately one tenth of the outflow rate of the uncovered cells and half of the next best performing non-sloped cover, cell 8.

Cell 7 consists of 0.3m uncompacted Avalon soils overlying compacted Avalon soils and has a typical configuration of store & release cover systems (Bews *et al*, 1997). Rainfall water infiltrates the cover and is stored in the uncompacted and compacted Avalon soils. The fine coal discard acts as a capillary break, limiting water infiltration into the fine coal discard. The soil water is then removed by means of evapotranspiration processes.

The compacted Avalon soils increase the retention capabilities of the cover, thereby ensuring that water does not flow into the fine coal discard, as is the case with cell 8. The cover is 1.0 m in thickness, which proves to be adequate in storing infiltrating rainfall water, even for wet years. In addition, the whole cover is constructed with Avalon soils, which ensure hydraulic continuity throughout the cover and for all soil water contents. The Avalon soils do not act as a capillary break for upward moving water, as is the case with cell 6 and 8. Soil water doesn't become entrapped in the compacted layer because the similar hydraulic characteristics of compacted and uncompacted Avalon soils ensure hydraulic continuity through the cover.

The outflow results indicate that annual outflow rates varies considerably for the different rainfall years with a maximum of 9.5% of MAP for the wet 1995/1996 rainfall year to almost zero outflow for the dry 2000/2001 rainfall year. The outflow rates are also not directly related to rainfall with 1.3% of MAP outflow recorded for the wet 1996/1997 year and 5.4% of MAP measured for the below-average 1998/1999 year. This indicates that (as with cell 6) outflow is not only related to the volume annual rainfall but also rainfall intensity and frequency.

For the wet 1995/1996 rainfall year, most of the rainfall occurred in December and January, thereby not allowing enough time for the water to be removed by means of evapotranspiration. Breakthrough occurred and rainfall water percolated into the fine coal discard. In contrast, rainfall was spread throughout the wet season of the 1996/1997 rainfall year, thereby allowing soil water to be removed by means of evapotranspiration. 50% of the rainfall which occurred in the 1998/1999 rainfall year occurred in December. The high frequency and intensity of rainfall events during this month resulted in breakthrough and outflow rates of more than 5% for the year. This is much higher than the outflow rates for the 1996/1997 rainfall season (1.3%), even though twice as much rainfall occurred compared to the 1998/1999 rainfall year.

The outflow results also showed that outflow was almost completely prevented for the dry 2000/2001 rainfall year. The cover was adequate to store and release all of the rainfall water that infiltrated the cover during the 2000/2001 rainfall year.

5.4.5 SLOPED COVERS (CELLS 9 AND 10)

The outflow results of the sloped cells are mixed with cell 9 (1:10 slope) performing relatively poorly and cell 10 (1.5 slope) performing satisfactorily. The average outflow rates for cell 9 are 13.6% of MAP, which is slightly higher than the double layer cells and slightly lower than cell 5. The average outflow rates for cell 10 is 7.2% of MAP, which is the second best performing cover after cell 7.

Both sloped covers have similar configurations to cell 6, i.e. 0.3m uncompacted Avalon overlying 0.7m compacted Estcourt soils. Because the covers are sloped, it is believed that capillary barrier flow processes govern outflow. It is believed that soil water flows through the cover and accumulates at the interface between the compacted Estcourt soils and fine coal discard. The soil water then flows down-slope towards the bottom part of the sloped cells.

To measure the effects of capillary barrier processes, the sloped cells were designed to intercept soil water from the interface between the Estcourt soils and fine coal discard. Unfortunately, the design details of these interceptors could not be obtained and no comments can be made of the working status of these interceptors. The outflow from the interceptors report to tipping buckets 9(top) and 10(top). No outflow was recorded in both 9(top) and 10(top) during the monitoring period. This suggests that the diversion length for the compacted Estcourt is less than length of the cover (10m) and that breakthrough occurred before it reached the interceptors, resulting in infiltration into the fine coal discard. However, it is also possible that the design details of the interceptors might be at fault resulting in that capillary water never reaching the interceptors.

For non-sloped cells, soil water accumulates along the fine coal discard interface and is then removed by evaporation processes. For sloped cells, soil water moves down-slope, accumulating water as it flows along the fine coal discard interface, which result in breakthrough. One would therefore expect that breakthrough would occur more readily in sloped cells and outflow rates would therefore be higher compared to non-sloped cells. That would explain the high outflow rates in cell 9, which is higher compared to cell 6 even though they have similar cover configurations.

The above-mentioned explanation does not explain why the outflow rates are much lower for cell 10, which have a similar configuration to cell 9 but with a steeper slope. One possible explanation is that run-off on cell 10 is significantly higher compared to cell 9 and the non-sloped cells. One would therefore expect lower infiltration rates and therefore lower outflow rates for that cover. This is in contrast to conventional infiltration theory, which states that the top 1cm of soils would first need to become saturated before run-off is generated. The run-off quantities for gradual slopes would therefore be similar to steep slopes provided that ponding does not occur (though run-off would accumulates at a much faster rate on steep slopes). It is possible that run-off is generated on unsaturated soils of cell 10, resulting in higher run-off.

The reasons for the difference of outflow rates for the sloped cells remain inconclusive. One needs to form a better understanding of capillary barrier processes before satisfactorily explanations can be given for the outflow rates. One also needs to form a better understanding of infiltration and run-off processes on steep slopes to interpret the outflow results of the sloped cells.

5.5 OXYGEN AND CARBON DIOXIDE CONCENTRATIONS

Oxygen and carbon dioxide readings were collected throughout the monitoring period and for all the cells at the experimental site. The purpose of these measurements was to attain an understanding of oxygen flux into the fine coal discard. A high oxygen flux rate, mainly caused by oxygen diffusion, indicates that oxygen is readily available in the fine coal discard, contributing to high sulphide oxidation rates, which could result in acid generation and salination of leachate water. In contrast, low oxygen flux rates inhibit sulphide oxidation and could prevent acid drainage.

Where oxygen is not restricted in moving into the top portions of fine coal discard, high oxygen concentrations are measured whereas low oxygen concentrations occurs at cells which are provided with soil covers, impeding oxygen ingress. Likewise, high carbon dioxide concentrations occur in cells where carbon dioxide (formed by sulphide oxidation and plant transpiration processes) is restricted in diffusing into the atmosphere.

The results of the oxygen and carbon dioxide measurements are shown in **Tables 5.5 (a)** and **(b)** and **Figures 5.5 (a)**, **(b)** and **(c)**. The gas analyser broke down in 1998 and no measurements were collected up to 2000, when a new gas analyser was purchased.

The results indicate high oxygen concentrations, similar to atmospheric concentrations, for the uncovered cells 1, 2 and 3. The concentrations suggest that oxygen diffuses almost unrestricted into the fine coal discard. The oxygen concentrations remained almost constant between 17 and 21% for all uncovered cells and were little effected by rainfall or other events. The oxygen concentrations differs little for the uncovered cells with slightly higher oxygen concentrations measured in cell 3. This is surprising since it was expected that the compaction of coal discard would restrict oxygen ingress to some degree into cell 2. The results suggest that compaction of fine coal discard have little effect in oxygen ingress.

Table 5.5(a): Average oxygen concentrations at the experimental site (%)

Season	Cell									
	1	2	3	4	5	6	7	8	9	10
Oct 1993 – Mar 1994	17.0	17.0	19.0	13.3	0.9	1.2	0.7	0.7	0.0	0.0
Apr 1994 – Sep 1994	18.2	18.1	19.5	15.6	1.9	0.2	0.0	0.0	0.0	0.1
Oct 1994 – Mar 1995	19.0	18.7	18.9	16.8	2.6	0.5	0.0	0.2	0.2	0.5
Apr 1995 – Sep 1995	18.9	19.0	19.6	16.2	6.3	4.0	3.9	3.4	3.4	5.2
Oct 1995 – Mar 1996	16.5	15.8	17.7	15.3	11.4	10.3	9.9	10.0	10.3	11.2
Apr 1996 – Sep 1996	19.0	19.1	19.5	17.4	6.8	0.8	0.7	0.1	0.0	0.0
Oct 1996 – Mar 1997	18.5	18.6	19.8	15.3	0.0	0.0	0.0	0.0	0.0	0.0
Apr 1997 – Sep 1997	17.9	18.3	19.8	15.8	0.0	0.0	0.0	0.0	0.0	0.0
Oct 1997 – Jan 1998	17.6	17.9	19.7	14.9	0.0	0.0	0.0	0.0	0.0	0.0
Dec 1999 - Mar 2000	18.2	17.8	19.9	16.0	5.9	2.7	1.9	2.7	1.7	2.2
Apr 2000 – Sep 2000	20.2	19.9	20.4	18.3	9.1	4.7	3.5	7.9	1.3	3.2
Oct 2000 – Mar 2001	19.6	19.6	20.4	15.9	7.8	3.0	3.9	5.1	1.6	3.1
Apr 2001 – Sep 2001	19.7	19.7	20.3	14.0	9.4	2.4	2.9	4.6	0.7	5.5
Average (%)	**18.5**	**18.4**	**19.6**	**15.8**	**4.8**	**2.3**	**2.1**	**2.7**	**1.5**	**2.4**

Table 5.5(b): Average carbon dioxide concentrations at the experimental site (%)

Season	Cell									
	1	2	3	4	5	6	7	8	9	10
Oct 1993 – Mar 1994	1.2	1.2	0.5	2.0	4.3	3.8	4.1	3.4	4.7	5.0
Apr 1994 – Sep 1994	1.2	1.2	0.3	2.1	4.7	5.0	5.0	5.0	4.9	5.0
Oct 1994 – Mar 1995	1.4	1.5	0.5	1.5	4.5	5.0	5.0	5.0	5.0	5.0
Apr 1995 – Sep 1995	1.3	1.4	0.3	2.4	4.8	5.0	5.0	5.0	5.0	5.0
Oct 1995 – Mar 1996	1.1	1.3	0.8	1.6	2.9	4.0	3.7	4.0	4.4	4.2
Apr 1996 – Sep 1996	1.2	1.2	0.3	1.5	3.5	4.9	4.9	5.0	5.0	5.0
Oct 1996 – Mar 1997	1.1	1.2	0.3	1.6	5.0	5.0	5.0	5.0	5.0	5.0
Apr 1997 – Sep 1997	1.2	1.2	0.3	1.5	5.0	5.0	5.0	5.0	5.0	5.0
Oct 1997 – Jan 1998	1.2	1.2	0.2	1.6	5.0	5.0	5.0	5.0	5.0	5.0
Dec 1999 - Mar 2000	2.1	2.3	1.6	4.8	12.9	16.6	17.1	16.1	16.9	16.8
Apr 2000 – Sep 2000	0.5	0.8	0.4	2.3	9.4	14.2	15.4	11.4	16.9	15.1
Oct 2000 – Mar 2001	1.1	1.4	0.6	3.6	10.8	15.4	15.6	12.5	15.8	16.1
Apr 2001 – Sep 2001	0.3	0.8	0.3	2.5	9.8	15.2	16.1	13.5	17.5	14.8
Average (%)	**1.1**	**1.3**	**0.5**	**2.2**	**6.4**	**8.0**	**8.2**	**7.4**	**8.5**	**8.2**

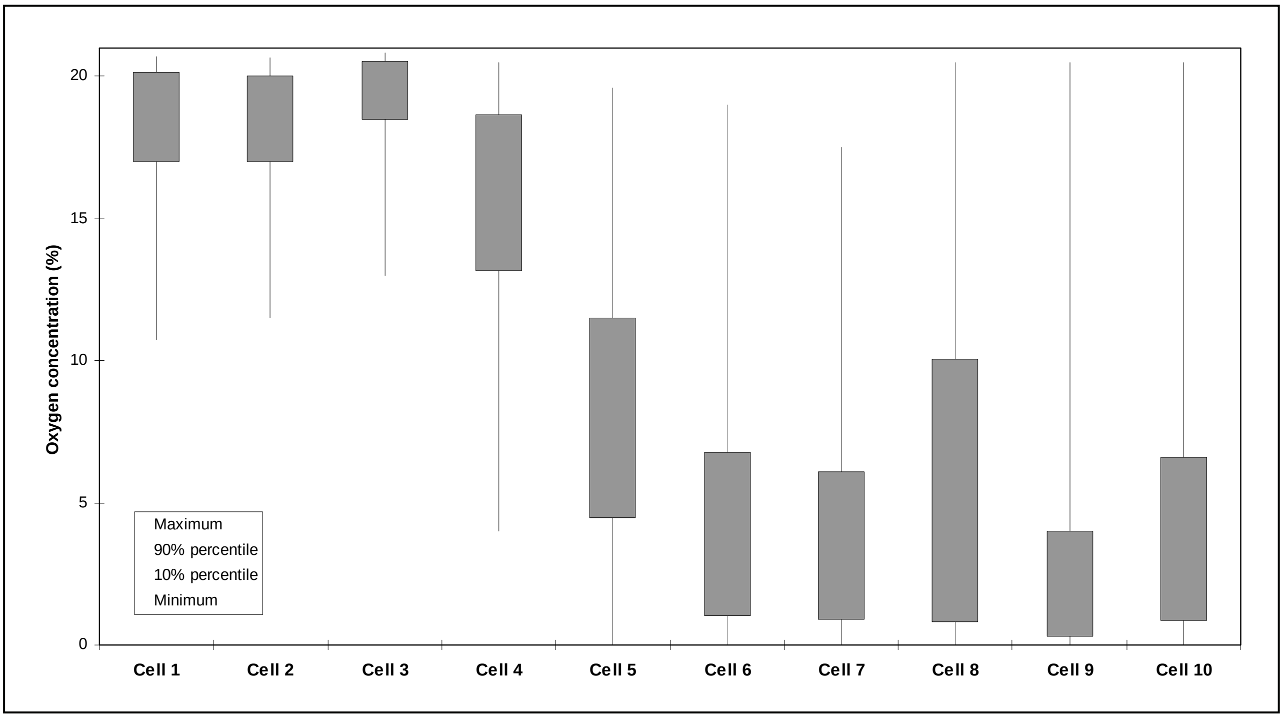


Figure 5.5(a): Variation in oxygen concentrations measured in the respective cells

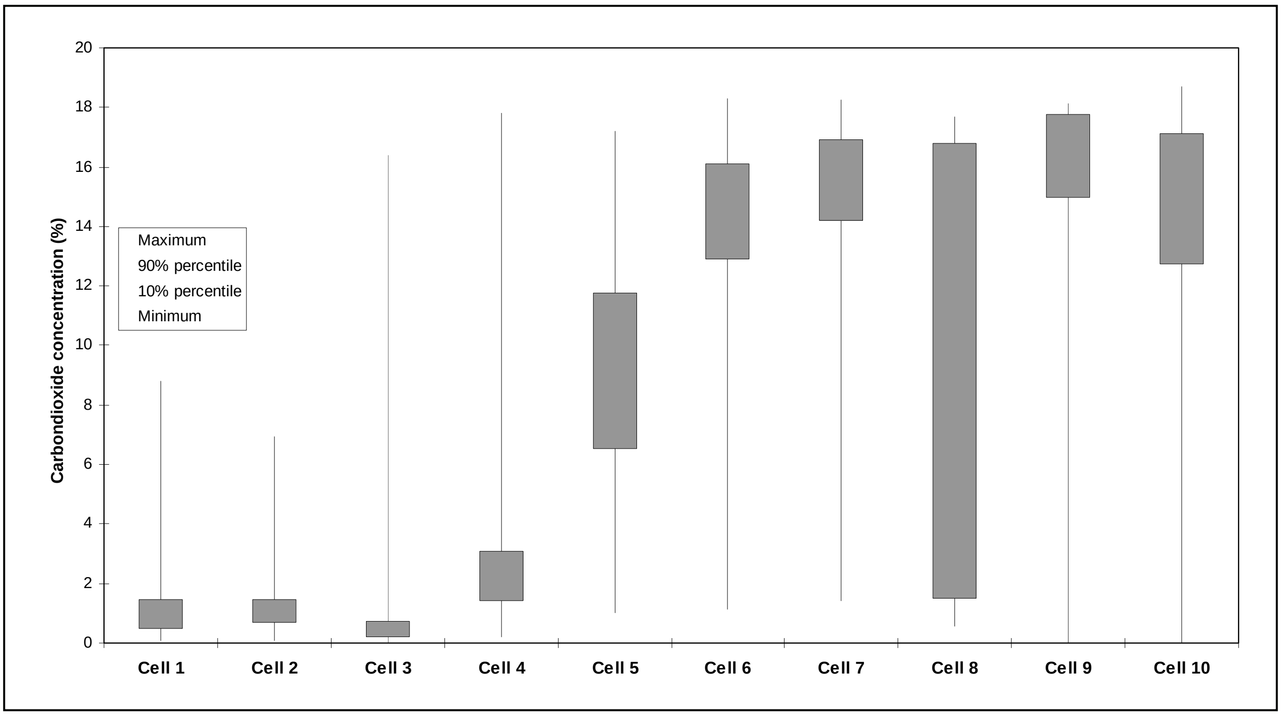


Figure 5.5(b): Variation in carbon dioxide concentrations measured in the respective cells

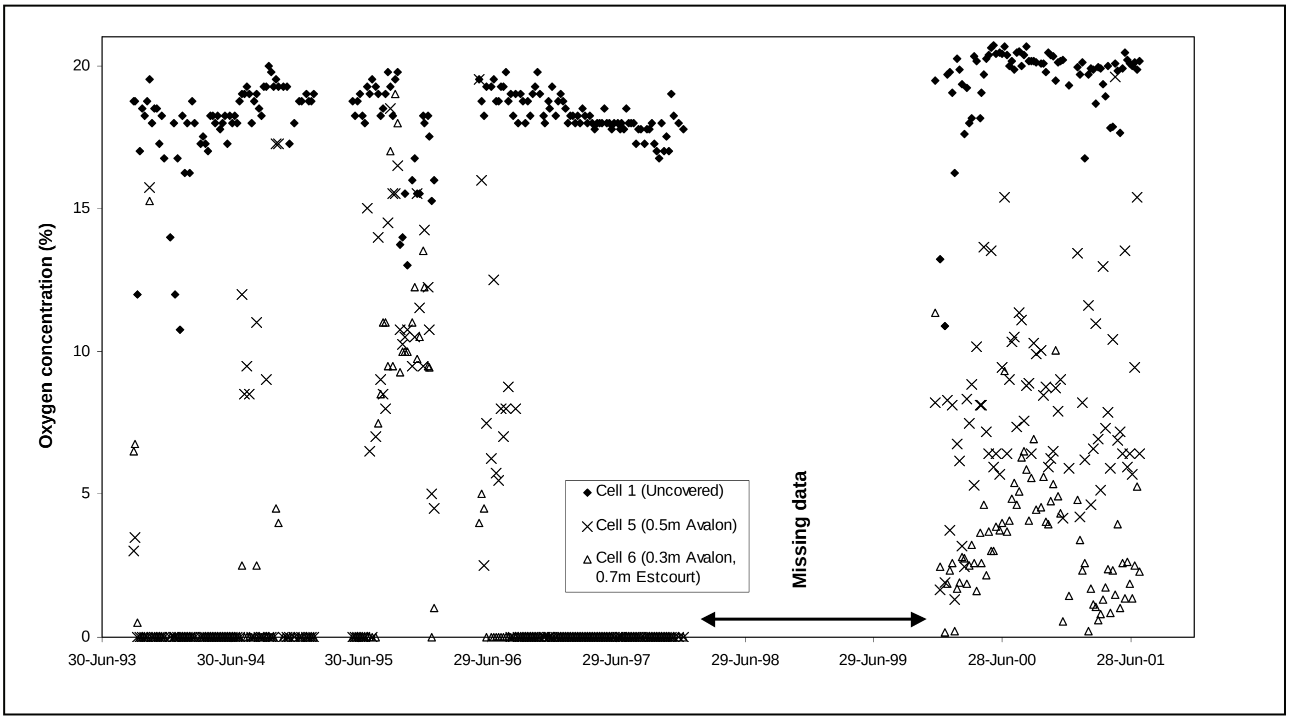


Figure 5.5(c): Change of oxygen concentrations throughout the monitoring period

Carbon dioxide concentrations in uncovered cells are low suggesting that carbon dioxide, generated by sulphide oxidation processes, are unrestricted in diffusing into the atmosphere. Carbon dioxide concentrations vary between 0.3 and 2.4% compares to 0.04% in the atmosphere, and slightly lower carbon dioxide concentrations were measured in cell 3.

Oxygen concentrations in cell 4, provided with 0.3m uncompacted Avalon soils, varies between 14% and 18%, which is slightly lower compared to the uncovered cells. The results indicate that oxygen is slightly restricted in diffusing into the fine coal discard. However, the relatively high oxygen concentrations suggest that oxygen is readily available and that sulphide oxidation rates are not significantly affected. Carbon dioxide concentrations are slightly higher compared to the uncovered cells, suggesting that carbon dioxide is slightly restricted in diffusing to the atmosphere.

Oxygen concentrations in cell 5, provided with 0,5m compacted Avalon soils, are low and vary between 0% and 11%. The results indicate that oxygen is restricted in diffusing into the fine coal discard. At times, the cover is able to prevent oxygen from diffusing into the cover, but at other times, significant oxygen concentrations are measured, suggesting high oxygen ingress. It is believed that the variation in oxygen ingress is caused by wetting and drying of the soil cover. It is known that soil covers with high moisture contents restricts oxygen diffusion (**Chapter 2**). The high oxygen concentrations measured for cell 5 correspond to the dry periods of the monitoring programme where the cover dried out, thereby allowing oxygen to diffuse into the fine coal discard (**Figure 5.5(c)**).

Low oxygen concentrations were measured for all 1.0 m thick covers (cells 6, 7, 8, 9 and 10). Oxygen concentrations vary from 0% to 10%, but are mostly below 5%. This suggests that the 1.0 m thick covers are effective in restricting oxygen ingress, but the covers do not completely prevent oxygen ingress into the fine coal discard.

Oxygen concentrations were close to 0% for most of the monitoring period. However, exceptional high oxygen concentrations were measured at times, coinciding with dry periods of the monitoring period. The variation in oxygen ingress is particularly apparent for cell 8, which unlike other 1.0 m cells only has a 0.3 m compacted layer. It is possible that the high oxygen flux is caused by the covers drying out, thereby allowing a more oxygen to diffuse into the fine coal discard. However, the rapid increase in oxygen concentrations suggests preferential oxygen flow, possibly along desiccation cracks in the cover.

Carbon dioxide concentrations were high for all the 1.0 m thick covers. Carbon dioxide concentrations vary between 5 and 17%, which is much higher than atmospheric carbon dioxide concentrations. This suggests that carbon dioxide is restricted in diffusing to the atmosphere. Exceptional low carbon dioxide concentrations were measured at times, especially in cell 8, which suggest that the carbon dioxide flux rate increased during dry periods when the covers dried out.

The oxygen flux rate is shown to be closely related to the leachate quality for the respective cells. The relationship between oxygen flux rate and leachate quality is described in more detail in **Chapter 7**.

5.6 WATER QUALITY RESULTS

The water quality results are discussed in **Chapter 7**.

CHAPTER 6

UNSATURATED FLOW MODELLING RESULTS

6.1 INTRODUCTION

Simulation can be defined as the application of models as a substitute for the study of real or hypothesised systems. These models could be either physical or numerical models. With advances in the processing capability of personal computers, most researchers have focussed on the development of easy-to-construct and low-cost numerical models. The main advantage associated with simulation modelling is that it is a powerful tool for understanding a particular problem. Researchers can either stretch or compress time which either happens too fast for observation or too slow for practical observation. Ultimately, numerical models can be used as prediction and decision-making tools. "*What if*…" scenarios can be simulated and relevant designs can be optimised for particular problems.

In the case of soil covers, numerical unsaturated flow models can be used to determine the effectiveness of hypothetical covers to limit rainfall infiltration (and oxygen ingress) into waste. Numerical unsaturated models are especially useful in evaluating engineered systems as opposed to engineered structures. An engineered structure refers to a static structure whose effectiveness is measured by the integrity of the construction materials (e.g. low permeability barriers or capillary barriers). Engineered systems refer to dynamic systems whose effectiveness is measured by their harmonisation with particular ecological and climate settings (e.g. store and release covers which depend on evapotranspiration potential to be effective).

The numerical model can be used to evaluate the effectiveness of hypothetical covers for a particular climate and ecological setting which is differentiated by the following variables:

1. Types of covers (low permeability barriers, store and release covers, wet cover systems).
2. Cover configurations (including or excluding capillary break).
3. Cover materials (the choice of cover materials are usually restricted to the soil materials available for rehabilitation).
4. Cover thickness.

5. Compaction (whether the cover materials are compacted or not).

The model can therefore be used to design a cover that is not only effective in limiting percolation rates to acceptable limits but also cost effective.

The numerical model, however, can only be used for cover design purposes once it is proven that the model is able to predict percolation for a specific climatic and ecological setting accurately. One of the main objectives of this research project was to verify the reliability of numerical models for use in the South African coalfields.

Another objective was to understand better the flow of soil water through covers in order to model recharge accurately. The model could then be calibrated to soil moisture data as measured *in situ* by the reflectometers. To reach these objectives, several unsaturated flow models were constructed to simulate the flow of soil water through the covers and into the waste for the respective experimental cells. The models were calibrated to the soil water content, for which a continuous soil water profile was obtained from the experimental cells 5 and 6. The model was also calibrated to the outflow volumes recorded by the tipping buckets.

6.2 CONCEPTUAL UNSATURATED FLOW MODEL

The conceptual model for unsaturated flow through a porous medium has been discussed in **Chapter 3**. It was mentioned that several processes are involved in the flow of soil water through covers, classified as soil-atmosphere interactions and unsaturated flow. The conceptual models for the eight experimental cells are shown in **Figure 6.2(a)**.

It was assumed that the flow of water through the soil covers could be represented by a one-dimensional model. This assumption is true only if no lateral movement occurs in the covers and apart from the sloped cells (cells 9 and 10), insignificant lateral movement of water is expected. The lateral flow along the boundaries of the respective cells caused by the cell walls was deemed insignificant. It was further assumed that all surface runoff will flow off the cover surfaces and that no ponding will occur.

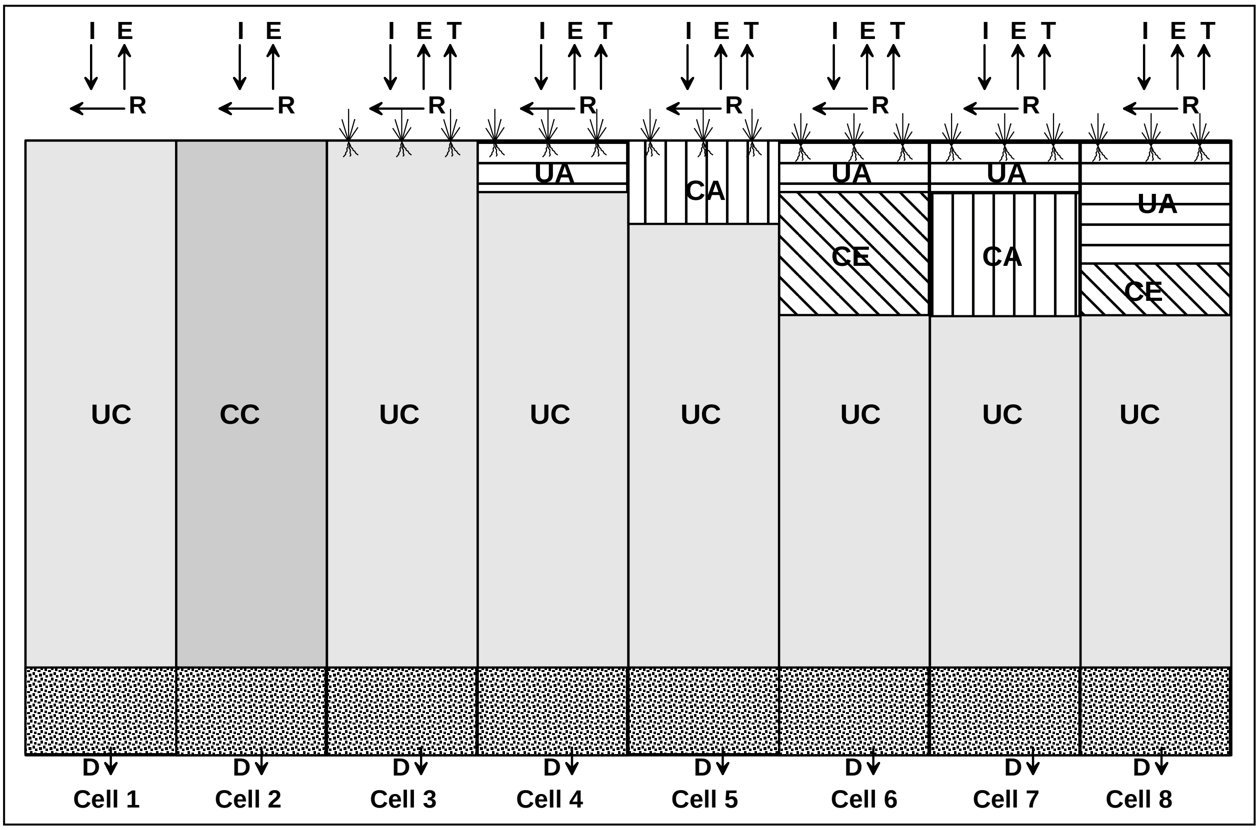


Figure 6.2(a): Conceptual models of the eight experimental cells.

The conceptual model comprises six different materials as indicated in **Figure 6.2(a),** namely, uncompacted coal (UC), compacted coal (CC), uncompacted Avalon soil (UA), compacted Avalon soil (CA), compacted Estcourt soil (CE) and drainage gravel (G). Each of these materials has different retention and hydraulic characteristics. These properties were discussed in **Chapter 4**.

The conceptual models each have top and bottom boundary conditions. The top boundary conditions include infiltration (I), evaporation (E) and run-off. Transpiration (T) also occurs from cells 3 to 8. The bottom boundary condition comprises free drainage (D) and is present at all cells. All of the boundary conditions are dynamic and changes occur with changes in potential evaporation, rainfall and moisture content at the surface and at the bottom of the respective cells.

6.3 SELECTION OF THE MATHEMATICAL MODEL

There are many unsaturated flow models available that can be used to simulate water flow through a soil cover and these have been discussed in detail by Rykaart *et al* (2001). The most popular unsaturated flow models include SoilCover, UNSAT-H, HELP, SEEP/W and SWACROP. However, not all these models are applicable to the experimental site as they need to reflect the actual conditions as described by the conceptual models. This implies that the model needs to simulate soil-atmosphere interactions (SoilCover and UNSAT-H do) and soil-water retention and flow processes (SoilCover, UNSAT-H, SEEP/W and SWACROP) accurately. The accuracy of the model should also be demonstrated for climates similar to that of the South African coalfields. The model, SoilCover, meets all these requirements and was successfully used in the evaluation of soil covers for the rehabilitation of Kidston Gold Mine in Queensland, Australia (Durham *et al*, 2000; Bews *et al*, 1997). The climate at Kidston mine is similar to that of the Mpumalanga coalfields.

The model, SoilCover Version 4.01 (Geo-Analyses 2000 Ltd), was used to simulate soil water flow through the respective experimental cells. This finite-element model calculates infiltration, evapotranspiration, liquid and vapour flow and oxygen ingress into the cover as expressed by Fick's law and Darcy's law (Wilson, 1990): The unsaturated flow theory has been described in **Chapter 3**.

6.4 MODEL SET-UP

Eight soil cover models were constructed representing the experimental cells 1 to 8. The sloped covers, experimental cells 9 and 10, were not modelled as it was believed that lateral flow for these covers was significant and could therefore not be simulated using a one-dimensional model such as SoilCover. The models were set up according to the eight cover configurations and required the user to specify and define the water retention and hydraulic characteristics of the respective materials according to the conceptual model. They also required daily climate data, used to calculate daily infiltration, evapotranspiration and run-off. Boundary conditions at the start of the simulation needed to be specified (i.e. water content and temperature profile through each experimental cell).

The general SoilCover model parameters used for the eight models representing the eight non-sloped experimental cells are summarised in **Table 6.4(a)**. The bottom boundary was assigned free drainage for all cells. A soil water content of 0.11 cm^3/cm^3 equal to the residual water content of fine coal discard, was assigned to the bottom node, implying that the bottom node was drained.

The material properties as required by SoilCover are summarised in **Table 6.4(b)**. The soil water retention characteristic curve for the different materials is expressed by the Fredlund & Xing (1994) empirical equation. SoilCover estimates the fitting parameters using non-linear regression techniques and then estimates the unsaturated hydraulic conductivity using the Fredlund *et al* (1994) model.

Table 6.4(a): General model parameters used for the eight soil cover models.

	Cell 1	Cell 2	Cell 3	Cell 4	Cell 5	Cell 6	Cell 7	Cell 8
Cover configuration	3.0 UC	3.0 CC	3.0 UC	0.3 UA 2.7 UC	0.5 CA 2.5 UC	0.3 UA 0.7 CE 2.0 UC	0.3 UA 0.7 CA 2.0 UC	0.7 UA 0.3 CE 2.0 UC
FE Nodes					97	98	98	98
Bottom boundary	Free drainage	Free drainage	Free drainage	Free drainage	Free drainage	Free drainage	Free drainage	Free drainage
Bottom WC	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11
Bottom temperature	20	20	20	20	20	20	20	20
Growing season start	NA	NA	October	October	October	October	October	October
Growing season end	NA	NA	May	May	May	May	May	May
Max. rooting depth (cm)	NA	NA	30	30	30	30	30	30
LAI	NA	NA	2	3	3	3	3	3

Table 6.4(b): Water retention and hydraulic characteristics of the different materials used in the SoilCover models.

	Uncompacted coal discard	Compacted coal discard	Uncompacted Avalon	Compacted Avalon	Compacted Estcourt
Porosity (dec)	0.38		0.40	0.36	0.308
Specific gravity	1.69	1.69	2.55	2.55	2.55
Saturated Hydraulic conductivity (cm/s)	5.2×10^{-3}		3.2×10^{-3}	3.0×10^{-4}	1.7×10^{-5}
Coefficient of volume change	2.0×10^{-5}	2.0×10^{-5}	2.0×10^{-5}	2.0×10^{-5}	2.0×10^{-5}
A*	1.19		1.60		54.08
N*	2.02		1.21		5.47
M*	0.68		0.27		0.04
Quartz content (dec.)	0.2	0.2	0.54	0.54	0.52
Solid specific heat (J/kg^3 C°)	850	850	850	850	850

* Soil water characteristic fitting parameters (Fredlund & Xing, 1994)

One of the drawbacks of the current version of the SoilCover model is that the maximum time period is restricted to 365 days. To accommodate this restriction, seven separate climate data files were compiled for the years 1993 to 2000. These files were compiled from climatic data measured at the experimental site and from data obtained from the South African Weather Bureau. The climatic data files used in the model are presented in **Appendix B**.

The eight models were solved in batches spanning the seven years of monitoring. The volumetric water content profile at the end of each model run was used for the initial water content profile for the subsequent model run.

The execution period for a single model run varied between 1 and 2 hours and the execution period for one experimental cell for the whole monitoring period was approximately 11 hours.

6.5 MODEL CALIBRATION

The calibration of the SoilCover model demonstrates that the modelled values are a true reflection of the actual situation. With any model, there are uncertainties of input parameters adversely affecting modelled values and the calibration process entails modifying the uncertain parameters until the modelled values reflect the actual situation. The model can then be used for prediction purposes.

The SoilCover model was calibrated to both soil water content and outflow (bottom flux). The calibration was undertaken on experimental cells 5 and 6 for which continuous soil water content profiles were obtained. Volumetric water content was calibrated to measured volumetric water content as measured by the *in situ* reflectometers installed at various depths in the two cells. Bottom flux was calibrated to outflow volumes as measured by the tipping buckets.

The calibration process entailed changing model parameters on a trial-and-error basis until the modelled volumetric water content and bottom flux reflected actual situations. Changes were thus made to the bottom boundary conditions and soil properties, ensuring that the changes were within realistic expectations.

After initial runs, it was found that the model underestimated the conductive characteristics of compacted Avalon and compacted Estcourt soils. It is considered that the *in situ* measurements of the compacted soils, other than the large diameter double infiltrometer tests, were an inaccurate reflection of field hydraulic conductivity. Excellent calibration curves were obtained after increasing the saturated hydraulic conductivity value to that measured by the large diameter infiltrometer tests.

It is believed that the small *in situ* areas tested were not representative of the compacted material. Preferential flow paths (e.g. desiccation cracks) and areas not adequately compacted might have been overlooked. It is therefore considered that the values of the large diameter infiltrometer tests, using an adequately large soil area, are more representative of the compacted soils.It has also been found that the model over-estimated the retention characteristics of the compacted Avalon and Estcourt soils. The model predicted that soil water content would remain near-saturated for the Estcourt soils which is in contrast to measured soil water contents which shows a significant reduction of soil water content, especially for the top portion of the compacted Estcourt soils.

The compaction of soils causes a reduction in average pore size by placing soil particles closer to each other And this lower average pore size retains soil water more tightly than in uncompacted soils. Compacted soils are therefore characterised by higher air-entry values and higher retention capabilities, as is evident from the soil-water characteristic curves of compacted Avalon and Estcourt soils.

It is possible that the Avalon and Estcourt soils were not adequately compacted in the field and that the soil samples used to obtain soil water retention characteristics were more adequately compacted than the *in situ* soil covers. Measured water retention characteristics could therefore have overestimated the actual retention characteristics of the field soils. After reducing the air entry values of the compacted Avalon and Estcourt soils and reducing the retention capabilities of these soils, the model simulated more accurately the soil water contents for cells 5 and 6.

The model accurately simulated soil water flow through uncompacted Avalon soils and fine coal discard and no changes were made to the hydraulic and retention characteristics of these materials. The values used in the initial model runs and values obtained after calibration are presented in **Table 6.5(a)**. The initial and modelled soil water characteristic curves are shown in **Figure 6.5(a)**.

Table 6.5(a): Initial and calibrated hydraulic and retention characteristics of compacted Avalon and Estcourt soils.

Property	Compacted Avalon		Compacted Estcourt	
	Initial value	**Calibrated value**	**Initial value**	**Calibrated value**
Porosity	0.36	0.37	0.31	0.31
Saturated hydraulic conductivity (cm/s)	3.0×10^{-4}	6.0×10^{-4}	1.7×10^{-5}	8.5×10^{-5}
A*	38.55	1.60	54.08	2.21
N*	3.32	1.21	5.47	0.88
M*	0.13	0.27	0.04	0.21

The fitting parameter A is related to the air entry value.

* Fredlund & Xing (1994) fitting parameters.

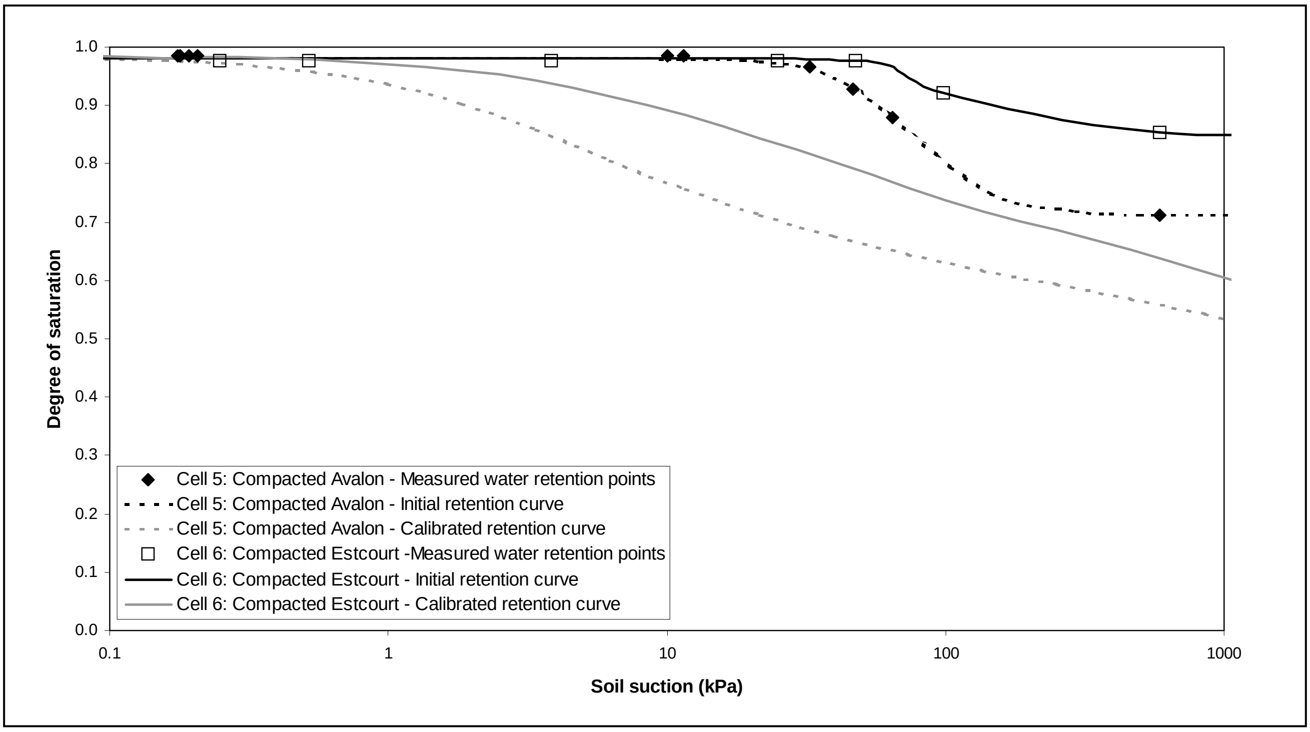


Figure 6.5(a) Initial and calibrated soil water characteristic curves for compacted Avalon and Estcourt soils

Figures 6.5(b) to **(e)** present measured and modelled volumetric water content values for experimental cells 5 and 6. The abrupt change in water content on day 55 corresponds to the infiltrometer tests conducted on that day. The infiltrometer test has been discussed in **Chapter 5** and resulted in a rapid increase of soil water content throughout the cell 6 cover.

Excellent calibration curves were achieved, suggesting that the SoilCover model is able to simulate unsaturated flow through soil covers accurately, provided that the soil properties are an accurate reflection of the field soils. The large diameter double ring infiltrometer test, rainfall infiltration, drainage and evapotranspiration were all well simulated.

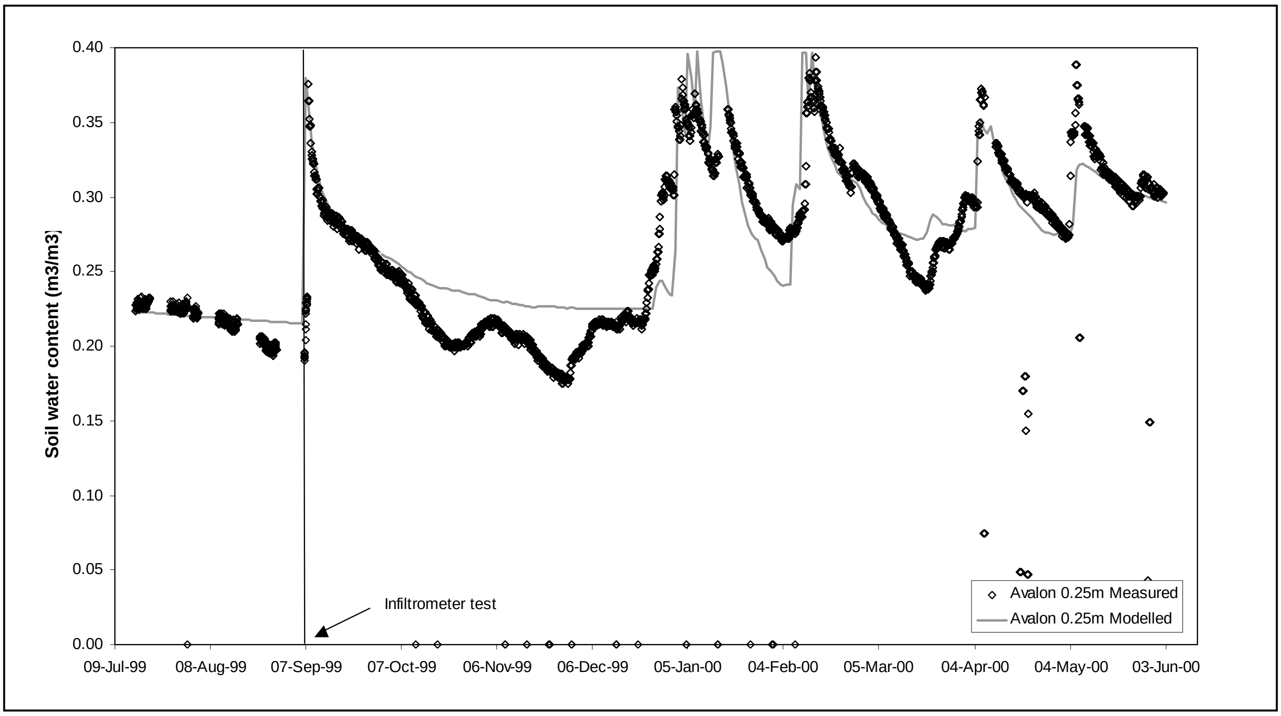


Figure 6.5(b): Measured and modelled soil water contents for cell 6 at depth 0.25m, uncompacted Avalon soils

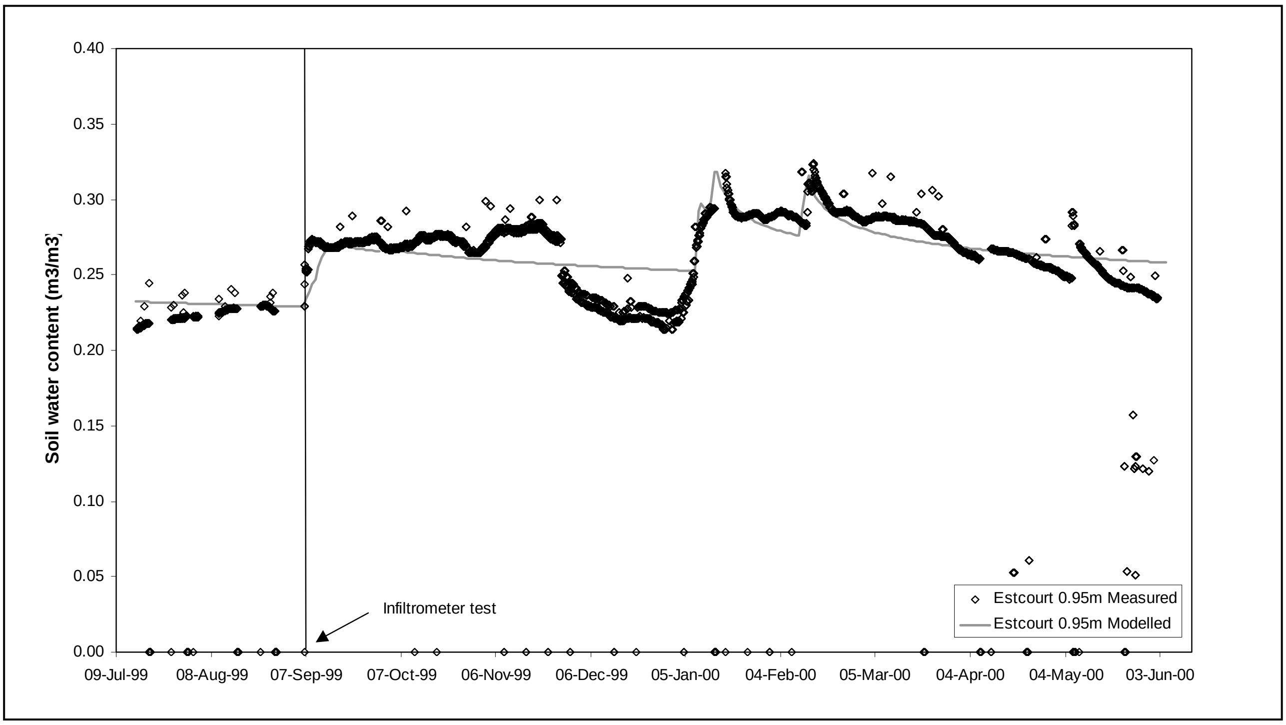


Figure 6.5(c): Measured and modelled soil water contents for cell 6 at depth 0.95m, compacted Estcourt soils.

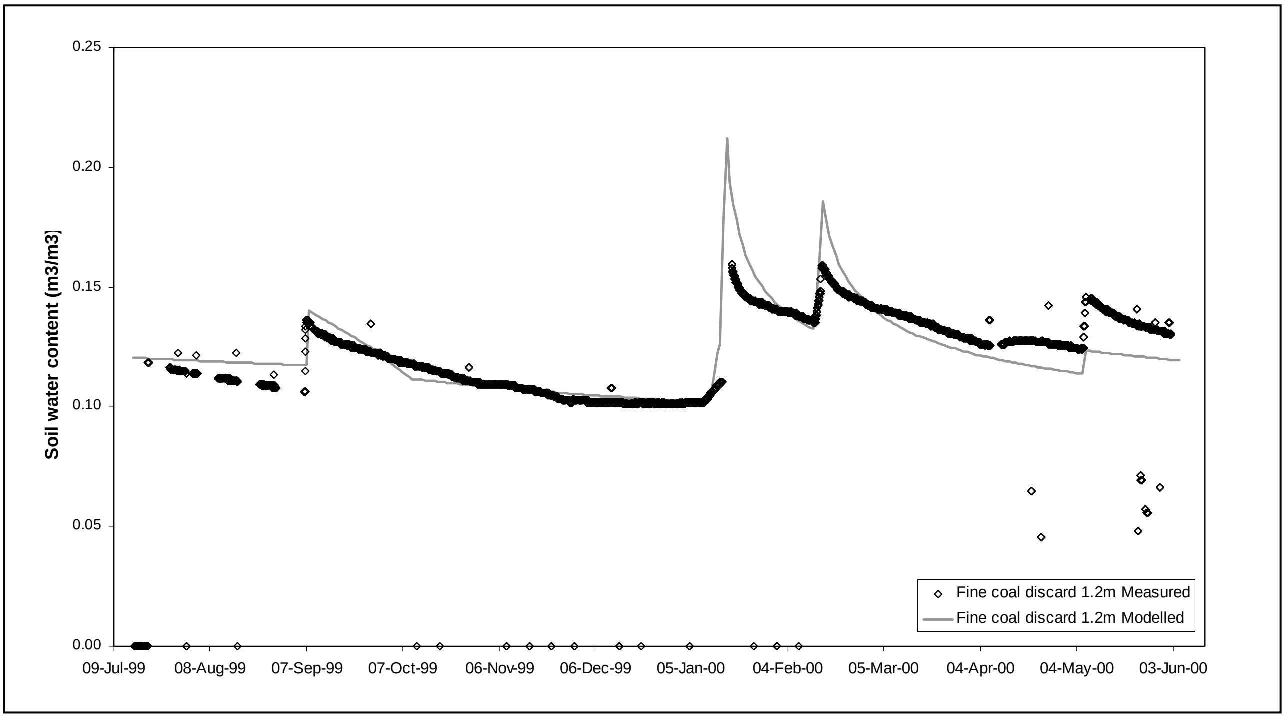


Figure 6.5(d): Measured and modelled soil water contents for cell 6 at depth 1.20 m, uncompacted fine coal discard.

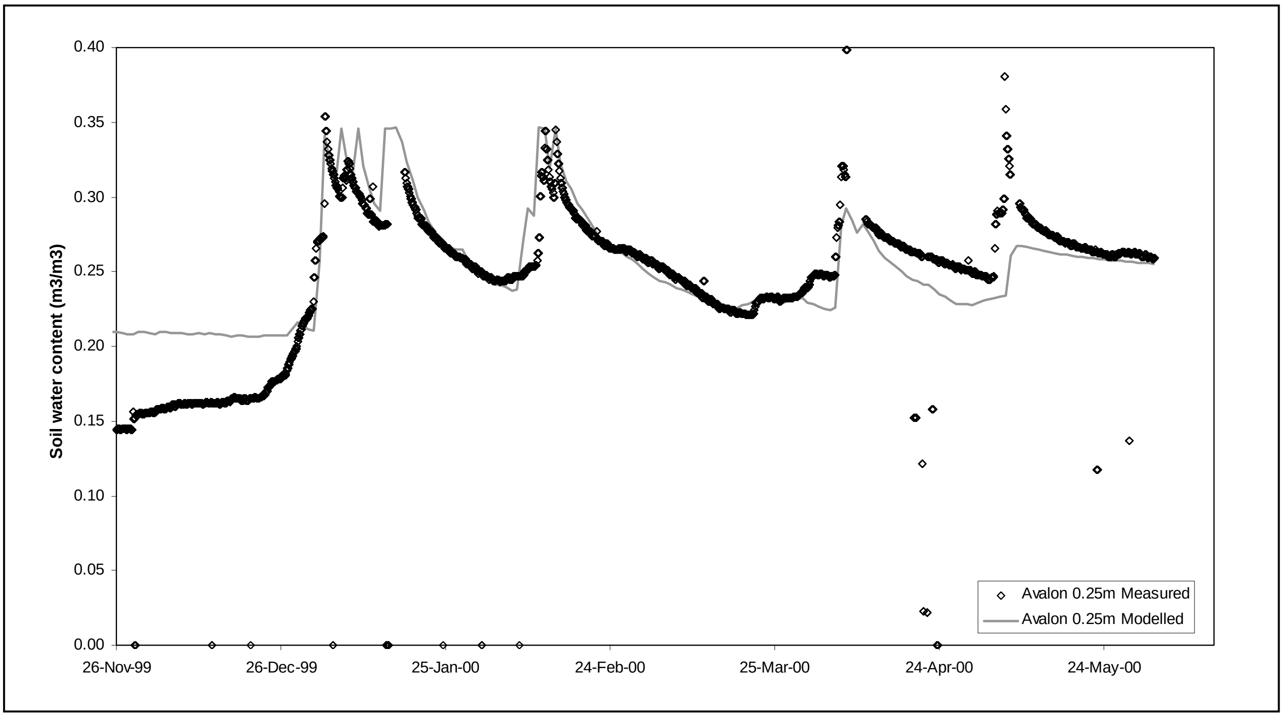


Figure 6.5(e): Measured and modelled soil water contents for cell 5 at depth 0.25 m, compacted Avalon soils

Even though excellent calibration was achieved, there were occasions when the model did not accurately simulate soil water contents. Firstly, the model over-estimated soil water content in cell 6 for the period November to January 1999 (**Figures 6.5(b)** and **(c)**). This period coincided with the start of the growing season when little rainfall fell and it is possible that the grass extracted more soil water than predicted by the model for that dry period. Since insignificant outflow occurs when the soils are dry, this will not affect outflow predictions significantly.

Secondly, the model did not accurately simulate the change of water contents resulting from the rainfall events of April 2000 and thus underestimated the soil water contents for that period (**Figures 6.5(a), (b), (c)** and **(e)**). This anomaly could therefore result in an under-estimation of outflow for that period.

Figure 6.5(d) shows that actual water contents for the fine coal discard are much lower compared with the modelled values and it is considered that the apparent discrepancy can be explained by fingering flow. As explained in **Chapter 2**, whenever breakthrough occurs in a capillary break, as in the case of cell 6, finger-like flow will occur and soil water will flow mainly along these fingers directly into the fine coal discard. It is considered that the reflectometer only intercepted a portion of these fingers and that the measured soil water content was therefore lower than expected.

Figure 6.5(f) and **(g)** show the modelled fluxes (i.e. precipitation, net-infiltration, evapotranspiration, run-off and outflow) for cells 5 and 6 in the 1999/2000 rainfall season. Modelled outflow is compared with measured outflow as provided by the tipping buckets.

Figure 6.5(f) shows that, for cell 5, 15% of precipitation resulted in run-off, 66% was removed by evapotranspiration and 17% of precipitation resulted in outflow. The results also show that the modelled outflow rates are similar to the measured outflow rates, suggesting that, once calibrated, the model is able to simulate outflow accurately. .

Figure 6.5(g) shows that, for cell 6, 10% of precipitation resulted in run-off, 78% was removed by evapotranspiration and 13% resulted in outflow. As with cell 5, outflow rates were accurately simulated, suggesting that, once calibrated, the model is able to simulate outflow through complex covers accurately.

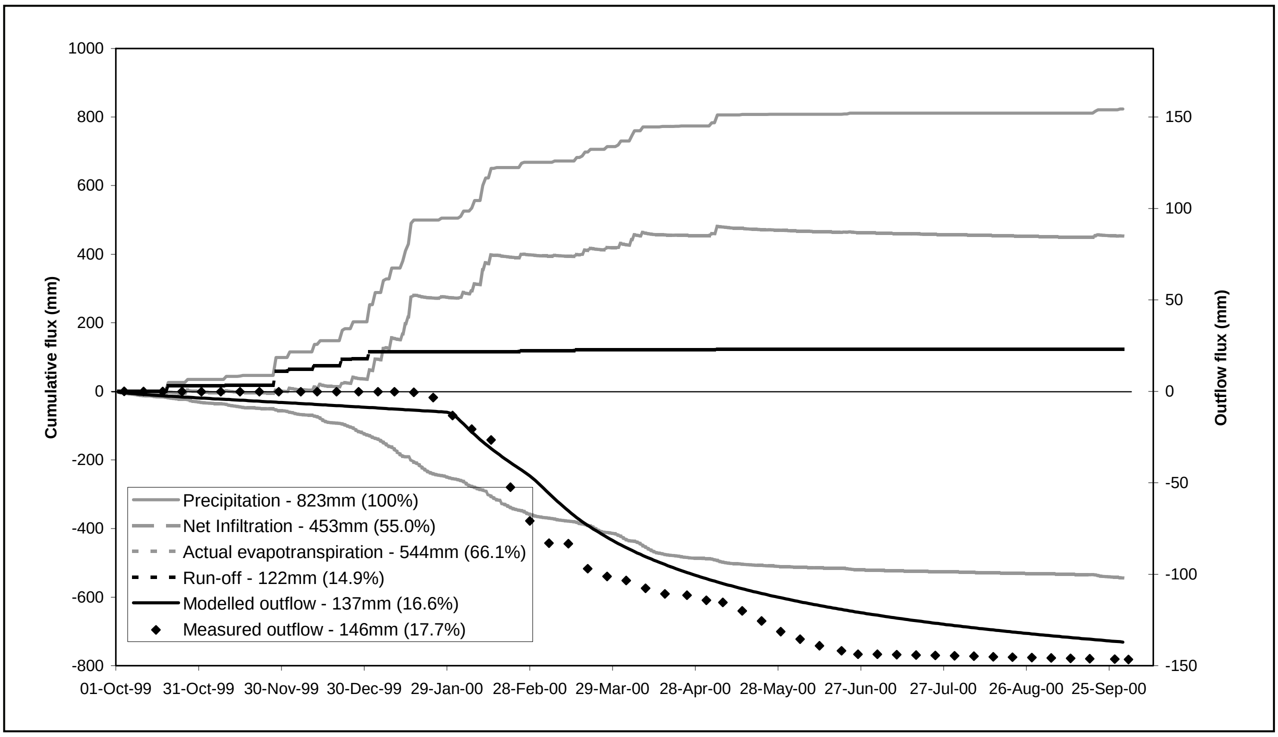


Figure 6.5(f): Modelled cumulative fluxes and measured cumulative outflow for cell 5 in the 1999/2000 rainfall season.

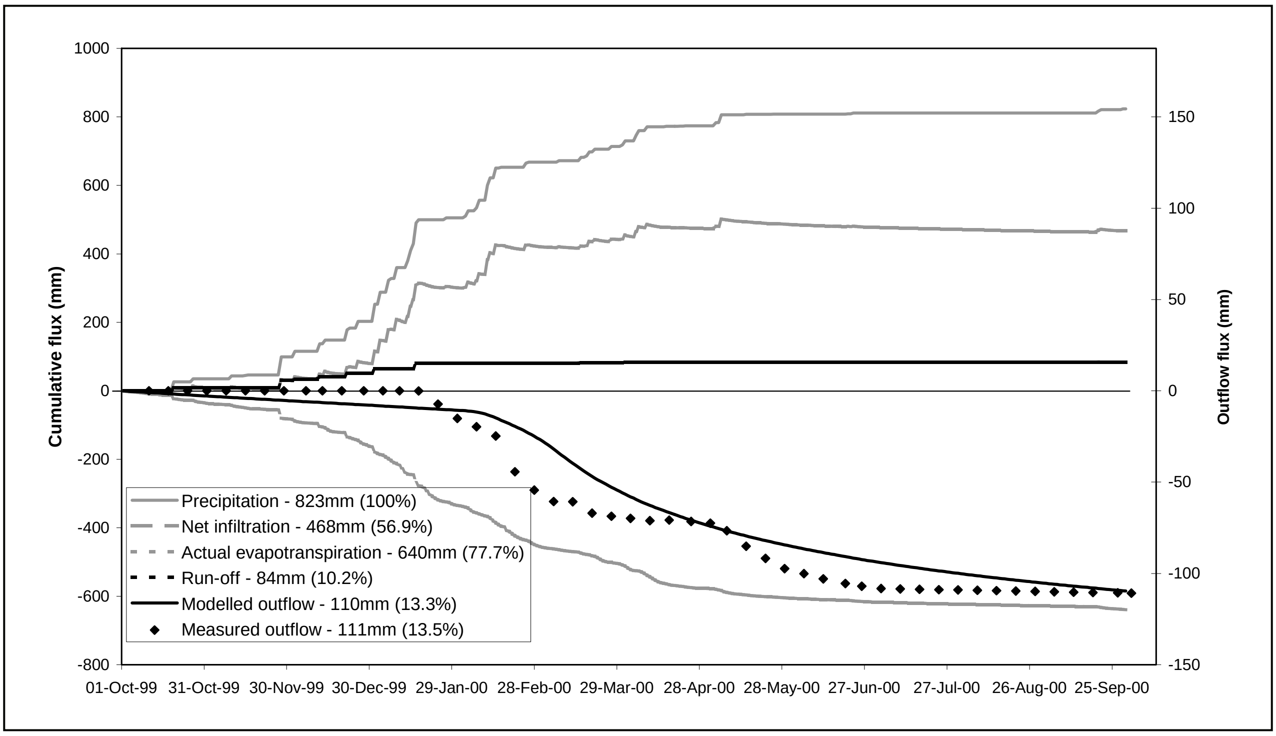


Figure 6.5(g): Modelled cumulative fluxes and measured cumulative outflow for cell 6 in the 1999/2000 rainfall season.

6.6 OUTFLOW MODELLING RESULTS

The outflow modelling results of the eight experimental covers are summarised in **Table 6.6(a)**.

Table 6.6(a): Annual outflow rates at the experimental site.

Test cell	Outflow rate (mm)							
	1994/ 1995	1995/ 1996	1996/ 1997	1997/ 1998	1998/ 1999	1999/ 2000	2000/ 2001	1994- 2001
Measured								
1	104.3	622.2	390.5	Data not reliable	273.8	319.4	92.8	1803.0
2	97.7	566.9	316.7		201.4	243.7	71.7	1498.1
3	97.8	508.8	414.0		218.5	257.7	N.M.	1496.8
4	16.0	395.4	274.4		144.0	185.2	59.4	1074.4
5	4.4	284.8	221.7		117.0	145.7	10.5	784.1
6	21.9	294.5	106.7		87.2	111.1	15.0	636.4
7	26.2	131.3	15.2		38.3	5.8	0.1	216.9
8	21.9	243.3	187.6		45.4	40.3	3.2	541.7
Modelled								
1	222.1	618.5	423.8	Not calculated	243.4	294.2	101.6	1903.6
2	190.2	582.8	382.6		192.4	248.7	72.2	1668.9
3	218.1	592.5	410.4		231.4	294.2	N.C.	1746.6
4	137.1	421.2	253.1		131.6	190.2	58.7	1191.9
5	102.4	321.6	283.1		112.8	136.8	18.2	974.9
6	94.0	282.9	121.3		82.3	110.4	22.1	713.0
7	22.1	114.4	31.6		21.0	16.0	5.2	210.3
8	52.1	242.2	153.2		42.3	52.1	25.3	567.2
Rainfall	**729.1**	**1382.6**	**1172.8**		**709.3**	**823.2**	**466.8**	**5283.8**

The model over-predicted the outflow of all cells except cell 7. The high modelled outflow rates stem from the over-prediction of outflow for the 1994/1995 rainfall year. There is no explanation for the exceptionally low measured outflow rates for that year, considering that rainfall was similar to that of 1998/1999. Apart from that year, the model was able to simulate outflow trends for the different rainfall years accurately and was also able to simulate outflow trends for the different cover configurations fairly accurately. However, modelled values are not always similar to measured values.

It is concluded that the model can be used to estimate outflow through soil covers fairly accurately, provided that the hydraulic and water retention characteristics of the covers accurately reflect the field soils. It should be remembered that the fairly accurate predictions of outflow could only be made after changing the soil properties in the model and were it not for those changes, predicted outflow would have been considerably underestimated.

The results therefore suggest that the use of models prior to cover construction should be restricted to the performance comparison of different cover configurations for different climatic situations (i.e. wet, average and dry years). Modelled outflow rates are not necessarily accurate reflections of what may be expected after cover construction, because the hydraulic and retention characteristics of the *in situ* cover material is not known.

After deciding on an optimal cover configuration, the performance of that cover configuration should be tested by means of field trials. The experimental covers should be monitored and soil water content and outflow measured. Changes may then be made to the model so that the model reflects the *in situ* properties of the cover soils. Only then can modelled outflow rates be used with more confidence, allowing cover configurations to be changed according to the results of the field trials.

CHAPTER 7

LEACHATE QUALITY

7.1 INTRODUCTION

The main processes determining the quality of leachate from coal discard facilities are pyrite oxidation and pH buffering. In general, these processes have the effect of acidification and salinisation of water percolating through the discard material. The processes are very complex in nature and are determined by site-specific factors listed in **Table 7.1** (Morin and Hutt, 1997).

Table 7.1: Key factors affecting pyrite oxidation and acid 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 in each of the cells at the experimental site have been influenced by these physical, chemical and biological processes. It can therefore be assumed that the recorded leachate qualities are indicative of the ability of the different soil covers to inhibit or accelerate the various geochemical processes associated with the discard material.

Apart from the leachate qualities that were recorded, oxygen concentrations and temperature (Cell 6) were also monitored. All this data together provide an excellent opportunity to evaluate the ARD prevention potential of the various soil covers and combinations of soil covers used in the Kilbarchan experiment under controlled boundary conditions.

