The project does, however, have implications for a wider field than the Sappi Enstra landfill site. Many sites in South Africa, which now require to be closed according to the Minimum Requirements, have been operating for at least 20 years. Given the absence of regulations then, no provision was made for the final capping of the landfills, and no material stockpiled for the purpose. Once material has to be imported for capping, costs increase by orders of magnitude. In addition, South Africa as a whole does not have an abundance of clay, and areas rich in good clay are often prized for other uses, such as hazardous waste sites and brickwork quarries. The use of alternative capping materials, which are readily available at low cost, would therefore be of considerable benefit in the waste management field.

The use of waste products as capping materials also reduces the waste stream that is landfilled, and ensures that a waste product is reused as a material with a beneficial use. This is in line with waste re-use practices.

1.2. Objectives

The objectives of the project were:

- To conduct an extensive literature survey, particularly to determine the extent and behaviour of paper mill pulp used for landfill capping, and
- To determine whether the pulp produced by Sappi Enstra could meet the hydraulic conductivity requirements specified by the Department, by means of a series of laboratory and field tests, as well as the mixture of primary pulp and secondary sludge suitable for this purpose.

1. INTRODUCTION

1.1. Background

This project was initiated because the Sappi Enstra landfill was nearing the end of its site life, making closure and rehabilitation necessary. In accordance with the South African Department of Water Affairs & Forestry's "Minimum Requirements for Waste Disposal by Landfill" (Department of Water Affairs & Forestry, 1994), the rehabilitation of the site includes the construction of a clay cap with a maximum hydraulic conductivity of 2,78 x $10^{[illegible]}$ cm/s, as well as a topsoil layer to support vegetation. Tenders received for capping the landfill showed the cost of the clay capping and topsoiling to be extremely high, as all this material would have to be imported from sources remote from the Enstra site. Apart from this, the excavation of some 120 000m^3 of clay and topsoil could create an environmental scar elsewhere which would also need to be rehabilitated.

Ms T. Walton of Sappi's Research and Development (R & D) Department had previously conducted a literature review of references relating to the successful use of mixtures of primary and secondary sludges and fly ash to form capping layers on landfills in the United States of America (USA). The results of several studies on the subject have been published, and sludges have been successfully employed to both line and cap several landfills internationally (NCASI, 1989; NCASI, 1990). Considering that Enstra Mill produces large quantities of primary sludge, and has produced secondary sludge since the commissioning of its activated sludge treatment plant, an investigation into the suitability of mixtures of these materials for use as a capping layer on the Enstra site was certainly worthwhile when considering the potential cost savings to be achieved.

Jarrod Ball & Associates, together with Sappi Enstra, presented the concept to the Department of Water Affairs & Forestry (the Department), outlining the investigational approach to be used in identifying suitable sludge capping layers. The Department showed interest in the project, and it was therefore undertaken.

LIST OF TABLES

LIST OF FIGURES

TABLE OF CONTENTS

finding suitable clay, and Falk Hedrich and John Harrower of Engineered Linings gave excellent service in leakage prevention on the cells.

My family also have my appreciation for their continued support and encouragement.

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I would also like to thank my colleagues at Jarrod Ball & Associates, who encouraged me to undertake this project as part of my studies, and who offered much advice and practical assistance, particularly Peter Legg and Jarrod Ball.

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ABSTRACT

As attempts are made, through new regulations, to improve landfill standards in South Africa, while competition is experienced for limited resources, acceptable alternative technologies for landfills are sought. Paper mill pulps and sludges have been tested, and used, extensively for capping landfills, particularly in the USA. The purpose of this study was to determine whether the pulp and combined sludge produced by the Sappi Enstra Mill, in Springs South Africa, is suitable for the capping of their landfill.

Trends in the landfilling of waste, the use of various hydraulic barrier systems, and comparative testing programmes are reviewed. Laboratory and field tests indicate that the Enstra pulp and combined sludge are suitable for the capping of the landfill as they meet hydraulic conductivity specifications, and results are similar to the tests conducted in the USA. In addition, the use of the pulp and sludge has advantages over the use of clay.

DECLARATION

I declare that this project report is my own, unaided work. It is being submitted for the degree of Master of Science in Engineering, to the University of the Witwatersrand, Johannesburg. It has not been submitted before, towards any degree or examination at any other institution.

Brown

R.A. BROWN

December 1997

DETERMINATION OF THE SUITABILITY OF THE PRIMARY AND SECONDARY SLUDGE PRODUCED BY SAPPI ENSTRA AS LANDFILL CAPPING MATERIAL

RIVA ANNE BROWN

A project report submitted to the Faculty of Engineering, University of the Witwatersrand, Johannesburg, in partial fulfilment of the requirements for the degree of Master of Science in Engineering.

JOHANNESBURG, 1997

evaporation and water balance are not always applicable. Blight (1992) shows that the concept that moisture cannot evaporate from the landfill once it has passed through the landfill cap is incorrect. The in-situ monitoring exercise reported by Blight (1992) also showed that the concept that moisture can only be drawn out of a profile to depth of 300mm is erroneous, but that evaporation extends to depths of at least 1m, and may have affected the entire profile, to a depth of 15m. This work was done on the Linbro Park landfill in the Johannesburg area, about 45km west of the Sappi Enstra landfill.

Simple water balance studies involving general estimates of quantities of water infiltrating, evaporating and being stored, without considering the actual mechanisms of moisture movement, can lead to wide margins of error (Blight, 1992). On account of channeling, the concept that the landfill will drain only once field capacity is reached appears to be false.

The validity of the water balance approach in predicting leachate generation in arid and semi-arid conditions has been questioned (Parsons, 1995). He contends that the approach is not compatible with groundwater recharge knowledge in these conditions. This is due to the approach ignoring the effects of local ponding and recharge through discontinuities, which are significant in these climates. The approach must therefore be used with caution in evaluating landfills in arid and semi-arid regions, and a conservative approach should be adopted.

2.5 Landfill Caps

Final covers, or caps, serve a variety of functions for both new waste disposal sites as well as old sites that require remediation. Final cover systems are a critical component in the overall process of managing liquid and gas movement into and out of a waste body. D o the wide variety of wastes landfilled, as well as site specific conditions, such as climate, which influence the processes generated by landfill sites. (Blight, 1992).

From the water balance equation above, however, the influence of caps in potentially reducing the quantities of leachate generated may be seen. The design and slope of the cap may serve to reduce the infiltration term, by maximizing runoff and interception. The steeper the gradient of the cap, the more rainfall will become runoff, as seen from Table 1. If the cap has low permeability (barrier) layers within it, less precipitation will infiltrate into the waste body. Ponding occurs more readily on barrier layers, so that runoff will be increased. A percentage of the moisture stored in the upper portion of the cap will become available for evapotranspiration before it permeates the barrier layers. The choice of vegetation can also serve to maximize evapotranspiration.

Table 1

Percentage of Runoff Guidelines (adapted from Peyton and Shroeder, 1993)

Description of grass covered soil	Slope of grass surface	Percentage of runoff expected
Sandy soil	Flat (<2%)	5 to 10
	Mild (2-7%)	10 to 15
	Steep (>7%)	15 to 20
Clayey soil	Flat (<2%)	13 to 17
	Mild (2-7%)	18 to 22
	Steep (>7%)	25 to 35

Liners and drainage systems serve to ensure that the leachate generated is prevented from entering the underlying soil except in certain specified quantities, but is collected for storage, treatment or disposal.

In South African conditions, particularly with the low rainfall and high evaporation found on the Highveld, the findings of overseas studies on

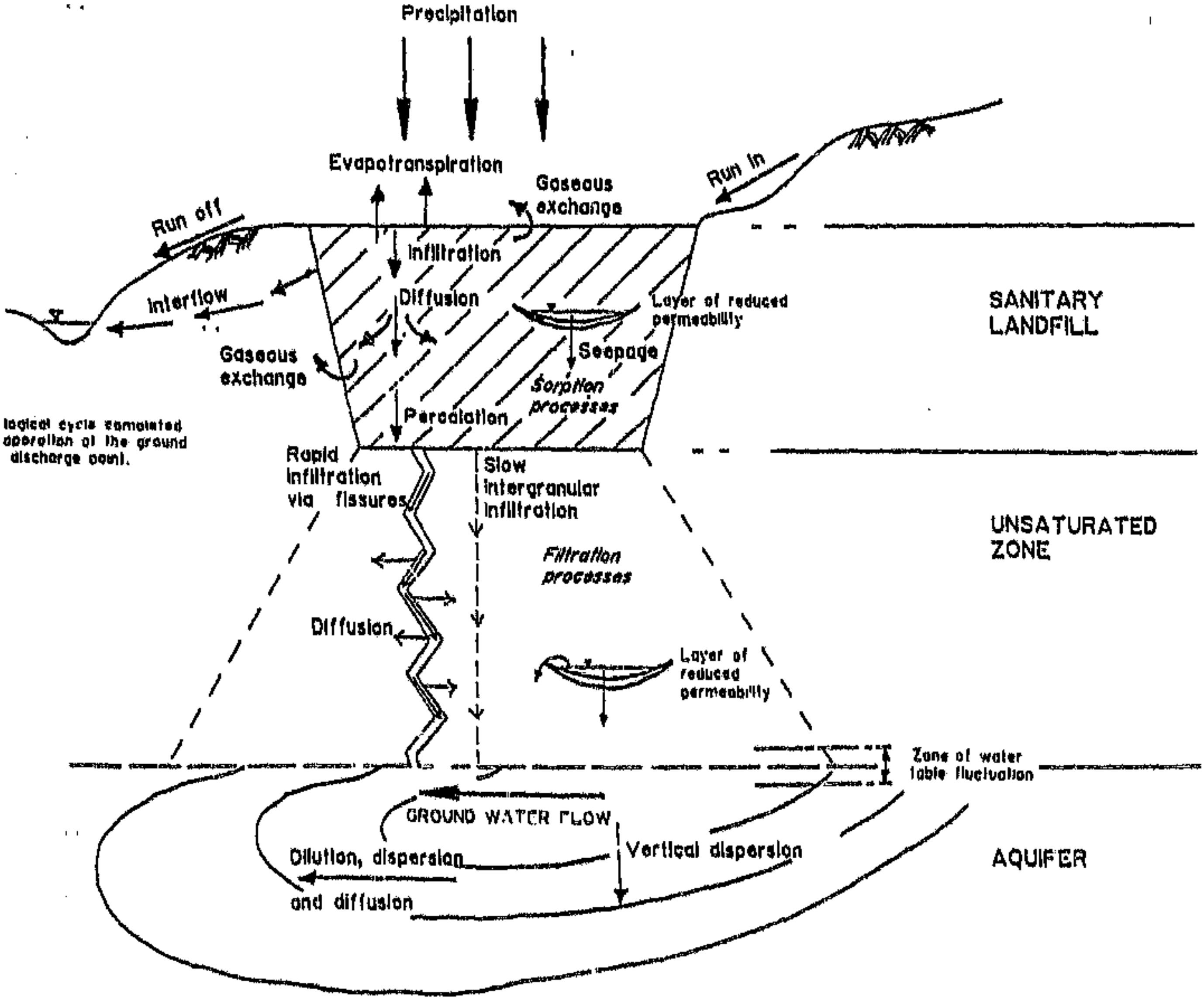


Figure 2.1 Detailed Water Balance Diagram (Hojem, 1988)

stored within the cap and liner.

The water balance can therefore be written as:

$$W + I = L + ET + S$$

where W is the initial moisture content of the refuse
I is the fraction of precipitation which infiltrates
L is the flow of leachate from the landfill
ET is the evapotranspiration from the landfill
S is the water absorbed by and stored in the refuse

Rewriting the equation to calculate the volume of leachate generated gives:

$$L = W + I - ET - S$$

The infiltration term could alternatively be expressed as net precipitation, or precipitation, *P*, minus interception, *C*, minus runoff, *R*. This gives the equation:

$$L = W + P - C - R - ET - S$$

W, the initial moisture content of the waste makes a single contribution to the water balance, at deposition, while infiltration, evapotranspiration, and leachate movement out of the waste body may occur continuously. The water balance equation is therefore rewritten as:

$$\sum L = W + \sum P - \sum C - \sum R - \sum ET - S$$

Figure 2.1 shows the detailed water balance in a sanitary landfill (Hojem, 1988).

The water balance principle is used to determine crop water requirements, water requirements of cities, ecological zones, and to predict quantities of leachate to produce leachate, estimating the expected quantities is vital for the design of collection, storage and treatment systems. (Peyton and Shroeder, 1993) According to the law of the conservation of mass, the mass of water entering a system must be equal to the sum of the masses of water leaving the system and retained by the system.

In the case of a landfill site, the water entering the system comprises the following:

- Initial water content of the refuse
- That fraction of incident precipitation which infiltrates
- The fraction of surface water running onto the landfill, which infiltrates
- Groundwater moving into the waste body from surrounding soils
- Water produced by chemical and biochemical reactions

The last component is assumed to be small, and is usually neglected in water balance calculations. Sanitary landfills should be sited such that runoff from other sub-catchments does not run onto the landfill, and groundwater does not flow into the waste. These two terms are therefore neglected. (Blight, 1992)

The water leaving the landfill comprises the following:

- evaporation
- transpiration
- flow of leachate from the bottom and sides of the landfill

The evaporation and transpiration terms are generally combined to give evapotranspiration.

Water stored in the system includes water storage within the waste body, and may include any water present in drainage systems within the landfill, and water support attenuation, assuming a hypothetical landfill situation.

The main objective of a waste disposal facility is to contain the waste in a manner that is protective of human health and the environment (Daniel, 1993a). Regulations often dictate the minimum technology that is required to minimise risks associated with waste containment facilities. The goal of waste containment is to minimize leachate generation, and to remove and treat any leachate that is generated. This concept is generally achieved by encouraging drainage and limiting infiltration, using bottom liners, underdrainage systems, and caps. A potential flaw in this concept is that the life of bottom liners and caps is limited, while leachate collection and treatment can be necessary for considerable periods. However, the "dilute and attenuate" strategy (where chemical, physical and biological processes within the waste body and the underlying soils are relied upon to attenuate pollutants) is no longer seen as sufficient for many sites. Sites are, however, still selected based on attenuation capacity of soils, among other factors, so that pollutant attenuation occurs for allowable underlying soil infiltration rates.

The objective of the landfill design should not be to stop the release of all chemical species for an infinite period of time, as this is unrealistic. Of concern should be how much leachate will be released from the landfill over time, and what the environmental impact of this release will be. For well-designed facilities, the quantities of chemical species released in the leachate are limited and the short and long term environmental impacts are negligible, as attenuation capacity is not exceeded. (Daniel, 1993a)

2.4 The Water Balance Principle

The water balance principle accounts for the effects of many hydrological processes on water movement at a site, and governs the quantity of leachate generated by a landfill. Water balance or water budget calculations are useful in determining whether a site is likely to produce leachate. For those sites expected to conserve space. The sanitary landfill began to become commonplace in the USA shortly after World War II. The sanitary landfill represents a significant improvement over the open dump, due to reductions in public health risks, and general improvement in the aesthetics of waste disposal. Engineered liners for waste disposal facilities did not become routine in the USA until the 1970s. Regulations have driven the improvement of landfill practices in the USA and most other countries (Daniel, 1993a).

Waste disposal sites, if not sited, designed and operated properly, can have significant health and environmental impacts. Uncontrolled dumps host rodents and flies, which carry disease. Uncontrolled burning causes air pollution. If waste is not covered, odours and windblown litter cause impacts on the surrounding environment and communities. If landfill sites are not properly designed, and drainage systems are not provided to divert upslope runoff around the waste body and to drain contaminated runoff and seepage away from the waste body, leachate (the liquid that seeps from the landfill) and contamination problems may arise. The leachate produced may seep through the soils underlying the waste body to contaminate the ground water, and may flow into surface water bodies, contaminating these. In some instances, the groundwater may be in direct contact with the waste, so that pollutants are leached directly from the waste body into the ground water. If wastes are not covered, it has generally been accepted that more precipitation and runoff are absorbed, increasing the potential for leachate generation. In South Africa, where water is a scarce resource over most of the country, its pollution is irresponsible.

In a study conducted by Ham and Bookter (1997), the benefits of covering were questioned. Lysimeters run for seven years indicated that more runoff but less evapotranspiration was achieved with soil cover, so that leachate rates were approximately the same with or without cover. Carey et al (1997) used numerical modelling to show that the use of low permeability caps may cause an impact on groundwater if insufficient microbes are released by the landfill to with the reduction in the moisture content of the incoming wastes, as well as evaporation of recirculated leachate, the leachate quantities collected have reduced by some 75% in the last year.

An augering exercise was carried out on 20 and 21 February 1997 at the landfill site to confirm that the entire site is underlain with clay. This was done using a Williams LDH80 Digger, equipped with a 450mm diameter flight. Fourteen holes were drilled through the waste body into the underlying clay, under the full time supervision of the consultants. From a consideration of the auger holes drilled, it is evident that the entire landfill is underlain by clay materials with extremely low permeabilities, i.e. the site has a natural clay liner. The moisture in the landfill has kept this liner moist (Jarrod Ball &Associates, 1997b). Although not the objective of the study, the condition of the paper sludge in the landfill was noted by the author during the exercise. The majority of the sludge excavated had compacted to a dense, seemingly impermeable, grey mass, similar in appearance and texture to clay. No evidence of burning or significant decomposition was visible on the samples taken.

The mean annual precipitation for the Springs area, in which the Sappi Enstra Mill is situated, is 728mm, and the mean annual evaporation in the vicinity is between 1500 and 2000mm (South African Weather Bureau, 1997). The temperature extremes experienced are 0°C to 27°C, so that freeze-thaw cycles are unlikely to occur as they do in the USA, and so are unlikely to affect hydraulic barrier layers in the area.

2.3 Landfills

Landfills are generally the final repositories for unwanted or unusable wastes. Until the middle of the twentieth century, nearly all wastes were discarded in open, unengineered dumps. The most common waste dumps were natural depressions, such as flood plains, and mined out areas. Waste was often burned aesthetically acceptable. (Ball et al. 1993)

The use of low cost, alternative materials in achieving the objectives of the Minimum Requirements could make a significant contribution to economically and environmentally responsible waste management in South Africa.

2.2 Sappi Enstra Background

The Sappi Enstra Mill has been in operation for over 50 years, and produces fine papers. The Mill currently produces primary pulp and secondary sludge (which are mixed prior to dewatering on a belt press), coarse ash, and small volumes of fly ash, builders' rubble and general office wastes, all of which are disposed of on the Sappi Enstra landfill site. The waste quantities and characteristics have recently changed significantly, particularly with the commissioning of the new belt press and the effluent treatment plant in 1996.

The Enstra Mill landfill site is located immediately to the south of the Mill, within the Mill property. The landfill appears to have been in operation for as long as the Mill, and the incoming waste stream has varied considerably over the years, due to changes in processes, expansion, and waste minimisation programs. The site covers an area of 27 hectares, and is to have a maximum height of 14m once completed. The climatic water balance of the region is negative; i.e. the landfill should not produce significant leachate as a result of the ambient climate. However, on account of the high moisture content of pulp disposed of in the past, and the siting of the landfill adjacent to a water body, leachate formation has occurred. In terms of the Minimum Requirements, the landfill is classified as a G:M:B$^+$ landfill (i.e. the landfill accepts general waste, the waste stream, at its maximum, will be between 25 and 500 tons per day, and significant leachate is generated), and all the Minimum Requirements specified for G:M:B$^+$ landfills must be adhered to. Full drainage and barrier systems have been installed, and surprising. However, the activities of reclaimers and the sanitary landfill operation are contradictory, as the reclaimers prefer to keep the waste open for reclaiming for as long as possible, while sanitary landfilling aims to confine and contain the waste body in the shortest time possible. The landfilling of hazardous and medical wastes on general waste sites, although illegal, still occurs, and has serious health implications for reclaimer communities. The disposal of spoilt foodstuffs and animal carcasses on general sites is also of concern.

Waste disposal in South Africa is regulated and enforced by the Department of Water Affairs & Forestry. With the publication of the Minimum Requirements series in September 1994, the minimum acceptable technology for waste disposal sites was specified. South Africa has developed a unique graded system for its requirements, whereby sites are classified according to incoming waste type, the size of the incoming waste stream, and the water balance. Sites expected to produce significant quantities of leachate from the water balance calculations require liners and leachate management systems Requirements are progressively more stringent for larger incoming waste streams. Hazardous waste sites have the most stringent requirements. The graded minimum requirements concept works well in a country that has a wide range of climates, as well as regions that vary from extremely sparsely to extremely densely populated.

The Minimum Requirements have the objective of ensuring that the most cost-effective means are used to protect the environment and public health from both short and long term adverse impacts of waste disposal. Particular objectives are:

- To avoid degradation of the general environment in which the landfill is sited,
- To prevent pollution of the adjacent surface and ground water regimes, and
- To ensure that the landfilling process is in itself environmentally and

2. BACKGROUND AND LITERATURE REVIEW

2.1 The Waste Disposal Situation in South Africa

South Africa is currently undergoing transformation, with the competition for scarce resources often making responsible landfilling economically unfeasible. In a status quo analysis of the waste disposal situation in South Africa conducted in early 1997, many municipalities listed housing and the provision of basic services such as water and sanitation as higher priorities than waste disposal.

Many of the waste sites in South Africa do not conform with the most basic sanitary landfilling principles, with at least 43% not having upslope drainage, 35% not having sufficient cover material available on site, 41% sited in quarries, and at least 19% having no access to plant. (Jarrod Ball & Associates, 1997a: database)

In the investigation, it was found that only 44% of the general remaining airspace in landfills complies with Minimum Requirements regulations, with the majority of acceptable airspace in the larger landfills. By February 1997, only 26% of operating municipal landfills had been granted permits by the Department of Water Affairs & Forestry (Jarrod Ball & Associates, 1997a). In order to improve this state of affairs, the concept of progressive upgrading and the use of simpler, sustainable technologies has been advocated, to avoid the use of limited resources in areas of diminishing returns (Jarrod Ball & Associates, 1997a; Ball and Legg, 1997).

South Africa also has many waste reclaimers, who live by reclaiming materials from waste disposal sites for resale, as well as taking food from the wastes. As many landfills were sited adjacent to poor, "black" areas in the apartheid era, and approximately 40% of South Africans are estimated to be unemployed, the fact that most urban landfill sites support reclaimer communities is not

- To compare, in broad terms, the behaviour of the Sappi Enstra pulp capping with the corresponding behaviour of similar testing carried out overseas, to determine whether the cappings behaved in a similar manner.

- To compare the behaviour of the Sappi Enstra pulp capping with the corresponding behaviour of the clay control test installed, to compare performance, as requested by the Department.

1.3. Project Overview

To meet the above objective, the scope of the project comprised a literature review, laboratory and field testing. The methodology and design used for the testing was loosely adapted from the National Council of the Paper Industry for Air and Stream Improvement (NCASI) field studies completed in the USA.

subjected to freeze-thaw conditions (Othman and Benson. 1991).

Waste liquids may attack and effectively destroy earthen liners. Certain clay minerals are affected by certain chemicals, resulting in significant increases in hydraulic conductivity. The consideration of, and testing for, chemical incompatibilities are therefore recommended in compacted clay liner design (Daniel, 1993b).

The statistical distribution of the hydraulic conductivity of clay has been investigated for the purposes of predicting hydraulic conductivity, and for establishing the sample size necessary to determine that a specified standard is met with an acceptable degree of confidence. Hydraulic conductivity is often assumed to be log-normally distributed (Bogardi et al, 1989), which means that the logarithms of hydraulic conductivity are normally distributed. Harrop-Williams (1986) established the probability distribution of clay liner permeability as the gamma distribution. Benson (1993) analysed data collected from 57 sites, and determined that two- and three-parameter log normal probability distributions may be used to describe the hydraulic conductivity of the majority of compacted clay hydraulic barriers. Benson (1993) gives that the statistical properties of hydraulic conductivity vary widely, so that a flexible distribution is needed to account for site-specific conditions. It is therefore recommended that the distribution of the results achieved be tested for fit with the distribution assumed.

To summarize, compacted clay has been observed to exhibit the following characteristics, which must be taken into account in its use:

- Laboratory testing of hydraulic conductivity of compacted clay barrier layers has generally underestimated field performance, depending on specimen size, and construction practice. Field testing is therefore usually required to verify predicted hydraulic conductivity clay soil. The compaction curves for solid with initially large (19mm) and small (4.8mm) clods compacted with standard Proctor effort were significantly different. For smaller clods, the compaction curve was much flatter, suggesting less sensitivity to molding water content. Examination of the samples showed the fate of clods and interclod pores during soil processing and compaction controlled the hydraulic conductivity of the compacted soil. Soils with large clods that were compacted dry of optimum had large, visible interclod voids. Large interclod pores can be minimised and the effects of clods overcome in highly plastic soils by compacting soil at a moisture content large enough to soften the clods so that they can be remolded by the compaction equipment, and using a sufficiently large compactive energy to destroy even relatively dry, hard clods.

Benson and Boutwell (1992) consider compaction control and scale-dependent hydraulic conductivity of clay liners. The field-scale hydraulic conductivity of a clay liner depends on the water content and dry unit weight at which it is compacted. A criterion used to control construction should ensure compaction wet of the line of optimums. This condition results in remolding of clods, elimination of interclod voids, low hydraulic conductivity at field and laboratory scales.

Several studies (Othman and Benson, 1991; Othman and Benson, 1993; and Bowders and McClelland, 1994) have shown that freeze-thaw causes changes in the hydraulic conductivity of compacted clays. The hydraulic conductivity of compacted clay has been shown to increase by one to two orders of magnitude because of freeze-thaw, but the magnitude of change depends on the rate and temperature of freezing. The changes in hydraulic conductivity experienced in the studies were limited to 0.3m below the depth of frost penetration, and the increase in hydraulic conductivity can be reduced when effective stress on the soil is increased. This has brought about regulations requiring that compacted clay liners be covered with protective soil or waste layers prior to being within each lift. The field data and models show that soil liners that are only 15-30cm thick (one or two lifts) tend to be much more permeable than liners that are 60-90cm thick (four to six lifts). Decreasing hydraulic conductivity with increasing thickness was observed for poorly built liners as well as well-built liners. Little reduction in hydraulic conductivity is achieved, however, when the thickness is increased beyond 60-90cm (four to six lifts). If at least four lifts are used, the degree of bonding between lifts, i.e. the degree to which zones of high horizontal hydraulic conductivity at lift interfaces are eliminated, is far more important than the number of lifts. A reasonable minimum thickness for low hydraulic conductivity, compacted soil liners is 60-90cm (four to six lifts). Regulators have used the results of this study worldwide.

Details of construction are extremely important. Construction should be inspected to ensure that deleterious materials are not used, that compaction water content and compactive effort are correct, that large clods are properly hydrated and adequately broken down, and that the liner is not allowed to dry out once construction is complete. To prevent desiccation it may be necessary to cover the liner with soil, a flexible material liner, or some other protective material (Daniel, 1984). Benson et al (1994c) correlated laboratory-measured hydraulic conductivities with associated index measurements collected during construction of 67 compacted soil liners. Lower hydraulic conductivity generally occurred at higher initial (as-compacted) saturation. Focussing on conditions that result in higher initial saturation without sacrificing compactive effort will often result in lower hydraulic conductivities. Lower hydraulic conductivity was also associated with heavier compactors, and compactors classified as sheepsfoot rather than those classified as rubber tyre.