7.2 EVALUATION OF LEACHATE QUALITY TRENDS

7.2.1 TIME SERIES AND STATISTICAL EVALUATION

Statistical analyses were conducted of the mean, average, maximum, minimum and standard deviation of the recorded leachate qualities of the respective cells. All leachate data and their statistical analyses are shown in **Appendix C**. Also included in **Appendix C** are time series plots of key water quality variables, including Ca, Mg, SO_4, Alk, pH, Mn, Fe, and Al, for each of the cells. At the bottom of each data table are key statistical summary data including mean, average, minimum, maximum and 95 percentile.

There are various data gaps in the leachate quality database during the last two years, caused by fire damage to the instrumentation.

Table 7.2.1 presents a summary of key trends in chemical parameters as reflected by the time series plots for each cell (**Appendix C**).

Table 7.2.1: Summary of key trends in leachate quality data.

Uncovered cells: Cell 1, Cell 2 and Cell 3

- An acid breakthrough has occurred in Cell 1 during the latter part of 1997. This is reflected in a sharp decrease in pH (over a two-week period) and an increase in metal concentrations. This is a very quick breakthrough since one would have expected a stepwise decrease in pH as a result of buffering caused by secondary minerals. This is perhaps indicating that secondary precipitation of minerals was either prevented or flushed from the discard.
- An increase in Fe concentration was recorded, due to lower pH conditions, probably catalysed by bacterial reactions and the oxidation of Fe^{2+} to Fe^{3+}, decreasing the pH even further.
- The decrease in pH recorded in Cells 2 and 3 during 2000 seems to be controlled by buffering processes associated with secondary minerals such as Fe and Al compounds. Cells 2 and 3 have broken through the buffering processes in 2001, with pH values at 3.7 and 4.9 for the respective cells.
- Both Cells 2 and 3 show a gradual decrease in alkalinity and an increase in Mn and SO_4 concentration due to the lower pH. In Cell 1, an increase in Mg concentration just prior to the acid breakthrough was recorded. A similar increase in Mg concentration is recorded at Cell 2.
- The Ca concentration in all three cells stayed relative constant at approximately 500mg/l regardless of a change in pH. This is mainly due to gypsum solubility controlling the concentration of Ca and SO_4 in solution (see Section 7.2.3).

Single layer soil covered cells: Cell 4 and Cell 5

- Cell 4 turned acidic in February 2000:
  - An increase in the Fe concentration is a result of acidic pH levels.
  - An increase in Mg, Mn and SO_4 concentration levels reflect the increasingly acidic conditions.
  - The constant Ca concentration is mainly due to the solubility of gypsum, controlling Ca and SO_4 in solution.
- The pH levels, Mg and SO_4 concentration recorded at Cell 5 do not show any signs of acid breakthrough.
  - A slight increase in Mg and SO_4 levels might be indicative of the start of acidification.

Multi-layered soil covered cells: Cell 6, Cell 7 and Cell 8

- A very stable chemical trend is indicated in these cells. SO_4 and Fe indicate no concentration change, as pH values stay neutral at 8.05 in Cell 6 and 7.6 in both Cells 7 and 8.

Multi-layered sloped soil covered cells: Cell 9 and Cell 10

- Cell 9 has not yet turned acidic, but shows signs of acidification with an increase in metals, Mg and SO_4 concentration levels. Both the top and bottom samples appear to reflect the same chemistry since early 2001.
- Cell 10 turned acidic in April 2000 and shows an increase in Mg and SO_4 concentration levels over time. Both the top and bottom samples appear to reflect the same chemistry since early 2001. Acidification at this steeper sloped cell needs to be explained.

Statistical analyses undertaken on the leachate quality data from the cells show very strong correlation between pH, SO_4 and metals, including Mn, Al, and Fe (Rykaart *et al*, 2001). This is expected due to the sensitivity of the metals' solubility to pH. Al was well correlated with Mn but Fe and Mn were not well correlated. This is mainly due to their different pH metal solubilities, with Mn being more soluble at higher pH levels than Fe. It could also be due to the presence of different redox states of Fe. Ferrous or reduced Fe^{2+} is more soluble at neutral pH levels than ferric or oxidised Fe^{3+} which is only soluble at lower pH levels and precipitates from solution at neutral pH levels (Bezuidenhout *et al*, 2000).

Good correlation was found between Mg and SO_4 indicating the reaction of base minerals, probably Ca and Mg carbonates, to the production of acidity of which SO_4 is an indication. The lack of significant correlation between Ca and SO_4 is because the concentration of Ca in SO_4-rich waters are known to be controlled by gypsum ($CaSO_4.2H_2O$) mineral solubility (Bezuidenhout *et al*, 2000).

Water type analyses of the leachate qualities revealed that the neutral saline leachate waters are characterised by Mg-Ca-HCO_3-(SO_4) systems, whereas the acidic leachate waters are characterised by Mg-Ca-SO_4 (Rykaart *et al*, 2001).

7.2.2 ACID ROCK DRAINAGE (ARD) POTENTIAL EVALUATION

Acid Base Accounting analyses of samples of the discard material indicated that the materials have excess Acid Potential compared with Neutralisation Potential (NP) and that it is possible for the material to generate acidic drainage (Loos *et al*, 1998).

Covers which do not cut-off oxygen and water supply completely are expected eventually to produce acidic drainage. The reason why certain cells have not yet turned acidic is therefore a function of the ability of the cover material or remediation method to help inhibit water and/or oxygen supply.

The potential of the discard material to produce acidic leachate is substantiated by the acid breakthrough recorded during the latter part of 1997 in Cell 1 where the discard material was uncompacted and exposed to natural weathering processes. Paste pH of discard samples taken from the top of the discard cells for microbiological studies indicated that the discard pH of all cells except Cells 6 and 8 decreased for the period 1993 to 1997 (Loos *et al*, 1998).

Although the initial leachate qualities of Cell 1 had neutral pH levels, ARD processes were already taking place in the cells. At that time, however, sufficient buffering capacity was available to neutralise the acidity produced by the ARD processes, leading to an increase in salinity levels. Acid breakthrough took place in the latter part of 1997 when all NP was consumed and resulted in acidic leachate, buffered only by hydrated Fe oxides. This pH decrease to acidic levels took place over a two week period and was not in a step wise fashion as expected. This possibly indicates how quickly the NP can be consumed in an open system and how much neutralisation can be retained in the form of secondary minerals.

It can therefore be assumed that, where any cell cover does not completely exclude or prevent oxygen and water ingress, ARD processes will take place and eventually consume all available NP. The question of how long the various covers and combination of covers may postpone or prevent the onset of acidic drainage remains.

As indicated in **Section 7.2.1**, Cells 2, 3, 4 and 10 are showing signs of turning acidic, observed through a general decrease in pH and alkalinity and increases in Mg, SO_4 and metals concentration levels. This indicates that, even for cells that are either compacted and ameliorated *in situ* or covered with a single layer of soil material, this does not prevent the significant ingress of oxygen or water and results in postponing acid breakthrough for only 2-3 years. Due to the expected retention of secondary mineral buffering capacity caused by lower recharge rates, however, acid breakthrough is expected to occur over a longer period than happened with Cell 1.

The acid breakthrough in Cell 10 is anomalous since it is the only multi-layer covered cell showing any signs of active ARD processes. One possible explanation for the anomaly is the presence of advective airflow caused by preferential flow paths in the retaining brick wall on the lower side of the cell. The brick wall was not cemented and it is possible that airflow was induced through openings between the bricks during differences in barometric pressures and perhaps through diffusion.

7.2.3 EVALUATION OF ONSET OF ACIDIC DRAINAGE

In order to develop an understanding of the factors indicating the onset of acidic drainage, four methods of analysis were used to investigate empirical relationships that could provide indications of when the leachate will turn acidic as a function of discard material, leachate quality and cover geometry. These methods include:

- Analysis of mineral solubility and chemical speciation
- Analysis of concentration vs. time of selected chemical species

- Analysis of molar ratios of selected chemical species and their change over time, and
- An assessment of the rates at which acidity is produced and neutralisation capacity is consumed.

MINERAL SOLUBILITY AND CHEMICAL SPECIATION ANALYSIS

The geochemical speciation software, MINTEQA2, was used to evaluate the possible mineral species which are likely to be in equilibrium with the leachate from the cells during different periods in the monitoring period. The aim of the analysis was to evaluate any changes in the MINTEQA2-predicted equilibria occurring during the monitoring period that would indicate the onset of acidic drainage. The water quality data recorded for Cell 1 was used for the analysis because acid breakthrough had occurred and distinct acid drainage had been recorded for that cell. Leachate qualities from the beginning, middle and end of the monitoring period s selected and speciated with MINTEQA2.

The results of the analysis indicate that, for all cells, Al will precipitate from solution, probably in the form of Al-OH minerals, and that the leachate is in equilibrium with gypsum. To maintain this equilibrium, MINTEQA2 predicted that a proportion of the Ca and SO_4 in solution will precipitate from solution, indicative of the mineral solubility of gypsum.

The results of the analysis also indicate that neutral drainage water and acid drainage water will have different minerals in equilibrium. To demonstrate this, the MINTEQA2 results for Cell 1 for the beginning, middle and end of the monitoring period are shown in **Table 7.2.3**. The beginning and middle readings are during neutral drainage and the last reading is after the drainage has turned acidic.

Table 7.2.3 indicates that the leachate was predicted to be in equilibrium with gypsum, regardless of the pH of the leachate. This coincides with the time series trend analyses which show Ca concentrations to be stable across the acid breakthrough since the concentration of Ca in solution is controlled by gypsum precipitation.

For the neutral leachate recorded during the beginning and middle of the monitoring period, minerals such as leonhardite, diaspoor, anite and $MnHPO_4$ were predicted to be in equilibrium with the leachate. After the acid breakthrough, MINTEQA2 predicted that none of these minerals, except gypsum, would be in equilibrium. However, additional minerals which MINTEQA2 predicted to be in equilibrium after the pH breakthrough include hematite and $Al(OH)_3$. Assuming that all Fe was in the Fe^{2+} state, hematite was predicted because a relative oxidizing redox state was set (Eh 400mV) for the leachate, resulting in some of the Fe^{2+} being oxidised to Fe^{3+} during water movement through the cells. The reason why hematite was predicted and not goethite (FeOOH) is unclear but is, however, expected to be related to the activity ratios of species and Fe^{2+} in solution. The Fe^{2+} was predicted to stay in solution (Stumm and Morgan, 1981).

Table 7.2.3: MINTEQA2-predicted mineral Saturation Indices (SI) for selected water qualities recorded in Cell 1.

Mineral and formula	Beginning	Middle	End
Anhydrite ($CaSO_4$)	-0.21	-0.21	-0.21
Diaspore (AlO(OH))	0	0	-2.33
Gypsum ($CaSO_4$*$2H_20$)	0	0	0
Kaolinite ($Al_2Si_2O_5(OH)_4$)	-0.65	-0.56	-0.91
Leonhardite (hydrated Ca-Al-silicate)	0	-0.67	-33.562
Anite (hydrated K-Al-silicate)	0	np	-26.8
$MnHPO_4$	0	0	-1.028
$Al(OH)_3$	np	np	0
Hematite (Fe_2O_3)	np	np	0
Leachate pH	7.4	7.6	2.8

np → not predicted

ANALYSIS OF CONCENTRATION VS TIME OF SELECTED CHEMICAL SPECIES

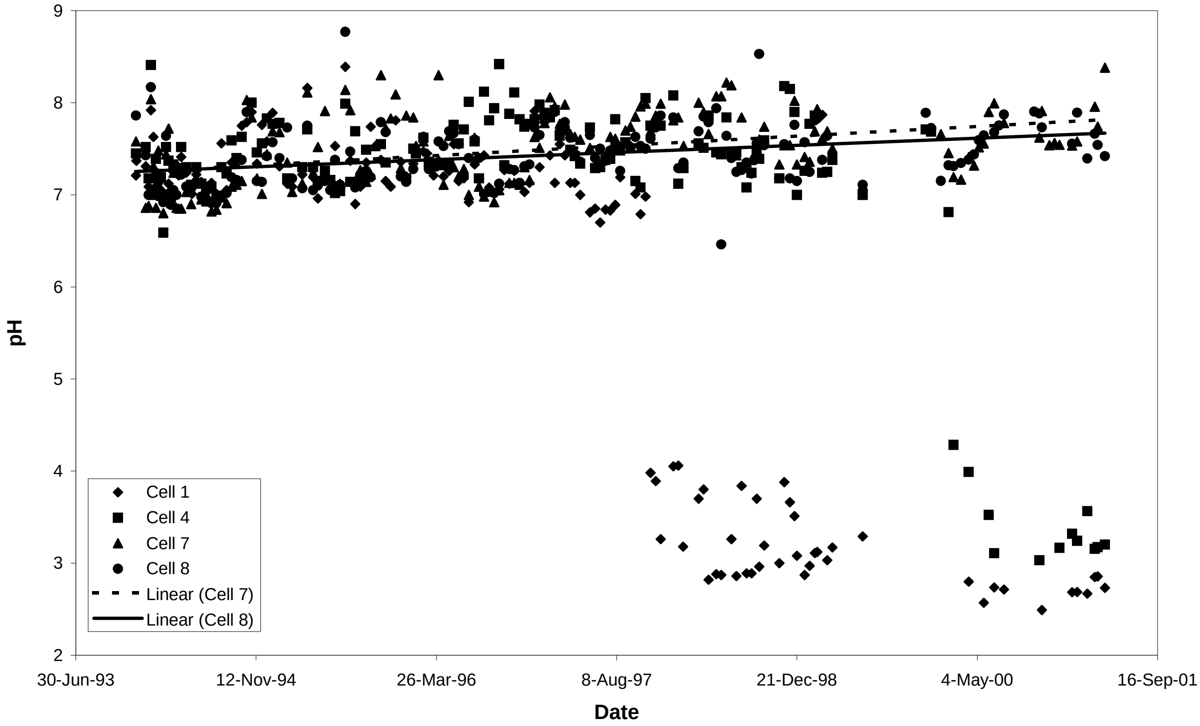
This assessment is based on the change in specific element concentration over the study period. The Ca concentrations reflect acid neutralisation, while the SO_4 concentrations reflect acid production.

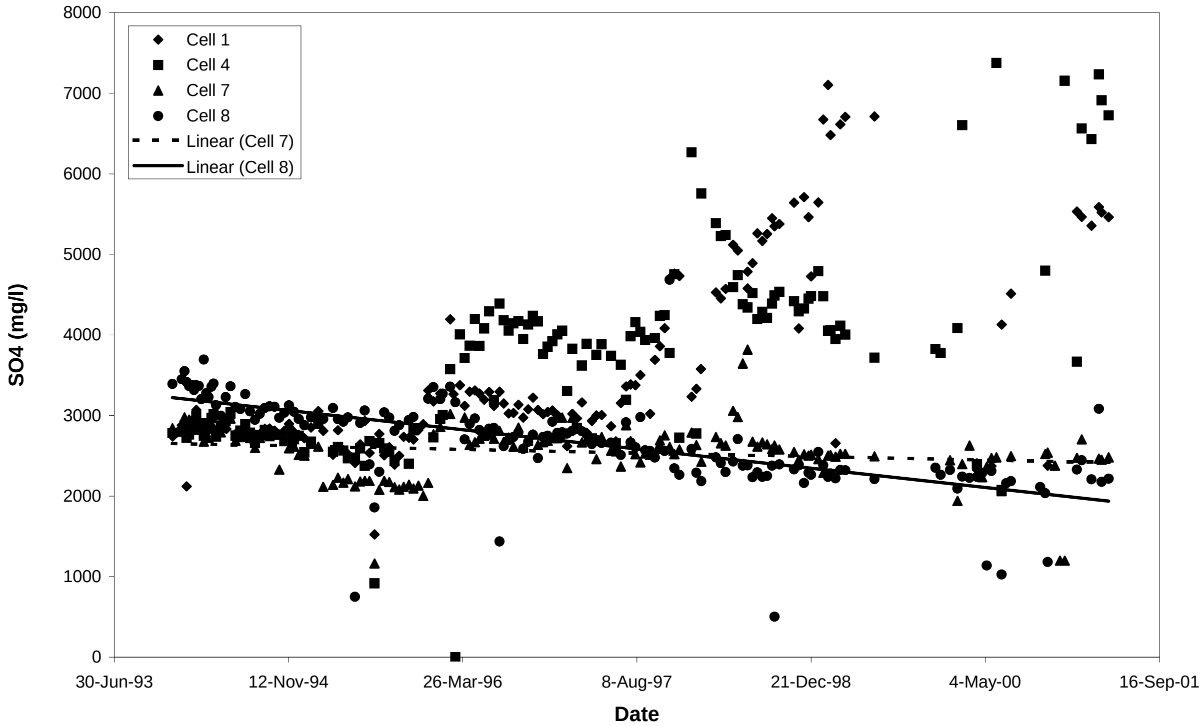
The pH, Ca and SO_4 concentrations for Cells 1, 4, 7 and 8 have been plotted on graphs and are presented in **Figure 7.2.3 (a)**. The cells were grouped to represent uncovered, single layer covered and multi layer covered discard cells. The following key inferences can be drawn from **Figure 7.2.3 (a)**:

- All cells start with pH values at a neutral level. Acidification of Cell 1 at the latter part of 1997 and Cell 4 in February 2000 is clearly indicated. The continuing neutral pH values in Cells 7 and 8 indicate that there is a balance between the acidity produced and the neutralisation of that acidity by possible carbonate minerals.
- The expected increase in SO_4 concentration due to pyrite oxidation / acid generation in Cells 1 and 4 is clearly visible during the latter part of 1997 for Cell 1 and in February

2000 for Cell 4. No SO_4 concentration increase is visible for Cells 7 or 8 and demonstrates the effective oxygen and water infiltration prevention of the multi-layered cover

- Cells 1 and 4 indicate a drop in Ca concentration over the study period due to the buffering potential of the carbonate minerals being exceeded by the increased acid`-generating processes in these cells. The trend lines for Cells 7 and 8 show a slight increase in Ca concentration with time which is controlled by the precipitation of gypsum.





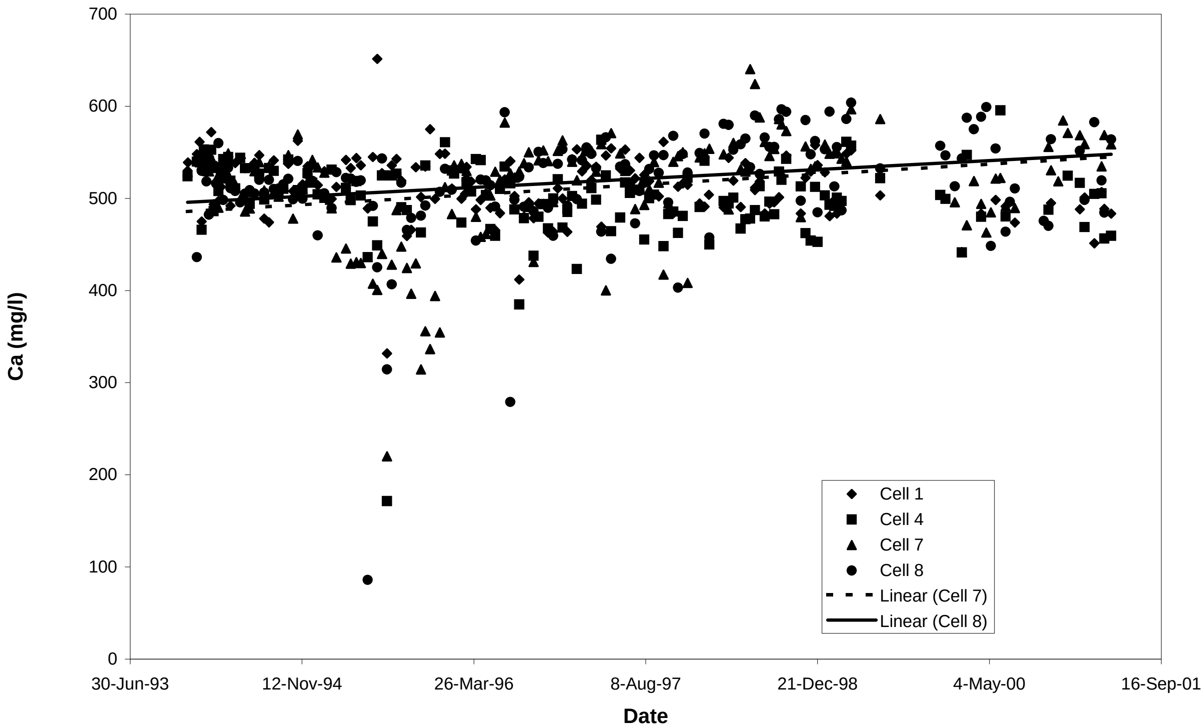


Figure 7.2.3(a): pH, Ca and SO_4 concentrations over time for Cells 1, 4, 7 and 8.

MOLAR RATIOS OF SELECTED CHEMICAL SPECIES

This assessment is based on the molar ratios of Ca+Mg compared with that of SO_4 over the monitoring period. The Ca and Mg molar values refer to the release of Ca and Mg from typical carbonate base minerals during acid neutralisation. The SO_4 molar values are used as a direct measure of acid production. This is not always true for SO_4 and Ca since their concentrations in solution are also a function of the solubility of gypsum.

The pH, Ca and SO_4 concentrations for all cells have been plotted on graphs and are presented in **Figure 7.2.3(b)**. The cells were grouped to represent uncovered, single layer covered and multi-layer covered discard cells. The following key inferences can be drawn from **Figure 7.2.3(b)**:

- All cells start with molar Ca, Mg and SO_4 ratios slightly above one, except the sloped multi-layer covered cells 9 and 10. Molar ratios close to one indicate that there is some sort of balance between the acidity produced and the neutralisation of that acidity by possible carbonate minerals. It is not clear at this stage why the sloped multi layer covered cells start with molar ratios slightly below one, but could be explained by different equilibrium conditions caused by different material properties.

- Since SO_4 will increase due to pyrite oxidation/acid generation relative to the Ca and Mg produced by neutralisation, the molar ratio is expected to change once all neutralisation capacity is consumed.. This can be clearly seen in Cell 1 where the molar ratio decreased to approximately 0.4 after the pH breakthrough in the latter part of 1997.

- Although the leachate quality trends suggest that Cells 2, 3, 4 and 10 show signs of turning acidic, this is not as clear in their calculated molar ratios. All four of these cells, however, showed molar ratios of less than one during the last year, although not at the levels recorded for Cell 1 after the acid breakthrough. It is expected that acidification of the leachate in these cells will take place over a longer than in Cell 1 where the changeover took only two weeks.

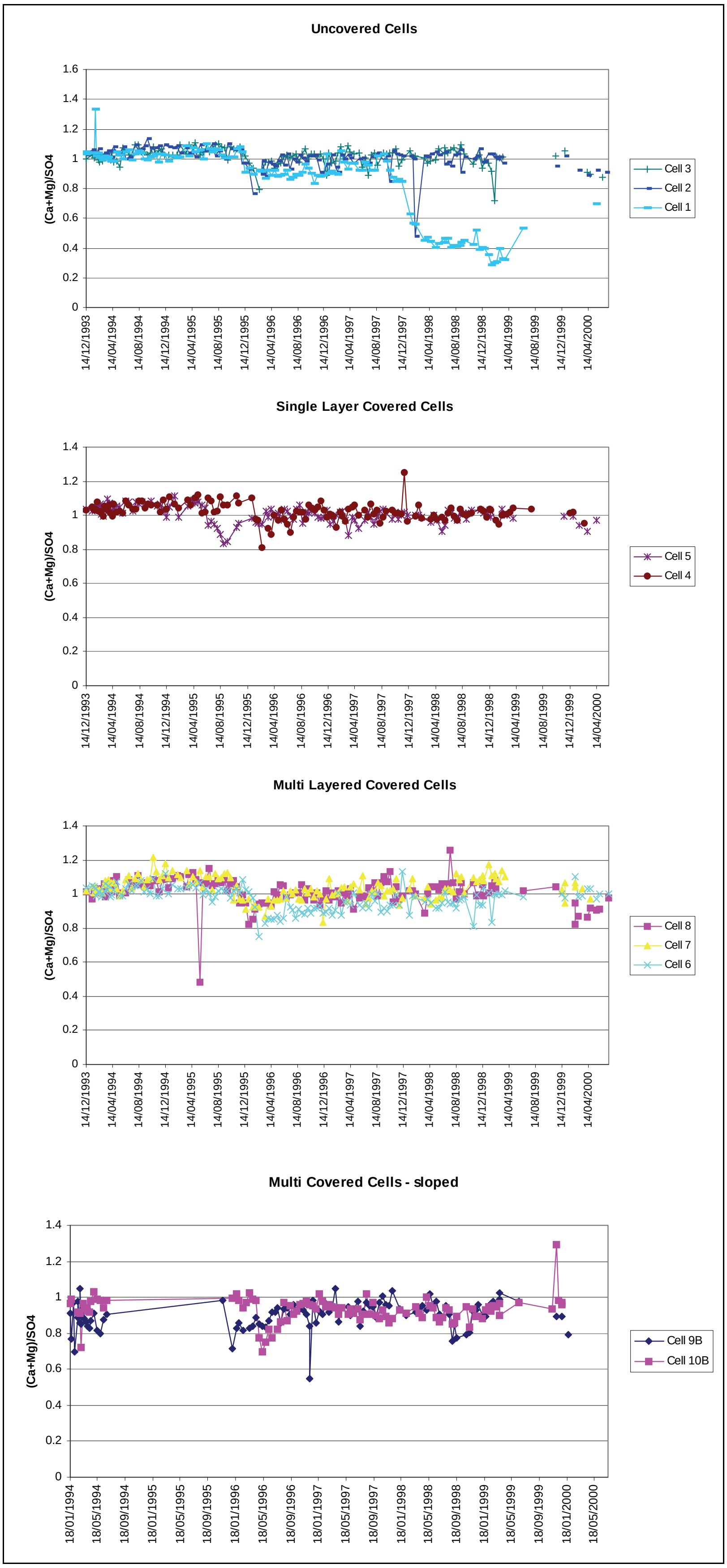


Figure 7.2.3(b): Ca, Mg and SO_4 molar ratios over time for all cells.

ACID GENERATION AND NEUTRALISATION RATE ASSESSMENT

This assessment is based on the Acid Generation Rate (AGR) and Neutralisation Consumption Rate (NCR) calculated from the water quality and flow results recorded in the cells. The calculations were based on algorithms similarly used for humidity cell results as provided by Morin and Hutt, (1997).

For comparative purposes, only Cells 1, 4 and 8 were analysed, representing uncovered, single layer covered and multi-layer covered discard cells. The calculated AGR and NCR for Cells 1, 4 and 8 are presented graphically in **Figure 7.2.3 (c)** which the following inferences were drawn:

- There is very little difference between the AGR and NCR calculated for Cell 8. This suggests that acidity produced by ARD processes is neutralised at the same rate by base minerals.
- For Cell 1 and immediately after the acid breakthrough, significant differences were recorded between the calculated AGR and NCR. The high AGR suggests the influence of bacteria and it is possible that localised pockets of acidity created favourable conditions for bacteria to grow which led to an explosion in bacteria populations and resulted in high AGR. This high level of acidity generation could be so large in comparison with the neutralisation capacity created by the secondary minerals that the sharp decrease in pH over a short period of time rather than a stepwise decrease can be explained.
- Various periods were recorded for Cell 4 when AGR’s were higher than NCR’s. This would suggest that an acid breakthrough should have taken placebut it is only just starting to show signs of turning acid. Possible explanations for this anomaly are:
    - Formation of acid pockets within the discard matrix.
    - Finger flow or preferential flow taking place through the various acid and neutral components of the discard matrix. It is possible that acid pockets situated in the main flow path are flushed to the bottom of the cell without having sufficient time to react with base minerals to neutralise the acidity. However, other neutral leachate might have sufficient base capacity to buffer against the acidity skewing the ratio between SO_4 and Ca+Mg.

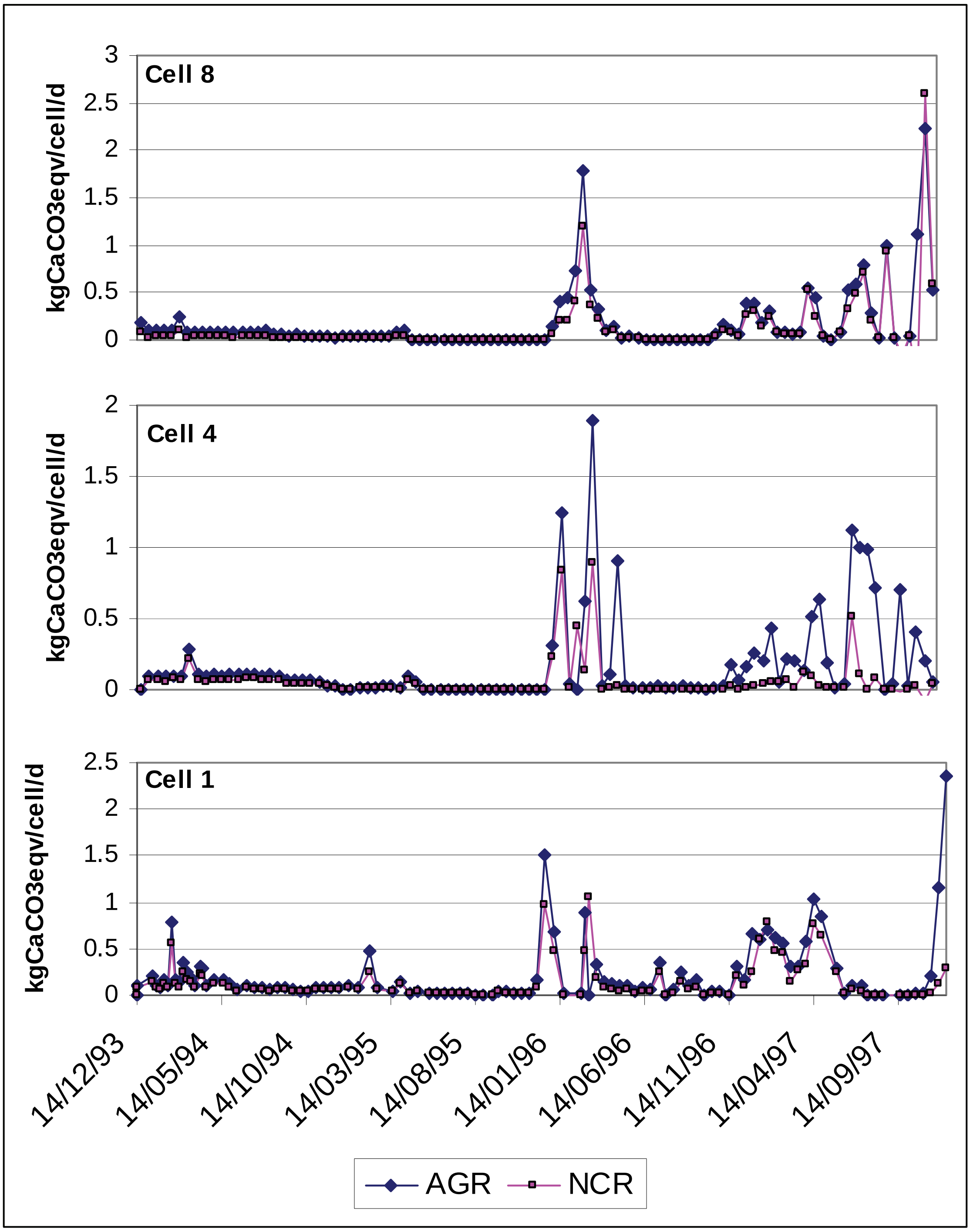


Figure 7.2.3 (c): Acid Generation Rate (AGR) and Neutralisation Consumption Rate (NCR) calculated for Cells 1, 4 and 8.

The AGR and NCR graphs track each other, with the AGR generally slightly higher than the NCR. This suggests that sufficient buffering capacity, in the form of neutralising minerals, is available in the cells to cope with variations in the amount and rate of acidity produced through oxidation processes.

Variations in the calculated AGR and NCR are mainly due to high recharge rates causing high leachate volumes and mobilisation of salt.

The results of the evaluation are summarised in **Figure 7.2.3(d)**, which is a plot of the AGR:NCR ratios for Cells 1, 4 and 8. The AGR:NCR for Cell 4 is similar to that of Cell 1, except at the end of 1996 and 1997 when large variations in AGR and NCR were recorded for Cell 4. From **Figure 7.2.3 (d)**, it can be seen that the AGR:NCR ratio for the uncovered cell increases with time, especially after the pH breakthrough in the last part of 1997. This indicates the rate at which excess acid is being generated in the discard material through oxidation processes. The AGR:NCR ratios for Cell 8 decrease with time, indicating a reduction in oxidation processes and consequent neutralisation. This decrease in AGR:NCR ratios therefore suggests that acidic mine drainage processes are decreasing in Cell 8.

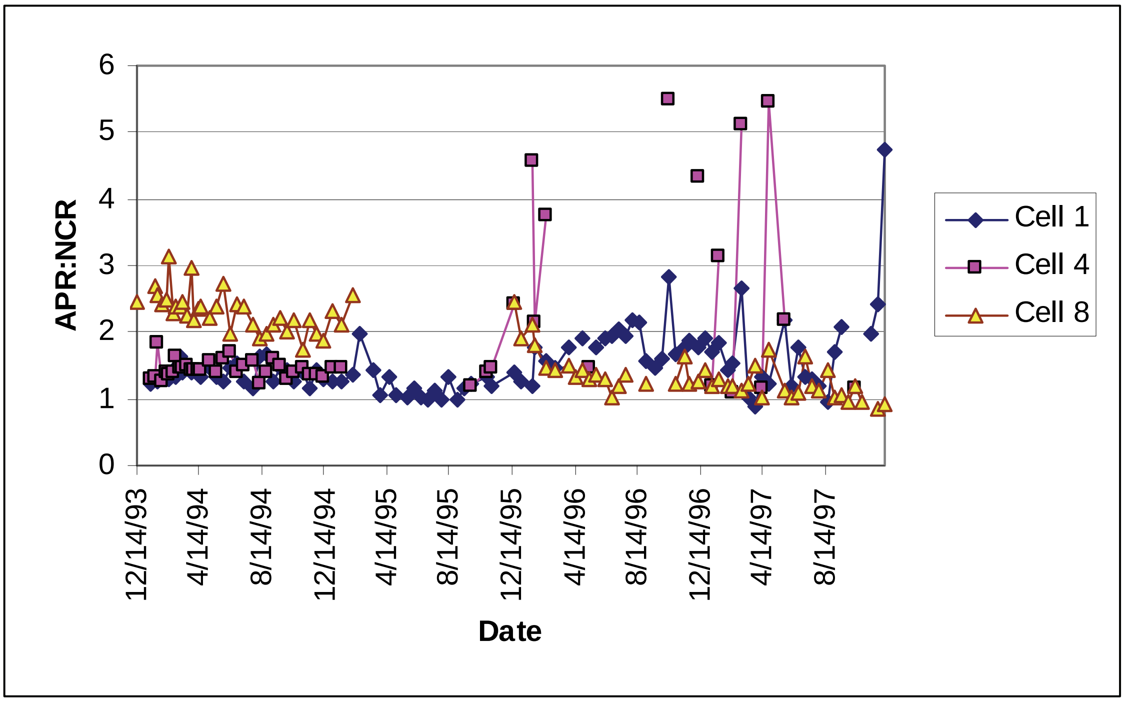


Figure 7.2.3 (d): Acid Generation Rate (AGR): Neutralisation Consumption Rate (NCR) ratios for Cells 1, 4 and 8

7.3 OXYGEN INGRESS AND ITS RELATIONSHIP WITH LEACHATE QUALITY

The research has shown that there is a prominent relationship between oxygen ingress and leachate quality for the experimental cells. This relationship is demonstrated in **Figures 7.3(a)** and **(b)** which show the oxygen and sulphate concentrations of two cells and the rainfall that occurred during the experiment period. **Figure 7.3(a)** shows the result for Cell 4, covered by 0.3 m uncompacted Avalon soils. As indicated by the high oxygen concentrations which are similar to atmospheric oxygen concentrations, it is evident that the cover is not effective in limiting oxygen ingress.. The high oxygen concentrations resulted in high sulphide oxidation rates, evidenced by the sulphate concentrations, which increased during this period and resulted in acid drainage in June 2000.

Figure 7.3(b) shows the results for Cell 8, covered by 0.7 m uncompacted Avalon topsoil overlying 0.3 m compacted Estcourt soils. It is evident that the cover is effective in limiting oxygen ingress as can be seen by oxygen concentrations of almost 0% for most of the monitoring period. The exception occurs during the latter parts of 1995 and 2000 which correspond to exceptionally dry seasons. It is hypothesised that preferential oxygen ingress occurred through desiccation cracks which developed during this period. Nonetheless, the results suggest that the low oxygen concentrations impeded sulphide oxidation. The low oxidation rates resulted in leachate quality actually improving slightly with time, as can be seen by the decreasing trend of sulphate concentrations.

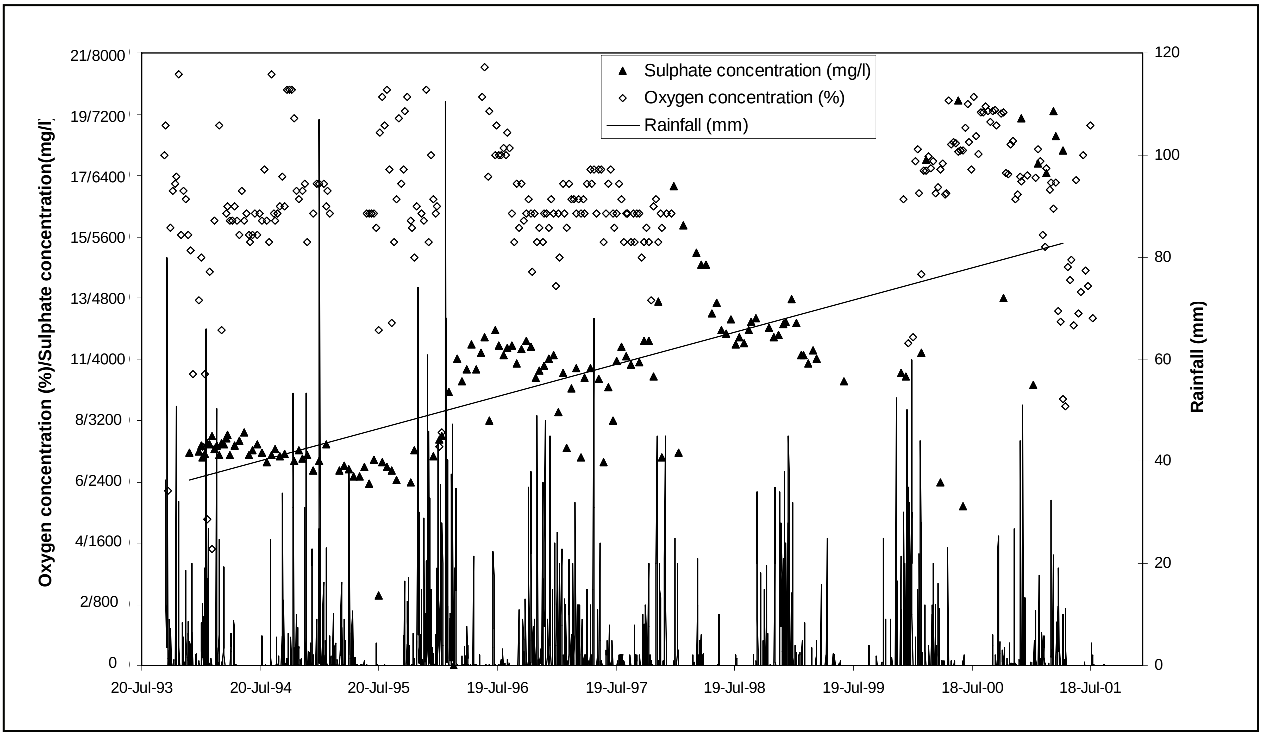


Figure 7.3(a): Relationship between oxygen ingress, sulphate concentration and rainfall for Cell 4 comprising 0.3 m Avalon soils.

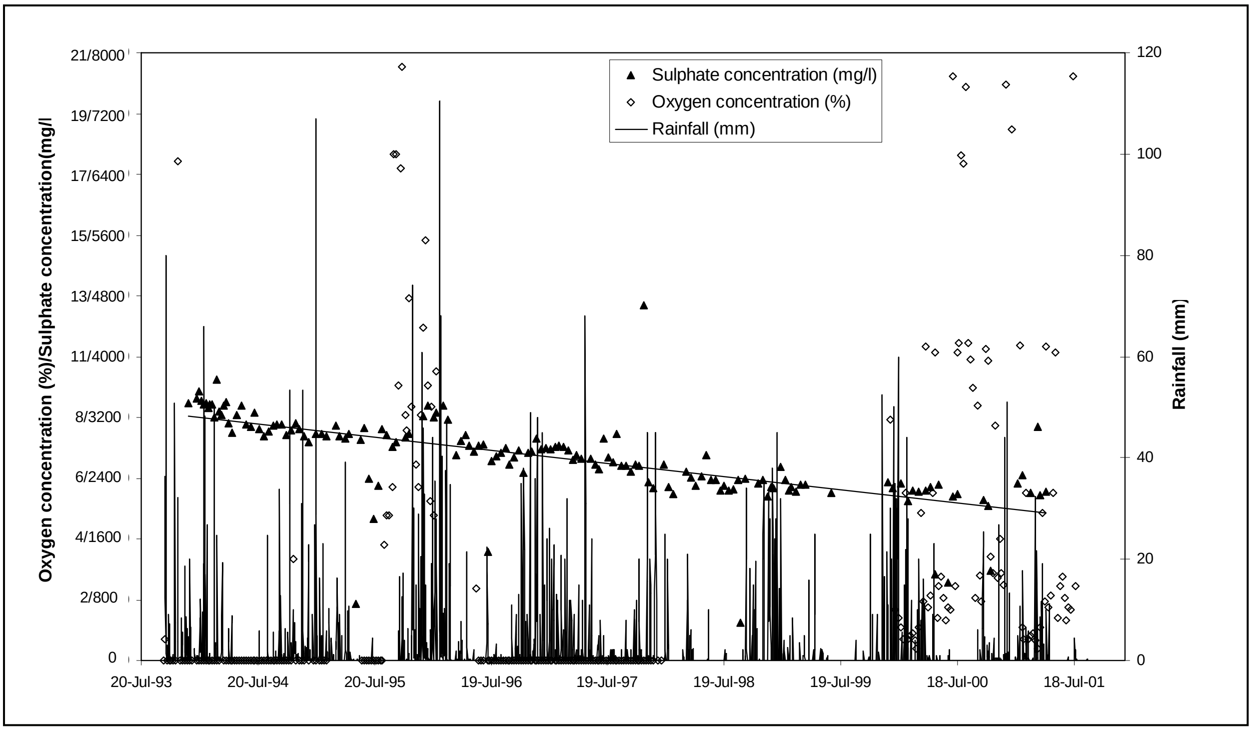


Figure 7.3(b): Relationship between oxygen ingress, sulphate concentration and rainfall for Cell 8 comprising 0.3 m Avalon and 0.7 m compacted Estcourt soil.

7.4 DISCUSSION OF RESULTS

These empirical evaluations of water quality data from the Kilbarchan experiment indicated that there are definite water quality and quantity benefits in the use natural soil covers for the rehabilitation of opencast coal mines and discard dumps. In general, the soil covers reduced the amount of recharge from rainfall and the ingress of oxygen and carbon dioxide. The leachate water quality database further indicates that natural soil covers have further benefits in that they can improve the quality of leachate by reducing oxidation processes in the discard material.

Conclusions from the original research indicated that unsaturated flow processes are highly complex and that soil cover systems are dynamic. Desiccation cracks developed in response to cyclic wetting and drying and bio-activities (root penetration and burrowing animals) could contribute significantly to soil cover degradation, especially in dry seasons. These processes will have an effect on the effectiveness of the soil covers to inhibit water and oxygen ingress. The original research further indicated that multi-layered soil covers out-performed single layer soil covers with respect to water infiltration and oxygen ingress.

The water quality evaluations confirmed that the single soil layer covers were not as effective as the multiple soil layer covers in preventing or decreasing the oxidation processes in the discard cells. An acid breakthrough recorded in the uncovered cells indicates that, under the right circumstances and time, the discard material will turn acid. The single soil layer covers managed to prevent this acid breakthrough by decreasing the amount of water and oxygen infiltrating into the discard material. However, the evaluation indicates that the single soil layer discard cells are not effective in creating anaerobic conditions, leading to the continuation of pyrite oxidation and consequent consumption of neutralisation potential. This is evidenced in increases in SO_4 and Mg concentrations over the monitoring period as well as an increase in the AP relative to NC. The pH breakthrough in Cell 4 suggests that a single soil cover would only be able to postpone acid breakthrough by –two to three years compared with an uncovered cell.

Multiple soil layer covers were effective in creating anaerobic conditions in the discard which led to a significant reduction in oxidation processes. This resulted in decreases in Mg and SO_4 concentrations over the monitoring period as well as a decrease in AP. The evaluation showed that the cells covered with multiple layer soil covers are progressing towards stability which will ultimately determine whether or not an acid breakthrough will take place in these cells. This stability situation is dependent on the stability of the soil covers in terms of creating and sustaining anaerobic conditions.

It is noted that unsaturated flow processes are complex in nature and are determined by both site-specific climatic conditions and hydraulic properties of the soils and discard material. The geochemical processes associated with discard material are also complex and difficult to simulate or model. However, this empirical analysis has shown that, given the site-specific conditions of the WRC experiment, natural soil covers can be effectively utilised in the rehabilitation of opencast coal mines and discard dumps. These covers do not just support vegetation but also have a beneficial effect on leachate quality and quantity and will influence the magnitude of closure liabilities.

Caution should be exercised when extrapolating these results to actual discard dumps. Although this experiment describes most of the flow and geochemical processes and provides some understanding of the processes, factors influencing ARD processes at coal discard dumps are very site-specific.

CHAPTER 8

FRAMEWORK FOR THE DEVELOPMENT OF A COVER ASSESSMENT SOFTWARE PROGRAM

8.1 INTRODUCTION

One of the aims of the research project is to make a product available, which can be used by the mining industry, authorities and design engineers to optimise soil cover design used in the rehabilitation of coal discard dumps and opencast mines. The results in this report have shown that the unsaturated flow model, SoilCover, can be used to optimise soil cover design. However, one of the identified limitations of SoilCover (and other similar models) is that data requirements for such a program are very demanding. In addition, considerable knowledge on unsaturated flow processes is required to obtain meaningful results. The use of SoilCover, and other similar models, should be reserved for professionals working in the field of cover design and there is a danger that such models may be misused by people not knowledgeable in cover design and unsaturated flow processes. The mining industry and authorities do not have the human resources (and capital resources) to evaluate different cover designs.

There is a need for a tool that can be used to assess the effectiveness of different cover configurations quickly. Such a tool could be used, for example, by the mining industry to assess whether there is sufficient material available to construct a cover that could effectively reduce infiltration to acceptable limits at mine closure. Similarly, authorities could assess a cover design proposed by a mine for placement over a coal discard dump, or mined out area. In short, there is a real need for a tool that can be used to assess cover configurations for planning purposes.

At the Water Research Commission steering committee meeting held in October 2000, it was recognised that the research team should aim to develop such a cover assessment tool. However, it was also recognised that, in view of the time and capital constraints, such a development could not form part of the existing research project.. It was thus decided that the research team should aim to develop a framework for such a tool and that priority should be given to developing the tool in future research projects. It is envisaged that the tool would take the form of a computer program.

One of the dangers of developing a computer program that can be used to assess covers for planning purposes is that the program could be misused for design purposes. The research team recommends that an extensive testing programme be initiated before deciding on a particular cover design for the rehabilitation of potentially acid-forming coal discard. This testing programme should comprise testing of the cover materials, modelling using SoilCover or similar models, evaluation of a particular cover by means of experimental field plots and monitoring of the cover effectiveness. This recommended testing programme is described in **Chapter 9**. The envisaged computer programme should be restricted to planning purposes only.

8.2 DEVELOPMENT APPROACH

The objective of the cover assessment program is to compare the effectiveness of different soil covers used in the rehabilitation of a particular facility in the South African coal mining region. The program will be used to compare outflow rates for different cover configurations. It should be borne in mind that only a limited amount of data would be available during the planning stages. Further, the program would be used by people who are not necessarily knowledgeable in cover design or unsaturated flow processes. The program should therefore be simple to use and the results and interpretation easy to understand.

Due to the significant uncertainties in estimating outflow from limited amounts of data, especially for particular input parameters such as the hydraulic and retention characteristics of the cover materials, it is envisaged that a risk-based approach would be followed in estimating outflow. . These uncertainties stem from the variation of natural soils and in quantifying the properties of the soil materials. Input distributions would be defined as a range of possible input values for the risk-based model. Monte Carlo techniques could then be employed to estimate outflows based on the input distributions. Estimated outflow would also be presented as an output distribution and would indicate the probability of the estimated outflow being higher than a particular value.

The amount of outflow through soil covers depends on both climatic characteristics and the hydraulic and retention characteristics of the cover material. As most of the South African coalfields are situated in one geographical region and the climate is more or less similar for most of the coalmines, only the hydraulic and retention characteristics of the soil materials available for the construction of the cover would need be considered.

The cover assessment programme would incorporate the following factors which would require input by the user:

1. Cover configuration (e.g. low permeability barrier, store and release cover, wet cover system).
2. Hydraulic and retention characteristics of soils used for cover material.
3. Cover and layer thickness.
4. Compaction state of the cover materials.

The user would therefore need to specify the cover configuration, cover thickness and compaction state of the cover materials. The user would also need to indicate the soil types used for cover construction. The programme would then assign input distributions for the hydraulic and retention properties typical of the particular soil type used.

8.2.1 DEVELOPMENT METHODOLOGY

It is envisaged that an empirical approach would be followed to estimate outflow quantities for a particular cover. A series of SoilCover models would be run for the different input factors, as listed in **Section 5.2,** and outflow rates would be determined for each of these model runs. The climatic data file used in the model runs would be representative of the coalmining region of South Africa. The estimated outflow would then be related to the input factors by means of regression analysis.

The following procedure would be followed in developing the cover assessment program:

1. Obtain climatic data representative of the main South African coalfields region. Compile a climatic database, to be used as input into SoilCover models.
2. Identify in the coalmining region the soil groups that could be used to construct soil covers. The typical geotechnical properties of these materials (e.g. particle size distribution, clay content) can then be obtained or estimated.
3. Estimate the retention and hydraulic characteristics of the different soil groups. Compile a soil property database for the different soil groups, which is then used as input into SoilCover models. Several references are available on methods to estimate retention and hydraulic characteristics from readily available soil data (e.g. Van Schalkwyk & Vermaak, 2000).
4. Compile a number of SoilCover models using the climatic database for the coalmining region. The models will consider different cover configurations, hydraulic and retention properties, cover thickness and compaction states. Obtain outflow rates from each of the model runs.
5. Relate the input parameters to modelled outflow rates employing regression analyses techniques.

6. Compare estimated outflow rates with actual outflow rates (i.e. the measured outflow rates at the experimental site) and make adjustments as required.

This procedure provides a framework for the envisaged methodology in developing a cover assessment program.

8.3 PROGRAM LAYOUT

It is envisaged that the cover assessment program will comprise a loose-standing application, which can be used from the Windows™ operating system. Example screenshots of such an application are shown in **Figure 8.3(a)** and **(b)**.

Figure 8.3(a) is an example input screen of the cover assessment program. In this example, the user specifies the type of cover (i.e. low-permeability barrier or store & release cover), the type of soils to be used in the cover and the thickness of the layers. The user may also specify whether or not the materials will be compacted during placement.

The input screen is simple and does not require any knowledge of the hydraulic and retention characteristics of the cover materials As the program automatically estimates the hydraulic and retention properties of the cover materials. However, the user can specify certain other properties (e.g. saturated hydraulic conductivity), if such data is available.

Figure 8.3(b) is an example output screen of the cover assessment program. The output screen simply provides the estimated outflow rates over 10 years which period is representative of wet, average and dry years occurring in the coalmining region. The output screen provides minimum, likely and maximum outflow rates for each of the ten years and the overall average. The variation in outflow for each of the years represents the variation and uncertainty of the input parameters. The output screen also contains recommendations on ways to improve the effectiveness of the cover.

Because of the large variation in soil property values for a specific soil type, it is unlikely that the outflow results will be meaningful in evaluating cover effectiveness. However, the program can be used to compare different cover designs.

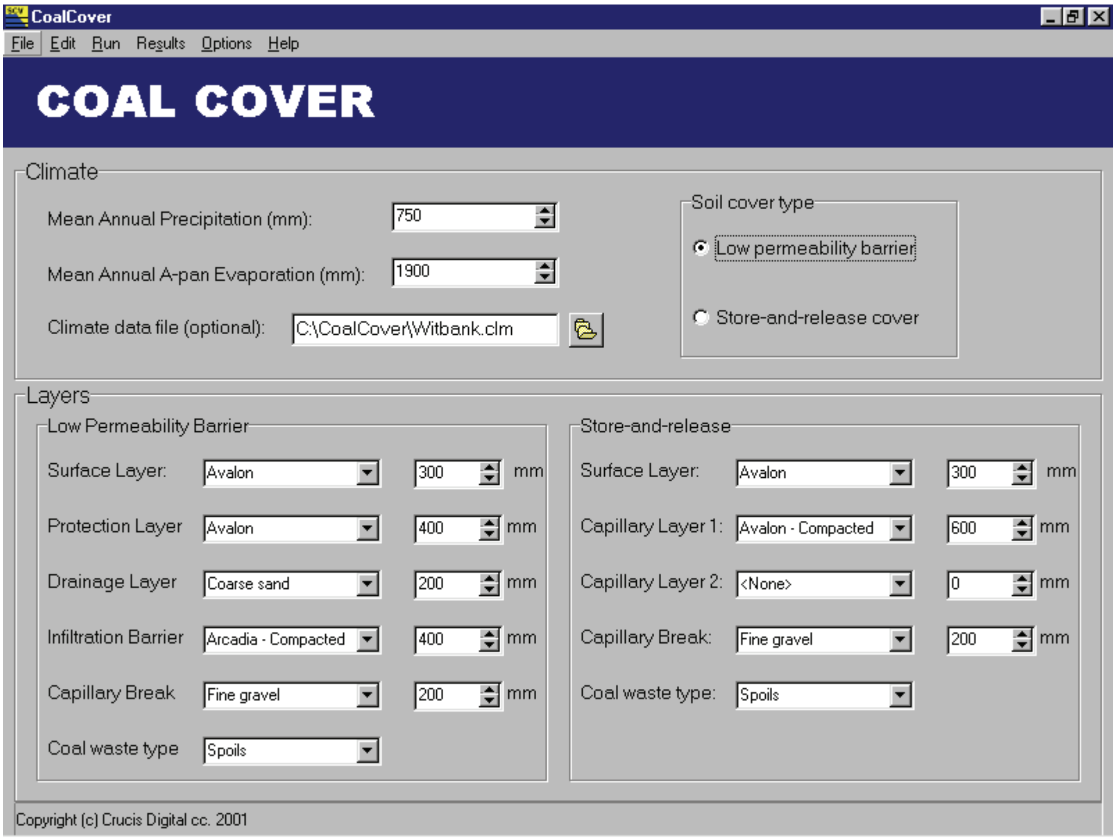


Figure 8.3(a): Example input screenshot of the cover assessment program

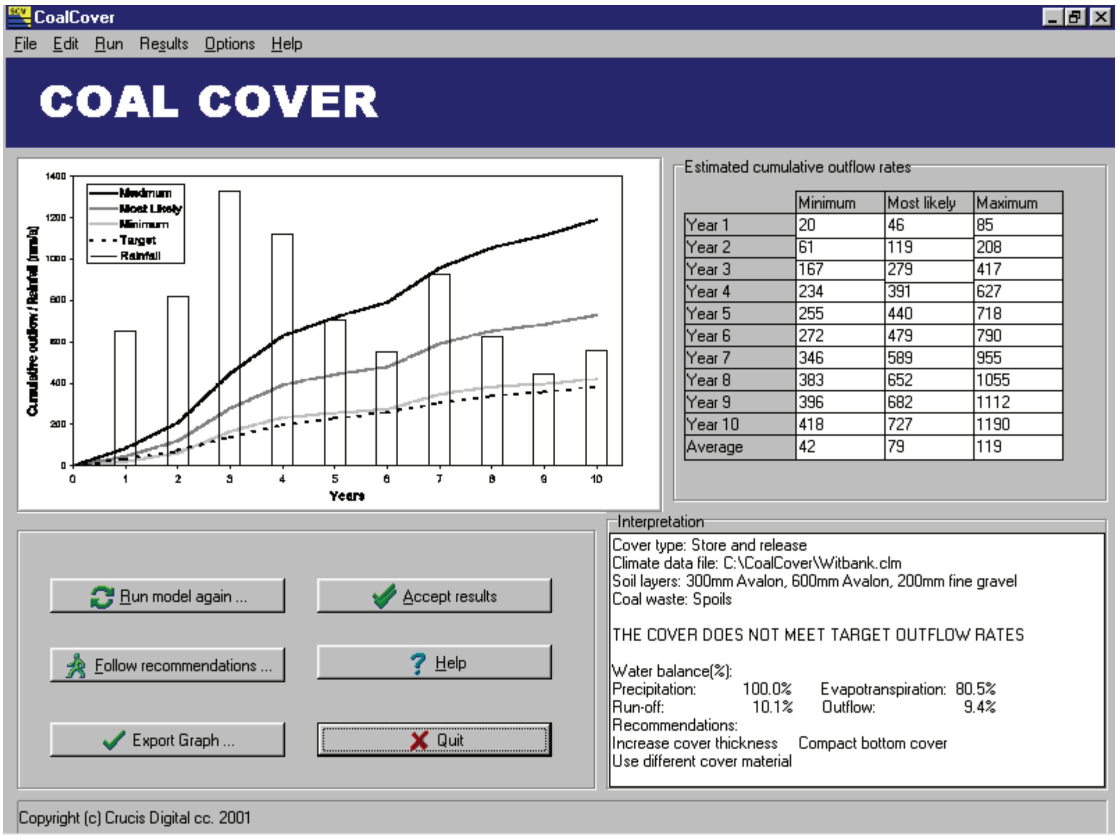


Figure 8.3(b): Example output screenshot of the cover assessment program

CHAPTER 9

DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

9.1 DISCUSSION

The literature survey revealed that the rehabilitation practices of the South Africa coal mining industry are similar to those practised in other coal-producing countries in that the focus of rehabilitation is to redress the post-mining land use. However, it has been identified that some coal mines may have major long-term water impacts caused by acid generation and salinisation. Rehabilitation practices at these mines should therefore focus on limiting contamination of the groundwater and surface water regimes.

Soil covers can be used to limit the generation of leachate from coal discard dumps and opencast mines. The main objectives of these covers should be to limit water infiltration into the coal discard or spoils, to impede oxygen ingress and to inhibit the growth of large iron-oxidising bacteria populations. In this way, the leachate volumes are significantly reduced while the quality of leachate is improved because of lower sulphide oxidation rates.

The literature has shown that soil covers are used worldwide to limit the generation of leachate from mine wastes. However, the degree of success varies considerably. In some case studies, water infiltration into mine wastes has been completely prevented while, in other case studies, covers were able to prevent oxygen ingress completely, thereby improving leachate quality. There are also numerous case studies where covers were unsuccessful in limiting water infiltration and/or oxygen ingress. At some mines, covers degraded significantly and had to be replaced. Designers should be cautious when designing infiltration-limiting covers and should understand that covers are a comparatively new technology and hence relatively poorly understood. The literature study, however, also showed that covers performed satisfactorily when correctly designed and constructed.

The general belief is that dry covers are not effective in limiting oxygen ingress into mining waste because the covers would not remain saturated throughout the year. The oxygen ingress results proved that this is not necessarily an accurate observation as the 1.0m thick covers were able to reduce the oxygen flux rate significantly for most of the time during the monitoring period. However, the oxygen measurements did show exceptionally high oxygen concentrations during the latter part of some dry seasons, caused by either oxygen ingress through dry covers or preferential oxygen ingress pathways through desiccation cracks.

9.1.1 REDUCTION OF WASTE LOADS

Table 9.1.1 and **Figure 9.1.1** present the estimated outflow and sulphide loads for a hypothetical 10 ha coal discard facility, eight years after the placement of different soil covers. The results are based on the results of the Kilbarchan experiments.

Table 9.1.1: Estimated outflow rates and sulphate loads for a hypothetical 10 ha coal discard dump, eight years after the placement of different soil covers.

Cell no.	Cover configuration	Outflow (m^3/a)	Change in outflow (%)	Sulphate concentration (mg/l)	Sulphate load (t/a)	Change in load (%)
1:	Uncovered	22 538	0	5 500	124	96
2:	Uncovered, compacted coal discard	18 726	-17	4 000	75	19
4:	0.3m uncompacted Avalon	13 430	-40	6 200	83	32
5:	0.5 m compacted Avalon	9 801	-57	3 300	32	-49
6:	0.3m uncompacted Avalon, 0.7m compacted Estcourt	7 955	-65	2 400	19	-70
7	0.3m uncompacted Avalon, 0.7m compacted Avalon	2 711	-88	2 400	7	-90
8	0.3m uncompacted Avalon, 0.7m compacted Estcourt	6 771	-70	2 400	16	-74
9	As with cell 6, but sloped 1:10	8 995	-60	2 700	24	-62
10	As with cell 6, but sloped 1:5	4 763	-79	4 500	21	-66

*Leachate sulphate concentration prior to rehabilitation = 2 400 mg/l.

It was assumed that the coal discard in the hypothetical facility had characteristics similar to the fine coal discard in the Kilbarchan experiment. The outflow rate prior to the placement of cover was approximately 22 500 m^3/a, based on a 30% outflow rate. The sulphate concentration of the leachate originating from the coal discard facility prior to placement of the cover was assumed to be 2 400 mg/l, based on the initial leachate quality originating from the experimental cells.

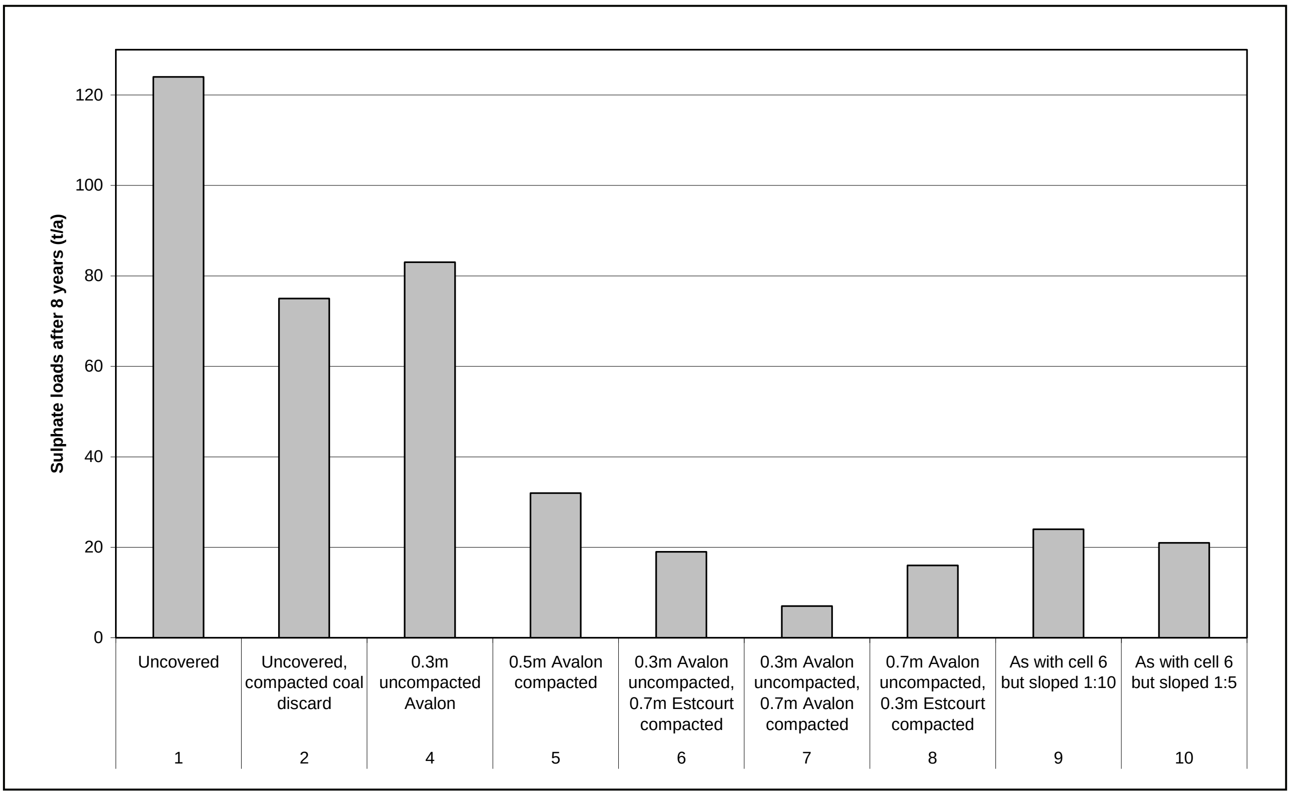


Figure 9.1.1: Expected sulphate loads after eight years for a hypothetical coal discard dump with different soil covers.

It is expected that, over the eight year period, sulphate loads will increase for the hypothetical uncovered coal discard dumps and also for the coal discard dumps covered by 0.3m uncompacted Avalon soils. The increased sulphate loads are mainly the result of higher sulphate concentrations caused by acid drainage processes. The higher sulphate load is expected, despite lower outflow rates from the compacted coal discard and 0.3m soil cover.

Significantly lower sulphate loads (between 49% and 90%) are expected for the hypothetical coal discard dumps covered with 0.5m and thicker covers. It is shown that sulphate loads can be reduced by up to 90% if provided with a 1.0m cover (0.7m compacted Avalon and 0.3m uncompacted Avalon). The lower sulphate loads are mainly the result of reduced infiltration rates. Sulphate concentrations remain constant or are slightly higher (0.5m compacted Avalon), but could increase if acid drainage occurs.

Significantly lower sulphate loads are also expected for the sloped cover systems, even though acid breakthrough occurred for one of the sloped systems. The lower sulphate loads are mainly due to lower rainfall infiltration rates, despite almost twice as high sulphate concentrations following acid breakthrough.

9.1.2 ESTIMATED ACID BREAKTHROUGH PERIODS

Acid breakthrough was observed for five experimental cells during the eight years of monitoring. The oxygen monitoring data showed that 1.0m thick covers are effective in impeding oxygen ingress, thereby reducing acid generation processes and extending the period before acid breakthrough occurs.

The cells in which acid breakthrough were recorded provide a basis for estimating the time interval when acid breakthrough may be expected for the cells in which acid breakthrough has not yet occurred. If one assumes that the geochemical characteristics of the fine coal discard are similar for all experimental cells, the period before acid breakthrough is mainly a function of the oxygen flux entering the coal. One could then calculate the cumulative oxygen flux that has moved into the coal discard before acid drainage occurred for all cells where acid breakthrough has occurred. This cumulative flux value represents the amount of oxygen needed to consume all the neutralisation potential in the coal discard after which acid breakthrough occurs. If one assumes that the neutralisation capacity per cubic metre of the coal discard is similar in all cells, and that the rate at which oxygen will penetrate the coal discard will remain similar to that of the previous eight years, one could calculate the period when all neutralisation potential will be consumed and acid breakthrough will follow.

The oxygen required to consume the neutralisation potential of coal discard at the experimental site where acid breakthrough occurred, varies from 21.4 to 33.8 kg/m^3. Approximately 37.3 kg/m^3 oxygen was required to consume the natural and added (lime) neutralisation potential of Cell 3. Based on these calculations, the acid breakthrough period was estimated for cells where acid breakthrough is yet to occur. The acid breakthrough periods for the respective cells, as well for a hypothetical 20m coal discard dump (which has similar geochemical characteristics to the fine coal discard) is summarised in **Table 9.1.2**.

It is expected that all cells will experience acid breakthrough within 16 years, assuming that the rate of oxygen ingress will be similar to that of the first eight years. Acid breakthrough for Cell 5 is expected within 3 to 10 years.

For the hypothetical 20m high coal discard dump, acid breakthrough is expected to occur at between 80 and 120 years. This period can be extended to between 200 and 500 years by providing the coal discard with a soil cover of at least 0.5m thickness.

Table 9.1.2: Actual and estimated acid breakthrough periods for the experimental cells and for a hypothetical 20m high coal discard dump.

Cell no.	Cover configuration	Break-through period (y)	O_2 flux (kg/m^3)	Acid breakthrough period (y) - 21 kg/m^3		Acid breakthrough period (y) - 33 kg/m^3	
				Experiment cell	20m discard	Experiment cell	20m discard
1	Uncovered	4.1	21.4	4.0	80	6.3	125
2	Uncovered, compacted coal discard	6.4	33.8	4.0	80	6.3	126
3	Uncovered, treated with lime	6.7	37.3	3.8	75	5.9	118
4	0.3m uncompacted Avalon	6.5	32.8	4.2	83	6.6	131
5	0.5 m compacted Avalon	>8	NA	11.8	237	18.6	372
6	0.3m uncompacted Avalon, 0.7m compacted Estcourt	>8	NA	12.6	252	19.8	396
7	0.3m uncompacted Avalon, 0.7m compacted Avalon	>8	NA	14.6	291	22.9	458
8	0.3m uncompacted Avalon, 0.7m compacted Estcourt	>8	NA	15.4	307	24.2	483
9	As with cell 6 but sloped 1:10	>8	NA	13.3	265	20.8	417
10	As with cell 6 but sloped 1:5	6.7	22.7	7.3	145	11.4	228

The monitoring results indicate that, for covered cells, oxygen influx occurs mainly during dry periods when the cover dries out and oxygen readily enters the coal discard. This gives rise to a ratchet effect where very little neutralisation potential is consumed during normal rainfall years, but significant neutralisation potential is consumed during dry periods, when oxygen readily enters the coal discard through the dried-out covers.

9.1.3 EXTRAPOLATION OF RESULTS TO MPUMALANGA COAL MINES

Although the research study has significantly broadened the knowledge base of soil cover performance, one should be careful when extrapolating these results to particularly the Mpumalanga coal fields. There are numerous restrictions in extrapolating the results of this study to other coal mines, including:

- Only one type of coal discard was used in the experimental cells. The physical properties of the fine coal discard are probably not representative of those of coal discard dumps. The geochemical properties of coal discard vary considerably for different coal discard dumps.

- Only two types of soil were used in the experimental cells. The properties of soils used for rehabilitation purposes vary significantly and the design of covers should be adjusted (increase the thickness or compaction of covers) depending on the properties of the soils.

- Eight of the experimental covers were placed on horizontal cells whereas in reality, the larger portion of covers are placed on the slopes of a coal discard facility. The research results suggest significant differences in infiltration rate between soil covers placed on horizontal and sloped surfaces.

- The Kilbarchan experiment was conducted in Northern KwaZulu-Natal, which receives more rainfall than the Mpumalanga highveld region. One would expect that infiltration rates through covers situated in the Mpumalanga region would be lower than covers situated in Northern KwaZulu-Natal. On the other hand, soils in the Mpumalanga area could dry out more frequently than the soils of Northern KwaZulu-Natal, which could result in higher oxygen fluxes into the coal discard.

The results of the Kilbarchan experiment cannot readily be extrapolated to other coal mines, but the findings provide insight into the possible performance of soil covers in other areas. Each soil cover should be assessed individually, in view of the unique physical and geochemical properties of the coal discard, the soils considered for covers, the slope distance and angle of the dump and the climate in which the mine is situated.

The research results indicate that modelling software, such as SoilCover, can be used to assess the performance of a particular cover, taking into consideration the physical properties of the cover material and the climate in which the mine is situated. This software can therefore be used to extrapolate to Mpumalanga, provided that the model is calibrated.

9.1.4 ASSESSING THE PERFORMANCE OF EXISTING SOIL COVERS

There is currently very little knowledge of how existing soil covers are actually performing on covered coal discard dumps and opencast coal mines. It would be valuable to assess the performance of covers at full scale. A monitoring programme should thus form part of the rehabilitation of future coal discard dumps and opencast mines where a soil cover has been provided to limit the contaminant impacts on water sources. The monitoring programme should focus on assessing the performance of soil covers both directly (e.g. by means of lysimeters installed below soil covers) and indirectly (e.g. by means of monitoring boreholes measuring the deterioration in groundwater quality caused by leachate originating from the coal discard dump). The recommended monitoring programme to monitor the performance of soil covers is discussed in Section 9.3.2.

9.1.5 AGRICULTURAL AND ECONOMIC IMPACTS

When an opencast mine is developed, topsoil is often stockpiled during excavation, which soils are then used for rehabilitation purposes. Sometimes, topsoil is also removed from the base of a new coal discard dump prior to placement of the coal discard and the topsoil stockpiled for rehabilitation purposes. The volume of soil used for the rehabilitation of opencast mines and coal discard dumps is typically restricted to the topsoil that has been stockpiled. These soil volumes may not be adequate to construct a cover of a particular thickness that is necessary to limit rainfall infiltration and to impede oxygen ingress. Cover soils must then be sourced from surrounding areas, which have not been affected by mining.

The soils overlaying the Mpumalanga coal fields often have high agricultural potential and the removal of these soils for the construction of a soil cover has direct economic impact. The topsoil in the Mpumalanga coal fields region is often of limited thickness, thus requiring that large areas need to be disturbed to provide adequate quantities of material for the soil cover.

Where possible, alternative sources should be found to construct, or partially construct, the soil cover. These sources could include power station fly ash and non-reactive gold and coal tailings.

9.1.6 USE OF POWER STATION FLY ASH IN COVER DESIGN

Fly ash could potentially perform well as a cover. Preliminary indications are that the hydraulic properties of fly ash favour its use in store-and-release applications. Fly ash occurs in large quantities in the Mpumalanga coalfields and could be placed at relatively low cost. Fly ash is volumetrically stable which means that it is not susceptible to cracking or drying. Apart from limiting infiltration, fly ash may also introduce alkalinity into the potentially acid-forming waste, thereby providing neutralisation properties.

Van den Berg *et al* (2001) stated that fly ash could be applied as a cover to minimise rain-water and oxygen ingress into spoils. The fly ash could be treated by the addition of cement or bentonite to lower its hydraulic conductivity. However, they also stated that the alkalinity, which is released from fly ash, is insufficient to neutralise acid production in the underlying spoil. They also commented that the cost of ash application could be high because of the undulating spoil surface.

The cost of ash covers could be reduced if used as a store-and-release system of between 0.5m and 1.0m in thickness. As such, the cover could provide an effective barrier to oxygen ingress and rainfall infiltration. The fly ash used for this purpose should have high water retention capabilities and medium-to-low saturated hydraulic conductivities.

Other potential materials for store-and-release covers could include gold tailings or coal tailings, provided that they are not potentially acid-forming.

9.1.7 APPROPRIATENESS OF SOIL COVERS

Soil covers may not always be appropriate at all opencast mines and the hydrogeological situation should be well understood before embarking on a rehabilitation programme. The literature study revealed that, for USA surface coal mines, soil covers on their own were only partly successful in limiting groundwater contamination and that other rehabilitation strategies, such as the construction of a grout curtain around the mine or placement of power station fly ash into the pit, should be considered. In South Africa, store and release covers would be more effective.

Store and release covers perform well in climates where evapotranspiration exceeds rainfall by a significant margin. Monitoring results of the Kidston mine in Queensland, Australia, showed that store and release covers prevented infiltration into the mine waste almost completely.

Natural clay low permeability barriers should be designed with caution in climates characterised by distinct wet and dry seasons, as is the case for the coal mining region in South Africa. There are numerous examples where the infiltration barrier has desiccated, thus compromising the integrity of the barrier. Stringent CQA should also be considered as the infiltration barrier could be rendered ineffective if not correctly constructed.

9.1.8 ASSESSMENT OF SOIL COVERS BY MEANS OF NUMERICAL MODELS

Initial SoilCover model runs of experimental cells at the Kilbarchan experimental site showed that the model over-estimated the retention capabilities of the cover soils and under-estimated saturated hydraulic conductivity. It is believed that these discrepancies were caused by the measured soil water characteristic curves not being representative of the characteristic soil in the field. In addition, it is believed that the hydraulic conductivity tests did not measure field conductivity correctly. These discrepancies could have been brought about by differences between field and laboratory densities and by structures introduced into the soils by desiccation cycles. After the soil water retention characteristics and hydraulic conductivity values of the compacted soils were modified slightly to represent field conditions, excellent calibration was achieved.

The modelling exercise demonstrated that the programme, SoilCover, is able to simulate changes in soil water content and flow rates through soil covers accurately, provided that representative soil properties are used. Field tests should be used wherever possible to determine the required soil properties.

9.2 CONCLUSIONS

9.2.1 OUTFLOW RESULTS

- Outflow rates are related to rainfall, with high outflows corresponding to above average rainfall years and low outflows corresponding to below average rainfall years.
- Outflow rates are not only a function of the amount of rainfall but also rainfall intensity and frequency, as illustrated by the difference in outflow rates for two above-average rainfall years where higher outflow was recorded for the year when most rainfall occurred in two months.
- Outflow rates through fine coal discard are considerably higher than for most naturally-occurring soil profiles.
- Slightly lower outflow rates can be achieved if the coal discard is compacted, but the reduction in outflow rate is insignificant when compared with that which can be secured by even a relatively thin soil cover.
- Outflow rates through coal discard are significantly reduced by a soil cover. Outflow rates are related to the thickness of the cover and the properties of the soil, with lower outflow occurring with thicker covers.
- Store and release type covers perform well in semi-arid climates with distinct wet and dry seasons, but need to be of adequate thickness to store infiltrating rainfall water.
- Soils with good moisture retention capability (i.e. soils containing significant silt and clay percentages) are best for store and release covers. Volumetrically-unstable soils are, however, susceptible to cracking when desiccated and should not be used.

- The storage capacity of store and release covers can be increased by compacting the base layers of the cover. The upper layer needs to be left uncompacted to allow penetration of some precipitation to support vegetation.
- Gravel-sized coal discard material could act as a capillary break, limiting downward flow of soil water through store and release cover systems. It may therefore not be necessary to construct capillary breaks on coal discard material. However, this theory requires verification.
- Low permeability barriers will be rendered ineffective if the soil property compaction criteria and *in situ* permeability specifications are not met.
- Outflow rates through composite covers (i.e. layered covers comprising two soil types with different hydraulic characteristics) could be significantly higher or lower than covers comprising one soil type, depending on how the covers are arranged and constructed.
- Topsoils may act as a capillary break, thereby limiting upward movement and removal of soil water through evaporation and resulting in increased outflow rates. This is particularly true where the hydraulic characteristics of the topsoils differ markedly from those of the underlying soils.
- It appears that outflow through sloped covers are affected by the slope angle, with outflow decreasing as slope angle increases. However, the results from the experimental work are, inconclusive.

9.2.2 MODELLING RESULTS

- Numerical modelling is the most effective way to simulate and predict accurately the change in soil water content and outflow rates through soil covers. This is due to the complex nature of flow through soil covers and the erratic nature of rainfall events.
- Existing numerical models have strenuous data requirements and need considerable computer time to compute soil water flow. The models that are sufficiently accurate are therefore unsuitable for use as a planning tool.
- A comprehensive climatic database, with daily records of rainfall, temperature, humidity, radiation and wind speed, is required to model flow of water through soil covers.
- Accurate predictions of soil water content and outflow rates are only possible if accurate measurements are obtained of the hydraulic and water retention properties of the cover material.
- The hydraulic and water retention characteristics determined through laboratory tests may not be representative of field characteristics. This is especially true for compacted soils and soils with structure.

- The model, SoilCover, is able to simulate accurately changes in soil water content and outflow rates, provided that the soil properties used in the model are representative of the field soils.
- Unsaturated flow models can be used to evaluate different cover configurations to limit outflow through mine waste. However, there may be significant uncertainties as to whether the soil properties used in the model are representative of the cover soils. Cover configurations that are shown through modelling to hold promise, need to be tested by means of field trials to confirm performance.

9.2.3 OXYGEN AND LEACHATE QUALITY RESULTS

- A distinct relationship exists between oxygen ingress rates and leachate quality. High oxygen ingress rates result in the deterioration of leachate quality due to increased sulphide oxidation rates. Similarly, low oxygen ingress rates result in the improvement of leachate quality due to lower sulphide oxidation rates.
- The quality of leachate can be improved by restricting oxygen ingress into sulphide-rich mine wastes.
- Oxygen diffusion into uncovered coal discard, either uncompacted or compacted, is not restricted.
- Covers of less than 1.0 m in thickness do not significantly restrict oxygen ingress into the underlying coal discard. Thin soil covers are prone to desiccation, thereby facilitating oxygen diffusion into the underlying coal discard.
- Covers systems which are 1.0 m or thicker are able to restrict oxygen ingress into coal discard, provided that the cover is able to retain soil water.
- A capillary break would improve water retention and reduce through flow. The coal discard may fulfil the role of a capillary break.
- The climatic extremes of the KwaZulu-Natal region resulted in the drying out of the covers at times during the dry season, resulting in significant short-term oxygen ingress into the coal discard.
- In spite of occasional high oxygen ingress into the coal discard, 1.0 m thick covers are able to restrict oxygen concentrations to almost zero for most of the time, resulting in an improvement in leachate quality.
- Sloped covers are less effective in limiting oxygen ingress. Capillary flow processes cause soil water to flow downslope, resulting in the top portion being desaturated and allowing higher oxygen ingress rates.

9.3 RECOMMENDATIONS

9.3.1 FURTHER RESEARCH

The results of this research project have shown that infiltration rates could be significantly reduced if a soil cover is placed on the discard or spoils. Notwithstanding the success of this research project, there are concerns about the validity of extrapolating the results, situated in KwaZulu-Natal, to the situation of the Mpumalanga coal fields, where different soils are used for rehabilitation, and which have a slightly different climate, notably lower mean annual rainfall. There is thus a need to validate the results of this research project for different cover soils and different climates in other parts of South Africa.

During this research project, a thorough understanding of the unsaturated flow processes in soil cover systems has been achieved. Despite these successes, the results of the sloped cover system remains inconclusive. There is thus a need to develop an understanding of the unsaturated flow processes in sloped covers systems.

Since initiation of this research project, store and release covers have been recognised as a specific category of covers and have been shown internationally, and by this research project, to be promising. However, only one of the covers used could be defined as a true store and release system. There is therefore merit in investigating store and release cover configurations in order to test and identify an optimum cover design.

Another new capping technology that has been introduced is that of capillary barriers. Capillary barriers rely on the unsaturated properties of the layers to drain infiltrating water along unsaturated drainage layers from where it can be intercepted and removed. A typical capillary barrier system comprises a silty topsoil underlain by highly permeable medium-grained sand (the unsaturated drainage layer, UDL) and a coarse sand and gravel base (capillary block). Infiltrating water flows along the interface between the UDL and capillary block but does not infiltrate the capillary block because of differences in soil suction. The water is then collected at collection drains. There is a need to test the effectiveness of this new capping technology.

It was noted that fly ash could form part of cover systems and could probably assist in limiting rainfall infiltration. Its physical properties are similar to those of soils typically used for store and release covers. With the addition of small amounts of cement, fly ash can also be used as a low-permeability barrier. In addition, the ash may provide alkalinity, thereby assisting to neutralise acid generation. It is hypothesised that fly ash can be used as part of the cover design and assist in limiting rainfall infiltration, thereby lowering the demand on soils for cover material, which are generally expensive to transport and, in any event, often have significant agricultural potential.

It is recommended that the needs mentioned above be tested by means of both laboratory tests and field trials. A new experimental site, similar to that at Kilbarchan, should be constructed in the region of the Mpumalanga coal fields where the performance of the following covers should be tested:

- Store-and-release covers using soils which are generally considered for rehabilitation purposes of coal mines in the Mpumalanga region;

- Sloped store-and-release covers where their performance should be tested for different slope lengths and different slope angles;

- Store-and-release covers in which fly ash is used in part or in whole as cover material;

- Capillary barriers, in which an unsaturated drainage layer could be incorporated.

9.3.2 MONITORING THE PERFORMANCE OF SOIL COVERS

It is important to validate theory by measuring the performance of soil covers in the field. Monitoring should therefore be implemented where full scale covers are used.

The monitoring programmes should focus on measuring the performance of soil covers both directly (e.g. installation of lysimeters) and indirectly (e.g. back-calculation of waste loads based on results of groundwater monitoring data). Direct measurements would facilitate the measurement of the performance of soil covers at a given point on the coal discard dumps. Indirect measurements and calculations would facilitate the assessment of the performance of the cover as a whole.

The main properties that need to be measured directly include:

- Rainfall infiltration into the coal discard (e.g. by means of lysimeters)

- Oxygen concentration profile within the coal discard and cover

- Temperature profile through the coal discard

- Climatic variables

- Moisture content and suction gradient profile through the cover.

RAINFALL INFILTRATION

Although lysimeters are widely used to measure the quantity of rainfall infiltration and to obtain water samples in the unsaturated zone, one should be cautious in interpreting their results. Lysimeter installation results in soil cover disturbance, and hence, their results may not be representative of the whole soil cover. Many lysimeters are also of small diameter and do not capture rainfall infiltration that is representative of the soil cover. In addition, wicking effects can render lysimeter readings incorrect.

It is proposed that large diameter (at least 1m diameter) lysimeters be installed within the coal discard or spoils prior to placement of the soil cover. The lysimeter should be partially filled with coal discard to minimise wicking effects. Normal procedures should be followed to place the soil cover over the lysimeter to ensure that rainfall infiltration is representative of the soil cover.

OXYGEN CONCENTRATION PROFILE

The measurements of oxygen concentration provide a quick way to assess the performance of soil covers. Low oxygen concentrations in the coal discard imply low oxygen flux and high moisture contents in the cover, while high oxygen concentration implies that the cover has dried out or that it is ineffective in retarding air flow.

Oxygen probes, comprising a steel canister with a pipe protruding through the surface, can easily be installed at various depths in the coal discard and cover. Oxygen concentrations are measured by means of a hand-held gas analyser.

TEMPERATURE PROFILE

The temperature profile provides an indication of the sulphide oxidation rate in coal discard. Sulphide oxidation is a exothermic reaction and high temperatures are related to high sulphide oxidation rates.

Temperature probes can be installed at various depths in the coal discard. The probes can be connected to a datalogger to measure temperature in the coal discard on a continuous basis.

CLIMATIC VARIABLES

The performance of covers cannot be assessed without consideration of climactic variables, including rainfall and evapotranspiration. Evapotranspiration can be estimated from temperature, relative humidity and net radiation.

Weather stations are available which record rainfall, temperature, relative humidity and net radiation on a continuous basis.

MOISTURE CONTENT AND SUCTION GRADIENT PROFILES THROUGH THE COVER

A continuous profile of moisture content and suction gradient through the soil cover profile may be used to back-calculate throughflow and hence assess soil cover performance. The continuous moisture content and suction gradient profiles can be compared to those predicted by unsaturated flow models and the performance of the cover quantified.

Various products are available to measure moisture content and suction gradients continuously. These include electrical resistance blocks, TDRs, reflectometers, tensiometers and psychrometers. Once-off measurements of moisture content and soil density can be made with a neutron probe.

9.3.3 PROCEDURES FOR DESIGNING SOIL COVERS

It is recommended that the following procedures be implemented for the design of a soil cover:

1. Reach agreement with the authorities concerning how much infiltration can be tolerated for the specific dump or opencast mine and how the seepage would be managed after closure.
2. Embark on a study to design a soil cover which will limit rainfall infiltration to the agreed infiltration rate. This study should include:
    a. Identification of the soils that can be used for the cover.
    b. Embark on a soil testing programme to determine the geotechnical and hydraulic properties of the cover materials.
    c. Embark on a modelling programme to optimise the configuration of the cover, using cover design software such as SoilCover, HELP or Unsat-H. The optimum thickness of the cover and the degree of compaction should be determined in the design process.
3. Demonstrate the effectiveness of the soil cover design by means of experimental field trials. The trial plots could be constructed on the mining premises or could form part of a centralised experimental site in the climatic region in which the mine is located.

4. After completion of the trials and further refinement of the design, construct the soil cover according to the design as modified by the experience gained from the trial plots.

5. Initiate a monitoring programme to measure the performance of the cover.

CHAPTER 10

REFERENCES

Adelman, D.D., Stansbury, J. USDOE, Washington, DC [United States of America] (1997). A sensitivity analysis of hazardous waste disposal site climatic and soil design parameters using HELP3. Pp. 396-399 in International Containment Technology Conference: Proceedings, 1140 pp. Report Number: CONF-970208--Proc.

Anglo American Corporation (1986). Amcoal Surface Rehabilitation. Soil Depth, Soil Compaction and Ripping Studies : Land Rehabilitation, 1984/1985 Season. Report No. Gen 41/86, May 1986.

Anon –1 MIKE SHE WM Release 5.1 (1994). Water Movement Modules, A Short Description Geoenvironmental Engineering 123(5):469-473

Appelo, C.A.J. & Postma, D.(1993). Geochemistry, Groundwater and Pollution. A.A. Balkema Publishing.

Atkinson, K & Mitchell, PB.(1994). The Environmental Impact of Mining and Some Novel Methods of Reclamation. Proceedings. International Symposium on the Impact of Mining on the Environment, Problems and Solutions. Nagpur, India. January 11-16, 1994.

Azis, ML, Ferguson, KD. (1997), Equity Silver Mine – Integrated Case Study. Proceedings. Fourth International Conference on Acid Mine Drainage. Vancouver, B.C. Canada. May 31 – June 6, 1997.

Barth, RC, Williams, DD and Griffith, JJ. (1988), Reclamation Practises at Selected Brazilian Mines. Proceedings. American Society of Surface Mining and Reclamation and the U.S. Department of the Interior Conference of Mine Drainage and Surface Mine Reclamation, pp 179-185. Pittsburg, PA, April 17-22, 1988.

Bear, J. and Verruijt, A. (1992) Modelling Groundwater Flow and Pollution. D. Reidel Publishing Company, The Netherlands.

Bell, AV. (1988). Acid Waste Rock Management at Canadian Base metal Mines. Proceedings. American Society of Surface Mining and Reclamation and the U.S. Department of the Interior Conference of Mine Drainage and Surface Mine Reclamation, pp 192-199. Pittsburg, PA, April 17-22, 1988.

Bell, RM, Parry, GDR and Gilden, A. (1986). Isolating Metal Contaminated Waste by Covering Potential Upward Mitigation of Metals Into Surface Soil and Vegetation. Conservation and Recycling, Vol. 7, No. 2 - 4, 1984. pp 99 - 105.

Belmans, C., Wesseling, J.G. and Feddes, R.A. (1983). Simulation model of the water balance of a cropped soil: SWATRE. Journal of Hydrology. 63(3/4): 271-286.

Bennet, JW, Harries, JR and Ritchie, AIM. (1988). Rehabilitation of Waste Rock Dumps at the Rum Jungle Mine Site. Proceedings. American Society of Surface Mining and Reclamation and the U.S. Department of the Interior Conference of Mine Drainage and Surface Mine Reclamation, Pittsburg, PA, April 17-22, pp 104-108.

Benson, G.H. and Daniel, D.E. (1994). Minimum thickness of compacted soil liners: I. Stochastic models. Journal of Geotechnical Engineering 120(1):129-172.

Beven, H. and Germann, P. (1981). Water flow in soil macropores II: A combined flow model, Journal of Soil Science, 32:15-29.

Beven, K. and Germann, P. (1982). Macropores and water flow in soils. Water Resources Research 18(5):1311-1325.

Bews, BE, O’Kane, MA, Wilson, GW, Williams, D, Currey, N. (1997),.The design of a low flux cover System, Including Lysimeters, For Acid generating Waste Rock in Semi-Arid Environment. Proceedings. Fourth International Conference on Acid Mine Drainage, Vancouver, B.C. Canada. May 31 – June 6.

Bezuidenhout, N., Van Niekerk, A.M., Vermaak, J.J.G., (2000). The effects of Natural Soil Covers on Geochemical Processes associated with Coal Discard Deposits – Results from a Pilot Scale Study. Proceedings from 5th International Conference on Acid Rock Drainage, Colorado, USA.

Bjerrum, L & Huder, J (1957). Measurement of the Permeability of Compacted Clays. Proceedings of the Fourth International Conference on Soil Mechanics and Foundation Engineering, London, 1:9-10.

Blight, GN. (1997)., Personal Communication.

Booth. C.J. & Price, B.C. Infiltration, soil moisture, and related measurements at land fill with a fractured cover. ILLINOIS. Journal of Hydrology (Amsterdam) Issue 1 Issue 4 Vol. 108 Pages:175-188

Brooks, R.H & Corey, A.T. (1964). Hydraulic properties of porous medium. Hydrology paper 3, Colorado State University.

Bussiè B, Nicholson, RV, Aubertin, M, Servant, S. (1998). Effectiveness of covers built with Desulphurized Tailings: Column Test Investigation. Proceedings. Fourth International Conference on Acid Mine Drainage, Vancouver, B.C. Canada. May 31 – June 6, 1997.

Cabalka, D, Newton, P. Fire and Ice. Geotechnical Fabrics Report. Pp. 30 – 35, January – February. 1999

Campbell, G.S. (1974). A simple model for determining unsaturated conductivity from moisture retention data. Soil Science 117:311-314.

Chiado, ED, Bowders, JJ, and Sencindiver, JC. (1988). Phosphatic Clay Slurries for Reducing Acid Mine Drainage from Reclaimed Mine Sites. Proceedings. American Society of Surface Mining and Reclamation and the U.S. Department of the Interior, Mine Drainage and Surface Mine Reclamation Conference Pittsburg, PA. USA. April 17.

Cleghorn, C. Effect of Soil Covers on coal Waste Dumps in KwaZulu-Natal on Abiotic Factors and Bacteria Causing Acid Mine Drainage. Master of Science thesis submitted to the University of Stellenbosch, South Africa, March 1997.

Daniel, D.E. and Koerner, R.M. (1993). Geotechnical practice for waste disposal. Chapman & Hall, London.

Daniel, DE (1984). Predicting hydraulic conductivity of clay liners. Journal of Geotechnical Engineering, 110(2):285-300.

Delaney, T, Hockley, D, Sollner, D. (1977). Applications of Methods for delaying the Onset of Acidic Drainage. Proceedings. Fourth International Conference on Acid Mine Drainage, Vancouver, B.C. Canada. May 31 – June 6.

Drever, I.J, (1982). The Geochemistry of Natural Waters. Prentice hall, Inc.

Durner, W. (1994). Hydraulic conductivity estimation for soils with heterogeneous pore structure, Water Resources Research 30(2):211-223.

United States Environmental Protection Agency (1995). Rehabilitation on Vegetation. One Module in a Series on: Best Practise Environmental Management in Mining. Commonwealth of Australia.

Fergusson, DC, Marais, C. (1994). Air Permeabilities of Coal Mine Heaps: Obtaining Reliable Results. Proceedings. First Conference on Environmental Management Technology and Development, Fourways, South Africa, March 7 – 8.

Feasby, DG, Tremblay, GA, Wetherell, CJ. (1997). A Decade of Technology Improvement to the Challenge of Acid Drainage – A Canadian Perspective. Proceedings. Fourth International Conference on Acid Mine Drainage, Vancouver, B.C. Canada. May 31.

Feddes, R.A., Kabat, P., Van Batiel, P.J.T., Bronswitji, J.J.B. and Halbertsma, J. (1988). Modelling soil water dynamics in the unsaturated zone - State of the art. Journal of Hydrology. 100, pp. 69-111.

Flury, M., Flürer, H., Jury, W. A. and Leuenberger, J. (1994). Susceptibility of soils to preferential flow of water: A field study. Water Resources Research 30(7):1945-1954.

Fourie, AB and Strayton G (1996). Evaluation of a new method for the measurement of permeability in the field. SAICE Journal, First Quarter, 1996 pp 10 –14.

Fredlund, D.G., Xing, A. & Huang, S. (1994) Predicting the permeability function for unsaturated soils using the soil-water characteristic curve. Can. Geotech. J. 31:533-546

Gardiner, RT, Dawson, BB, Gibson, GG. Application of ARD Abatement Technology in Reclamation of Tailings Ponds at Cominco Ltd, Sullivan Mine. Proceedings. Fourth International Conference on Acid Mine Drainage, Vancouver, B.C. Canada. May 31 – June 6, 1997.

Germann, P. and Beven, K. (1981a). Water flow in macropores: I. An experimental approach, Journal of Soil Science, 32:1-13.

Germann, P. and Beven, K. (1981b) Water flow in macropores: III. An statistical approach, Journal of Soil Science, 32:31-39.

Gibson, DK, and Pantelis, G. (1988). Forecasting the Effect of Mine Site Rehabilitation Works on Local Groundwater Mining and reclamation. Proceedings. American Society for Surface Mining and Reclamation and the U.S. Department of the Interior, Mine Drainage and Surface Mine Reclamation Conference. Pittsburg, PA, April 17 - 22, 1988. pp 248 -252.

Greadel, T.E., & Crutzen, P.J.,(1993). Atmospheric Change – An Earth System Perspective. W.H. Freeman and Company.

Hallaire, V. (1984). Evolution of crack networks during shrinkage of a clay soil under grass and winter wheat crops. In: Bouma, J and Raats, P.A.C. (Editors) Proceedings of the ISSS symposium on water and solute movement in heavy clay soils. Wageningen, The Netherlands.

Harrison, BV, Sudicky E.A. & Cherry, J.A. (1992). Numerical analysis of solute migration through fractured clayey deposits into underlying aquifers. Water Resources Research, 28(2): 515-526.

Haverkamp, R. & Parlange, J.Y. (1986). Predicting the water retention curve from particle-size distribution: 1. Sandy soils without organic matter. Soil Science, 142(6): 325-339.

Helling, C.S. & Gish, T. J. (1991). Physical and chemical processes affecting preferential flow in Preferential Flow, Proceedings National Symposium, Editors: Gish, T.J. and Shirmohammadi, A.; American Society of Agricultural Engineers, St. Joseph, MI, pp 77.

Hutson, J.L. (1984). Estimation of hydrological properties of South African soils. Unpublished PhD Thesis, University of Natal, Pietermaritzburg.

Jambor,J.L(Ed) & Blowes, D.W. (Ed) (1994). Environmental Geochemistry of Sulfide Mine-Wastes. Mineralogical Association of Canada, Short Course Handbook vol.22.

James, A.R.,(1999). Prediction of Pollution Loads from Coarse Sulphide-Containing Waste Materials. Research Report for WRC (559/1/97).

Jelinek, D. (1995). Sealing Properties of Five Different Capillary Barrier Systems under Natural Climatic Conditions. Proceedings. Sardinia 95, Fifth International Landfill Symposium. S. Margherita di Pula, Cagliari, Italy. 2 - 6 October 1995. Vol II pp 555 - 564.

Juwarkar, AS, Thawale, PR, Mowade, S, Shrivastava, S, Deshbhratar, PB and Juwarkar, A. (1996). Reclamation of Coal Mines Spoil Dump through Integrated Biotechnological Approach. Proceedings. International Symposium on The Impact of Mining on the Environment, Problems and Solutions. Visvesvaraya Regional College of Engineering, Nagpur, India. January 11 - 16, 1994. pp 339 - 347.

Khire, M.V., Benson, C.H., Bosscher, P.J., (1997). Water balance modelling of earthen final covers. Journal of Geotechnical and Geoenvironmental Engineering, 123(8) :744-754, ISSN: 1090-0241.

Knox, K and Gronow, J. (1988). A Review of landfill Cap Performance and its Application for Leachate Management. Proceedings. Sardinia 93, Fourth International Landfill Symposium. S. Margherita di Pula, Cagliari, Italy. October 11-15, 1993. pp 207-223.

LaGory, KE, Pentecost, ED and Vinikour, WS. Reclamation Success at an Abandoned Deep Coal Mine Site Near Staunton, Illinois. Proceedings. American Society of Surface Mining and Reclamation and the U.S. Department of the Interior Conference of Mine Drainage and Surface Mine Reclamation, Pittsburg, PA, April 17-22, 1988. pp 221-227.

Lambe, TW. (1954). The engineering behaviour of compacted clay, Journal of the Soil Mechanics and Foundation Division, ASCE, 34(SM2):1655-1 – 1655-32.

Lauren, J. G., Wagnent, R, J., Bouma, J. and Wosten, J. H. M. (1988). Variability of saturated hydraulic conductivity in a Glassaquic Hapludalf with macropores. Soil Science 145(1):20-28.

Leong, E.C. and Rehardjo, H (1997). Permeability functions of unsaturated soils. Journal of Geotechnical and Geoenvironmental Engineering, Vol 123, No 12.

Loos, M. (1998), An Investigation of the Occurrence of the Bacteria Causing Acid Mine Drainage in the Outer Layers of Coal Waste Dumps. Water Research Commission, project no. K5/454. In press, 1998.

Loos, M.A., Cleghorn, C. & Modinger, H.,(1996). Occurrence of Bacteria causing Acid Mine Drainage in the Outer Layers of Coal Waste Dumps in Relation of Abiotic Ecological Determinants and Soil Covers Used for Dumps in Rehabilitation. Research Report for WRC project 454.

Lorentz, S.A., Ballium, F., Musto, J.W. (1995). Hydraulic and Physical Properties of Soil Covers for Mine and Waste Dump Rehabilitation. Department of Agricultural Engineering, University of Natal.

Maiti, SK and Banerjee, SP. (1994). Revegetation of Coal Mine Spoils by Application of Domestic Raw Sewage. Proceedings. International Symposium on The Impact of Mining on the Environment, Problems and Solutions. Visvesvaraya Regional College of Engineering, Nagpur, India. January 11 - 16, 1994. pp 369 - 381.

McBrayer, M.C., Mauldon, M. Drumm, E.C., and Wilson, G.V. (1997). Infiltration tests on fractured compacted clay.

Megges, T, Holzlöhner, U and August, H. (1995). Improving the Technical Barrier for Landfills. Proceedings. Sardinia ‘95, Fifth International Landfill Symposium, S. Margherita di Pula, Cagliari, Italy. 2 - 6 October 1995. Vol II pp 89 - 102.

Melchior, SK, Berger, K, Vielhaber, B, and Miehlich, G. Comparison of the effectiveness of different liner systems for top cover. Proceedings. Sardinia 93. Fourth International Landfill Symposium. S. Margherita, Cagliari, Italy. 11 - 15 October 1993. pp 225 - 234.

Melchoir, S. USDOE, Washington, DC [United States of America] (1997). In-situ studies on the performance of landfill caps (compacted soil liners, geomembranes, geosynthetic, clay liners, capillary barriers). pp. 365-373 in International Containment Technology Conference: Proceedings., 1140 pp. Report Number : CONF-9070208-Proc.

Mitchell, JK, Hooper, DR and Campanella, RG. (1965). Permeability of compacted clay. Journal of the Soil Mechanics and Foundation Division, ASCE, 92(SM4):41-63.

Miyazaki, T. (1993). Water flow in soils. Marcel Dekker Inc. 270 Madison Avenue, New York, New York.

Morin, K.A., & Hutt, N.M.,(1997). Environmental Geochemistry of Minesite Drainage-Practical Theory and Case Studies. MDAG Publishing.

Mualem, Y. (1992) Modelling the hydraulic conductivity of unsaturated porous media. In: Proceedings of an international Workshop on Indirect methods for estimating the hydraulic properties of unsaturated soils (Editors: van Genuchten, M. Th., Leij, F.J. and Lund, L.J.) Univ. of California, Riverside, CA, pp 142-42.

Münnich, K. (1993). Reduction of the Migration of Contaminants through Mineral Barrier Systems by Hydraulic Means. Proceedings. Fourth International Landfill Symposium, Sardinia, Cagliari, Italy. October 11 – 15, 1993.

Murray, EW, Goudey, SP, McCready, RGL and Salley, J. (1998). Laboratory and Field Testing of a Salt-Supplemented Clay Cap as an Impermeable Seal Over Pyritic Slates. Proceedings. American Society of Surface Mining and Reclamation and the U.S. Department of the Interior Conference of Mine Drainage and Surface Mine Reclamation, Pittsburg, PA, April 17-22, 1988. pp 52-58.

Naidu, B.P., Harwood, M.R., Hacker, J.B., Thumma, B.R., Mott, J.J. (1997). Pasture species selection for revegetation of open-cut coal mine areas in central Queensland, Australia. International Journal of Surface Mining, 11(1): 21-25, ISSN: 0920-8119.

Nawrot, JR, Sandusky, J and Klimstra, WB. (1988). Acid soils Reclamation : Applying the principles. Proceedings American Society for Surface Mining and Reclamation and the U.S. Department of the Interior, Mine Drainage and Surface Mine Reclamation Conference. Pittsburg, PA, April 17 - 22, 1988. pp 93 - 103.

Nicholson, R.V. Gillham, R.W., Cherry, J.A. and Reardon, E.J. (1989). Reduction of acid generation in mine tailings through the use of moisture-retaining cover layers as oxygen barriers. Canadian Geotechnical Journal, 26:1-8.

Norton, PJ. (1988). Recent Developments in the Use of Mining and Other Wastes in Land Reclamation in the United Kingdom. Proceedings. American Society for Surface Mining and Reclamation and the U.S. Department of the Interior, Mine Drainage and Surface Mine Reclamation Conference. Pittsburg, PA., USA. April 17 - 22, 1988.

Nyhan, JW, Hakonson, TE and Drennon, BJ. (1990). A Water Balance Study of Two Landfill Cover Designs for Semiarid Regions. J. Environ. Qual., Vol. 19, April-June 1990. pp 281-288.

Nyhan, J.W., Schofield, T.G., Salazar, J.A., Los Alamos National Lab., NM(United States) (199710A water balance study of four landfill cover designs varying in slope for semiarid regions. 9pp. Report Number: LA-UR –96-4092,CONF-970208--6.

O'Kane, M, Wilson, GW, Barbour, SL. (1993). SoilCover, A New Computer Model to Aid in the Design of Soil cover systems for Acid Generating Waste Rock and Tailings. In, Proceedings of the Seventeenth Annual British Columbia Mine Reclamation Symposium, Port Hardy, BC, Canada. May 4 – 7, 1993. 177 – 189.

Oweis, I.S., Dakes, G., Marturano, T., Wierer, R.(1994). Soil-covers success. Civil Engineering, Vol 64 Issue 10, p. 58-59.

Pulles, W, Howie, D, Otto, D, Easton, J. (1996). Appendix to WRC Report no TT80/96: A manual on Mine Water Treatment and Management Practises in South Africa. Volume 4, Overseas Study Tour Report No 527/4/76, 1996.

Richards, L.A. (1931). Capillary conduction of liquids through porous medium. Physics 1: 318-333.

Rollin, AL, Lafleur, J, Lemieux, R, Wyglinski, T and Zanescu A. (1993),.Capping of Mining Wastes Using Textured HDPE Geomembranes. Proceedings. Sardinia 93, Fourth International Landfill Symposium. S. Margherita, Cagliari, Italy. 11-15 October 1993. pp 243 - 251.

Ross, PJ. (1990). SWIM – a simulation model for Sil Water Infiltration and Movement. Reference Manual. CSIRO Division of Soils, Davies. Laboratory, Townsville, Australia. 1990.

Schroeder, P.R., Gibson, A.C. and Smolen, M.D. (1989). Documentation for the Hydrologic Evaluation of Landfill Performance (HELP V 205) Model.

Schulze, R. (1995). Hydrology and Agrohydrology. A text to accompany the ACRU 3.00 Agrohydrological Modelling System. W R C, Pretoria report, TT 69/95. 1995.

Smith, M, Allen, R, Monteith, Jl, Perier, A, Santos Pereira, L, Segeren, (1990). A. Report on the Expert consultation on procedures for Revision of FAO Guidelines for Prediction of Crop Water Requirements. Land and Water Development Division, Food and Agriculture Organisation of the United Nations. Rome, Italy. 28 – 31 May 1990.

Smyth, C.R., (1997). Early succession patterns with native species seed mix on amended and unamended coal mine spoil in the Rocky Mountains of southeastern British Columbia. Arctic and Alpine Research, 29(2): 184-195, ISSN:0004-0851.

Sobek, A.A., Schulder, W.A., Freeman, J.R.& Smith, R.M., (1987). Field and Laboratory Methods Applicable to Overburdens and Minesoils.EPA-600/2-78-054.USEPA, Cincinnati, Ohio.

Soil Classification Workgroup (1981). Soil Classification: A Taxonomic System for South Africa. Memoirs on the Agricultural and Natural Resources of South Africa, no 15.

Stark, T.D. (1997). Effect of swell pressure on GCL cover stability. pp. 30-44 In: Testing and acceptance criteria for geosynthetic clay liners. West Conshohocken, PA (United States of America): American Society for Testing and Materials, 279 pp. ASTM special technical publication 1308. (Well, L.W., [ed(s)]) ISBN: 0-8031-2471-6 Report Number: CONF-9601137.

Steffen Robertson & Kirsten (B.C.) (1989). Inc. Draft Acid Rock Drainage Technical Guide. Volume I - Technical Guide. Prepared for the British Columbia AMD Task Force. Report No. 66 002/1. August 1989.

Stumm, W, and Morgan, J.J, (1981). Aquatic Chemistry. An introduction Emphasising Chemical Equilibrium in Natural Waters 2nd Edition. John Wiley & Sons.

Thompson, DG, Manly, JK, Kitchin, RF, Eenkooren, NE, Davies, MP, Gibson, GG, Dawson, BB. (1997). Mark Creek Improvement Project of ARD in the Lower Mine Yard Kimberly, British Columbia. Proceedings. Fourth International Conference on Acid Rock Drainage, Vancouver, BB. Canada. May 31 June 6, 1997.

Van den Berg JJ, Cruywagen L, de Necker E and Hodgson FDI (2001). The Suitability and Impact of Power Station Fly Ash for Water Quality Control in Opencast Mine Rehabilitation. WRC Report No 745/1/01, Pretoria.

Van Genuchten, M.Th. (1980). A closed-form equation for predicting the hydraulic conductivity of unsaturated soils. Soil Sci. Soc. Am. J. 44:892-898.

Van Genuchten, M.Th. Leij, F.J. & Yates, S.R. (1996). The RETC code for quantifying the hydraulic functions of unsaturated soils. Soil Parameter Estimator computer program manual, Draper Aden Environmental Modelling Inc. 2206 South Main Street, Blacksburg, Virginia.

Van Schalkwyk and Vermaak (1998). Research on the relationship between geotechnical and hydrogeological properties of residual soils and rocks in the vadose zone. Draft Final Report WRC Report No.5/275, Pretoria.

Van Tonder, G.J. & Kirchner, J. (1990). Estimation of natural groundwater recharge in the Karoo aquifers of South Africa. Journal of Hydrology, 121:395-419.

Vogel, L, Huang, K, Zhang, R, van Genuchten, MTh. (1996). The HYDRUS Code for Simulating One-Dimensional Water Flow, Solute Transport, and Heat Movement in Variably Saturated Media: Version 5.0 Research Report no 140. US Salinity Laboratory, Agricultural Research Service, US Department of Agriculture, Riverside, California. August 1996.

Wallace, RB. (1993). The stability and Integrity of Landfill Closure Systems. Proceedings. Sardinia 93 Fourth International Landfill Symposium. S. Margherita, Cagliari, Italy. 11 -15 October 1993. pp 225 - 234.

Wang, D. Norman, J.M. Lowery, B. And Mcsweeney, K. (1994). Non-destructive determination of hydrogeometrical characteristics of soil macropores. Soil Sci. Soc. Am J., 58:294-303.

Wates, J.A., Rykaart, E.M. (1994). Design of Cover for Control of Infiltration. Proceedings of the First Environmental Management Technology and Development Conference. Fourways, South Africa, 7-9 March 1994.

Wates, J.A., Rykaart, E.M., Vermaak, J.J.G & Bezuidenhout, N. (1998). The Performance of Natural Soil Covers in Rehabilitating Opencast Mines and Waste Dumps in South Africa. Draft WRC Report.

Wesseling, JG, Kabat, P, van den Broek and BJ, Feddes, R. (1989). Instruction for Input: SWACROP. The Winand Staring Centre for Integrated Land, Soil and Water Research, Wageningen, Netherlands, March 1989.

Wilson, GW, Barbour, SL, Swanson, D, O'Kane, (1997). M. Instrumentation and Modelling for Saturated/Unsaturated performance of Soil Covers on Acid Generating Waste Rock. Paper submitted for review to the revue, Hydrogeologie. 1996.

Wilson, GW, Newman, L, Barbour, SL, O'Kane, M, Swanson, DA. (1997). The Cover Research Program at Equity Silver Mine Ltd. Proceedings. Fourth International Conference on Acid Rock Drainage, Vancouver, B.C. Canada. May 31 – June 6, 1997.

Woyshner, M.R., Yanful, E.K. (1995). Modelling and field measurements of water percolation through an experimental soil cover on mine tailings. Canadian Geotechnical Journal, Vol 5, Issue 32, p 601-609.

Yanful, EK. (1993). Oxygen diffusion through soil covers on Sulphuric Mine Tailings. Journal of Geotechnical Engineering. Vol 119, No. 8. August, pp 1207 - 1228.

Yanful, E.K., Riley, M.D., Woyshner, M.R. and Duncan,N. (1993). Construction and monitoring of a composite soil cover on an experimental waste-rock pile near Newcastle, New Brunswick, Canada. Canadian Geotechnical Journal, Vol 30, Issue 4,p.588-599.

Yanful, E.K., Bell, A.V. and Woyshner, M.R.(1993). Design of a composite soil cover for an experimental waste rock pile near Newcastle, New Brunswick, Canada. Canadian Geotechnical Journal, Vol 30, Issue 4, p.578-587.

Wilson, GW, Newman, L, Barbour, SL, O'Kane, M, Swanson, DA. (1997). The Cover Research Program at Equity Silver Mine Ltd. Proceedings. Fourth International Conference on Acid Rock Drainage, Vancouver, B.C. Canada. May 31 – June 6, 1997.

Woyshner, M.R., Yanful, E.K. (1995). Modelling and field measurements of water percolation through an experimental soil cover on mine tailings. Canadian Geotechnical Journal, Vol 5, Issue 32, p 601-609.

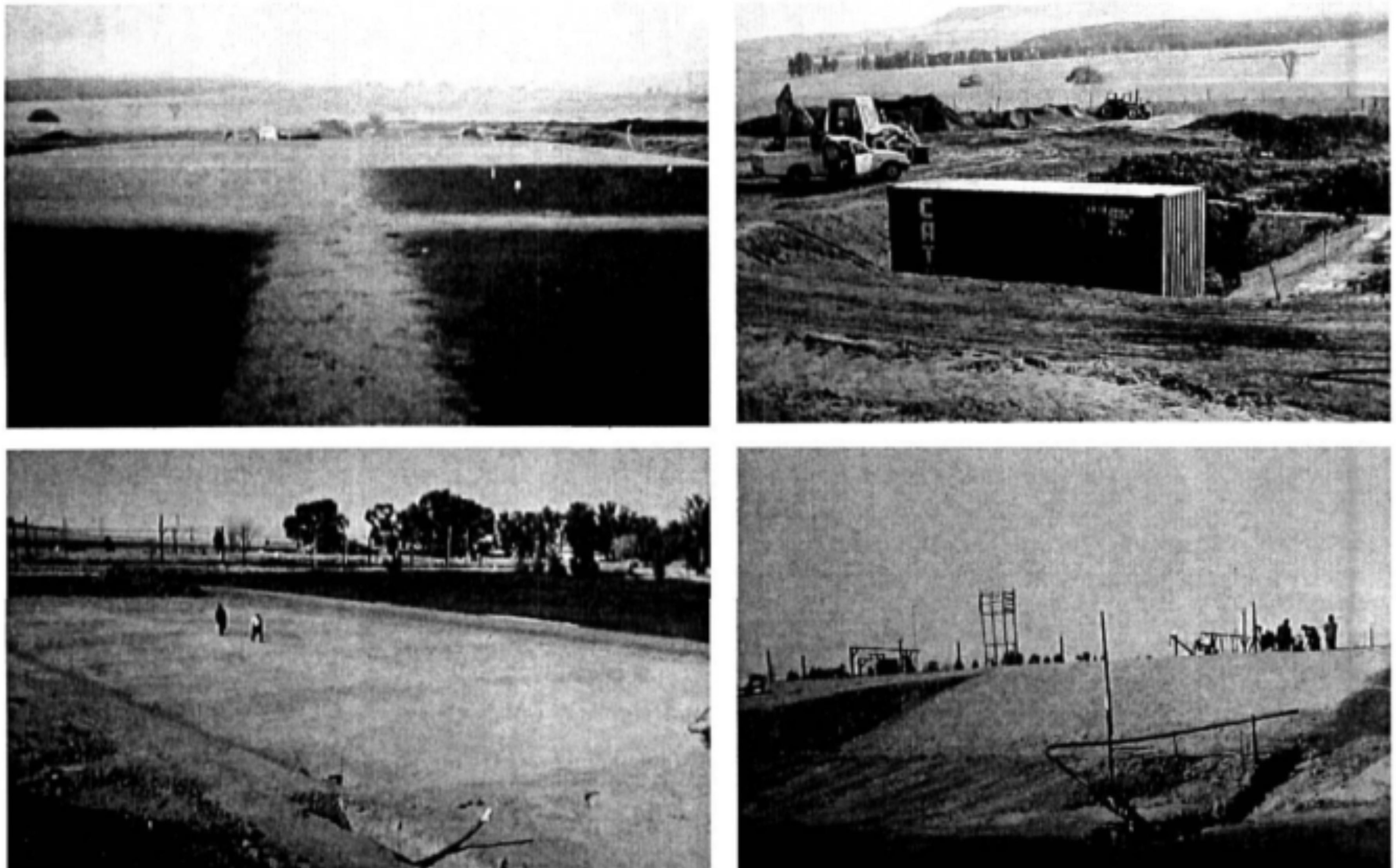
Yanful, EK. (1993). Oxygen diffusion through soil covers on Sulphuric Mine Tailings. Journal of Geotechnical Engineering. Vol 119, No. 8. August, pp 1207 - 1228.

Yanful, E.K., Riley, M.D., Woyshner, M.R. and Duncan,N. (1993). Construction and monitoring of a composite soil cover on an experimental waste-rock pile near Newcastle, New Brunswick, Canada. Canadian Geotechnical Journal, Vol 30, Issue 4,p.588-599.

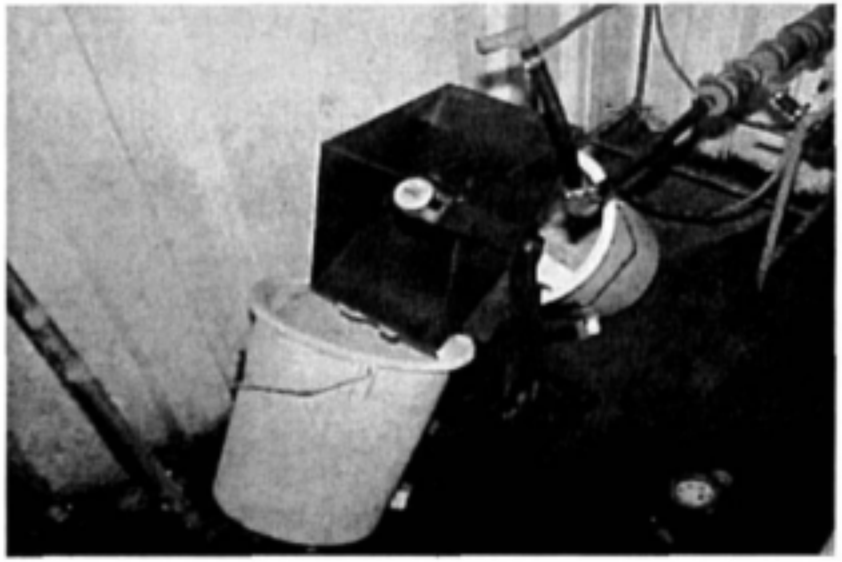
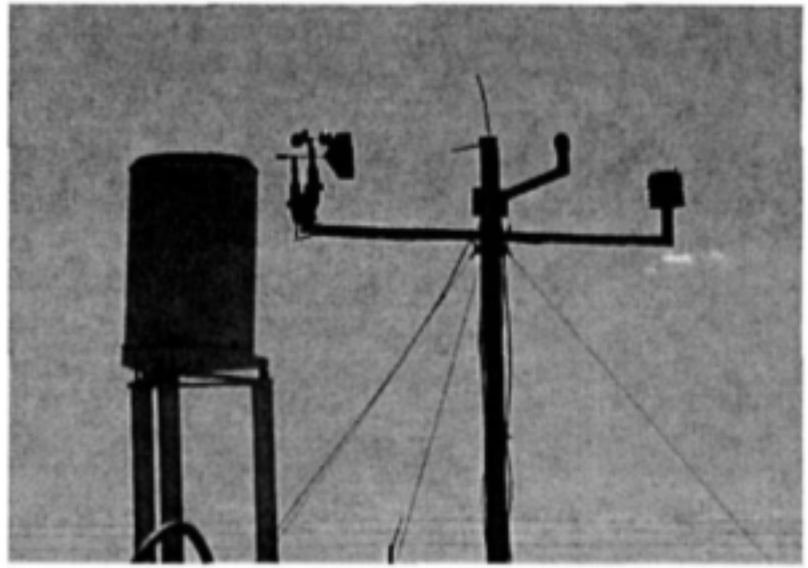
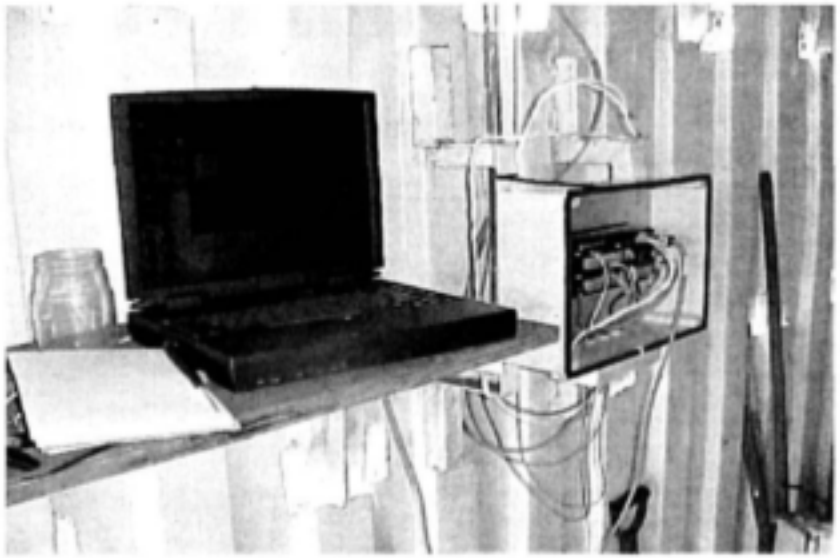
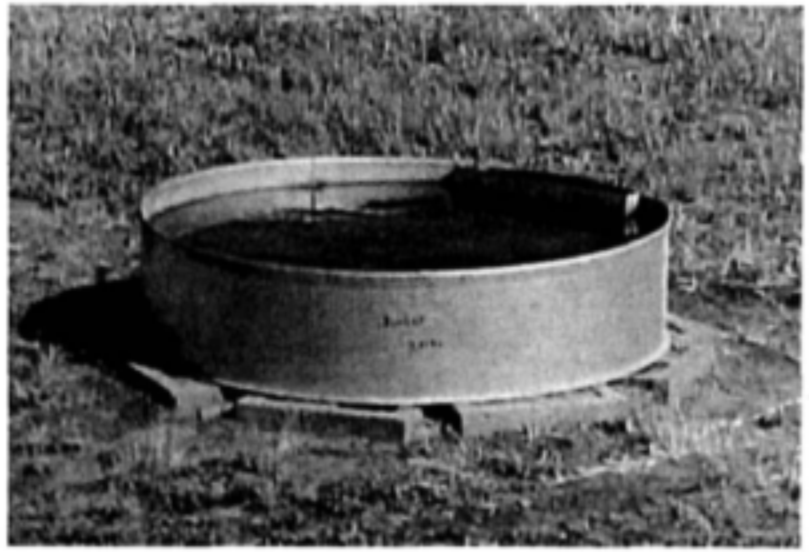
Yanful, E.K., Bell, A.V. and Woyshner, M.R.(1993). Design of a composite soil cover for an experimental waste rock pile near Newcastle, New Brunswick, Canada. Canadian Geotechnical Journal, Vol 30, Issue 4, p.578-587.