Benson and Daniel (1990) investigated the influence of clods on the hydraulic conductivity of compacted clay. The results presented demonstrated that clod size during soil processing and compaction significantly influenced the compaction curve and the hydraulic conductivity of a highly plastic, compacted regulatory authorities, including the South African Department of Water Affairs & Forestry (The Department of Water Affairs & Forestry, 1994).

2.6 Clay behaviour and performance

Many landfill sites have been lined and capped with clay, although its use has been fairly limited to date in landfills in South Africa. Given that the Minimum Requirements specify compacted clay liners and caps for many classes of landfills, its use is set to increase in the country.

Much experience has been gained through experience mostly in the USA, in the fields of compacted clay liner design, laboratory and field testing, construction practice, and construction quality assurance (CQA) in the last 10-15 years, mainly through changes in regulations.

Daniel (1984) presented data from four projects in which rates of leakage from ponds lined with clay significantly exceeded the rates that would have been predicted on the basis of laboratory permeability tests. The study concluded that thin clay layers should be avoided because they are too susceptible to damage from desiccation cracking and because a permeable zone in one lift has too detrimental an effect on overall liner performance. The case histories presented suggest that thicknesses of 20-60cm are not adequate for some applications (Daniel, 1984).

Benson and Daniel (1994a) investigated the minimum thickness of compacted soil liners, using 52 case histories of in-situ measurements of hydraulic conductivity of compacted soil liners. The study determined that the first-passage time of a solute passing through a soil liner increases with increasing thickness of a liner. Based on the modelling results, no optimum thickness could be defined from first-passage time. The equivalent hydraulic conductivity of a multilift soil liner decreases with decreasing mean hydraulic conductivity

Traditionally, compliance evaluation of earthen liners and caps was solely based on results of laboratory tests of small diameter specimens (7 to 10cm) (Trautwein and Boutwell, 1994). The emphasis on field testing arose in the mid-1980's because of discrepancies between small diameter laboratory and field test results. Daniel (1984) presented data from four projects in which rates of leakage from ponds lined with clay significantly exceeded the rates that would have been predicted on the basis of laboratory permeability tests. The study concluded that laboratory permeability tests are useful for preliminary design and for general guidance during the final design, e.g. in comparing several possible materials for use in constructing the liner, but that laboratory permeability tests may yield significant underestimates of the hydraulic conductivity of liners (Daniel, 1984). Field permeability tests are more likely to yield accurate estimates of hydraulic conductivity than laboratory tests and, for this reason, are recommended as part of either the final design process or construction verification. The findings were similar for a study by Day and Daniel (1985). These studies sparked interest in the apparent discrepancies between laboratory and field hydraulic conductivity testing, resulting in changes in regulations, and ultimately design and testing methods.

The use of field testing represents a significant change, because it is more costly, is sensitive to interpretation, and testing times are typically much longer and can adversely affect construction schedules. Benson et al. (1994b) give that an alternative to field measurement of hydraulic conductivity is to conduct laboratory hydraulic conductivity tests on specimens large enough to simulate field-scale conditions. From research done by Benson et al. (1994b), the test results showed that hydraulic conductivity at or near field-scale hydraulic conductivity can be measured using block specimens with a diameter of 0.3m and a thickness of 0.15m (sufficiently large to measure macropermeability effects). Trast and Benson (1995) came to the same conclusion, as did Wallace et al. (1994). The laboratory equipment necessary to test specimens of this size is not available is South Africa to date. Field testing is specified by most

A is the area of the liner, or the test
t is time

The hydraulic gradient is defined as:

$$i = \frac{D_p + D_f}{D_f}$$

Where D_p is the depth of ponding
D_f is the depth to the wetting front

Hydraulic conductivity is usually calculated using the equation

$$k = \frac{I}{i}$$

where I is the rate of infiltration measured

The most important geotechnical parameter for soil liners or caps for waste facilities is hydraulic conductivity. In typical practice, the vertical conductivity normally governs the barrier effect. Regulatory agencies have increasingly required in situ tests in addition to laboratory tests, to verify hydraulic conductivity. Several different in situ tests have been developed to determine in situ hydraulic conductivity, the most widely accepted of which is the sealed double ring infiltrometer (SDRI) (Trautwein and Boutwell, 1994).

An important point is that hydraulic conductivity is not an intrinsic property which depends only on the material type, but is dependent on a number of factors, including sample preparation, degree of saturation, stress level, void ratio, nature of the permeating fluid and direction of flow. These factors require consideration when evaluating the compliance of a hydraulic barrier (Trautwein and Boutwell, 1994).

Several alternative materials have been considered and investigated for use as barrier layers in landfill liners and caps, including fly ash (Edil et al, 1987; Bowders et al, 1987), water treatment plant sludge (Raghu et al, 1987), rocktailings (Weeks, 1993), blast furnace dust (Wagner and Schatmeyer, 1995), flue gas desulfurization sludge (Krizek et al, 1987) and steel process solidified residue (Pamucku et al, 1994). However, the alternative material that appears to have been investigated in the most detail, as well as used fairly extensively in practice, is paper mill pulp or sludge (Jedele, 1987; NCASI, 1989; NCASI, 1990).

2.6 Hydraulic Conductivity Theory and Testing Practice

Hydraulic conductivity, or permeability, is generally defined as the rate at which fluid passes through a medium. As hydraulic conductivity is dependent on material structure, which consists of both small and large pore volumes, it is necessary to define the terms "micropermeability" and "macropermeability". Micropermeability refers to flow through micropores, the small void spaces between soil particles or aggregates of soil particles, most of which are in contact with adjacent soil particles. Macropermeability refers to flow through macropores, the larger void spaces corresponding to secondary structure, such as clod interfaces, lift interfaces, shear surfaces and desiccation cracks. Trautwein and Boutwell (1994) give that if macropores are present, the flow through micropores will be negligible in comparison.

Saturated hydraulic conductivity is governed by Darcy's law where

$$Q = kiAt$$

where Q is the flow measured
k is the coefficient of hydraulic conductivity
i is the hydraulic gradient

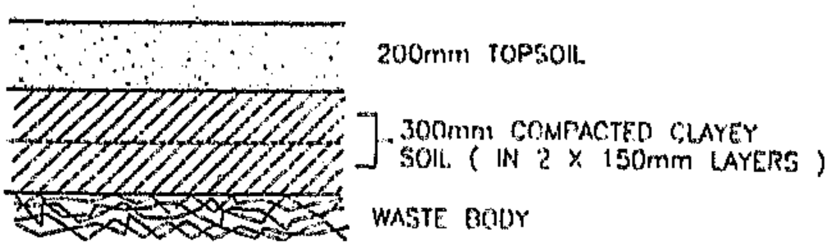


Figure 2.3 Capping Required For Sappi Enstra Landfill (The Department of Water Affairs & Forestry, 1994)

The choice of the capping system must be balanced with the availability of suitable material for capping and restoration both on site and in the locality. Most old existing sites do not have enough suitable soils on site, and it is necessary to import material. If clays and clayey subsoil are used for capping, this may take all readily available restoration material. In such cases an artificial capping system, such as geomembrane, bentonite mat, bentonite-enriched sand or shale, should be selected to retain available soil for the vegetative and protection layer (United Kingdom Department of the Environment, 1996).

The critical factors that affect selection of a barrier layer design are climate, the amount of differential settlement to which the cover will be subjected, the vulnerability of the cover soil to erosion or puncture, the amount of water percolation through the cover system that can be tolerated, the need for collection of waste-generated gas, and the steepness of the slope (Daniel and Koerner, 1993).

Materials commonly used as barrier layers in landfill caps include compacted clay, compacted soils modified by the addition of bentonite or attapulgite clays, geomembranes and geosynthetic clay liners (Daniel, 1987; Jesionek et al, 1995).

Environmental Protection Agency consists of an erosion and vegetation layer greater than 0.15m thick, and an infiltration layer greater than 0.45m thick with a minimum hydraulic conductivity of 1 x 10^{-5}cm/s (Jesionek et al, 1995; Moo-Young and Zimmie, 1996a). This basic design is shown in Figure 2.2. When an abundant source of clay is not readily available or not in close proximity to the construction site, the cost of landfill closure is greatly increased when alternative hydraulic barrier methods such as geomembranes and synthetic clays are used. In South Africa, the minimum final cover design depends on the site classification, which in turn depends on the waste type, incoming quantities and site water balance. The final capping design applicable to the Sappi Enstra landfill site is 300mm of clayey soil and 200mm of topsoil, vegetated (Jarrod Ball & Associates, 1995). This design is shown in Figure 2.3.

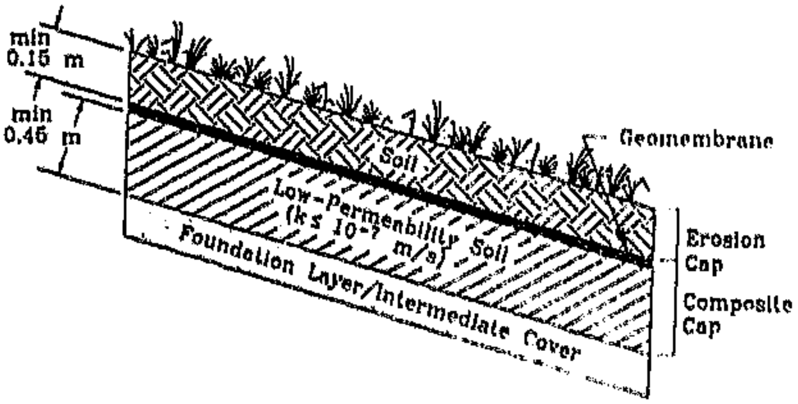


Figure 2.2 Typical EPA Capping Design (Jesionek et al, 1995)

as well as landfill liners, given that certain differences in performance exist. These differences can be summarized as:

- Liners are generally constructed on virgin soil, while caps are constructed over the waste body. Compaction of barrier layers on waste is often difficult, as waste generally serves as a poor foundation, so that inclusion of a foundation layer in the cap is sometimes necessary.
- The specified hydraulic conductivities for landfill caps are generally higher than for landfill liners, and caps carry less confining pressure.
- Landfill caps are more exposed to the elements than are landfill liners, and therefore carry a greater risk of desiccation and freeze-thaw damage.
- Landfill caps are often subject to large differential settlements, which may cause cracking and failure in compacted clay caps and tearing in geosynthetics.
- Landfill caps are not generally subject to leachate permeation, as only precipitation and runoff should come into contact with the landfill cap. The cap usually does, however, come into contact with landfill gases.

The components of a final cover system for a solid waste landfill ideally comprise a combination of some or all of the following:

- Surface erosion and vegetation layer
- Protection layer
- Drainage layer
- Barrier layer, and
- Foundation or gas collection layer.

Not all components are needed for all final covers. A drainage layer may be needed at a site that has high precipitation, but not at an arid site. (Daniel 1993)

For municipal solid waste facilities, the minimum cover specified by the USA

- The system's ability to withstand the effects of frost and hot weather
- Availability of required materials
- Construction of maintenance vehicle access tracks and public footpaths
- Durability of the system
- Installation of gas well heads and collection pipework
- Installation of leachate collection manholes and pipework
- Landscaping requirements including additional subsoil needs
- Low permeability to minimise gas emission and surface water infiltration
- The relationship between phasing of construction and the landscape design for the afteruse
- Recirculation of leachate if required
- Alterations caused by gas derived from volatile components of the waste or decomposition products
- Robustness against settlement stresses
- Stability on proposed restoration slopes
- Surface water drainage
- Erosion
- The effects of roots and burrowing animals on its integrity
- Deformations caused by earthquakes

(Daniel and Koerner, 1993; United Kingdom Department of the Environment, 1995; Jesionek, 1995)

Daniel and Koerner (1993) assert that because of these site-specific environmental stresses and conditions, the design of a cover system can be very challenging. It is often more difficult to provide an effective hydraulic barrier layer in a cover system than in a liner system because the cover system is challenged by unknown and unquantifiable stresses that do not act on liner systems buried deep beneath the waste.

Much of the research and experience documented can be applied to landfill caps.

that occur within the waste body, each cover design should be tailored to the particular site to be covered (Daniel and Koerner, 1993).

The objectives of the engineering cap are to:

- Contain the wastes
- Manage leachate production by controlling the ingress of rain and surface water into the underlying waste
- Prevent uncontrolled escape of landfill gas and odours or the entry of air into the wastes
- Provide protection for the emplaced wastes
- Accommodate the environmental control measures
- Provide a physical separation between waste and humans, animals and plants.

(Daniel and Koerner, 1993; United Kingdom Department of the Environment, 1993, Jesionek et al, 1995)

The prime objective in final cover is generally accepted to be keeping water out of the waste (Daniel and Koerner, 1993).

The cover system must perform these functions for an extended period of time. The design life of a cover depends primarily on the nature of the waste, the site hydrology, and the length of time that the maintenance of the cover will be provided. Daniel and Koerner (1993) contend that it would be preferable to construct a temporary cover for an actively decomposing and deforming body of waste, and then wait until substantial decomposition of the waste body has occurred before attempting to construct a final cover. This may, however, not be viable depending on the financial status of the responsible party.

The design of a capping system should consider some or all of the following aspects, depending on the site:

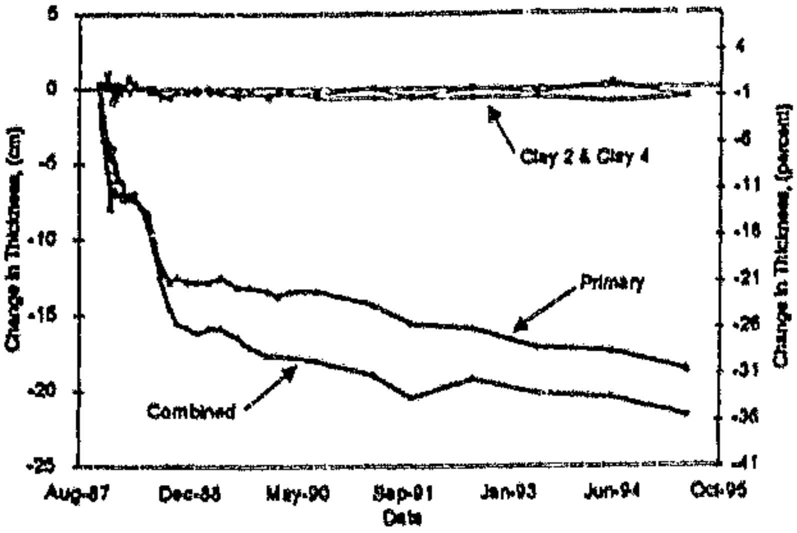


Figure 2.10 Ncasi Tests: Barrier Layer Consolidation (Maltby And Eppstein, 1996)

The long-term average hydraulic conductivity values for all four of the original test cells are shown in Figure 2.11. Combined sludge from primary and secondary treatment performed better than did sludge from only primary treatment. The hydraulic conductivity of both the primary and the combined sludge barrier layers decreased over the last five years of testing by approximately half an order of magnitude. The clay controls' hydraulic conductivity increased during this time, by almost as much. No explanation is given as to the peak occurring in the pulp hydraulic conductivity values after four years. Long-term average hydraulic conductivity values for the primary and combined residual barriers are 4.41 x 10^{-7} and 9.62 x 10^{-8} cm/s respectively. Barrier hydraulic conductivity values for the clay cells are 1.39 x 10^{-6} and 1.45 x 10^{-6} cm/s, respectively.

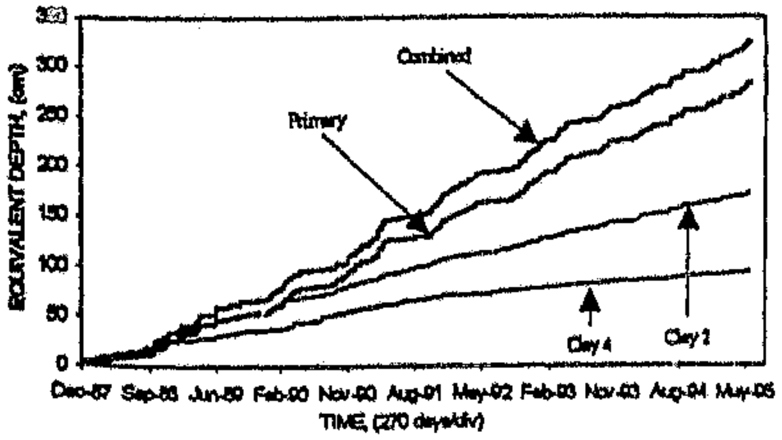


Figure 2.8 Ncasi Tests: Runoff Cumulative Equivalent Depth (Maltby And Eppstein, 1996)

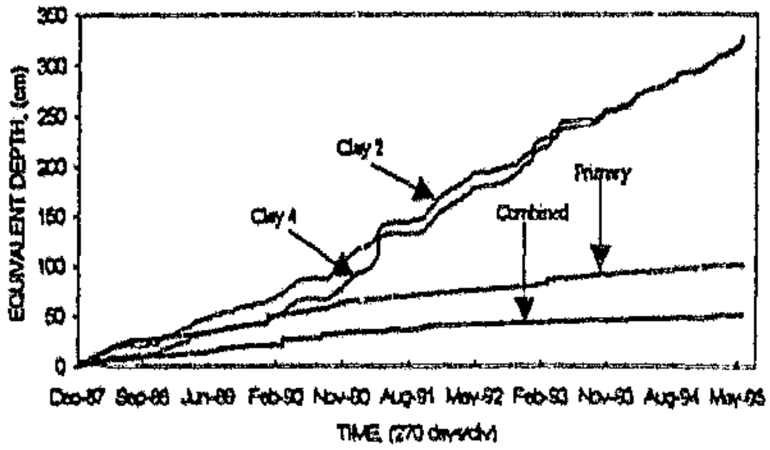
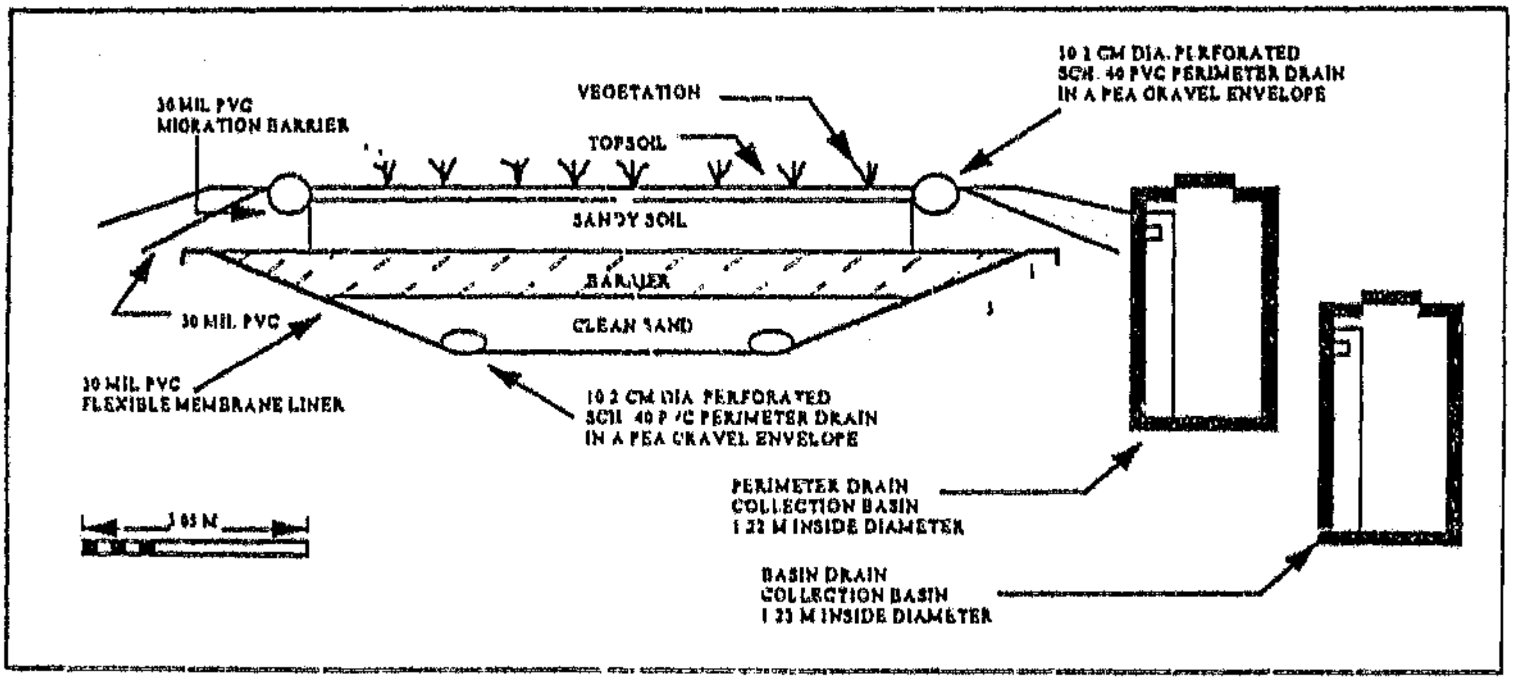


Figure 2.9 Ncasi Tests: Seepage Cumulative Equivalent Depth (Maltby And Eppstein, 1996)

Figure 2.7 NCASI Field Test Cell Design (Maltby And Eppstein, 1996)



conductivity of barrier layers in caps. It was also evident that the hydraulic conductivity of the sludges reduced with time, which was attributed to consolidation due to overburden on the sample. Biological activity in the sludge also resulted in reduced hydraulic conductivity. Two of the sludges tested in this study were used in the field tests carried out by NCASI (NCASI, 1990).

NCASI constructed four test pads in 1987, to evaluate the performance of paper sludge as a hydraulic barrier in landfill caps (NCASI, 1990). Two cells were constructed using paper sludge barrier layers, while the other two cells were constructed using a clay barrier layer, to form a baseline. The tests used barrier layers of 600mm thick. Each barrier layer was covered with a 450mm thick layer of sandy soil, and a 150mm thick layer of topsoil, to support vegetation. The area of infiltration of the barrier layers ranged between 64.8m^2 and 69.5m^2. Provisions were made for collecting and monitoring runoff and throughflow from the pads. The design of the test pads is shown in Figure 2.7. Note that there is no slope on the test pads, in order for them to act, conservatively, as large permeameters. These field tests were run for 8 years (November 1987 to June 1985), and were monitored throughout this period. (NCASI, 1990; Maltby and Eppstein, 1994; Maltby and Eppstein, 1996).

The results of the study are summarised in the graphs included as Figures 2.8, 2.9, and 2.10, which indicate runoff cumulative equivalent depth, seepage cumulative equivalent depth, and barrier layer consolidation, respectively. The sludge consolidated as much as 33 percent, with most consolidation occurring during the first year. Measured runoff from the sludge test pads was similar to that from the clay test pads during the first year. Thereafter, runoff from the sludge test pads exceeded runoff from the clay test pads. After the first year, measured throughflow in the sludge test pads was less than the through flow in the clay test pads.

Desiccation of paper sludges was proved to be of concern by Kraus et al (1997). Significant shrinking of the sludges tested occurred when they were dried, suggesting that barrier layers constructed with sludge should not be permitted to desiccate. Moo-Young and Zimmie (1997) give that during the construction of a landfill cover, the pulp sludge layer should be protected from the effects of desiccation and shrinkage cracks that would cause an increase in hydraulic conductivity.

Floess and de Mello (1997) note that the hydraulic conductivity of paper sludge is affected by decomposition and freeze-thaw cycles. As the organic solids decompose, the organic content of the sludge decreases and its hydraulic conductivity decreases. Freeze-thaw cycles adversely affect the hydraulic conductivity of paper sludge; however, the impact of freeze thaw cycles has been found to be less severe than for compacted clays.

The hydraulic conductivity of paper sludge is adequately characterized by the lognormal distribution. (Maltby and Eppstein, 1996).

The National Council of the Paper Industry for Air and Stream Improvement, NCASI, researched the feasibility of using sludge and fly ash from the pulp and paper industry as hydraulic barrier material in landfill covers (NCASI, 1989). A major component of the study was the laboratory measurement of the hydraulic conductivity of thirteen fresh sludges from the wastewater treatment systems of mills that encompass major pulp and paper production categories. The effect of biological activity was also examined on several sludges.

This NCASI study determined that the primary and combined sludges tested exhibited hydraulic conductivities of between 10^{-4} and 10^{-8} cm/s, with a geometric mean of 1.8×10^{-6} cm/s. The primary sludge for bleached kraft primary pulp (the category most comparable with Sappi Enstra) was determined as 1.1×10^{-5} cm/s. This meets the South African requirement for hydraulic

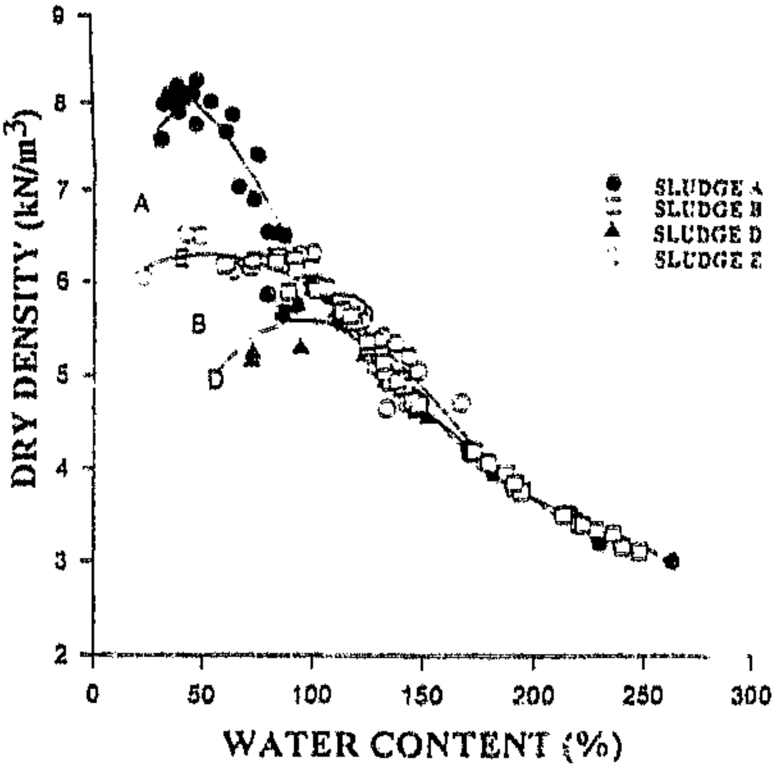


Figure 2.6 Typical Proctor Curves For Paper Sludge (Moo-Young And Zimmie, 1996b)

The study by Kraus et al (1997) also showed that field tests conducted on barrier layers constructed with paper sludge gave hydraulic conductivities similar to those measured on laboratory compacted samples at similar water contents. Laboratory tests on large and small undisturbed specimens removed from the field showed that no scale dependence existed in the field compacted specimens. The use of small diameter laboratory hydraulic conductivity tests in estimating field hydraulic conductivity is therefore feasible, which is not the case for clay (Kraus et al. 1997). This may be explained by the relative insensitivity of hydraulic conductivity to water content (when compared with clay), and the fibrous nature of the sludge, which appears to minimise the occurrence of macropores.

determined for sludges are similar for those for clays, albeit with lower maximum dry unit weights and higher moisture contents. (Kraus et al, 1997). The curves, are, however, much wider than for clay, i.e. the optimum water content is often a range of values of 30 or more percentage points, whereas for clay it is 1 or so percentage points. From compaction tests on paper sludge, optimum water content is markedly lower than the as-received water content (Kraus et al, 1997; Zimmie and Moo-Young, 1995). Typical Proctor curves for various sludges tested by Moo-Young and Zimmie (1996b) are shown in Figure 2.6.