APPENDIX A

Photographs of construction, instruments and vegetation cover



Construction of experimental site

WMB

Monitoring equipment

Seasonal vegetation cover

APPENDIX B

Model climate data file

Day	Rainfall	Average Temperature	Temperature (Max)	Temperature (Min)	Humidity	Radiation
28-Feb-94	0.00	25.54	31.57	14.28	37.66	10.24
01-Mar-94	0.00	21.42	32.44	9.61	67.89	18.20
02-Mar-94	0.00	20.80	25.56	16.71	71.07	11.50
03-Mar-94	0.00	19.97	26.38	16.73	88.47	10.36
04-Mar-94	0.00	18.08	22.75	15.59	92.06	8.73
05-Mar-94	0.00	20.22	27.66	15.04	78.17	12.33
06-Mar-94	0.00	19.73	28.19	14.85	87.32	12.38
07-Mar-94	0.00	22.05	31.77	12.87	76.17	18.16
08-Mar-94	0.00	19.96	27.82	15.96	85.44	9.39
09-Mar-94	0.00	20.81	32.01	12.15	74.94	18.21
10-Mar-94	0.00	21.24	30.30	13.07	71.36	18.76
11-Mar-94	0.00	21.30	33.91	10.81	73.12	19.51
12-Mar-94	0.00	23.29	31.92	17.29	70.69	18.58
13-Mar-94	0.00	22.41	34.41	12.69	68.31	19.36
14-Mar-94	0.00	19.07	28.19	14.60	84.06	14.35
15-Mar-94	0.00	18.04	27.27	14.72	95.25	12.42
16-Mar-94	0.00	19.16	27.33	12.41	80.80	20.44
17-Mar-94	0.00	20.81	29.46	14.92	73.39	20.03
18-Mar-94	0.00	18.77	26.05	13.40	86.68	12.05
19-Mar-94	0.00	18.91	26.43	14.41	76.13	15.89
20-Mar-94	0.00	18.22	26.62	11.89	78.31	18.67
21-Mar-94	0.00	18.75	29.28	10.59	76.12	17.61
22-Mar-94	0.00	18.85	30.40	10.40	82.30	17.56
23-Mar-94	0.00	20.78	32.68	10.78	74.24	18.66
24-Mar-94	0.00	21.34	33.06	13.49	77.69	14.91
25-Mar-94	0.00	20.84	32.53	10.25	73.02	18.78
26-Mar-94	0.00	22.35	34.04	13.82	68.36	18.10
27-Mar-94	0.00	22.98	33.24	14.02	67.51	15.90
28-Mar-94	0.00	15.93	17.64	14.68	109.47	2.69
29-Mar-94	0.00	20.06	29.85	14.47	88.09	15.37
30-Mar-94	0.00	19.47	27.78	16.65	95.66	10.95
31-Mar-94	0.00	19.24	29.29	13.84	82.28	15.18
01-Apr-94	0.00	19.93	28.96	10.37	77.42	17.21
02-Apr-94	0.00	21.04	29.57	16.14	80.75	16.78
03-Apr-94	0.00	20.07	27.49	13.89	80.76	15.58
04-Apr-94	0.00	19.09	27.59	12.83	78.99	17.50
05-Apr-94	0.00	18.25	31.91	7.64	79.42	18.04
06-Apr-94	0.00	18.99	30.15	9.22	77.26	17.43
07-Apr-94	0.00	19.26	27.25	13.82	81.44	13.48
08-Apr-94	0.00	18.01	27.83	11.98	88.43	13.24
09-Apr-94	0.00	18.78	31.10	9.62	79.50	14.49
10-Apr-94	0.00	17.95	27.40	11.53	91.44	11.93
11-Apr-94	0.00	18.78	27.63	10.83	83.00	13.10
12-Apr-94	0.00	17.32	28.97	7.67	82.03	16.12
13-Apr-94	0.00	17.74	27.75	10.37	85.13	13.95
14-Apr-94	0.00	16.49	29.62	6.03	77.32	16.94
15-Apr-94	0.00	17.03	31.26	5.57	74.11	16.50
16-Apr-94	0.00	16.35	27.57	6.78	77.11	9.99
17-Apr-94	0.00	19.46	29.64	9.83	57.66	13.96
18-Apr-94	0.00	18.88	29.28	12.12	73.49	16.11
19-Apr-94	0.00	17.62	30.87	9.44	85.83	11.38
20-Apr-94	0.00	14.27	19.61	11.94	104.56	4.33

21-Apr-94	0.00	16.64	23.51	11.55	82.75	8.57
22-Apr-94	0.00	14.31	21.87	7.41	78.75	12.03
23-Apr-94	0.00	13.14	25.03	3.83	80.24	15.80
24-Apr-94	0.00	14.17	22.75	7.53	83.76	13.66
25-Apr-94	0.00	9.95	21.11	1.68	86.35	13.75
26-Apr-94	0.00	11.08	22.88	4.21	90.94	13.26
27-Apr-94	0.00	13.63	27.78	1.71	73.62	15.30
28-Apr-94	0.00	16.68	29.24	3.40	66.01	14.86
29-Apr-94	0.00	12.78	15.37	12.02	108.85	1.10
30-Apr-94	0.00	13.36	19.29	10.66	105.06	7.85
01-May-94	0.00	15.39	23.64	7.24	85.99	9.83
02-May-94	0.00	15.30	24.53	8.95	82.98	4.91
03-May-94						
04-May-94						
05-May-94						
06-May-94						
07-May-94						
08-May-94						
09-May-94	0.00	21.63	28.71	12.95	39.97	8.77
10-May-94	0.00	14.55	28.22	4.32	78.76	13.18
11-May-94	0.00	14.30	29.50	3.34	74.52	13.71
12-May-94	0.00	14.91	24.51	5.84	89.11	11.72
13-May-94	0.00	15.64	26.32	7.65	89.37	11.45
14-May-94	0.00	13.03	27.24	3.55	82.94	12.94
15-May-94	0.00	12.79	27.28	1.57	78.24	13.32
16-May-94	0.00	12.42	26.81	1.37	78.37	13.03
17-May-94	0.00	12.70	27.33	1.30	74.14	12.91
18-May-94	0.00	12.29	26.56	1.54	76.59	12.42
19-May-94	0.00	11.55	26.54	1.16	78.04	12.58
20-May-94	0.00	11.14	26.53	-0.06	72.65	13.08
21-May-94	0.00	11.45	27.44	-0.83	67.72	12.63
22-May-94	0.00	8.34	22.40	-0.49	78.41	10.02
23-May-94	0.00	5.13	18.04	-2.36	85.19	12.28
24-May-94	0.00	6.73	22.24	-4.23	67.07	12.68
25-May-94	0.00	6.66	23.10	-4.91	69.89	12.58
26-May-94	0.00	8.11	26.18	-5.55	67.95	12.30
27-May-94	0.00	11.88	26.20	-2.69	51.47	11.81
28-May-94	0.00	7.13	14.78	-1.45	57.81	9.90
29-May-94	0.00	4.69	19.36	-6.21	69.68	11.98
30-May-94	0.00	18.03	20.01	-1.51	31.41	9.42
31-May-94	0.00	9.85	22.69	-2.26	67.31	11.61
01-Jun-94	0.00	8.48	20.70	-1.67	81.22	11.41
02-Jun-94	0.00	10.50	23.00	0.71	77.34	10.41
03-Jun-94	0.00	12.29	24.54	-0.04	63.18	11.55
04-Jun-94	0.00	9.23	25.16	-2.18	68.17	11.56
05-Jun-94	0.00	11.43	24.79	-2.40	59.47	11.02
06-Jun-94	0.00	8.70	18.49	-4.51	36.28	11.97
07-Jun-94	0.00	4.95	18.68	-5.85	65.98	11.75
08-Jun-94	0.00	6.19	21.16	-7.45	57.30	11.32
09-Jun-94	0.00	4.54	19.58	-7.48	53.83	11.50
10-Jun-94	0.00	5.82	19.09	-6.03	74.91	10.76
11-Jun-94	0.00	6.84	21.26	-2.88	86.40	10.71
12-Jun-94	0.00	8.00	22.83	-3.21	70.27	11.10

13-Jun-94	0.00	7.93	21.03	-3.92	62.95	10.85
14-Jun-94	0.00	6.47	20.53	-3.16	64.86	10.89
15-Jun-94	0.00	6.66	16.72	-5.13	69.13	8.42
16-Jun-94	0.00	9.84	19.71	0.72	66.13	10.18
17-Jun-94	0.00	11.00	19.75	-0.30	42.80	10.96
18-Jun-94	0.00	12.86	21.54	2.53	36.11	6.20
19-Jun-94	0.00	9.51	22.97	-5.32	33.25	11.68
20-Jun-94	0.00	9.53	23.79	-7.40	31.15	11.45
21-Jun-94	0.00	17.12	24.24	6.06	16.79	10.95
22-Jun-94	0.00	9.72	15.29	2.44	90.85	4.91
23-Jun-94	0.00	11.50	23.33	-0.48	68.70	10.13
24-Jun-94	0.00	17.35	24.40	10.21	37.69	10.75
25-Jun-94	0.00	16.53	25.85	10.03	19.40	11.47
26-Jun-94	0.00	13.36	26.74	-2.97	31.76	11.07
27-Jun-94	0.00	19.75	26.42	12.81	21.66	10.74
28-Jun-94	0.00	12.92	20.07	3.71	34.20	5.24
29-Jun-94	0.00	5.52	12.21	-1.65	39.86	11.04
30-Jun-94	0.00	3.43	12.25	-5.26	57.71	9.52
01-Jul-94	0.00	2.40	13.58	-5.92	78.75	7.36
02-Jul-94	0.00	3.57	16.28	-4.81	86.07	8.58
03-Jul-94	0.00	4.43	19.29	-4.09	73.97	10.47
04-Jul-94	0.00	-0.74	17.80	-7.88	83.81	5.24
05-Jul-94						
06-Jul-94						
07-Jul-94						
08-Jul-94						
09-Jul-94						
10-Jul-94						
11-Jul-94	0.00	8.49	16.31	-2.16	38.17	10.20
12-Jul-94	0.00	4.41	21.27	-7.49	57.63	11.16
13-Jul-94	0.00	8.13	27.15	-7.18	46.36	11.31
14-Jul-94	0.00	10.99	28.17	-4.74	35.80	11.59
15-Jul-94	0.00	7.18	21.44	-6.09	58.07	10.88
16-Jul-94	0.00	9.01	23.34	-0.09	65.33	9.80
17-Jul-94	0.00	7.09	23.69	-5.86	50.60	11.43
18-Jul-94	0.00	8.32	23.41	-4.04	53.07	11.10
19-Jul-94	0.00	10.84	23.71	-3.26	40.23	11.26
20-Jul-94	0.00	8.66	24.04	-3.98	61.45	11.01
21-Jul-94	0.00	7.84	23.51	-4.86	51.49	11.41
22-Jul-94	0.00	8.71	23.46	-4.19	48.51	11.16
23-Jul-94	0.00	14.45	24.80	3.09	21.87	11.72
24-Jul-94	0.00	17.85	25.86	11.36	14.70	10.18
25-Jul-94	5.80	10.98	19.04	1.13	47.60	5.13
26-Jul-94	0.00	9.49	19.98	1.44	61.50	11.92
27-Jul-94	0.00	7.22	18.90	-2.88	75.12	12.32
28-Jul-94	0.00	7.10	19.44	-3.14	77.08	12.20
29-Jul-94	0.00	7.07	21.07	-4.25	72.89	12.08
30-Jul-94	0.00	7.73	22.54	-4.74	68.17	12.29
31-Jul-94	0.00	8.30	23.45	-4.57	64.44	12.22
01-Aug-94	0.00	7.98	23.28	-5.01	62.88	12.42
02-Aug-94	0.00	8.37	22.97	-4.47	59.76	11.84
03-Aug-94	0.00	10.29	24.57	-3.21	65.05	11.97
04-Aug-94	0.00	11.79	17.86	6.85	80.48	7.36

05-Aug-94	0.20	11.43	17.35	5.65	78.27	6.62
06-Aug-94	0.00	10.93	22.79	-0.99	62.46	11.90
07-Aug-94	0.00	15.02	27.01	3.79	35.27	12.19
08-Aug-94	0.00	15.72	23.56	3.14	27.89	12.30
09-Aug-94	0.00	10.28	22.55	0.62	58.77	12.51
10-Aug-94	0.00	10.46	24.48	-1.94	65.93	12.91
11-Aug-94	0.00	13.07	25.63	4.37	54.10	12.99
12-Aug-94	0.00	16.19	28.09	1.00	51.66	9.44
13-Aug-94	0.00	17.99	28.98	5.57	56.84	9.32
14-Aug-94	0.00	13.79	20.81	7.00	55.41	9.50
15-Aug-94	0.00	11.43	22.96	2.31	65.67	12.26
16-Aug-94	0.00	12.30	23.48	1.86	56.39	11.75
17-Aug-94	0.00	12.06	25.02	0.07	58.86	11.32
18-Aug-94	0.00	14.70	27.25	1.69	55.42	11.32
19-Aug-94	0.00	20.10	28.69	13.79	42.38	11.70
20-Aug-94	25.20	9.05	13.70	4.94	108.61	1.32
21-Aug-94	2.60	7.33	13.41	3.79	84.83	9.87
22-Aug-94	0.00	7.41	16.10	0.81	84.39	15.34
23-Aug-94	0.00	8.86	22.79	-2.26	70.50	15.32
24-Aug-94	0.00	13.40	23.61	1.42	50.99	14.25
25-Aug-94	0.00	11.27	24.56	0.82	69.00	14.59
26-Aug-94	0.00	13.07	28.09	1.07	67.51	15.06
27-Aug-94	0.00	14.87	30.28	1.99	61.36	14.97
28-Aug-94	0.00	13.10	22.89	2.95	73.50	13.80
29-Aug-94	0.00	15.49	25.58	8.15	64.65	14.97
30-Aug-94	0.00	16.61	30.24	3.19	57.81	15.69
31-Aug-94	0.00	18.30	30.95	4.69	38.28	15.81
01-Sep-94	0.00	14.87	28.06	4.33	67.04	15.15
02-Sep-94	0.00	16.57	29.16	4.79	58.59	15.59
03-Sep-94	0.00	16.82	30.27	4.59	46.08	15.29
04-Sep-94	0.00	15.73	29.92	3.12	46.66	16.36
05-Sep-94	0.00	16.83	32.68	1.27	47.36	14.69
06-Sep-94	0.00	16.57	28.53	3.00	45.76	16.22
07-Sep-94	5.80	17.84	31.79	3.16	46.95	16.66
08-Sep-94	0.00	12.84	16.67	5.37	69.22	5.77
09-Sep-94	0.00	10.72	19.22	4.24	68.75	14.75
10-Sep-94	0.00	11.98	25.48	0.02	65.19	15.86
11-Sep-94	0.00	15.44	29.30	2.62	55.25	15.13
12-Sep-94	0.00	16.90	29.31	3.91	53.82	16.31
13-Sep-94	0.40	15.85	29.83	8.25	81.13	12.96
14-Sep-94	2.20	10.12	12.25	8.24	98.95	3.71
15-Sep-94	0.00	15.64	25.89	7.74	68.09	17.25
16-Sep-94	0.00	18.50	32.14	5.37	49.64	17.54
17-Sep-94	0.00	23.85	33.49	9.86	25.96	16.73
18-Sep-94	0.00	21.84	29.45	11.14	22.97	18.43
19-Sep-94	0.00	16.30	26.00	8.84	66.69	17.01
20-Sep-94	0.00	18.96	31.99	4.40	55.18	18.08
21-Sep-94	0.00	18.97	31.45	5.34	55.98	17.96
22-Sep-94	0.00	20.76	34.70	7.17	60.72	16.34
23-Sep-94	0.00	22.81	35.69	8.91	51.62	15.50
24-Sep-94	5.80	20.30	31.46	10.20	51.23	17.39
25-Sep-94	0.00	19.88	32.91	8.15	64.54	15.45
26-Sep-94	33.80	29.11	36.05	17.41	19.21	15.91

27-Sep-94	0.00	24.20	35.96	11.77	41.24	16.36
28-Sep-94	0.00	23.31	33.39	13.95	38.69	17.33
29-Sep-94	0.00	11.51	15.16	9.75	87.64	1.63
30-Sep-94	12.80	14.86	23.83	8.48	74.87	17.00
01-Oct-94	0.00	15.42	24.11	9.38	77.32	13.86
02-Oct-94	0.00	19.37	30.41	9.95	56.29	20.39
03-Oct-94	0.60	15.92	26.66	6.77	63.74	16.87
04-Oct-94	1.40	10.47	13.57	8.31	85.82	4.52
05-Oct-94	0.00	11.90	16.24	9.08	73.58	11.11
06-Oct-94	0.00	13.71	20.96	7.31	57.46	21.09
07-Oct-94	0.00	14.64	25.89	4.23	63.81	19.89
08-Oct-94	0.40	15.61	27.66	5.83	61.81	17.12
09-Oct-94	0.00	18.63	28.91	6.00	55.40	14.21
10-Oct-94	1.40	16.78	29.51	6.79	63.07	12.10
11-Oct-94	0.00	10.60	14.14	7.09	79.08	5.75
12-Oct-94	0.00	17.37	28.05	10.79	67.33	18.34
13-Oct-94	0.00	17.13	25.31	12.76	75.80	16.97
14-Oct-94	6.20	12.06	16.11	10.37	94.63	6.65
15-Oct-94	1.60	13.14	18.64	8.45	89.42	13.03
16-Oct-94	0.20	15.87	27.29	7.52	71.40	21.84
17-Oct-94	0.00	18.51	30.98	5.64	61.02	22.85
18-Oct-94	0.00	19.12	32.47	4.50	53.71	22.91
19-Oct-94	0.00	20.79	34.45	6.59	54.84	20.35
20-Oct-94	0.00	23.37	34.59	8.57	47.42	17.52
21-Oct-94	0.00	21.91	30.80	14.20	26.65	23.35
22-Oct-94	0.00	18.46	28.09	13.18	69.94	19.94
23-Oct-94	5.80	15.85	24.51	11.70	91.77	11.70
24-Oct-94	1.00	16.09	28.70	10.47	93.77	8.91
25-Oct-94						
26-Oct-94						
27-Oct-94						
28-Oct-94						
29-Oct-94						
30-Oct-94						
31-Oct-94	0.20	18.19	22.11	12.07	70.53	8.09
01-Nov-94	0.20	17.57	29.52	8.32	69.23	23.23
02-Nov-94	0.00	19.09	29.57	7.12	59.93	19.48
03-Nov-94	3.60	17.79	23.49	14.88	75.24	7.75
04-Nov-94	0.20	19.71	25.32	15.06	77.23	15.14
05-Nov-94	1.20	21.41	31.18	15.64	70.89	20.21
06-Nov-94	0.80	23.94	34.15	14.12	68.63	24.07
07-Nov-94	0.00	19.88	25.29	17.53	102.14	4.00
08-Nov-94						
09-Nov-94						
10-Nov-94						
11-Nov-94						
12-Nov-94						
13-Nov-94						
14-Nov-94	1.20	25.70	30.69	17.16	60.77	11.97
15-Nov-94	4.00	15.72	17.20	13.58	109.68	3.84
16-Nov-94	0.20	19.59	27.43	12.35	86.95	19.49
17-Nov-94	0.00	23.64	33.11	14.60	62.98	21.37
18-Nov-94	0.00	24.11	32.45	14.64	55.66	19.09

19-Nov-94	0.00	26.17	34.53	18.18	45.75	22.54
20-Nov-94	0.00	24.37	35.07	12.55	62.38	24.57
21-Nov-94	1.20	23.54	33.74	14.57	66.48	18.61
22-Nov-94	0.00	23.92	34.65	16.22	69.76	20.88
23-Nov-94	0.00	22.30	34.48	13.11	70.89	18.90
24-Nov-94	1.60	13.16	19.80	9.67	85.25	10.08
25-Nov-94	0.00	18.32	30.34	6.39	67.56	23.43
26-Nov-94	0.00	22.36	34.66	8.80	59.19	24.01
27-Nov-94	0.00	25.84	36.19	12.04	48.81	23.28
28-Nov-94	0.00	14.04	17.80	11.05	81.82	4.08
29-Nov-94	0.00	15.18	23.38	5.72	58.39	25.86
30-Nov-94	0.00	17.28	25.57	9.49	58.37	19.19
01-Dec-94	0.00	21.34	32.17	7.85	52.02	21.33
02-Dec-94	0.00	24.30	35.40	16.30	45.43	21.24
03-Dec-94	0.00	20.86	29.52	14.14	72.04	19.64
04-Dec-94	0.00	24.77	35.70	13.19	62.55	21.48
05-Dec-94	31.00	23.88	35.13	17.82	58.97	11.36
06-Dec-94	5.80	22.60	33.58	16.00	72.81	17.89
07-Dec-94	0.00	20.14	26.06	16.15	87.62	10.18
08-Dec-94	0.00	23.50	33.39	14.31	72.60	21.49
09-Dec-94	52.80	23.04	32.90	15.91	74.00	17.67
10-Dec-94	6.20	15.14	16.69	11.85	110.35	4.25
11-Dec-94	0.60	12.50	17.87	9.57	87.29	12.62
12-Dec-94	0.00	15.25	24.21	8.01	62.95	25.35
13-Dec-94	0.00	21.19	34.15	7.62	60.33	25.53
14-Dec-94	0.00	19.20	28.34	12.47	83.82	22.48
15-Dec-94	0.00	17.31	24.84	13.16	88.16	10.89
16-Dec-94	2.80	21.34	31.42	13.21	73.30	20.19
17-Dec-94	1.40	24.56	35.11	16.13	53.60	20.99
18-Dec-94	0.00	22.68	33.55	14.41	70.75	22.54
19-Dec-94	2.60	23.66	34.47	16.62	66.20	17.58
20-Dec-94	0.00	25.95	36.90	14.20	53.22	24.91
21-Dec-94	0.00	26.50	36.53	17.13	61.53	20.76
22-Dec-94	0.20	26.54	37.04	20.18	51.13	18.19
23-Dec-94	4.40	24.22	35.56	15.95	67.24	19.94
24-Dec-94	0.60	23.26	32.90	16.58	70.87	14.18
25-Dec-94	0.00	20.84	28.93	16.02	73.46	23.76
26-Dec-94	17.20	20.82	28.87	15.30	74.67	20.08
27-Dec-94	25.20	19.69	26.54	15.93	93.88	9.59
28-Dec-94	0.20	18.13	25.76	14.65	104.34	5.18
29-Dec-94						
30-Dec-94						
31-Dec-94						
01-Jan-95	0.00	21.69	27.44	16.18	80.69	22.55
02-Jan-95	0.00	24.82	35.88	16.78	67.89	23.17
03-Jan-95	0.00	23.37	29.76	18.55	80.21	13.22
04-Jan-95	0.00	24.39	34.76	16.64	75.43	20.78
05-Jan-95	0.00	25.60	36.56	14.45	62.97	24.18
06-Jan-95	0.00	26.00	36.29	14.40	56.20	25.27
07-Jan-95	0.00	25.82	37.11	12.50	56.37	24.49
08-Jan-95	9.20	21.31	29.09	14.58	88.32	14.01
09-Jan-95	1.20	14.04	17.62	12.22	99.22	4.47
10-Jan-95	0.20	17.65	24.97	11.61	82.32	15.94

11-Jan-95	0.00	20.25	28.53	12.07	80.26	20.35
12-Jan-95	0.00	23.10	32.31	13.53	71.74	21.10
13-Jan-95	0.00	24.55	33.11	14.47	65.34	21.00
14-Jan-95	0.00	23.34	31.58	17.42	72.24	14.73
15-Jan-95	26.80	21.65	30.27	14.05	80.43	13.04
16-Jan-95	4.20	21.06	28.90	15.98	89.41	15.69
17-Jan-95	0.40	22.30	28.73	16.69	88.02	20.08
18-Jan-95	104.20	23.85	35.11	16.99	85.10	21.85
19-Jan-95	31.60	18.92	23.29	14.84	97.78	9.82
20-Jan-95	0.00	19.99	29.50	14.28	92.46	20.59
21-Jan-95	0.00	19.83	27.08	15.54	77.97	19.40
22-Jan-95	3.20	21.23	29.92	12.15	78.29	18.33
23-Jan-95	2.00	23.57	33.03	16.48	79.09	23.50
24-Jan-95	0.00	23.32	32.71	16.36	75.88	22.01
25-Jan-95	0.00	25.10	35.06	16.78	68.15	22.32
26-Jan-95	0.00	26.88	37.01	16.71	67.86	23.76
27-Jan-95	1.00	26.86	37.61	20.87	79.15	19.48
28-Jan-95	4.60	27.39	39.11	18.47	69.66	19.47
29-Jan-95	11.60	24.20	33.07	18.80	76.07	18.79
30-Jan-95	16.40	20.63	32.00	17.03	98.62	11.82
31-Jan-95	0.20	23.44	31.26	16.07	83.57	25.19
01-Feb-95	0.00	25.74	35.80	17.49	72.07	21.10
02-Feb-95	2.20	21.26	26.44	18.43	97.47	7.15
03-Feb-95	0.00	23.85	31.07	17.77	84.05	19.59
04-Feb-95	0.00	26.45	37.78	16.72	78.43	23.27
05-Feb-95	5.00	25.87	35.81	18.59	78.85	20.65
06-Feb-95	0.00	26.29	38.26	18.80	61.99	20.10
07-Feb-95	0.00	25.21	31.61	19.03	64.37	15.05
08-Feb-95	22.80	18.97	22.70	15.92	99.19	5.54
09-Feb-95	1.00	18.90	26.75	14.60	88.94	15.49
10-Feb-95	0.00	22.47	32.47	14.89	78.30	23.54
11-Feb-95	0.00	24.48	35.45	14.16	75.74	23.25
12-Feb-95	0.00	23.50	33.76	13.87	72.52	23.75
13-Feb-95	0.00	23.85	36.17	11.70	70.51	23.85
14-Feb-95	0.00	25.09	37.25	13.63	68.68	23.57
15-Feb-95	0.00	23.84	33.22	12.95	71.04	23.38
16-Feb-95	0.00	23.88	33.27	17.26	73.50	22.83
17-Feb-95	0.00	22.18	30.30	15.51	81.74	16.00
18-Feb-95	5.80	19.26	21.87	17.18	109.34	5.49
19-Feb-95	5.00	23.56	31.05	18.73	90.94	16.14
20-Feb-95	0.00	25.01	33.00	17.03	78.75	20.34
21-Feb-95	1.80	21.12	27.54	16.77	99.43	12.50
22-Feb-95	1.60	19.85	25.64	16.92	101.15	8.55
23-Feb-95	0.20	23.62	33.91	16.03	84.19	20.91
24-Feb-95	0.00	22.70	32.72	15.93	92.62	17.67
25-Feb-95	0.00	23.29	32.85	15.13	75.08	21.53
26-Feb-95	0.00	22.84	33.85	11.74	74.02	21.78
27-Feb-95	0.20	23.13	33.28	12.89	71.52	22.42
28-Feb-95	0.00	23.14	33.17	11.92	78.16	18.27
01-Mar-95	10.20	22.66	31.45	15.87	81.67	17.92
02-Mar-95	7.40	17.69	21.86	15.12	110.22	6.51
03-Mar-95	0.00	21.43	28.97	16.09	91.14	16.17
04-Mar-95	0.00	22.57	31.77	14.46	85.99	21.09

05-Mar-95	0.00	22.25	31.89	13.41	82.29	21.75
06-Mar-95	0.00	21.05	29.50	12.11	87.43	18.19
07-Mar-95	0.00	21.53	29.02	14.71	86.88	18.93
08-Mar-95	3.80	21.96	33.12	13.24	88.33	16.96
09-Mar-95	4.40	17.90	20.33	16.13	115.47	2.85
10-Mar-95	0.20	16.88	23.02	10.96	102.17	11.38
11-Mar-95	0.20	18.25	30.70	8.77	88.45	19.46
12-Mar-95	0.00	20.98	32.28	9.08	77.35	20.65
13-Mar-95	0.00	20.87	27.32	15.31	86.21	14.23
14-Mar-95	0.00	20.30	28.44	15.44	87.10	15.90
15-Mar-95	1.20	18.31	26.83	12.86	91.12	14.96
16-Mar-95	0.00	19.61	31.14	10.45	80.32	19.82
17-Mar-95	0.00	21.49	33.22	9.59	69.91	20.41
18-Mar-95	0.00	22.18	34.72	9.93	76.47	20.10
19-Mar-95	0.00	23.81	34.92	12.22	74.83	18.69
20-Mar-95	0.00	23.90	34.68	15.00	77.31	15.74
21-Mar-95	0.00	19.90	24.17	16.26	85.61	14.56
22-Mar-95	0.20	19.86	28.46	13.69	85.91	11.34
23-Mar-95	3.80	18.44	26.21	13.70	103.30	8.24
24-Mar-95	2.00	15.75	16.96	15.13	125.77	2.45
25-Mar-95	10.60	15.74	17.84	14.76	128.39	3.59
26-Mar-95	10.20	17.56	21.06	14.90	117.33	4.55
27-Mar-95	16.40	19.78	29.15	13.38	95.23	12.08
28-Mar-95	0.60	17.02	21.91	14.12	111.99	7.04
29-Mar-95	0.00	19.81	27.60	13.05	99.10	15.29
30-Mar-95	7.40	20.61	27.41	16.54	89.75	13.97
31-Mar-95	0.00	18.65	27.09	12.28	90.73	17.42
01-Apr-95	0.00	17.32	25.26	10.44	91.42	16.49
02-Apr-95	0.20	15.90	27.90	9.30	99.05	15.67
03-Apr-95	0.00	17.40	29.88	6.96	91.19	17.96
04-Apr-95	9.00	16.02	23.48	8.63	107.09	11.41
05-Apr-95	0.00	18.07	26.06	12.23	102.10	14.06
06-Apr-95	0.00	19.06	30.45	10.30	97.14	16.38
07-Apr-95	0.00	19.34	30.93	9.78	92.42	17.46
08-Apr-95	0.00	19.65	31.13	8.88	85.47	17.11
09-Apr-95	4.80	18.67	26.75	13.82	94.14	11.78
10-Apr-95	0.00	13.93	17.07	10.38	98.99	6.88
11-Apr-95	0.00	12.00	18.06	6.30	94.28	13.14
12-Apr-95	0.00	15.28	25.09	7.55	83.79	16.36
13-Apr-95	0.00	13.65	23.57	4.67	101.28	14.34
14-Apr-95	0.00	16.62	29.50	7.09	84.99	16.24
15-Apr-95	0.00	17.32	30.16	4.60	69.76	16.61
16-Apr-95	0.00	13.27	21.15	6.05	92.14	8.78
17-Apr-95	0.00	16.34	25.35	10.80	74.33	14.61
18-Apr-95	0.00	17.46	29.22	7.08	86.41	15.40
19-Apr-95	0.00	19.38	29.66	7.69	75.93	14.49
20-Apr-95	2.00	18.75	27.38	10.30	71.31	11.30
21-Apr-95	39.20	13.39	17.30	8.98	126.39	2.73
22-Apr-95	2.20	17.38	26.85	10.67	100.64	15.19
23-Apr-95	1.40	18.72	27.80	10.79	94.48	8.94
24-Apr-95	0.00	18.29	27.20	9.61	62.13	14.88
25-Apr-95	0.00	17.68	28.89	8.82	77.46	15.57
26-Apr-95	0.00	13.74	26.76	4.86	90.55	15.55

27-Apr-95	0.00	15.62	27.51	5.40	82.42	14.37
28-Apr-95	6.40	12.75	14.08	10.56	132.44	1.92
29-Apr-95	9.80	12.55	14.10	11.39	137.75	2.04
30-Apr-95	0.00	15.86	23.79	12.52	107.31	11.23
01-May-95	0.80	14.57	21.92	10.44	122.97	8.12
02-May-95	10.80	15.06	24.97	9.70	121.44	9.45
03-May-95	0.20	14.22	21.28	9.88	117.45	7.52
04-May-95	0.00	15.26	22.88	8.78	109.71	13.26
05-May-95	0.40	15.40	27.88	7.68	108.96	13.72
06-May-95	0.00	17.12	27.97	7.13	95.92	13.60
07-May-95	1.60	18.61	26.74	13.34	85.63	10.75
08-May-95	0.00	15.72	24.26	8.86	85.43	14.61
09-May-95	0.00	13.84	23.02	5.95	101.77	13.67
10-May-95	0.00	14.67	23.19	7.40	101.23	10.79
11-May-95	0.20	12.79	24.51	5.33	100.38	13.89
12-May-95	0.00	12.77	25.15	2.87	90.76	13.91
13-May-95	0.00	11.42	23.10	1.47	95.38	14.19
14-May-95	0.00	10.55	24.84	0.28	94.95	14.29
15-May-95	0.20	10.70	26.78	-0.55	92.92	14.00
16-May-95	0.00	11.80	27.99	-0.64	84.96	13.84
17-May-95	0.00	12.08	24.97	0.81	92.93	13.46
18-May-95	0.00	11.63	26.39	2.19	99.66	12.93
19-May-95	0.00	12.52	26.96	0.92	84.70	13.11
20-May-95	0.00	14.86	25.02	2.30	72.18	12.08
21-May-95	0.00	17.29	23.73	5.30	47.62	12.82
22-May-95	0.00	5.02	14.16	2.04	121.23	2.27
23-May-95						
24-May-95						
25-May-95						
26-May-95						
27-May-95						
28-May-95						
29-May-95	0.00	14.51	22.57	4.14	71.02	8.00
30-May-95	0.00	13.61	24.30	3.45	78.27	12.54
31-May-95	0.00	11.09	22.16	1.11	93.46	12.02
01-Jun-95	0.00	12.31	21.23	5.95	87.32	11.22
02-Jun-95	0.00	8.69	19.16	-0.66	95.78	11.56
03-Jun-95	0.00	8.81	25.36	-3.40	82.37	12.51
04-Jun-95	0.00	11.00	25.91	-3.12	68.14	12.62
05-Jun-95	1.00	14.26	22.86	6.23	56.02	11.45
06-Jun-95	0.00	6.08	15.73	-2.94	77.70	8.20
07-Jun-95	0.00	3.92	17.78	-6.32	85.29	12.61
08-Jun-95	0.00	10.03	22.83	-3.61	68.08	12.26
09-Jun-95	0.00	13.15	22.98	4.09	52.10	12.24
10-Jun-95	0.00	11.13	24.71	0.64	74.23	12.16
11-Jun-95	0.00	10.53	27.12	-3.16	73.73	12.56
12-Jun-95	0.00	10.81	21.25	2.18	97.05	9.62
13-Jun-95	0.20	10.19	23.05	-0.80	76.28	11.98
14-Jun-95	0.00	9.75	24.05	-2.06	62.34	12.09
15-Jun-95	0.00	9.44	22.51	-1.84	62.38	9.34
16-Jun-95	0.00	6.48	13.70	-2.24	82.95	5.69
17-Jun-95	0.00	9.21	15.99	0.85	89.56	8.20
18-Jun-95	0.00	11.01	17.35	1.57	84.96	10.58

19-Jun-95	0.00	6.84	19.65	-1.68	99.11	11.70
20-Jun-95	0.00	7.80	23.85	-4.47	78.01	12.02
21-Jun-95	0.00	6.92	22.53	-5.04	71.06	11.71
22-Jun-95	0.00	7.24	24.12	-4.85	71.18	12.05
23-Jun-95	0.00	8.66	24.81	-5.03	58.74	11.88
24-Jun-95	0.00	8.05	22.46	0.18	98.14	9.21
25-Jun-95	0.00	7.47	23.56	-4.44	82.60	11.34
26-Jun-95	0.00	10.07	27.65	-3.99	65.57	11.55
27-Jun-95	0.00	9.10	25.56	-3.37	61.86	11.10
28-Jun-95	0.00	9.01	25.83	-5.00	64.79	12.14
29-Jun-95	0.00	10.82	23.94	-5.20	50.99	11.98
30-Jun-95	0.00	16.08	25.54	6.37	34.24	11.28
01-Jul-95	0.00	11.32	19.97	3.55	64.58	9.17
02-Jul-95	0.00	10.19	21.97	-0.21	80.09	11.21
03-Jul-95	0.00	14.54	23.45	7.00	63.51	10.11
04-Jul-95	0.00	12.87	20.73	3.25	70.37	9.13
05-Jul-95	0.00	12.71	23.18	1.49	55.57	12.18
06-Jul-95	0.00	7.82	19.57	0.14	90.52	11.27
07-Jul-95	0.00	13.23	23.08	-0.11	47.86	12.31
08-Jul-95	0.00	14.40	22.82	5.72	42.28	11.04
09-Jul-95	0.00	13.56	23.97	1.98	33.47	10.20
10-Jul-95	0.00	13.91	28.21	-1.10	33.60	12.40
11-Jul-95	0.00	10.28	23.11	-2.71	49.25	12.55
12-Jul-95	0.00	8.27	19.54	-2.93	75.50	11.76
13-Jul-95	4.40	6.66	8.33	5.09	131.63	1.62
14-Jul-95	0.00	8.97	15.60	3.03	107.98	7.42
15-Jul-95	0.20	8.09	22.19	-1.25	97.83	11.45
16-Jul-95	0.00	8.74	23.92	-2.59	86.27	12.37
17-Jul-95	0.00	12.30	22.06	2.64	58.34	12.27
18-Jul-95	0.00	11.03	18.15	1.11	46.03	11.93
19-Jul-95	0.00	5.73	21.33	-4.22	84.15	11.75
20-Jul-95	0.00	9.38	24.99	-4.92	54.05	12.95
21-Jul-95	0.00	10.90	21.87	-0.41	49.68	12.71
22-Jul-95	0.00	14.34	24.64	3.28	32.04	12.08
23-Jul-95	0.00	7.50	19.96	-4.62	73.91	12.21
24-Jul-95	0.00	10.20	24.45	0.82	84.49	11.97
25-Jul-95	0.00	10.85	25.04	-1.73	61.37	12.39
26-Jul-95	0.00	13.20	27.71	1.38	60.01	11.66
27-Jul-95	0.00	15.59	26.47	7.51	65.53	11.87
28-Jul-95	0.00	15.49	24.82	8.95	75.46	11.33
29-Jul-95	0.00	14.71	25.31	3.55	46.24	12.08
30-Jul-95	0.00	11.62	25.65	-3.51	51.48	13.82
31-Jul-95	0.00	11.13	26.68	-1.86	36.08	11.47
01-Aug-95	0.00	12.94	28.41	-1.15	52.95	14.37
02-Aug-95	0.00	12.87	28.19	-0.25	50.74	12.96
03-Aug-95	0.00	13.16	28.77	-1.64	46.52	13.54
04-Aug-95	0.00	14.78	28.22	1.96	39.84	13.46
05-Aug-95	0.00	19.04	26.82	9.53	28.78	12.08
06-Aug-95	0.00	9.59	15.99	-0.20	62.02	10.95
07-Aug-95	0.20	7.17	23.04	-4.63	72.46	13.95
08-Aug-95	0.00	11.90	29.61	-3.48	51.11	13.90
09-Aug-95	0.00	13.61	29.19	-2.86	43.58	14.19
10-Aug-95	0.00	12.23	26.37	-1.25	53.37	13.75

11-Aug-95	0.00	11.06	17.64	3.69	78.01	7.56
12-Aug-95	0.00	13.30	24.58	0.77	72.23	13.82
13-Aug-95	0.00	11.49	23.03	0.53	85.71	14.21
14-Aug-95	0.00	6.59	12.54	3.25	131.14	2.17
15-Aug-95						
16-Aug-95						
17-Aug-95						
18-Aug-95						
19-Aug-95						
20-Aug-95						
21-Aug-95						
22-Aug-95						
23-Aug-95						
24-Aug-95						
25-Aug-95						
26-Aug-95						
27-Aug-95						
28-Aug-95						
29-Aug-95						
30-Aug-95						
31-Aug-95						
01-Sep-95						
02-Sep-95						
03-Sep-95						
04-Sep-95						
05-Sep-95						
06-Sep-95						
07-Sep-95						
08-Sep-95						
09-Sep-95						
10-Sep-95						
11-Sep-95						
12-Sep-95						
13-Sep-95	0.00	20.40	27.69	13.92	59.48	9.86
14-Sep-95	0.00	14.51	18.92	8.18	89.21	6.36
15-Sep-95	0.00	15.63	27.22	5.54	81.91	15.49
16-Sep-95	0.00	18.05	29.31	5.92	64.73	14.06
17-Sep-95	0.00	18.84	29.03	7.31	69.69	15.24
18-Sep-95	0.00	15.52	22.78	10.42	83.01	10.71
19-Sep-95	0.00	13.08	21.87	8.95	90.83	10.18
20-Sep-95	0.00	17.02	26.51	6.25	75.59	12.04
21-Sep-95	0.00	18.92	27.90	7.77	68.23	16.42
22-Sep-95	0.00	20.58	32.63	10.89	74.88	14.79
23-Sep-95	0.00	22.44	33.54	9.72	58.20	16.60
24-Sep-95	0.00	24.99	33.20	14.98	37.69	15.17
25-Sep-95	0.00	21.75	33.51	14.03	75.46	17.72
26-Sep-95	0.00	22.53	34.15	11.63	62.92	17.16
27-Sep-95	0.00	24.09	36.16	11.65	61.76	19.78
28-Sep-95	0.00	20.79	27.77	14.87	67.66	16.88
29-Sep-95	0.00	21.12	32.17	10.68	64.43	19.67
30-Sep-95	0.00	21.67	34.26	10.11	61.99	18.89
01-Oct-95	0.00	20.68	31.04	14.46	68.77	17.58
02-Oct-95	0.00	23.61	32.76	16.05	44.69	18.80

03-Oct-95	0.00	20.83	32.56	12.30	69.64	17.02
04-Oct-95	0.00	20.28	31.25	11.00	81.81	15.02
05-Oct-95	5.80	19.74	33.30	10.34	78.31	12.64
06-Oct-95	0.00	22.63	32.63	14.02	60.46	15.94
07-Oct-95	16.60	16.67	21.61	13.13	97.19	8.40
08-Oct-95	2.40	19.88	30.59	13.87	92.90	16.47
09-Oct-95	0.40	20.57	32.29	14.60	82.95	14.35
10-Oct-95	0.00	21.50	33.00	14.55	87.79	17.48
11-Oct-95	0.00	24.49	35.90	13.73	61.26	20.68
12-Oct-95	0.00	28.06	36.57	13.23	27.41	15.58
13-Oct-95	0.00	18.18	24.48	13.38	76.66	10.47
14-Oct-95	4.20	11.49	13.29	10.04	115.11	3.98
15-Oct-95	0.00	13.58	18.79	10.02	100.05	6.50
16-Oct-95	12.60	18.92	29.58	11.89	88.55	14.78
17-Oct-95	8.60	19.83	25.78	13.91	88.92	7.17
18-Oct-95	0.00	20.42	23.40	17.75	73.96	5.86
19-Oct-95	17.40	16.10	21.90	13.45	98.45	5.35
20-Oct-95	0.00	17.58	24.82	11.19	83.73	20.06
21-Oct-95	0.00	19.39	28.41	10.23	70.53	21.72
22-Oct-95	0.00	19.86	30.95	7.54	57.38	22.66
23-Oct-95	4.00	19.03	31.68	11.50	77.80	11.99
24-Oct-95	0.00	19.32	27.74	11.17	64.77	21.23
25-Oct-95	0.00	21.03	26.49	12.98	27.25	21.43
26-Oct-95	0.00	18.63	27.56	11.31	30.55	22.51
27-Oct-95	0.00	18.84	30.33	5.32	55.10	22.46
28-Oct-95	0.00	20.03	32.79	7.18	66.40	22.43
29-Oct-95	0.00	14.41	16.86	12.72	92.06	4.06
30-Oct-95	0.20	14.28	18.01	10.37	102.62	6.13
31-Oct-95	0.00	18.44	30.13	7.15	79.75	21.74
01-Nov-95	0.00	21.06	31.11	8.31	67.63	20.95
02-Nov-95	0.00	24.83	32.91	17.64	53.07	19.82
03-Nov-95	6.40	19.11	25.35	16.59	96.04	7.44
04-Nov-95	0.00	24.63	33.37	14.79	58.35	18.95
05-Nov-95	1.40	15.54	19.00	13.26	112.15	3.32
06-Nov-95	0.00	15.34	22.06	13.22	106.44	5.17
07-Nov-95						
08-Nov-95						
09-Nov-95						
10-Nov-95						
11-Nov-95						
12-Nov-95						
13-Nov-95						
14-Nov-95						
15-Nov-95						
16-Nov-95						
17-Nov-95						
18-Nov-95						
19-Nov-95						
20-Nov-95						
21-Nov-95						
22-Nov-95						
23-Nov-95						
24-Nov-95						

25-Nov-95						
26-Nov-95						
27-Nov-95	0.00	22.87	29.41	15.65	71.64	15.28
28-Nov-95	9.20	20.22	29.79	13.02	87.96	16.95
29-Nov-95	6.00	21.19	29.09	13.06	77.04	19.31
30-Nov-95	0.00	20.85	26.66	14.14	54.11	21.62
01-Dec-95	0.00	15.54	22.84	7.24	71.26	23.92
02-Dec-95	0.00	18.19	27.52	10.13	74.52	20.36
03-Dec-95	1.20	20.72	31.42	12.88	76.39	16.64
04-Dec-95	1.00	18.49	23.74	14.32	93.26	10.57
05-Dec-95	0.00	21.21	29.78	14.18	84.82	16.28
06-Dec-95	28.80	20.64	29.55	13.24	84.55	16.48
07-Dec-95	21.20	18.43	28.06	12.22	108.16	18.97
08-Dec-95	1.00	16.68	22.17	12.91	94.63	13.08
09-Dec-95	3.40	18.78	26.88	13.74	93.86	18.57
10-Dec-95	11.80	19.58	27.04	13.43	94.05	19.42
11-Dec-95	0.00	18.93	25.62	14.90	87.82	17.35
12-Dec-95	0.00	18.52	25.54	13.86	82.36	20.49
13-Dec-95	20.60	19.78	30.36	10.74	90.25	23.00
14-Dec-95	0.00	21.09	29.14	13.56	86.72	19.15
15-Dec-95	0.00	23.71	31.89	14.14	66.17	20.98
16-Dec-95	2.20	17.79	20.12	15.71	110.70	3.63
17-Dec-95	62.60	15.51	16.34	14.99	135.75	3.95
18-Dec-95	5.00	17.90	22.00	14.70	119.73	5.74
19-Dec-95	0.20	22.61	30.30	14.86	81.42	20.73
20-Dec-95	0.00	24.36	32.42	14.64	67.87	24.83
21-Dec-95	0.00	23.67	31.54	15.99	80.05	24.16
22-Dec-95	46.80	17.67	23.33	15.12	116.44	7.81
23-Dec-95	0.40	16.64	22.42	13.56	114.53	8.29
24-Dec-95	32.60	18.55	24.98	15.09	110.93	11.70
25-Dec-95	2.60	20.78	28.46	15.41	94.24	18.18
26-Dec-95	1.00	19.20	26.82	14.17	91.14	15.18
27-Dec-95	0.20	18.33	28.48	11.00	104.45	14.60
28-Dec-95	0.00	25.20	30.84	16.85	68.21	15.49
29-Dec-95	0.00	20.24	27.75	15.70	87.28	17.53
30-Dec-95	0.00	23.40	34.69	15.59	79.94	21.85
31-Dec-95	2.00	25.77	37.08	16.74	66.23	23.37
01-Jan-96	0.00	23.23	31.30	16.87	82.85	21.86
02-Jan-96	0.00	24.77	36.18	15.39	79.98	20.52
03-Jan-96	2.40	24.97	35.40	17.16	74.85	21.96
04-Jan-96	0.00	25.13	36.40	15.98	74.91	21.28
05-Jan-96	0.40	25.12	35.03	17.10	82.45	21.74
06-Jan-96	0.40	25.33	34.12	15.76	71.99	23.91
07-Jan-96	0.00	25.80	34.46	18.08	67.67	22.40
08-Jan-96	0.20	23.12	30.55	16.94	90.46	13.85
09-Jan-96	0.00	23.07	30.47	18.23	89.24	11.75
10-Jan-96	0.00	23.98	31.27	19.02	84.57	14.59
11-Jan-96	0.00	19.38	23.09	17.77	132.99	1.44
12-Jan-96						
13-Jan-96						
14-Jan-96						
15-Jan-96						
16-Jan-96						

17-Jan-96						
18-Jan-96						
19-Jan-96						
20-Jan-96						
21-Jan-96						
22-Jan-96	0.00	25.05	29.33	18.53	72.12	12.43
23-Jan-96	0.00	22.89	33.06	16.90	106.74	18.48
24-Jan-96	9.60	24.13	31.26	18.22	102.49	17.54
25-Jan-96	13.20	21.93	28.89	19.10	117.77	13.34
26-Jan-96	27.80	22.30	29.40	18.86	113.90	15.92
27-Jan-96	35.80	16.30	19.41	14.01	128.57	2.91
28-Jan-96	6.80	14.86	19.59	11.04	100.89	14.61
29-Jan-96	0.00	15.09	21.56	12.01	97.39	10.29
30-Jan-96						
31-Jan-96						
01-Feb-96						
02-Feb-96						
03-Feb-96						
04-Feb-96						
05-Feb-96	0.00	24.77	29.76	18.44	79.19	12.86
06-Feb-96	0.00	22.17	29.93	15.51	83.79	23.31
07-Feb-96	0.00	22.18	32.07	13.63	93.60	23.58
08-Feb-96	0.00	23.63	33.95	15.19	95.37	22.57
09-Feb-96	0.00	25.18	33.62	17.78	88.08	22.45
10-Feb-96	4.20	22.85	29.19	20.12	114.62	12.62
11-Feb-96	110.20	18.64	20.25	16.47	144.43	3.49
12-Feb-96	7.00	19.34	25.42	15.59	117.75	10.48
13-Feb-96	0.60	23.23	27.24	19.81	90.85	12.38
14-Feb-96	67.60	18.20	24.95	13.56	122.06	9.96
15-Feb-96	10.00	12.69	13.82	11.32	125.68	2.37
16-Feb-96	14.20	15.28	21.87	10.96	124.94	8.96
17-Feb-96	1.20	20.93	30.83	16.31	108.20	18.53
18-Feb-96	39.40	21.29	30.02	16.84	106.26	14.93
19-Feb-96	1.80	22.25	32.80	15.30	101.29	22.36
20-Feb-96	0.20	23.25	33.79	15.15	97.68	22.05
21-Feb-96	0.00	23.62	33.64	17.46	96.77	19.42
22-Feb-96	0.00	23.84	31.57	16.22	94.74	18.47
23-Feb-96	9.40	22.11	28.48	18.24	109.01	13.88
24-Feb-96	6.20	20.55	27.15	18.01	119.50	9.26
25-Feb-96	0.00	22.00	29.74	17.23	103.78	14.94
26-Feb-96	11.20	19.53	23.85	15.92	116.41	7.10
27-Feb-96	0.00	17.41	22.01	13.69	106.57	8.99
28-Feb-96	1.80	20.76	32.19	14.45	93.82	17.98
29-Feb-96	1.40	22.15	31.02	15.60	103.42	18.32
01-Mar-96	37.60	20.88	29.35	17.13	114.69	13.00
02-Mar-96	1.00	23.98	33.95	16.95	95.82	18.98
03-Mar-96	43.80	20.30	28.72	12.87	117.52	11.07
04-Mar-96	35.40	11.88	14.18	10.34	126.00	5.45
05-Mar-96	0.20	14.22	19.89	10.20	94.01	15.14
06-Mar-96	0.00	18.02	27.29	10.22	94.61	21.06
07-Mar-96	0.00	20.52	30.58	12.93	97.60	20.39
08-Mar-96	0.00	22.54	32.35	13.46	93.49	20.82
09-Mar-96	0.00	22.13	30.19	16.75	101.32	19.16

10-Mar-96	0.00	22.42	33.76	13.76	95.77	20.12
11-Mar-96	0.00	22.51	34.62	12.88	93.73	20.26
12-Mar-96	18.00	21.87	33.73	12.15	98.51	18.98
13-Mar-96	15.60	13.79	16.78	11.75	125.78	5.21
14-Mar-96	35.00	16.25	24.47	12.04	103.13	11.78
15-Mar-96	0.40	18.40	26.36	12.85	100.29	15.75
16-Mar-96	0.20	19.21	29.65	10.88	103.91	16.74
17-Mar-96	0.00	18.64	25.47	13.17	101.25	16.58
18-Mar-96	0.00	15.27	15.27	15.27	118.40	0.00
19-Mar-96						
20-Mar-96						
21-Mar-96						
22-Mar-96						
23-Mar-96						
24-Mar-96						
25-Mar-96						
26-Mar-96						
27-Mar-96						
28-Mar-96						
29-Mar-96						
30-Mar-96						
31-Mar-96						
01-Apr-96	1.80	17.52	26.13	13.40	111.75	3.26
02-Apr-96	0.20	16.53	22.27	12.59	110.14	6.69
03-Apr-96	0.20	15.88	21.11	12.66	103.38	10.34
04-Apr-96	0.00	16.85	23.48	10.33	95.47	13.00
05-Apr-96	0.00	15.47	25.92	8.18	103.64	14.97
06-Apr-96	0.00	15.21	27.32	5.85	111.03	14.38
07-Apr-96	0.20	17.32	30.19	8.68	101.52	14.80
08-Apr-96	0.00	18.45	31.17	7.77	88.25	14.70
09-Apr-96	3.80	20.42	30.04	10.22	69.05	15.17
10-Apr-96	0.40	14.29	22.07	8.91	90.39	12.91
11-Apr-96	0.00	13.16	22.12	7.68	102.43	11.09
12-Apr-96	0.00	14.17	24.14	7.16	102.39	10.62
13-Apr-96	1.80	15.07	25.77	8.90	116.87	9.42
14-Apr-96	0.20	17.11	27.11	11.25	114.35	11.03
15-Apr-96	0.00	17.82	28.14	10.78	100.44	12.55
16-Apr-96	0.00	15.97	24.79	8.11	109.23	10.11
17-Apr-96	7.60	15.29	22.09	12.20	107.31	5.63
18-Apr-96	1.40	16.30	26.24	8.47	105.39	8.66
19-Apr-96	4.00	15.10	19.21	11.70	92.75	9.24
20-Apr-96	0.00	14.30	21.41	8.72	91.54	11.62
21-Apr-96	0.20	13.05	24.25	5.08	109.59	13.57
22-Apr-96	0.00	14.10	26.53	4.51	101.80	13.75
23-Apr-96	0.00	15.15	29.09	3.69	99.66	13.85
24-Apr-96	0.00	16.77	27.98	9.77	95.13	12.99
25-Apr-96	0.00	16.33	29.28	5.99	84.36	11.19
26-Apr-96	0.00	15.02	26.44	8.46	114.75	9.89
27-Apr-96	0.00	16.21	29.77	6.07	99.24	9.99
28-Apr-96	0.20	15.25	24.35	7.75	116.17	7.25
29-Apr-96	0.00	16.03	24.67	10.66	111.10	10.69
30-Apr-96	0.00	15.27	25.15	8.48	105.90	12.60
01-May-96	0.00	14.57	26.06	7.25	100.77	11.59

02-May-96	0.00	14.41	27.10	4.33	95.34	11.36
03-May-96	0.00	15.65	27.04	6.16	92.22	11.16
04-May-96	0.00	17.09	28.11	6.80	85.16	10.14
05-May-96	0.20	18.53	26.47	10.27	68.82	7.16
06-May-96	21.80	12.24	16.70	10.01	136.89	3.84
07-May-96	2.60	14.89	23.87	10.74	119.67	7.10
08-May-96	0.20	16.08	26.95	7.63	113.69	10.84
09-May-96	0.20	15.49	26.38	10.28	123.26	7.86
10-May-96	0.00	15.68	27.71	5.91	96.73	10.77
11-May-96	0.00	14.54	28.20	5.24	100.52	9.77
12-May-96	0.00	14.62	27.32	5.14	94.12	10.27
13-May-96	0.20	13.28	20.25	7.66	100.31	4.22
14-May-96	0.00	11.77	20.01	5.61	119.36	6.24
15-May-96	0.20	14.58	22.94	7.00	120.90	6.89
16-May-96	0.00	14.59	14.59	14.59	140.50	0.00
17-May-96						
18-May-96						
19-May-96						
20-May-96						
21-May-96						
22-May-96						
23-May-96						
24-May-96						
25-May-96						
26-May-96						
27-May-96						
28-May-96						
29-May-96						
30-May-96						
31-May-96						
01-Jun-96						
02-Jun-96						
03-Jun-96	0.00	13.07	20.09	3.25	57.97	6.08
04-Jun-96	0.00	6.34	19.97	-3.35	92.82	10.70
05-Jun-96	0.00	6.73	23.36	-6.00	84.82	10.46
06-Jun-96	0.00	11.81	27.36	-1.18	79.15	9.46
07-Jun-96	0.00	13.36	27.38	0.78	77.64	10.10
08-Jun-96	0.00	17.12	27.54	9.54	55.71	10.12
09-Jun-96	0.00	14.43	23.53	9.73	101.50	9.42
10-Jun-96	0.00	12.63	24.69	4.73	108.39	8.99
11-Jun-96	0.00	10.56	24.80	-0.17	95.72	9.88
12-Jun-96	0.00	10.92	24.26	-0.52	83.18	9.85
13-Jun-96	0.00	11.42	25.05	-0.49	72.30	10.06
14-Jun-96	0.00	12.01	24.18	1.01	62.90	8.07
15-Jun-96	0.20	13.56	24.69	-0.27	59.14	10.43
16-Jun-96	0.00	18.63	26.00	11.39	12.56	10.85
17-Jun-96	0.00	15.92	25.99	2.84	27.18	10.68
18-Jun-96	0.00	12.30	25.97	-0.79	56.97	10.75
19-Jun-96	0.00	11.17	18.28	3.49	91.85	10.20
20-Jun-96	0.00	8.69	20.90	0.97	104.91	9.06
21-Jun-96	0.00	5.22	16.99	-3.32	113.81	8.17
22-Jun-96	0.00	6.48	19.54	-2.34	113.75	9.57
23-Jun-96	0.20	8.09	22.11	-3.25	90.99	10.30

24-Jun-96	0.00	7.94	21.05	-2.87	85.97	9.78
25-Jun-96	0.00	9.30	22.18	-3.07	87.76	9.29
26-Jun-96	0.00	9.97	18.93	-1.66	92.83	9.84
27-Jun-96	0.00	7.69	23.51	-5.97	77.00	10.44
28-Jun-96	0.00	6.19	21.42	-4.77	86.15	10.01
29-Jun-96	0.00	6.35	23.72	-5.51	85.57	10.41
30-Jun-96	0.00	9.16	25.21	-6.39	65.83	10.66
01-Jul-96	0.00	11.47	25.67	-2.44	40.83	10.03
02-Jul-96	0.00	9.09	27.40	-4.61	63.36	9.92
03-Jul-96	0.00	15.29	25.32	0.93	24.98	7.74
04-Jul-96	0.00	13.85	22.99	-1.32	26.16	9.41
05-Jul-96	0.00	10.83	19.99	1.42	36.52	10.95
06-Jul-96	3.60	3.64	12.49	-5.42	82.92	6.64
07-Jul-96	21.80	1.05	2.64	0.20	149.16	1.78
08-Jul-96	18.20	3.17	8.48	0.20	134.66	7.28
09-Jul-96						
10-Jul-96	0.00	13.27	17.41	5.55	78.92	8.18
11-Jul-96	0.00	9.25	20.50	1.48	113.49	11.59
12-Jul-96	0.00	6.76	21.58	-3.01	104.77	11.72
13-Jul-96	0.20	7.64	22.06	-3.97	91.29	11.80
14-Jul-96	0.00	8.96	18.19	0.47	58.03	12.05
15-Jul-96	0.00	6.68	17.71	-3.34	68.23	11.56
16-Jul-96	0.00	3.96	12.77	-4.41	97.01	6.82
17-Jul-96	0.00	5.64	10.71	1.01	85.29	6.27
18-Jul-96	0.00	4.51	16.45	-3.83	102.82	11.33
19-Jul-96	0.00	5.72	19.52	-4.97	90.74	11.84
20-Jul-96	0.00	5.31	17.89	-4.66	89.97	11.65
21-Jul-96	0.00	7.80	18.43	0.93	88.21	8.55
22-Jul-96	0.00	7.68	17.90	-1.10	107.60	9.26
23-Jul-96	0.00	9.69	14.17	7.11	105.56	4.39
24-Jul-96	0.00	9.51	15.36	6.36	103.78	6.64
25-Jul-96	0.20	9.18	13.88	5.47	109.69	4.59
26-Jul-96	0.00	11.42	19.20	5.30	82.49	8.60
27-Jul-96	0.00	11.02	22.73	0.05	94.34	11.76
28-Jul-96	0.00	12.67	27.43	0.97	82.97	12.02
29-Jul-96	0.00	16.64	26.14	7.39	61.53	11.47
30-Jul-96	1.20	9.27	11.66	7.32	135.95	1.72
31-Jul-96	0.00	15.01	25.36	4.83	80.03	10.35
01-Aug-96	0.00	17.97	26.17	11.75	45.48	10.73
02-Aug-96	0.00	12.74	24.38	1.87	73.28	12.20
03-Aug-96	0.00	11.43	16.44	9.42	123.01	5.38
04-Aug-96	1.80	8.62	9.97	7.14	133.30	0.99
05-Aug-96	4.00	10.68	15.83	6.53	100.10	9.56
06-Aug-96	0.00	12.09	19.72	6.92	30.76	13.73
07-Aug-96	0.00	8.31	19.68	-2.69	74.99	13.75
08-Aug-96	0.00	9.02	21.51	1.23	96.06	12.60
09-Aug-96	0.00	9.79	25.70	-4.50	72.99	13.92
10-Aug-96	0.00	16.19	26.89	5.67	34.45	12.90
11-Aug-96	0.40	9.69	10.41	8.29	138.13	0.88
12-Aug-96						
13-Aug-96						
14-Aug-96						
15-Aug-96						

16-Aug-96						
17-Aug-96						
18-Aug-96						
19-Aug-96	0.00	8.50	10.18	6.30	125.78	1.40
20-Aug-96	1.60	6.96	8.94	5.58	118.20	2.66
21-Aug-96	0.00	10.20	18.59	4.76	81.85	13.43
22-Aug-96	0.00	9.23	18.81	3.41	96.91	11.26
23-Aug-96	0.00	10.83	21.81	4.13	89.27	13.60
24-Aug-96	0.00	13.84	27.69	0.79	65.84	14.22
25-Aug-96	0.00	17.69	28.84	7.82	39.36	11.60
26-Aug-96	0.40	20.72	29.89	10.57	25.97	11.94
27-Aug-96	0.00	16.24	26.68	9.15	38.82	13.09
28-Aug-96	0.00	11.02	22.41	1.82	70.56	14.87
29-Aug-96	0.00	10.84	23.04	2.42	98.25	12.65
30-Aug-96	0.00	11.91	26.20	-0.40	83.94	15.51
31-Aug-96	0.00	14.97	29.44	0.63	72.30	15.73
01-Sep-96	0.00	14.97	24.86	8.36	82.28	12.75
02-Sep-96	0.00	17.28	30.85	3.15	73.28	15.79
03-Sep-96	0.00	14.13	23.34	3.29	70.73	14.18
04-Sep-96	0.00	17.09	28.24	7.24	68.65	16.25
05-Sep-96	0.00	17.45	29.61	5.68	67.11	16.25
06-Sep-96	0.00	20.46	27.99	9.16	14.25	14.60
07-Sep-96	0.00	16.89	30.72	2.03	54.95	17.50
08-Sep-96	0.00	19.95	31.27	6.11	21.85	17.49
09-Sep-96	0.00	24.13	33.84	8.79	17.66	10.61
10-Sep-96	0.00	19.45	34.83	5.00	51.71	16.15
11-Sep-96	0.00	21.24	35.20	6.85	48.69	15.49
12-Sep-96	0.00	24.42	33.65	14.96	16.22	15.33
13-Sep-96	0.00	17.32	23.87	12.29	18.63	17.77
14-Sep-96	0.00	14.14	25.52	0.66	47.58	17.82
15-Sep-96	0.00	15.80	25.33	9.88	84.43	12.94
16-Sep-96	0.00	20.04	31.47	7.16	50.45	14.45
17-Sep-96	0.00	25.15	34.66	14.64	20.64	14.13
18-Sep-96	0.00	16.36	20.78	8.76	34.57	16.40
19-Sep-96	0.00	11.55	20.33	1.06	75.88	18.38
20-Sep-96	0.00	13.36	20.36	4.50	88.43	13.19
21-Sep-96	0.00	18.79	27.31	7.85	50.99	17.24
22-Sep-96	0.00	13.71	20.87	6.89	81.00	11.59
23-Sep-96	11.00	16.42	26.62	9.81	99.58	13.35
24-Sep-96	4.40	20.33	28.04	13.14	73.69	15.78
25-Sep-96	0.00	21.39	30.24	12.73	45.10	16.13
26-Sep-96	0.00	18.53	28.08	8.76	29.63	19.73
27-Sep-96	0.00	15.00	23.28	8.30	87.30	15.38
28-Sep-96	0.00	17.60	29.63	5.96	85.08	16.35
29-Sep-96	0.00	20.27	34.16	7.91	80.55	18.61
30-Sep-96	0.00	22.05	34.69	8.47	65.37	16.88
01-Oct-96	0.00	23.17	34.20	13.73	50.05	20.45
02-Oct-96	0.00	19.41	30.08	11.81	88.18	16.70
03-Oct-96	0.00	19.90	30.45	12.61	93.41	14.85
04-Oct-96	2.40	21.41	33.63	11.53	66.62	15.34
05-Oct-96	9.20	17.94	22.95	14.11	110.19	4.85
06-Oct-96	5.20	20.59	30.75	13.52	93.50	15.88
07-Oct-96	0.00	22.77	34.48	13.15	68.97	15.85

08-Oct-96	0.00	23.44	32.10	16.69	54.30	11.05
09-Oct-96	2.80	17.97	27.12	10.95	109.70	10.92
10-Oct-96	0.20	15.29	25.37	9.90	105.67	14.21
11-Oct-96	0.00	21.05	31.97	9.87	75.43	16.47
12-Oct-96	0.00	21.23	29.05	13.73	60.70	8.55
13-Oct-96	14.20	17.86	29.15	11.51	115.74	12.67
14-Oct-96	1.00	19.63	28.71	14.21	106.82	10.47
15-Oct-96	0.00	17.97	25.64	12.19	83.74	12.99
16-Oct-96	1.20	12.44	18.70	8.11	89.76	16.73
17-Oct-96	0.00	16.76	28.20	7.74	83.53	17.03
18-Oct-96	0.20	19.82	31.77	8.87	78.46	15.19
19-Oct-96	0.20	21.64	32.34	10.09	76.53	16.69
20-Oct-96	0.00	22.14	29.73	13.96	52.63	20.31
21-Oct-96	0.00	13.25	18.82	10.32	108.60	5.11
22-Oct-96	39.00	15.10	24.99	7.70	130.78	10.29
23-Oct-96	22.80	16.03	22.20	11.96	118.11	8.12
24-Oct-96	6.00	19.20	28.82	11.81	94.89	17.63
25-Oct-96	0.00	17.65	25.04	10.78	99.23	20.15
26-Oct-96	0.00	21.11	31.65	12.25	92.68	21.40
27-Oct-96	0.60	21.30	30.33	14.77	84.70	20.51
28-Oct-96	0.80	20.79	31.41	12.90	103.71	16.85
29-Oct-96	43.80	17.81	21.77	14.37	128.87	5.07
30-Oct-96	25.20	15.96	20.74	13.56	123.63	4.80
31-Oct-96	1.80	20.54	31.00	10.53	91.18	21.90
01-Nov-96	0.00	21.55	33.03	10.30	87.58	22.65
02-Nov-96	0.00	23.14	34.59	12.77	93.54	22.62
03-Nov-96	0.00	24.61	34.89	17.14	88.50	20.84
04-Nov-96	4.20	24.15	35.99	14.63	89.92	19.86
05-Nov-96	8.40	22.34	32.73	16.25	91.58	18.43
06-Nov-96	0.40	18.53	24.08	15.06	117.16	14.17
07-Nov-96	0.00	20.05	27.77	14.68	98.73	16.31
08-Nov-96	0.00	20.94	27.09	16.49	75.46	17.38
09-Nov-96	0.00	20.35	30.19	9.22	68.69	22.48
10-Nov-96	8.20	19.42	28.36	12.35	101.11	14.48
11-Nov-96	4.80	23.66	32.50	15.87	67.29	21.09
12-Nov-96	0.00	23.25	31.81	13.36	77.79	15.57
13-Nov-96	0.40	20.28	24.25	13.57	87.69	4.28
14-Nov-96	0.80	11.15	13.22	9.53	134.47	4.31
15-Nov-96	0.40	17.68	25.66	10.74	95.67	17.11
16-Nov-96	0.00	17.01	19.55	13.58	126.30	4.85
17-Nov-96	0.00	18.37	26.82	12.77	115.86	12.76
18-Nov-96	53.40	20.36	28.61	13.49	74.83	22.26
19-Nov-96	0.00	19.47	29.65	12.44	97.49	17.45
20-Nov-96	0.00	22.87	29.87	13.31	52.87	22.02
21-Nov-96	1.20	21.83	27.48	17.06	59.08	13.45
22-Nov-96	0.00	17.95	25.51	10.20	37.91	25.12
23-Nov-96	0.00	18.63	28.05	8.81	82.35	22.55
24-Nov-96	0.00	19.14	29.47	9.67	89.78	16.09
25-Nov-96	0.00	21.28	29.20	11.83	74.98	16.23
26-Nov-96	0.60	17.95	25.66	11.06	113.52	11.43
27-Nov-96	2.00	13.48	17.94	9.59	124.73	6.87
28-Nov-96	0.40	17.22	22.44	12.95	112.97	9.31
29-Nov-96	3.20	22.01	29.83	15.69	77.25	24.22

30-Nov-96	0.80	18.83	26.44	12.86	123.76	13.55
01-Dec-96	0.00	22.74	32.50	14.23	96.26	20.59
02-Dec-96	4.20	26.32	36.64	16.47	63.53	23.21
03-Dec-96	0.60	18.07	24.75	14.17	119.97	12.79
04-Dec-96	38.20	18.03	24.63	14.23	129.18	8.12
05-Dec-96	0.20	19.81	28.47	13.58	116.95	17.21
06-Dec-96	0.00	23.56	32.17	14.05	91.77	24.80
07-Dec-96	20.20	21.12	30.95	14.86	110.50	19.17
08-Dec-96	7.60	21.25	32.24	16.63	111.26	19.17
09-Dec-96	0.00	19.80	27.85	13.43	123.08	12.96
10-Dec-96						
11-Dec-96						
12-Dec-96						
13-Dec-96						
14-Dec-96						
15-Dec-96						
16-Dec-96						
17-Dec-96						
18-Dec-96						
19-Dec-96						
20-Dec-96						
21-Dec-96						
22-Dec-96						
23-Dec-96						
24-Dec-96						
25-Dec-96						
26-Dec-96						
27-Dec-96						
28-Dec-96						
29-Dec-96						
30-Dec-96						
31-Dec-96						
01-Jan-97	0.20	23.06	33.78	14.11	104.69	22.78
02-Jan-97	15.40	20.22	27.81	15.57	126.51	13.21
03-Jan-97	10.20	19.89	28.74	14.58	134.78	17.11
04-Jan-97	0.20	19.90	24.98	14.71	120.95	12.26
05-Jan-97	0.00	20.40	28.27	15.40	113.22	16.02
06-Jan-97	0.00	22.99	32.44	14.67	92.61	23.04
07-Jan-97	0.00	24.52	34.36	15.38	76.12	24.40
08-Jan-97	0.00	25.35	34.13	17.06	79.66	20.58
09-Jan-97	12.60	23.91	35.06	16.45	118.75	21.12
10-Jan-97	1.40	18.56	23.19	15.81	147.86	6.62
11-Jan-97	15.40	16.28	17.29	15.37	180.50	3.52
12-Jan-97	0.20	17.60	22.94	14.87	145.06	8.51
13-Jan-97	0.00	21.10	29.25	15.18	103.54	24.44
14-Jan-97	0.00	21.35	30.97	12.97	62.29	21.72
15-Jan-97	0.00	22.75	32.50	13.87	102.18	21.18
16-Jan-97	0.00	23.97	32.67	15.81	69.22	20.22
17-Jan-97	50.60	18.40	21.52	15.25	140.40	8.21
18-Jan-97	1.00	17.69	24.02	12.91	133.87	11.95
19-Jan-97	0.00	22.53	33.13	14.29	100.03	21.39
20-Jan-97	0.00	24.16	33.56	16.57	66.26	20.66
21-Jan-97	0.00	23.69	30.09	18.40	103.35	16.68

22-Jan-97	0.60	21.87	31.32	16.93	102.94	11.80
23-Jan-97	2.60	21.95	28.74	18.13	128.30	19.07
24-Jan-97	0.00	22.84	32.70	15.52	62.47	22.04
25-Jan-97	0.00	23.93	33.51	16.24	66.21	23.39
26-Jan-97	0.60	24.33	34.92	15.90	74.55	20.54
27-Jan-97	2.60	19.71	22.97	16.90	140.83	6.52
28-Jan-97	0.00	20.19	26.00	15.91	92.50	20.87
29-Jan-97	0.00	21.90	30.77	14.24	86.81	23.79
30-Jan-97	0.00	23.23	34.22	13.25	88.22	22.36
31-Jan-97	0.00	23.28	33.61	14.73	27.80	22.38
01-Feb-97	0.00	23.03	34.59	10.38	72.81	23.07
02-Feb-97	2.00	22.07	29.05	18.41	123.04	14.50
03-Feb-97	0.00	22.91	31.33	17.53	108.89	17.78
04-Feb-97	0.00	19.52	31.40	12.86	64.98	11.60
05-Feb-97						
06-Feb-97						
07-Feb-97						
08-Feb-97						
09-Feb-97						
10-Feb-97						
11-Feb-97						
12-Feb-97						
13-Feb-97						
14-Feb-97						
15-Feb-97						
16-Feb-97						
17-Feb-97						
18-Feb-97						
19-Feb-97						
20-Feb-97						
21-Feb-97						
22-Feb-97						
23-Feb-97						
24-Feb-97	0.00	23.35	30.34	14.75	93.10	12.96
25-Feb-97	0.20	23.59	35.76	14.22	38.92	21.45
26-Feb-97	2.20	20.65	28.61	14.97	111.21	12.69
27-Feb-97	8.00	16.55	22.98	13.14	154.33	6.19
28-Feb-97	0.20	19.97	28.12	15.03	109.91	13.22
01-Mar-97	2.20	20.84	29.44	15.24	60.34	14.56
02-Mar-97	0.00	21.52	29.65	17.04	79.59	10.44
03-Mar-97	0.00	24.71	33.99	18.14	81.43	16.12
04-Mar-97	8.80	22.22	34.42	16.05	80.30	15.18
05-Mar-97	12.40	18.88	23.56	16.43	93.39	5.56
06-Mar-97	14.60	20.35	26.38	17.17	61.11	7.54
07-Mar-97	1.60	21.65	28.79	18.26	45.45	9.49
08-Mar-97	0.20	24.52	34.70	16.72	54.33	18.30
09-Mar-97	12.60	22.61	29.37	18.08	105.02	14.70
10-Mar-97	0.00	23.07	30.12	18.23	61.03	15.13
11-Mar-97	0.00	21.59	30.82	14.22	110.26	12.16
12-Mar-97	2.80	15.03	18.95	11.34	154.59	6.02
13-Mar-97	10.80	19.31	27.28	14.44	127.94	14.06
14-Mar-97	0.00	17.26	21.23	14.33	132.18	6.04
15-Mar-97	0.00	18.79	26.84	13.60	109.72	17.42