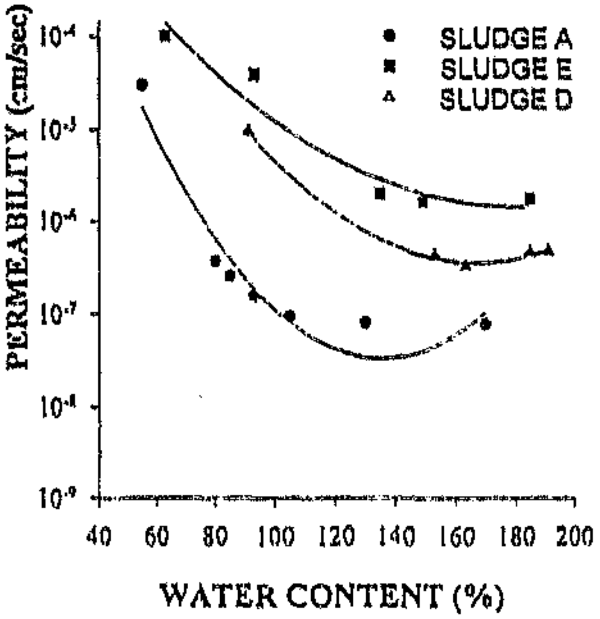


Figure 2.5 Permeability Versus Water Content Relationship For Paper Sludge (Moo-Young And Zimmie, 1996b)

Given that the geotechnical behaviour of paper sludges is not like that of typical clays used in landfill covers, the use of different indicator tests is advocated (Zimmie and Moo-Young, 1995). Atterberg limit tests are very difficult to perform on paper sludges and the results may not be meaningful in terms of classical geotechnical classification. Organic content, specific gravity, sludge age, natural water content, and compressibility are the major physical properties of sludges (Zimmie and Moo-Young, 1995).

In a comparison of paper sludge to clay as the hydraulic barrier in municipal landfill covers, Moo-Young and Zimmie (1997) compared paper mill sludges to kaolinite clays, to determine differences in behaviour. This study determined several differences. Paper sludges have high water content and organic content in comparison to clays. Paper sludge should be compacted far wet of the optimum water content (50 to 100% wet of optimum) to achieve minimum hydraulic conductivity. Moo-Young and Zimmie (1996b) give that permeability of the paper sludge increases as the molding water content decreases (approaches the optimum water content).

A study by Kraus et al (1997) determined that hydraulic conductivities less than 1 x 10^{-7}cm/s can be attained for these sludges at low effective stresses (<10kPa) when compacted using standard Proctor energy if the molding water content is 50 to 100 percentage points greater than the optimum water content. The lowest hydraulic conductivities were obtained in this range. At higher effective stresses (>20kPa), this hydraulic conductivity standard can be attained at higher molding water contents. The permeability versus water content relationship from a study by Moo-Young and Zimmie (1996a) is included as Figure 2.5.

Compaction curves for paper sludge should be performed from the wet side rather than the dry side, because of the high water content, and changes in behaviour with drying (Moo-Young and Zimmie, 1995). Compaction curves are highly compressible, and water content is a good indicator of compressibility. The change in void ratio with vertical pressure is shown in Figure 2.4 from Moo-Young and Zimmie (1996b).

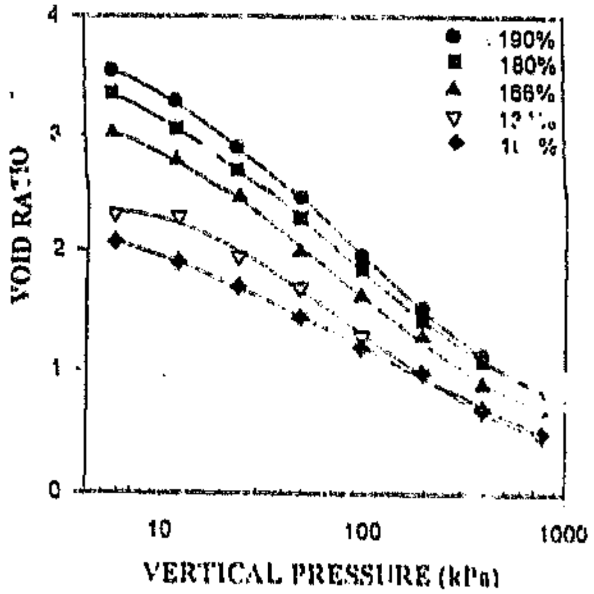


Figure 2.4 Consolidation Test Results For A Paper Sludge (Moo-Young And Zimmie, 1996b)

The hydraulic conductivity of paper sludge is a function of the sludge's organic content, degree of consolidation, and decomposition. The hydraulic conductivity of paper sludge and peat decreases as the ash content of the ash increases and the organic content decreases. Hydraulic conductivity of paper sludge and peat is sensitive to relatively small changes in confining pressure, since these materials are highly compressible. The hydraulic conductivity is also time dependent, which is generally attributed to long term secondary compression (Floess and de Mello, 1997). Thus, compressibility, water content and organic content significantly influence the permeability of paper sludges (Moo-Young and Zimmie, 1997).

construction, and subsurface cutoff walls. The sludge is also employed as a liner in the company owned landfill. Of 29 mills surveyed for the NCASI (1989) study, 14 had actual experience with landfill capping with either sludge or fly ash.

Sludge from the International Paper Company, Hudson River Mill, Corinth, NY, USA was used as the barrier layer material in the cap of this town's municipal landfill (Floess and De Mello, 1997). Cap construction was completed in 1995.

Champion International Courtland Mill, Alabama, USA has developed a closure design for its 33 acre landfill at the Mill, using dewatered wastewater treatment solids as the barrier layer in the cap. Construction in phases commenced in 1994 (McGee et al, 1996).

It may be seen that the use of paper and pulp mill sludge in landfill capping is an accepted alternative technology in the USA.

Paper mill sludge has also been used as daily cover on the Chianni landfill in Italy (Bracci et al, 1995). Spreading the sludge over the surface of the municipal solid waste is performed easily using a track-mounted bulldozer, on both flat and sloped surfaces. Bracci et al (1995) report that the material is reported to undergo very little degradation, even when exposed to water, making it easy to manage in all weather. The sludge cover has also found to be more resistant to erosion than comparative soil covers.

Much research has been done on the behaviour of paper sludge, and its use as barrier layers in landfill caps, which indicate interesting results, particularly as to the differences in behaviour exhibited by paper sludge and clay.

Floess and de Mello (1997) note that the physical behaviour of paper mill sludges is similar to peats and highly organic silts and clays. Paper mill sludges and secondary sludge. Because this sludge comprises mainly wood fibres and clay, it is also called "Fiber clay" (Floess and de Mello, 1997).

Paper mill sludges typically consist of inorganic and organic solids, plus water. Typical solids contents range from 20 to 45 percent after dewatering (NCASI, 1989), giving equivalent water contents of between 120 and 400 percent.

Pulp and paper mill wastes are generally known to be difficult to landfill, primarily due to high compression ratios and moisture contents (Dunbavan, 1993). The low strength found in many existing sludge landfills is due to high placement water content, low permeability, long drainage distance, decomposition of a certain proportion of the organics, and residual pore pressures (Oweis and Khera, 1990). The angle of friction of fresh paper mill waste has been determined as reducing from 75 to 45 degrees with a 30 percent decrease in organic content. Placing sludge at a lower water content than previously, mixing sludge with other mill wastes such as ash, using the area method of disposal as opposed to end-tipping into dams, and compacting the sludge using low pressure equipment such as a track-mounted bulldozer, all improve sludge landfill stability. This has been the case at the Sappi Enstra landfill.

Several studies have been conducted to evaluate paper mill sludges for use as a soil substitute (NCASI, 1989; NCASI, 1990; Moo-Young and Zimmie, 1995). Much experience has been gained in the USA with the use of paper and pulp mill sludge as landfill liners, intermediate or daily covers, final cover hydraulic barriers, and as the vegetative layer in caps. Thacker and Miner (1985) give that at least 12 mills with either full-scale industry experience or with experimental programs or full-scale programs awaiting approval. Primary sludge from one of the midwest mills has been used as the barrier layer in three municipal landfills. Yearly checks indicate that these caps are functioning well, and one had been in place for nine years at the time of the study. At one of the municipal landfills, sludge was also used for daily or intermediate cover, erosion control, berm

- Compacted clay barrier layer performance is extremely sensitive to construction practice, particularly to clod size, moisture content during compaction, compaction plant used, and desiccation if not protected soon after placement.
- Desiccation, freeze-thaw cycles, and incompatibility with certain chemicals affect compacted clay barrier layer hydraulic conductivity.

2.7 Paper and pulp mill sludge behaviour and performance

The treatment of municipal, and industrial, wastewater results in the formation of slurries high in suspended solids. These slurries, commonly referred to as sludges, are produced either by the concentration of the solids originally in the wastewater (such as raw primary sludge), or the formation of new suspended solids as the result of removing dissolved solids from the wastewater (such as waste activated sludge). Generally, it is neither environmentally or economically feasible to dispose of sludge directly into the environment. Vesilind et al (1986) give that sludge generally requires some method of stabilization and dewatering prior to disposal. There are two often conflicting concerns in sludge disposal: economics and environmental impact. Numerous disposal alternatives are utilized, some of which are no longer environmentally acceptable. These alternatives are landfilling, landspreading on agricultural land, landspreading on reclaimed land, land farming and ocean disposal. Of these methods, all have been or are used in South Africa.

Primary sludges resulting from sedimentation of untreated wastewater generally contain wood fibres as the principal organic component. The inorganic component, generally termed ash, can consist of kaolinite, calcium carbonate, titanium oxide and other materials used in the pulp and paper industry (NCASI, 1989). Clay is usually the principal component of ash. Solids from secondary sludges resulting from the sedimentation of biologically treated wastewater are typically microbial biomass. "Combined sludge" refers to a mixture of primary

3. RESEARCH STRATEGY

Based on the literature review conducted, the testing was to be carried out by means of laboratory tests and field tests. The laboratory tests were carried out first, with samples of the wastes to be used, or samples believed to be representative. For the sludge tests, different ratios of the primary pulp and secondary sludge produced were tested within the limits of Enstra's current and future production volumes, to determine which mixtures would be suitable for capping. In any event, in the laboratory tests all the mixtures tested complied with the hydraulic conductivity specification, so that the outer range mixtures were chosen for field testing.

A clay control was also used to satisfy the requirements of The Department of Water Affairs & Forestry, and to compare with the sludge behaviour. The clay was sourced from a quarry somewhat distant from the Enstra Mill, so that its use in capping the entire site would be extremely expensive. It was, however, the only source of clay that could be made available for capping that was sourced in this study.

The field tests had run for nine months at the time of writing, and are to run for at least another three months. The results presented and discussed here are therefore not the final results of the study.

The study by Jesionek et al (1995) did not investigate paper sludge capping in depth, but listed the only disadvantage as being that the sludge barrier layer must be protected from freeze-thaw effects.

In both the NCASI and Erving field tests detailed above, the pulp barriers outperformed the clay barriers tested, attributed to desiccation and freeze-thaw effects on the clay barriers. In both studies, the hydraulic conductivity of the clays increased over time, while the hydraulic conductivity of the pulp barriers decreased with time. This decrease is attributed to biological activity and settlement in the sludge. Pulp barriers are therefore seen as superior to clay barriers.

x 10^{-7}cm/s, and is therefore suitable for low permeability barrier material. Performance of test pads indicates that paper sludge may be superior to conventional clay since the hydraulic conductivity of the sludge tends to decrease with time. (Floess et al, 1997)

Jesionek et al (1995) evaluated the performance of various landfill final covers. Historically, a compacted clay liner with a minimum thickness of 0.30 to 0.60m and a maximum hydraulic conductivity of between 1 x 10^{-5} and 1 x 10^{-7} cm/s has been the most common barrier layer material in landfill covers in the USA. Jesionek et al (1995) give that it may be unfortunate that this is so, as several potential problems can make the long-term performance of a compacted clay liner questionable. The potential problems include the following:

- Compacted clay liners are difficult to compact properly on a soft foundation such as many waste materials, thus a suitable foundation is needed, and even then the highly compressible waste may adversely affect the compaction process.
- Compacted clay will tend to desiccate from above and/or below and crack unless adequately protected.
- Compacted clay is vulnerable to damage from freezing, and must be protected from freezing by a suitably thick layer of cover soil.
- Differential settlement of underlying compressible wastes will crack compacted clay if tensile stresses become excessive.
- Compacted clay liners are difficult to repair if they are damaged.

The above factors were confirmed by modelling field testing carried out by Melchoir et al (1993), where the compacted clay covers not protected by a geomembrane became extremely permeable within a period of four dry summers, attributed to desiccation and shrinkage cracking. The mechanisms of failure were modelled in a study by Miller and Mishra (1989).

and Moo-Young, 1995). The Hubbardston landfill cap has therefore met the capping requirement of 1 x 10^{-7} cm/s given for the landfill, and the cap is performing satisfactorily to date.

Settlement of the Hubbardston landfill has also been measured using a settlement gauge, and after 2 years the sludge had settled by approximately 19cm as had been predicted in the laboratory. Figure 2.17 shows the settlement of the pulp barrier. (Moo-Young and Zimmie, 1996b)

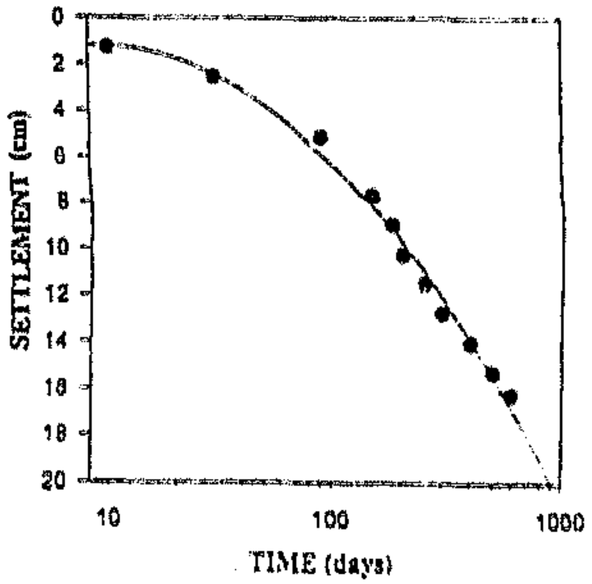


Figure 2.17 Settlement Measured in Sludge at the Hubbardston Landfill (Moo-Young and Zimmie, 1996b)

2.9 Comparisons of paper mill pulp and clay caps

Paper mill sludge has successfully been used as soil material, mostly for construction of landfill caps and for use as cover in active landfills. Paper sludge with more than about 50% ash typically has a hydraulic conductivity less than 1 sludge as barrier layer material in the cap of the 1.8ha Hubbardston, MA, USA municipal landfill (Aloisi and Atkinson, 1991). The barrier layer was thickened to 0,9m in lieu of the standard 0,45m of clay. The sludge was placed and compacted using low pressure track dozers. A paper mill roller was used for compaction, and to smooth the sludge surface. The paper sludge barrier layer was covered with 0,15m of sand and 0,30m of vegetative-support soil. Laboratory hydraulic testing of sludge Shelby tube samples shortly after completion of the layer indicated variable hydraulic conductivities, averaging about 3 x 10^{-7}cm/s (Aloisi and Atkinson, 1991).

Zimmie and Moo-Young, (1995) conducted sampling and testing of the sludge barrier layer capping the Hubbardston landfill 1 week, 9 months, 18 months and 24 months after construction. The results are shown in Table 4.

Table 4

Summary of Laboratory Permeability Tests on In Situ Samples taken from the Hubbardston Landfill Cap

Sample	Date	Time from Construction	Permeability [cm/s]	Water Content [%]
1	July 1991		1.06 x 10^{-7}	170
2	October 1991		4.0 x 10^{-8}	185
3	April 1992	9 months	4.47 x 10^{-8}	106
4	April 1992		4.2 x 10^{-7}	170
5	January 1993	18 months	3.4 x 10^{-8}	107
6	July 1993	24 months	3.8 x 10^{-8}	91.5

It can be seen from Table 4 that two years after completion of the cap indicated an average hydraulic conductivity of 4 x 10^{-8}cm/s, a decrease of about one order of magnitude. This was comparable to the performance of the test pads (Zimmie hydraulic conductivity of the primary sludge decreased to about one-third of its initial value. The better performance of the combined sludge was attributed to the presence of fine colloidal material in the secondary sludge. The clay test pad showed significant deterioration, which was attributed to freezing and thawing. The sludge, however, showed improved performance over the first winter. The average hydraulic conductivities measured in the Erving tests are indicated in Table 3.

Table 3

Average Calculated Field Permeability Values for the Erving Test Plots (Aloisi and Atkinson, 1991)

Test Plot	Description	1990 Permeability [cm/s]	1991 Permeability [cm/s]
1	18 inch Clay Control	2.8×10^{-7}	1.1×10^{-7}
2	18 inch Primary Sludge	2.9×10^{-7}	3.1×10^{-7}
3	18 inch Blended Sludge	1.4×10^{-7}	1.6×10^{-7}
4	36 inch Primary Sludge	3.2×10^{-7}	2.0×10^{-7}
5	36 inch Blended Sludge (1989)	1.3×10^{-7}	1.4×10^{-7}
6	36 inch Blended Sludge (1990)	1.6×10^{-7}	0.8×10^{-7}

From the results of the Erving tests, Aloisi and Atkinson (1991) concluded that paper mill sludge can provide equivalent or better performance compared to clay, as the field permeability of clay increased with time, while that of sludge decreased with time. They also concluded that laboratory determined permeability values were poor predictors of field permeability values, and that blended sludge performed better than primary sludge.

In 1991, a full scale demonstration project was completed using Erving paper

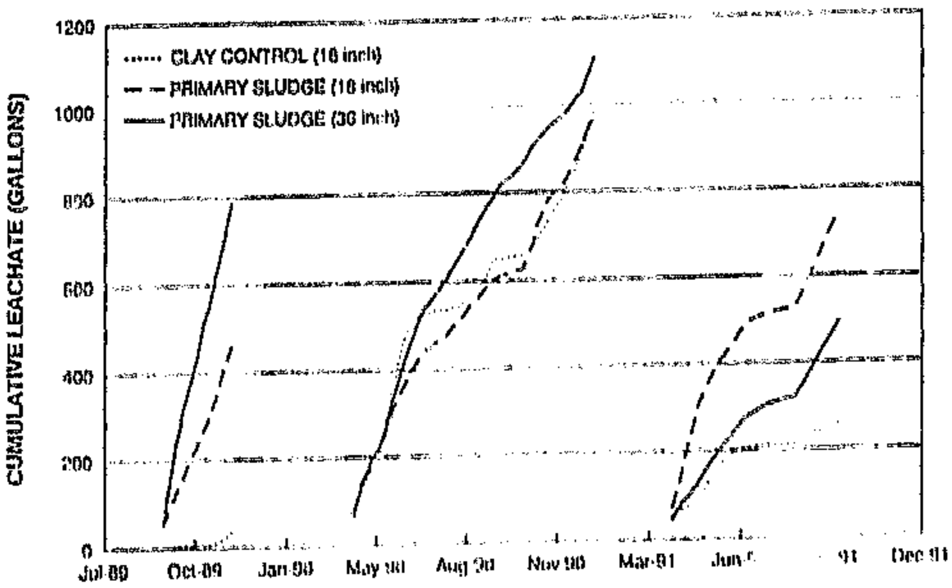


Figure 2.15 Erving Primary Sludge Test Plot Cumulative Leachate Production (Aloisi and Atkinson, 1991)

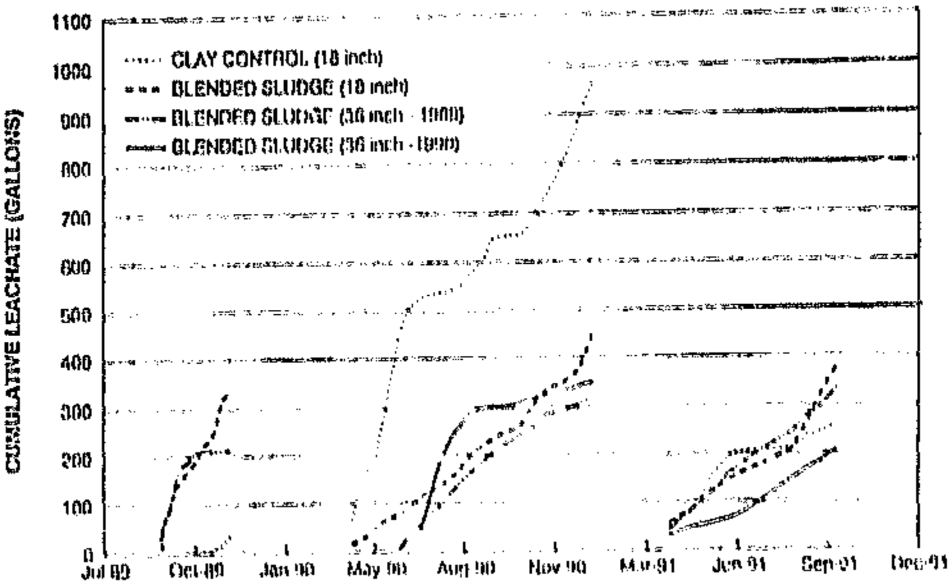


Figure 2.16 Erving Blended Sludge Test Plot Cumulative Leachate Production (Aloisi and Atkinson, 1991)

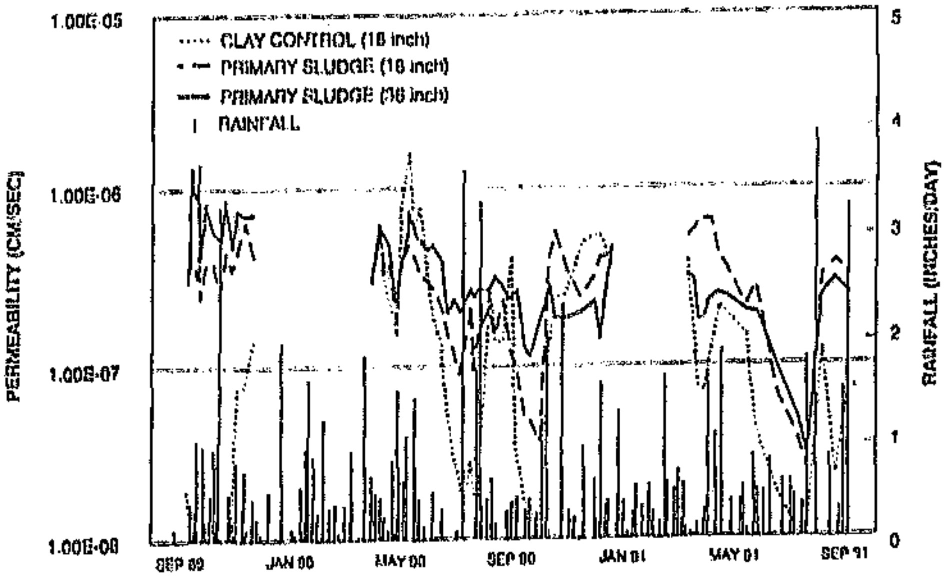


Figure 2.13 Erving Primary Sludge Test Plot Permeability (Aloisi and Atkinson, 1991)

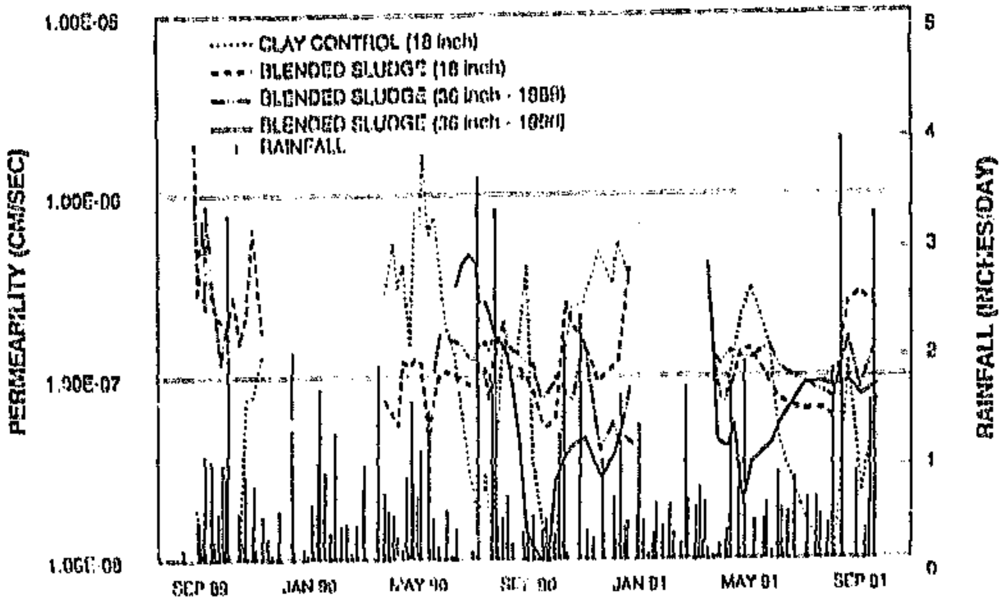


Figure 2.14 Erving Blended Sludge Test Plot Permeability (Aloisi and Atkinson, 1991)

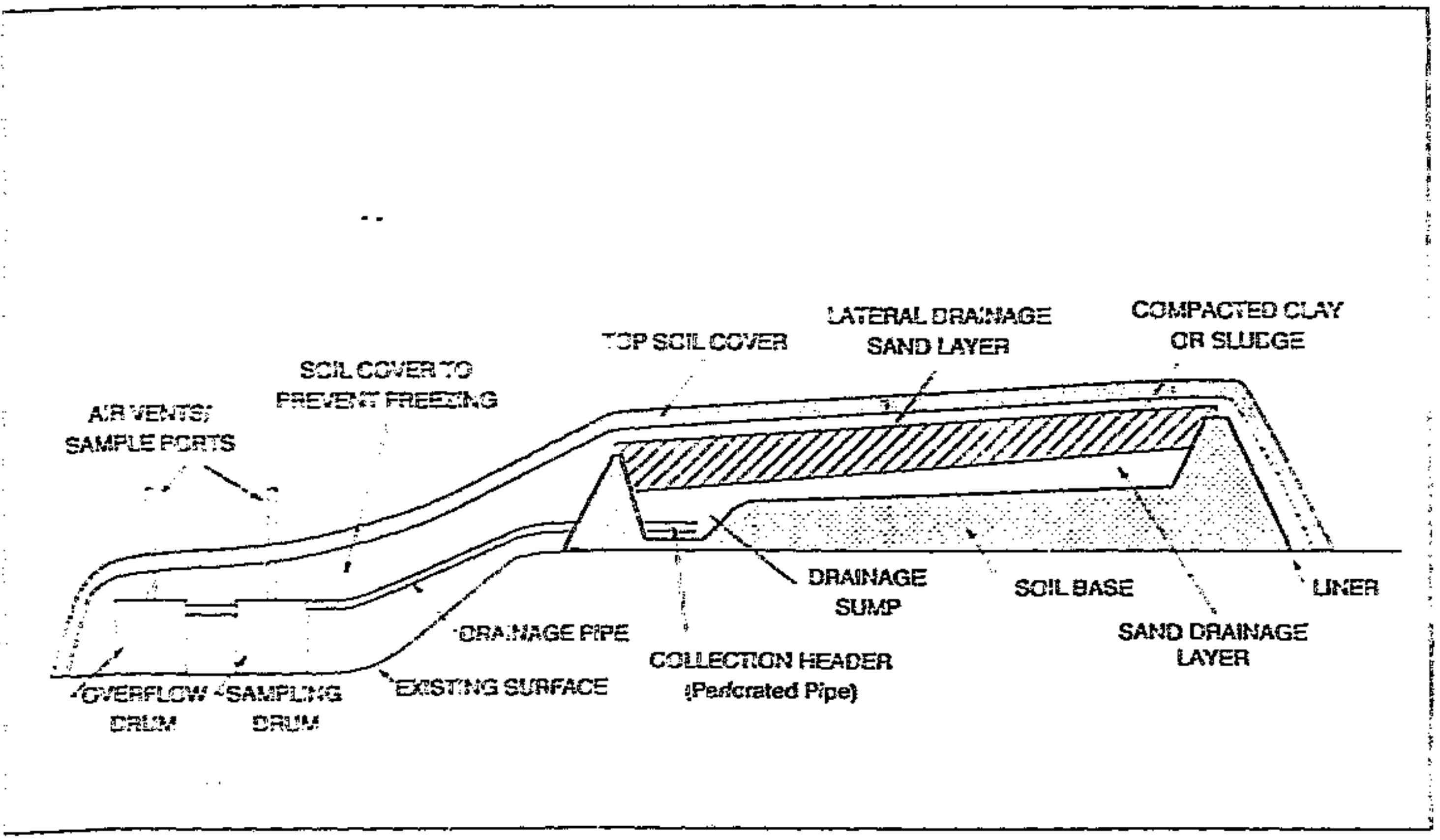


Figure 2.12 Erving Final Landfill Cover Test Plot Design (Aloisi and Atkinson, 1991)

barriers was within both moisture content and density specifications, full-scale compaction equipment could not be used on the field cells, and clods did not appear to be sufficiently broken up during construction.