16-Mar-97	0.00	18.55	28.99	9.39	73.44	17.41
17-Mar-97	0.00	18.54	26.57	12.64	66.40	11.21
18-Mar-97	0.00	19.53	28.63	11.36	76.33	14.36
19-Mar-97	0.00	20.02	26.92	13.53	50.85	11.19
20-Mar-97	3.20	20.28	29.63	14.51	118.36	11.85
21-Mar-97	0.60	18.19	25.19	14.53	104.94	11.44
22-Mar-97	0.00	18.42	26.91	13.01	114.20	12.44
23-Mar-97	0.20	18.72	30.04	10.45	44.51	13.84
24-Mar-97	19.80	19.03	29.98	13.95	42.97	12.36
25-Mar-97	4.80	19.56	29.58	14.12	60.15	14.23
26-Mar-97	10.80	16.50	19.71	13.26	149.65	2.83
27-Mar-97	1.40	15.62	20.54	12.69	122.50	6.55
28-Mar-97	3.40	18.24	26.80	13.69	76.99	11.41
29-Mar-97	0.20	20.01	28.68	12.37	42.71	16.63
30-Mar-97	1.20	18.58	25.55	11.87	105.01	8.81
31-Mar-97	0.00	18.26	28.98	9.69	59.78	16.87
01-Apr-97	23.20	17.91	25.03	14.37	95.85	10.39
02-Apr-97	18.60	15.75	20.81	12.90	79.72	4.77
03-Apr-97	8.60	17.89	25.86	11.95	54.67	12.32
04-Apr-97	0.00	18.81	27.15	12.04	50.63	13.79
05-Apr-97	0.00	18.47	28.17	9.01	48.41	15.90
06-Apr-97	0.00	17.95	25.43	10.48	63.39	17.79
07-Apr-97	0.00	12.86	23.35	4.01	68.60	17.79
08-Apr-97	0.00	13.04	23.14	4.13	40.44	17.16
09-Apr-97	10.80	13.90	24.69	4.56	64.66	14.68
10-Apr-97	4.40	13.29	21.02	7.92	44.41	6.90
11-Apr-97	0.00	14.23	27.54	4.17	33.28	16.19
12-Apr-97	0.00	13.28	22.97	6.78	44.45	9.94
13-Apr-97	0.00	16.20	28.45	8.11	36.38	14.42
14-Apr-97	0.00	16.82	29.53	6.32	40.86	14.90
15-Apr-97	0.20	15.87	26.27	8.43	52.68	10.76
16-Apr-97	0.00	15.22	27.30	6.33	40.93	13.79
17-Apr-97	0.00	15.82	28.17	5.00	24.27	14.28
18-Apr-97	0.00	17.89	29.85	8.71	100.57	12.56
19-Apr-97	1.80	19.80	29.74	11.80	73.48	12.35
20-Apr-97	4.80	16.37	20.25	12.61	81.73	5.19
21-Apr-97	0.20	15.51	26.15	7.78	66.60	14.71
22-Apr-97						
23-Apr-97						
24-Apr-97						
25-Apr-97						
26-Apr-97						
27-Apr-97						
28-Apr-97						
29-Apr-97	0.00	12.34	20.50	2.86	77.78	11.18
30-Apr-97	0.20	10.43	24.06	0.52	35.88	14.17
01-May-97	0.00	12.90	27.32	0.02	25.20	14.00
02-May-97	0.80	13.86	27.10	1.46	55.59	13.47
03-May-97	0.00	13.09	21.52	7.33	68.62	8.89
04-May-97	0.00	16.11	26.05	9.85	56.58	12.05
05-May-97	0.00	15.19	22.70	9.07	97.44	11.37
06-May-97	0.00	12.16	20.11	4.57	112.58	7.07
07-May-97	0.00	13.56	23.38	3.23	48.51	7.56

08-May-97	0.20	13.70	20.86	8.39	114.24	6.47
09-May-97	30.20	13.74	23.11	8.15	39.99	10.14
10-May-97	0.40	11.99	16.54	7.08	72.23	5.19
11-May-97	0.00	13.94	21.46	8.51	95.93	11.05
12-May-97	0.00	12.70	22.79	4.74	43.85	13.16
13-May-97	0.00	9.58	22.63	1.19	37.03	11.90
14-May-97	0.00	10.43	25.56	0.61	23.73	13.41
15-May-97	0.20	10.85	23.44	-0.23	36.83	13.03
16-May-97	0.00	13.12	25.41	3.25	45.69	12.32
17-May-97	0.00	11.05	28.40	0.58	43.05	13.13
18-May-97	0.00	11.84	27.26	-0.17	21.23	13.43
19-May-97	0.00	11.56	26.14	-0.80	49.76	12.99
20-May-97	0.00	13.85	25.31	2.81	78.94	11.66
21-May-97	0.20	13.62	24.61	3.95	71.74	8.34
22-May-97	0.00	13.21	23.43	4.70	88.27	11.41
23-May-97	0.00	12.44	21.93	4.17	100.93	8.64
24-May-97	0.00	17.66	24.14	11.33	69.98	9.11
25-May-97	20.80	12.70	17.61	11.29	32.40	1.45
26-May-97	23.20	10.75	19.44	6.83	79.77	3.61
27-May-97	0.20	10.72	16.17	7.92	69.93	12.44
28-May-97	7.20	4.41	7.16	2.50	149.13	2.38
29-May-97	0.00	6.03	12.81	0.81	104.24	11.13
30-May-97	0.00	7.85	12.95	1.80	69.69	7.40
31-May-97	0.00	9.91	19.15	0.77	104.61	11.80
01-Jun-97	0.00	8.77	20.63	-2.25	78.76	11.63
02-Jun-97						
03-Jun-97	0.00	13.92	24.11	-0.08	46.64	5.45
04-Jun-97	0.00	8.33	23.64	-3.91	96.50	11.91
05-Jun-97	0.00	7.12	24.69	-5.09	100.52	12.11
06-Jun-97	0.20	10.39	25.10	-0.65	67.66	10.41
07-Jun-97	0.00	8.33	25.39	-3.25	97.50	11.39
08-Jun-97	0.00	11.31	25.96	-0.65	87.39	8.20
09-Jun-97	0.00	17.55	25.61	10.29	25.26	6.67
10-Jun-97	13.80	10.50	16.65	4.01	111.72	3.03
11-Jun-97	26.20	10.94	16.69	7.50	55.78	4.07
12-Jun-97	25.80	8.10	11.76	2.15	58.57	1.95
13-Jun-97	0.20	10.75	20.07	1.74	34.64	11.66
14-Jun-97	0.00	11.20	23.41	0.72	41.82	11.53
15-Jun-97	0.00	10.21	20.67	-0.79	60.85	12.02
16-Jun-97	0.00	9.06	19.84	-0.77	78.62	11.77
17-Jun-97	0.00	10.50	25.71	-1.13	52.47	12.19
18-Jun-97	0.00	7.19	18.30	-2.36	120.46	9.82
19-Jun-97	0.00	8.29	16.33	-0.32	106.82	8.89
20-Jun-97	0.00	7.95	24.21	-2.44	61.36	10.99
21-Jun-97	0.20	10.36	27.24	-2.55	48.31	11.68
22-Jun-97	0.00	13.78	24.47	2.42	44.19	11.79
23-Jun-97	0.00	11.38	26.23	-0.68	76.35	11.58
24-Jun-97	0.00	12.15	23.91	-0.90	74.96	11.56
25-Jun-97	0.00	15.22	24.37	2.74	32.88	11.50
26-Jun-97	0.00	10.96	24.97	-0.84	74.61	11.48
27-Jun-97	0.00	15.41	26.33	5.05	27.00	11.56
28-Jun-97	0.00	16.98	26.59	7.79	19.77	11.47
29-Jun-97	0.80	14.73	24.76	4.46	65.83	10.51

30-Jun-97	23.60	2.55	5.72	0.89	165.72	1.46
01-Jul-97	0.00	8.28	14.10	3.98	121.01	6.22
02-Jul-97	0.00	8.65	19.87	0.25	48.58	11.24
03-Jul-97	0.20	8.11	20.32	-0.29	44.70	11.36
04-Jul-97	0.00	11.03	25.71	-1.13	12.25	12.03
05-Jul-97	0.20	6.18	14.03	-1.73	104.77	2.57
06-Jul-97	0.20	4.12	15.31	-4.17	89.93	10.39
07-Jul-97	0.00	5.84	17.70	-3.53	80.00	12.10
08-Jul-97						
09-Jul-97						
10-Jul-97						
11-Jul-97						
12-Jul-97						
13-Jul-97						
14-Jul-97	0.00	11.17	20.74	-0.45	73.74	9.51
15-Jul-97	0.20	8.06	24.45	-3.15	61.48	12.53
16-Jul-97	0.00	9.58	24.88	-3.00	51.68	12.42
17-Jul-97	0.00	9.52	23.17	-3.39	97.06	12.21
18-Jul-97	0.00	10.92	19.17	5.51	76.27	9.87
19-Jul-97	0.00	11.85	22.08	5.15	39.67	8.25
20-Jul-97	0.00	15.08	24.28	8.31	77.42	10.78
21-Jul-97	0.00	15.94	25.83	5.39	49.33	12.51
22-Jul-97	0.00	12.31	27.22	3.40	29.32	11.32
23-Jul-97	0.20	12.82	25.89	1.98	43.93	11.98
24-Jul-97	0.00	15.49	26.73	4.75	43.72	12.57
25-Jul-97	0.00	12.31	25.49	1.12	63.70	12.43
26-Jul-97	0.00	11.08	19.70	3.57	111.22	7.49
27-Jul-97	0.60	15.59	24.97	3.99	52.02	11.09
28-Jul-97	11.40	12.99	20.86	9.11	66.53	10.28
29-Jul-97	0.80	10.86	13.48	8.62	103.86	3.11
30-Jul-97	0.00	13.43	23.76	7.76	65.74	11.18
31-Jul-97	0.00	12.51	21.50	6.55	36.99	9.12
01-Aug-97	0.00	11.83	20.94	5.27	39.96	8.31
02-Aug-97	0.80	11.99	22.26	3.25	40.20	9.64
03-Aug-97	0.00	11.02	23.35	-0.97	30.75	13.83
04-Aug-97	0.00	12.04	26.66	1.11	60.19	12.24
05-Aug-97	19.80	9.61	19.76	0.86	85.77	3.70
06-Aug-97	1.40	9.42	16.82	2.44	72.30	6.93
07-Aug-97	0.20	9.72	20.20	-0.17	40.93	13.94
08-Aug-97	0.00	11.05	25.42	2.26	33.60	13.16
09-Aug-97	0.20	12.89	30.04	0.42	32.90	14.48
10-Aug-97	0.00	13.94	29.27	0.92	22.25	14.22
11-Aug-97	0.00	11.28	21.16	3.96	68.35	10.69
12-Aug-97	0.00	13.24	27.87	0.86	29.73	14.55
13-Aug-97	0.00	13.46	27.44	2.04	21.32	14.32
14-Aug-97	0.00	13.15	26.90	1.33	57.10	13.59
15-Aug-97	0.00	13.14	27.97	4.65	35.47	12.02
16-Aug-97	0.00	13.56	27.67	2.76	30.31	11.75
17-Aug-97	0.00	14.23	27.85	2.21	34.92	14.22
18-Aug-97	0.00	14.69	29.33	1.81	72.83	14.13
19-Aug-97	0.00	18.44	28.88	9.46	23.94	13.56
20-Aug-97	0.00	14.51	25.12	4.73	68.52	13.39
21-Aug-97	0.00	15.39	26.52	6.28	10.90	14.88

22-Aug-97	0.00	13.07	28.76	1.63	67.47	15.29
23-Aug-97	0.00	12.05	22.51	0.28	88.37	13.65
24-Aug-97	0.00	14.70	25.24	7.73	36.79	12.88
25-Aug-97	0.00	16.97	30.27	6.22	44.73	14.01
26-Aug-97	0.00	17.23	31.77	4.50	23.96	14.15
27-Aug-97	0.00	17.70	29.44	7.25	50.88	14.38
28-Aug-97	0.00	15.68	29.37	4.00	30.31	14.58
29-Aug-97	0.00	16.03	26.02	7.07	33.52	12.28
30-Aug-97	0.00	17.74	27.64	8.27	61.64	11.78
31-Aug-97	0.40	17.74	26.20	9.65	69.53	12.76
01-Sep-97	0.20	15.54	21.02	11.61	115.68	9.39
02-Sep-97	0.00	16.31	26.53	8.66	54.09	14.06
03-Sep-97	0.00	17.12	27.65	6.90	72.56	13.93
04-Sep-97	0.80	12.89	18.29	8.35	135.38	4.38
05-Sep-97	0.00	17.53	26.19	8.39	47.48	14.52
06-Sep-97	8.60	20.16	29.37	13.98	71.84	14.07
07-Sep-97	1.80	15.77	19.89	12.82	102.70	3.32
08-Sep-97						
09-Sep-97						
10-Sep-97						
11-Sep-97						
12-Sep-97						
13-Sep-97						
14-Sep-97						
15-Sep-97						
16-Sep-97						
17-Sep-97	0.00	19.07	26.24	11.21	70.62	4.61
18-Sep-97	0.00	15.35	25.49	10.44	77.45	13.09
19-Sep-97	0.00	18.91	28.65	8.97	14.58	16.92
20-Sep-97	0.00	19.04	29.19	9.60	55.67	11.47
21-Sep-97	0.00	18.74	27.35	14.31	99.95	15.80
22-Sep-97	0.00	19.08	31.05	12.62	42.55	11.53
Grand Total	2,611.00	16.30	39.11	-7.88	77.93	14,876.35

APPENDIX C

Leachate data and time series plots

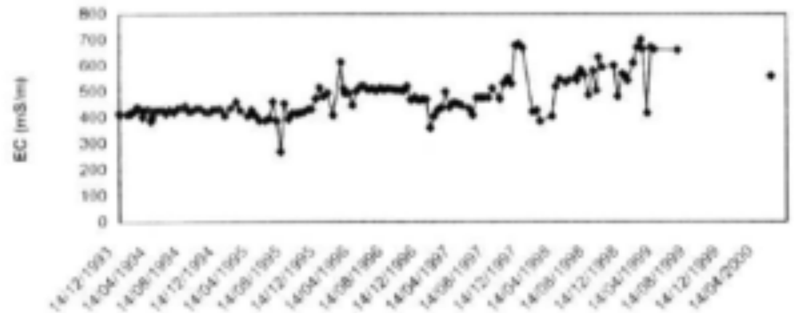
Cell 1

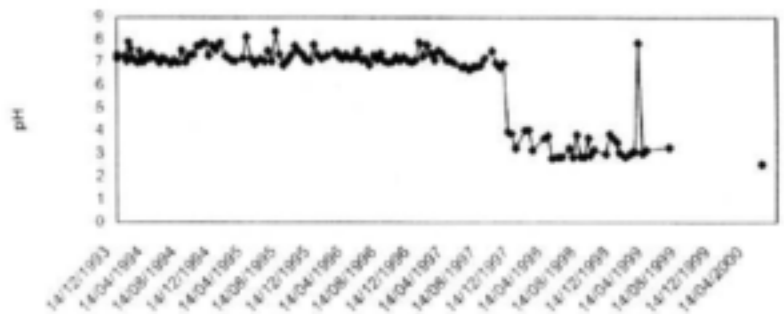
Date	EC	TDS	pH	Na	Mg	Ca	Fl	Cl	NO3	SO4	PO4	ALK	Si	K	NH4	Al	Fe	Mn
14/12/1993	419	4178	7.21	76.5	416	530	0.2	18.6	0.012	2803.7	0.005	265.8	4.69	7.95	0.407	0.365	0.035	10.245
15/12/1993	411	4115	7.37	72.3	404	539	0.22	19.5	0.013	2740.3	0.006	271	4.49	8.41	0.425	0.471	0.046	8.665
10/01/1994	412	4304	7.31	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
18/01/1994	420	4392	7.09	95	422.9	561.3	0.22	17.5	0.018	2883.1	0.008	329.5	4.74	9.59	0.401	0.313	0.007	4.179
24/01/1994	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
31/01/1994	422	4411	7.63	106	422.4	547	0.22	24.5	0.025	2898.5	0.015	328.9	4.69	10.33	0.335	0	0.009	8.82
07/02/1994	428	4378	7.25	101.2	424.2	549.7	0.23	24.1	0.028	2857.8	0.007	338.7	5.09	9.68	0.375	0.072	0	8.37
14/02/1994	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
21/02/1994	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
28/02/1994	414	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
07/03/1994	402	4408	7.52	124.5	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
14/03/1994	430	4183	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
21/03/1994	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
28/03/1994	432	4502	7.25	153.8	432.7	535.5	0.29	23.3	0.016	2927.6	0.025	338.5	4.79	14.95	0.771	0.108	0.274	12.06
05/04/1994	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
11/04/1994	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
18/04/1994	427	4235	7.41	132.9	397.2	492	0.27	22.5	0.023	2776.5	0.011	326.8	4.55	14.29	0.946	0.127	0	13.42
02/05/1994	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	0.189	13.54
18/05/1994	430	4435	7.01	126.6	409.5	543.7	0.23	67	0.035	2832.6	0.006	360.6	4.52	14.38	0.879	0.116	0.018	10.42
30/05/1994	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
13/06/1994	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
27/06/1994	420	4326	6.97	120.4	412.9	538.6	0.28	21	0.017	2735.4	0.004	395.5	4.04	13.47	0.806	0.109	0.006	8.66
11/07/1994	436	4345	7.13	127.3	374.3	547	0.28	20.2	0.017	2797.6	0.007	379.8	4.35	15.39	0.858	0.133	0.052	8.79
25/07/1994	437	4232	7.09	98	424.8	478.1	0.24	77.6	0.064	2712.7	0.009	347	3.68	16.13	0.922	0.117	0.552	10.14
08/08/1994	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
22/08/1994	424	4313	7.05	132.7	406.1	541.4	0.19	22.3	0.07	2798.7	0.002	349.6	3.53	15.8	1.018	0.418	0.335	9.94
05/09/1994	429	4386	7.35	133.5	410.7	508.2	0.17	26.6	0.033	2828.8	0.008	377.7	3.56	15.82	1.089	0.469	0.047	11.43
19/09/1994	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
03/10/1994	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	0.528	0.126	0.019	9.26
17/10/1994	422	4272	7.79	128.7	407.4	506.1	0.21	27.1	0.791	2760.8	0.001	344.8	3.47	15.38	0.106	0.156	0.015	8.215
31/10/1994	420	4378	7.9	136.4	400.3	562.5	0.23	13.5	0.623	2809.2	0.012	381.3	3.67	12.6	0.17	0.128	0.025	8.516
14/11/1994	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	3.428
28/11/1994	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	6.302
12/12/1994	434	4270	7.58	131.3	398.2	536.4	0.19	3.3	0.147	2758.9	0.012	347.6	4.13	15.83	1.028	0.139	0.145	9.461
28/12/1994	408	4212	7.89	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
16/01/1995	438	4355	7.31	96.6	417.7	529.5	0.21	14.9	0.291	2850.7	0.009	349.3	3.82	16.9	0.838	0.109	0	9.229
06/02/1995	462	4700	7.12	163.4	478.5	499.4	0.18	22.6	0.006	3054.4	0.002	376.3	4.28	21.45	0.834	0.12	0.008	6.914
20/02/1995	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
20/03/1995	408	4045	7.22	96.3	367.4	541.7	0.22	38.1	0.004	2513.2	0.009	386.5	4.5	15.98	0.499	0.168	0.794	5.334
03/04/1995	431	4245	8.96	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
19/04/1995	407	4390	7.19	94.4	373.6	543.8	0.21	21.5	0.012	2568.3	0.007	388.2	4.57	16.27	0.408	0.157	0.053	3.587
02/05/1995	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
22/05/1995	389	3845	7.18	95.5	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
06/06/1995	398	4112	7.06	104.8	341.5	545	0.45	15.4	0.019	2642.5	0.026	364.7	4.47	17.19	0.473	0.069	0.001	5.033
19/06/1995	463	4733	7.53	112.1	426.6	651.3	0.15	108.3	0.042	2931.1	0.01	390.9	4.59	28.42	0.51	0.15	0.045	5.033
03/07/1995	388	4028	7.08	98	371.4	527.4	0.33	33.8	0.016	2533.8	0.035	364.8	5.82	17.67	0.623	0.159	0.283	6.747
17/07/1995	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	2.065
31/07/1995	455	4470	7.37	138.7	427.6	535.9	0.66	89.4	0.021	2769.6	0.036	396.6	4.5	22.64	1.185	0.166	0.104	6.661
14/08/1995	395	3977	6.9	91.9	349.1	542.9	0.24	28.7	0.027	2505.5	0.001	381	4.27	17.19	0.632	0.103	0.017	6.99
28/08/1995	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	0.495	5.989
13/09/1995	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
26/09/1995	419	3851	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	0.083	6.732
09/10/1995	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
24/10/1995	432	4217	7.38	101.3	398.1	501.5	0.21	31.6	0.059	2723.8	0.006	361.8	4.85	18.08	0.738	0.166	0	7.99
08/11/1995	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	9.989
20/11/1995	474	4423	7.09	114.9	427.9	575	0.17	47.5	0.009	2819.7	0.005	336.5	4.43	25.09	1.068	0.233	0.004	9.197
04/12/1995	516	4457	7.81	163.3	465.2	499.5	0.19	37.5	0.022	2801.4	0.014	311.6	4.32	28.15	0.975	0	0	3.831
18/12/1995	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
02/01/1996	495	4722	7.2	184	424.9	548.5	0.21	37.6	0.006	3173.5	0.01	282.9	4.85	27.14	0.74	0.098	0	5.721
22/01/1996	410	5018	7.34	297.4	436	513.8	0.22	55.6	0.04	3272.1	0.01	343.8	4.58	25.86	0.418	0.11	0.013	2.288
19/02/1996	615	6267	7.47	373.8	680.2	499.8	0.35	43.9	2.66	4191.9	0.006	358.5	5.01	27.79	0.213	0.133	0.491	3.624
29/02/1996	512	4893	7.45	275.2	456.4	504.9	0.29	36.6	0.89	3263.8	0.01	285	4.64	3.62	0.326	0.113	0.039	2.984
05/03/1996	494	5203	7.3	311.4	427.4	534.1	0.26	46.2	0.715		0.005	321.5	4.55	24.9	0.101	0.282	0	2.456
18/03/1996	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
01/04/1996	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	0.006	0.186

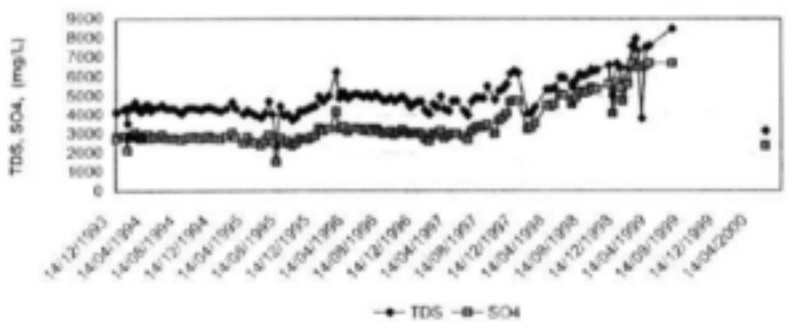
15/04/1996	504	5047	7.2	370.4	445.5	498.3	0.21	50.1	0.019	3295.1	0.004	295.4	4.12	25.43	0.409	0.102	0	4.77
30/04/1996	521	5126	7.26	329.6	474	505.4	0.25	37.0	0.012	3309.0	0.006	363.3	4.54	25.28	0.543	0.378	0.071	4.952
13/05/1996	521	5058	7.55	318.7	436.1	489.7	0.31	30.2	0.034	3272.5	0.004	400	4.33	21.7	0.554	0.113	0	4.686
27/05/1996	507	4980	7.15	328.4	442.7	485.5	0.23	31.1	0.032	3104	0.007	403.6	4.37	25.29	0.577	0.074	0	5.22
10/06/1996	512	5073	7.18	326.6	459.5	483.9	0.26	37.7	0.011	3202	0.009	366.8	4.66	24.7	0.668	0.083	0	5.08
24/06/1996	504	4917	6.92	334.8	419	520.7	0.3	31	0.008	3115.9	0.018	385.3	5.06	23.09	0.766	0	0	5.32
10/07/1996	515	5123	7.33	346.8	394.9	540.4	0.23	38.2	0.027	3294.8	0.01	392.0	4.99	27.65	0.816	0.12	0	5.71
22/07/1996	507	4982	7.17	366	399	502.6	0.23	51.2	0.019	3165.2	0.011	401.4	4.83	24.77	0.682	0.138	0	5.22
05/08/1996	512	4783	7.43	390.7	439.8	481.8	0.23	38.6	0.022	3023.8	0.003	395.4	4.74	25.24	0.684	0.114	0	4.388
19/08/1996	510	4807	7.08	345.9	395.4	480.2	0.24	44.7	0.023	3030.9	0.004	394.5	4.80	27.26	0.557	0	0	3.508
02/09/1996	508	4940	7.02	340.8	426.1	495.8	0.21	44.1	0.047	3133	0.02	388.4	4.64	27.57	0.675	0	0	1.295
16/09/1996	505	4739	7.06	330.8	438.3	478.5	0.18	41.7	0.019	2974.8	0.013	377.8	4.79	13.13	0.574	0.215	0.039	4.476
30/09/1996	504	4890	7.27	335.3	433	494.4	0.21	42.0	0.008	3076.1	0.012	380	4.04	13.43	0.645	0.166	0.055	4.533
14/10/1996	521	4992	7.12	355.1	442.7	404	0.21	30.1	0.037	3221.6	0.002	355.1	4.59	14.06	0.544	0	0	1.011
28/10/1996	470	4764	7.28	359.4	370.9	402.8	0.16	40.5	0.034	3068.6	0.028	366.9	4.67	13.95	0.327	0.078	0	2.613
12/11/1996	477	4457	7.11	292.0	403.3	483.8	0.49	34.6	0.03	3018.4	0.002	102.6	5.01	12.05	0.321	0.342	0	2.27
25/11/1996	469	4507	7.03	292.6	377.5	510.6	0.61	37.4	0.012	3044.3	0.008	295.3	4.89	12.87	0.345	0.347	0	6.73
09/12/1996	473	4701	7.13	284	389.7	409.9	0.57	30.6	0.02	3051.6	0.009	344.9	5.96	13.4	0.378	0.359	0	5.934
23/12/1996	471	4720	7.91	168.5	508.8	463.6	0.1	39.1	0.021	3002.8	0.008	424	5.39	18.49	1.035	0.362	0.085	1.521
06/01/1997	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
20/01/1997	406	4046	7.79	245.5	275.8	553.3	0.35	18.2	0.05	2618.1	0.003	290	6.43	10.09	0.338	0	0	2.696
04/02/1997	432	4598	7.43	251.1	374.4	529.5	0.5	10.6	0.029	3019.3	0.006	320.9	3.9	11.77	0.452	0	0	4.808
17/02/1997	439	4422	7.13	222.5	351.6	535.4	0.35	17.5	0.034	2963.6	0.007	292	6.63	10.57	0.417	0	0	7.53
03/03/1997	500	5008	7.55	162.8	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
17/03/1997	441	4321	7.43	208.4	370.1	534.4	0.48	15.7	0.014	2785.5	0.039	324.1	6.87	10.85	0.377	0	0	7.38
01/04/1997	459	4217	7.13	221.5	410.3	469.4	0.51	17.1	0.036	2932.2	0.01	526.1	6.63	11.11	0.442	0.122	0	1.193
14/04/1997	456	4741	7.13	232.6	409.9	548.4	0.51	20.9	0.024	2969.3	0.015	428.6	6.68	10.95	0.469	0.159	0	1.441
29/04/1997	449	4707	7	241.2	406.2	554.3	0.65	26.5	0.014	3004.2	0.018	427.5	6.74	11.62	0.45	0.149	0	7
26/05/1997	436	4227	6.81	195.1	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	1.03
09/06/1997	410	3987	6.85	187.2	298.5	553	0.48	18.1	0.014	2677.3	0.003	201.4	8.44	8.76	0.316	0.093	0	5.82
23/06/1997	477	4710	6.7	207.7	494.1	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
08/07/1997	478	4942	6.84	207.9	503.2	521.8	0.56	29.9	0.032	3359	0.007	253.2	6.38	10.45	0.388	0.065	0	13.41
21/07/1997	477	4912	6.83	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
04/08/1997	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
18/08/1997	514	5533	7.19	235.7	593.8	518.0	0.16	35.3	0.023	3501.8	0.005	515	4.8	16.52	1.083	0.106	0	6.54
15/09/1997	474	4816	7.53	178.1	490.1	502.1	0.19	30.9	0.041	3029.8	0.004	459.5	5.22	19.62	1.186	0	0	0
29/09/1997	532	5293	7.61	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
13/10/1997	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	0.102	49.18
27/10/1997	531	5639	6.58	227	618.1	483.7	1.95	25.4	0.047	4083.4	0.017	150.8	4.63	14.41	0.47	0	0.095	64.68
10/11/1997	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
24/11/1997	684	6307	3.89	214	733.5	516.2	0	59.8	0	4760.2	0.047	0	21.8	22.56	0.607	282	96.56	223.4
08/12/1997	670	6217	3.28	208.3	707.5	514.8	0	30.7	0	4731.7	0.043	0	23.59	23.21	0.565	285.6	5.79	219.6
12/01/1998	424	4074	4.05	99.4	221.4	494.5	0	13.6	0.004	3233.8	0.032	0	21.4	11.02	0.471	130.9	96.9	72
26/01/1998	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
08/02/1998	385	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	102.298	63.72
23/03/1998	406	5386	3.7	116	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
06/04/1998	520	5350	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
20/04/1998	550	5451	2.82	106.8	206.7	510.3	0	30.2	0	4571.3	0.021	0	25.94	16.52	0.217	377.112	339.324	91.929
11/05/1998	535	5090	2.88	108.0	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
25/05/1998	545	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
22/06/1998	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
22/06/1998	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
06/07/1998	586	5831	2.86	124.1	266.3	518.4	0	17.2	0	4890.6	0.016	0	95.31	13.84	0.087	249.96	452.76	52.28
20/07/1998	585	6157	3.84	129.6	249.8	483.7	0	19.1	0	5259.5	0.098	0	95.62	14.56	0.134	257.31	681.71	85.1
03/08/1998	488	6068	2.89	126.9	249	494.3	0	17.7	0	5155.9	0.11	0	96.71	13.17	0.091	282.55	547.03	75.06
17/08/1998	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	310.39	604.34	74.11
31/08/1998	506	6398	3.7	133.3	275.8	501.3	<0.1	22.3	<0.04	5449.1	0.025	<4	31.39	15.93	0.23	303.4	664	89.49
07/09/1998	634	6311	2.96	131.1	277.7	524.6	<0.1	13.5	<0.04	5348.8	0.033	<4	28.9	15.31	0.072	309.8	549	86.62
21/09/1998	595	6371	3.19	126.8	287.8	546.5	<0.1	18.7	<0.04	5377	0.02	<4	30.55	14.43	0.123	322	634.6	90.52
02/10/1998	603	6611	3	126.5	316.5	483.8	<0.1	27.7	<0.04	5842.3	0.082	<4	50.94	13.68	0.14	311.6	753.8	90.8
16/11/1998	483	5009	3.88	146.1	225.5	522.5	<0.1	23.2	<0.04	4079	0.008	<4	22.28	12.55	0.057	173.4	445.8	56.2
04/12/1998	570	6694	3.06	144.2	248.8	529.2	<0.1	10.8	<0.04	5711.1	0.013	21.6	49.55	14.15	0.075	488.2	451	81.2
14/12/1998	561	6472	3.51	141.3	225	557.8	0.5	73.2	<0.04	5451.5	0.023	<4	56.95	12.41	0.068	434	410.6	63.22
21/12/1998	544	5546	3.08	100.0	152.7	536.2	<0.1	21.3	<0.04	4726.1	0.019	<4	67.13	8.83	0.054	417	363.8	49.98
11/01/1999	613	6482	2.87	101.8	188.4	528.2	<0.1	13.4	<0.04	5843.6	0.031	<4	42.63	6.25	0.234	445.4	706.8	50.1
25/01/1999	671	7568	2.97	202	203.4	480.8	<0.1	12	0.057	6672.8	0.045	<4	78.41	16.29	0.369	544	856.8	58.58
08/02/1999	702	7089	3.11	125.6	238.5	498.2	<0.1	13.1	<0.04	7103.5	0.045	<4	72.19	9.11	0.352	455.6	958	58.18
15/02/1999	665	7341	3.12	125.2	221.6	483.5	<0.1	10.4	<0.04	6480.8	0.029	<4	60.77	8.58	1.238	408.97		51.576

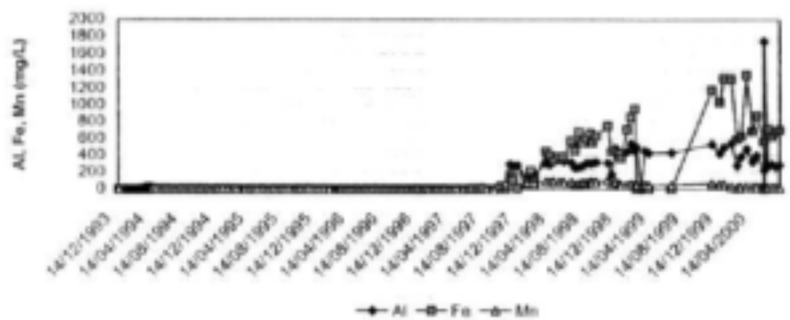
01/03/1999	410	3815	7.87	111	357.9	495.1	1.44	19.3	<0.04	6480	0.014	124.1	4.79	21.55	1.243	<0.02	<0.003	26.75
15/03/1999	673	7514	3.03	120.7	217.3	548.6	<0.1	6.4	<0.04	6812.5	0.032	<4	66.0	7.87	0.409	452.5		50.5
29/03/1999	604	7613	3.17	121.6	212.3	552.2	<0.1	11	<0.04	6706.2	0.028	<4	69.21	8.84	0.732	431		45.82
21/06/1999	661	8477	3.29	610	610.6	503.3	<0.1	16.7	<0.04	6710.5	0.018	<4	75.44	24.82	1.051	435.95		47.93
15/11/1999																532.18	1183	68.02
13/12/1999																425.35	1032.5	61
28/12/1999																498.25	1313.5	59.04
24/01/2000																544.5	1312.5	31.23
14/02/2000																282.4	592	17.25
28/02/2000																385.5	627.42	23.4
20/03/2000																478.5	1355	29.33
10/04/2000																324	598.5	21.15
25/04/2000																402	877	28.04
22/05/2000																225.6	570.8	15.76
22/05/2000	561	3163.635	2.569	135.396	122.966	498.242	<0.1	25.57	<0.04	2371.464	0.156	<4	29.236	4.857	1.619	1750.608	13.89	5.661
05/06/2000																275	715.6	17.82
20/06/2000																295.63	624.35	19.28
03/07/2000																271.34	687	20.08
17/07/2000																285.17	732.29	20.5
Min	270	2402	2.569	56.8	122.966	331.7	0	3.3	0	1523.2	0.001	0	3.46	3.62	0.054	0	0	0
Max	702	8477	8.39	610	733.5	651.3	1.44	108.3	2.66	7103.5	0.156	515	29.41	28.15	1.619	1750.608	1355	227.6
Mean	479.5507	4891.323	6.328471	176.6027	385.7170	516.1967	0.280733	29.09109	0.085934	3483.924	0.015167	264.7024	12.27026	15.75846	0.543783	117.4165	179.9554	26.60599
Median	439	4495	7.16	133.5	410.7	518.4	0.23	27.1	0.022	2970.45	0.009	338.5	4.66	15.36	0.496	0.133	0.017	7.36
95-percentile	394.1	3959.6	2.89	90.25	205.64	465.84	0	13.485	0	2511.66	0.002	0	3.7735	8.73	0.09055	0	0	1.92145

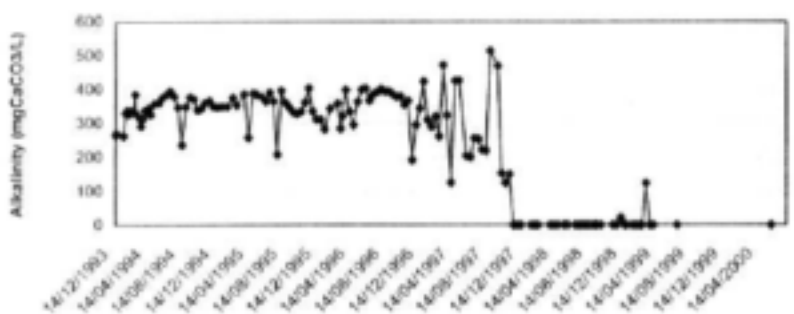
Cell 1

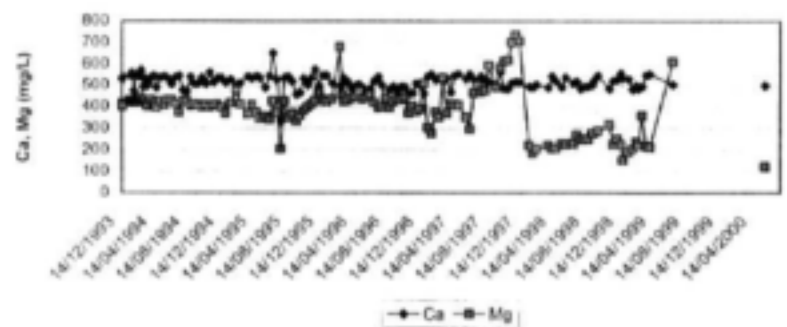

EC (mS/m)


pH


TDS, SO4, (mg/L)
TDS
SO4


Al, Fe, Mn (mg/L)
Al
Fe
Mn


Alkalinity (mgCaCO3/L)


Ca, Mg (mg/L)
Ca
Mg

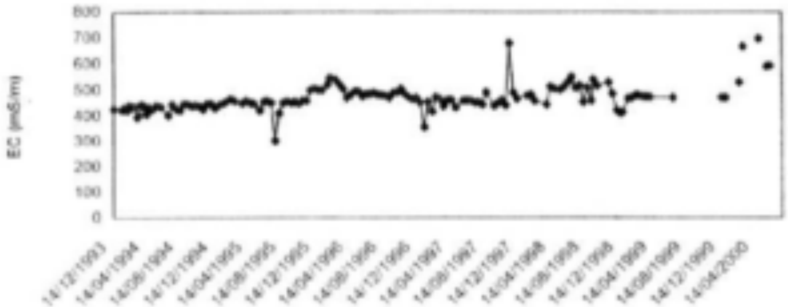
Cell 2

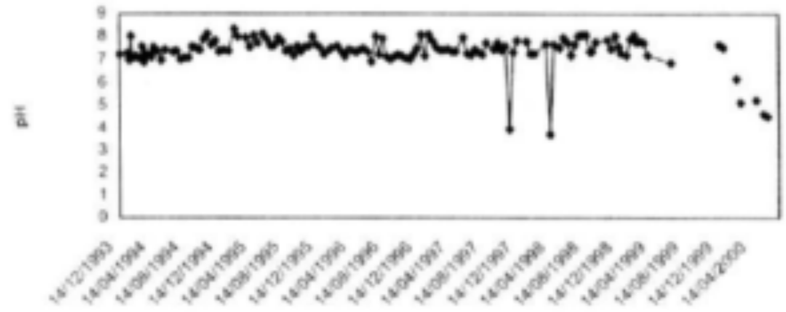
Date	EC	TDS	pH	Na	Mg	Ca	Fl	Cl	NO3	SO4	PO4	ALK	Si	K	NH4	Al	Fe	Mn
14/12/1993	428	4242	7.24	78.7	445	522	0.18	31	0.012	2853.7	0.008	247	4.19	9.85	0.378	0.215	0.013	10.855
10/01/1994	424	4402	7.29	83.4	447.5	542.6	0.29	50.5	0.026	2974.8	0.015	239.5	4.05	10.52	0.359	0.32	0.02	8.39
18/01/1994	431	4372	7.01	95	441.9	555.3	0.21	42	0.032	2989.2	0.008	276	4.15	11.35	0.38	0.118	0	5.56
24/01/1994	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
31/01/1994	422	4494	7.1	93.2	445.3	550	0.22	53.4	0.023	2985.8	0.019	274.2	3.98	12.12	0.349	0	0.017	11.78
07/02/1994	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
14/02/1994	432	4291	7.95	90.1	434.9	530.1	0.25	92.5	0.028	2779.7	0.007	288.5	4.32	11.66	0.385	0.171	0.012	10.8
21/02/1994	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
28/02/1994	435	4351	7.07	88.5	426.2	523.2	0.3	57.2	0.014	2865.7	0.01	309.8	3.55	11.53	0.363	0.188	0	10.42
07/03/1994	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
14/03/1994	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	0.398	0.504	1.1	12.08
21/03/1994	445	4500	7.27	99.7	451.4	532.8	0.26	46.7	0.016	2989.1	0.017	290.3	4.27	15.09	0.549	0.129	0	12.92
28/03/1994	442	4479	7.2	112.2	455.1	533.3	0.3	49.6	0.009	2938.6	0.023	297.8	4.42	16.16	0.594	0.122	0.009	13.08
05/04/1994	429	4524	7.24	104.3	447.8	538.9	0.3	43.4	0.024	3015.5	0.005	295	4.26	14.93	0.725	0.104	5.18	15.08
11/04/1994	409	4553	7.13	100.5	448	545.4	0.32	51.5	0.029	3020.4	0.009	300.7	4.34	15.17	0.752	0.154	0.565	12.75
18/04/1994	434	4295	7.55	99.4	446.4	515.6	0.2	44.5	0.016	2831.7	0.008	279	4.32	14.76	0.751	0.123	0.019	13.91
02/05/1994	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
16/05/1994	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
30/05/1994	436	4605	7.45	99.4	473.4	536.7	0.31	56.8	0.011	3028.5	0.007	322.9	4.24	15.57	0.764	0.065	0	11.18
27/06/1994	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	13.88
11/07/1994	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
25/07/1994	427	4238	7.02	114.5	404.6	497.3	0.32	22.4	0.054	2731.8	0.007	370.4	3.78	14.26	0.97	0.134	0.053	8.01
08/08/1994	422	4152	7.1	124.8	390.6	506	0.32	24	0.081	2654	0.041	356.9	3.82	15.27	0.956	0.134	0.058	9.27
22/08/1994	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	13.58
05/09/1994	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	0.068	14.53
19/09/1994	440	4425	7.52	100.8	452.7	512.3	0.33	85	0.168	2790.8	0.008	373.8	3.52	16.24	0.806	0.181	0	13.17
03/10/1994	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
17/10/1994	439	4219	7.91	107.4	442.8	512.2	0.28	96.1	0.45	2698.5	0.002	354.5	3.4	16.57	0.381	0.078	0.012	14.345
31/10/1994	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
14/11/1994	448	4553	7.66	105.7	445	520.7	0.3	88.2	0.972	2918.8	0.004	371.1	3.08	16.8	0.297	0.15	0.032	10.875
28/11/1994	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
12/12/1994	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
28/12/1994	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
16/01/1995	452	4474	7.39	113.4	446.3	548	0.27	124.4	0.293	2798.4	0.01	345.9	4.18	19.36	0.824	0.148	0	12.701
06/02/1995	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	15.493
20/02/1995	460	4437	8	124.9	427.7	541.8	0.28	105.6	0.016	2783	0.009	371.8	4.78	19.44	1.05	0.156	0.256	6.343
20/03/1995	450	4417	7.96	130.1	414.8	534.9	0.33	144.7	0.003	2984.7	0.011	414.6	4.8	20.63	1.018	0.153	0.539	11.146
03/04/1995	490	4912	7.57	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
19/04/1995	451	4372	8.07	130.7	411	547.5	0.32	98.2	0.009	2716.9	0.006	384	4.88	21.38	1.092	0.184	6.423	8.907
02/05/1995	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
22/05/1995	423	4325	8.14	145.6	435.1	470	0.27	84.8	0.041	2709.7	0.003	367	4.92	30.19	1.092	0.218	0.944	12.7
06/06/1995	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	1.058	0.066	0.036	10.6
19/06/1995	459	4068	7.6	127.4	395.9	490	0.25	98.6	0.022	2480.4	0.01	371.7	4.44	20.96	1.01	0.135	0.029	9.874
03/07/1995	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	0.136	11.335
17/07/1995	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	0.087	0.119	0	5.264
31/07/1995	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
14/08/1995	452	4304	7.38	127.2	421.8	528.5	0.22	72	0.042	2551.2	0.004	393.7	4.39	21.1	1.241	0.11	0.036	12.835
28/08/1995	457	4312	7.5	124.2	405.3	590	0.34	21.8	0.056	2758.5	0.005	384.8	5.08	21.17	1.299	0.142	0.079	11.417
13/09/1995	452	4118	7.18	115.6	389.1	527.8	0.28	63.7	1.947	2557.8	0.009	372.6	4.77	19.58	1.248	0.178	0.338	12.818
25/09/1995	457	4228	7.6	123	421.6	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
09/10/1995	449	4535	7.37	126.9	419.1	533.7	0.19	75	0.011	2910.4	0.013	395.4	4.79	21	1.417	0.171	0	13.365
24/10/1995	451	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	13.168
06/11/1995	450	4440	7.59	128.8	444.8	409.3	0.2	65.5	0.056	2754.5	0.012	423.5	4.85	28.66	1.407	0.191	0	13.72
20/11/1995	501	4411	8.03	128.3	438.3	523.8	0.17	70.8	0.24	2782.8	0.013	349.1	4.4	28.45	1.248	0.209	0.059	11.308
04/12/1995	508	4271	7.66	142	417.5	512.6	0.19	97.6	0.031	2648.2	0.012	343.8	4.99	31.1	1.681	0	0	0.373
18/12/1995	503	4453	7.54	166.4	420.4	527.8	0.2	93.3	0.124	2778.4	0.012	352.9	4.86	24.89	1.018	0.149	0.013	5.639
02/01/1996	501	4834	7.24	154.1	447.6	555.8	0.19	58.8	0.006	3183	0.007	347.6	5.24	31.93	1.067	0	0	6.532
22/01/1996	524	4890	7.47	187.5	480.4	513.7	0.22	37.6	0.05	3183.3	0.009	363.8	5.23	31.82	1.04	0.128	0.053	7.28
29/01/1996	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
19/02/1996	542	5533	7.61	242.8	481.3	432.9	0.23	47.6	0.042	3805.5	0.008	403.2	4.66	30.63	0.55	0.138	2.716	6.59
05/03/1996	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
18/03/1996	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	5.78
01/04/1996	473	4867	7.45	280.3	455.5	522.3	0.22	51.3	0.024	3089.4	0.007	392.1	4.88	28.32	0.767	0.134	0.011	0.534
15/04/1996	482	4919	7.4	280.4	420.2	449.3	0.23	54.7	0.049	3078.3	0.006	398.6	4.39	171.92	0.806	0.126	0.011	5.61
30/04/1996	498	4904	7.33	255.7	488.6	511.6	0.2	45.9	0.022	3117.7	0.007	389.7	5.08	30.05	0.851	0.5	0.186	7.68

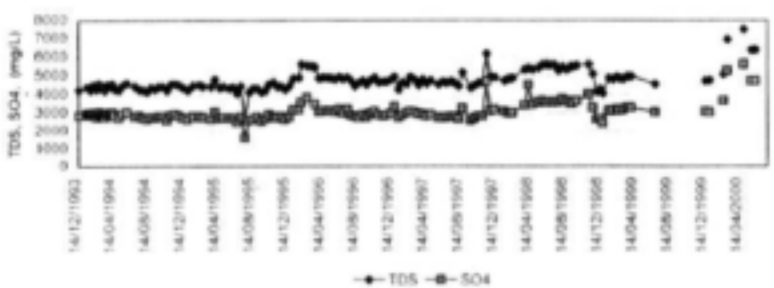
13/05/1996	497	4853	7.44	219.2	480.3	498.4	0.37	30.7	0.057	3107.3	0.008	449.7	4.85	27.44	0.935	0.01	0	7.6
27/05/1996	477	4830	7.49	224.1	458.2	471	0.38	31.3	0.041	3068.9	0.005	450	4.9	27.69	0.914	0.195	3.062	8.02
10/06/1996	486	4938	7.38	211.4	495.5	502.6	0.24	38.2	0.03	3186.8	0.008	388.6	5.52	28.13	0.903	0.11	0	7.64
24/06/1996	487	4847	6.92	208.9	454.8	550.5	0.36	31.3	0.021	3023.4	0.016	450	5.7	27.88	0.971	0.126	0	8.06
10/07/1996	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	5.31
22/07/1996	485	4758	7.24	228.1	456.9	499.2	0.23	53.9	0.03	2893.5	0.011	489.3	5.95	27.89	1.062	0.134	0	7.655
05/08/1996	482	4445	7.94	254.4	443.3	367.7	0.18	47.7	0.055	2829.4	0.003	395.9	5.06	27.35	1.002	0	0	3.031
19/08/1996	480	4556	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
02/09/1996	471	4735	7.62	260.7	442.5	482.3	0.21	56.2	0.038	2906.5	0.021	472.8	5.06	28.47	1.011	0	0	7.066
16/09/1996	490	4528	7.15	218	451.2	456.2	0.19	51.7	0.016	2777.9	0.004	457	5.43	14.48	1.056	0.153	0.035	3.37
30/09/1996	492	4780	7.22	221.8	459.7	484.4	0.21	53.8	0.008	2980.2	0.014	482	5.22	16.91	1.09	0.146	0.077	0.14
14/10/1996	508	4942	7.16	238.3	452.8	510.5	0.2	41.5	0.046	3082.7	0.005	458.3	5.24	17.4	1.092	0	0	7.347
28/10/1996	486	4653	7.07	237.5	457.1	465	0.15	40.7	0.031	2880.3	0.029	444.1	5.29	19.15	1.023	0.101	0.097	4.907
12/11/1996	473	4675	7.63	252.1	418.8	522.2	0.15	51.7	0.032	2830.6	0.011	477	5.2	16.42	0.915	0.331	0	5.335
25/11/1996	498	4891	7.23	210	445.7	508.9	0.18	48.3	0.016	2888.6	0.01	468.1	5.02	15.7	0.988	0.252	0.011	7.58
09/12/1996	471	4788	7.51	250.7	434.4	522.3	0.16	30.5	0.02	2968.7	0.013	455.3	5.93	16.87	1.026	0.35	0	1.618
23/12/1996	452	4952	8.09	223.9	521.2	495.7	0.01	24.8	0.027	3341.5	0.005	334.4	5.36	19.26	1.07	0.288	0.032	3.656
08/01/1997	356	4282	7.18	251.6	299	543.3	0.42	18.5	0.024	2778	0.007	312.8	6.65	11.03	0.223	0.454	0.096	5.884
20/01/1997	456	4640	8.11	224.1	392.3	522.7	0.18	30.2	0.131	2888.6	0.004	452.1	4.94	16.94	1.14	0	0	0
04/02/1997	417	4579	7.81	247.5	374.8	524.8	0.42	19.4	0.069	3019.5	0.004	312	3.05	12.08	0.27	0	0	0.233
17/02/1997	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
03/03/1997	468	4799	7.44	224.7	418	524.6	0.12	34.3	0.004	3057.2	0.007	430	5.21	15.83	1.233	0.536	0.049	2.415
17/03/1997	439	4587	7.44	213.9	369.4	527.1	0.49	18	0.035	2968.2	0.008	326.5	6.91	11.12	0.404	0	0	7.45
01/04/1997	452	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
14/04/1997	462	4603	7.36	232.2	445.3	449.1	0.22	36	0.025	2832.4	0.013	481.7	5.45	17.41	1.223	0.162	0	0.284
29/04/1997	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	1.181	0.153	0	2.495
26/05/1997	460	4542	7.98	226.4	400.2	507.8	0.21	34.9	0.193	2763.9	0.009	483.6	4.98	16.04	0.991	0.084	0	3.772
09/06/1997	460	4680	7.26	271.8	349.9	551	0.19	35.5	0.019	2757.4	0.006	572.9	5.26	15.29	0.842	0.051	0	2.372
23/06/1997	460	4631	7.21	243.3	398.1	505.1	0.19	32.2	0.028	2769.4	0.006	543	5.42	15.28	0.935	0.031	0	1.178
08/07/1997	453	4676	7.45	244.5	398	530.8	0.2	24.5	0.05	2805.1	0.006	538.6	5.21	14.8	0.958	0.010	0	0.482
21/07/1997	455	4638	7.33	242.8	372.5	522	0.19	10.1	0.065	2898.2	0.007	530.9	4.98	14.1	0.938	0.05	0	1.565
04/08/1997	445	4450	7.23	240.5	387	487	0.22	29.8	0.063	2683.2	0.004	521.7	5.55	15.04	0.951	0.045	0	4.688
18/08/1997	402	5173	7.74	238.5	529.4	518.2	0.18	36.3	0.03	3262.3	0.005	470.1	4.82	15.89	1.074	0.004	0	3.839
15/09/1997	440	4358	7.45	223	358.5	518.1	0.21	22.9	0.055	2590.9	0.006	518.7	5.02	14.38	1.044	0	0	0.71
29/09/1997	451	4484	7.73	207.9	382.3	538.6	0.21	21.7	0.113	2705.8	0.006	494	4.89	14.93	0.968	0	0	3.584
13/10/1997	402	4609	7.41	205.9	412.3	508	0.27	20.5	0.069	2842.7	0.013	486.4	5.16	15.28	1.08	0	0	5.83
27/10/1997	443	4627	7.59	206.8	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
10/11/1997	680	8180	3.97	215.2	782.8	507.5	0	30.8	0	4700.9	0.018	0	21.82	22.66	0.615	304.4	103.2	235.2
24/11/1997	491	4973	7.34	196.4	516	528.3	0	40.8	0.016	3125.8	0.006	440.8	5.27	15.63	1.011	0	0.015	2.471
08/12/1997	467	4936	7.83	199.2	509	532.5	0	35.6	0.851	3188.6	0.008	388.7	4.25	15.96	0.045	0	0	5.54
12/01/1998	480	4737	7.79	180.9	489.3	530.3	0	29.3	0.532	3093.8	0.003	324.3	4.9	15.08	0.483	0	0.046	7.24
26/01/1998	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
09/02/1998	480	4878	7.28	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
23/03/1998	445	5332	7.69	224.7	545	540.1	0.21	16.6	0.453	3420.2	0.005	464.8	4.07	15.94	0.44	0	0.132	5.93
06/04/1998	518	5415	3.72	108.9	230.7	531.9	0	25.9	0	4501.9	0.012	0	32.90	15.48	0.2	327.716	496.858	92.026
20/04/1998	507	5354	7.67	209.6	585.5	595.7	0.15	34.9	0.675	3454.4	0.011	438.9	4.62	14.5	0.569	0	0.15	3.66
11/05/1998	503	5445	7.52	203.7	628.8	489.4	0	35.5	0.157	3589.7	0.028	302.7	4.39	17.23	0.957	1.148	1.285	8.46
25/05/1998	514	5590	7.98	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
08/06/1998	533	5601	7.77	202.6	641.8	517.2	0	32.2	0.005	3580.1	0.006	409.5	5.68	16.22	1.215	0.318	0.131	7.46
22/06/1998	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
06/07/1998	511	5585	7.67	194.8	627.1	542.1	0	27.5	0.06	3578.9	0.033	487.1	5.34	18.49	1.322	0.163	0.15	0.992
20/07/1998	520	5290	8.05	212.2	598.6	485.3	0	31.7	0.758	3603.2	0.045	293	5.14	18.22	0.318	0.174	0.152	7.32
03/08/1998	455	5459	8.07	214.4	646	485.3	0	24	0.754	3744.3	0.045	289.6	4.96	17.86	0.348	0.189	0.126	6.95
17/08/1998	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	0.333	0.181	0.14	7.51
31/08/1998	461	5492	7.37	193.2	587.7	544.1	<0.1	31.2	<0.04	3515	0.011	463.9	6.90	17.16	1.052	<0.02	0.405	0.313
07/09/1998	542	5500	7.38	194.5	598.3	541.5	<0.1	20.6	<0.04	3519.5	0.009	498.7	6.65	17.63	1.594	0.248	0.551	3.34
21/09/1998	519	5544	7.77	193.9	660.7	534.4	<0.1	32.9	0.898	3654.2	0.009	366.4	4.93	17.27	<0.04	0.337	0.792	4.226
02/11/1998	532	5610	7.86	210.8	604.2	435	<0.1	39.1	1.49	4012.3	0.015	185.1	3.57	16.26	0.059	<0.02	0.678	6.83
16/11/1998	488	5113	7.48	168.8	558.2	479.7	0.16	30.7	0.092	3284.9	0.005	409.2	5.78	17.46	1.316	<0.02	0.372	1.929
01/12/1998	422	4153	8.05	148.6	386	476.5	0.15	26.3	<0.04	2654.5	0.005	365.2	5.89	14.26	1.294	<0.02	0.014	1.176
14/12/1998	413	4282	7.58	142.2	362.1	543.4	0.18	24	<0.04	2655.6	0.01	442.4	5.53	13.09	1.183	<0.02	<0.003	0.482
21/12/1998	416	4064	7.29	162.4	318.3	571.2	0.13	23.4	<0.04	2435.2	0.006	441.4	5.36	13.35	1.119	<0.02	<0.003	0.118
11/01/1999	470	4876	7.2	182.7	434.7	582.2	0.31	30.3	<0.04	3117.4	<0.008	436.5	5.29	15.07	1.113	<0.02	0.012	6.66
25/01/1999	472	4917	7.9	181.9	468.3	523.4	<0.1	35.1	0.072	3142.1	0.01	368.2	5.58	15.63	1.086	0.112	0.58	3.899
08/02/1999	483	4947	8.07	170.3	403.9	576	0.16	31	<0.04	3109.9	0.025	374.7	5.12	16.89	1.233	<0.02	<0.003	5.26
15/02/1999	482	4877	7.76	172.9	509.8	528.8	0.34	32.2	<0.04	3151.4	0.006	380	5.22	16.12	1.352	<0.02	<0.003	8.88
01/03/1999	477	4851	7.79	169.3	496.8	533.6	0.28	24.8	<0.04	3185.2	0.015	345.3	5.27	16.7	1.224	<0.02	<0.003	9.8
15/03/1999	476	4968	7.74	173.8	492.6	569	<0.1	17.2	<0.04	3299	0.014	328	6.14	14.94	1.158	0.06	0.825	9.52

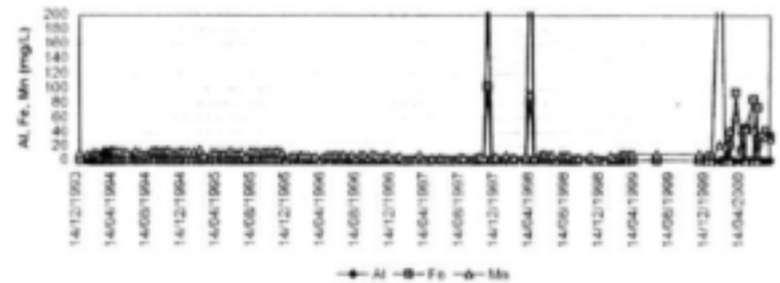
20/03/1999	475	4977	7.2	171.5	499.4	579.5	<0.1	12.7	<0.04	3298.9	0.008	326.1	6.77	15.96	1.357	<0.02	0.484	9.34
21/06/1999	473	4563	6.87	173	451.9	504.2	<0.1	27.6	<0.04	3054.1	0.012	273.8	6.02	16.75	1.385	<0.02	0.881	9.12
15/11/1999																<0.035	<0.005	9.5
13/12/1999																0.105	0.857	9.11
13/12/1999	473	4743.221	7.852	166.965	436.636	516.89	0.238	39.273	1.582	3081.925	0.018	370.803	5.76	13.029	0.08			
28/12/1999																<0.035	<0.005	9.3
28/12/1999	472	4774.385	7.533	175.799	471.036	528.981	0.223	35.709	1.847	3056.47	0.026	393.863	5.846	18.446	0.101			
24/01/2000																0.083	360.5	23.4
14/02/2000																<0.035	0.282	21.63
14/02/2000	533	5087.21	6.187	194.689	577.854	473.677	0.71	27.922	<0.04	3080.336	0.012	93.247	3.396	16.715	1.157			
28/02/2000																0.133	23.28	43.6
28/02/2000	567	6954.558	5.143	210.351	920.921	655.079	0.448	26.125	<0.04	5285.244	0.047	27.594	3.814	20.859	1.286			
20/03/2000																0.164	95.4	63.3
10/04/2000																0.126	14.86	43.93
25/04/2000	597	7506.295	5.253	200.787	1035.275	609.885	0.421	22.563	<0.04	5630.396	0.029	102.056	3.884	20.33	1.575			
25/04/2000																0.212	47.17	60.23
22/05/2000																0.731	86.3	44.93
22/05/2000	591	6394.31	4.838	243.398	710.333	632.929	0.121	24.016	<0.04	4724.438	0.011	28.519	4.806	22.647	1.214			
05/06/2000																<0.059	75.4	35.3
05/06/2000	505	6411.019	4.534	237.252	714.743	629.079	0.167	24.753	<0.04	4741.895	0.02	25.726	4.55	30.108	1.168			
20/06/2000																0.492	34.34	38.8
03/07/2000																0.214	43.34	34.76
17/07/2000																0.479	34.73	31.75
Min	303	2633	3.72	78.2	230.7	323	0	12.7	0	1640.7	0.002	0	3.05	9.85	0.045	0	0	0
Max	597	7506.295	8.34	404.8	1035.275	632.929	0.71	156	1.947	5630.396	0.047	572.8	32.99	171.82	1.687	327.716	466.858	236.2
Mean	469.6056	4754.268	7.37336	175.6557	467.5405	517.5846	0.231463	49.9946	0.177712	3066.172	0.011346	371.3076	5.138038	19.66679	0.882411	4.931707	16.01754	12.0046
Median	450	4624.5	7.445	182.3	445.35	524.2	0.22	39.95	0.036	2931.1	0.009	372.85	4.925	16.805	0.957	0.135	0.0285	8.02
95-percentile	413.15	4214.25	5.872	93.29	367.105	449.589	0	20.315	0.006	2648.2	0.003	179.685	3.4035	11.5365	0.27	0	0	0.5026

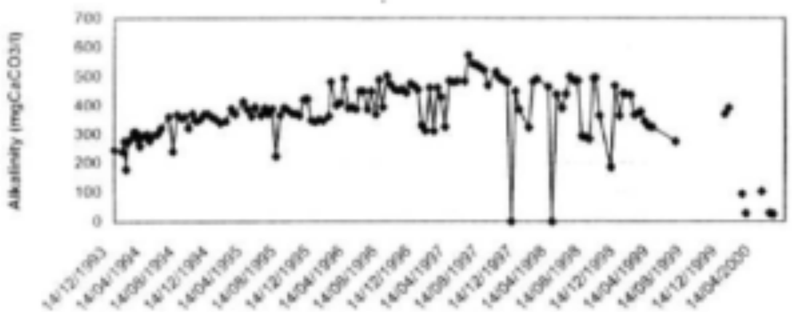
Cell 2

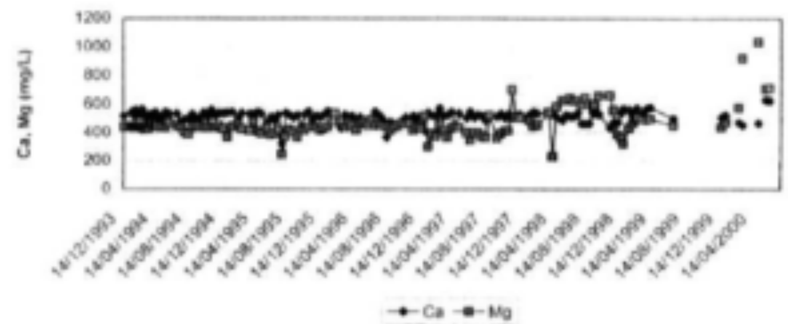

EC (mS/m)


pH


TDS, SO4 (mg/L)
TDS
SO4


Al, Fe, Mn (mg/L)
Al
Fe
Mn


Alkalinity (mgCaCO3/l)


Ca, Mg (mg/L)
Ca
Mg

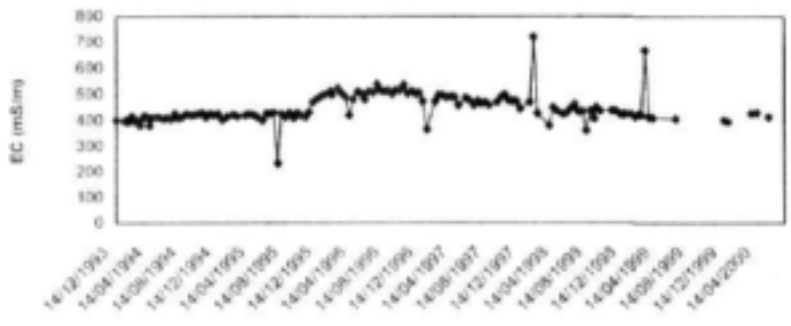
Cell 3

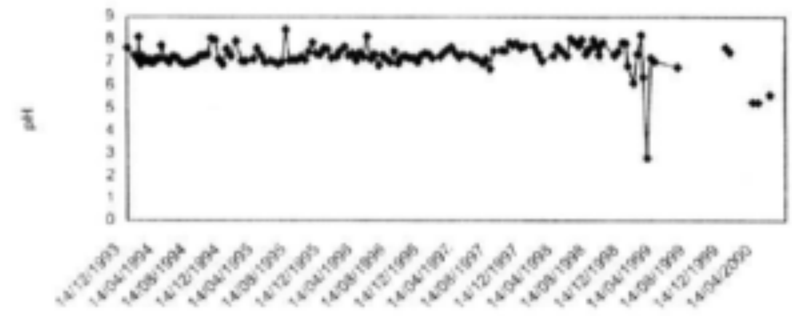
Date	EC	TDS	pH	Na	Mg	Ca	Fl	Cl	NO3	SO4	PO4	ALK	Si	K	NH4	Al	Fe	Mn
14/12/1993	403	4002	7.65	67.3	394	532	0.22	34.9	0.017	2696.2	0.006	220.4	4.49	7.64	0.3	0.613	0.068	7.995
10/01/1994	399	4004	7.31	81	356.8	546.9	0.29	48.9	0.032	2697	0.012	215.9	4.4	9.17	0.292	0.059	0	11.49
18/01/1994	405	4147	7.18	89.1	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
24/01/1994	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
31/01/1994	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
07/02/1994	420	4149	7.27	89.2	393.3	543	0.3	42.4	0.005	2748	0.009	263.8	4.88	10.29	0.307	0.222	0	8.94
14/02/1994	408	4173	7.12	97.1	372.7	543.6	0.28	31.7	0.016	2779.4	0.007	278.7	4.92	10.13	0.306	0.378	0.036	9.2
21/02/1994	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
28/02/1994	400	4045	7.05	98.7	381	528.6	0.31	37.9	0.016	2678	0.008	271.3	4	10.64	0.312	0.19	0	9.52
07/03/1994	382	4120	7.14	102.7	364.6	536.2	0.31	34.6	0.025	2780.5	0.022	287.4	5	14.3	0.445	0.368	0.022	10.4
14/03/1994	409	3948	6.99	113.8	377	500.2	0.29	39.8	0.017	2610.4	0.006	239.6	4.61	13.4	0.299	0.51	1	10.63
21/03/1994	420	4196	7.02	100.3	395.1	534.5	0.31	34.6	0.005	2787.7	0.025	289.7	4.86	14.12	0.509	0.107	0.037	12.35
28/03/1994	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	12.97
05/04/1994	414	4259	7.17	100.4	394	542.6	0.3	32.4	0.044	2848.8	0.006	287.4	4.75	13.7	0.594	0.134	2.934	13.59
11/04/1994	393	4317	7.21	95.5	399	551.1	0.31	33.6	0.032	2892.7	0.007	271	4.83	13.57	0.602	0.179	0	12.98
18/04/1994	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
02/05/1994	414	4242	7.18	100.2	393.1	519.9	0.22	35.7	0.017	2848.5	0.008	269.3	4.5	14.34	0.672	0.067	0.199	13.05
16/05/1994	415	4222	7.02	99.2	371.7	548.2	0.32	48	0.024	2704.9	0.004	282.6	4.66	14.06	0.693	0.128	0.02	12.88
30/05/1994	408	4319	7.28	97.6	382.3	544.6	0.39	45.9	0.037	2881.1	0.005	304.6	4.61	14.29	0.743	0.074	0	12.86
13/06/1994	412	4153	7.23	107.5	410.3	517.9	0.34	58	0.025	2840.6	0.008	330.2	4.5	15.02	0.821	0.144	0.042	11.87
27/06/1994	406	4121	7.03	102.7	374.4	542.9	0.42	62.8	0.014	2606.9	0.005	339.1	4.12	13.73	0.816	0.124	0.019	12.34
11/07/1994	430	4241	6.95	113.5	368.5	564.2	0.43	63.2	0.015	2708.7	0.011	332.2	4.52	15.98	0.885	0.136	0.037	11.72
25/07/1994	410	4037	6.99	103.3	380.7	528.6	0.35	31.5	0.092	2606.1	0.007	319.9	4	14.51	0.922	0.144	2.998	10.51
08/08/1994	417	3973	7.08	107	367.3	538.2	0.37	72	0.057	2479.6	0.012	321.2	4.09	15.35	0.853	0.118	1.037	12.4
22/08/1994	428	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
05/09/1994	422	4080	7.3	107.1	370.8	532.9	0.31	63.1	0.039	2604.2	0.008	315.9	3.8	15.48	0.949	0.068	0.089	13.52
19/09/1994	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
03/10/1994	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	0.006	12.354
17/10/1994	432	4084	8.07	106.1	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
31/10/1994	415	4228	8.01	114.8	382.5	569.6	0.36	70.2	0.038	2641.9	0.008	356.3	4.26	12.76	0.993	0.116	0.023	11.709
14/11/1994	429	4291	7.15	108.1	392	533.4	0.35	90.2	0.023	2708.5	0.004	361	3.95	16.35	1.117	0.123	0.041	7.729
28/11/1994	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
12/12/1994	429	4144	7.6	108	380.4	536.2	0.3	108.2	0.03	2585.1	0.006	336.2	4.22	14.2	1.03	0.14	0.138	12.353
28/12/1994	405	4112	7.29	112.5	357.3	533.1	0.26	37.8	0.074	2637.6	0.012	331.1	4.68	18.39	1.195	0	0.054	0
16/01/1995	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
06/02/1995	425	4141	7.08	130.8	369.2	508.4	0.3	69.8	0.01	2591.4	0.003	362.2	5.12	19.53	1.006	0.05	0.006	12.74
20/02/1995	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
20/03/1995	422	4084	7.17	135.6	356.5	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
03/04/1995	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
19/04/1995	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	0.903
02/05/1995	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
22/05/1995	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
06/06/1995	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
19/06/1995	429	3880	6.93	147.8	336.2	488.2	0.27	61.1	0.053	2376	0.01	366.1	4.8	21.88	1.043	0.178	0.06	9.57
03/07/1995	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	1.188	0.135	0.085	10.123
17/07/1995	235	1921	8.44	70.1	164.9	253.6	0.27	37.3	0.142	1193.1	0.003	158.9	4.24	9.65	0.426	0.114	0	2.734
31/07/1995	428	4150	7.12	146.2	358	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
14/08/1995	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
28/08/1995	432	4125	7.12	138.8	338.9	593.6	0.38	79.2	0.029	2486.5	0.007	381.3	5.73	22.23	1.189	0.147	0.343	9.525
13/09/1995	411	3522	7.26	133.3	335.3	498.1	0.29	67.2	0.017	2314.5	0.008	379.6	5.1	19.99	1.114	0.155	0.048	10.751
26/09/1995	432	3836	7.13	135.7	357.4	457.8	0.32	84.9	0.045	2318.7	0.005	376	5.36	20.37	1.23	0.205	0.223	10.079
09/10/1995	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	1.104	0.108	0	9.835
24/10/1995	414	3838	7.88	138.8	330.4	495	0.24	86.2	0.057	2286	0.018	393.1	5.25	20.07	1.154	0.109	0	9.904
06/11/1995	434	3932	7.41	140.2	353.3	454.3	0.22	80.8	0.037	2340.8	0.009	434.6	5.04	21.04	1.248	0.132	0.014	11.061
20/11/1995	473	4114	7.38	137.9	348.4	548.2	0.18	78.8	0.021	2501.4	0.007	384.4	4.65	27.95	1.421	0.231	0.082	8.867
04/12/1995	483	4161	7.63	159.3	354.3	538.2	0.19	190.7	0.013	2458	0.016	342.5	5.36	31.33	1.18	0	0	2.424
18/12/1995	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
02/01/1996	500	4581	7.22	186.2	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
22/01/1996	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
29/01/1996	500	5037	7.48	268.7	453.9	530.6	0.27	45.7	0.045	3256	0.012	376.8	5.28	20.80	0.859	0.127	0.025	7.04
19/02/1996	525	5521	7.71	214.7	484.1	486	0.25	39.9	0.047	3903.7	0.009	393.7	4.99	31.41	0.731	0.137	0.29	6.37
05/03/1996	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
18/03/1996	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
01/04/1996	423	4714	7.11	211.4	445.2	514	0.25	15.2	0.009	3037.4	0.006	383.5	5.04	21.58	0.768	0.159	0.014	1.209
15/04/1996	483	4771	7.45	229.4	486.2	455.7	0.25	42.7	0.049	3065	0.005	377.8	4.57	29.56	0.775	0.172	0.014	3.821

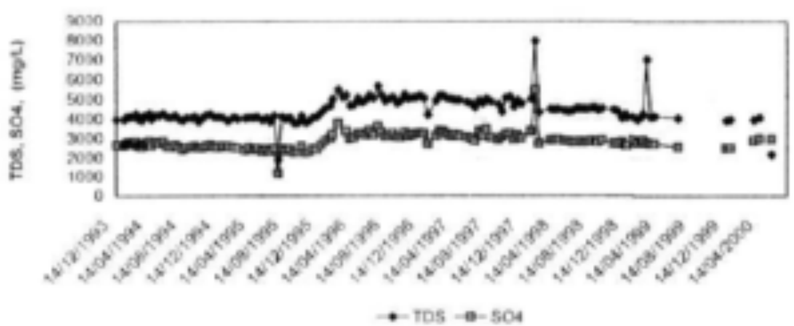
30/04/1996	511	5095	7.26	245.4	504.6	523.7	0.25	38	0.023	3287.4	0.006	378.2	5.3	34.35	0.809	0.513	0.068	7.9
13/05/1996	506	4888	8.16	210.3	526.3	430.2	0.33	27.4	0.055	3300.9	0.004	296	5.02	30.31	1.023	0.007	0	8.85
27/05/1996	483	4903	7.16	212.5	510.7	474.9	0.4	28	0.018	3248.4	0.007	390	5.1	30.61	0.99	0.229	0	5.86
10/06/1996	513	5241	7.38	208.1	547	504.3	0.26	35.8	0.015	3442	0.008	386	5.48	31.27	0.996	0.142	0	8.39
24/06/1996	507	5404	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
10/07/1996	540	5699	7.52	208	604.8	584	0.23	38.1	0.027	3085.5	0.01	452.3	5.7	32.84	1.121	0.101	0	10.12
22/07/1996	517	5259	7.18	198.6	566.1	494	0.23	44.7	0.005	3367.3	0.01	453.3	5.37	31.78	1.073	0.087	0	4.257
05/08/1996	513	4541	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
19/08/1996	517	5054	7.51	212.9	526.8	505.9	0.23	47.1	0.021	3151	0.011	484.8	5.41	32.27	1.025	0	0	1.219
02/09/1996	503	5148	6.98	222.2	549	452.3	0.22	45.4	0.051	3297.8	0.012	447.7	5.23	32.22	1.098	0	0	3.123
16/09/1996	519	4829	7.26	208.8	532.6	468.3	0.14	45.4	0.035	3105.2	0.004	387	5.49	19.1	1.07	0.163	0.041	4.375
30/09/1996	518	4972	7.29	214.7	544.9	485.1	0.22	47	0.014	3099	0.015	458.2	5.38	20.31	1.183	0.207	0.059	9.81
14/10/1996	537	5285	7.22	213	544.5	507.4	0.22	33.6	0.038	3350	0.004	479.6	5.3	21.08	1.174	0	0	5.545
28/10/1996	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
12/11/1996	514	5133	7.03	203.1	545.5	508.3	0.15	28.8	0.087	3255.1	0	488.6	5.42	18.87	0.953	0.28	0	9.577
25/11/1996	505	5140	7.31	176.3	533	514.6	0.19	42.8	0.085	3285.5	0.011	485.8	5.25	18.34	1.036	0.219	0.012	4.56
09/12/1996	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
23/12/1996	478	5103	7.39	174.1	525.6	516.4	0.14	35.1	0.026	3288.1	0.006	444.9	5.59	20.21	1.052	0	0	2.768
06/01/1997	367	4248	7.21	253.1	300.2	537.5	0.38	17.8	0.03	2754.9	0.007	306.1	7.85	10.94	0.246	0.563	0.021	3.046
04/02/1997	475	4981	7.27	160	537.8	498.5	0.17	30.3	0.029	3174.1	0.004	458.6	5.27	18.55	1.372	0	0	2.352
17/02/1997	500	5233	7.43	169.8	554.6	464.9	0.17	31.1	0.037	3423	0.007	457	5.21	20.61	1.472	0	0	0.653
03/03/1997	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	2.028
17/03/1997	491	5094	7.69	139.3	558.5	507.4	0.22	30.7	0.019	3290.8	0.007	465.8	6.39	19.73	1.221	0	0	4.349
01/04/1997	493	5040	7.42	161.5	554.2	525.6	0.21	35	0.017	3179.5	0.013	481.3	5.53	19.32	1.277	0.113	0	0.008
14/04/1997	492	4959	7.23	169.5	562.9	423.4	0.21	33	0.03	3222.1	0.014	464.4	5.6	20.57	1.298	0.183	0	0.614
29/04/1997	461	5000	7.36	170.1	597.2	455.4	0.2	31.1	0.028	3195.3	0.015	458	5.42	19.68	1.269	0.172	0	1.928
26/05/1997	489	4895	7.32	158	524.2	493	0.2	33.1	0.013	3097.4	0.009	465.2	5.84	19.8	1.203	0.097	0	2.474
09/06/1997	480	4810	7.21	158.6	408.1	494.8	0.19	32.8	0.095	3049.7	0.014	462.3	5.64	18.78	1.052	0.073	0	2.826
23/06/1997	481	4839	7.13	160.5	471.9	489.5	0.17	30.6	0.027	2904.9	0.008	459.3	5.55	19.86	1.011	0.026	0	2.813
08/07/1997	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
21/07/1997	467	4829	7.17	192.5	486.9	527.2	0.38	23.5	0.096	3155.6	0.009	348.3	5.29	15.96	0.587	0.089	0	8.92
04/08/1997	473	5058	6.73	223.9	476.3	529.4	0.87	30.5	0.027	3513.5	0.008	223.4	6.25	10.83	0.454	0.096	0	20.41
18/08/1997	451	4929	7.52	190.8	484	528.8	0.19	32.8	0.08	3081.6	0.004	485.3	5.1	16.43	1.024	0.076	0	6.57
15/09/1997	474	4788	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
29/09/1997	492	4418	7.52	185.2	528	383.7	0.19	32.3	0.054	3116	0.008	128.1	5.29	18.6	1.188	0	0	0.229
13/10/1997	501	5115	7.88	155.5	550.4	506.2	0.23	27.3	0.155	3260.5	0.014	471.7	5.24	19.87	1.144	0	0	4.561
27/10/1997	480	5165	7.78	162.5	561.9	507.7	0.06	27.3	0.137	3312.3	0.023	468	5.34	20.42	1.118	0	0	4.933
10/11/1997	477	4658	7.84	167.5	551.2	405.2	0.13	29.3	0.057	3012.7	0.004	387.7	5.31	18	1.083	0	0.036	2.753
24/11/1997	477	4982	7.64	162.1	558.7	477	0	38.8	0.009	3107	0.007	434.9	5.47	18.16	1.112	0	0	6.47
08/12/1997	449	4893	7.72	157.9	513.2	519	0.01	19.7	0.057	3051.9	0.04	434.2	5.33	17.36	1.097	0	0	2.57
12/01/1998	474	5063	7.72	146.4	502.8	539.9	0.38	28.7	0.087	3425.8	0.003	328.6	5.6	17.92	1.113	0	0.007	9.19
26/01/1998	721	7992	7.42	254.9	1904.2	453.8	0.05	49.2	0.049	5497	0.016	500.1	4.53	21.42	1.031	0	0	1.98
09/02/1998	430	4388	7.09	133	424	540.2	0.33	15.9	0.014	2793.4	0.009	370.4	5.28	18.63	0.889	0	0	0.959
23/03/1998	382	4546	7.32	136.7	427.4	550.9	0.11	14.4	0.954	2954.2	0.002	352.4	5.76	18.65	1.034	0	0.12	7.56
06/04/1998	451	4537	7.72	130.7	433.3	555.2	0.27	14.2	0.129	2966.3	0.007	342.6	5.07	17.87	1.037	0	0.109	1.769
20/04/1998	440	4550	7.54	124.7	434	533.9	0.29	17.7	0.305	2966	0.02	373.3	5.56	16.16	0.789	0	0.044	14.91
11/05/1998	429	4474	7.3	127.7	425.4	432.5	0	19.8	0.025	2916.8	0.015	395.3	5.96	19.09	1.24	0.007	0	12.63
25/05/1998	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	0.381	0	11.68
08/06/1998	450	4480	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
22/06/1998	466	4586	7.76	130.7	456.9	533.5	0	30.5	0.016	2857.3	0.01	448.1	5.94	19.33	1.343	0.23	0.028	10.65
06/07/1998	438	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	9.758
20/07/1998	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
03/08/1998	364	4570	7.61	119.7	445.9	528	0	17.8	0.066	2892.5	0.057	447.5	5.65	18.68	1.285	0.12	0.028	2.05
17/08/1998	440	4616	8.01	118.7	466.4	533.4	0.02	21.7	0.08	2033.8	0.012	427.9	5.79	18.24	1.226	0.135	0.1	0.476
31/08/1998	410	4817	7.72	109.7	461.5	544.2	0.49	93.6	0.374	2892	0.01	465	7.69	18.5	1.45	<0.02	<0.003	<0.001
07/09/1998	454	4506	7.34	116.2	467.9	461.1	<0.1	18.8	<0.04	2849.4	0.007	473.4	7.69	15.74	1.323	<0.02	0.014	1.793
21/09/1998	440	4585	7.87	113.4	475	540.2	<0.1	19.7	0.043	2958.3	0.009	378.5	7.54	18.8	1.273	<0.02	0.022	0.816
02/11/1998	441	4523	7.32	114.4	442.8	558.4	<0.1	21.9	0.183	2796	0.01	467.1	5.3	18.56	0.875	<0.02	<0.003	3.514
16/11/1998	440	4439	7.51	112.9	438.5	481.8	0.17	22.2	0.688	2773.5	0.006	482.9	5.71	18.5	0.862	<0.02	<0.003	2.365
01/12/1998	428	4092	7.87	116.5	465.6	379	0.15	21.9	0.418	2834	<0.005	206.6	6.02	19.14	1.252	<0.02	<0.003	0.309
14/12/1998	426	4283	7.84	113.5	405.7	479.5	0.31	20.6	0.158	2853.8	0.018	441	6.04	18.79	1.297	<0.02	<0.003	0.639
21/12/1998	429	4128	6.87	909.6	366.3	557.7	1.03	18.1	<0.04	2690.7	0.01	298.9	5.9	19	0.864	<0.02	0.008	29.74
11/01/1999	428	4135	6.13	111.5	378.9	541.9	0.04	15.3	<0.04	2955.9	0.01	89.4	5.33	20.21	1.1	<0.02	0.028	40.79
25/01/1999	419	4043	7.38	112.4	358.6	557.4	0.58	19.7	<0.04	2814.8	0.010	117.7	5.32	21.22	1.162	<0.02	0.015	32.29
08/02/1999	427	4173	8.21	117.4	320	537.3	1.28	17.8	<0.04	2816.8	0.023	236.3	4.76	22.02	1.33	<0.02	<0.003	23.33
15/02/1999	425	4303	6.38	113.5	370.8	534.9	0.65	20.6	<0.04	2985	0.006	224.8	5.07	21.54	1.385	<0.02	0.248	26.5
01/03/1999	670	7054	2.82	142.9	209.9	506.4	<0.1	19.6	<0.04	2820	0.024	<4	68.07	8.42	0.587	445.5	929.25	53
15/03/1999	416	4153	7.21	113	369.6	569	0.75	13.6	<0.04	2776.2	0.013	237.8	5.55	19.53	1.41	<0.02	0.073	25.24

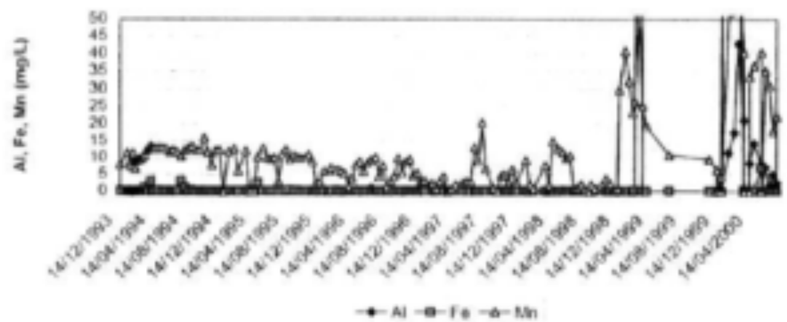
29/03/1999	412	4182	7.07	118.8	366.1	587	0.7	25	<0.04	2770.9	0.008	256.3	5.55	20.84	1.496	<0.02	0.045	19.35
21/06/1999	409	4090	6.81	121.7	335	557.6	0.41	22.3	<0.04	2602.8	0.007	353.9	4.75	16.62	1.467	<0.02	0.151	10.85
15/11/1999																<0.035	<0.005	9.52
13/12/1999																<0.035	<0.005	6.29
13/12/1999	404	3966.874	7.66	98.038	334.187	535.007	0.564	26.083	1.315	2540.052	0.013	332.67	3.782	21.408	0.05			
28/12/1999																<0.035	<0.005	4.303
28/12/1999	397	4010.367	7.459	93.785	333.573	585.345	0.333	21.89	1.318	2553.676	0.011	323.492	3.586	21.405	0.056			
24/01/2000																11.52	400	51
14/02/2000																17.5	304.4	50.9
28/02/2000																42.98	85.25	66.43
20/03/2000																21.2	0.383	40.49
20/03/2000	430	4006.971	5.304	104.323	336.654	565.906	1.092	15.477	<0.04	2038.046	0.006	15.326	2.942	24.172	1.171			
10/04/2000	433	4120.533	5.279	110.347	345.292	572.748	1.542	17.105	0.056	3020.721	0.007	22.765	4.202	23.19	1.213			
10/04/2000																8.32	0.094	33.64
25/04/2000																14.3	0.294	38.7
22/05/2000																8.98	5.69	40.55
22/05/2000	416	2220.249	5.605	99.244	325.724	577.612	1.567	15.096	<0.04	3022	0.021	29.421	2.521	20.31	1.275			
05/06/2000																7.96	<0.006	35.32
20/06/2000																1.687	0.217	31.07
03/07/2000																4.943	0.085	17.9
17/07/2000																2.42	0.05	22.2
Min	235	1921	2.82	67.3	184.9	253.6	0	13.6	0.005	1193.1	0	15.326	2.521	7.64	0.05	0	0	0
Max	721	7092	8.44	287.2	1104.2	593.6	1.567	190.7	1.318	5407	0.057	500.1	68.07	34.38	1.496	445.5	929.25	66.43
Mean	445.65	4401.386	7.283336	145.4086	432.3709	516.6308	0.312559	43.28465	0.071352	2689.357	0.010612	354.8041	5.58125	19.38739	0.964454	4.50074	12.53092	11.05401
Median	431	4311.5	7.295	134.4	402.2	528.7	0.27	34.45	0.0285	2649.4	0.008	372.6	5.245	18.95	1.061	0.128	0.014	9.435
95-percentile	355	3930.5	6.806	93.60075	334.7594	449.56	0.0075	15.87665	0.09	2416.32	0.003	172.92	3.7991	10.282	0.29995	0	0	0.62275

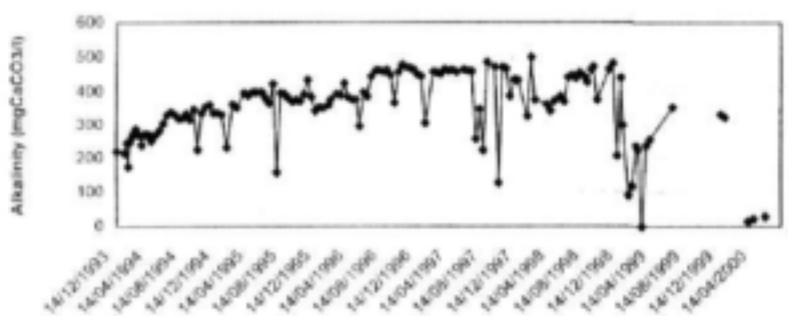
Cell 3

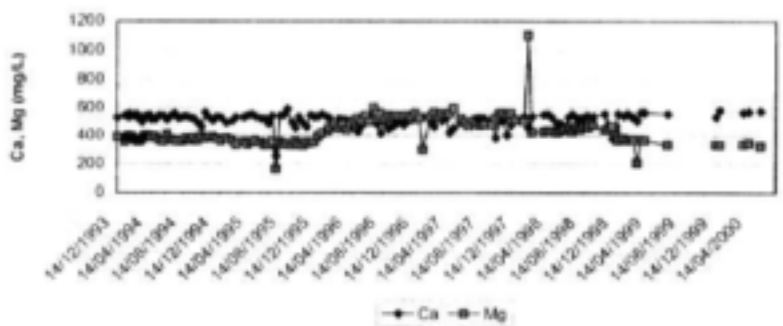

EC (mS/m)


pH


TDS, SO4, (mg/L)
TDS
SO4


Al, Fe, Mn (mg/L)
Al
Fe
Mn


Alkalinity (mgCaCO3/l)


Ca, Mg (mg/L)
Ca
Mg

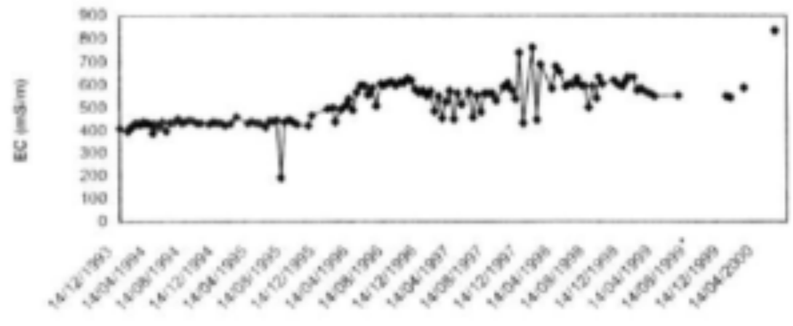
Cell 4

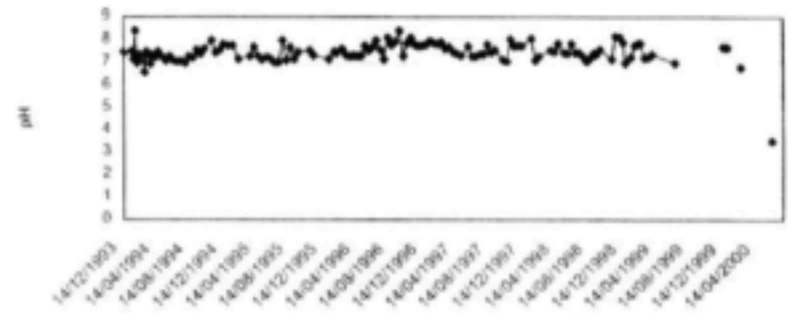
Date	EC	TDS	pH	Na	Mg	Ca	Fl	Cl	NO3	SO4	PO4	ALK	Si	K	NH4	Al	Fe	Mn
14/12/1993	412	4099	7.45	72.5	411	524	0.21	39.5	0.02	2779.9	0.006	215.9	4.29	8.43	0.361	0.47	0.053	13.715
10/01/1994	397	4154	7.52	80.5	421.2	540	0.28	35.3	0.024	2797	0.011	221.5	4	9.35	0.28	0.134	0.001	16.51
18/01/1994	416	4266	7.18	80.9	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
24/01/1994	415	4086	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
31/01/1994	421	4202	7	85.4	425.7	553.1	0.17	50.4	0.026	2761.7	0.015	251.1	3.88	9.82	0.317	0	0.02	14.79
07/02/1994	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
14/02/1994	437	4337	7.19	86	427.3	540.6	0.27	57.4	0.021	2886.8	0.006	267.5	4.41	9.84	0.326	0.311	0.027	13.86
21/02/1994	429	4403	7.19	87.1	437.4	552.8	0.26	63.4	0.014	2993.5	0.008	284.3	3.68	11.18	0.329	0.156	0	16.22
28/02/1994	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	0.175	0.003	15.22
07/03/1994	441	4367	7.52	106.4	446.9	533.3	0.46	70.2	0.012	2895.8	0.032	266.9	4.47	14.45	0.42	0.331	0.026	18.91
14/03/1994	433	4176	7.37	111.7	420.6	508.1	0.26	78.2	0.026	2749.3	0.007	242.7	3.05	13.58	0.31	0.132	0.037	19.36
21/03/1994	439	4368	6.97	99.5	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
28/03/1994	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
05/04/1994	429	4455	7.29	106.4	437.7	540.7	0.27	61.2	0.022	2970.5	0.007	273.9	4.37	13.6	0.635	0.279	5.28	21.55
11/04/1994	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
18/04/1994	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
02/05/1994	416	4373	7.3	106	435.4	510.9	0.46	71.3	0.031	2875.3	0.016	293.8	4.33	13.92	0.647	0.082	0.014	17.52
16/05/1994	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	0.129	0.023	16.11
30/05/1994	400	4526	7.3	108	453.2	532.8	0.62	75.7	0.083	3039.1	0.012	321.1	4.33	14.32	0.667	0.098	0.181	15.48
13/06/1994	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
27/06/1994	437	4414	7.07	109	436.7	533.6	0.42	88.5	0.035	2810.5	0.008	345.9	3.67	13.67	0.76	0.131	0.03	16.31
11/07/1994	456	4492	7.09	115.8	442.2	526.9	0.42	89.6	0.019	2886.9	0.01	338.8	4.03	15.33	0.834	0.145	0.033	15.91
25/07/1994	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
08/08/1994	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
22/08/1994	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
05/09/1994	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
19/09/1994	435	4333	7.4	100	434.5	510.4	0.33	97.1	0.022	2741.7	0.008	347.8	3.09	14.7	0.793	0.154	0	16.69
03/10/1994	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	0.898	0.16	0.015	16.3
31/10/1994	431	4235	8	117.5	416.1	509	0.35	94.5	0.238	2579.3	0.009	332.1	3.03	11.28	0.733	0.106	0.017	16.199
14/11/1994	440	4407	7.45	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	14.855
28/11/1994	438	4298	7.56	111.1	429.8	527.3	0.25	108.8	0.818	2703	0.003	325.6	2.54	17	0.293	0.155	0	12.23
12/12/1994	435	4230	7.83	113.3	410.7	516.9	0.3	6.4	0.952	2748	0.007	340.2	2.74	15.10	0.221	0.14	0.026	12.703
28/12/1994	425	4196	7.77	114.2	413.1	504.4	0.27	225.4	0.906	2542.3	0.008	308.6	2.91	15.75	0.173	0	0	0.493
16/01/1995	433	4143	7.78	90.5	421.8	500.6	0.28	32	0.979	2674.5	0.006	329.9	2.74	16.26	0.1	0.112	0	11.635
06/02/1995	493	4471	7.18	127.5	445.1	531.1	0.31	111	0.005	2801.6	0.002	277	4.41	25.37	1.064	0.065	0.016	13.580
20/03/1995	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
03/04/1995	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	0.285
19/04/1995	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
02/05/1995	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
22/05/1995	416	4008	7.25	126.1	374.9	436.2	0.3	111.4	2.016	2477.2	0.003	372.7	3.51	17.05	0.229	0.217	0.016	0.032
06/06/1995	445	4155	7.15	139.7	385.2	475	0.35	190.5	2.252	2591.1	0.016	356.2	3.61	18.03	0.257	0.089	0.03	0.02
19/06/1995	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
03/07/1995	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	0.67	0
17/07/1995	191	1531	7.99	67.3	133.5	171.5	0.25	50.6	0.877	915.2	0.006	149.3	3.18	6.52	0.086	0.075	0	0
31/07/1995	430	4230	7.14	125.9	374.7	524.8	0.38	106.3	2.32	2686	0.018	337.2	3.58	17.67	0.121	0.015	0	0
14/08/1995	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
28/08/1995	442	4099	7.18	120.2	392.2	490.4	0.35	106.3	2.681	2548.3	0.007	312.4	3.69	18.25	0.401	0.151	0.027	0.01
13/09/1995	420	3914	7.49	111.1	383.5	487.2	0.28	95.4	2.257	2430.8	0.011	327.5	3.88	16.24	0.145	0.147	0.044	0.007
24/10/1995	423	3985	7.55	116	390.5	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
06/11/1995	458	4544	7.35	184.2	443.8	535.8	0.10	152.7	2.505	2814.3	0.01	389.3	3.96	27.25	0.192	0.057	0	17.382
02/01/1996	498	4458	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
22/01/1996	504	4582	7.5	176.4	414.6	539.2	0.2	70.5	0.007	2953	0.009	331.7	5.11	30.36	1.606	0.139	0.037	10.54
29/01/1996	440	4601	7.45	171.9	422.9	527	0.24	45.9	0.060	3005.2	0.01	334.8	4.78	18.45	0.887	0.181	0.634	9.85
10/02/1996	495	5187	7.62	175.4	451.9	473.7	0.23	32.9	0.115	3572.3	0.01	367.1	4.59	31.47	0.683	0	1.194	8.54
05/03/1996	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
18/03/1996	542	5964	7.31	237.8	633.5	507.6	0.22	38.2	0.056	4005.7	0.017	415.3	4.72	33.09	0.649	0.11	0	7.08
01/04/1996	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
15/04/1996	569	5855	7.32	249	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
30/04/1996	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	6.66	9.07
13/05/1996	599	5889	7.76	217.9	720.2	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
27/05/1996	558	6092	7.56	219.7	733.4	459.3	0.41	29.8	0.025	4078.8	0.005	442	4.49	30.3	0.859	0.289	0.285	9.12
10/06/1996	589	6282	7.71	220.2	722.4	510.2	0.24	37.1	0.025	4280.8	0.01	386.1	4.63	30.5	0.826	0.111	0	2.544
24/06/1996	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
10/07/1996	606	6522	7.58	210.4	789.2	516.3	0.2	41.5	0.029	4387.9	0.016	446.3	4.04	31.48	0.876	0.12	0	10.43
22/07/1996	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	10.983

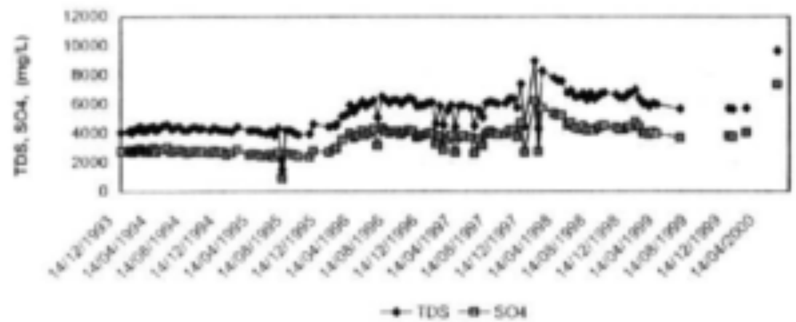
05/08/1996	619	5520	8.12	225.3	814.9	385	0.2	44.2	0.016	4054.3	0.006	454	4.85	29.56	0.791	0.07	0	10.23
19/08/1996	615	5504	7.81	234.1	780.5	478.5	0.17	47.6	0.017	4142	0.016	482.5	4.85	31.4	0.741	0	0	9.442
02/09/1996	600	5303	7.94	237.5	735.0	490.7	0.18	50.7	0.041	4173.3	0.011	474	4.58	31.03	0.793	0	0	10.56
16/09/1996	613	5046	8.42	223.7	797.2	437.7	0.16	45.3	0.028	3948.1	0.006	472.2	4.79	18.62	0.843	0.217	0.046	10.071
30/09/1996	612	6295	7.32	243	804.2	480.1	0.19	45	0.003	4127.4	0.018	459.1	4.62	19.09	0.918	0.177	0.049	9.98
14/10/1996	630	6434	7.86	233.4	805.0	493.9	0.19	42.7	0.025	4237.5	0.003	488.8	4.57	19.04	0.327	0.087	0	8.562
28/10/1996	622	6346	8.11	251.3	824.8	467.6	0.13	43.2	0.008	4166.5	0.065	470.3	4.74	18.29	0.606	0.102	0	6.626
12/11/1996	582	5801	7.82	235.9	731.4	500	0.13	52.4	0.013	3761	0.005	484.1	4.81	18.39	0.945	0.238	0	11.753
25/11/1996	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
09/12/1996	578	5945	7.77	225.2	698.8	403.3	0.13	40.7	0.015	3919.3	0.013	456.7	5.57	19.22	1.04	0.306	0	7.718
23/12/1996	555	6102	7.82	245.4	732.1	487.7	0.12	47	0.028	4095.2	0.006	450.2	4.57	20.5	1.954	0.055	0.004	3.146
06/01/1997	575	5146	7.98	227.6	721.6	502.7	0.13	42.7	0.019	4052.2	0.007	472.2	5.34	21.31	1.962	0.422	0.021	6.095
20/01/1997	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
04/02/1997	552	5891	7.84	229.2	691.9	494.3	0.13	44.5	0.033	3827.5	0.005	483.2	4.77	21.01	1.651	0	0	0.804
17/02/1997	456	4587	7.92	109.3	387.2	551.1	0.15	69.7	0.049	2845.1	0.005	424	4.19	16.38	2.826	0	0	0.098
03/03/1997	529	5584	7.64	231.2	581.2	511.1	0.18	36	0.043	3618.9	0.006	461.9	5.09	18.21	1.296	0.536	0.032	2.414
17/03/1997	576	5951	7.7	205.1	725.3	498.5	0.21	39.2	0.034	3888.9	0.009	469	5.66	20.07	1.318	0	0	5.94
01/04/1997	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
14/04/1997	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
29/04/1997	517	5836	7.34	231.1	206.6	464.4	0.18	38.8	0.048	3882.7	0.013	484	4.94	20.55	1.339	0.172	0	2.88
26/05/1997	574	6270	7.73	217.4	890.2	479.2	0.17	37.1	0.025	3740.3	0.008	485.6	4.85	20.38	1.32	0.112	0	1.875
09/06/1997	490	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
23/06/1997	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
08/07/1997	484	5118	7.38	228.3	518	508.4	0.2	33.9	0.046	3194.4	0.008	511.3	5.11	16.28	1.021	0.032	0	0.284
21/07/1997	586	6083	7.39	219.8	734.4	509.4	0.14	26.9	0.035	3582.8	0.005	483.2	4.8	19.06	1.084	0.083	0	2.672
04/08/1997	565	6299	7.82	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
18/08/1997	566	6147	7.48	229.3	714.9	500.1	0.16	37.7	0.036	4039.3	0.007	496.4	4.64	18.39	1.223	0.109	0	5.69
01/09/1997	535	6045	7.57	227.9	721.4	504.2	0.17	35.5	0.053	3934.5	0.004	492.7	4.64	19.06	1.133	0.152	0	0.329
25/09/1997	504	6087	7.15	239	287	448.1	0.16	35.1	0.026	3962.3	0.006	504.1	4.92	19.48	1.184	0	0	3.429
13/10/1997	690	6366	7.08	212.6	739.3	493	0.21	30.7	0.015	4237	0.017	501.2	5.4	20.98	1.075	0	0	6.98
27/10/1997	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
10/11/1997	541	5778	7.75	217	689.1	462.5	0.04	47.7	0.085	3776.1	0.008	463.8	4.67	18.27	0.933	0	0	4.197
24/11/1997	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	1.086
08/12/1997	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	0.935	0	0	0.091
12/01/1998	795	8691	8.08	273.6	1286.2	490.7	0.1	30.9	0.489	6206.7	0.008	506.5	4.52	22.53	0.738	0	0.055	10.48
26/01/1998	446	4369	7.12	131.7	421.7	540.9	0.29	15.6	0.043	2776.5	0.011	379.2	5.46	18.35	0.924	0	0	8.47
09/02/1998	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
23/03/1998	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	8.97
06/04/1998	683	7844	7.51	251.3	1002.9	494.5	0.14	27.7	0.938	5228	0.006	481.1	4.9	20.72	1.182	0	0.045	9.9
20/04/1998	661	7609	7.86	235.6	908.1	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
11/05/1998	594	6801	7.46	221.2	871.0	487.3	0.01	32.8	0.03	4590.5	0.013	488	4.95	20.19	1.174	0	0	11.93
25/05/1998	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
08/06/1998	604	6519	7.84	221.1	835.4	478.1	0.02	31	0.025	4379.3	0.007	452.7	4.90	17.69	1.163	0.293	0.016	3.55
22/06/1998	632	6574	7.46	226.4	854.7	487.2	0.05	28.1	0.013	4339.8	0.01	506.7	5.2	16.9	1.113	0.258	0.015	11.23
06/07/1998	601	6767	7.46	223.6	831.9	513.1	0.01	34.1	0.021	4515.9	0.016	515.4	5.15	18.06	1.134	0.114	0.024	3.231
20/07/1998	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
03/08/1998	503	6778	7.08	233.1	829	498.5	0.01	284.7	0.027	4285.7	0.056	515.2	5.52	18.01	1.102	0.114	0.017	0.759
17/08/1998	596	6393	7.24	218.4	785.2	482.9	0.03	38.2	0.034	4212.2	0.011	512.1	5.07	18.02	1.107	0.129	0.019	6.92
31/08/1998	544	6632	7.45	223	794.3	529.2	<0.1	32.3	<0.04	4387.2	0.013	529.3	6.37	18.95	1.259	<0.02	<0.003	5.46
07/09/1998	637	6735	7.39	221.2	831.5	529.1	<0.1	15	<0.04	4486.2	0.007	525.5	6.13	17.49	1.003	<0.02	<0.003	6.63
21/09/1998	606	6823	7.59	224.5	837.4	543	<0.1	29	<0.04	4535	0.009	520.1	6.5	18.01	1.221	<0.02	<0.003	4.705
02/11/1998	622	6689	7.18	227.8	853.3	512.9	0.16	42.7	0.064	4417.2	0.008	504.1	4.74	18.36	1.174	<0.02	<0.003	6.34
16/11/1998	604	6493	8.18	222.4	836.4	462.4	0.19	43.6	0.375	4289.4	0.008	497.1	4.78	17.58	0.623	<0.02	<0.003	0.096
03/12/1998	595	6488	8.15	225.8	812.1	454.1	0.11	42.4	0.504	4326	0.01	497	4.7	18.59	0.51	<0.02	<0.003	<0.001
14/12/1998	619	6731	7.9	223.9	863	512.4	0.12	42	0.463	4451.1	0.015	507.6	4.47	18.32	0.64	<0.02	<0.003	2.386
21/12/1998	637	6759	7	223.1	898.2	452.9	0.11	40.7	<0.04	4481.9	0.008	526	4.92	18.98	1.387	<0.02	0.053	8.57
11/01/1999	636	7027	7.26	214.9	878.6	503.2	0.26	38.2	<0.04	4789	0.007	476.5	5.14	20.18	1.452	<0.02	0.019	10.3
25/01/1999	578	6410	7.77	108.5	781.1	493.1	<0.1	44.1	<0.04	4478.3	0.009	322.1	5.18	20.38	1.37	<0.02	<0.003	12.09
08/02/1999	588	6058	7.86	188.3	734.9	491.8	0.22	37.3	<0.04	4050.9	0.011	435.9	4.84	19.48	1.36	<0.02	0.115	11.7
15/02/1999	579	6081	7.86	188.6	736.8	500.7	0.15	44.3	<0.04	4057.5	0.016	435.5	5.16	19.44	1.533	<0.02	0.057	7.12
01/03/1999	570	5861	7.24	184.7	708.6	497.2	0.21	46.7	<0.04	3944.8	0.014	375.1	5.51	19.25	1.375	<0.02	0.328	11.39
15/03/1999	562	6115	7.25	202	727.1	561.3	0.13	25.1	<0.04	4113.5	0.012	381.7	5.96	18.58	1.455	<0.02	0.161	12.07
29/03/1999	553	5989	7.38	195.2	723.8	557.3	0.17	24.4	<0.04	4002.7	0.009	381.1	6.14	18.42	1.421	<0.02	0.044	10.84
21/06/1999	555	5680	7	199.4	661.1	522	0.13	37.7	1.102	3716.7	0.007	434.1	5.44	17.83	0.094	<0.02	0.042	3.47
15/11/1999																<0.035	<0.005	0.001
13/12/1999																<0.035	<0.005	0.001
13/12/1999	553	5720.632	7.71	190.914	671.161	503.786	<0.1	37.58	1.515	3823.106	0.013	376.080	5.088	20.815	<0.04			
28/12/1999																<0.035	<0.005	0.001

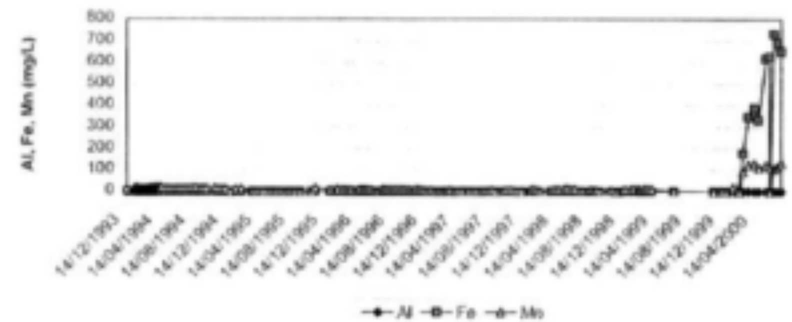
28/12/1999	547	5661.613	7.685	192.069	678.139	499.378	0.298	39.519	1.576	3775.414	0.025	367.534	4.79	20.558	0.052			
24/01/2000																<0.035	0.543	18.75
14/02/2000																<0.035	0.12	21.42
14/02/2000	588	5735.578	6.813	197.725	722.237	441.323	0.276	37.248	<0.04	4081.81	0.023	180.221	4.432	20.841	1.577			
28/02/2000																0.705	177.74	92.3
20/03/2000																0.872	348	125.5
10/04/2000																0.662	388	129.75
25/04/2000																<0.035	333.4	110.5
22/05/2000																1.164	619	122.2
05/06/2000																<0.059	628.8	113.655
05/06/2000	837	9668.693	3.523	273.989	1351.56	595.587	<0.1	24.742	<0.04	7374.704	0.021	13.184	5.731	30.829	0.78			
20/06/2000																0.259	733.02	106.2
03/07/2000																0.187	632.26	117.6
17/07/2000																0.134	652.2	129.6
Min	191	1531	3.523	67.3	133.5	171.5	0	6.4	0.003	915.2	0.001	13.184	2.54	6.52	0.052	0	0	0
Max	837	9668.693	8.42	369.1	1351.56	595.587	0.62	284.7	3.160	7374.704	0.065	570.9	9.07	33.06	1.861	1.164	733.02	129.75
Mean	520.4135	5423.162	7.454565	180.2323	616.7225	501.8012	0.221921	50.38769	0.378006	3561.1	0.011	395.7265	4.519333	18.99476	0.817447	0.050392	34.78433	15.28228
Median	529	5661.613	7.45	199.4	656.2	504.4	0.21	43.6	0.0335	3728.5	0.009	387.4	4.59	18.27	0.8505	0.134	0.0165	9.441
95-percentile	416	4093.5	7	84.84	384.96	448.64	0.013	27.32	0.00995	2545.6	0.003	243.06	3.022	9.832	0.1342	0	0	0.0013

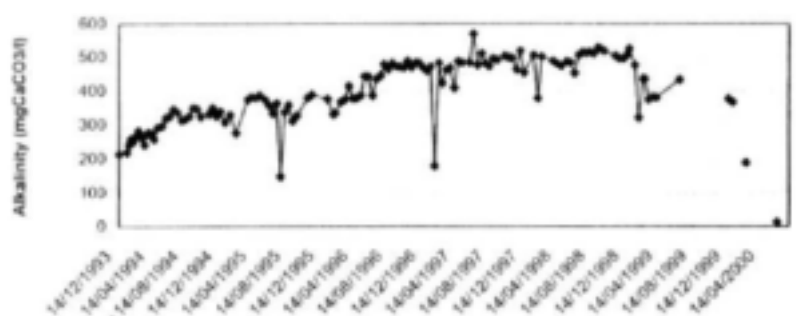
Cell 4

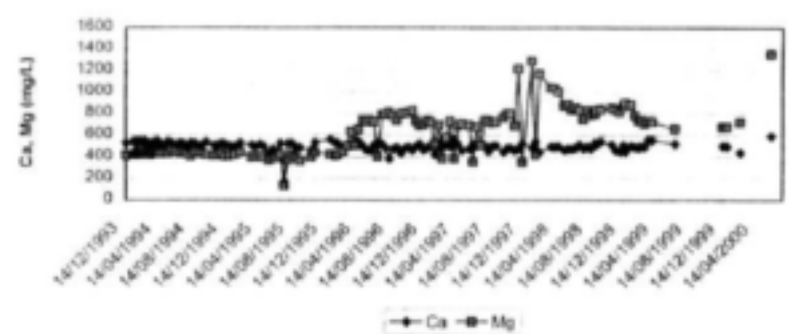

EC (mS/m)


pH


TDS, SO4, (mg/L)
TDS
SO4


Al, Fe, Mn (mg/L)
Al
Fe
Mn


Alkalinity (mgCaCO3/l)


Ca, Mg (mg/L)
Ca
Mg

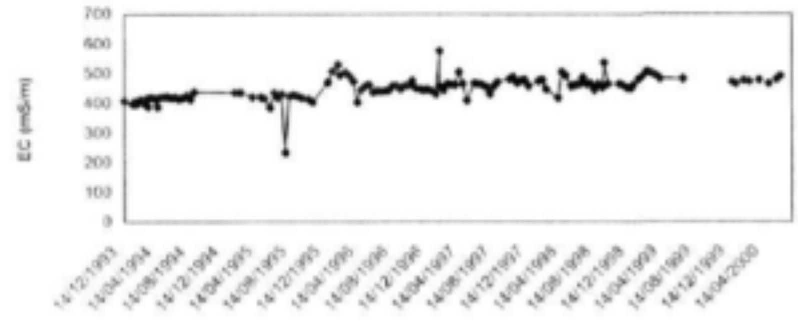
Cell 5

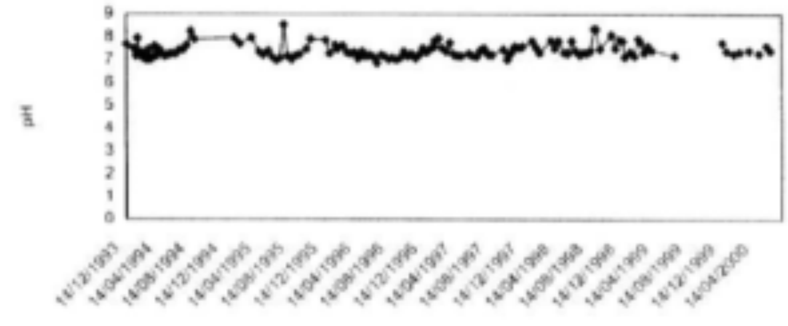
Date	EC	TDS	pH	Na	Mg	Ca	Fl	Cl	NO3	SO4	PO4	ALK	Si	K	NH4	Al	Fe	Mn
14/12/1993	409	4037	7.7	69.6	393	538	0.21	45	0.017	2716.6	0.007	218	4.44	7.7	0.439	0.42	0.05	14.975
10/01/1994	399	4007	7.54	69.7	398.8	547.6	0.28	54.9	0.015	2674.3	0.012	231.8	4.44	8.36	0.476	0.114	0.006	16.37
18/01/1994	407	4114	7.21	81	388.5	554.2	0.29	45.3	0.018	2714.1	0.003	253.3	4.48	9	0.645	0.366	0.026	23.71
24/01/1994	399	4106	7.97	85	400.7	549.8	0.3	33.4	0.02	2740.8	0.012	234.3	4.12	9.07	0.677	0.023	0	23.47
31/01/1994	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
07/02/1994	413	4072	7.36	83.6	387.3	535.4	0.3	55.9	0.02	2557.5	0.005	271.3	4.45	9.52	0.806	0.397	0.018	20.3
14/02/1994	411	4114	7.1	83.3	393	535.1	0.28	101.9	0.014	2840.1	0.011	285.5	4.57	9.72	0.937	0.369	0.042	22.16
21/02/1994	401	4100	7.18	84.7	377.8	521	0.28	64.8	0.034	2691.4	0.01	281.5	3.74	8.98	0.957	0.173	0	24.75
28/02/1994	414	4551	7.03	111.5	479.7	528.1	0.27	73.8	0.009	3155.1	0.009	264	3.42	10.45	0.472	0.108	0.011	36.27
07/03/1994	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
14/03/1994	421	4016	7.07	101.4	389.5	509.1	0.28	72.6	0.022	2619.5	0.007	254.1	3.61	13.9	0.823	0.258	0.018	23.16
21/03/1994	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
28/03/1994	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
05/04/1994	415	4271	7.24	100.4	403	540.5	0.28	61.3	0.023	2782.4	0.007	294.7	4.32	12.45	1.361	0.369	2.447	24.32
11/04/1994	389	4325	7.5	93.2	404.8	554.5	0.27	65.1	0.025	2824.3	0.007	302.9	4.57	12.95	1.37	0.159	1.579	23.47
18/04/1994	421	4053	7.44	95.5	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
02/05/1994	423	4048	7.21	92	385	546.3	0.28	67.7	0.022	2583	0.009	310	4.51	14.04	1.39	0.097	2.824	21.13
16/05/1994	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
30/05/1994	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	0.065	0	23.04
13/06/1994	422	4104	7.29	89.8	428.3	498.3	0.34	93.2	0.045	2540.5	0.01	351.1	4.82	13.62	1.383	0.126	17.8	23.87
27/06/1994	416	4115	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
11/07/1994	420	4156	7.47	89.3	385.5	538.1	0.4	87.2	0.025	2547.9	0.01	336.9	4.78	14.71	1.378	0.154	0.042	18.73
25/07/1994	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
08/08/1994	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	0.184	0.035	11.95
22/08/1994	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	0.385	0.111	11.86
15/01/1995	437	4362	7.98	96.4	431.7	525	0.26	115.1	1.148	2763.4	0.008	295.6	2.55	16.97	0.123	0.154	0	5.986
06/02/1995	435	4229	7.73	140.2	391.3	510.5	0.29	108.6	1.188	2576.1	0.005	390	4.9	17	1.441	0.064	0.017	24.86
20/03/1995	422	4032	8	152.3	353	505.9	0.34	108.1	0.022	2391	0.01	410	5.1	16.09	4.385	0.175	0.258	25.44
19/04/1995	422	3866	7.38	151.7	330.3	482.6	0.32	97.4	0.028	2314.6	0.01	382.8	5.21	16.07	4.399	0	0	14.81
02/05/1995	418	4080	7.24	152	381.9	510	0.27	90.5	0.044	2457.9	0.007	390	5.38	15.23	4.795	0.15	0.174	20.784
22/05/1995	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
06/06/1995	436	4053	7.13	175.6	337.2	471.1	0.31	95.2	0.024	2456.1	0.013	395.8	5.12	16.55	4.944	0.087	0.026	21.16
19/06/1995	419	3924	7.01	152.3	342.6	479.6	0.23	84.2	0.005	2374.6	0.008	384.1	4.72	16.06	4.519	0.171	0.04	21.701
03/07/1995	433	3909	7.11	167.3	358.9	458.3	0.34	120.6	0.902	2250.6	0.014	420	5.39	13.25	3.226	0.012	0.083	10.842
17/07/1995	235	1939	8.54	99	166.2	224.2	0.27	55.6	0.855	1197.1	0.008	149.1	3.76	7.38	2.571	0.051	0	2.481
31/07/1995	424	4064	7.19	162.5	341.9	511.5	0.28	126.8	1.144	2418.3	0.013	392	5.59	16.10	2.87	0	0	13.798
14/08/1995	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
28/08/1995	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
13/09/1995	420	3755	7.26	150.8	218.5	494.5	0.26	85.4	1.095	2245.8	0.01	353	5.28	15.47	0.429	0.141	0.04	23.701
09/10/1995	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
24/10/1995	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	0.458	0.095	0	18.667
18/12/1995	473	4256	7.89	256.9	344.1	495.9	0.18	58.2	3.335	2687.3	0.007	316.6	4.97	18.75	1.967	0.098	0	4.156
02/01/1996	510	4536	7.31	213	402.3	569.1	0.19	123.6	0	3038.5	0.017	329	5.39	29.38	1.846	0.11	0	4.882
22/01/1996	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
29/01/1996	495	5086	7.49	364.7	406.5	546.8	0.27	99	11.447	3127.8	0.014	386.1	5	18.1	0.888	0.146	0.072	6.69
19/02/1996	505	4770	7.65	276.1	376.3	526	0.25	49.4	1.263	3072.3	0.005	357.9	4.51	28.9	0.458	0	2.918	6.66
05/03/1996	491	4942	7.35	337.2	376.5	531.5	0.24	53.5	0.055	3276	0.006	278.5	4.91	26.22	0.48	0.1	0	5.47
18/03/1996	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
01/04/1996	405	4820	7.36	299.4	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	7.99
15/04/1996	447	4478	7.08	241.1	391	493.8	0.24	63.2	0.017	2841.5	0.005	351.2	4.49	18.04	0.704	0	0	0.901
30/04/1996	460	4452	7.4	194	390.7	624.1	0.24	47.7	0.011	2828.1	0.003	360.4	5	27.61	0.677	0.024	0.09	7.64
13/05/1996	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
27/05/1996	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	0.019	0.96	8.02
10/06/1996	444	4357	7.17	175.2	371.9	508.5	0.25	17.3	0.017	2823.6	0.006	383.5	5.05	18.33	0.775	0.071	0	2.55
24/06/1996	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
10/07/1996	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
22/07/1996	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
05/08/1996	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	0.778	0.262	0	7.75
19/08/1996	462	4450	7.11	205.7	388.8	522.8	0.22	53.2	0.019	2734.6	0.008	431.3	5.41	27.38	0.722	0.11	0	12.578
02/09/1996	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
16/09/1996	460	4334	7.11	192	397	501.3	0.18	52.7	0.019	2854.8	0.008	428.2	5.39	12.83	0.892	0.159	0.036	6.837
30/09/1996	483	4482	7.39	219.2	399.2	524	0.22	53.9	0.032	2749.8	0.015	427.5	5.22	12.95	0.971	0.118	0.073	7.79
14/10/1996	476	4515	7.19	214.9	401.9	536.2	0.21	41.2	0.03	2865.7	0.004	442.4	5.07	13.4	1.079	0.054	0	3.572
28/10/1996	452	4430	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
12/11/1996	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

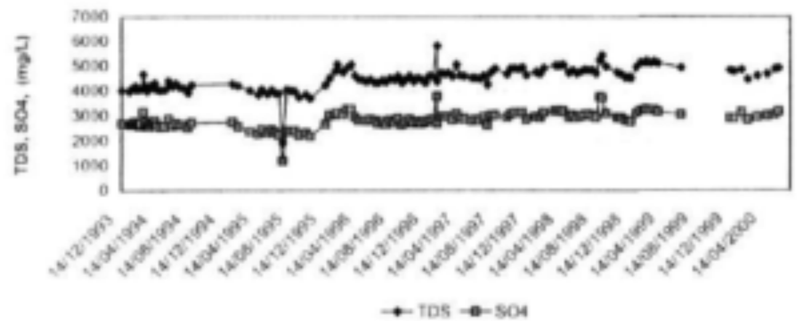
25/11/1996	447	4470	7.25	176.7	402.7	552.9	0.19	52.3	0.02	2725.9	0.011	445.5	5.35	13.16	1.073	0.36	0	7.06
09/12/1996	449	4343	7.53	183.9	369	495.7	0.15	45.7	0.014	2760.8	0.012	384	6.15	15.9	1.11	0.349	0	2.32
23/12/1996	444	4611	7.35	223.1	413.1	536.7	0.14	49.4	0.02	2842.3	0.007	434.3	5.6	14.90	1.088	0	0	5.729
06/01/1997	433	4582	7.52	194.6	410	540.4	0.15	50.2	0.023	2864.5	0.007	425.8	5.66	14.89	1.107	0.434	0.017	1.951
20/01/1997	579	5823	7.66	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
20/01/1997	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	1.508	0	0	0.836
04/02/1997	445	4745	7.08	189.5	427.8	540.2	0.15	49.3	0.028	2987.7	0.008	437.1	4.98	15.54	1.506	0	0	0.204
17/02/1997	458	4700	7.54	174.3	444.8	498.2	0.17	53.6	0.041	2980.6	0.008	435	5.67	15.13	1.589	0	0	3.712
03/03/1997	465	4734	7.41	196.2	419.5	544.6	0.2	53	0.03	2979.1	0.006	429.8	5.25	15.17	1.331	0.587	0.065	5.86
17/03/1997	464	4598	7.77	173.1	430.6	537.2	0.2	53.9	0.005	2865.5	0.009	430.2	6.31	15	1.313	0	0	1.488
01/04/1997	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
14/04/1997	458	4534	7.21	202.2	440.8	455.9	0.19	57.8	0.034	2917.6	0.012	444.5	5.52	15.83	1.367	0.18	0	0.962
29/04/1997	411	4617	7.19	195.4	459.2	450	0.19	48.6	0.036	2894.9	0.013	443.5	5.55	15.78	1.355	0.18	0	3.527
26/05/1997	460	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
09/06/1997	462	4547	7.21	195.1	439.6	509.6	0.17	39.5	0.046	2859	0.004	399.5	5.39	14.86	1.121	0.071	0	6.8
23/06/1997	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
08/07/1997	457	4620	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
21/07/1997	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
04/08/1997	450	4783	7.28	208.2	430.9	522.1	0.10	32.6	0.056	3028	0.004	445.7	5.53	14.61	1.202	0.052	0	7.84
18/08/1997	474	4911	7.25	348.1	393.5	526.8	0.16	45.4	0.045	3034.8	0.004	445.3	4.62	16.73	0.974	0.095	0	0.77
29/09/1997	483	4583	7.48	203.7	474.6	424.6	0.18	39.8	0.053	2955.6	0.007	465.5	5.08	15.15	1.275	0	0	0.793
13/10/1997	490	4902	7.03	210.3	485.8	512.8	0.22	35.6	0.038	3078.1	0.014	469.4	5.24	16.14	1.15	0	0	5.15
27/10/1997	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
10/11/1997	476	4897	7.6	205.3	471.9	467.5	0.01	43.6	0.062	3131.5	0.005	459.9	5.27	16.03	1.232	0	0	3.595
24/11/1997	480	4961	7.56	202.3	472.7	528.5	0.03	48.3	0.026	3139.9	0.009	452.4	5.26	15.59	1.194	0	0	0.633
08/12/1997	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
12/01/1998	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
26/01/1998	481	4714	7.57	200.2	445.2	515.7	0.15	31.5	0.047	2938.8	0.014	461.9	5.1	16.12	1.121	0	0	0
09/02/1998	450	4913	7.34	205.9	458.5	518.3	0.16	22.5	0.051	3142.7	0.008	457.8	5.06	15.14	1.08	0	0	0.541
23/03/1998	420	5032	7.87	209.1	507.7	533	0.09	18.8	0.066	3199.9	0.005	445.4	5.43	17.46	1.303	0	0.037	0.309
06/04/1998	508	5139	7.53	202	495	504.5	0.03	28.3	0.042	3221.9	0.01	487	5.4	15.93	1.386	0	0.038	3.344
20/04/1998	496	5061	7.66	226	490.4	538	0.17	38.4	0.05	3194.1	0.014	459.4	4.88	13.42	1.176	0	0.045	8.1
11/05/1998	460	4739	7.33	213.4	451.8	495.8	0.07	34.8	0.042	2941.4	0.014	473	5.38	16.38	1.219	0	0	7.83
25/05/1998	464	4837	7.32	213.8	467.2	504	0.06	34	0.033	3030.5	0.008	457.4	5.34	16.1	1.194	0.35	0	8.81
08/06/1998	495	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
22/06/1998	480	4795	7.43	222.8	444.6	524.4	0.1	32.6	0.013	2984.4	0.008	457.2	5.72	15.13	1.114	0.248	0.021	7.11
06/07/1998	487	4871	7.25	217.3	432	556.1	0.08	35.4	0.021	3043.5	0.055	495.6	5.86	17.24	1.176	0.084	0.01	2.113
20/07/1998	469	4852	7.34	207.1	427.9	527.8	0.07	33.7	0.03	3067.4	0.023	471	5.86	15.15	1.176	0.083	0.007	4.791
03/08/1998	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
17/08/1998	467	4723	7.43	219.9	422.3	505.0	0.06	43.8	0.027	2939.4	0.015	472.2	5.77	14.56	1.144	0.105	0.007	0.555
31/08/1998	456	5260	8.38	275.9	566.3	463.7	<0.1	35.7	1.078	3764.2	0.073	90.6	6.35	18.55	<0.04	<0.02	<0.003	1.646
07/09/1998	539	5447	8.38	270.3	570	534.7	0.1	44.4	0.839	3733.6	0.098	223.4	6.32	17.69	<0.04	<0.02	<0.003	1.465
21/09/1998	458	5000	7.51	208.4	462.4	582.8	<0.1	39.4	<0.04	3103.3	0.01	482.3	7.36	14.39	1.123	<0.02	<0.003	6.39
02/11/1998	462	4754	8.12	210	432.2	543.7	<0.1	40.3	0.056	2946.4	0.017	455.4	4.91	13.71	0.223	<0.02	<0.003	4.705
16/11/1998	463	4607	7.53	206.4	441.5	480.4	0.16	36.5	<0.04	2934.2	0.006	478	5.37	14.46	0.061	<0.02	0.005	2.093
01/12/1998	453	4559	7.91	207.9	416.6	459.5	0.12	34.2	<0.04	2835.3	0.033	475.9	5.48	13.83	0.055	<0.02	<0.003	0.269
14/12/1998	453	4579	7.86	218.5	417	509.1	0.16	36.5	<0.04	2813.7	0.01	467.9	6.02	12.52	0.963	<0.02	0.009	0.321
21/12/1998	463	4538	7.15	200.6	410.4	512.1	<0.1	40.9	<0.04	2784.7	0.011	473	5.96	13.76	1.544	<0.02	<0.003	1.395
11/01/1999	484	4906	7.37	209.5	462.2	522.6	<0.1	42.3	<0.04	3129.6	0.008	433.5	5.78	15.6	1.698	<0.02	0.015	2.871
25/01/1999	493	5135	7.19	218.5	512.7	521.9	<0.1	44.4	0.071	3211.8	0.01	498.4	5.75	18.15	1.808	<0.02	<0.003	7.99
08/02/1999	500	5137	7.94	215.4	529.5	517.8	<0.1	38.3	<0.04	3215.3	0.012	492.5	5.35	18.14	1.728	<0.02	<0.003	4.542
15/02/1999	508	5106	7.82	216.5	537.6	520.8	0.11	49.3	<0.04	3253.3	0.006	490.7	5.72	18.51	1.908	<0.02	<0.003	2.861
01/03/1999	501	5128	7.34	214.6	517.4	514.3	0.19	44.2	<0.04	3212	0.006	469.6	5.68	18.44	1.899	<0.02	<0.003	6.83
15/03/1999	496	5179	7.63	223.4	503.5	556.5	0.12	31	<0.04	3246.1	0.014	489.2	6.51	17.05	1.834	<0.02	0.083	9.08
29/03/1999	494	5111	7.45	230.7	481	582.2	0.13	34.5	<0.04	3166.5	0.01	488.7	6.81	17.44	1.857	<0.02	0.004	7.85
21/06/1999	483	4931	7.19	237.3	449.7	524.2	0.11	46.9	0.46	3050.8	0.011	494	6.62	16.63	0.318	<0.02	0.019	7.18
15/11/1999																<0.035	<0.005	5.36
13/12/1999																<0.035	<0.005	5.04
13/12/1999	474	4825.701	7.778	237.341	433.395	553.381	0.302	41.172	0.562	2910.256	0.023	517.4	5.863	16.408	0.058			
28/12/1999																<0.035	<0.005	5.22
28/12/1999	467	4790.827	7.403	235.739	416.801	536.212	<0.1	52.75	0.321	2910.702	0.025	500.1	6.278	18.247	0.082			
24/01/2000																<0.035	<0.005	7.56
24/01/2000	479	4854.211	7.281	190.568	468.188	522.385	<0.1	29.274	<0.04	3142.216	<0.005	386.952	5.814	20.844	2.147			
14/02/2000																<0.035	<0.005	5.41
14/02/2000	475	4463.243	7.368	190.506	448.293	458.334	0.239	38.302	<0.04	2660.256	0.028	359.341	5.528	16.531	1.775			
28/02/2000																<0.035	0.353	5.69
20/03/2000																<0.035	0.19	1.65
20/03/2000	460	4609.151	7.434	201.036	418.752	543.615	<0.1	23.493	<0.04	2958.108	<0.005	383.744	5.589	17.728	1.458			