Erving Paper, in Massachusetts, USA, conducted a comprehensive study on the use of their sludge as barrier layer material in landfill caps (Aloisi and Atkinson, 1991). Six test plots were constructed in August 1989 to evaluate the performance of Erving Paper Mill's sludge as hydraulic barrier in landfill caps. Both primary and combined sludge were evaluated. One of the test pads was constructed with clay as control. The thickness of the barrier layers used was either 450mm or 900mm. Each barrier layer was covered with a 150mm thick sand drainage layer, and a 300mm sand and topsoil layer for supporting vegetation. One cell was built later than the others, in June 1990, to determine the reproducibility of results. The test pads again included provisions for monitoring and collecting runoff and throughflow. The design of the test pads is included as Figure 2.12. The infiltration area of the test cells was approximately 58m^2. Note that the slope on these test pads was 6% so that more runoff can be expected than for the NCASI test pads. The tests were run for 2 years.

Figures 2.13 and 2.14 indicate the change in permeability with precipitation over the first two years of testing. Note that the hydraulic conductivity calculated is not smooth, but generally varies widely depending on incident rainfall. The travel time through the barrier layer following a precipitation event was reported to be up to 4 weeks at this stage (Aloisi and Atkinson, 1991).

The results of the Erving Field tests were, in many ways, similar to those for the NCASI tests. Figures 2.15 and 2.16 show cumulative leachate production for the six plots. The sludge barriers were found to be less susceptible to precipitation levels than the clay barriers, at least initially. The hydraulic conductivity of the sludge decreased with time. The measured hydraulic conductivity of the combined sludge decreased by about one order of magnitude. The measured

Table 2

Summary of Field Hydraulic Conductivities on Termination of NCASI Field Tests (Maltby and Eppstein, 1996)

Test Method	Primary [cm/s]	Combined [cm/s]	Clay 2 [cm/s]	Clay 4 [cm/s]
1995 Water Balance	9×10^{-8}	8×10^{-8}	6×10^{-6}	2×10^{-6}
SDRI	6×10^{-7}	2×10^{-7}	7×10^{-7}	8×10^{-6}
TSB-1	NR	3×10^{-7}	6×10^{-7}	4×10^{-6}
TSB-2	NR	1×10^{-7}	8×10^{-7}	NR
Block Specimens	8×10^{-8}	4×10^{-8}	NC	NC

NR - not reported because TSBs leaked

NC - test not conducted

The dye tracer study was conducted to detect the presence of macroscopic flow pathways. Dye was allowed to infiltrate the pulp barrier layers for several weeks, and the clay barrier layers for 10 days. Each barrier layer was then visually examined by sequentially removing 15cm thick vertical cross-sections by hand. Macroscopic flow pathways were identified as finger-like purple-red areas of the barrier. Extensive macroscopic flow pathways were visible in both of the clay barriers, both in the vertical and horizontal planes. The vertical paths traversed the full thickness of the clay barriers, allowing the dye to infiltrate into the clean sand layer below. In the combined pulp barrier, one macroscopic pathway was detected near the outer edge of the dyed barrier area. No macroscopic pathways were detected in the primary pulp barrier (Benson and Wang, 1996). Maltby and Eppstein (1996) attribute the macroscopic pathways in the clay barrier to either desiccation cracking, or more probably, the presence of clods in the clay barrier when compacted. Although the construction of the clay

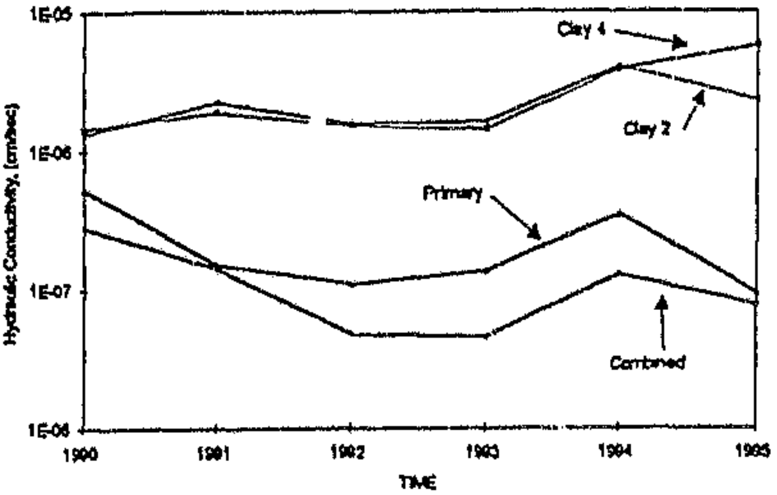


Figure 2.11 Ncasi Tests: Averaged Annual Hydraulic Conductivity From Water Balance Data (Maltby And Eppstein, 1996)

At the end of the field study, the test cells were diagnostically examined and excavated in order to maximise the understanding of the differences between the pulp and clay barrier layers. This examination consisted of an infiltration study and a dye tracer study of the barrier layers, and a close inspection of other components of the test cells (Maltby and Eppstein, 1996; Benson and Wang, 1996). The infiltration study included sealed double ring infiltrometers (SDRIs) and two-stage borehole permeameters (TSBs). Gas emanating from the pulp layers interfered with results until the SDRIs were modified. For the pulp layers, the results from the SDRIs were higher than were determined from the long term water balance. This was attributed to the fact that the overburden layer was removed from the barrier layers to facilitate testing, thereby reducing effective stress. Laboratory testing of block specimens removed from the layers, at effective stresses equivalent to those experienced in the field, gave hydraulic conductivities almost identical to those determined in the field. The TSB tests did not yield usable data for the primary sludge. The results were as follows:

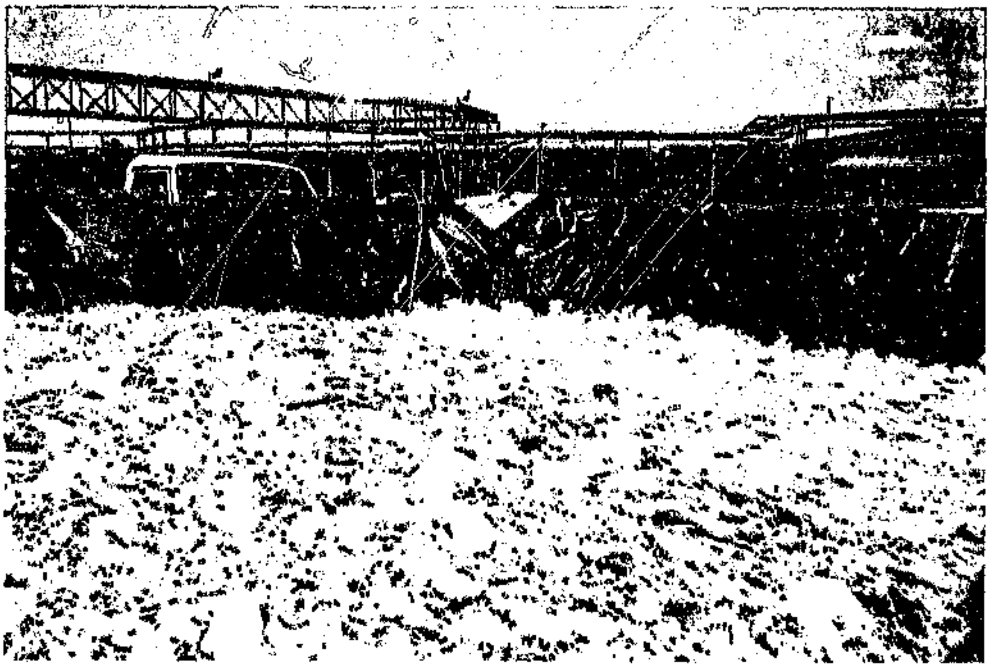


Figure 5.6 Primary Pulp in Cell before Compaction

The combined pulp layers were placed in Cell 3, also with nominal compaction, and from the belt press. The cell received one of the first loads of combined pulp produced by the Mill once the effluent treatment plant had been commissioned and its operation stabilised. The combined pulp was approximately in the 80:20 maximum mass ratio expected.

From the above, it may be seen that the construction of the barrier layers in Cells 2 and 3 was considerably easier than the construction of the clay cap in Cell 1.

The results of the compaction testing carried out on the barrier layers is included as Appendix 3. It is noted that the Troxler equipment used did not measure the moisture content of the sludges, and the moisture content figures given in the Matrolab results for sludge are irrelevant.

All three cell barrier layers were covered with approximately 200mm of topsoil.

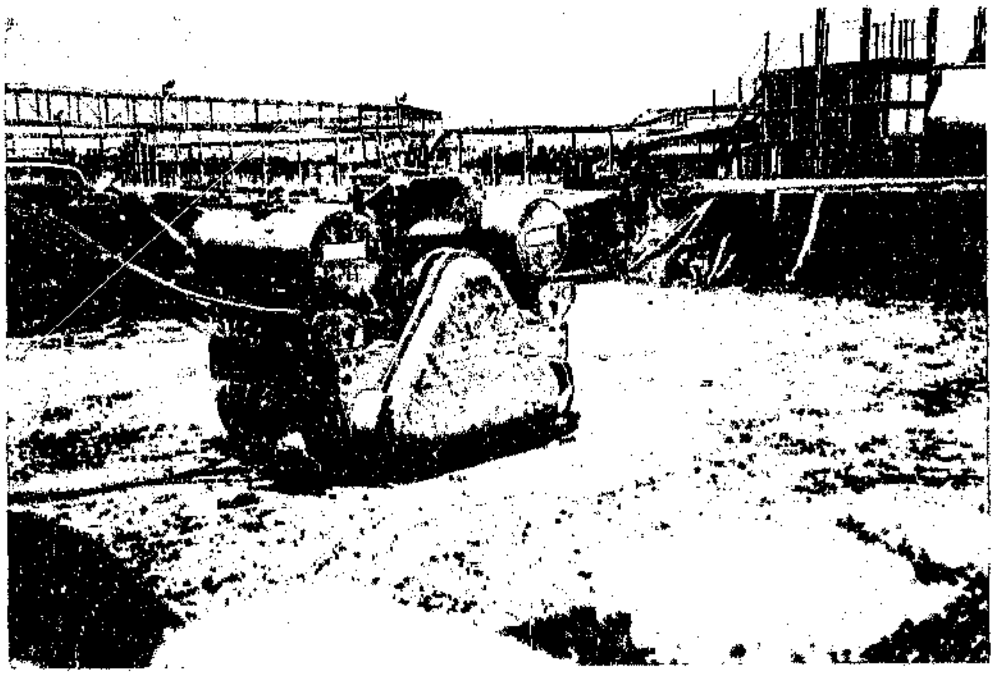


Figure 5.5 Compactor on Compacted Clay Barrier

The placement and compaction of the pulp barrier layers was somewhat easier. The primary pulp coming off the belt press was transported to the second cell and was placed in layers. The layers were given nominal compaction using hand compactors and manual labour. The compactor used for the clay layers was not used for the pulp as the pulp could not support the weight of the plant, and moved laterally, achieving little compaction, but much redistribution. Figure 5.6 shows the primary pulp in Cell 2, before compaction.

collected in the sumps was pumped out using a small submersible pump.

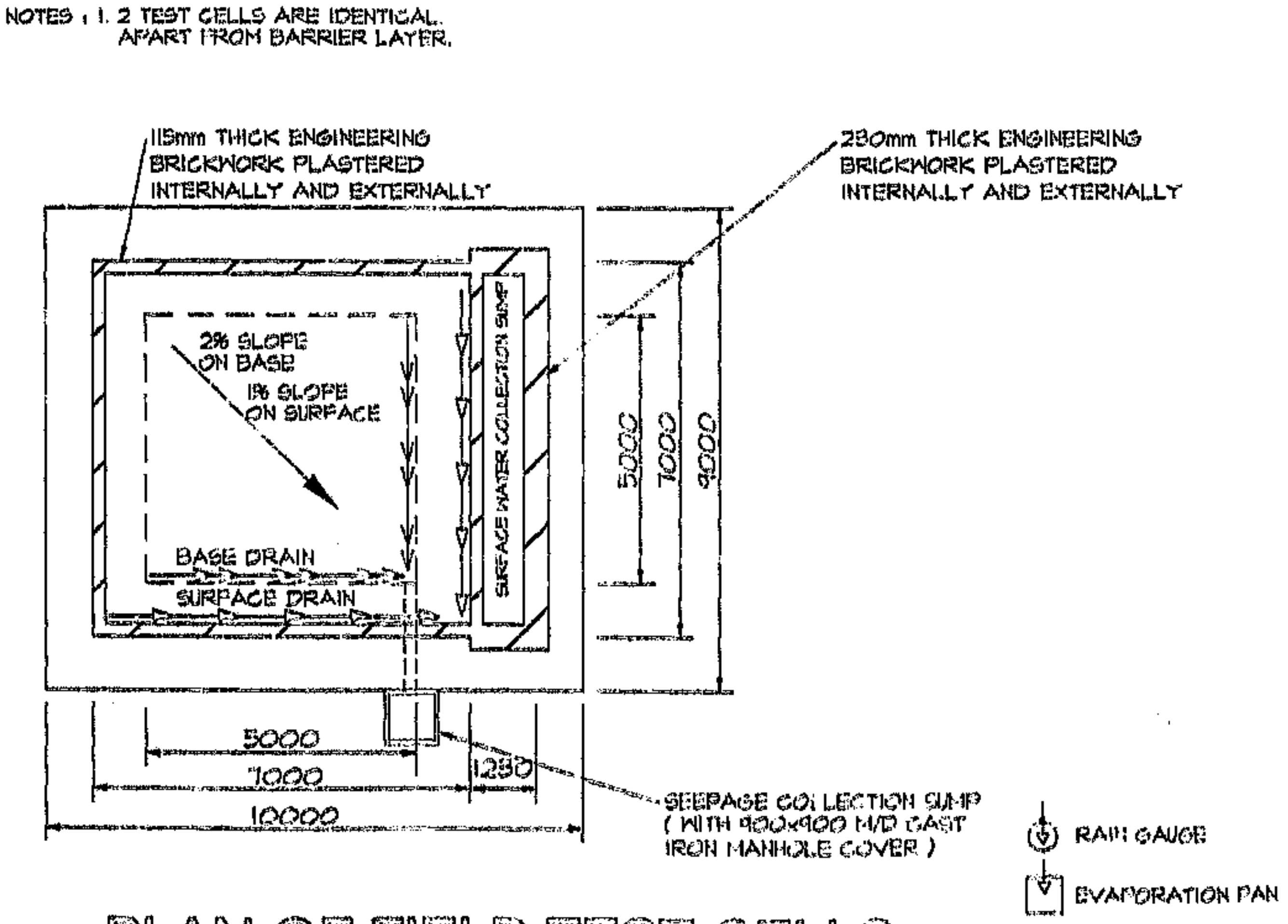
Each surface water system comprised perforated pipes laid on two sides of the top of the topsoil layers. These perforated pipes were connected to a pipe that carried collected runoff into the adjacent runoff sump. Each runoff sump was 7m by 1m in plan, and 1.3 m high. The sumps were fitted with release valves at their base, so that the collected runoff could be discharged after each measurement.

The field cells were constructed using concrete bricks for the outer walls, ash-fill from the Mill to form the inside slopes, and reinforced concrete slabs to waterproof these slopes. The underdrain pipework was then constructed, and the sand drainage layer placed over this. The sand drainage layer was given nominal compaction. Thereafter a geotextile blanket was placed over the sand layer, so that the sand was not clogged with fines from the barrier layers. Thereafter the barrier layers were constructed. The barrier layers in each cap were 450mm thick, immediately after placement.

The clay control cap was constructed first. As the contractor was a builder, with little experience in earthworks, the placement and compaction of the clay cap proved to be problematic. Firstly, the clay obtained contained many clods, and had to be broken down. The initial compaction process was unsuccessful, as the clay was compacted approximately 11% wet of optimum, to relatively low densities. The clay was recompacted thereafter, at lower moisture contents, to approximately 100% Proctor dry density. The moisture contents were still not within the prescribed optimum moisture content to optimum moisture content plus 2%. Also, the compaction equipment used was not particularly heavy, nor was it of the sheepsfoot variety. The clay was therefore not expected to reach optimal hydraulic conductivity. Considering the effort already put in by a frustrated builder, it was decided not to revisit the clay compaction. The clay barrier, with compaction equipment is shown in Figure 5.5.

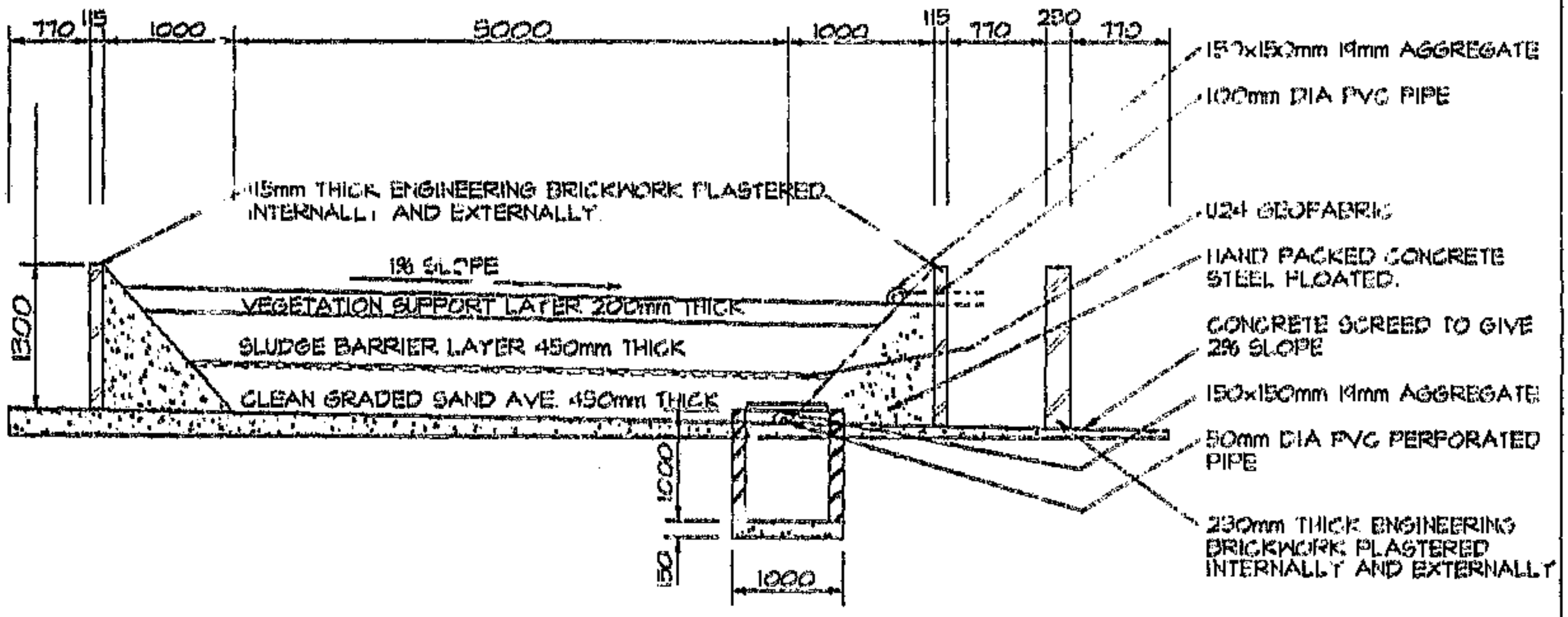
Figure 5.3 Cell Construction

Figure 5.4 Sand Layer Placement



PLAN OF FIELD TEST CELLS

FIGURE 5.2



CROSS SECTION OF FIELD TEST CELLS

FIGURE 5.1

5. FIELD TESTING

5.1. Design and construction of field cells

Three test cells were designed and constructed. The three test cells were constructed on the Enstra Mill property, within the Mill's security fence. Each cell contained a different cap, so that the range of sludge mixtures could be tested, and so that a clay control could also be monitored, in accordance with the wishes of the Department. The design of each cell was exactly the same. The design was based on the NCASI cells, with some modifications. A tender was put out to three building companies, and the lowest tenderer was appointed to construct the cells. The construction took longer than expected, and was completed in February 1997.

The field cells are 7m by 7m by 1.3m high, and were constructed above ground. The cells narrow to 5m by 5m at their base, so that the barrier layers had dimensions of approximately 6m by 6m at placement. The infiltration area was therefore approximately 36m^2 for the first few months of testing, which reduced to approximately 25m^2 once the side-liner was constructed. Each cell was equipped with both underdrainage and surface water drainage systems. The details of the field test cells are given in Figures 5.1 and 5.2. Construction at an early stage is shown in Figure 5.3.

Each underdrainage system comprises the sand beneath the barrier layer, see Figure 5.4. Perforated pipes were placed on the downslope sides of the cell base, to collect the seepage that had passed through the barrier layer. The perforated pipes were connected to a pipe that carried the seepage through the cell walls, and into the leachate sumps. These sumps were constructed adjacent to each cell, and have dimensions 1m by 1m by 1,1m height, i.e. a capacity of 1,1m^3. The sumps were fitted with removable steel lids, to prevent incident precipitation from entering, and to allow for easy monitoring. The seepage that

An example of the sludge test results and the clay test results are found in Appendix 1 and 2, respectively.

4.4. Interpretation

Given that the laboratory testing was not as extensive as first planned, mainly due to the time taken for each test, and the availability of the equipment, the results achieved were good. As the required hydraulic conductivity for the capping of the Sappi Enstra landfill is specified as 2,78 x 10^{-5} cm/s, all the test results are within specification by at least one order of magnitude. It was therefore decided to proceed with the field tests. As the range of possible mixtures met the specification, it was decided to test both mixtures in the field cells.

As was expected from the NCASI field studies, the hydraulic conductivity for the combined mixture was lower than for the primary pulp only.

The clay hydraulic conductivity achieved was excellent, which was expected from the high quality of clay obtained.

with the lower moisture content sludge when the new press was brought on line.

As each of the hydraulic conductivity tests took more than a month to carry out, and only one apparatus was available for the testing, only the 80:20, and 100:0 percentage mixtures were tested. (Ratios refer to the ratio of primary pulp to secondary sludge, by mass.)

4.3. Results

The compaction curves determined were extremely flat, with optimum moisture contents in the range of 100 to 150%. The compaction curves determined were similar to those determined by Moo-Young and Zimmie (1996b), as included as Figure 2.6, in the literature review.

The laboratory tests were conducted at between 60% of and at optimum moisture content and at maximum Proctor density.

The results of the laboratory hydraulic conductivity tests were as follows:

Table 5

Results of Laboratory Tests on Enstra Materials

Material Used	Hydraulic conductivity Achieved [cm/s]	Average Hydraulic conductivity for material [cm/s]	Laboratory Used
Primary Sludge	5.0×10^{-7}	1.3×10^{-6}	Wits Civils Labs
Primary Sludge	2.1×10^{-6}		Wits Civils Labs
80:20 Sludge Mixture	8.0×10^{-7}	8.0×10^{-7}	Wits Civils Labs
Clay Control	2.5×10^{-8}	2.5×10^{-8}	Soiltech

moisture contents of the samples.

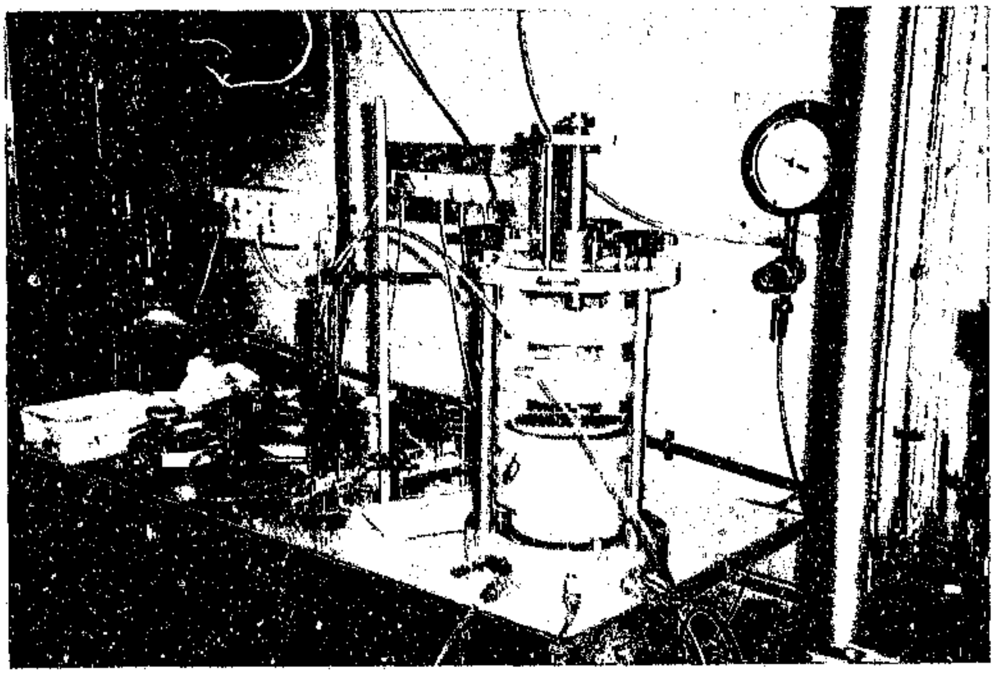


Figure 4.1 Triaxial Laboratory Hydraulic Conductivity Test on Sappi Enstra Waste

The first hydraulic conductivity tests done leaked, so that 2 membranes and 4 O rings were used in all subsequent tests. The membranes also appeared to be degraded by the samples as they developed blobs of a black substance and stains.

Sappi Enstra implemented changes in their plant during this project, which changed conditions. The first was that they were not yet producing secondary sludge when the testing was started, so that activated sewage sludge was substituted. Further tests were done when the Mill's activated sludge plant was brought on line.

Also, the Mill installed a new dewatering press, which changed the characteristics of the primary sludge somewhat, so that further tests were done

Two tests were carried out per mixture, so that the results could be cross-checked.

The objective of the compaction (i.e., density versus moisture content) tests was to determine the maximum compaction of the material possible, which could be used to check field cell barrier layer compaction on already compacted layers. The objective of the hydraulic conductivity tests was to determine the lowest hydraulic conductivity of the barrier layer samples. These results were used to determine the mixture to be used in the field test cells.

The hydraulic conductivity achieved in the laboratory tests was compared with the maximum allowable hydraulic conductivity specified by the Department to assess the feasibility of continuing the investigations.

It must be noted that much of the sludge behaviour and testing results included in the literature review were published, or became available, following the commencement of testing for this study. Thus aspects such as compacting sludge at moisture contents of 50 to 100% wet of optimum as given by Kraus et al (1997) were not used in this study. The use of these findings, however, would only improve the results achieved in this study.

4.2. Methodologies

Hydraulic conductivity testing was done in the large triaxial apparatus owned by Wits University, with samples of 10cm diameter. The apparatus, with a test running, is shown in Figure 4.1. The samples were given nominal compaction.

The moisture content of the sludge was difficult to measure and adjust, as the sludge was extremely susceptible to atmospheric moisture, and changed significantly in the main sample within the time taken to carry out the test. The determination of compaction curves was made difficult by fluctuations in the

4. LABORATORY TESTING

4.1. Outline of tests done

Laboratory testing was undertaken to determine the mixture of primary and secondary sludges (taking into account the ratio of sludges produced by the Mill) which gives the lowest hydraulic conductivity. The Mill has produced 80% primary sludge and 20% secondary sludge from September 1996, given that fibre recovery from the primary clarifier has reduced, so that the percentage of secondary sludge used in the testing did not exceed 20%. As Enstra was not producing secondary sludge at the time the laboratory testing was undertaken, sewage sludge from the Olifantsfontein Sewage Works in Midrand was used.

The Mill produces a small quantity of fly ash relative to the sludge. As fly ash is shown to decrease permeability in the literature (NCASI, 1989), a small percentage was originally included in the mixes. The use of fly ash was discontinued because a relatively insignificant percentage is produced, and it was difficult to mix into the sample being tested. The corresponding mixing for on-site capping would have proved unfeasible.

The following laboratory tests were carried out on the sludge samples by the University of the Witwatersrand Department of Civil and Environmental Engineering:

- Moisture content
- Compaction
- Hydraulic conductivity.

Originally, Atterberg limits were to have been determined in the laboratory, but this proved extremely problematic. It was therefore decided to concentrate on hydraulic conductivity testing.

Figure 5.11: Hydraulic Conductivity and Precipitation- Cell 1(Clay)

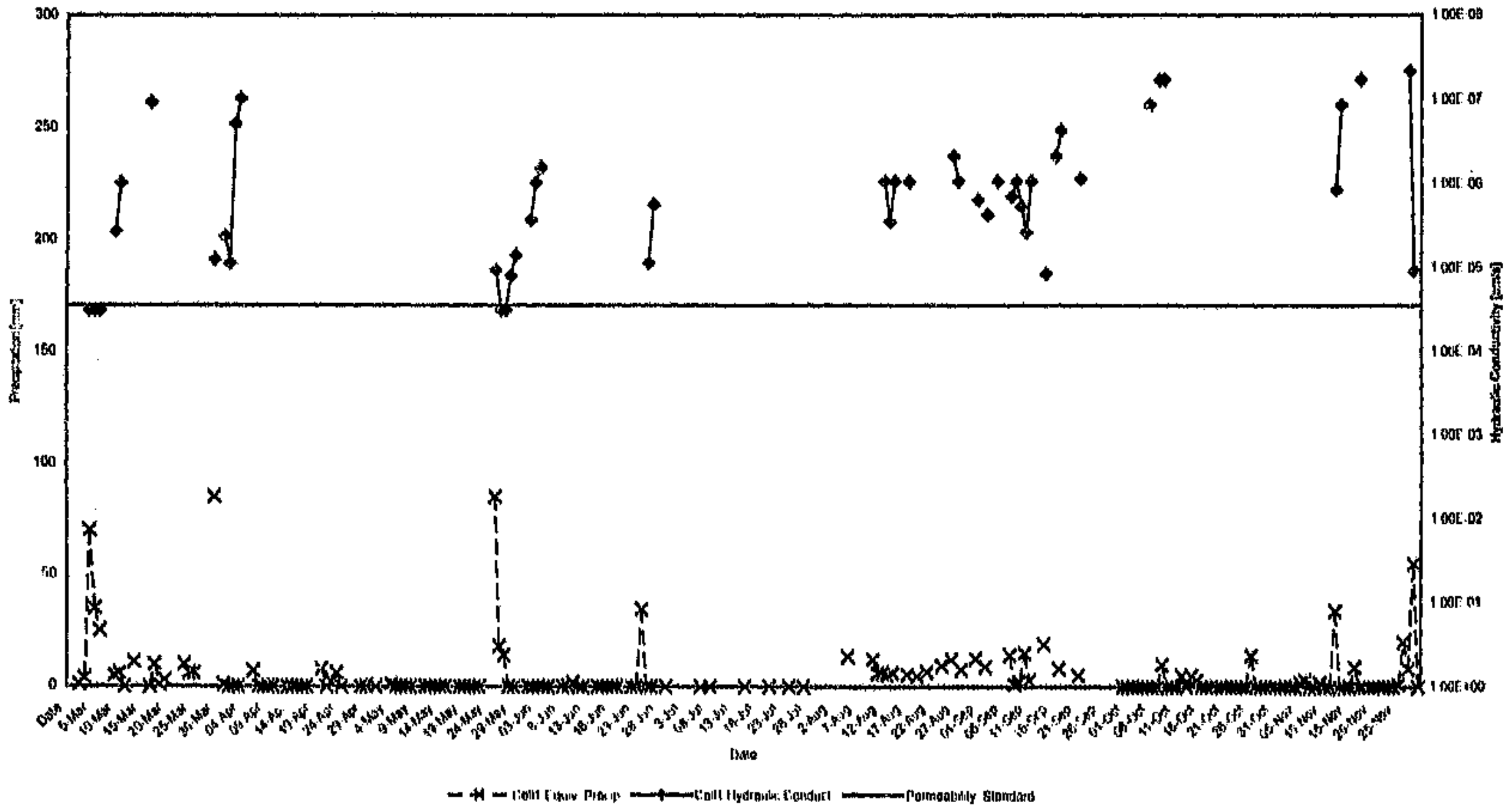
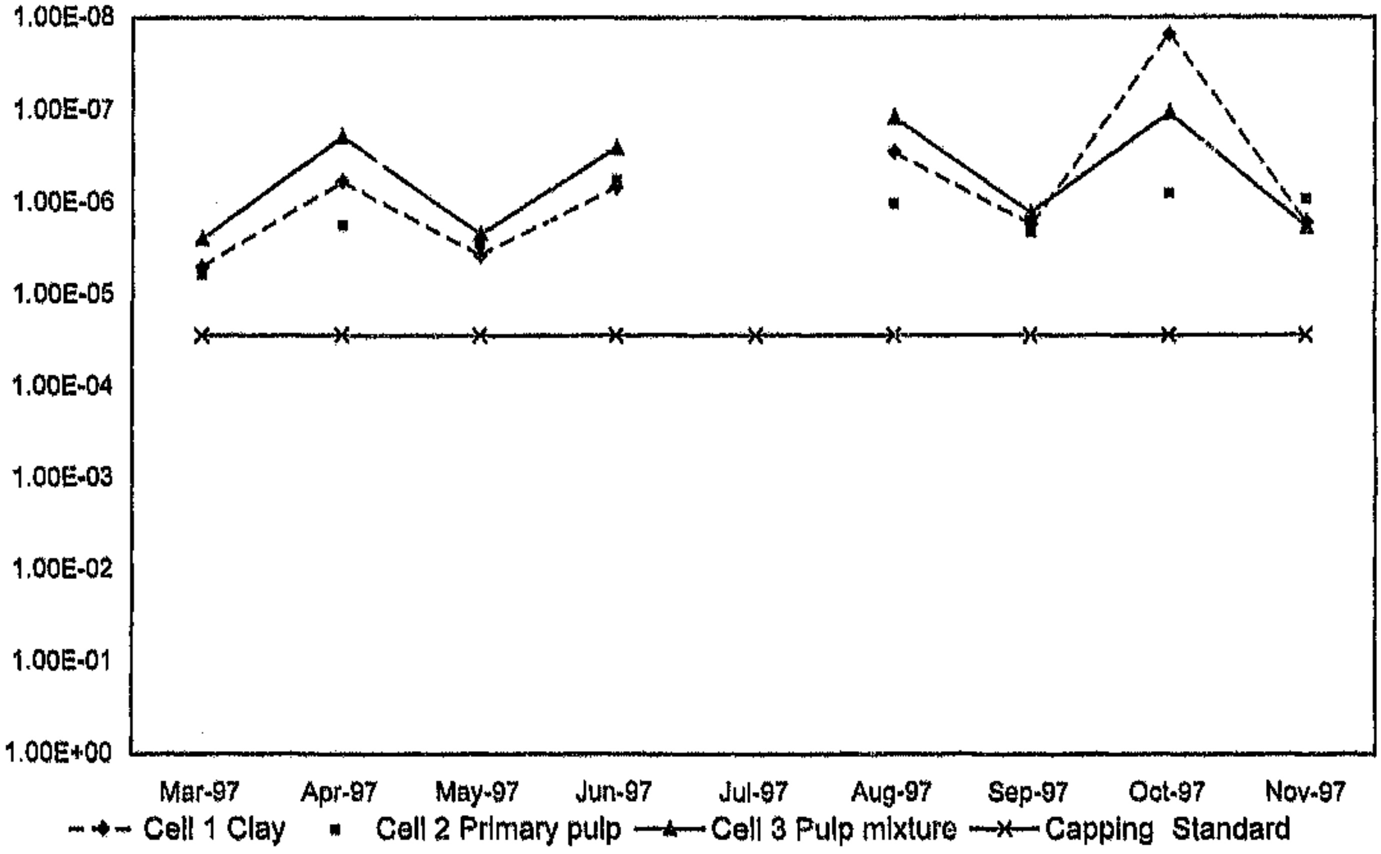


Figure 5.10: Hydraulic Conductivity Averages



clay. This fact that the clay shows a decrease in hydraulic conductivity is attributed to the short-circuit which occurred down the sides of the cells in the early months of testing. This indication can be confirmed by monitoring the results from the tests over the next few months.

Figures 5.11, 5.12, and 5.13 show the precipitation and hydraulic conductivity for the nine months of monitoring for each of the three test cells. The format in which these graphs are given has been chosen for comparison with the test results published internationally. However, it is recognised that it may appear misleading. Hydraulic conductivity does not fluctuate with fluctuating precipitation: the rate of transmission does, which is a function of both the hydraulic conductivity and the hydraulic gradient. From Figure 5.11, it can be seen that the clay barrier in cell 1 in fact exceeded the required standard on five days of the nine months. All these incidents were before the side-lining was constructed for the cells, and is attributed to a short circuit down the sides of the cells following ponding from high rainfall events. Since the lining has been placed, the hydraulic conductivity standard has not been exceeded once. From Figure 5.12, it can be seen the primary pulp barrier layer exceeded the required standard for two days shortly after placement of the layers. Again, this was attributed to short-circuiting. The primary pulp has not exceeded the standard since the first week of testing. Figure 5.13 shows that the combined pulp barrier has not exceeded the required standard on a single occasion. The hydraulic conductivity results plotted on these three graphs may appear somewhat scattered. This is attributed to the scatter in precipitation events that occurred during testing, and is also apparent in the Erving test results, as seen in Figures 2.13 and 2.14, included in the literature review.

and field testing of the hydraulic conductivity of compacted clay liners do differ by two orders of magnitude, particularly where small diameter samples are tested.

The results of the water quality analyses on the seepage are included in Appendix 5. It can be seen that the quality of seepage from Cell 1 is better than that from Cells 2 and 3. The seepage from Cell 2 certainly did not meet effluent standards, and had a particularly strong odour. As the seepage will flow into the waste body, which contains the same material, the quality of the seepage is not of major concern. This would be re-evaluated however, should the pulp layers be considered for use as a landfill liner.

5.5. Interpretation

Comparing the laboratory and field test results on the capping materials used, it may be seen that for both the primary pulp and the combined sludge caps, the hydraulic conductivities achieved in the field are within ten percent of the laboratory results achieved. The clay cap test results, however, exhibit almost two orders of magnitude difference, as could be expected from the literature review. The use of small scale laboratory tests has been found to be sufficient for predicting field hydraulic conductivities of paper pulp, but may not be relied upon for the design of clay caps.

Figure 5.10 plots the average monthly hydraulic conductivities with time for all three cells. It can be seen that the averages for all three cells are well within the required specification for hydraulic conductivities for landfill caps in South Africa, indicating that the material is suitable for this use. It was hoped that this graph would mirror the decreasing trend of hydraulic conductivities of pulp with time, as shown in both the NCASI and Erving tests. In fact, the graph gives some indication of this. From the graph, it can be seen that the general trend for hydraulic conductivity for all three cells is reduction with time, including the

From these results it can be seen the specified hydraulic conductivity of 2.8 x 10^{-5} cm/s is met by all three barrier layers. From the results, it may also be seen that the combined pulp barrier has outperformed both the primary pulp and the clay barrier layers, as was the case in the NCASI test cells, albeit only marginally in the case of the clay.

As has been noted, the cells leaked down the sides if sufficient ponding occurred (in high rainfall events). From the results, it can be seen that while the monthly hydraulic conductivity figure was within specification there were instances where the hydraulic conductivity of a cell fell below the standard for a day or two. Strictly speaking therefore, the high rainfall events that occurred within the testing period before 17 July 1997 should be ignored. (The plastic side-liner construction was completed on 17 July 1997).

Settlement was not measured as part of the testing program, but has certainly occurred in the pulp barriers. Estimating from the height difference between the top of the pulp barriers and the surface water outlet pipe, this is estimated as approximately 10cm, or approximately 20% even though there was little overburden. The total settlement will be determined at the end of the tests.

As has been shown in the literature review, the careful construction of clay barrier layers is vital to their performance, and this became a case in point. The hydraulic conductivity achieved in the clay cap was almost two orders of magnitude greater than predicted in the laboratory tests. This is attributed to the moisture content at compaction being outside of the acceptable moisture content envelope, and the compaction equipment being lighter than would normally be allowed when compacting clay barrier layers. It may also be as a result of desiccation cracking. This behaviour was very similar to that reported for the NCASI clay control barrier (Maltby and Eppstein, 1996). The reason can be established by hand excavation and evaluation, as was carried out after the NCASI testing came to an end. It must be noted that in many cases, laboratory of barrier layer tested. Equivalent precipitation refers to the incident precipitation that has occurred on each cell as a result of both rainfall and irrigation. Graphs of these results are included as Figures 5.10 to 5.17, and are discussed in the interpretation section.

The hydraulic conductivity results can be summarised as follows:

Table 6

Results of Field Tests on Enstra Materials

	Hydraulic conductivity [cm/s]		
Field Cell Results: 1997	**Cell 1** **Clay**	**Cell 2** **Primary pulp**	**Cell 3** **Pulp mixture**
March	5.0×10^{-6}	6.0×10^{-6}	2.5×10^{-6}
April	5.8×10^{-7}	1.8×10^{-6}	1.9×10^{-7}
May	3.7×10^{-6}	2.9×10^{-6}	2.8×10^{-6}
June	6.7×10^{-7}	5.7×10^{-7}	2.5×10^{-7}
July	-	-	-
August	2.8×10^{-7}	1.0×10^{-6}	1.2×10^{-7}
September	1.7×10^{-6}	2.1×10^{-6}	1.3×10^{-7}
October	1.5×10^{-8}	8.0×10^{-7}	1.1×10^{-7}
November	1.6×10^{-6}	9.1×10^{-7}	1.8×10^{-6}
Average since testing commenced	$\mathbf{1.7 \times 10^{-6}}$	$\mathbf{2.0 \times 10^{-6}}$	$\mathbf{1.1 \times 10^{-6}}$
Average since side liner was installed	$\mathbf{9.0 \times 10^{-7}}$	$\mathbf{1.2 \times 10^{-6}}$	$\mathbf{8.3 \times 10^{-7}}$
Guelph Permeameter Results 20 June 1997	$\mathbf{1.4 \times 10^{-6}}$	$\mathbf{4.2 \times 10^{-6}}$	$\mathbf{1.7 \times 10^{-7}}$

D_f is the depth to the wetting front

The depth to the wetting front was not measured as part of the field study as this would have involved complicated and expensive testing equipment. This depth would have changed as saturated and unsaturated flow occurred. The hydraulic gradient was assumed to be one in all calculations. This is conservative, as the hydraulic conductivity would be more than one, given that ponding occurred during testing. This assumption was also used in the Erving tests.

Hydraulic conductivity is usually calculated using the equation

$$k = \frac{I}{i}$$

where I is the rate of infiltration measured

Taking $i = 1$, The infiltration rate was therefore calculated as:

$$k = I = \frac{Q}{At}$$

5.4. Results

The measurements taken, and the consequent calculations are included, in spreadsheet format, in Appendix 4. From the measurements, it can be seen that no precipitation fell, or irrigation was undertaken, in the month of July. This month has subsequently been omitted from the calculations of averages. The second set of spreadsheets includes calculations of potential evaporation, seepage flow, hydraulic conductivity and equivalent precipitation for each cell. Each of these has been calculated as equivalent for the infiltration area of the cells; i.e. evaporation, seepage and equivalent precipitation are given as per square metre

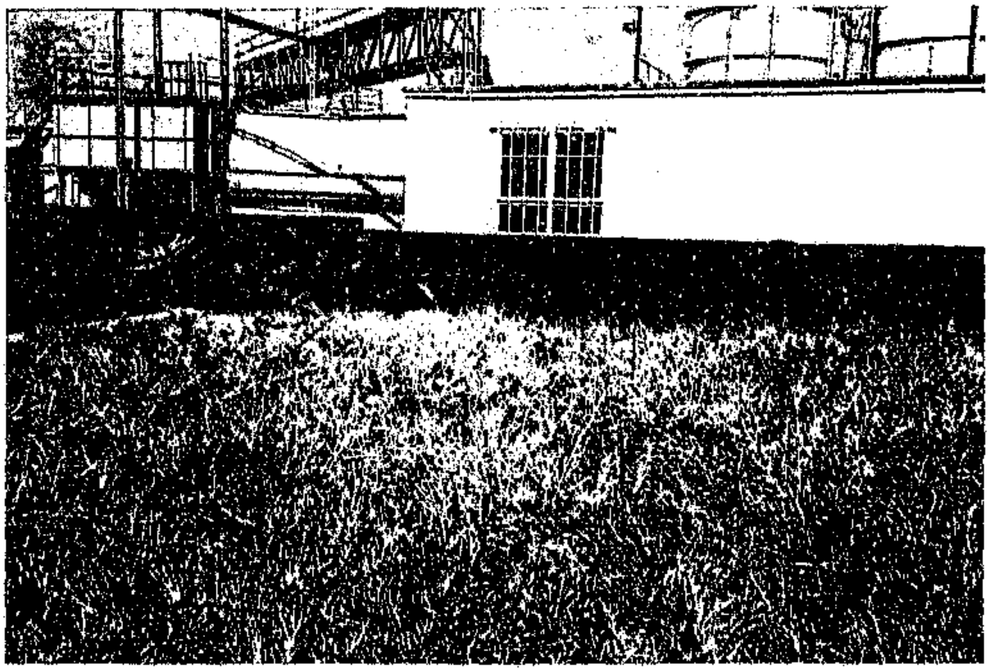


Figure 5.9 Irrigation of Cell 1 showing Side-liner

The results were calculated based on Darcy's law:

$$Q = kiAt$$

where Q is the flow measured

k is the coefficient of hydraulic conductivity

i is the hydraulic gradient

A is the area of the test

t is time

The hydraulic gradient is defined as:

$$i = \frac{D_p + D_t}{D_t}$$

where D_p is the depth of ponding

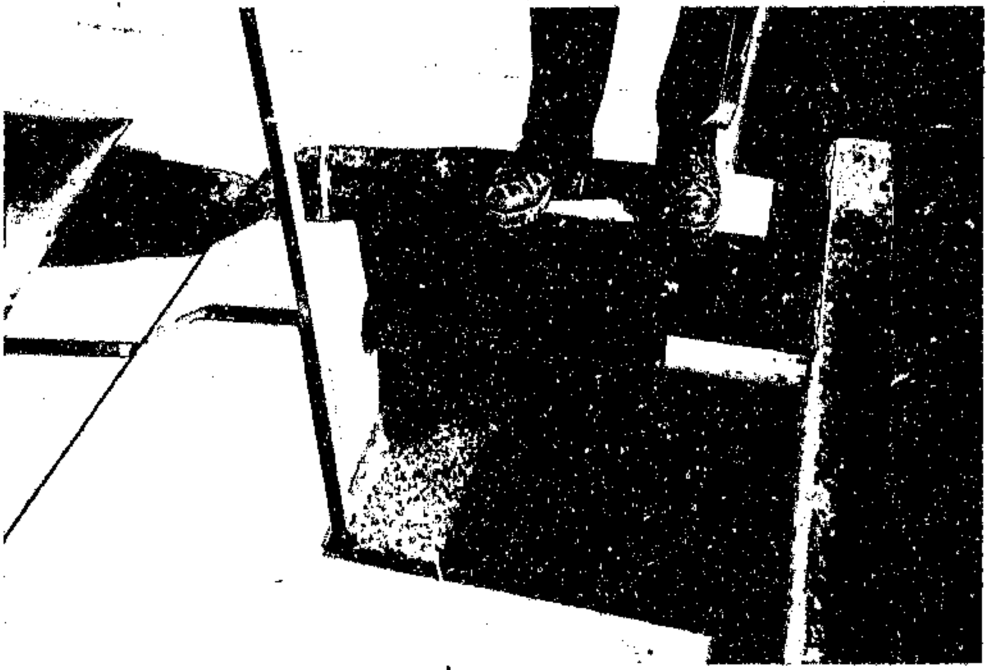


Figure 5.7 Measuring Seepage in Sump

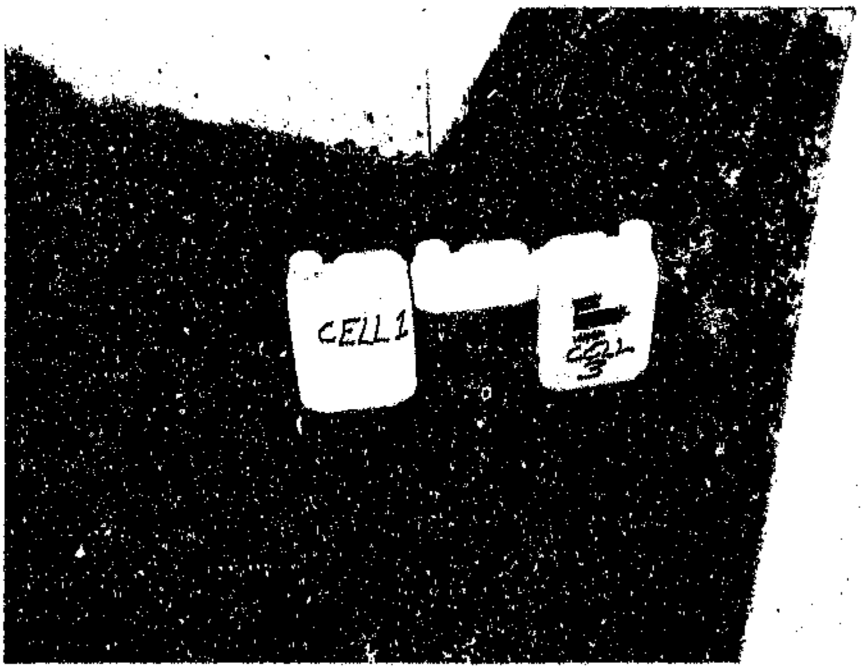


Figure 5.8 Samples of Seepage Taken in August 1997

as it appeared clean. Sappi Enstra's laboratory undertook the water quality testing for the parameters commonly associated with leachate.

5.3. Methodologies

Precipitation, evaporation, runoff and seepage were measured by Sappi Enstra staff on a daily basis where possible. Figure 5.7 shows measurement of the seepage in the sump of Cell 2, which contains the primary pulp barrier. Samples of seepage were taken and analysed. The samples taken are shown in Figure 5.8.

The cells were irrigated using a hosepipe fitted with a flow meter. This was done during August and September, mainly to determine whether the construction of the side-liner had improved the results obtained. The irrigation was not conducted according to irrigation theory, but was of a rather basic nature. The hose had a fixed flow rate of 0.17l/s, which is of fairly high intensity when considering the frequency of daily rainfall events. This method can be considered to be somewhat harsher than natural rainfall, therefore, and is therefore conservative. Irrigation of Cell 1 is shown in Figure 5.9. Note the polypropylene side-liner over the edges of the cells in this Figure.

cells. As the sludge is known to compress significantly, the top of the cap was expected to settle significantly during the tests. Both the design of the NCASI and Erving test cells allowed for settlement without significantly changing the surface water drainage systems. The Enstra cells, however, were built above ground, and the drainage system outlets were fixed in the test cells walls. Thus, as the sludge barrier layers settled, more and more ponding was allowed to occur on the caps. The Enstra tests can therefore be considered to be more conservative than both the NCASI and Erving field tests.

5.2. Outline of tests done

It was originally envisaged that the mixture of primary and secondary sludges that achieved the lowest hydraulic conductivity in the laboratory would then be tested in the field to determine whether the mixture would act as an effective capping layer in the Enstra environment. However, as the range of laboratory samples achieved permeabilities below the standard, the extremes of the range were tested in field cells.

Precipitation, evaporation, run-off and seepage were measured daily for the period of the field tests, except for weekends and public holidays. This measurement was undertaken by the Sappi Enstra staff with the author's involvement and supervision.

The field testing period has been nine months to date, which covered portions of two wet seasons and a dry season (albeit an unusually wet dry season). The field tests were accelerated by watering the cells to simulate storm events that typically occur at Enstra during the wet season. A flow meter on the watering hose was used to measure the volume of water used.

The quality of seepage water from the test cells was tested. Runoff was not tested, and were vegetated using "kweek" seeds. The clay cells vegetation took better than that for the other cells, which is attributed to the fact that the clay cell was completed well within the wet season, and the grass was well wetted initially. The vegetation on the other two cells did take eventually.

It became evident after several months of measurements had been taken that hydraulic conductivity results were higher than expected, and this was attributed to a short-circuit occurring down the sides of the cells. After this fact was confirmed by means of Guelph permeater tests to determine actual permeabilities, a polypropylene side-liner was made up for each cell, which sealed the sides, and concentrated throughflow to the central portion of each cell.