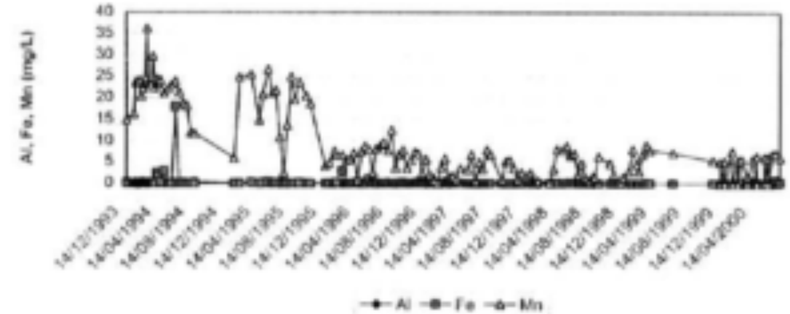
10/04/2000																<0.035	0.508	5.59
25/04/2000	468	4600.026	7.299	221.580	436.085	470.746	0.214	25.316	<0.04	3011.158	0.009	416.3	6.279	14.324	1.584			
25/04/2000																<0.035	0.211	6.47
22/05/2000																<0.059	0.012	5.24
22/05/2000	482	4880.440	7.632	232.081	381.798	533.311	0.177	28.91	<0.04	3043.87	0.025	377.585	5.886	197.922	1.43			
05/06/2000																<0.059	0.022	5.23
05/06/2000	410	4916.823	7.433	229.581	447.629	559.344	0.198	29.629	<0.04	3179.124	0.022	368.72	6.12	19.775	1.432			
20/06/2000																<0.059	0.31	5.97
03/07/2000																<0.059	0.765	7.04
17/07/2000																<0.059	0.321	5.04
Min	235	3039	6.88	60.6	166.2	224.2	0.01	17.3	0	1197.9	0	90.6	2.15	7.38	0.055	0	0	0
Max	570	5823	8.54	384.7	715.7	582.6	0.4	120.6	11.447	3765	0.073	517.4	7.36	197.922	4.944	0.610	17.9	38.27
Mean	451.7209	4522.864	7.449984	186.0000	418.1414	513.8218	0.210758	55.20833	0.349232	2853.753	0.012016	389.9414	5.12436	17.37247	1.296433	0.125962	0.282308	9.575680
Median	457	4547	7.37	196.508	412	521.6	0.21	47.7	0.033	2850.256	0.009	410	5.24	15.76	1.15	0.008	0.0055	6.77
95-percentile	401.6	3915	7.058	86.56	339.08	455.98	0.069	29.0556	0.006	2352.76	0.004	242.22	3.844	9.6	0.3256	0	0	0.5508

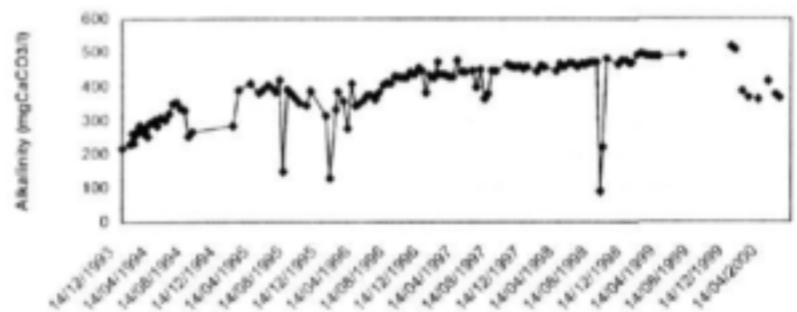
Cell 5

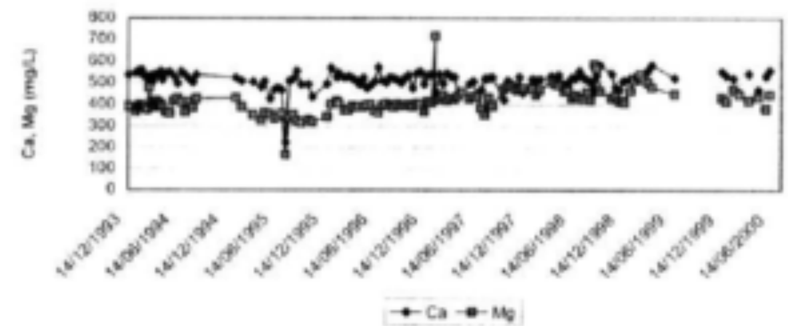

EC (mS/m)


pH


TDS, SO4, (mg/L)
TDS
SO4


Al, Fe, Mn (mg/L)
Al
Fe
Mn


Alkalinity (mgCaCO3/l)


Ca, Mg (mg/L)
Ca
Mg

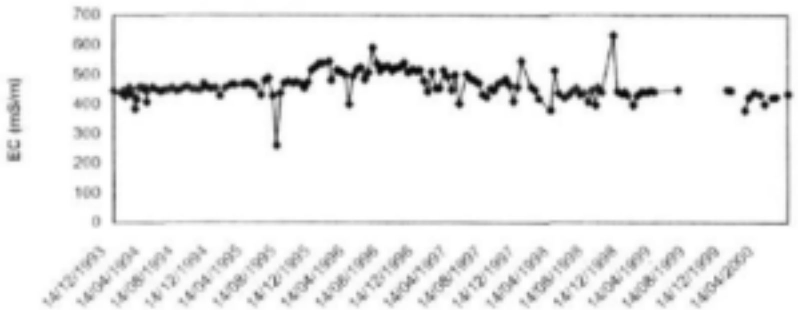
Cell 6

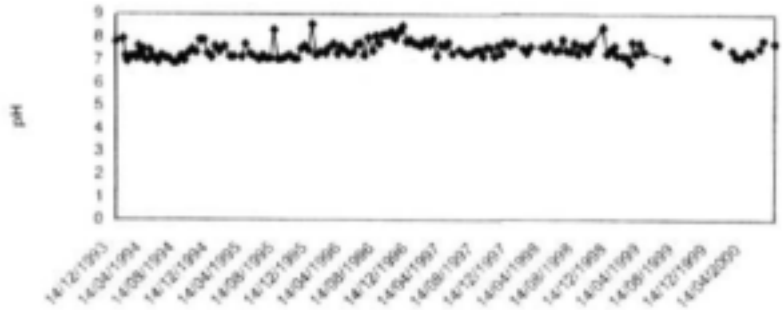
Date	EC	TDS	pH	Na	Mg	Ca	Fl	Cl	NO3	SO4	PO4	ALK	Si	K	NH4	Al	Fe	Mn
14/12/1993	448	4443	7.83	91	480	524	0.19	52.9	0.017	3019.2	0.008	218.5	4.25	8.83	0.453	0.59	0.068	19.115
10/01/1994	439	4440	7.05	93.7	483.6	529	0.23	61.1	0.013	3016.2	0.018	202.3	3.92	8.93	0.415	0.029	0	26.61
18/01/1994	450	4493	7.19	101.2	482	527.2	0.24	59.2	0.018	3023.4	0.004	237	3.92	10.29	0.458	0.226	0.007	31.78
24/01/1994	428	4498	6.97	98.6	482.3	537.3	0.28	38.9	0.021	3081.1	0.01	206.1	3.69	9.48	0.439	0.004	0	28.9
31/01/1994	439	4643	7.14	109.7	468.5	539.9	0.2	76.4	0.028	3154.1	0.014	237.2	3.81	9.87	0.445	0	0.019	31.24
07/02/1994	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	28.3
14/02/1994	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
21/02/1994	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	0.184	0.001	29.97
28/02/1994	386	4322	7.1	105.6	394.6	548.3	0.32	67	0.009	2844.1	0.012	291.8	3.57	10.03	0.023	0.112	0.02	29.92
07/03/1994	419	4602	7.04	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
14/03/1994	459	4336	7.38	106.4	480.8	402.4	0.26	80.2	0.021	2878	0.007	231.6	3.54	15.14	0.444	0.153	0	26.91
21/03/1994	452	4584	7.12	115.3	479.5	525	0.27	70.6	0.007	3061.1	0.022	266.1	4.03	15.58	0.813	0.131	0.006	21.04
28/03/1994	454	4541	7.5	126.4	481.7	520.9	0.29	82.6	0.019	2982.1	0.018	272	4.19	14.03	0.631	0.144	0.009	27.62
05/04/1994	458	4674	7.01	121.6	476.6	516	0.27	69.2	0.02	3147.5	0.007	260.5	3.97	13.07	0.898	0.124	0.665	27.74
11/04/1994	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	0.800	0.005	0.158	31.7
18/04/1994	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
02/05/1994	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
16/05/1994	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	28.74
30/05/1994	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	0.960	0.096	0	24.96
13/06/1994	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
27/06/1994	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
11/07/1994	458	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
25/07/1994	447	4485	6.92	121	476.9	489.8	0.34	103.3	0.090	2895.8	0.009	296.7	2.98	14.23	1.08	0.211	0.031	27.18
08/08/1994	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
22/08/1994	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
05/09/1994	463	4596	7.33	94.9	462.8	519	0.28	97.5	0.039	3008.7	0.007	298	2.96	16.13	1.118	0.433	0.041	28.71
19/09/1994	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
03/10/1994	453	4445	7.38	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
17/10/1994	449	4285	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
31/10/1994	474	4367	7.01	116.3	418.1	492.2	0.33	93	0.063	2849.9	0.007	315.3	2.89	10.52	1.108	0.13	0.027	27.617
14/11/1994	458	4540	7.31	109.3	450.2	476.4	0.3	113.4	0.022	2965.3	0.005	328.1	2.94	14.48	1.291	0.141	0.047	16.571
28/11/1994	455	4534	7.15	143.6	456.5	510.9	0.24	123.3	0.082	2912.2	0.003	302.1	2.76	16.96	1.301	0.178	0	24.56
12/12/1994	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
28/12/1994	430	4242	7.39	125.1	374.9	522.8	0.25	124.9	0.274	2705.6	0.006	303.7	3.15	15.43	1.065	0	0	13.851
16/01/1995	457	4471	7.64	131.3	460.5	503.7	0.27	132.3	0.62	2848.8	0.007	306.9	2.05	15.89	0.740	0.135	0	24.87
06/02/1995	469	4577	7.17	163.9	466.2	480.6	0.27	109	0.138	2885.7	0.004	357.7	3.4	20.97	1.433	0.153	0.023	25.703
20/02/1995	468	4514	7.18	158.2	429.5	522.8	0.29	106.1	0.028	2843	0.007	353.2	3.99	21.39	1.772	0.03	0.138	24.824
20/03/1995	469	4526	7.17	170.5	418.8	532.1	0.34	113.6	0.009	2799	0.011	381.7	4.15	22.88	2.554	0.201	0	28.676
03/04/1995	475	4618	7.72	165.8	467.7	503.5	0.29	92.5	0.019	2895.5	0.01	385.2	4.1	20.57	1.779	0.186	1.233	27.301
19/04/1995	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
02/05/1995	463	4507	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
22/05/1995	433	4574	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
06/06/1995	482	4582	7.23	199	422.2	502.4	0.28	108.1	0.008	2872.3	0.011	364.7	3.91	29.53	2.521	0.062	0.015	26.408
19/06/1995	490	4590	7.08	167.8	463.3	534.9	0.23	80.1	0.051	3000.5	0.009	344.9	3.73	25.43	2.299	0.196	0.021	24.327
03/07/1995	430	4567	7.11	157.5	447.7	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
17/07/1995	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	7.228
31/07/1995	440	4410	7.05	176.1	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
14/08/1995	473	4525	7.07	192.4	390.5	568.6	0.22	104.8	0.057	2830.2	0.015	381	3.95	24.68	2.444	0.118	0.007	31.01
28/08/1995	479	4539	7.15	193.1	428.7	530.1	0.31	106.1	0.048	2860.3	0.009	345.4	4.3	24.96	2.436	0.152	0.025	24.862
13/09/1995	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	0.004	29.439
26/09/1995	478	4479	7.09	170.8	430.6	502.5	0.27	108.3	0.341	2832.7	0.008	331.4	4.95	25.69	2.092	0.236	0.06	24.417
09/10/1995	472	4554	7.07	191.6	406.7	515.6	0.17	114.3	1.283	2923.8	0.013	296.4	4	24.81	0.245	0.116	0	25.87
24/10/1995	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
06/11/1995	476	4549	7.67	165.1	455	478.4	0.18	98.9	2.257	2834.7	0.009	394.2	4.08	25.42	0.075	0.200	0	26.443
20/11/1995	517	4559	7.45	163.4	433.8	522.7	0.15	97.8	1.902	2929.5	0.007	309.8	3.64	25.29	0.081	0.271	0.05	21.001
04/12/1995	528	4417	8.57	193.7	433.6	528	0.15	128.1	1.981	2725	0.016	304.9	3.76	27.6	0.015	0.148	0.016	22.135
18/12/1995	540	4610	7.23	183.2	448.9	511.6	0.17	100.5	0.017	2898.5	0.009	356.4	4.59	29.84	1.48	0.074	0	15.922
02/01/1996	540	5225	7.37	229.8	509.2	580.2	0.18	107.1	0	3342.4	0.006	346.9	5.08	31.53	0.91	0.131	0	3.058
22/01/1996	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	1.087	0.158	0.173	10.36
29/01/1996	482	4828	7.52	243.5	472.2	474.5	0.13	85.3	2.38	3233.5	0.009	236.8	4.83	18.56	0.805	0.154	0.024	10.42
10/02/1996	517	5178	7.73	221.5	417.5	438.9	0.24	57.4	0.045	3577.6	0.008	355.6	4.25	29.98	0.494	0	0.033	8.39
05/03/1996	511	5114	7.3	437.1	383.4	511.4	0.22	54.6	0.004		0.006	395.7	4.32	30.27	0.465	0.09	0	5.15
18/03/1996	502	5267	7.63	404.2	394.6	514.4	0.21	31.7	0	3344.6	0.008	445.6	4.55	31.78	0.516	0.097	0	6.53
01/04/1996	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
15/04/1996	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

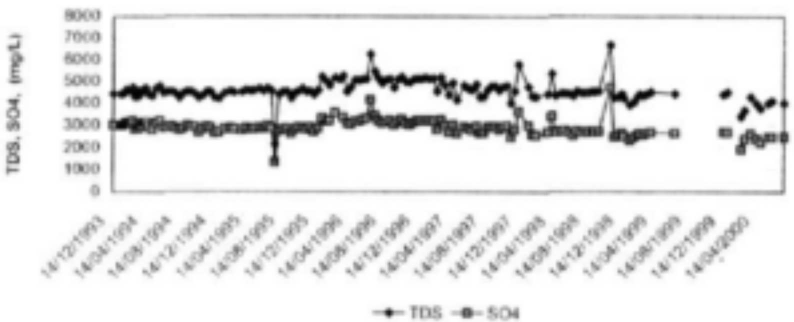
30/04/1996	519	5074	7.37	396	495.3	445.3	0.19	47.4	0.035	3173.2	0.006	458.2	4.67	31.12	0.717	0.089	0.207	8.46
13/05/1996	526	5058	7.72	367.2	424	471.9	0.34	33	0.042	3188.3	0.004	443.7	4.29	28.97	0.72	0.01	0	9.42
27/05/1996	486	5113	7.73	370.6	490.1	472.1	0.32	34.4	0.042	3262.1	0.004	437.2	4.36	29.22	0.71	0.709	0	8.85
10/06/1996	510	5142	7.24	357.8	426.9	489.3	0.22	39.2	0.008	3304.7	0.006	396.1	4.67	30.25	0.605	0.119	0	8.94
24/06/1996	592	8258	8	233.2	725.2	518.2	0.42	31.3	0.096	4187.4	0.014	450	5.05	30.1	0.768	0	0	8.81
10/07/1996	539	5463	7.43	372	475	552.1	0.2	45.9	0.035	3448	0.02	440	5.03	31.54	0.796	0.085	0	9.7
22/07/1996	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	0.708	0	0	2.971
05/08/1996	527	4929	7.73	362.6	444.7	387.5	0.2	43.3	0.277	3109	0.007	452.3	4.82	28.68	0.450	0.215	0	8.69
19/08/1996	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
02/09/1996	515	5118	8.14	358.2	444	468	0.2	51.4	0.451	3216	0.011	448.9	4.6	30.83	0.058	0	0	10.577
16/09/1996	524	4724	8.27	354.9	416.7	398.3	0.15	46.8	0.283	3027.5	0.008	381.1	4.78	17.61	0.087	0.173	0.029	3.951
30/09/1996	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	0.187	0.037	8.99
14/10/1996	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
28/10/1996	510	4997	8.5	383	442.5	495.4	0.18	44.4	0.065	3105.3	0.015	440	4.54	18.84	0.05	0	0	8.827
12/11/1996	520	4973	7.84	379.5	437.1	454	0.13	63.9	0.014	3041.9	0.015	473.7	4.71	17.89	0.778	0.26	0	5.006
25/11/1996	516	5108	7.9	361.9	431.7	513.1	0.18	58.9	0.011	3145.2	0.01	473.1	4.59	18.33	0.909	0.486	0.016	10.28
09/12/1996	517	5137	7.77	379.5	449	490.4	0.15	45	0.018	3217.1	0.012	492.5	5.58	19.16	0.954	0.358	0	2.144
23/12/1996	481	5141	7.72	377.9	425.7	501.7	0.12	49.8	0.027	3211.8	0.006	453.7	4.75	19.09	0.792	0.305	0	4.33
06/01/1997	445	5175	7.63	397.8	433.7	516	0.13	47.8	0.028	3198	0.005	480	4.95	20.08	0.97	0.419	0.014	2.301
20/01/1997	511	5130	7.87	351.4	414.9	502.7	0.14	50.3	0.032	3220.4	0.004	496.8	4.47	19.82	0.942	0	0	1.14
04/02/1997	458	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
17/02/1997	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	0.868
03/03/1997	516	5200	7.21	383	411.7	518.1	0.18	53	0.039	3245	0.005	486	4.88	18.78	1.205	0.556	0.055	4.308
17/03/1997	493	4822	7.71	283.7	417.1	517.6	0.17	58.4	0.018	3005	0.006	443.9	5.59	17.47	1.056	0	0	4.206
01/04/1997	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	0.857	0.151	0	1.852
14/04/1997	501	4047	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	0.186	0	1.425
29/04/1997	462	4168	7.31	203.4	376.4	493.6	0.16	66.7	0.019	2639.9	0.053	303	4.68	16.75	0.885	0.177	0	2.703
26/05/1997	503	4518	7.49	343	404.6	487.7	0.18	49.6	0.029	2941	0.01	488.6	4.84	19.12	1.134	0.067	0	2.366
09/06/1997	489	4574	7.35	342.6	368	497	0.14	44.1	0.03	2858.3	0.01	446.4	4.06	18.54	0.947	0.057	0	0.356
23/06/1997	482	4928	7.27	333.4	387.6	470.2	0.14	31.3	0.025	2785.4	0.005	493.9	4.98	19.53	0.905	0.023	0	2.14
08/07/1997	474	4873	7.33	343.2	387.5	505.1	0.15	45.8	0.07	2970.2	0.009	403.6	4.85	17.41	0.935	0.031	0	2.347
21/07/1997	435	4312	7.46	221.1	365.4	517.1	0.14	51.3	0.051	2659.8	0.008	394.1	4.43	15.06	0.884	0.076	0	3.671
04/08/1997	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	0.097	0	4.429
18/08/1997	455	4530	7.19	215.1	434.2	516.8	0.17	33.7	0.008	2530.9	0.004	398.7	5.06	13.77	1.155	0.095	0	3.315
01/09/1997	449	4801	7.6	326.9	300	514.7	0.16	38.2	0.037	2950.9	0.004	485.4	4.62	16.76	0.994	0.17	0	0.952
15/09/1997	471	4782	7.58	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
29/09/1997	478	4590	7.19	316.5	384	431.8	0.15	40.4	0.022	2824.3	0.007	478	4.75	17.76	1.043	0	0	0.811
13/10/1997	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
27/10/1997	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
10/11/1997	411	4018	7.8	176.1	343.5	474.2	0	49.3	0.141	2493.3	0.004	388.3	4.59	16.1	0.808	0	0	3.517
24/11/1997	461	4577	7.68	276.1	391.2	460.7	0.05	52.8	0.098	2820	0.006	457	5.03	17.17	0.905	0	0	2.756
08/12/1997	548	5784	7.76	277.7	726.5	598	0.03	44.8	0.004	3610.7	0.005	474	4.74	19.39	1.094	0	0	3.381
12/01/1998	460	4758	7.52	272	340.8	541.4	0.09	33.5	0.055	2991.3	0.004	459.1	5.2	17.24	0.994	0	0	2.644
26/01/1998	451	4344	7.33	266.7	318.4	553.6	0.13	20.4	0.035	2596.2	0.01	486.7	4.82	18.43	0.885	0	0	0
09/02/1998	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	0.935	0	0	0
23/03/1998	379	4429	7.58	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
06/04/1998	514	5364	7.48	290.5	513.5	542.4	0	29.2	0.052	3407.6	0.006	460.4	5.12	18.01	1.115	0	0.037	2.905
20/04/1998	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
11/05/1998	421	4478	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
25/05/1998	431	4454	7.49	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
08/06/1998	446	4444	7.52	282.1	349.7	492.3	0.1	25	0.038	2691.4	0.008	480.1	5.12	16.46	1.05	0.257	0.01	5.19
22/06/1998	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
06/07/1998	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
20/07/1998	440	4485	7.77	286.2	319.7	538.4	0.08	34	0.409	2694.4	0.052	498.3	5.08	17.09	0.447	0.108	0.054	0.093
03/08/1998	408	4493	7.28	285.2	319.4	520.5	0.09	34.2	0.415	2703.5	0.048	485.2	5.11	16.31	0.448	0.072	0.002	0.15
17/08/1998	448	4507	7.64	285.4	326.0	520.2	0.06	35	0.479	2738.3	0.014	477.9	5.07	16.72	0.43	0.09	0.003	0.038
31/08/1998	397	4543	7.55	280.6	360	515.3	<0.1	35.1	0.363	2727.6	0.013	496.6	6.4	17.04	0.056	<0.02	<0.003	0.108
07/09/1998	458	4533	7.6	267.7	341.3	545.3	<0.1	35.8	0.354	2715.8	0.007	497.8	6.19	18.54	<0.04	<0.02	<0.003	4.641
21/09/1998	442	4565	7.74	273.4	353.3	545.5	<0.1	34.5	0.357	2729.7	0.007	500.7	6.17	16.65	<0.04	<0.02	<0.003	<0.001
02/11/1998	632	6908	8.43	499.7	629	565.4	<0.1	68.4	0.72	4723.8	0.015	123.2	2.4	27.91	<0.04	<0.02	<0.003	2.303
16/11/1998	444	4208	7.29	277.9	338.2	488.5	0.14	35	0.228	2406.6	0.006	504.5	4.46	16.81	<0.04	<0.02	<0.003	5.3
01/12/1998	436	4313	7.51	273.9	322.8	479.9	0.17	37.8	0.105	2564.7	0.006	505.6	4.56	16.64	0.047	0.084	0.459	3.493
21/12/1998	433	4239	7.23	239.9	323.9	563.9	0.15	37.1	<0.04	2509.1	0.062	448.3	5.11	16.65	1.29	<0.02	<0.003	0.033
14/12/1998	442	4424	7.63	268.7	348	479	0.18	34.5	0.062	2862.7	0.011	505.7	4.35	16.37	<0.04	0.097	0.517	2.043
11/01/1999	367	3927	7.2	167.5	247	584.9	0.21	50.4	<0.04	2332.1	<0.005	432	5.25	16.36	1.221	<0.02	0.008	5.26
25/01/1999	429	4065	7.17	250.7	257	450.6	<0.1	38.5	0.07	2482.2	0.009	467	5.44	14.53	1.047	<0.02	<0.003	0.636
08/02/1999	441	4311	6.89	242	333.4	537.7	0.2	37.7	<0.04	2578.6	0.015	480.6	5.01	18.18	1.184	<0.02	<0.003	2.282
15/02/1999	443	4409	7.8	248.6	344.8	536	0.17	42.4	<0.04	2642.5	0.005	471.5	5.38	18.36	1.051	<0.02	<0.003	0.941

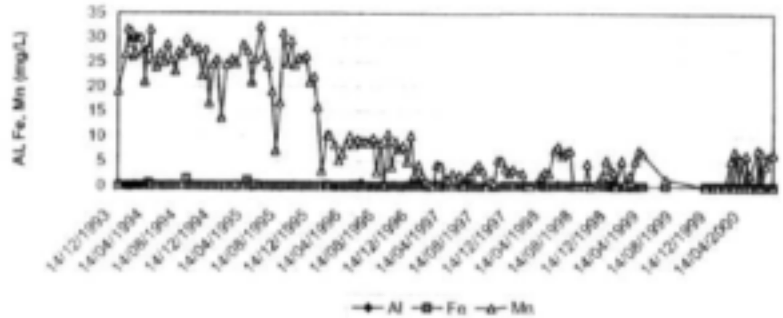
01/03/1999	441	4353	7.3	243.3	336.6	536.9	0.16	41.4	<0.04	2595.2	0.011	475.3	5.8	18.64	1.185	<0.02	<0.005	5.22
15/03/1999	446	4443	7.76	260.1	348	536.4	0.13	38.6	<0.04	2653.9	0.012	480.3	6.05	18.53	1.301	<0.02	<0.003	7.31
29/03/1999	443	4520	7.41	258.8	352.2	572.6	0.14	38.6	<0.04	2686.2	0.01	485.2	6.09	18.4	1.263	<0.02	<0.003	6.57
21/06/1999	450	4436	7.09	250.7	327.6	557.1	0.12	44.2	0.659	2653	0.009	477.5	5.38	18.23	<0.04	<0.02	0.008	1.516
15/11/1999																<0.035	<0.005	0.001
28/12/1999																<0.035	<0.005	0.001
13/12/1999																<0.035	<0.005	0.001
13/12/1999	450	4406.817	7.824	241.866	342.434	569.926	0.256	44.088	1.144	2698.63	0.019	397.514	4.788	19.797	<0.04			
28/12/1999	447	4516.261	7.738	230.942	328.975	565.445	0.242	43.43	1.18	2688.804	0.018	453.1	4.92	100.674	<0.04			
24/01/2000																<0.035	<0.005	0.001
14/02/2000																<0.035	<0.005	5.31
28/02/2000	423	3683.002	7.192	164.85	314.285	470.764	0.176	36.467	0.06	2393.975	0.096	230.311	5.984	18.617	1.941			
14/02/2000	379	3404.754	7.454	132.15	277.898	441.736	0.2	49.479	0.139	1939.025	0.199	449.5	6.626	83.715	0.985			
28/02/2000																<0.035	0.143	7.13
20/03/2000	442	4288.261	7.166	170.165	345.349	518.781	0.193	41.471	0.055	2626.497	0.031	462.6	6.148	18.104	1.828			
20/03/2000																<0.035	<0.006	5.73
10/04/2000	433	3987.862	7.41	174.162	332.395	493.984	0.208	42.353	0.049	2408.528	0.013	433.7	5.796	14.921	1.757			
10/04/2000																<0.035	0.108	6.45
25/04/2000	401	3773.455	7.319	164.723	304.906	453.094	0.197	35.581	<0.04	2233.3	0.013	452.7	6.68	14.288	1.771			
25/04/2000																<0.035	0.025	2.582
22/05/2000																<0.059	0.226	7.53
05/06/2000																<0.059	<0.006	6.95
22/05/2000	423	4002.257	7.557	180.063	298.47	521.57	0.198	39.408	0.643	2473.174	0.082	380.253	6.327	20.962	1.311			
05/06/2000	426	4123.167	7.899	177.403	317.254	522.674	0.108	40.215	0.069	2479	0.035	395.642	6.051	102.025	1.775			
20/06/2000																<0.059	<0.006	4.41
03/07/2000																<0.059	0.057	6.14
17/07/2000																<0.059	0.051	6.67
17/07/2000	436	4019.871	7.781	181.997	341.257	480.487	0.188	47.923	<0.04	2496.306	0.009	365.426	5.741	15.036	1.493			
Min	266	2142	6.89	91	104.6	225.7	0	20.4	0	1362.9	0.002	123.2	2.4	4.01	0.016	0	0	0
Max	632	6999	8.57	499.7	729.2	584.9	0.63	180.8	2.38	4723.8	0.199	505.7	6.68	102.025	2.951	5.15	1.489	32.37
Mean	453.619	4506.889	7.452517	229.1682	411.9058	507.0908	0.207493	64.35248	0.195609	2903.718	0.013267	384.1602	4.475857	19.8489	1.019029	0.137382	0.057527	12.30544
Median	456	4550	7.43	221.5	418.8	514.7	0.1975	52.9	0.04	2895.65	0.009	395	4.56	17.85	0.959	0.119	0.004	7.427
95-percentile	401.3	4018.581	7.04	104.45	315.3752	448.99	0.0805	29.38	0.00585	2479.6	0.004	230.0877	2.95	9.918	0.0595	0	0	0.06275

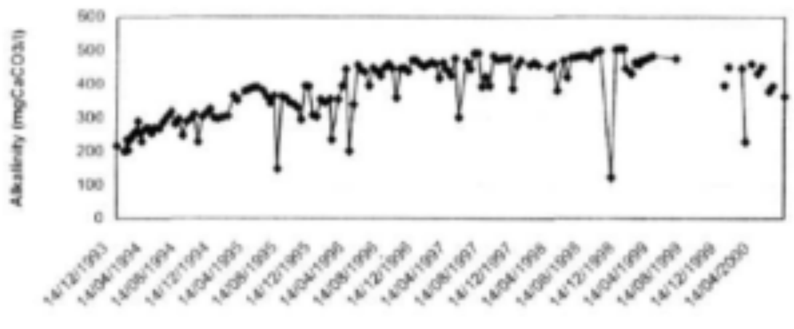
Cell 6

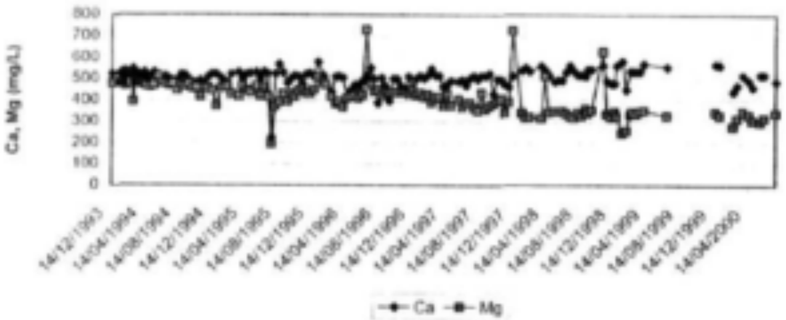

EC (mS/m)
700
600
500
400
300
200
100
0
14/12/1993
14/04/1994
14/08/1994
14/12/1994
14/04/1995
14/08/1995
14/12/1995
14/04/1996
14/08/1996
14/12/1996
14/04/1997
14/08/1997
14/12/1997
14/04/1998
14/08/1998
14/12/1998
14/04/1999
14/08/1999
14/12/1999
14/04/2000


pH
9
8
7
6
5
4
3
2
1
0
14/12/1993
14/04/1994
14/08/1994
14/12/1994
14/04/1995
14/08/1995
14/12/1995
14/04/1996
14/08/1996
14/12/1996
14/04/1997
14/08/1997
14/12/1997
14/04/1998
14/08/1998
14/12/1998
14/04/1999
14/08/1999
14/12/1999
14/04/2000


TDS, SO4, (mg/L)
8000
7000
6000
5000
4000
3000
2000
1000
0
14/12/1993
14/04/1994
14/08/1994
14/12/1994
14/04/1995
14/08/1995
14/12/1995
14/04/1996
14/08/1996
14/12/1996
14/04/1997
14/08/1997
14/12/1997
14/04/1998
14/08/1998
14/12/1998
14/04/1999
14/08/1999
14/12/1999
14/04/2000
TDS
SO4


Al, Fe, Mn (mg/L)
35
30
25
20
15
10
5
0
14/12/1993
14/04/1994
14/08/1994
14/12/1994
14/04/1995
14/08/1995
14/12/1995
14/04/1996
14/08/1996
14/12/1996
14/04/1997
14/08/1997
14/12/1997
14/04/1998
14/08/1998
14/12/1998
14/04/1999
14/08/1999
14/12/1999
14/04/2000
Al
Fe
Mn


Alkalinity (mgCaCO3/l)
600
500
400
300
200
100
0
14/12/1993
14/04/1994
14/08/1994
14/12/1994
14/04/1995
14/08/1995
14/12/1995
14/04/1996
14/08/1996
14/12/1996
14/04/1997
14/08/1997
14/12/1997
14/04/1998
14/08/1998
14/12/1998
14/04/1999
14/08/1999
14/12/1999
14/04/2000


Ca, Mg (mg/L)
800
700
600
500
400
300
200
100
0
14/12/1993
14/04/1994
14/08/1994
14/12/1994
14/04/1995
14/08/1995
14/12/1995
14/04/1996
14/08/1996
14/12/1996
14/04/1997
14/08/1997
14/12/1997
14/04/1998
14/08/1998
14/12/1998
14/04/1999
14/08/1999
14/12/1999
14/04/2000
Ca
Mg

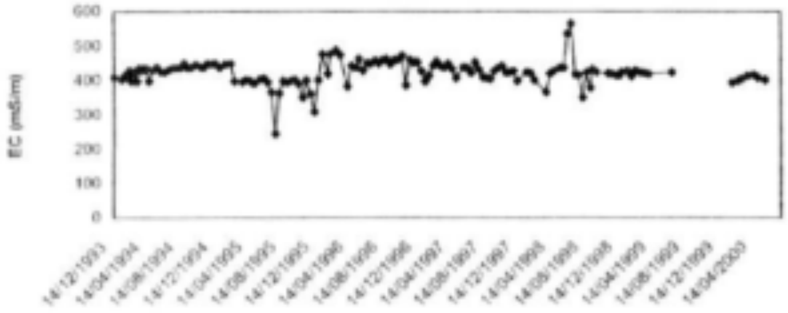
Cell 7

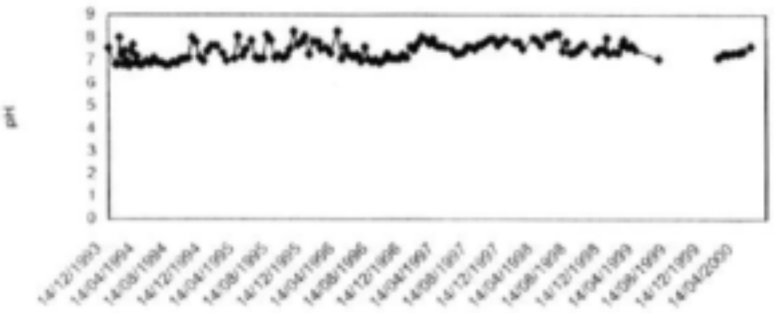
Date	EC	TDS	pH	Na	Mg	Ca	Fl	Cl	NO3	SO4	PO4	ALK	Si	K	NH4	Al	Fe	Mn
14/12/1993	411	4106	7.58	68.5	417	528	0.18	50.7	0.016	2841.2	0.007	156.4	3.71	7.73	1.027	0.662	0.001	24.645
10/01/1994	403	4124	6.86	70.1	427.2	541.9	0.15	56.6	0.013	2840.9	0.016	148.1	3.46	8.04	0.842	0	0.107	37.93
18/01/1994	414	4357	6.88	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
24/01/1994	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
31/01/1994	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
07/02/1994	430	4274	6.86	72.7	422.3	531	0.3	61.6	0.023	2870.7	0.008	250.7	3.6	8.11	1.029	0.228	0.001	20.77
14/02/1994	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	0.026	0.001	22.46
21/02/1994	426	4414	6.09	77.2	433	543.9	0.3	72.6	0.018	2953.2	0.011	264.3	3.11	8.87	0.958	0.148	0.003	20.78
28/02/1994	422	4210	6.8	77.3	426.5	469.6	0.27	78.2	0.016	2821.1	0.012	251.6	3.14	9.42	0.935	0.151	0.007	18.89
07/03/1994	398	4352	7.44	86	456.8	520.3	0.3	74.1	0.011	2872.3	0.021	260.5	3.46	12.98	0.615	0.267	0.029	19.81
14/03/1994	437	4097	7.72	104.9	438.4	490	0.19	81.7	0.028	2675.1	0.005	240.6	3.26	11.49	0.888	0.136	0.511	18.66
21/03/1994	426	4354	6.91	84.4	450.9	523.2	0.28	78.4	0.016	2851.2	0.010	287.8	3.84	13.12	1.207	0.116	0.018	17.95
28/03/1994	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
05/04/1994	431	4366	6.86	80.7	437.9	529.9	0.27	71.5	0.016	2885.4	0.004	284.1	3.79	12.43	1.506	0.15	7.24	17.87
11/04/1994	435	4380	6.85	83.8	442.1	549	0.48	80.1	0.03	2846.3	0.01	297.7	3.87	12.72	1.561	0.197	2.543	17.73
18/04/1994	399	4199	6.85	81	430.2	515	0.41	89.2	0.013	2738.3	0.016	270.5	4.02	12.82	1.518	0.15	0.184	18.15
02/05/1994	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
16/05/1994	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
30/05/1994	427	4516	7.15	82.5	474.7	485.7	0.32	109.1	0.035	2961.8	0.003	316.7	3.84	13.23	1.508	0.071	0	16.34
13/06/1994	426	4234	6.95	88.6	447.2	469.1	0.32	107.4	0.031	2686.2	0.006	327.7	3.67	13.75	1.491	0.133	0	17.44
27/06/1994	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	18.35
11/07/1994	437	4308	6.82	90.5	398.5	539.4	0.39	117.9	0.021	2746.1	0.006	327.4	3.68	14.49	1.542	0.149	0.066	13.12
25/07/1994	438	4322	6.84	87.8	447.3	508.7	0.35	122.9	0.106	2718.9	0.01	343.1	3.35	14.65	1.624	0.237	0.028	16.62
08/08/1994	438	4201	6.97	94.9	418	535.1	0.33	123.8	0.017	2586	0.027	341.2	3.33	14.97	1.473	0.16	0.074	15.69
22/08/1994	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
05/09/1994	437	4473	7.09	91.5	446.5	502	0.28	130.9	0.051	2833.7	0.008	370	3.17	14.68	1.679	0.451	0.046	16.13
19/09/1994	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	1.388	0.177	0	16.19
03/10/1994	447	4422	7.15	90.6	436.6	547	0.35	128.8	0.012	2759.1	0.006	362	3.43	15.56	1.847	0.132	0.005	14.873
17/10/1994	442	3931	8.03	90	430	476	0.26	140	0.029	2328	0.015	367	3.56	15.1	1.837	0.163	0.022	14.102
31/10/1994	439	4420	7.84	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
14/11/1994	450	4191	7.18	97.8	406	519	0.3	131	0.049	2582	0.007	359.4	3.62	11.94	2.407	0.146	0.037	18.447
28/11/1994	448	4284	7.01	90.5	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
12/12/1994	451	4202	7.44	93.7	427.2	541.7	0.27	151.3	0.035	2508.1	0.01	377.6	4	16.36	2.345	0.17	0.479	15.58
28/12/1994	439	3956	7.69	97.5	374.8	533.6	0.26	110.3	0.07	2501	0.009	281.3	3.74	16.55	2.519	0	0.011	2.82
16/01/1995	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
06/02/1995	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
20/02/1995	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
20/03/1995	397	3806	7.12	151.7	349.2	445.7	0.37	91.9	0.095	2138.1	0.013	490.2	4.61	17.17	3.97	0.187	0.019	19.34
03/04/1995	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
19/04/1995	398	3779	7.24	150.6	346	430.7	0.34	81.6	0.003	2185.3	0.006	477.2	4.44	17.49	3.938	0	0	11.287
02/05/1995	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
22/05/1995	404	3720	7.91	154.5	351.6	435.4	0.28	82.9	0.011	2120	0.027	451.3	4.4	18.41	4.168	0.243	0.088	18.92
06/06/1995	407	3799	7.16	174.8	332.1	437.5	0.3	82.9	0.003	2180.9	0.01	489	4.28	18.88	3.945	0.06	0.044	16.914
19/06/1995	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
03/07/1995	387	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
17/07/1995	248	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
31/07/1995	384	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
14/08/1995	399	3828	7.15	148.7	313.4	487.4	0.22	83.6	0.041	2180.7	0.007	477.2	4.41	17.83	4.081	0.079	0.005	19.184
28/08/1995	396	3795	7.27	147.5	337	447.6	0.32	78.4	0.188	2172.4	0.012	492.7	4.81	17.79	3.891	0.13	0.022	14.511
13/09/1995	400	3671	7.16	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
28/09/1995	402	3657	7.22	154.7	358.1	396.7	0.3	92.7	1.71	2082.1	0.008	440.9	4.74	18.42	1.256	0.23	0.053	14.007
09/10/1995	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
24/10/1995	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
06/11/1995	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
23/11/1995	362	3300	7.83	166.2	322.9	336.4	0.18	74.1	2.706	2129	0.017	196.4	3.78	19.61	0.082	0.251	0.041	11.061
04/12/1995	309	3096	8.09	123.9	254.7	304.2	0.19	81.4	2.778	2002	0.017	148.3	3.86	16.54	0.062	0.126	0	0.352
18/12/1995	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
02/01/1996	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	0.002	0	3.473
22/01/1996	420	4805	7.84	345.9	380.8	463	0.18	121.6	7.878	2855.6	0.009	449.1	5.19	30.83	3.783	0.06	0.117	7.91
29/01/1996	477	4894	7.53	332.9	394.6	536	0.22	111.1	9.815	3008	0.009	366.4	4.2	18.62	1.83	0.138	0.295	8.5
19/02/1996	488	4817	7.58	290.2	383.2	537.5	0.24	78.2	4.218	3018.7	0.006	379.8	4.38	28.13	0.681	0.165	0	5.62
05/03/1996	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
01/04/1996	383	4290	8.3	249.6	356.4	480.2	0.14	80.6	0.01	2974	0.007	96.8	3.93	19.36	0.765	0	0	8.97
15/04/1996	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
30/04/1996	440	4281	7.64	232.5	353.7	461.5	0.2	73.9	0.007	2688.4	0.003	386.4	4.18	18.22	0.812	0.207	0.354	7.17

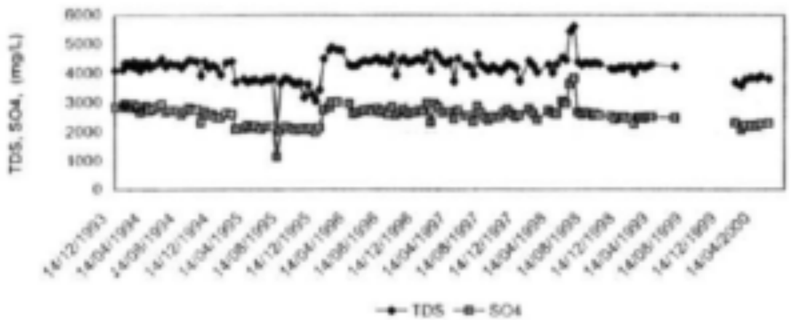
13/05/1996	464	4388	7.3	210	361.5	503.1	0.33	49.7	0.015	2711.1	0.007	430	4.02	25.60	0.887	0.241	0	8.45
27/05/1996	429	4453	7.2	210.2	356.5	529	0.31	55.8	0.027	2745.6	0.008	440	4.09	17.60	0.887	0.797	0	7.95
10/06/1996	452	4403	7.28	211.2	360.7	520.1	0.23	49.7	0.011	2763.3	0.008	385.2	4.11	18.11	0.84	0.125	0.053	7.88
24/06/1996	451	4450	7	217.3	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
10/07/1996	459	4542	7.62	204.4	378.6	527.2	0.19	65	0.073	2809.5	0.012	439.5	4.26	18.95	0.841	0.081	0	8.35
22/07/1996	452	4411	7.09	208	379.1	522.8	0.2	85.3	0.017	2573.6	0.012	445.2	4.09	18.22	0.81	0.175	0	7.554
05/08/1996	460	4440	6.98	200.1	376.1	529.2	0.2	80	0.03	2726.4	0.003	432.2	4.22	25.73	0.765	0.302	0	7.99
19/08/1996	463	4348	7.06	212.9	356.1	535.2	0.2	63.4	0.019	2613.6	0.013	438.8	4.26	26.11	0.731	0	0	4.427
02/09/1996	449	4520	6.92	211.3	371.4	550	0.19	71.4	0.042	2850.5	0.019	446.8	4.06	19.15	0.851	0	0	9.86
16/09/1996	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
30/09/1996	462	4436	7.32	220.8	376.6	541.4	0.2	63.6	0.168	2683	0.015	433.5	4.19	13.55	0.997	0.188	0.051	8.12
14/10/1996	473	4528	7.13	221	374.1	552.1	0.2	48.7	0.025	2765	0.008	451.8	4.15	13.49	1.012	0.055	0	7.252
28/10/1996	397	4359	7.13	213.4	368	543.4	0.16	47.3	0.016	2635.3	0.017	445.4	4.56	13.02	0.993	0	0	7.748
12/11/1996	451	4492	7.11	221.3	366.8	498.1	0.15	72.3	0.027	2667.1	0.01	462.7	4.12	12.72	1.028	0.389	0.006	2.498
25/11/1996	454	4456	7.3	211.7	383.7	551.7	0.17	61.4	0.019	2684.7	0.008	465.9	3.94	12.81	1.056	0.489	0.015	1.477
09/12/1996	455	4497	7.16	225.6	354.1	563	0.14	59	0.021	2717.9	0.013	460.8	5.02	13.71	1.142	0.431	0	7.366
23/12/1996	428	4422	7.63	398.8	284.2	485.5	0.14	59.2	0.023	2717.1	0.006	383	5.95	9.5	0.506	0.045	0	3.378
06/01/1997	398	4702	7.51	109.6	407.3	539.7	0.14	45.5	0.03	2673.6	0.005	426.1	5.75	15.32	1.133	0.476	0.02	6.062
20/01/1997	415	4092	7.79	158.2	336.8	519.8	0.17	70.6	0.047	2346.8	0.006	520	4.38	13.48	1.698	0	0	0.034
04/02/1997	444	4717	8.06	191.4	422.5	544.7	0.16	47.2	0.034	2969.8	0.006	420.1	4.96	15.88	1.138	0	0	0.09
17/02/1997	457	4588	7.98	195	389.1	553	0.14	70.9	0.054	2843	0.004	425.4	4.21	15.99	0.811	0	0	0.057
03/03/1997	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
17/03/1997	440	4325	7.58	142	391.8	529	0.14	85.3	0.046	2692.9	0.004	384.9	4.58	13.23	1.1	0	0	3.48
01/04/1997	450	4442	7.66	215.2	377.4	558.9	0.17	71.6	0.046	2686.2	0.017	422.3	4.55	16.33	0.878	0.136	0	0.036
14/04/1997	435	3732	7.63	157.6	357	400.1	0.17	19.1	0.032	2458.9	0.012	287.6	5.29	13.94	1.432	0.166	0	0.629
29/04/1997	400	4519	7.6	229	325.7	570.8	0.16	70.9	0.048	2738.4	0.013	434	4.62	16.53	0.87	0.163	0	2.074
26/05/1997	440	4272	7.51	153.6	350.2	548.7	0.10	77.3	0.017	2561.5	0.006	455.2	5.25	14.25	1.376	0.079	0	1.605
09/06/1997	430	4241	7.31	184	347.8	529.9	0.15	63.6	0.015	2555.5	0.004	446	5.49	13.91	1.336	0.052	0	0.915
23/06/1997	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	5.05
08/07/1997	455	4647	7.4	272.9	395	488.4	0.15	29.1	0.078	2878.1	0.013	468	4.80	14.11	0.783	0.035	0	3.472
21/07/1997	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	0.885	0.068	0	0.434
04/08/1997	411	4181	7.61	184	357	480	0.18	84.1	0.03	2517.8	0.002	450.2	5.45	13.64	1.407	0.011	0	2.821
18/08/1997	400	4005	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
01/09/1997	408	4237	7.7	171.6	359.3	539.5	0.16	70.9	0.03	2527.8	0.004	452.9	5.32	14.12	1.179	0.61	0.042	0.664
15/09/1997	428	4145	7.74	183.2	357.5	516.9	0.16	69.1	0.030	2509.9	0.004	421.5	4.99	13.75	1.148	0	0	0.026
29/09/1997	437	4056	7.85	163.1	388.8	417.3	0.15	69.6	0.04	2523.6	0.004	397.7	4.27	14.13	1.25	0	0	0.154
13/10/1997	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
27/10/1997	424	4325	7.99	157.9	386.1	539.8	0.13	66.7	0.082	2751.6	0.011	333.6	3.59	15.2	1.036	0	0.016	3.102
10/11/1997	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
24/11/1997	428	4193	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
08/12/1997	399	3738	7.93	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
12/01/1998	425	4432	7.81	135.1	363.7	544.4	0.05	42.8	0.053	2788.2	0.004	443.6	5.53	14.72	1.425	0	0	1.638
26/01/1998	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
09/02/1998	401	4042	7.53	134.8	339.8	554	0.14	39.1	0.026	2424.7	0.007	443.4	5.28	16.27	1.35	0	0	0
23/03/1998	397	4306	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	0.454
06/04/1998	421	4017	7.9	187	365	487.9	0.05	34.9	0.079	2654.9	0.003	234.8	4.97	16.48	0.384	0	0.035	0.245
20/04/1998	429	4320	7.66	159.8	358.6	560.2	0.15	42.4	0.022	2625.4	0.116	457.5	5.49	13.32	1.437	0	0.065	5.58
11/05/1998	439	4547	8.07	176.5	413.4	531.7	0.03	43.8	1.2	3050.6	0.032	244.5	4.72	17.93	0.072	0	0	2.683
25/05/1998	435	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
08/06/1998	536	5438	8.22	279.8	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
22/06/1998	565	5813	8.10	218.7	575.2	624.2	0.03	63.9	1.877	3817.1	0.080	232.1	4.84	22.06	0.096	0.262	0	2.808
06/07/1998	419	4387	7.43	149.9	345.8	588	0.09	46.6	0.509	2675.3	0.047	452.2	5.64	14.8	0.069	0.076	0.005	6.33
20/07/1998	417	4200	7.84	159.2	345.7	561.3	0.08	50.3	0.512	2612.9	0.047	445	6.04	15.17	0.088	0.08	0.002	0.082
03/08/1998	352	4360	7.35	159.7	364.8	546.1	0.09	44.9	0.551	2660	0.049	460.1	5.55	14.58	0.064	0.095	0.004	1.06
17/08/1998	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
31/08/1998	380	4344	7.48	152.1	383.3	586.2	0.11	47.8	0.687	2581.5	0.009	471.2	7.13	14.88	0.061	<0.02	<0.003	0.65
07/09/1998	434	4366	7.6	150.4	374.2	580.2	0.1	45.1	0.669	2625.8	0.007	470.1	6.93	14.48	0.042	<0.02	<0.003	<0.001
21/09/1998	426	4313	7.74	149.4	377.5	573.1	<0.1	45.4	0.666	2577.3	0.01	468.6	6.97	14.47	0.056	<0.02	<0.003	<0.001
02/11/1998	422	4167	7.33	155.3	361.6	479.7	<0.1	50.7	0.782	2545.7	0.03	457.4	4.98	12.59	0.114	<0.02	<0.003	1.002
16/11/1998	420	4141	7.54	150.5	347.4	556.3	0.11	49.5	0.766	2451.5	0.011	466.8	5.2	14.07	0.044	<0.02	<0.003	0.039
01/12/1998	416	4194	7.54	145.4	364.4	532.2	<0.1	47.4	0.717	2518.2	0.005	466.6	5.24	13.78	<0.04	<0.02	<0.003	0.023
21/12/1998	426	4209	7.33	148.1	369.7	535.1	0.15	45.7	0.723	2513.1	0.012	473.4	4.86	14.4	0.059	<0.02	<0.003	0.251
14/12/1998	417	4187	8.02	146.8	365	534.8	0.16	45.8	0.711	2502.9	0.009	470.1	5.14	14.49	0.043	<0.02	<0.003	<0.001
11/01/1999	429	4228	7.41	150	354.7	558.5	0.2	43.7	0.088	2455.6	<0.005	526.8	5.36	14.12	0.404	<0.02	0.01	3.665
25/01/1999	413	4018	7.36	113.4	354	548.5	<0.1	49.1	<0.04	2280.7	0.013	522.7	6.3	16.79	1.267	<0.02	<0.003	0.125
08/02/1999	430	4248	7.69	115.6	374.2	548.9	0.16	52.2	<0.04	2502.8	0.012	514.9	5.71	16.7	1.011	<0.02	<0.003	4.936
15/02/1999	428	4262	7.93	112	384.4	551	0.17	55.9	<0.04	2509.1	0.005	516.9	6.14	16.75	1.984	<0.02	<0.003	1.192
01/03/1999	424	4203	7.61	111.3	351.9	543.1	<0.1	53.5	<0.04	2487.8	0.012	513.5	6.01	16.55	1.611	<0.02	<0.003	2.488

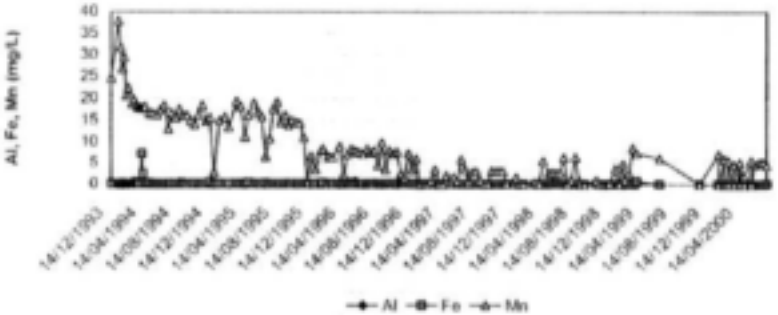
15/03/1999	422	4245	7.69	115.2	363.5	540.3	0.13	51.1	<0.04	2523.9	0.016	518.8	6.83	15.59	1.892	<0.02	0.098	8.64
29/03/1999	429	4309	7.5	116.6	369.5	596.6	0.14	49	<0.04	2523.3	0.011	520.9	6.89	15.71	1.995	<0.02	0.777	7.39
21/06/1999	425	4231	7.1	102.9	345.6	585.1	0.13	57.5	0.998	2493	0.009	508.5	6.3	21.34	0.05	<0.02	0.007	6.17
15/11/1999																<0.035	<0.005	0.077
24/01/2000																<0.035	<0.005	7.18
24/01/2000	395	3699.247	7.182	198.511	251.884	513.088	<0.1	38.781	0.043	2323.751	0.006	313.787	6.154	18.213	1.688			
14/02/2000																<0.035	<0.005	6.01
28/02/2000	406	3785.42	7.311	190.752	230.277	587.489	0.156	50.847	<0.04	2240.008	0.015	382.973	6.259	17.193	1.259			
14/02/2000	400	3590.368	7.322	194.781	239.414	543.447	0.173	46.876	0.048	2091.054	0.014	398.448	5.518	15.736	1.414			
28/02/2000																<0.035	0.068	5.63
20/03/2000	414	3847.689	7.348	195.797	244.877	574.969	0.187	55.521	<0.04	2225.136	0.017	436.8	5.479	17.508	0.969			
20/03/2000																<0.035	<0.005	4.754
10/04/2000	418	3845.535	7.381	179.565	253.951	588.505	0.16	62.48	0.044	2238.139	0.009	413.2	5	17.46	0.98			
10/04/2000																<0.035	0.063	5.17
25/04/2000	410	3912.317	7.438	182.733	239.163	599.081	0.173	61.625	<0.04	2283.791	0.007	433	5.609	16.409	1.005			
25/04/2000																<0.035	<0.005	2.046
22/05/2000																<0.059	<0.008	5.67
05/06/2000																<0.059	<0.008	4.709
22/05/2000	403	3817.78	7.644	178.14	236.86	554.26	0.14	40.088	<0.04	2310.3	0.01	392.903	5.583	16.9	1.028			
20/06/2000																<0.059	<0.008	5.19
03/07/2000																<0.059	<0.008	5.24
17/07/2000																<0.059	0.961	4.599
Min	249	2048	6.8	68.6	179.9	220.1	0	19.1	0.003	1153.2	0.002	96.8	2.63	7.73	0.031	0	0	0
Max	565	5613	8.3	398.8	575.2	640.3	0.45	151.3	9.816	3817.1	0.136	525.8	8.91	61.51	4.166	0.797	7.24	37.93
Mean	424.3916	4198.33	7.461077	156.9068	374.0568	511.7933	0.206343	72.33298	0.448481	2502.166	0.013218	384.0483	4.508336	16.06601	1.338669	0.138805	0.122346	8.921324
Median	420	4272	7.44	153.6	358.8	529.3	0.15	56.7	0.035	2532	0.009	422.3	4.4	15.2	1.144	0.1215	0.005	6.775
95-percentile	368.3	3558.4	6.862	78.09	254.0258	400.15	0.058	38.9717	0.0106	2114.94	0.003	204.87	3.332	9.24	0.0581	0	0	0.0426

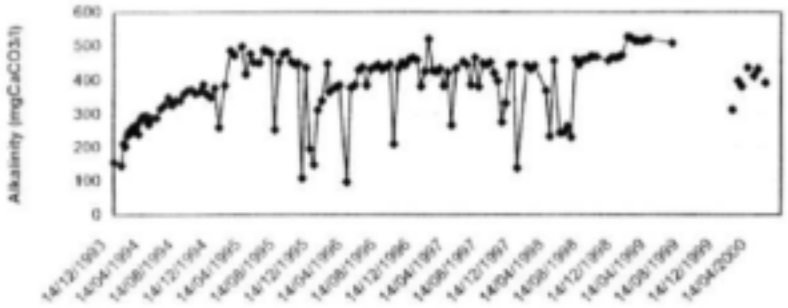
Cell 7

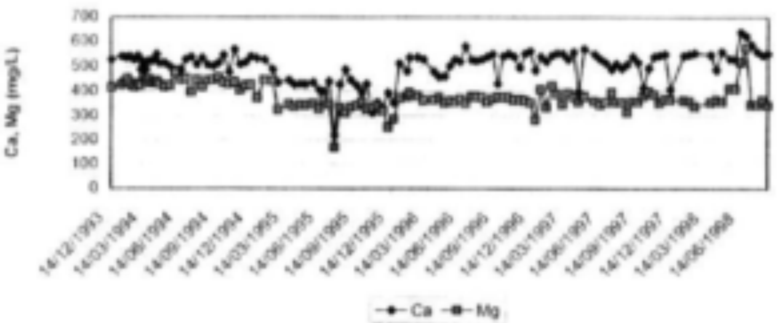

EC (mS/m)


pH


TDS, SO4, (mg/L)
TDS
SO4


Al, Fe, Mn (mg/L)
Al
Fe
Mn


Alkalinity (mgCaCO3/l)


Ca, Mg (mg/L)
Ca
Mg

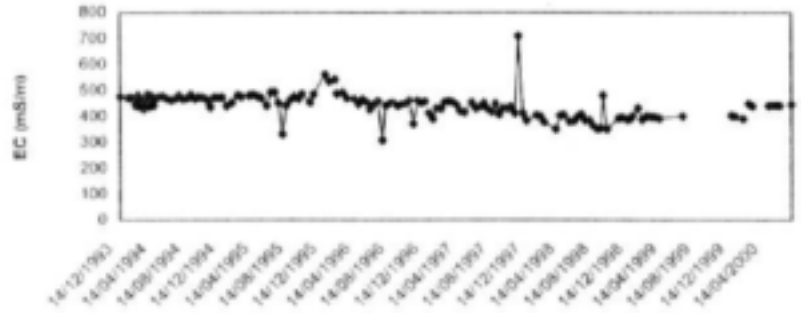
Cell 8

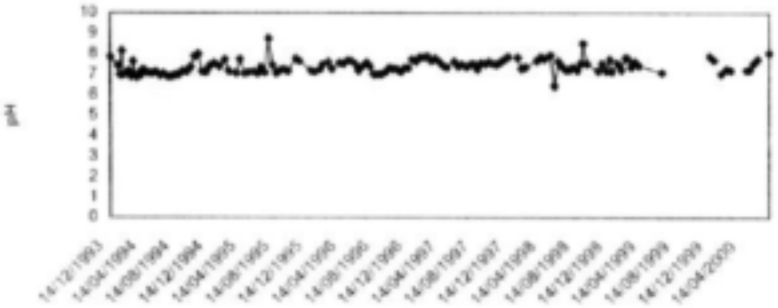
Date	EC	TDS	pH	Na	Mg	Ca	Fl	Cl	NO3	SO4	PO4	ALK	Si	K	NH4	Al	Fe	Mn
14/12/1993	478	4884	7.86	87	555.6	524.5	0.1	50.7	0.017	3390.6	0.004	217.3	3.71	9.38	0.66	0.096	0.004	26.275
10/01/1994	471	4908	7.43	89.1	588.9	435.1	0.19	45.5	0.012	3450.4	0.014	236.2	3.53	9.4	0.72	0.003	0	31.15
18/01/1994	475	5149	7	88.9	594.6	540.4	0.37	48.7	0.033	3546.8	0.01	260	3.87	9.24	0.769	0.341	0.021	28.8
24/01/1994	471	4930	8.17	89.3	572.9	520.9	0.3	34.9	0.02	3416.9	0.013	225.4	3.5	10	0.633	0	0.047	32.18
31/01/1994	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
07/02/1994	443	4914	7.07	84.7	550.5	516.3	0.42	62.6	0.016	3380.1	0.016	251.2	3.78	9.71	0.68	0.267	0.01	27.39
14/02/1994	452	4760	7.14	87.5	556.2	482.4	0.25	69.2	0.019	3316.7	0.008	194.7	3.65	9.11	0.652	0.296	0.028	19.56
21/02/1994	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	0.115	0	33.12
28/02/1994	454	4979	6.92	94.4	560.4	532.8	0.4	78.5	0.017	3358.4	0.014	272.4	3.03	11.28	0.707	0.126	0	29.68
07/03/1994	430	4782	7.54	94.6	551.6	516.2	0.3	78.4	0.016	3202.6	0.027	265	3.72	13.95	0.983	0.375	0.038	25.08
14/03/1994	473	5313	6.97	87	586	560	0.26	78	0.023	3603	0.007	243.9	3.16	10.3	0.67	0.216	0.1	23.41
21/03/1994	486	4895	6.80	94.8	552.3	533.2	0.28	78.2	0.071	3276.9	0.018	279.3	3.66	17.38	0.836	0.128	0	25.32
28/03/1994	440	4865	7.05	108.6	575.4	498.4	0.43	92.2	0.018	3228.6	0.026	283	3.8	15.03	0.838	0.169	0.011	26.76
05/04/1994	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
11/04/1994	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
18/04/1994	456	4689	7.22	93.9	547.5	511.2	0.28	80.1	0.023	3125.9	0.011	254.8	3.72	17.15	1.23	0.141	0.072	25.17
02/05/1994	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
16/05/1994	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	0.028	25.16
30/05/1994	460	4960	7.14	92.1	556.6	505	0.36	79.8	0.118	3360.9	0.003	289.9	3.45	29.28	1.265	0.087	0	24.19
13/06/1994	494	4582	6.98	93.1	488.2	508.9	0.33	97.4	0.031	3105.9	0.005	303.7	3.31	15.86	1.278	0.142	0.268	22.55
27/06/1994	457	4738	7.04	91.6	545.7	505.2	0.34	100.7	0.026	3080.2	0.018	324.2	3.03	16.63	1.356	0.113	0.011	25.49
11/07/1994	482	4949	6.91	91.4	550.5	520.1	0.4	124.5	0.043	3253.3	0.005	309.7	3.19	10.41	1.403	0.188	0.053	16.51
25/07/1994	468	4898	6.91	94.1	515.2	506.5	0.36	112.8	0.106	3049.8	0.015	300.5	2.85	18.41	1.388	0.253	0.044	23.64
08/08/1994	470	4868	6.90	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
22/08/1994	485	4576	7.02	93.6	500.3	510.3	0.31	107.8	0.043	3018.7	0.003	286.2	2.78	18.55	1.39	0.448	0.067	25.12
05/09/1994	460	4701	7.19	87.3	517.7	510.7	0.3	104.9	0.036	3092.3	0.007	300.9	2.81	10.03	1.453	0.441	0.055	25.19
19/09/1994	476	4786	7.16	93	535.1	515.3	0.33	121.5	0.006	3113	0.009	317.5	2.82	10.15	1.304	0.175	0	23.17
03/10/1994	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
17/10/1994	466	4808	7.9	95.1	518.4	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
31/10/1994	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	21.304
14/11/1994	475	4735	7.15	94.8	504.5	499.7	0.3	135.3	0.012	3125.8	0.009	289.4	2.79	10.62	1.655	0.145	0.105	21.463
28/11/1994	474	4715	7.14	97	522	528	0.27	125.7	0.057	3046.9	0.005	306.7	2.84	20.23	1.73	0.145	0	19.312
12/12/1994	475	4530	7.42	97.6	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
28/12/1994	441	4382	7.57	101	479.1	450.9	0.28	139.8	0.022	2877.9	0.005	242.9	2.89	25.48	1.982	0	0.001	6.804
16/01/1995	454	4949	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
06/02/1995	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	10.564
20/02/1995	477	4676	7.18	98	508.3	528.6	0.32	125.1	0.021	2956.4	0.006	355.8	3.79	21.85	2.348	0	0.021	17.625
20/03/1995	481	4844	7.07	104.1	505.1	522.2	0.36	148.1	0.001	3061.6	0.009	364	4.03	24.17	3.551	0.217	0.075	23.86
03/04/1995	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
19/04/1995	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	0.054	0	14.788
02/05/1995	473	4736	7.1	102.4	507.5	519.5	0.44	126.3	0.014	2976.3	0.006	389.9	4.06	23.28	3.728	0.14	0.547	10.706
22/05/1995	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
05/06/1995	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	0.045	19.536
19/06/1995	495	4752	7.38	109	567	425.2	0.28	122.4	0.043	3061	0.006	358	3.74	25.32	3.687	0.2	0.057	19.917
03/07/1995	452	4039	7.11	109.4	371.6	543.4	0.32	148	0.023	2391.6	0.011	380	3.97	19.28	4.014	0.172	0.013	21.982
17/07/1995	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
31/07/1995	443	3820	7.47	124.1	373.8	408.8	0.31	143.8	0.019	2298.5	0.022	368.3	3.88	18.08	3.85	0.95	0	23.939
14/08/1995	465	4776	7.08	98.8	514.9	526.8	0.29	124.5	0.041	3037.6	0.007	382.8	3.86	24.78	4.251	0.148	0.044	20.34
28/08/1995	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
13/09/1995	469	4421	7.26	99.2	492.1	465.6	0.27	109.6	0.372	2808.5	0.009	339.8	3.91	24.71	3.661	0.24	0.043	16.465
26/09/1995	487	4393	7.19	100.9	455.3	478.8	0.3	55.4	1.207	2877.9	0.008	319.4	4.1	25.84	2.782	0.266	0.051	12.376
24/10/1995	455	4676	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	14.182
06/11/1995	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
18/12/1995	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	0.088	0	11.108
02/01/1996	535	5036	7.14	158.4	488.4	532	0.16	111.7	0	3351.9	0.008	298.9	4.56	30.25	1.228	0.122	0	11.674
22/01/1996	542	4931	7.28	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
29/01/1996	488	5100	7.48	274.2	487	527.5	0.21	98.2	2.9	3268.5	0.01	352.6	4.1	20.18	0.731	0.148	0.114	8.36
19/02/1996	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	0.302	0.146	3.821	6.44
05/03/1996	471	5002	7.28	389.5	373.6	519.4	0.22	64	0	3184	0.012	378.4	4.08	29.27	0.346	0	0	5.51
01/04/1996	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	0.691	0.261	0.027	1.37
15/04/1996	447	4556	7.53	243.2	378.2	520.3	0.2	60.8	0.063	2894.9	0.005	359	3.98	20.07	0.581	0.181	0.015	1.831
30/04/1996	465	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
13/05/1996	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
27/05/1996	428	4328	7.55	199.7	369.8	491.1	0.28	41.9	0.022	2755.7	0.004	369.4	4.22	18.28	0.454	0.998	0.681	6.72
10/06/1996	447	4408	7.2	199.5	361.6	510.7	0.23	39.5	0.011	2834.5	0.036	363.2	4.81	18.63	0.459	0.114	7.02	7.7