The cells constructed differed from the NCASI and Erving test cells in several ways. Firstly, both the NCASI and Erving test cells had more material placed over them in the capping design than did the Enstra tests. The NCASI test cells had a total thickness of 600mm of sandy soil and topsoil placed over them, while the Erving test cells had a total thickness of 450mm of sand and topsoil placed over them. The Enstra cells had only 200mm of topsoil placed over the barrier layers, in keeping with the capping design required for the site according to the Minimum Requirements (The Department of Water Affairs & Forestry, 1994). This translates to less effective stress being induced in the Enstra barrier layers as a result of overburden than in the other tests, and therefore less compression and related reduction in hydraulic conductivity of the sludge barrier layers being expected. In addition, hydraulic barrier layer covering provides protection against freeze-thaw cycles and desiccation. While freeze-thaw effects are not of concern in South Africa, desiccation certainly is.

Secondly, the slope on the Enstra cells was insignificant, as was the slope on the NCASI test cells, so that the test cells could act as large permeameters. The Erving test cells, however, were constructed with a 6% slope, so that runoff was encouraged. The third difference was in the surface water drainage from the test

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capping within nine months.

The stability of the pulp capping layer on the landfill slopes has not been determined as part of this project, but obviously requires consideration before the project results can be used on slopes in practice.

The use of the Sappi Enstra pulp as a general landfill liner is viable, as the various field tests results are in the range of the specified hydraulic conductivity. Literature reviewed indicates that the pulp would perform considerably better under the larger effective stresses induced by the weight of the waste body. This could be investigated using large-scale laboratory and field tests.

7. RECOMMENDATIONS FOR FURTHER RESEARCH

The results achieved from this project indicate that the pulp produced by Sappi Enstra Mill is suitable for capping their landfill, at least with regard to the required hydraulic conductivity. The long term stability of the pulp as landfill capping material has not been determined, but indications from literature, as well as from auger holes through the pulp placed within the landfill, indicate that this type of pulp is suitable for use as landfill capping in the long term.

Unfortunately, the period in which the tests have been run to date has not included a typical South African dry season, and the wet season experienced in the first few months of testing was unusually wet. The results cannot therefore be expected to include desiccation effects, which are the biggest concern in the South African environment. The tests were originally to be run for one year, and so would terminate in March 1998. Given the need to include desiccation effects in the testing program, however, it would be expedient to include a representative dry period. If the predicted drought, caused by El Nino, does not materialise in the forthcoming summer, it would be expedient to extend the testing period over the winter of 1998.

The field cells did not simulate the effects of differential settlement of waste beneath the caps. Although the effect on clay is given as far greater than that on pulp sludge, this could be investigated. As full-scale trials of capping with pulp are to be undertaken on the Sappi Enstra landfill from January 1998, this can be monitored on the landfill.

It was not determined which type of vegetation established itself best on the capping, as this would have introduced another variable when comparing results between cells. The success of various vegetation types will be measured independently from this test series, on the Enstra landfill itself. It did, however, appear that the kweek grass used on the test cells was suitably established on the

6. CONCLUSIONS

From the results of this project, it may be concluded that:

- The pulp produced by Sappi Enstra is well within the hydraulic conductivity requirements specified by the Department for barrier layers in landfill caps.

- The extremes of Sappi Enstra primary and secondary sludge production ratios were tested, and both performed within the given specification, so that any mixture of primary pulp and secondary sludge produced within 100:0 and 80:20 ratios are suitable for capping. Sappi Enstra may thus use all pulp mixture coming off their belt press to cap the landfill, without having to measure the mixture achieved.

- The behaviour of the Sappi Enstra pulp capping corresponded with the behaviour of similar testing carried out in the United States of America, so that it may be inferred that the Sappi Enstra pulp is suitable for landfill capping.

- The Sappi Enstra combined pulp capping outperformed the clay control test installed, as was predicted from comparisons within the literature reviewed

- Construction of pulp capping layers is considerably easier than the construction of clay capping layers.

- Sappi Enstra pulp may have application as a general landfill liner hydraulic barrier material, as the results achieved in these tests are within the range of the specified hydraulic conductivity.

and was drained towards the leachate sumps. The tests, therefore, did not model the retention of any moisture within the waste below the cap, and the evaporation of that moisture through the cap, as has been shown to occur by Blight (1992). The pulp capping may well therefore perform better on the landfill than in the field test cells. Also, the vegetative cover did not take well on the pulp cells until at least August, so that the transpiration from these cells must have been minimal.

As the cells were not placed on waste, but on sand drainage layers, the effect of differential settlement in the waste beneath the caps has not been simulated. From the literature, however, this is believed to affect clay far more than it does paper pulp. From observations on the Enstra Mill landfill, the pulp is capable of deforming into differential settlement zones without compromising its integrity. This behaviour is attributed to the fibres making up the pulp giving it improved shear strength.

As the compaction of the sludge can be nominal and still achieved the required hydraulic conductivity, it is possible to compact the sludge to the required level on a foundation of waste. For a clay cap, however, achieving the required compaction on the poor foundation waste would usually be problematic, if not impossible. This has not been modelled in the field tests, as no waste was included in the field cells. The results achieved in the field tests for the clay cap are therefore not conservative, and may in fact underestimate the hydraulic conductivity achievable on a landfill.

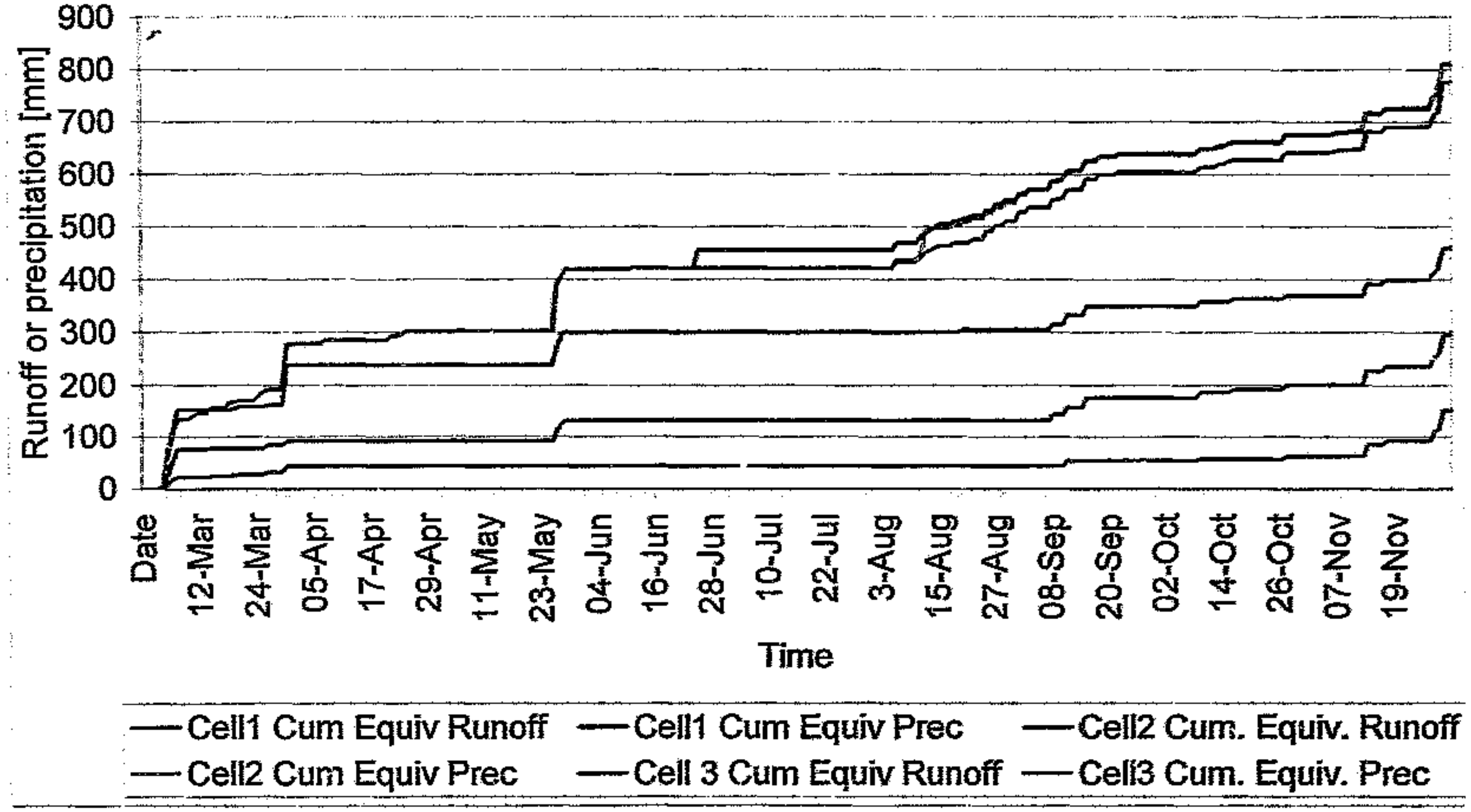


Figure 5.17: Cell Runoff and Precipitation

Figure 5.16: Cumulative Seepage and Precipitation- Cell 3 (Combined Sludge)

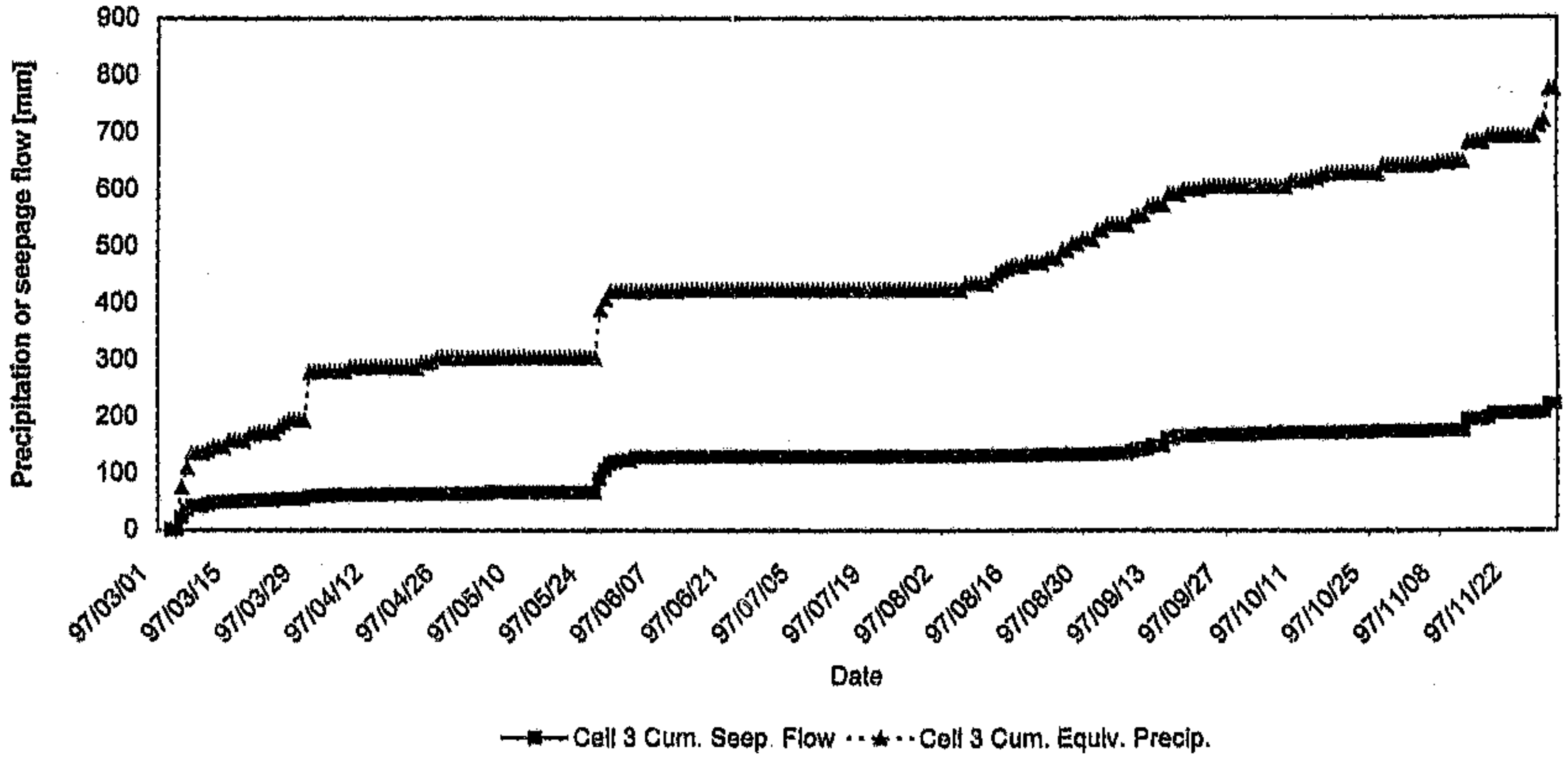


Figure 5.15: Cumulative Seepage and Precipitation- Cell 2 (Primary Pulp)

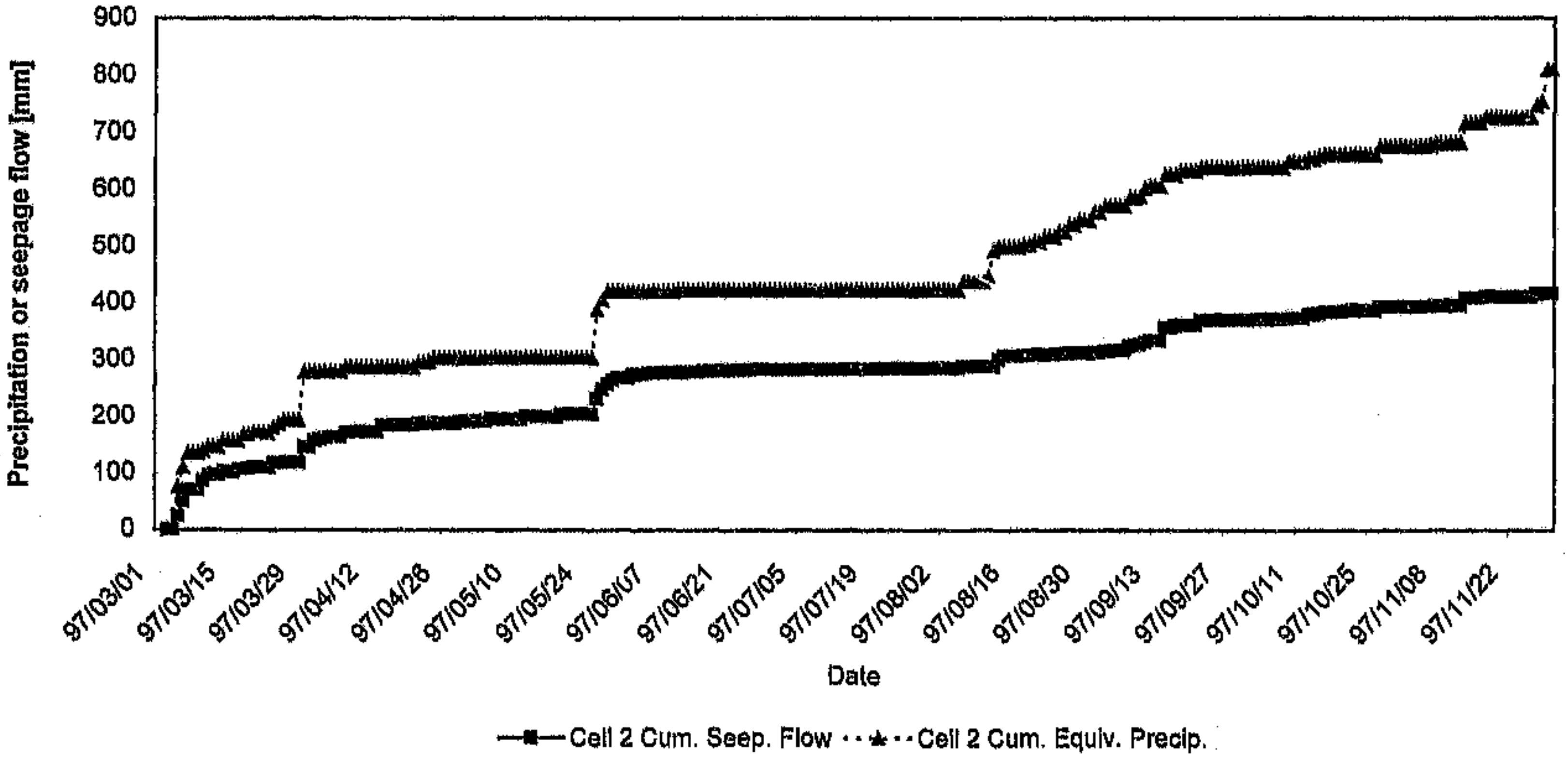
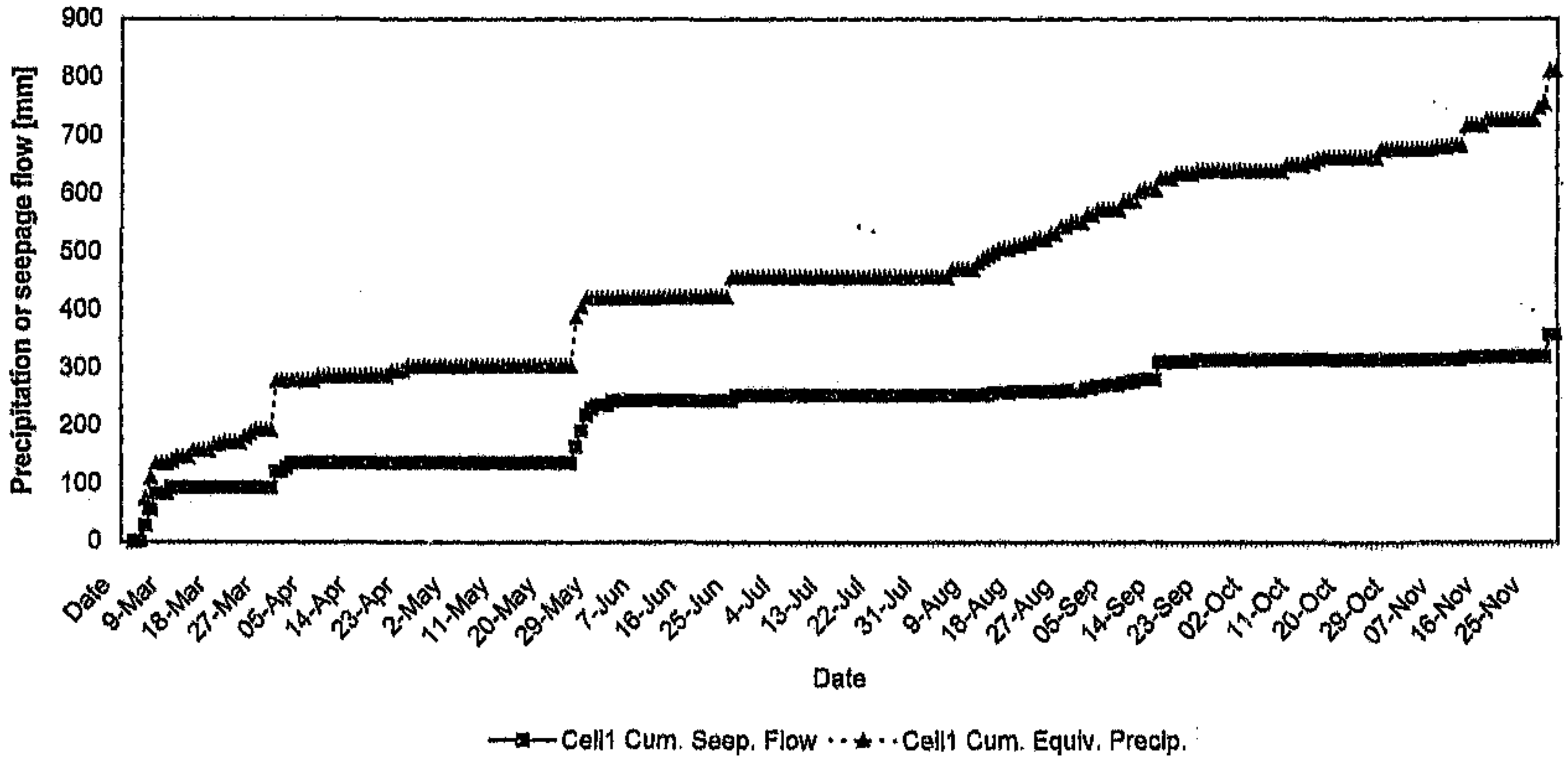


Figure 5.14: Cumulative Seepage and Precipitation- Cell 1 (Clay)



Figures 5.14, 5.15 and 5.16 show cumulative leachate flow and cumulative precipitation flow with time. Comparing these three graphs clearly shows that the combined pulp barrier has produced less seepage than have the clay and primary pulp barriers. Also clear on these graphs are the reductions in the rate of seepage since the side-lining of the field cells was completed on 17 July 1997.

Figure 5.17 shows the cumulative runoff and precipitation of the three cells with time. It can be seen that Cell 1 (clay) has generated less runoff than have Cells 2 and 3 (primary and combined pulp). As Cells 1 and 2 have produced similar quantities of seepage, this means that the clay cell has lost substantially more moisture to evapotranspiration than have Cells 2 and 3. As the vegetation cover on Cell 1 established far better than did the cover on the other cells, this explanation makes sense. Another explanation could, however, be that moisture is more easily evaporated from the clay barrier, making it more susceptible to desiccation than the sludges. This second explanation is supported by both the findings of the NCASI and the Erving tests. A third explanation may be that the clay cell structure was damaged during the intensive compaction of the clay cap, so that moisture has been lost from the system. This explanation is supported by cracks in the outer walls, and some seepage from the base of the cell, which appeared during testing. Given this explanation, the hydraulic conductivity of the clay cap may well have been underestimated during testing, as not all seepage was collected in the sump.

The hydraulic conductivity results achieved in the field tests are considered to be conservative, for several reasons. The capping layers were not constructed with a significant slope, so that ponding was allowed to occur, and runoff from the cell surfaces was considerably lower than could be expected on the landfill. The capping layers settled with time, so that the surface water drainage system outlets were well above the level of the capping, within a few months, further limiting surface water runoff. No waste was placed beneath the capping layers, so that any moisture travelling through the cap reached the sand drainage layers

Figure 5.13: Hydraulic Conductivity and Precipitation - Cell 3 (Combined Sludge)

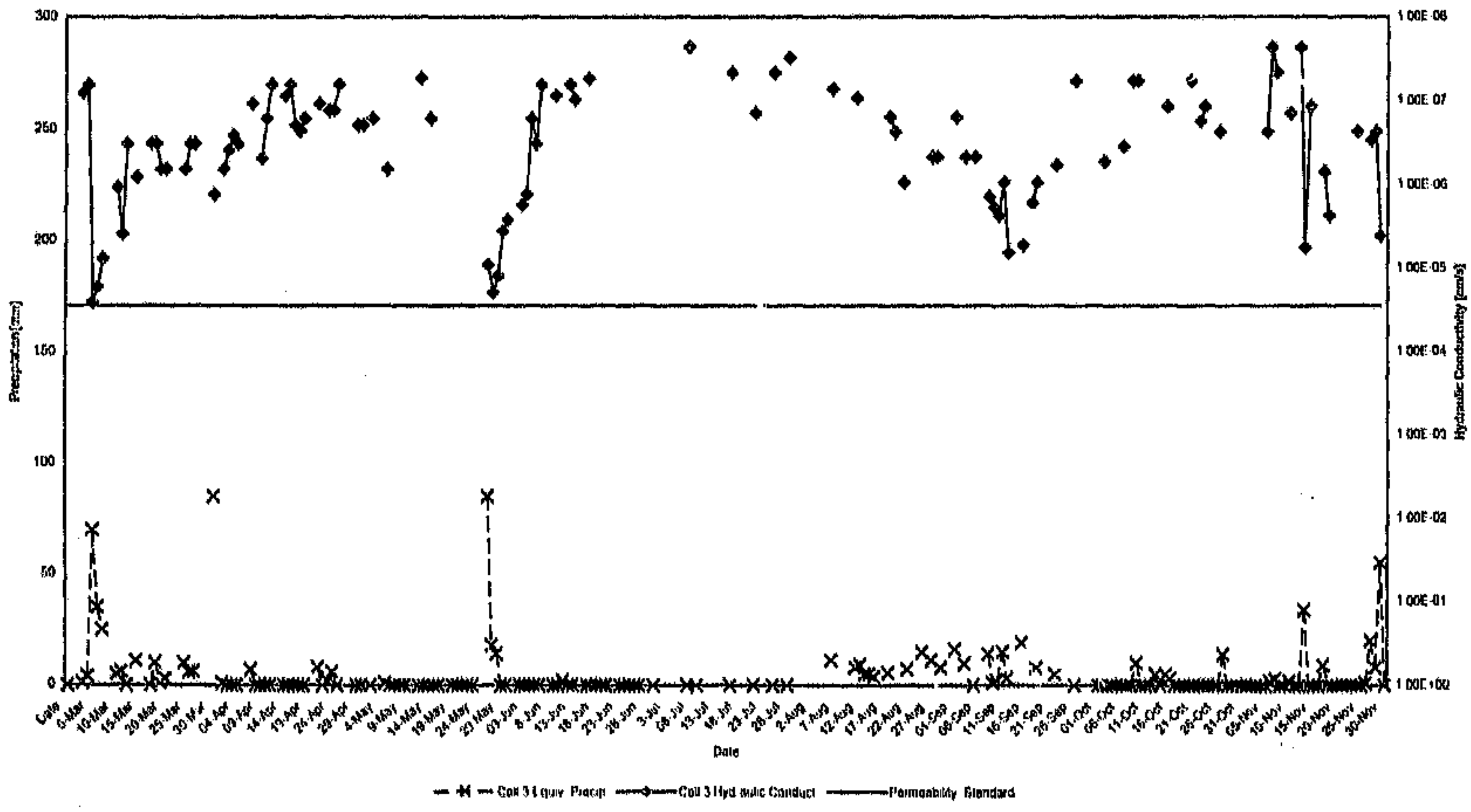
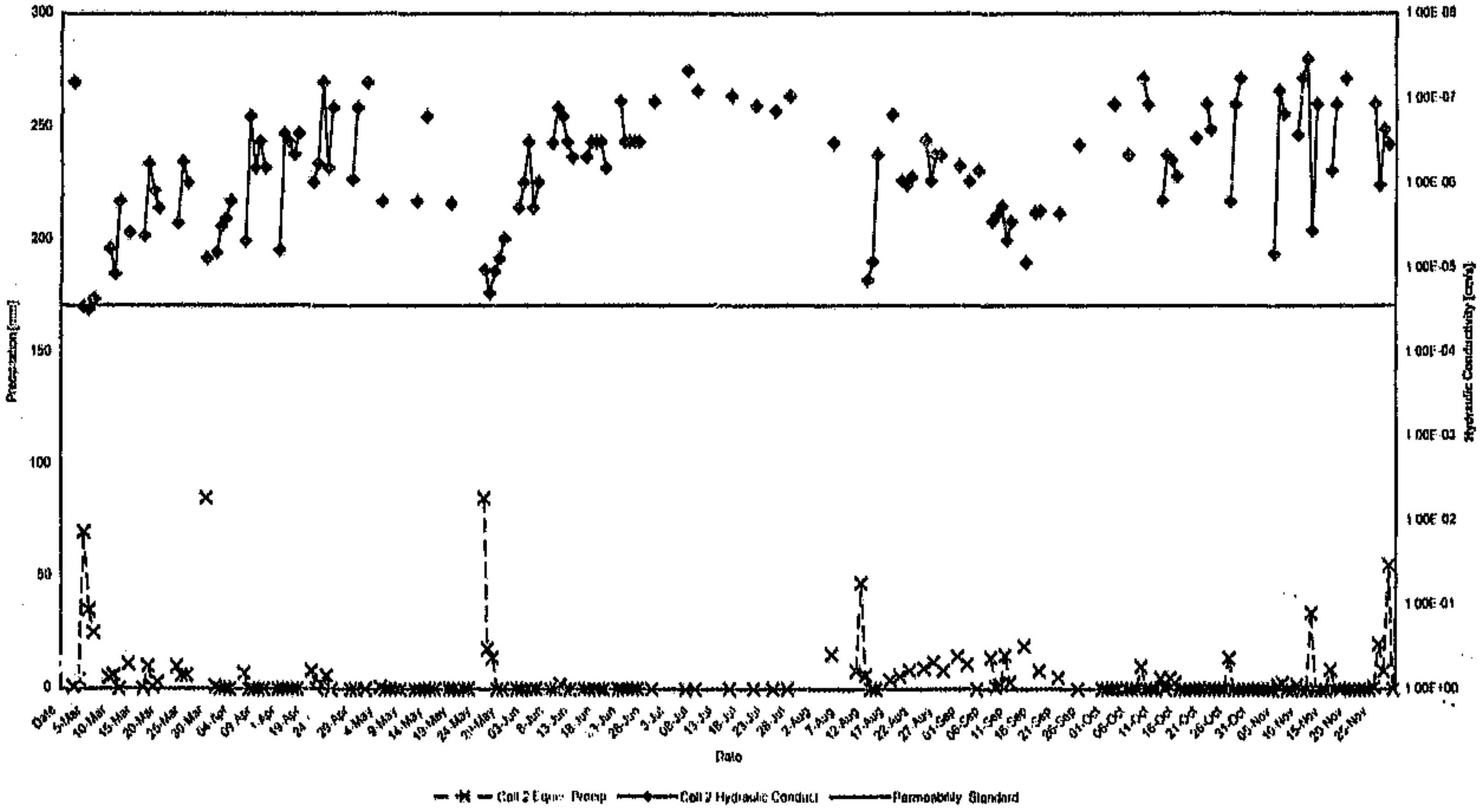


Figure 5.12: Hydraulic Conductivity and Precipitation - Cell 2 (Primary Pulp)



SOILTECH

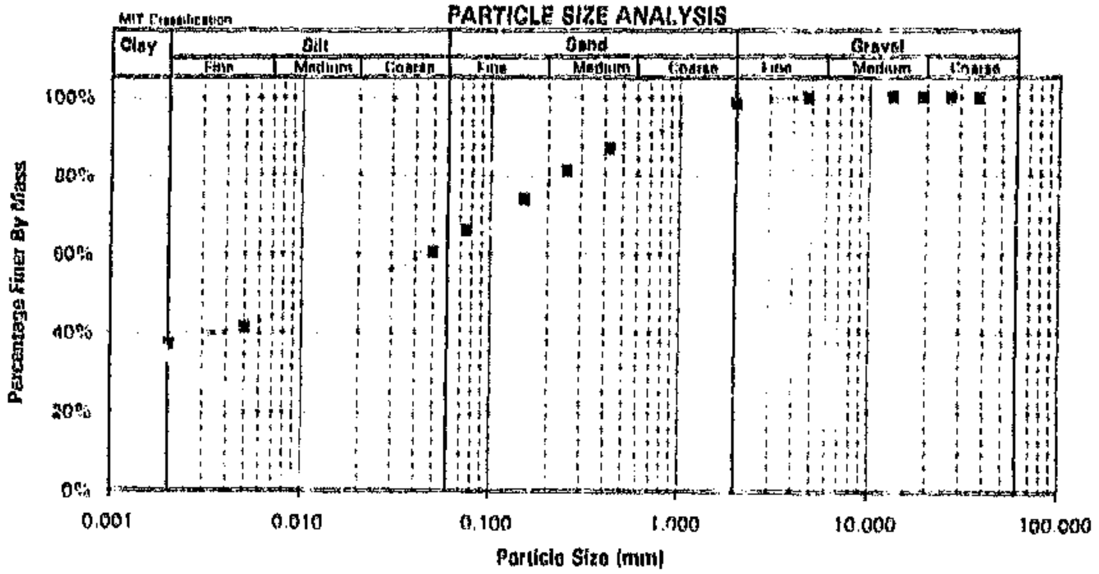
QUALITY IS OUR FOUNDATION

FOUNDATION INDICATOR

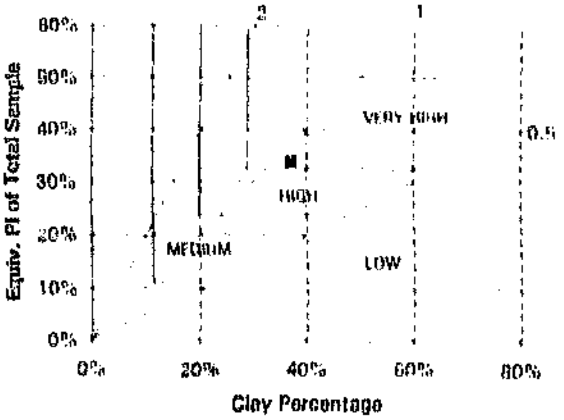
Client Project Site	Jarrod Ball & Associates Sappi Enstra Capping -	Date Job #	3/6/98 19117
Test Pos Sample	- Benoni Sand Clay	Depth	-

SIEVE ANALYSIS				ATTERBERG LIMITS				
Sieve(mm)	% Passing	Sieve(mm)	% Passing		Test 1	Test 2		
37.500	100%	0.250	81%	Liquid Limit	58.6%	59.0%	PRA Classification	A 7-6 (17)
26.500	100%	0.150	74%	Average	58.8%		Unified Classification	CH
19.000	100%	0.075	66%	Plastic Limit	20.6%	20.7%	PI of whole sample	33.0%
13.200	100%	0.050	60%	Average	20.6%		% Gravel	1.7%
4.750	100%	0.005	41%	Plasticity Index (PI)	38.3%		% Sand	35.5%
2.000	98%	0.002	37%	Linear Shrinkage	10.3%		% Silt	25.7%
0.425	87%			Grading Modulus	0.40		% Clay	37.1%

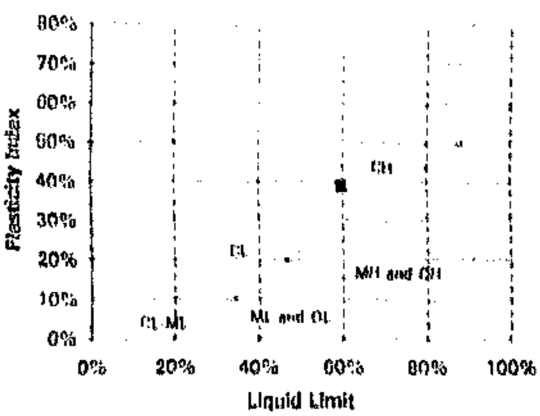
PARTICLE SIZE ANALYSIS



POTENTIAL EXPANSIVENESS



CASAGRANDE 'A' LINE

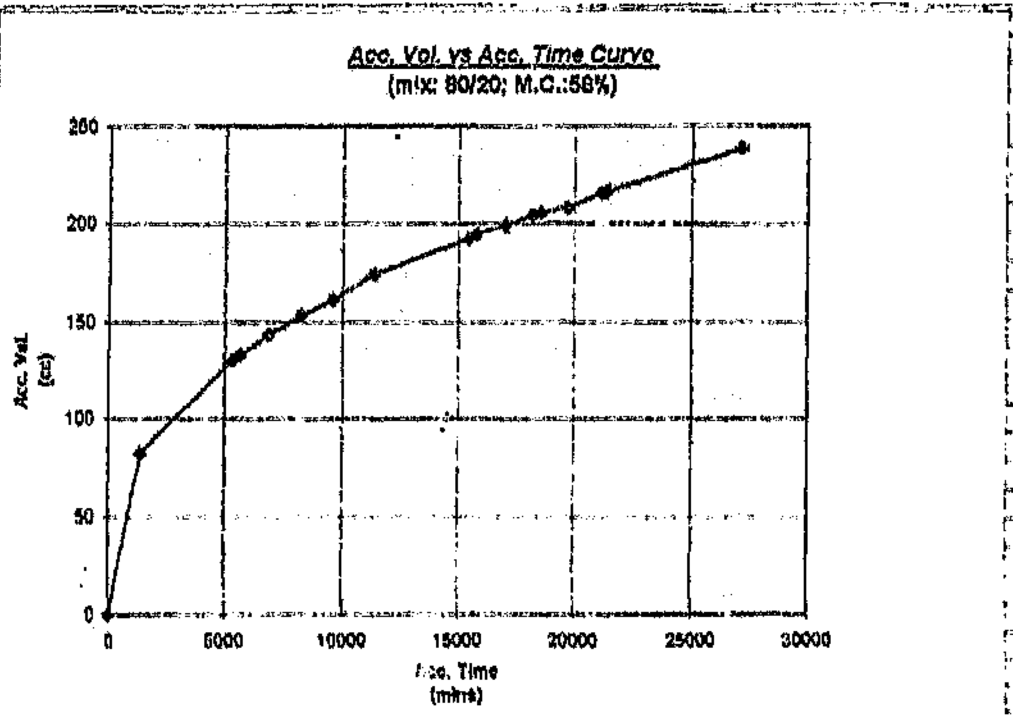


APPENDIX 2

LABORATORY TEST RESULTS FOR CLAY USED

Sheet1

Time	Elapsed Time	Delta Time	Time (min)	Vol	Delta Vol	Time (mins	Vol (cc)
5/30/96 15:53	1/0/00 20:37	20.37	1237	50	78	1237	78
5/31/96 12.30				128		162	4
						3963	48
5/31/96 12:42	1/0/00 2 42	2:42	162	24	4	303	3
5/31/96 15.24	1/2/00 18 03	66.03.00	3963	28	48	1199	10
6/3/96 9:27	1/0/00 5:03	5:03	303	76	3	1407	10
6/3/96 14:30	1/0/00 19 59	19:59	1199	79	10	1336	8
6/4/96 10:29	1/0/00 23:27	23:27	1407	89	10	1763	13
6/5/96 9:56	1/0/00 22:16	22:16	1336	99	8	4131	18
6/6/96 8 12	1/1/00 5:23	29 23:00	1763	107	13	331	2
6/7/96 13 36				120		1254	5
						1156	5
6/7/96 13.41	1/2/00 20.51	68:51:00	4131	26	18	362	1
6/10/96 10 32	1/0/00 5:31	5:31	331	44	2	1100	3
6/10/96 16 03	1/0/00 20:54	20:54:00	1254	46	5	1441	7
6/11/96 12.57	1/0/00 19.16	19:16	1156	51	5	227	1
6/12/96 8 13	1/0/00 6.02	6:02	362	56	1	5757	22
6/12/96 14 15	1/0/00 18:20	18:20	1100	57	3		
6/13/96 8 35	1/1/00 0 01	24:01:00	1441	60	7		
6/14/96 8:36	1/0/00 3 47	3:47	227	67	1		
6/14/96 12:23	1/3/00 23 57	95 57 00	5757	68	22		
6/18/96 12:20				90			



APPENDIX 1

TYPICAL HYDRAULIC CONDUCTIVITY LABORATORY TEST FOR ENSTRA PAPER SLUDGE

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SAPPI ENSTRA
LANDFILL CAPPING FIELD TEST RESULTS

Month	Jul 97						Cell 1										Cell 2										Cell 3									
	Precipitation			Evaporation			Runoff		Seepage		Equiv	Hydraulic	Irrigation			Total	Runoff		Seepage		Equiv	Hydraulic	Irrigation			Total	Runoff		Seepage		Equiv	Hydraulic	Irrigation			Tot
	Read	Calc		Read	Calc		Read	Calc	Read	Cell	Flow	Conduct	Read	Cell	Equiv	P	Read	Cell	Read	Cell	Flow	Conduct	Read	Cell	Equiv	P	Read	Cell	Read	Cell	Flow	Conduct	Read	Cell	Equiv	P
Date	mm	mm		mm	mm		mm	mm	mm	mm	mm	cm/s	m3	m3	mm	mm	mm	mm	mm	mm	mm	cm/s	m3	m3	mm	mm	mm	mm	mm	mm	mm	cm/s	m3	m3	mm	mm
01 Jul																																				
02 Jul																																				
03 Jul																																				
04 Jul																																				
05 Jul																																				
06 Jul																																				
07 Jul				124	124	20			300	300	0.0	0.0E+00				0.0			320	320	0.3	4.6E-08				0.0			35	35	0.1	2.3E-08				
08 Jul																																				
09 Jul				120	120	4			300	300	0.0	0.0E+00				0.0			325	325	0.1	8.4E-09				0.0			35	35	0.0	0.0E+00				
10 Jul																																				
11 Jul																																				
12 Jul																																				
13 Jul																																				
14 Jul																																				
15 Jul																																				
16 Jul				109	104	11			300	300	0.0	0.0E+00				0.0			345	345	0.6	9.2E-08				0.0			45	45	0.3	4.6E-08				
17 Jul																																				
18 Jul	Liner complete																																			
19 Jul																																				
20 Jul																																				
21 Jul				94	94	15			300	300	0.0	0.0E+00				0.0			350	358	0.6	1.2E-07				0.0			60	60	0.0	1.4E-07				
22 Jul																																				
23 Jul																																				
24 Jul																																				
25 Jul				05	05	9			300	300	0.0	0.0E+00				0.0			370	370	0.9	1.4E-07				0.0			64	64	0.2	4.6E-08				
26 Jul																																				
27 Jul																																				
28 Jul				77	77	0			300	300	0.0	0.0E+00				0			376	376	0.2	9.4E-08				0.0			60	60	0.1	3.4E-08				
29 Jul																																				
30 Jul																																				
31 Jul																																				
						73					0.0	0.0E+00			0%	0.0					2.2	8.5E-08			0%	0.0					1.3	4.7E-08			0%	

SAPPI ENSTRA
LANDFILL CAPPING FIELD TEST RESULTS

Month	Jun 97						Cell 1										Cell 2										Cell 3									
	Precipitation			Evaporation			Runoff		Seepage		Equiv	Hydraulic	Irrigation			Total	Runoff		Seepage		Equiv	Hydraulic	Irrigation			Total	Runoff		Seepage		Equiv	Hydraulic	Irrigation			Total
	Read	Left		Read	Left		Read	Left	Read	Left	Flow	Conduct	Read	Left	Equiv	I-	Read	Left	Read	Left	Flow	Conduct	Read	Left	Equiv	I-	Read	Left	Read	Left	Flow	Conduct	Read	Left	Equiv	I-
Date	mm	mm		mm	mm		mm	mm	mm	mm	mm	cm/s	m3	m3	mm	mm	mm	mm	mm	mm	mm	cm/s	m3	m3	mm	mm	mm	mm	mm	mm	mm	cm/s	m3	m3	mm	mm
01 Jun																																				
02 Jun	0	0	0	239	239	11	0	0	860	860	6.0	2.7E-06				0.0	0	0	900	900	5.0	1.9E-06				0.0	0	0	730	730	4.4	1.7E-06				0.0
03 Jun	0	0	0	235	235	4	0	0	890	890	0.8	8.6E-07				0.0	0	0	930	910	0.2	9.6E-07				0.0	0	0	770	770	1.1	5.3E-06				0.0
04 Jun	0	0	0	233	234	2	0	0	910	0	0.6	6.4E-07				0.0	0	0	940	0	0.3	3.2E-07				0.0	0	0	775	0	0.1	1.6E-07				0.0
05 Jun	0	0	0	229	229	4	0	0	0	0	0.0	0.0E+00				0.0	0	0	60	60	1.7	1.9E-06				0.0	0	0	10	10	0.3	3.2E-07				0.0
06 Jun	0	0	0	225	225	4	0	0	0	0	0.0	0.0E+00				0.0	0	0	90	90	0.0	8.0E-07				0.0	0	0	12	12	0.1	6.4E-08				0.0
07 Jun																																				
08 Jun																																				
09 Jun	0	0	0	210	210	0	0	0	0	0	0.0	0.0E+00				0.0	0	0	121	121	3.9	3.3E-07				0.0	0	0	20	20	0.2	0.0E+00				0.0
10 Jun	0	0	0	212	212	4	0	0	0	0	0.0	0.0E+00				0.0	0	0	125	125	0.1	1.3E-07				0.0	0	0	20	20	0.0	0.0E+00				0.0
11 Jun	2	0	2	210	210	2	0	0	0	0	0.0	0.0E+00				2.0	0	0	130	130	0.1	1.6E-07				2.0	0	0	20	20	0.0	0.0E+00				2.0
12 Jun	0	0	0	208	208	2	0	0	0	0	0.0	0.0E+00				0.0	0	0	140	140	0.1	3.2E-07				0.0	0	0	22	22	0.1	6.4E-08				0.0
13 Jun	0	0	0	205	205	3	0	0	0	0	0.0	0.0E+00				0.0	0	0	150	155	0.4	4.8E-07				0.0	0	0	25	25	0.1	9.6E-08				0.0
14 Jun																																				
15 Jun																																				
16 Jun	0	0	0	198	198	7	0	0	0	0	0.0	0.0E+00				0.0	0	0	200	200	1.3	4.8E-07				0.0	0	0	30	30	0.1	5.4E-08				0.0
17 Jun	0	0	0	195	195	3	0	0	0	0	0.0	0.0E+00				0.0	0	0	210	210	0.3	3.2E-07				0.0	0	0	30	30	0.0	0.0E+00				0.0
18 Jun	0	0	0	193	191	2	0	0	0	0	0.0	0.0E+00				0.0	0	0	220	220	0.3	3.2E-07				0.0	0	0	30	30	0.0	0.0E+00				0.0
19 Jun	0	0	0	189	189	4	0	0	0	0	0.0	0.0E+00				0.0	0	0	230	230	0.3	3.2E-07				0.0	0	0	30	30	0.0	0.0E+00				0.0
20 Jun	0	0	0	185	185	4	0	0	0	0	0.0	0.0E+00				0.0	0	0	250	250	0.6	6.4E-07				0.0	0	0	30	30	0.1	0.0E+00				0.0
21 Jun																																				
22 Jun																																				
23 Jun	0	0	0	178	178	0	0	0	0	0	0.0	0.0E+00				0.0	0	0	260	260	0.3	1.1E-07				0.0	0	0	30	30	0.0	0.0E+00				0.0
24 Jun	0	0	0	173	173	3	0	0	0	0	0.0	0.0E+00				0.0	0	0	270	270	0.3	3.2E-07				0.0	0	0	30	30	0.0	0.0E+00				0.0
25 Jun	0	0	0	169	169	4	0	0	0	0	0.0	0.0E+00	3040.7	3045	34.5	31.5	0	0	280	280	0.3	3.2E-07				0.0	0	0	30	30	0.0	0.0E+00				0.0
26 Jun	0	0	0	166	166	3	0	0	270	270	7.5	0.7E-06				0.0	0	0	290	290	0.3	3.7E-07				0.0	0	0	30	30	0.0	0.0E+00				0.0
27 Jun	0	0	0	164	164	2	0	0	325	325	1.5	1.1E-06				0.0	0	0	300	300	0.3	3.2E-07				0.0	0	0	30	30	0.0	0.0E+00				0.0
28 Jun																																				
29 Jun																																				
30 Jun	0	0	0	150	150	14	0	0	325	325	0.0	0.0E+00				0.0	0	0	310	310	0.3	1.1E-07				0.0	0	0	30	30	0.0	0.0E+00				0.0
			2			100					17.4	6.7E-07			40%	36.5					14.7	5.7E-07			7.9%	2.0					0.5	2.5E-07			320%	2.0

SAPPI ENSTRA
LANDFILL CAPPING FIELD TEST RESULTS

Month May 97

	Precipitation			Evaporation			Cell 1 Runoff		Seepage		Equiv	Hydraulic	Irrigation			Total
	Read	Calc		Read	Calc		Read	Calc	Read	Calc	Flow	Conduct	Read	Calc	Equiv	P
Date	mm	mm		mm	mm		mm	mm	mm	mm	mm	cm/s	m3	m3	mm	mm
01 May																
02 May	0	0	0	160	160	7	0	[illegible]	0	0	0.0	0.0E+00				0.0
03 May																
04 May																
05 May	1	0	1	163	163	13	0	0	0	0	0.0	0.0E+00				1.0
06 May	0	0	0	150	150	3	0	0	0	0	0.0	0.0E+00				0.0
07 May	0	0	0	145	145	5	0	0	0	0	0.0	0.0E+00				0.0
08 May	0	0	0	141	141	4	0	0	0	0	0.0	0.0E+00				0.0
09 May	0	0	0	130	130	3	0	0	0	0	0.0	0.0E+00				0.0
10 May																
11 May																
12 May	0	0	0	330	210	0	0	0	0	0	0.0	0.0E+00				0.0
13 May	0	0	0	204	204	6	0	0	0	0	0.0	0.0E+00				0.0
14 May	0	0	0	200	200	4	0	0	0	0	0.0	0.0E+00				0.0
15 May	0	0	0	190	190	2	0	0	0	0	0.0	0.0E+00				0.0
16 May	0	0	0	190	190	2	0	0	0	0	0.0	0.0E+00				0.0
17 May																
18 May																
19 May	0	0	0	183	183	13	0	0	0	0	0.0	0.0E+00				0.0
20 May	0	0	0	170	170	4	0	0	0	0	0.0	0.0E+00				0.0
21 May	0	0	0	178	178	4	0	0	0	0	0.0	0.0E+00				0.0
22 May	0	0	0	172	172	3	0	0	0	0	0.0	0.0E+00				0.0
23 May	0	0	0	170	170	2	0	0	0	0	0.0	0.0E+00				0.0
24 May																
25 May																
26 May	85	0	85	244	244	0	0	0	1000	0	27.8	1.1E-05				85.0
27 May	18	0	18	240	240	0	0	0	990	0	27.5	3.2E-05				18.0
28 May	14	0	14	254	254	0	0	0	990	0	27.5	3.2E-05				14.0
29 May	0	0	0	253	253	1	0	0	390	390	10.0	1.4E-05				0.0
30 May	0	0	0	250	250	3	0	0	610	610	6.1	7.1E-06				0.0
31 May																
			118			87					99.7	3.7E-06			85%	118.0

	Cell 2 Runoff		Seepage		Equiv	Hydraulic	Irrigation			Total
	Read	Calc	Read	Calc	Flow	Conduct	Read	Calc	Equiv	P
Date	mm	mm	mm	mm	mm	cm/s	m3	m3	mm	mm
01 May										
02 May	0	0	120	120	0.1	6.4E-08				0.0
03 May										
04 May										
05 May	0	0	160	160	4.2	1.6E-06				1.0
06 May	0	0	150	150	0.0	0.0E+00				0.0
07 May	0	0	160	160	0.0	0.0E+00				0.0
08 May	0	0	150	150	0.0	0.0E+00				0.0
09 May	0	0	150	150	0.0	0.0E+00				0.0
10 May										
11 May										
12 May	0	0	150	150	4.2	1.6E-06				0.0
13 May	0	0	150	150	0.0	0.0E+00				0.0
14 May	0	0	155	155	0.1	1.6E-07				0.0
15 May	0	0	155	155	0.0	0.0E+00				0.0
16 May	0	0	165	165	0.0	0.0E+00				0.0
17 May										
18 May										
19 May	0	0	160	160	4.4	1.7E-06				0.0
20 May	0	0	160	160	0.0	0.0E+00				0.0
21 May	0	0	160	160	0.0	0.0E+00				0.0
22 May	0	0	160	160	0.0	0.0E+00				0.0
23 May	0	0	160	160	0.0	0.0E+00				0.0
24 May										
25 May										
26 May	120	0	980	0	27.2	1.1E-05				85.0
27 May	60	0	610	0	16.9	2.0E-05				18.0
28 May	30	0	340	340	9.4	1.1E-05				14.0
29 May	0	0	500	500	6.7	7.7E-06				0.0
30 May	0	0	720	720	3.5	4.5E-06				0.0
31 May										
					77.2	2.8E-06			65%	118.0

	Cell 3 Runoff		Seepage		Equiv	Hydraulic	Irrigation			Total
	Read	Calc	Read	Calc	Flow	Conduct	Read	Calc	Equiv	P
Date	mm	mm	mm	mm	mm	cm/s	m3	m3	mm	mm
01 May										
02 May	0	0	60	0	0.3	1.6E-07				0.0
03 May										
04 May										
05 May	0	0	60	60	1.7	6.4E-07				1.
06 May	0	0	60	60	0.0	0.0E+00				0
07 May	0	0	60	60	0.0	0.0E+00				0
08 May	0	0	60	60	0.0	0.0E+00				0
09 May	0	0	60	60	0.0	0.0E+00				0
10 May										
11 May										
12 May	0	0	65	65	0.1	5.4E-08				0
13 May	0	0	65	65	0.0	0.0E+00				0
14 May	0	0	70	70	0.1	1.6E-07				0
15 May	0	0	70	70	0.0	0.0E+00				0
16 May	0	0	70	70	0.0	0.0E+00				0
17 May										
18 May										
19 May	0	0	70	70	0.0	0.0E+00				0
20 May	0	0	70	70	0.0	0.0E+00				0
21 May	0	0	70	70	0.0	0.0E+00				0
22 May	0	0	70	70	0.0	0.0E+00				0
23 May	0	0	70	70	0.0	0.0E+00				0
24 May										
25 May										
26 May	100	0	910	0	23.3	9.0E-06				8
27 May	120	0	600	0	10.7	1.9E-05				18
28 May	20	0	300	300	10.0	1.2E-05				1
29 May	0	0	490	490	3.1	3.5E-06				1
30 May	0	0	570	570	2.2	2.6E-06				0
31 May										
					98.1	2.2E-06			49%	11