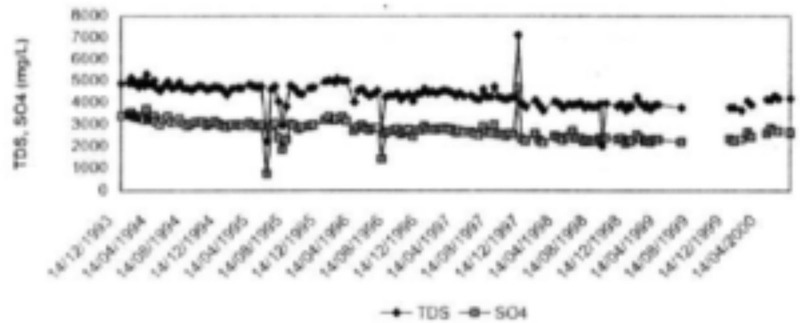
24/06/1996	460	4566	7.4	196.8	376.3	583.5	0.31	63.4	0.029	2844.1	0.012	380.1	4.73	26.9	0.475	0	0	7.21
10/07/1996	309	2778	7.6	252	194.6	279	0.92	33.8	0.024	1436.6	0.014	482.9	8.39	15.98	0.637	0.047	0	3.632
22/07/1996	442	4250	7.4	179.9	403.1	498.5	0.93	54.5	0.016	2619.2	0.011	399.9	4.85	18.29	0.439	0.082	0	7.586
05/08/1996	454	4351	7.01	171.2	403.8	523.4	0.18	46	0.048	2662.9	0.003	405.8	4.87	17.72	0.414	0.535	0	6.4
19/08/1996	452	4339	7.03	172.6	392.6	490.8	0.19	49	0.098	2732.9	0.015	402.7	4.88	18.78	0.279	0	0	3.781
02/09/1996	441	4444	7.02	185.5	383.9	533.6	0.18	56.7	0.141	2789.3	0.000	388.7	4.65	19.43	0.178	0	0	8.98
16/09/1996	448	4148	7.12	181.3	370.6	486.2	0.13	47.6	0.107	2584.5	0.011	397.3	4.88	12.28	0.094	0.173	0.034	6.625
30/09/1996	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	0.082	0.216	0	6.84
14/10/1996	462	4393	7.28	183.4	381.8	538.3	0.17	46.6	0.079	2759.1	0.082	385.2	6.29	14.04	0.07	0	0	6.283
28/10/1996	373	4079	7.27	184	358.7	450.8	0.14	45.9	0.095	2470	0.012	411.0	4.7	13.58	0.064	0.064	0	7.881
12/11/1996	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	0.781	0.351	0	1.772
25/11/1996	452	4430	7.35	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
09/12/1996	455	4648	7.33	223.4	409	553.3	0.13	56.1	0.021	2922.6	0.012	384.3	5.35	14.3	0.639	0.407	0	3.917
23/12/1996	414	4455	7.73	238.2	394.5	492.1	0.11	57.6	0.029	2782.3	0.006	394.9	4.75	17.42	0.78	0.33	0	2.882
06/01/1997	391	4524	7.65	248.3	388.3	542.2	0.12	64.5	0.024	2792.2	0.005	410	4.79	17.12	0.752	0.482	0.017	1.995
20/01/1997	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
04/02/1997	431	4535	7.84	201	370.6	541.4	0.13	65.9	0.028	2858.4	0.005	434	4.3	16.56	1.032	0	0	0.902
17/02/1997	457	4583	7.9	195.6	398.1	555.3	0.14	70	0.053	2829.4	0.008	423.5	4.2	16.62	0.822	0	0	1.314
03/03/1997	460	4540	7.68	230.8	358.4	548.4	0.17	73.2	0.032	2804.9	0.008	417.1	4.57	14.88	0.758	0.652	0.061	2.654
17/03/1997	458	4473	7.79	191.1	395.8	532.8	0.16	74	0.021	2798.5	0.005	414.5	5.32	15.97	0.855	0	0	2.327
01/04/1997	446	4326	7.62	218.5	379.8	483.9	0.18	81.5	0.049	2844.7	0.013	427.6	4.56	16.57	0.885	0.153	0	1.67
14/04/1997	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
25/04/1997	417	4310	7.35	222.9	377.3	434.5	0.16	73.2	0.034	2657.1	0.015	412.5	5.2	16.53	0.885	0.167	0	0.089
26/05/1997	456	4343	7.65	214.1	358.8	534.6	0.17	71.3	0.02	2863.2	0.008	395.4	4.61	16.78	1.05	0.055	0	2.152
09/06/1997	432	4189	7.4	204.2	327.1	537	0.14	53.7	0.013	2580.8	0.002	384.2	5.75	16	0.987	0.093	0	0.055
23/06/1997	430	4147	7.5	223.6	348.5	585.5	0.12	58.2	0.02	2509	0.006	388.6	4.87	17.06	0.902	0.015	0	0.061
08/07/1997	454	4617	7.37	290.5	390.1	472.9	0.14	33.7	0.003	2913.3	0.013	411.6	4.61	12.99	0.559	0.066	0	9.593
21/07/1997	431	4283	7.48	216.2	354.5	507.9	0.12	55.9	0.045	2895.6	0.006	382.7	4.33	14.93	0.895	0.05	0	3.963
04/08/1997	420	4272	7.53	210.2	343.7	596.8	0.15	57.8	0.045	2806.9	0.080	426.6	4.84	15.31	0.9	0.036	0	4.045
18/08/1997	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
01/09/1997	400	4265	7.56	199.9	348.2	546.7	0.15	60.4	0.063	2568.4	0.004	432	4.46	15.28	0.885	0.08	0.079	1.583
15/09/1997	434	4214	7.51	200.6	345.3	527.8	0.14	54.6	0.037	2560.2	0.006	417.1	4.42	15.59	0.86	0	0	0.07
29/09/1997	433	4163	7.63	180	343.7	547	0.13	55.6	0.094	2477.8	0.005	436	4.45	15.54	0.890	0	0	0.045
13/10/1997	436	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
27/10/1997	415	4253	7.5	173.8	351.8	587.9	0.16	57.9	0.142	2560.4	0.011	429.1	6.47	16.21	0.939	0	0	4.702
10/11/1997	711	7129	7.61	275.1	1065.3	403.1	0.04	41.5	0.024	4883	0.012	522.8	4.82	22.01	1.358	0	0	7.04
24/11/1997	414	3954	7.73	174.1	309.4	548	0.07	48.1	0.155	2344	0.008	422.3	4.78	15.3	0.838	0	0	0.905
08/12/1997	386	3804	7.86	176.2	333.1	528	0.05	62.5	0.904	2264.1	0.009	345	4.78	15.48	0.025	0	0	0.829
12/01/1998	406	4124	7.84	176.7	293.8	549.1	0.09	34	0.113	2581.5	0.002	386.3	4.83	16.01	0.94	0	0	2.913
26/01/1998	403	3870	7.29	173.8	265.4	579.3	0.13	39.3	0.013	2290	0.007	421.6	4.84	15.37	0.91	0	0	0
09/02/1998	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	0.827	0.062	0	0
23/03/1998	352	4060	7.69	195.3	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
06/04/1998	405	3980	7.85	200.3	274.8	679.7	0.08	32.6	0.542	2408.3	0.009	382.1	5.03	15.6	0.338	0	0.029	0.166
20/04/1998	408	3757	7.79	180.1	261.3	552.8	0.14	32.8	0.023	2298	0.011	333.3	4.92	15.12	0.877	0	0.051	7.49
11/05/1998	381	3941	7.94	170.9	281.6	558.7	0.08	21.7	0.053	2428.5	0.013	379.6	4.81	15.57	0.793	0	0	6.77
25/05/1998	384	3893	6.45	165.3	271.1	564.9	0.23	39.2	0.046	2704.9	0.038	107.4	5.25	15.97	0.685	0.57	4.028	16.31
08/06/1998	401	3939	7.04	168.5	283.7	533.8	0.1	37.8	0.05	2377.7	0.013	427.4	5.22	15.08	0.785	0.271	0	6.22
22/06/1998	410	3992	7.4	173.8	278.0	580.9	0.11	34.1	0.038	2378.2	0.013	427.5	5.36	16.26	0.785	0.253	0	6.38
06/07/1998	386	3779	7.25	164.1	276	526.5	0.1	46.9	0.288	2233.8	0.039	420.5	5.25	18.64	0.353	0.071	0.004	2.393
20/07/1998	387	3888	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	3.006
03/08/1998	365	3812	7.35	171.1	268.3	555.9	0.09	48.6	0.290	2238.2	0.051	419.7	5.35	16.13	0.373	0.096	0.003	0.13
17/08/1998	353	3826	7.23	174.4	268.1	555.9	0.16	50.5	0.298	2247.4	0.017	421	5.45	16.54	0.354	0.122	0.008	3.466
31/08/1998	358	3947	7.56	185.4	289.4	585.8	0.1	46.7	0.202	2376	0.011	381.3	6.64	16.54	0.272	<0.02	<0.003	0.055
07/09/1998	483	2931	8.53	244.3	399.4	598.7	0.1	68.7	0.848	2376	0.067	158.5	2.96	23.34	<0.04	<0.02	<0.003	0.43
21/09/1998	353	3971	7.54	161.5	259.7	504	<0.1	49.5	0.301	2391.6	0.005	382.1	6.85	15.78	0.213	<0.02	<0.003	0.479
02/11/1998	306	3835	7.18	163.5	275.8	497.4	<0.1	47.6	0.322	2329.4	0.013	414.6	4.57	13.81	<0.04	<0.02	<0.003	<0.001
16/11/1998	367	3952	7.55	159.8	268.6	585	0.15	44.5	0.167	2378.5	0.005	423	5.05	16.23	<0.04	<0.02	0.015	0.085
01/12/1998	390	3570	7.18	160.3	258.1	547.8	0.16	46.1	0.208	2161.7	0.01	392.4	4.95	16.16	<0.04	<0.02	0.085	0.006
21/12/1998	402	3809	7.15	168.9	284.5	484.9	<0.1	48.9	<0.04	2283.3	0.007	442.8	4.88	16.63	1.38	<0.02	<0.003	0.567
14/12/1998	392	3876	7.76	180.5	281.5	562.2	0.15	45.2	0.27	2289.5	0.011	425.9	4.74	16.63	<0.04	<0.02	<0.003	<0.001
11/01/1999	434	4284	7.57	237.3	308	553.3	<0.1	34.4	<0.04	2548	0.006	484	5.38	17.52	1.108	<0.02	0.085	1.277
25/01/1999	390	3949	7.25	174.7	244.5	584.3	<0.1	54.7	0.072	2381.3	0.005	395.1	4.44	16.27	0.957	<0.02	<0.003	4.435
08/02/1999	400	3786	7.81	178.2	255.9	512.9	<0.1	58.9	<0.04	2238.2	0.009	429.7	4.83	16.92	1.041	<0.02	<0.003	5.56
15/02/1999	402	3804	7.83	167.7	276.1	555.7	<0.1	67.7	<0.04	2279.3	0.008	431.8	5.1	16.73	0.955	<0.02	<0.003	0.531
01/03/1999	430	3703	7.38	161.7	275.7	487	<0.1	67.8	<0.04	2220.1	0.012	386.9	7.25	17.01	0.937	<0.02	<0.003	6.47
15/03/1999	390	3887	7.64	167.8	266.3	586	0.14	62.7	0.172	2321.8	0.012	381.4	5.67	15.87	0.495	<0.02	<0.003	4.428
29/03/1999	394	3908	7.45	167.2	278.5	603.8	0.14	64.2	0.295	2319.1	0.014	376.1	5.58	16.78	0.07	<0.02	0.283	2.548
21/06/1999	433	3768	7.11	169.6	259.5	532.5	0.12	64.9	0.686	2209.2	0.009	420.6	5.07	16.28	<0.04	<0.02	<0.003	<0.001

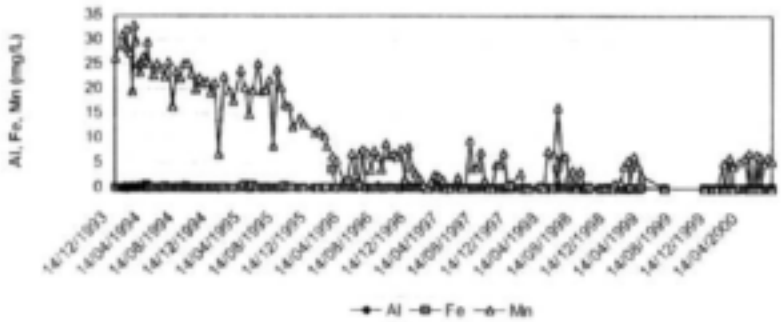
15/11/1999																<0.035	<0.005	0.001
28/12/1999																<0.035	<0.005	0.001
13/12/1999																<0.035	<0.005	0.001
13/12/1999	405	3762.251	7.89	152.451	275.075	557.11	<0.1	63.059	0.966	2350.826	0.01	287.551	5.23	18.58	0.05			
28/12/1999	402	3781.761	7.725	174.742	269.847	548.748	0.313	66.605	1.298	2263.25	0.027	387.875	4.88	18.281	0.05			
24/01/2000																<0.035	<0.005	5.11
28/02/1994																		
22/01/1996																		
29/01/1996																		
09/12/1996																		
24/01/2000	393	3654.564	7.039	295.576	231.141	431.331	<0.1	29.400	0.05	2339.108	0.006	258.104	0.007	12.334	0.528			
14/02/2000																<0.035	<0.005	6.13
28/02/2000	441	3904.448	7.215	255.523	309.071	463	0.201	29.521	<0.04	2448.095	0.016	314.068	6.077	15.277	0.538			
14/02/2000	450	4064.009	7.287	279.94	327.769	428.168	0.136	24.92	0.047	2644.428	0.016	287.474	6.545	14.729	0.749			
28/02/2000																<0.035	<0.005	4.422
20/03/2000																<0.035	<0.005	5.3
10/04/2000																<0.035	<0.005	6.12
08/05/2000	445	4146.783	7.265	238.02	328.717	484.337	<0.1	32.262	<0.04	2830.466	0.018	178.918	5.032	13.901	0.584			
25/04/2000	442	4162.923	7.236	240.398	312.444	492.653	0.183	33.787	<0.04	2612.932	0.019	376.224	6.81	11.023	0.524			
25/04/2000																<0.035	0.034	7.12
22/05/2000																<0.059	<0.006	6.86
05/06/2000																<0.059	0.063	6.42
05/06/2000	444	4203.386	7.762	244.245	312.743	505.648	0.193	40.239	<0.04	2684.492	0.015	329.205	6.073	13.798	0.396			
22/05/2000	445	4324.042	7.578	295.815	323.839	511.608	0.131	33.766	<0.04	2733.544	0.024	336.273	6.058	15.212	0.436			
20/06/2000																<0.059	<0.006	5.1
03/07/2000																<0.059	<0.006	6.31
17/07/2000																<0.059	0.121	5.45
17/07/2000	447	4200.218	8.064	229.707	339.207	523.366	<0.1	40.004	0.106	2639.974	0.01	341.164	5.396	11.024	0.326			
Min	309	2031	6.48	78.5	40.6	85	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	1085.3	603.8	0.92	338.4	3.969	4683	0.051	522.8	0.007	38.25	4.259	0.998	7.02	33.12
Mean	442.7902	4357.531	7.409657	166.4301	405.4969	514.1305	0.221427	74.28931	0.205414	2767.964	0.011266	354.5067	4.454392	17.63095	1.092788	0.156949	0.172532	10.73127
Median	447	4409	7.38	169.7	379.8	520.3	0.18	63.059	0.041	2775.3	0.009	376.224	4.46	15.57	0.838	0.129	0.0105	6.797
95-percentile	373.7	3708.4	6.991	88.92	259.68	431.6479	0.08	32.8	0.009	2234.24	0.003	236.58	2.811	10.5793	0.0798	0	0	0.01155

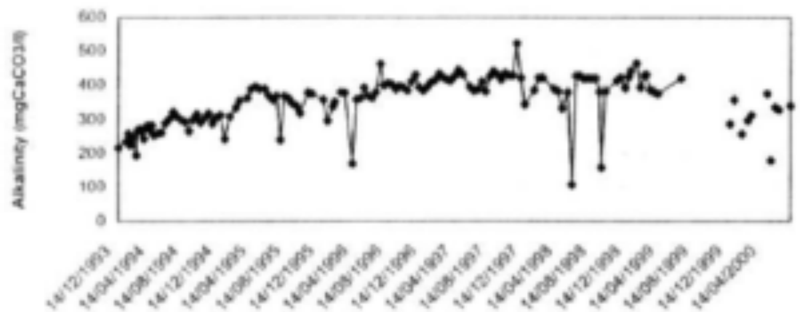
Cell 8

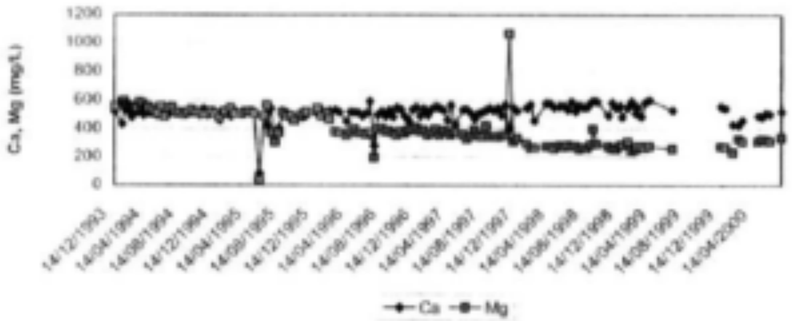

EC (mS/m)


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 9A

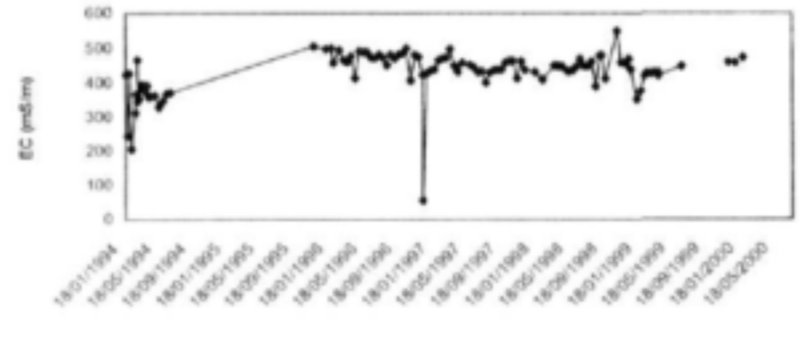
Date	EC	TDS	pH	Na	Mg	Ca	Fl	Cl	NO3	SO4	PO4	ALK	Si	K	NH4	Al	Fe	Mn
28/02/1994	90.3	652	4.35	14.2	40	115.3	0.72	2.1	4.286	455.2	0.007	1	6.55	2.41	0.494	12.5	0.067	3.938
22/01/1996	41	254	7.74	22.1	12.2	28	0.18	9.6	0.02	125	0.009	44.2	5.07	2.53	0.053	0	0	0
29/01/1996	34.8	242	7.42	20.6	11.4	28.5	0.21	8.2	0.036	117.5	0.014	43.3	5.18	2.88	0.071	0.034	0.004	0
09/12/1995	17.9	127	6.91	5.2	5.8	17.2	0.11	3.1	0.017	29.5	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	29.5	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	9.6	4.286	455.2	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	5.75	1.08975	181.8	0.00925	36.2	5.325	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	5.125	2.47	0.062	0.0535	0.002	0.069
95-percentile	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

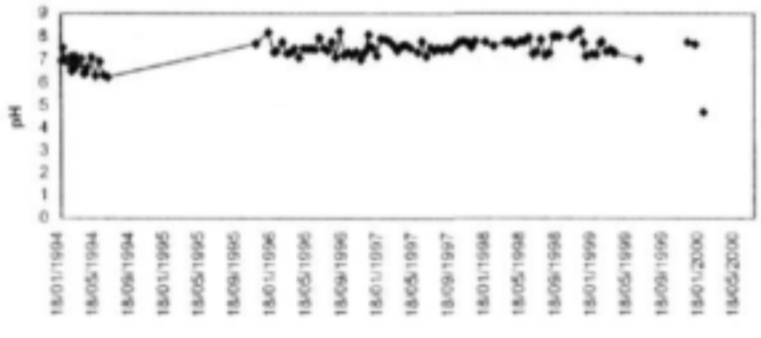
Cell 9B

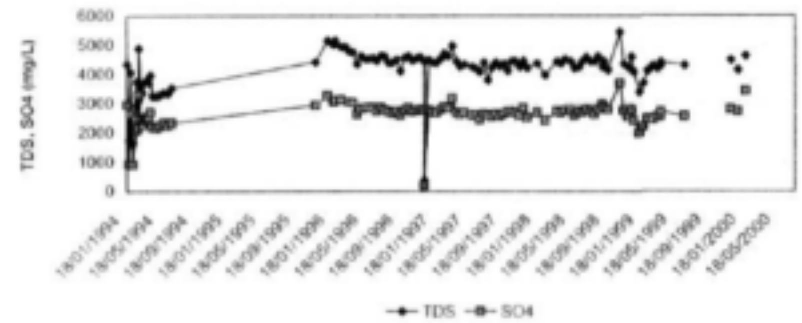
Date	EC	TDS	pH	Na	Mg	Ca	Fl	Cl	NO3	SO4	PO4	ALK	Si	K	NH4	Al	Fe	Mn
21/02/1994	314	2964	6.53	117.7	225.1	415	0.27	54	0.291	2102.9	0.044	30.4	3.85	8.65	1.05	0.118	12.33	72.9
28/02/1994	348	3131	6.57	163.4	227.4	414.4	0.24	64.3	0.114	2186.5	0.062	52.6	3.83	8.54	1.698	0.154	2.325	55.4
07/03/1994	356	3522	7.19	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	45.61
14/03/1994	396	3387	6.77	113.2	272	457.8	0.22	88.2	0.04	2288.7	0.022	104.2	3.44	30.41	1.317	0.162	22.02	43.79
21/03/1994	398	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	45.18
28/03/1994	377	3798	7.08	249.7	267.2	483.8	0.27	89.6	0.095	2533.7	0.02	128.6	3.78	14.3	1.955	0.153	0.031	47.88
05/04/1994	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
11/04/1994	360	3904	5.44	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
18/04/1994	363	3278	6.71	182.7	226.8	441.4	0.21	65.1	0.013	2226.2	0.006	95	3.54	12.77	2.629	0.128	13.88	55.4
02/05/1994	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
16/05/1994	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	40.26
30/05/1994	343	3391	6.05	161.6	229.5	412	0.34	73.6	0.04	2345.5	0.006	124.4	3.15	12.54	2.96	0.041	5.43	45.91
13/06/1994	370	3351	6.35	164.1	234.6	450.8	0.28	78.6	0.02	2259.1	0.029	120.3	3.14	12.48	3.024	0.148	10.09	48.77
27/06/1994	373	3545	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
02/01/1996	409	5175	8.19	551.8	305.5	484.4	0.19	122.1	0	3252.2	0.008	320.7	5.3	28.94	0.942	0.066	0	1.7
22/01/1996	504	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	5.81
29/01/1996	459	5858	7.4	508.1	359.3	527.2	0.23	133.7	22.98	3111.6	0.016	336.3	4.59	15.18	0.62	0.081	0.019	5.37
19/02/1996	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
05/03/1996	487	4963	7.29	473.1	318.8	520.7	0.24	83.6	0.508		0.007	339.8	4.99	23.99	0.293	0	0	4.235
18/03/1996	459	4803	7.35	367.4	325.3	525	0.21	44.3	0	3052.6	0.008	379.5	5.25	24.79	0.272	0.301	0	4.868
01/04/1996	478	4770	7.51	375.7	327.9	538.3	0.22	88.9	0.018	3037.4	0.006	310.7	4.51	23.08	0.418	0.111	0.016	8.45
15/04/1996	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
30/04/1996	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
13/05/1996	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	0.035	0.032	6.5
27/05/1996	490	4555	7.5	353.6	302	506.8	0.39	72.6	0.036	2895.2	0.01	359.3	4.84	15.82	0.367	1.056	1.157	5.78
10/06/1996	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
24/06/1996	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	6.025
10/07/1996	483	4880	7.51	327.2	345.4	532.2	0.23	92.4	0.035	2892.6	0.006	388.5	5.21	25.42	0.39	0.083	0	7.22
22/07/1996	475	4830	7.42	345.8	350.6	523.6	0.22	98.5	0.02	2790.1	0.01	467.3	5.12	23.56	0.403	0	0	3.941
05/08/1996	453	4434	7.8	323.5	337.5	427.1	0.21	85.6	0.018	2729.9	0.005	390	5.3	23.65	0.412	0.546	0	6.39
19/08/1996	483	4425	7.12	325	326.9	513.7	0.2	84.2	0.015	2571.9	0.009	400	5.27	17.93	0.377	0	0	2.351
02/09/1996	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
16/09/1996	483	4134	7.23	314.6	357	405	0.14	68.8	0.02	2611.5	0.007	361.2	5.17	8.69	0.391	0.178	0.026	1.057
30/09/1996	487	4587	7.38	344.2	362	520.6	0.2	84.6	0.022	2772.8	0.02	403.6	4.98	9.27	0.458	0.173	0	7.068
14/10/1996	509	4639	7.22	338.8	367.8	514.5	0.2	70.7	0.048	2860.6	0.003	390.1	4.84	9.68	0.498	0.05	0	6.475
28/10/1996	409	4483	7.37	318.8	354.6	473.6	0.17	89.4	0.018	2734.3	0.006	403.9	4.77	8.72	0.476	0	0	3.078
12/11/1996	482	4573	7.03	382	339.5	520.2	0.16	88.4	0.019	2781	0.009	385.9	5.35	10.73	0.422	0.390	0.012	6.92
25/11/1996	476	4594	7.35	353.1	331	520.7	0.17	81.6	0.023	2816.5	0.011	386.1	5.12	10.79	0.459	0.781	0.043	7.53
09/12/1996	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
23/12/1996	429	4510	7.55	225.2	386.5	518	0.11	58.2	0.027	2791.4	0.006	421.9	4.68	16.78	0.865	0.43	0.014	3.259
06/01/1997	438	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
20/01/1997	442	4437	7.93	317.2	332.9	409.9	0.16	67.5	0.043	2604.6	0.008	395.2	5.1	11.62	0.841	0	0	0.921
04/02/1997	467	4556	7.89	318.8	323.5	536.3	0.21	72.2	0.038	2904	0.006	399.8	5.11	12.34	0.756	0	0	1.175
17/02/1997	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
03/03/1997	474	4543	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
17/03/1997	499	4903	7.42	288	472.4	484.9	0.17	59	0.028	3103.3	0.006	393.5	5.47	14.17	0.493	0	0	5.1
01/04/1997	451	4498	7.61	223.8	378.1	583.4	0.16	72.6	0.062	2887.4	0.019	428.1	4.58	16.56	0.887	0.141	0	0.591
14/04/1997	434	4283	7.65	341.2	326.8	419.8	0.17	20.5	0.029	2538	0.014	430	5.48	11.08	0.605	0.154	0	0.008
29/04/1997	459	4351	7.54	250.4	309.2	422.7	0.19	58.5	0.047	2590.1	0.019	429.5	4.66	14.83	0.722	0.961	0	1.643
26/05/1997	454	4269	7.34	298.5	326.5	499.5	0.18	67.3	0.02	2603.5	0.009	377.6	5.28	11.78	0.855	0.077	0	2.314
09/06/1997	447	4208	7.81	293.4	314.5	474	0.15	51.3	0.027	2516.5	0.004	363.7	5.08	11.88	0.821	0.103	0	0.003
23/06/1997	433	4101	7.18	292.2	300.5	488.2	0.13	52.4	0.02	2453.8	0.01	427.7	5.41	11.05	0.689	0	0	1.558
08/07/1997	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
21/07/1997	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
04/08/1997	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	3.501
18/08/1997	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
01/09/1997	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	1.408
15/09/1997	441	4372	7.46	285.1	325.7	515.1	0.16	64.9	0.034	2547.3	0.005	427.7	5.05	10.17	0.679	0.067	0	0.098
29/09/1997	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
13/10/1997	466	4458	7.75	239.6	358.1	524.5	0.2	68.8	0.055	2721.7	0.021	437.7	5.66	12.3	0.66	0	0	5.15
27/10/1997	495	4463	7.82	253	357.3	552	0.22	66.9	0.053	2690.7	0.01	433.6	5.65	12.69	0.649	0	0	3.77
10/11/1997	415	4277	7.77	247.9	306.4	544	0.08	51.3	0.025	2508.3	0.008	424	5.18	10.86	0.721	0	0	0.727
24/11/1997	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
08/12/1997	449	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
12/01/1998	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
09/02/1998	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
23/03/1998	452	4450	7.78	311.7	295.6	567.4	0.17	40.7	0.37	2738.5	0.013	397.2	5.62	9.46	0.296	0	0.046	0.142

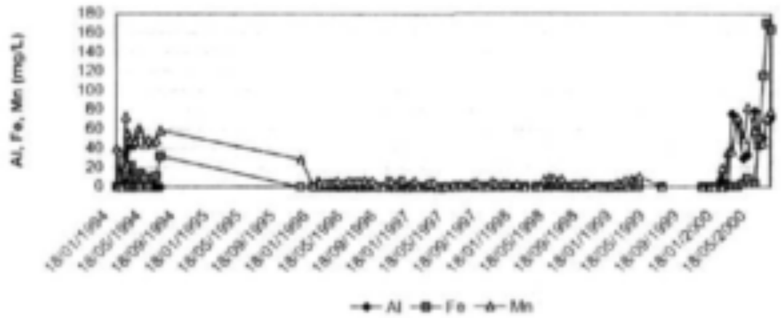
08/04/1998	451	4385	7.8	300.1	296.4	565.1	0.11	41.1	0.352	2888.5	0.005	395.3	5.6	10.38	0.302	0	0.028	0.217
20/04/1998	449	4526	7.68	277.8	339.9	547.1	0.17	53.3	0.091	2756.2	0.009	443.9	5.48	9.3	0.718	0	0.058	7.54
11/05/1998	435	4452	7.81	234.6	355.9	491.4	0.11	51	0.06	2759.6	0.017	448	5.08	12.19	0.803	0	0	9.75
25/05/1998	438	4223	7.83	245.6	372.3	499.2	0.13	55.2	0.07	2905.3	0.006	354.9	5.07	11.43	0.821	0.511	0	8.72
08/06/1998	446	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
22/06/1998	471	4488	7.28	274.2	344.7	539.6	0.14	49	0.023	2896.9	0.008	449.9	5.49	11.2	0.835	0.258	0.004	8.51
06/07/1998	451	4592	7.37	314.7	365.3	467.8	0.11	76.6	0.025	2803.6	0.05	451.5	5.43	11.84	0.632	0.089	0.003	1.709
20/07/1998	451	4450	7.88	320.5	322.7	400.8	0.09	81	0.148	2745.7	0.05	390.5	4.95	11.4	0.658	0.087	0	0.047
03/08/1998	463	4445	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
17/08/1998	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	2.645
31/08/1998	480	4271	8.02	385.9	331.2	398.3	0.15	93.2	0.286	2977	0.014	64	6.66	14	0.327	<0.02	<0.003	0.443
07/09/1998	482	4451	8.04	395.3	329.6	478.6	0.1	87.2	0.273	2881.5	0.007	217.9	6.61	12.07	0.089	<0.02	<0.003	3.935
21/09/1998	414	4157	8.02	380.7	274	401.8	0.11	88.9	0.153	2792.1	0.009	120.5	6.81	11.94	<0.04	<0.02	<0.003	3.175
02/11/1998	549	5462	7.98	480.7	423.5	532.6	<0.1	120.9	0.225	3897.8	0.018	157.7	2.64	12.78	0.084	<0.02	<0.003	1.164
16/11/1998	460	4357	8.16	351.8	319.2	406.5	0.16	88.6	<0.04	2752.6	<0.005	349.2	5.18	12.04	0.043	<0.02	<0.003	0.017
01/12/1998	458	4285	8.26	356.1	322.1	464.3	<0.1	86.7	<0.04	2570.2	0.053	371.4	5.12	12.23	<0.04	<0.02	<0.003	<0.001
21/12/1998	441	4097	7.17	271.4	340.9	414.7	0.17	74.5	<0.04	2420.7	0.009	459.2	5.99	13.86	0.866	<0.02	0.211	1.213
14/12/1998	471	4621	7.74	339.1	341.3	527.5	0.18	92	0.100	2785.4	0.012	428.7	5.21	12.2	0.046	<0.02	0.078	<0.001
11/01/1999	353	3405	7.28	240.6	198.6	412.5	0.14	32.3	<0.04	2007.1	0.012	395.8	6.29	9.56	0.806	<0.02	0.011	3.57
25/01/1999	378	3702	7.25	258.8	214.4	482.6	0.15	38.6	0.078	2224.4	0.007	385.6	6.52	11.32	0.8	<0.02	<0.003	3.08
08/02/1999	423	4118	7.75	278.5	202.5	503.2	<0.1	37.4	<0.04	2487.6	0.011	429.9	5.87	13.22	0.867	<0.02	0.393	6.67
15/02/1999	429	4187	7.8	278.8	309.4	499.6	0.17	46.2	<0.04	2484.3	0.007	437.3	5.99	14.24	0.846	<0.02	<0.003	1.061
01/03/1999	429	4294	7.37	271.2	295.8	520	0.14	47.7	<0.04	2454.7	0.013	397	6.24	14.11	0.985	<0.02	<0.003	7.97
15/03/1999	431	4203	7.45	286.7	286.5	556.6	0.17	44.4	<0.04	2513.6	0.012	395.1	6.75	12.25	1.024	<0.02	<0.003	7.03
29/03/1999	431	4309	7.37	291.3	298.9	578.8	0.25	69.2	<0.04	2571.6	0.045	306.6	6.87	12.02	0.987	<0.02	0.33	6.78
29/03/1999	422	4417	7.3	206.2	350.8	587.6	0.18	129.9	<0.04	2709.9	0.012	339.6	5.23	15.09	0.772	0.034	0.78	10.68
21/06/1999	449	4311	7.05	298.3	293.5	565.3	0.13	52.4	0.183	2557.2	0.007	435.5	5.95	11.95	<0.04	<0.02	<0.003	<0.001
15/11/1999																<0.035	<0.005	0.001
28/12/1999																0.082	<0.005	0.001
13/12/1999																<0.035	<0.005	0.001
03/12/1999	451	4495.901	7.765	315.572	337.612	403.988	0.429	67.580	0.893	2800.48	0.028	377.495	5.251	15.983	<0.04			
28/12/1999	459	4150.434	7.687	290.028	330.462	464.88	0.274	65.061	0.875	2725.226	0.025	291.068	5.356	16.374	<0.04			
24/01/1994	246	1761	7.54	296.1	102.4	134	0.3	118	28.307	938	0.01	35	7.58	3.59	0.224	<0.02	<0.003	0.664
31/01/1994	429	4384	7.06	231	342	518	0.13	82.5	<0.04	2654.6	0.014	200.8	3.07	9	1.157	<0.02	0.028	38.4
16/01/1994	426	4363	6.98	218.5	380.3	507.6	0.18	61.1	<0.04	2068.4	<0.005	179.3	3.23	8.84	0.943	0.264	0.02	40.26
07/02/1994	207	1674	6.9	202.8	88.3	126.2	0.18	122.9	24.188	926.7	0.005	30.2	6.4	2.95	0.098	0.211	<0.003	0.432
28/02/1994	468	4304	6.82	85.5	567.9	528	0.26	81	<0.04	3321.9	0.008	252.9	3	9.92	0.7	0.169	<0.003	24.37
21/02/1994	368	3769	7.16	138.8	393.1	377.9	0.26	84.1	7.808	2508.1	0.012	184	3.38	7.32	0.511	0.145	<0.003	10.18
20/11/1995	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
09/12/1995	56.6	390	7.61	72.7	17.2	23.5	<0.1	19.2	0.126	225.1	0.012	25.3	3.04	0.5	0.064	0.094	<0.003	0.057
24/01/2000																6.51	0.912	19.57
24/01/2000	474	4843.348	4.721	283.241	418.554	452.58	<0.1	29.317	<0.04	3435.156	0.018	<4	14.238	21.584	0.22			
14/02/2000																3.337	<0.005	36.03
28/02/2000																75.75	0.127	37.19
20/03/2000																67.5	0.976	72
10/04/2000																30.04	3.548	49.73
25/04/2000																33.3	9.1	82.55
22/05/2000																78.85	4.055	58.45
05/06/2000																51.232	49.01	44.24
20/06/2000																51.557	115.76	46.17
03/07/2000																69.11	170.069	72.1
17/07/2000																71.428	164.056	78.5
Min	56.6	390	4.721	72.7	17.2	23.5	0.09	19.2	0	225.1	0.003	25.3	1.78	0.5	0.043	0	0	0
Max	549	5462	8.26	551.6	567.9	587.6	0.429	133.7	28.367	3897.8	0.062	461.1	14.236	30.41	3.523	78.85	170.069	82.55
Mean	432.9265	4216.064	7.412981	292.6766	317.0488	483.0443	0.19153	72.11111	1.276736	2637.165	0.013356	320.8641	5.0566	13.79515	0.82735	5.738531	6.815583	15.60474
Median	448	4386	7.43	291.3	325.6	499.5	0.15	72	0.036	2695.75	0.008	378.55	5.12	12.23	0.67	0.12	0.011	4.866
95-percentile	348.2	3268.4	6.458	158.52	220.54	405.3	0.11	37.84	0.0155	2181.06	0.004	68.65	3.064	8.658	0.08875	0	0	0.0134

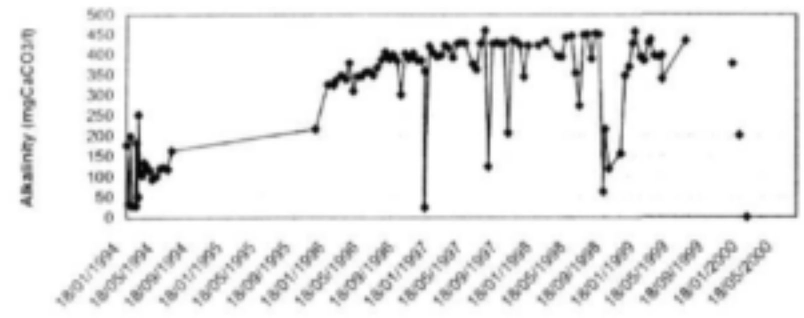
Cell 9B

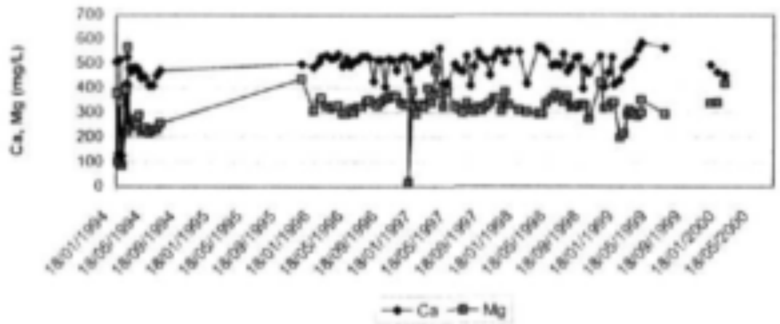

EC (mS/m)


pH


TDS, SO4 (mg/L)
TDS
SO4


Al, Fe, Mn (mg/L)
Al
Fe
Mn


Alkalinity (mgCaCO3/l)


Ca, Mg (mg/L)
Ca
Mg

Cell 10A

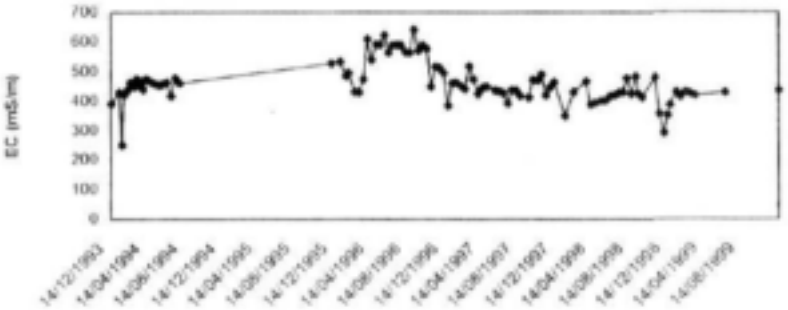
Date	EC	TDS	pH	Na	Mg	Ca	Fl	Cl	NO3	SO4	PO4	ALK	Si	K	NH4	Al	Fe	Mn
18/01/1994	426	4363	6.96	216.5	380.3	507.6	0.18	61.1	0.018	2968.4	0.004	179.3	3.23	8.84	0.043	0.264	0.02	40.26
24/01/1994	245	1761	7.54	206.1	102.4	134	0.3	118	28.307	938	0.01	35	7.58	3.59	0.224	0	0	0.664
31/01/1994	429	4084	7.06	231	342	518	0.13	82.5	0.031	2654.6	0.014	200.8	3.07	9	1.157	0	0.028	38.4
07/02/1994	207	1674	6.9	262.8	88.3	126.2	0.18	122.9	24.186	926.7	0.005	30.2	6.4	2.95	0.098	0.211	0	0.432
21/02/1994	368	3769	7.18	138.8	393.1	377.9	0.28	84.1	7.808	2508.1	0.012	184	3.38	7.32	0.511	0.145	0	19.18
28/02/1994	458	4904	6.82	85.5	567.9	528	0.25	81	0.014	3321.9	0.008	252.9	3	9.92	0.7	0.169	0	24.37
20/11/1995	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
05/12/1995	56.6	390	7.61	72.7	17.2	23.5	0.09	19.2	0.125	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	206.1	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	330.225	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-percentile	109.24	839.4	6.849	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

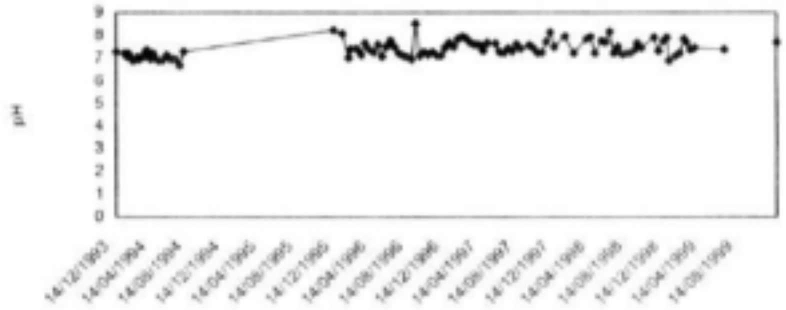
Cell 10B

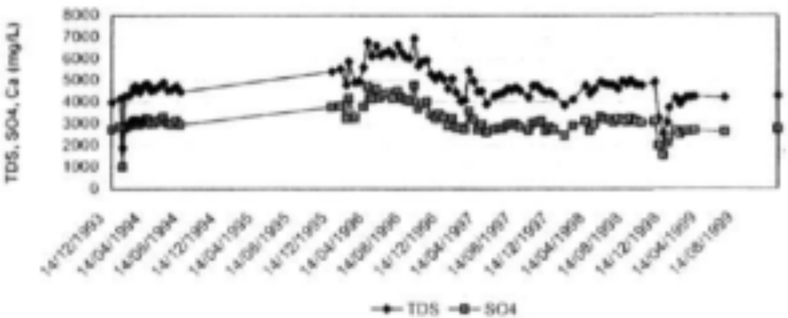
Date	EC	TDS	pH	Na	Mg	Ca	Fl	Cl	NO3	SO4	PO4	ALK	Si	K	NH4	Al	Fe	Mn
14/12/1993	391	3984	7.29	165	338.3	497.1	0.32	59	0.024	2728	0.012	158.2	3.49	7.92	0.811	0.593	0.073	26.736
10/01/1994	430	4165	7.22	198.3	405.8	431.8	0.15	56.2	0.027	2963.8	0.016	164.9	3.34	9.1	0.736	0	0	41.33
18/01/1994	251	1699	7.09	300.5	96.2	158.5	0.23	126.8	29.583	1036.1	0.002	32.3	8	3.65	0.184	0.328	0.003	0.632
24/01/1994	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	0.089	42.42
07/02/1994	440	4308	6.9	184	386.9	499.2	0.22	73.5	0.017	2893.5	0.008	205.8	3.27	8.59	0.951	0.458	0.032	35.84
14/02/1994	463	4403	6.96	173.5	405.4	501.8	0.18	75.5	0.589	2970	0.009	218.9	3.37	7.38	0.852	0.436	0.045	31.52
21/02/1994	454	4561	7.07	205.7	407.3	541.1	0.2	82.7	0.024	3115	0.017	244.1	2.89	9.42	0.836	0.157	0.004	41.57
28/02/1994	450	4733	6.98	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	0.082	39.79
07/03/1994	475	4565	7.04	219.7	438.8	533.9	0.27	85.5	0.008	3064.3	0.026	248.9	3.46	17.13	1.246	0.348	0.051	37.05
14/03/1994	475	4852	7.06	120.3	453	538.6	0.25	95.7	0.025	2965	0.008	229	3.05	8.2	0.753	0.509	0.552	36.22
21/03/1994	451	4579	7.33	180.4	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	41.55
28/03/1994	441	4770	7.34	217.8	460.2	533	0.2	98.4	0.013	3118.6	0.016	267.8	3.36	13.1	1.248	0.179	0.137	35.43
05/04/1994	474	4831	6.99	180.7	450.2	539.5	0.11	76.4	0.079	3248.5	0.002	260.2	3.23	14.97	1.506	0.135	4.853	39.18
11/04/1994	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	1.524	0.188	0.297	35.95
18/04/1994	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
02/05/1994	465	4580	6.91	154.8	470.6	514.9	0.22	85.7	0.027	3024.1	0.008	259.3	2.97	13.87	1.439	0.108	0.041	38.18
16/05/1994	455	4713	6.92	151.5	457.3	542	0.43	92	0.117	3138.4	0.095	259.1	2.67	12.79	1.5	0.143	0.03	42.4
30/05/1994	457	4897	7.15	151.1	494.5	495.7	0.38	98.2	0.031	3307.3	0.006	275.3	2.78	12.51	1.616	0.027	0	41
13/06/1994	464	4550	6.96	135.2	439.1	506.4	0.24	95.7	0.054	3029.4	0.082	282.5	2.79	6.65	1.521	0.179	1.024	39.29
27/06/1994	419	4580	6.09	139.4	465.3	520.6	0.2	100.7	0.032	2985.8	0.008	289.9	2.53	11.05	1.521	0.132	0.209	47.55
11/07/1994	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	1.596	0.188	0.045	38.92
25/07/1994	462	4495	7.31	143.2	440.9	501	0.31	96.2	0.098	2979.3	0.01	243	1.71	15.18	1.554	0.263	0.033	43.87
04/12/1995	528	5435	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
02/01/1996	534	5519	8.08	543.9	335.5	561.9	0.32	84.5	0.005	3813.4	0.026	125.9	3.57	26.23	0.52	0.107	0	8.278
22/01/1996	486	4782	7.02	421.5	334.1	437.9	0.34	73.1	0.031	3266.8	0.083	149.7	4.36	25.74	0.229	0.227	0.033	9.44
29/01/1996	497	5895	7.4	429.5	566.9	500	0.3	95.3	1.509	4164	0.01	72.1	6.54	14.3	0.195	0.323	0.122	17.73
19/02/1996	432	4903	7.43	453.8	356.3	482.8	0.25	53.5	0.802	3284.7	0.009	207.6	4.58	14.61	0.193	0.365	3.329	4.356
05/03/1996	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
18/03/1996	475	5566	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	0.006	5.44
01/04/1996	609	6772	7.39	374.9	700.9	548.5	0.18	84.7	0.015	4715.6	0.007	281.8	4.69	23.48	0.309	0.163	0	9.11
15/04/1996	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	0.365	0.15	0.017	6.43
30/04/1996	593	6591	7.61	350.1	724.6	482.7	0.22	57.4	0.008	4589.4	0.009	301.2	4.25	19.35	0.342	0.535	0.035	7.67
13/05/1996	591	6057	7.09	308.9	744.1	452	0.21	43.1	0.014	4200.5	0.008	323.7	3.64	9.86	0.312	0.088	0.058	8.04
27/05/1996	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
10/06/1996	564	6364	7.77	298.5	742.6	478	0.22	48.9	0.018	4402.2	0.012	315.6	3.6	10.33	0.231	0.113	0	4.686
24/06/1996	560	6140	7.51	292.4	700.7	519.4	0.19	42.9	0.034	4175	0.022	331.6	3.8	13.28	0.201	0.086	0	9.2
10/07/1996	580	5850	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	8.72
22/07/1996	588	6296	7.13	297.4	743.2	501.1	0.17	69	0.019	4219.8	0.014	379.2	3.64	11.76	0.411	0.167	0	7.823
05/08/1996	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
19/08/1996	564	6108	6.96	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
02/09/1996	642	6945	8.51	360.8	833.8	492.8	0.17	86.7	0.063	4751	0.014	325.4	2.7	16.68	0.269	0	0	8.118
16/09/1996	571	5607	7.12	277.5	686.4	457.6	0.18	62.1	0.069	3795.1	0.014	392.2	3.13	5.76	0.286	0.163	0.039	8.479
30/09/1996	590	5834	7.28	309.4	682	481.3	0.22	61.1	0.148	3921	0.026	353.9	2.93	6.06	0.28	0.276	0	9.03
14/10/1996	577	5837	7.18	306.8	672.6	482.4	0.19	49.1	0.189	3997.1	0.01	346.4	2.71	6.12	0.907	0.046	0	6.678
28/10/1996	450	5289	7.28	303	586.6	410.5	0.16	78.6	0.018	3429.6	0.009	388.2	3.91	6.03	0.238	0	0	5.171
12/11/1996	517	5061	7.13	330	520	445.8	0.14	83.6	0.02	3278.6	0.041	322.5	4.64	6.8	0.308	0.348	0.011	3.61
25/11/1996	514	5252	7.13	292	528	495.3	0.17	75.6	0.015	3447.8	0.017	329.5	4.11	11.8	0.349	0.906	0.074	10.14
09/12/1996	497	5352	7.47	342.6	458.8	495.8	0.15	58.1	0.03	3275.2	0.019	343.2	5.07	10.81	0.27	0.389	0	6.243
23/12/1996	385	4808	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	0.082	2.437
06/01/1997	482	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
20/01/1997	484	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
04/02/1997	451	4334	7.94	219.4	387.7	434.3	0.15	64.5	0.044	2808.7	0.006	83.4	4.33	18.34	0.82	0	0	0.041
17/02/1997	442	4086	7.87	230.8	371.2	459.1	0.18	62.9	0.084	2725.6	0.007	205.2	4.23	14.86	0.719	0	0	0.692
03/03/1997	516	5430	7.7	347.1	488.4	506.5	0.2	64.9	0.044	3570.4	0.011	356	4.2	14.15	0.47	0.745	0.089	10.05
17/03/1997	475	4959	7.62	292.9	450.6	459.7	0.19	57.1	0.018	3196.3	0.016	391.4	5.43	14.44	0.46	0	0	10.47
01/04/1997	425	4471	7.61	205	364.5	563.2	0.19	72.2	0.057	2720	0.017	433.8	4.6	15.29	0.958	0.132	0	0.303
14/04/1997	445	4501	7.34	314.7	405.1	452.1	0.18	52.3	0.058	2947.8	0.015	258	4.8	13.34	0.428	0.175	0	3.317
29/04/1997	449	3904	7.68	222.8	381.7	435.4	0.18	63.8	0.063	2595.8	0.013	137.3	5.09	13.77	0.883	0.159	0	0.157
28/05/1997	438	4277	7.65	288.3	361.1	442.6	0.18	43.5	0.033	2738.6	0.006	310.8	4.27	12.44	0.488	0.043	0	0.238
09/06/1997	434	4357	7.28	313	349.8	480.2	0.15	38.4	0.031	2795.9	0.008	316.7	4.39	13	0.394	0.106	0	6.01
23/06/1997	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	2.585
08/07/1997	393	4010	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	0.025	0	0.848
21/07/1997	437	4567	7.32	395.8	385	495.5	0.14	32.6	0.03	2981.7	0.008	318.8	4.13	11.06	0.385	0.049	0	12.88
04/08/1997	437	4662	7.82	321.1	384.8	498.8	0.18	45.2	0.035	2987.3	0.006	370.9	4.38	11.85	0.508	0.032	0	10.25
18/08/1997	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

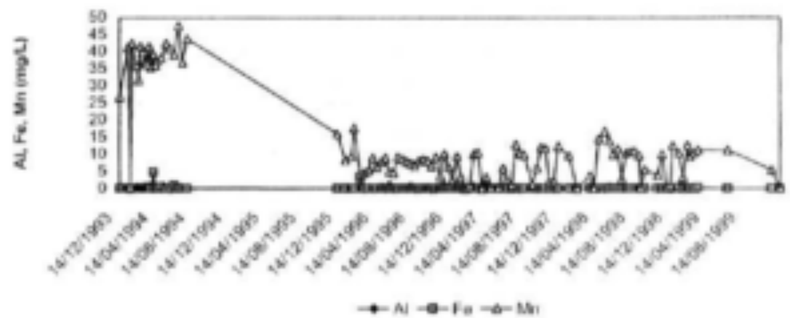
15/09/1997	413	4228	7.57	252.8	341.4	460.4	0.18	35.4	0.034	2590.2	0.006	349.8	4.96	11.18	0.419	0.136	0	1.2
29/09/1997	472	4738	7.48	329.3	467.7	527.6	0.17	43.1	0.027	3005.1	0.009	338	4.18	12.42	0.433	0	0	5.96
13/10/1997	470	4751	7.24	270.1	469.5	499.6	0.21	38.7	0.045	3069.2	0.024	369.8	4.53	12	0.373	0	0	12.06
27/10/1997	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
10/11/1997	421	4412	7.73	256.8	348.1	545	0.01	60.7	0.075	2664.8	0.008	427.2	5.09	11.34	0.641	0	0	2.036
24/11/1997	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
08/12/1997	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
12/01/1998	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
09/02/1998	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
23/03/1998	467	4752	7.84	284	399.4	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
06/04/1998	388	4373	7.95	305.6	298.9	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
20/04/1998	394	4593	7.23	281.6	387.5	519.3	0.19	31.8	0.065	2967.8	0.025	323.2	5.07	9.98	0.415	0	0.066	14.5
11/05/1998	403	4032	7.77	300.1	423.9	494.8	0.17	29.8	0.341	3298.9	0.137	312.7	4.47	10.65	0.043	0	0	16.75
25/05/1998	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
08/06/1998	417	4802	8.16	315	421.8	510.4	0.18	26.2	0.027	3206.1	0.022	254.6	4.68	8.75	0.415	0.344	0.135	9.95
22/06/1998	420	4779	7.24	299.9	424.1	521.3	0.17	31.2	0.033	3060.9	0.016	350.7	4.77	9.81	0.396	0.309	0.112	11.64
06/07/1998	429	4605	7.52	304.3	400.8	466.5	0.21	36.7	0.304	3227.2	0.001	129.4	4.58	9.31	0.057	0.09	0.005	2.751
20/07/1998	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
03/08/1998	478	4839	7.23	303.8	392.9	525.6	0.14	42.4	0.414	3115.1	0.009	395.9	4.66	9.14	0.072	0.122	0.008	10.82
17/08/1998	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
31/08/1998	484	4813	7.39	299.7	404.3	501.1	0.15	46.6	0.352	3153.3	0.011	325.5	5.75	9.06	0.046	<0.02	<0.003	9.74
07/09/1998	428	4814	7.68	298.8	409.2	544.6	<0.1	36.2	0.238	3117.9	0.01	325.8	5.60	8.55	<0.04	<0.02	<0.003	0.218
21/09/1998	415	4771	7.47	306.8	404.9	552.2	0.15	37.3	0.3	3061.2	0.009	326.1	5.88	9.09	<0.04	<0.02	<0.003	5.84
02/11/1998	480	4901	7.92	304.2	397.3	559.3	0.18	45.7	<0.04	3117.1	0.012	385.9	3.33	6.91	<0.04	<0.02	<0.003	3.907
16/11/1998	357	3232	7.34	188.3	266.4	351	0.19	35.3	0.054	1974.1	0.012	335.6	5.31	7.02	0.421	<0.02	<0.003	10.01
01/12/1998	291	2522	7.76	156.8	193.2	285.1	<0.1	32.1	<0.04	1514.3	<0.005	273.4	5.41	6.49	0.417	<0.02	<0.003	0.178
21/12/1998	387	3725	6.89	186.4	309.3	442.8	<0.1	30	<0.04	2351.8	0.007	321.3	4.63	11.59	0.618	<0.02	<0.003	12.57
14/12/1998	352	3004	7.9	184.7	279.2	331.8	0.19	33.6	0.047	2095.2	0.011	97.6	4.83	9.02	0.593	<0.02	<0.003	0.645
11/01/1999	432	4180	7.12	213.5	348.7	517.7	<0.1	27.4	<0.04	2670.1	0.007	317.2	4.72	15.39	0.625	<0.02	0.474	10.38
25/01/1999	416	3885	7.23	201.9	335.8	423	<0.1	29	0.08	2486.8	0.016	322.6	4.97	14.07	0.661	<0.02	<0.003	3.133
08/02/1999	432	4134	7.84	196.6	324.9	522.7	0.16	27.5	<0.04	2623.4	0.012	346.1	4.49	15.92	0.723	<0.02	<0.003	12.73
15/02/1999	431	4212	7.72	206.3	351.4	520.8	0.13	29.5	<0.04	2653.8	0.007	354.5	4.79	16.54	0.744	<0.02	<0.003	9.41
01/03/1999	426	4202	7.37	205.1	338.9	880.9	0.2	28.9	<0.04	2641.9	0.019	72.7	5.5	16.31	0.75	<0.02	<0.003	10.5
15/03/1999	421	4239	7.48	201.4	328.4	557.1	0.21	31.3	<0.04	2688.3	0.015	341.4	5.28	15.15	0.815	<0.02	0.36	11.35
21/06/1999	430	4187	7.39	211.1	319	560.7	0.19	31.6	0.729	2612.4	0.012	355.7	4.48	14.9	0.076	<0.02	<0.003	11.23
15/11/1999																<0.035	<0.005	5.51
13/12/1999	436	4259.946	7.701	213.671	336.193	561.704	0.32	31.307	0.977	2739.024	0.017	293.071	2.781	15.995	<0.04	<0.035	<0.005	0.093
Min	251	1889	6.7	120.3	96.2	154.5	0.01	15.8	0	1036.9	0.001	32.3	1.71	0	0.043	0	0	0
Max	642	6940	8.51	543.9	633.8	880.9	0.43	126.8	29.583	4751	0.137	433.5	6	30.2	1.624	1.049	4.863	47.55
Mean	461.7822	4784.139	7.410496	268.2658	444.79	493.3931	0.192708	56.51333	0.445011	3151.012	0.01349	289.9472	4.223772	12.36917	0.584649	0.188212	0.15406	13.55864
Median	450	4579	7.34	284	407.3	499.2	0.16	52.3	0.036	3066.75	0.0105	317.2	4.38	12.25	0.417	0.136	0.004	9.4235
95-percentile	385	3849	6.96	151.1	305.1	410.5	0.1175	28.6	0.013	2462.095	0.0058	99.2	2.71	6.06	0.0618	0	0	0.17905

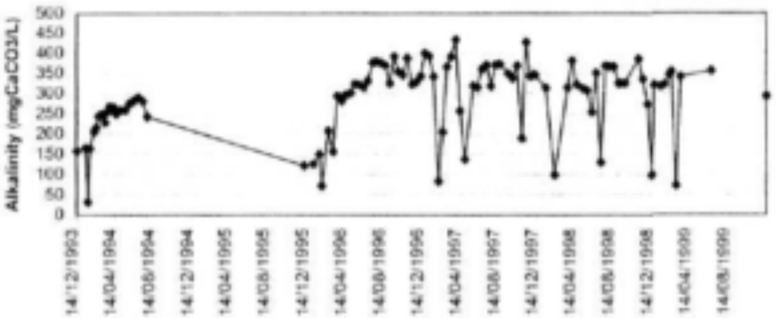
Cell 10B

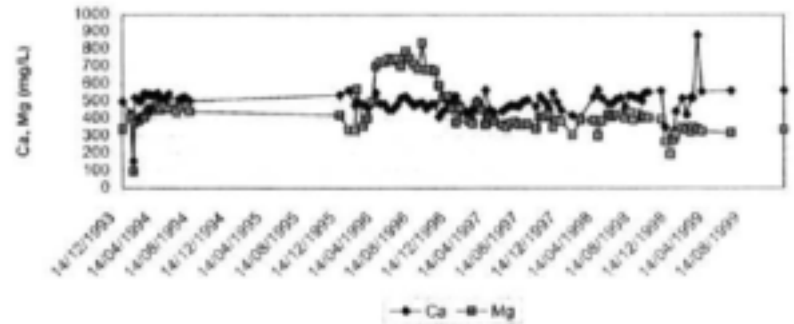

EC (mS/m)


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

Other related WRC reports available:

The performance of natural soil covers in rehabilitating opencast mines and waste dumps in South Africa

Wates JA; Rykaart EM

By covering mine waste materials with a layer of soil, the potential to generate acid mine leachate is reduced because the cover reduces both the ingress of oxygen (which is required to oxidise pyrite and produce sulphuric acid) and the throughflow of percolate. This project made use of an experimental facility of DWAF, where different soil materials (most of them vegetated) were used to cover coal discard, in order to evaluate the effectiveness of different soil cover designs and the predictive potential of mathematical models. Single-layered covers inhibited pyrite oxidation when compared to uncovered discard, while multi-layered soil covers largely prevented pyrite oxidation by creating permanent anaerobic conditions. Uncovered cells were least effective in reducing throughflow of water, while multi-layered covers were only slightly better than single-layer covers. Model calibration was unsuccessful in that higher than observed outflows were predicted. This aspect will be further investigated in a follow-on project (Project No 1002).

Report Number: 575/1/99 **ISBN: 1 86845 613 9**

TO ORDER: Contact **Publications** -	Telephone No:	012 330 0340
	Fax Number:	012 331 2565
	E-mail:	publications@wrc.org.za

1770051147

Water Research Commission
Private Bag X03, Gezina, 0031, South Africa
Tel: +27 12 330 0340, Fax: +27 12 331 2565
Web: http://www.wrc.org.za