SAPPI ENSTRA
LANDFILL CAPPING FIELD TEST RESULTS

Month	Apr 97						Cell 1										Cell 2										Cell 3									
	Precipitation			Evaporation			Runoff		Seepage		Equiv	Hydraulic	Irrigation			Total	Runoff		Seepage		Equiv	Hydraulic	Irrigation			Total	Runoff		Seepage		Equiv	Hydraulic	Irrigation			Total
	Read	Cell		Read	Cell		Read	Cell	Read	Cell	Flow	Conduct	Read	Cell	Equiv	P	Read	Cell	Read	Cell	Flow	Conduct	Read	Cell	Equiv	P	Read	Cell	Read	Cell	Flow	Conduct	Read	Cell	Equiv	P
Date	mm	mm		mm	mm		mm	mm	mm	mm	mm	cm/s	m3	m3	mm	mm	mm	mm	mm	mm	mm	cm/s	m3	m3	mm	mm	mm	mm	mm	mm	mm	cm/s	m3	m3	mm	mm
01-Apr	1	0	1	240	240	12	0	0	260	0	7.2	4.2E-06				1.0	0	0	410	0	11.4	6.6E-06				1.0	0	0	330	0	1.1	8.4E-07				1.0
02-Apr	0	0	0	235	235	6	0	0	271	271	7.5	8.7E-06				0.0	0	0	100	100	2.0	3.2E-06				0.0	0	0	12	12	0.3	3.0E-07				0.0
03-Apr	0	0	0	230	230	6	0	0	277	277	0.2	1.0E-07				0.0	0	0	100	100	2.2	2.6E-06				0.0	0	0	20	20	0.2	2.6E-07				0.0
04-Apr	0	0	0	222	222	0	0	0	280	0	0.1	9.6E-08				0.0	0	0	230	230	1.4	1.6E-06				0.0	0	0	30	30	0.3	3.2E-07				0.0
05-Apr																																				
06-Apr																																				
07-Apr	7	7	7	215	215	7	0	0	0	0	0.0	0.0E+00				7.0	0	0	295	295	[illegible]	4.7E-06				7.0	0	0	40	40	0.3	1.1E-07				7.0
08-Apr	7	0	0	213	213	2	0	0	0	0	0.0	0.0E+00				0.0	0	0	300	300	0.1	1.6E-07				0.0	0	0	40	40	0.0	0.0E+00				0.0
09-Apr	0	0	0	209	209	4	0	0	0	0	0.0	0.0E+00				0.0	0	0	[illegible]	320	0.6	8.4E-07				0.0	0	0	65	65	0.4	4.0E-07				0.0
10-Apr	0	0	0	204	204	5	0	0	0	0	0.0	0.0E+00				0.0	[illegible]	0	330	330	0.3	3.2E-07				0.0	0	0	60	60	0.1	1.1E-07				0.0
11-Apr	0	0	0	200	200	4	0	0	0	0	0.0	0.0E+00				0.0	0	0	350	350	0.6	8.4E-07				0.0	0	0	62	62	0.1	6.4E-08				0.0
12-Apr																																				
13-Apr																																				
14-Apr	0	0	0	184	184	10	0	0	0	0	0.0	0.0E+00				0.0	0	0	380	0	10.6	6.1E-06				0.0	0	0	70	0	0.2	9.6E-08				0.0
15-Apr	0	0	0	230	230	0	0	0	0	0	0.0	0.0E+00				0.0	0	0	8	8	0.2	2.6E-07				0.0	0	0	2	2	0.1	8.4E-08				0.0
16-Apr	0	0	0	224	224	6	0	0	0	0	0.0	0.0E+00				0.0	0	0	18	18	0.3	3.2E-07				0.0	0	0	8	8	0.2	1.9E-07				0.0
17-Apr	0	0	0	216	216	9	0	0	10	0	0.0	0.0E+00				0.0	0	0	32	32	0.4	4.5E-07				0.0	0	0	15	15	0.2	2.3E-07				0.0
18-Apr	0	0	0	219	219	0	0	0	0	0	0.0	0.0E+00				0.0	0	0	40	40	0.2	2.6E-07				0.0	0	0	20	20	0.1	1.0E-07				0.0
19-Apr																																				
20-Apr																																				
21-Apr	8	0	8	210	210	8	0	0	0	0	0.0	0.0E+00				8.0	0	0	60	60	1.7	9.6E-07				8.0	0	0	30	30	0.3	1.1E-07				8.0
22-Apr	0	0	0	206	206	4	0	0	0	0	0.0	0.0E+00				0.0	0	0	70	70	0.5	5.0E-07				0.0	0	0	30	30	0.0	0.0E+00				0.0
23-Apr	2	0	2	204	204	2	0	0	0	0	0.0	0.0E+00				2.0	0	0	80	80	0.1	8.4E-08				2.0	0	0	34	34	0.1	1.3E-07				2.0
24-Apr	6	[illegible]	0	200	200	4	0	0	0	1	0.0	0.0E+00				6.0	0	0	100	100	0.6	8.4E-07				6.0	0	0	38	38	0.1	1.3E-07				6.0
25-Apr	0		0	102	102	0	0	0	0	0	0.0	0.0E+00				0.0	0	0	104	104	0.1	1.3E-07				0.0	0	0	40	40	0.1	8.4E-08				0.0
26-Apr																																				
27-Apr																																				
28-Apr																																				
29-Apr	0	0	0	175	175	17	0	0	0	0	0.0	0.0E+00				0.0	0	0	112	112	3.1	9.0E-07				0.0	0	0	64	64	0.7	1.0E-07				0.0
30-Apr	0	0	0	173	173	2	0	0	0	0	0.0	0.0E+00				0.0	0	0	116	116	0.1	1.3E-07				0.0	0	0	70	70	0.2	1.9E-07				0.0
			24			120					15.0	6.8E-07			63%	24.0					45.3	1.7E-06			100%	24.0					5.0	1.1E-07			21%	24.0

SAPPI ENSTRA
LANDFILL CAPPING FIELD TEST RESULTS

Month	Mar 97						Cell1										Cell 2										Cell 3									
	Precipitation			Evaporation			Runoff		Seepage		Equiv	Hydraulic	Irrigation			Total	Runoff		Seepage		Equiv	Hydraulic	Irrigation			Total	Runoff		Seepage		Equiv	Hydraulic	Irrigation			Total
	Read	Left	Nett	Read	Left	Nett	Read	Left	Read	Left	Flow	Conduct	Read	Left	Equiv	P	Read	Left	Read	Left	Flow	Conduct	Read	Left	Equiv	P	Read	Left	Read	Left	Flow	Conduct	Read	Left	Equiv	P
Date	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	cm/s	m3	m3	mm	mm	mm	mm	mm	mm	mm	cm/s	m3	m3	mm	mm	mm	mm	mm	mm	mm	cm/s	m3	m3	mm	mm
1-Mar	0	0		227	227		0	0	0	0							0	0	70	70							0	0	10	10						
2-Mar																																				
3-Mar	1	1	1	206	206	21	0	0	0	0	0.0	0.0E+00				1.0	0	0	72	72	0.1	6.4E-08				1.0	0	0	15	15	0.1	8.0E-08				1.0
4-Mar	5	5	4	190	190	0	0	0	0	0	0.0	0.0E+00				4.0	0	0	72	72	0.0					4.0	0	0	17	17	0.1	6.4E-08				4.0
5-Mar	75	0	70	252	252	0	60	0	1000	0	27.0	3.2E-05				70.0	150	0	960	0	24.7	2.8E-05				70.0	370	0	810	0	22.0	2.5E-05				70.0
6-Mar	35	0	35	252	252	0	60	0	1000	0	27.0	3.2E-05				35.0	130	0	950	0	26.4	3.1E-05				35.0	240	0	540	0	14.2	1.6E-05				35.0
7-Mar	25	0	25	250	250	2	20	0	1000	0	27.0	3.2E-05				25.0	115	0	725	0	20.1	2.3E-05				25.0	210	0	235	0	6.5	7.6E-06				25.0
8-Mar																																				
9-Mar																																				
10-Mar	8	6	5	230	230	12	0	0	340	340	9.4	3.0E-06				5.0	0	0	545	545	15.1	5.0E-06				5.0	0	0	100	100	2.0	1.1E-06				6.0
11-Mar	11	0	6	235	235	3	0	0	370	0	0.0	9.6E-07				6.0	0	0	930	0	10.1	1.2E-05				6.0	0	0	220	220	3.3	3.9E-06				6.0
12-Mar	0	0	0	233	233	2	0	0	0	0	0.0	0.0E+00				0.0	0	0	60	60	1.4	1.6E-06				0.0	0	0	230	230	0.3	3.2E-07				0.0
13-Mar																																				
14-Mar	11	0	11	239	239	0	10	0	0	0	0.0	0.0E+00				11.0	10	0	235	235	6.1	3.0E-06				11.0	0	0	280	280	1.4	8.0E-07				11.0
15-Mar																																				
16-Mar																																				
17-Mar	0	0	0	229	229	13	0	0	10	10	0.3	1.1E-07				0.0	0	0	300	0	4.3	4.2E-06				0.0	0	0	310	0	0.0	3.2E-07				0.0
18-Mar	10	0	10	227	227	0	0	0	10	10	0.0	0.0E+00				10.0	0	0	10	10	0.5	5.8E-07				10.0	0	0	10	10	0.3	3.2E-07				10.0
19-Mar	1	0	1	225	225	2	8	8	10	10	0.0	0.0E+00				1.0	0	0	55	55	1.0	1.2E-06				1.0	10	10	30	31	0.8	9.4E-07				1.0
20-Mar	3	0	3	224	224	1	10	0	10	0	0.0	0.0E+00				3.0	0	0	115	115	1.7	1.9E-06				3.0	20	0	50	50	0.6	6.4E-07				3.0
21-Mar																																				
22-Mar																																				
23-Mar																																				
24-Mar	10	0	10	210	210	14	0	0	0	0	0.0	0.0E+00				10.0	0	0	273	273	7.0	8.1E-06				10.0	0	0	110	110	1.7	8.4E-07				10.0
25-Mar	0	0	0	212	212	0	0	0	0	0	0.0	0.0E+00				6.0	0	0	290	290	0.5	5.5E-07				6.0	0	0	120	120	0.3	3.2E-07				6.0
26-Mar	0	0	0	215	215	0	20	0	0	0	0.0	0.0E+00				6.0	40	0	320	0	0.0	9.0E-07				6.0	70	0	130	130	0.3	1.2E-07				6.0
27-Mar																																				
28-Mar																																				
29-Mar																																				
30-Mar	85	0	85	252	252	0	60	0	990	0	27.5	8.0E-06				85.0	70	0	960	0	26.7	7.7E-06				85.0	370	0	790	290	4.4	1.3E-06				85.0
31-Mar																																				
			270			79					121.4	5.0E-06			44%	270.0					146.1	6.0E-06			53%	270.0					90.6	2.8E-06			21%	275.0

APPENDIX 4

SITE MEASUREMENTS AND CALCULATIONS FROM DATA TO DATE

MATROLAB (EDMS.)BPK. (PTY.)LTD.
SIVIELE INGENIEURSDIENSTE · CIVIL ENGINEERING SERVICES

28 B BOUNDARY WEG / ROAD BRAKPAN
POSBUS / P.O.BOX 2393 TREKKER 1547
Tel: (011) 7409410
Fax: (011) 7401949

SUPER STEAM ENGINEERING
Posbus / P O Box 10699
Strubenvale
1570

AANDAG :
ATTENTION : MR. PIETER VAN WYK

PROJEK :
PROJECT : WATER TREATMENT PLANT
U VERW. :
YOUR REF. :
ONS VERW. :
OUR REF. : 0/OR/48903(a)
DATUM GERAPPORTEER :
DATE REPORTED : 12/12/1996

IN-SITU DROËDIGTHEIDSVERSLAG
IN-SITU DRY DENSITY REPORT
(TMH1 A10(b))

SEKSIE :
SECTION : SEE SKETCH COMBINED PULP

LAAG TIPE :
LAYER TYPE : FINAL

GETOETS DEUR :
TESTED BY : ANDRE POTGIETER

DATUM GETOETS :
DATE TESTED : 10/12/1996

VERDIGTINGSENERGIE :
COMPACTION ENERGY : MOD AASHTO

POSISIES/ POSITIONS	DIEPTE/ DEPTH (mm)	MATERIAAL BESKRYWING/ MATERIAL DESCRIPTION	MAKS.DROË DIGTHEID/ MAX.DRY DENSITY (kg/m³)	OPTIMUM VOGINHOUD/ MOISTURE CONTENT (%)	IN-SITU DROËDIGTHEID/ DRY DENSITY (kg/m³)	VOGINHOUD/ MOISTURE CONTENT (%)	RELATIEWE KOMPAKSIE/ RELATIVE COMPACTION (%)
1	0-300	PULP	480	95.0	329	264.1	68.5
1	0-150	PULP	480	96.0	342	264.1	71.2
2	0-300	PULP	480	95.0	326	251.1	67.9
2	0-150	PULP	480	95.0	353	251.1	73.5
				N/A			

TOETSE GEDOEN DEUR MIDDEL VAN STRALINGSMETODE / TESTS DONE BY MEANS OF NUCLEAR METHOD.

Toets Posisies / Test Positions

REFER TO ATTACHED SKETCH ON REF.No.0/OR/48903(a)

OPMERKINGS/REMARKS: MOD AASHTO SUPPLIED BY CLIENT.

AFSKRIF/COPY

VORM/FORM: A10(b) Program ver 3.3

nms/for Matrolab (Edms.)Bpk./(Pty.)Ltd.

MATROLAB (EDMS.)BPK. (PTY.)LTD.
SIVIELE INGENIEURSDIENSTE · CIVIL ENGINEERING SERVICES

28 B BOUNDARY WEG / ROAD BRAKPAN
POSBUS / P.O.BOX 2393 TREKKER 1547
Tel: (011) 7409410
Fax: (011) 7401949

SUPER STEAM ENGINEERING
Posbus / P O Box 10699
Strubenvale
1570

AANDAG :
ATTENTION : MR. PIETER VAN WYK

PROJEK :
PROJECT : WATER TREATMENT PLANT
U VERW. :
YOUR REF. :
ONS VERW. :
OUR REF. : D/OR/47176(c)
DATUM GERAPPORTEER
DATE REPORTED : 28/11/1996

IN-SITU DROËDIGTHEIDSVERSLAG
IN-SITU DRY DENSITY REPORT
(TMH1 A10(b))

SEKSIE
SECTION : SEE SKETCH PRIMARY PULP
LAAG TIPE
LAYER TYPE :
GETOETS DEUR
TESTED BY : ANDRE POTGIETER

DATUM GETOETS
DATE TESTED : 27/11/1996
VERDIGTINGSENERGIE
COMPACTION ENERGY : MOD AASHTO

POSISIES/ POSITIONS	DIEPTE/ DEPTH (mm)	MATERIAAL BESKRYWING/ MATERIAL DESCRIPTION	MAKS.DROË DIGTHEID/ MAX.DRY DENSITY (kg/m^3)	OPTIMUM VOGINHOUD/ MOISTURE CONTENT (%)	IN-SITU DROËDIGTHEID/ DRY DENSITY (kg/m^3)	VOGINHOUD/ MOISTURE CONTENT (%)	RELATIEWE KOMPAKSIE/ RELATIVE COMPACTION (%)
1	0-300	PULP	480	95.0	306	264.4	63.7
1	0-150	PULP	480	95.0	323	264.4	67.3
2	0-300	PULP	480	95.0	313	267.5	65.2
2	0-150	PULP	480	95.0	301	267.5	62.7
				P/A			

TOETSE GEDOEN DEUR MIDDEL VAN STRALINGSMETODE / TESTS DONE BY MEANS OF NUCLEAR METHOD

Toets Posisies / Test Positions

REFER TO ATTACHED SKETCH ON REF.No D/OR/47176(c)

OPMERKINGS/REMARKS: MOD AASHTO SUPPLIED BY CLIENT.
MATERIAL WAS DRIED @ 60°C TO PREVENT BURNING ON PAPER PULP.

AFSKRIF / COPY

VORM/FORM: A10(b) Program ver 3.3

nms/for Matrolab (Edms.)Bpk./(Pty.)Ltd.

MATROLAB (EDMS.)BPK. (PTY.)LTD.
SIVIELE INGENIEURSDIENSTE - CIVIL ENGINEERING SERVICES

28 B BOUNDARY WEG / ROAD BRAKPAN
POSBUS / P.O.BOX 2393 TREKKER 1547

Tel: (011) 7409410
Fax: (011) 7401949

SUPER STEAM ENGINEERING
Posbus / P O Box 10699
Strubenvale
1570

AANDAG :
ATTENTION : MR. PIETER VAN WYK

PROJEK :
PROJECT : WATER TREATMENT PLANT
U VERW. :
YOUR REF. :
ONS VERW. :
OUR REF. : 0/OR/47176(b)
DATUM GERAPPORTEER :
DATE REPORTED : 07/11/1996

IN-SITU DROËDIGTHEIDSVERSLAG
IN-SITU DRY DENSITY REPORT
(TMH1 A10(b))

SEKSIE :
SECTION : SEE SKETCH CLAY
LAAG TIPE :
LAYER TYPE :
GETOETS DEUR :
TESTED BY : ANDRE POTGIETER

DATUM GETOETS :
DATE TESTED : 06/11/1996
VERDIGTINGSENERGIE :
COMPACTION ENERGY : PROCTOR

POSISIES/ POSITIONS	DIEPTE/ DEPTH (mm)	MATERIAAL BESKRYWING/ MATERIAL DESCRIPTION	MAKS.DROEDIGTHEID/ MAX.DRY DENSITY (kg/m³)	OPTIMUM VOGINHOUD/ MOISTURE CONTENT (%)	IN-SITU DROEDIGTHEID/ DRY DENSITY (kg/m³)	VOGINHOUD/ MOISTURE CONTENT (%)	RELATIEWE KOMPAKSIE/ RELATIVE COMPACTION (%)
1	0-300	DARK OLIVE CLAY	1415	19.3	1470	18.3	103.9
1	0-150	DARK OLIVE CLAY	1415	19.3	1518	18.3	107.3
2	0-300	DARK OLIVE CLAY	1415	19.3	1418	26.3	100.2
2	0-150	DARK OLIVE CLAY	1415	19.3	1466	26.3	103.6

TOETSE GEDOEN DEUR MIDDEL VAN STRALINGSMETODE / TESTS DONE BY MEANS OF NUCLEAR METHOD.

Toets Posisies / Test Positions

REFER TO ATTACHED SKETCH ON REF.No.0/OR/47176(b)

OPMERKINGS/REMARKS: PROCTOR SUPPLIED BY CLIENT.

AFSKRIF/COPY

VORM/FORM: A10(b) Program ver 3.3

nms/for Matrolab (Edms.)Bpk./(Pty.)Ltd.

APPENDIX 3

SITE COMPACTION TEST RESULTS

CLIENT Jarrod Ball	DATE 5.6.96	FRANKI
PROJECT Sappi Enstra Capping	JOB No	
SITE Benoni Sand's Clay	TEST No 1	

FALLING HEAD PERMEABILITY

SAMPLE NO.	AREA OF SAMPLE A	HEIGHT OF SAMPLE L	AREA OF STANDPIPE a	INITIAL HEAD (cm) h_1	FINAL HEAD (cm) h_2	HEAD DIFFERENCE (cm)	TOTAL TIME t		COEFFICIENT OF PERMEABILITY
							MIN.	SEC.	
DD: 1415 kg/m³	40.00	2.0720	0.12178	100.0	98.5	1.5	60	–	2.5×10^{-8} cm/sec.

$$K = 2.3 \left(\frac{aL}{AT}\right) \log_{10} \left(\frac{h_1}{h_2}\right)$$

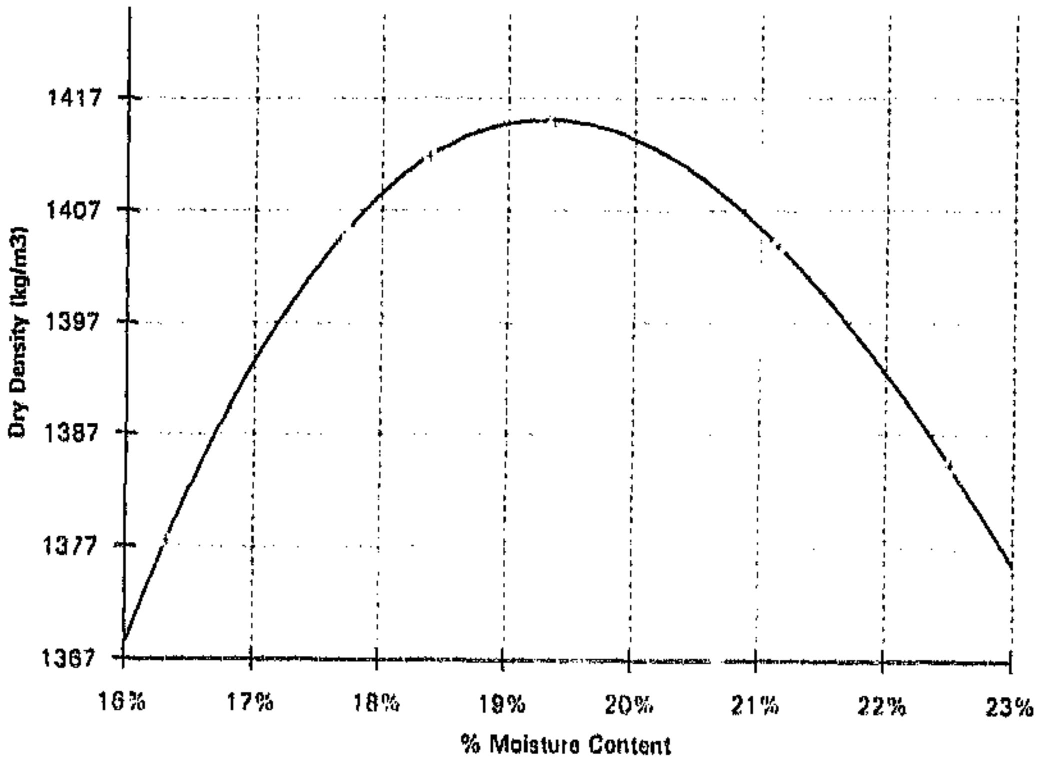
SOILTECH

SOILTECH

QUALITY IS OUR FOUNDATION

MOISTURE DENSITY TEST

Client Project Site	Jarrod Ball Sappi Enstra Capping -		Date Job #	3/6/96 19117
Test Pos Sample	- Benoni Sand's Clay		Depth	-
	Moisture Content	Dry Density (kg/m3)	Maximum Dry Density (kg/m3)	1415
1	16.3%	1377.6		
2	18.4%	1411.8		
3	21.1%	1403.9	Optimum Moisture Content	19.3%
4	22.5%	1384.3		
5				
6				
Compactive Effort		Standard Proctor		
Remarks		Unstabilised		



Sa Enstra Capping Results: Selected Data and Cumulative Totals

	All	Cum.	Cell1							Cell 2							Cell 3						
	Potent.	Pot'nt.	Runoff	Cum.	Seepage	Cum.	Hydraulic	Equiv.	Cum.	Runoff	Cum.	Seepage	Cum.	Hydraulic	Equiv.	Cum.	Runoff	Cum.	Seepage	Cum.	Hydraulic	Equiv.	Cum.
	Evap	Evap	Sump	Equiv	Flow	Seep.	Conduct.	Precip.	Equiv.		Equiv	Flow	Seep.	Conduct.	Precip.	Equiv.		Equiv	Flow	Seep.	Conduct.	Precip.	Equiv.
Dat	mm	mm	mm	Runoff	mm	Flow	cm/s	mm	Precip.	mm	Runoff	mm	Flow	cm/s	mm	Precip.	mm	Runoff	mm	Flow	cm/s	mm	Precip.
0 Oct		707		55		315		0	639		177		371		0	638		350		169		0	604
0 Oct	44	751		55	0	315	0.0E+00	0	639		177	0	371	0.0E+00	0	638		350	2	170	5.2E-07	0	604
0 Oct	9	760		55	0	315	0.0E+00	0	639		177	0	372	1.2E-07	0	638		350	0	170	0.0E+00	0	604
0 Oct		760		55		315		0	639		177		372		0	638		350		170		0	604
0 Oct		760		55		315		0	639		177		372		0	638		350		170		0	604
0 Oct	23	783		55	0	315	1.2E-07	0	639		177	2	373	4.6E-07	0	638		350	1	172	3.5E-07	0	604
0 Oct	9	792		55	0	315	0.0E+00	0	639		177	0	373	0.0E+00	0	638		350	0	172	0.0E+00	0	604
0 Oct	10	802		55	0	315	5.8E-08	0	639		177	0	373	0.0E+00	0	638		350	0	172	5.8E-08	0	604
09 Oct	5	807	10	58	0	315	5.8E-08	10	649	40	188	0	373	5.8E-08	10	648	30	359	0	172	5.8E-08	10	614
10 Oct	0	807		58	0	315	0.0E+00	0	649		188	0	374	1.2E-07	0	648		359	0	172	0.0E+00	0	614
11 Oct		807		58		315		0	649		188		374		0	648		359		172		0	614
12 Oct		807		58		315		0	649		188		374		0	648		359		172		0	614
1 Oct	16	823		58	0	315	0.0E+00	5	654		188	5	379	1.6E-06	5	653		359	0	172	0.0E+00	5	619
1 Oct	6	829		58	0	315	0.0E+00	0	654		188	2	381	4.6E-07	0	653		359	0	172	0.0E+00	0	619
1 -Oct	0	829		58	0	315	0.0E+00	5	659		188	2	383	6.2E-07	5	658		359	0	172	1.2E-07	5	624
1 -Oct	0	829		58	0	315	0.0E+00	3	662	20	193	3	385	8.1E-07	3	661	20	364	0	172	0.0E+00	3	627
1 -Oct	13	842		58	0	315	0.0E+00	0	662		193		385		0	661		364		172		0	627
8-Oct		842		58		315		0	662		193		385		0	661		364		172		0	627
9-Oct		842		58		315		0	662		193		385		0	661		364		172		0	627
0-Oct	15	857		58	0	315	0.0E+00	0	662		193	1	386	2.9E-07	0	661		364	0	173	5.8E-08	0	627
1-Oct	7	864		58	0	315	0.0E+00	0	662		193	0	386	0.0E+00	0	661		364	0	173	0.0E+00	0	627
22-Oct	3	867		58	0	315	0.0E+00	0	662		193	0	387	1.2E-07	0	661		364	1	173	1.7E-07	0	627
23-Oct	11	878		58	0	315	0.0E+00	0	662		193	1	388	2.3E-07	0	661		364	0	174	1.2E-07	0	627
24-Oct	11	889		58	0	315	0.0E+00	0	662		193		388		0	661		364		174		0	627
25-Oct		889		58		315		0	662		193		388		0	661		364		174		0	627
26-Oct		889		58		316		0	662		193		388		0	661		364	1	174	2.3E-07	0	627
27-Oct	18	907	20	63	0	315	0.0E+00	14	676	30	202	6	393	1.6E-06	14	675	20	370	0	174	0.0E+00	14	641
28-Oct	6	913		63	0	315	0.0E+00	0	676		202	0	394	1.2E-07	0	675		370	0	174	0.0E+00	0	641
29-Oct	8	921		63	0	315	0.0E+00	0	676		202	0	394	6.8E-08	0	675		370	0	174	0.0E+00	0	641
30-Oct	11	932		63	0	315	0.0E+00	0	676		202	0	394	0.0E+00	0	675		370		174		0	641
31-Oct		932		63		315			676		202		394		0	675		370		174		0	641

Sappi Enstra Capping Results: Selected Data and Cumulative Totals

	All	Cum.	Cell1							Cell 2							Cell 3						
	Potent.	Potent.	Runoff	Cum.	Seepage	Cum.	Hydraulic	Equiv.	Cum.	Runoff	Cum.	Seepage	Cum.	Hydraulic	Equiv.	Cum.	Runoff	Cum.	Seepage	Cum.	Hydraulic	Equiv.	Cum.
	Evap	Evap	Sump	Equiv	Flow	Seep.	Conduct.	Precip.	Equiv.		Equiv	Flow	Seep.	Conduct.	Precip.	Equiv.		Equiv	Flow	Seep.	Conduct.	Precip.	Equiv.
Date	mm	mm	mm	Runoff	mm	Flow	cm/s	mm	Precip.	mm	Runoff	mm	Flow	cm/s	mm	Precip.	mm	Runoff	mm	Flow	cm/s	mm	Precip.
01-Sep	5	604		44	4	265	1.5E-06	12	564		133	2	314	6.17E-07	14	560		306	0	134	1.54E-07	16	528
02-Sep	5	609		44		265			564		133		314			560		306		134			528
03-Sep	5	614		44	4	269	2.3E-06	9	572		133	2	316	9.26E-07	11	571		306	1	135	4.63E-07	10	537
04-Sep		614		44		269			572		133		316			571		306		135			537
05-Sep	20	634		44	2	271	9.3E-07		572		133	1	317	6.94E-07	0	571		306	1	136	4.63E-07	0	537
06-Sep		634		44		271			572		133		317			571		306		136			537
07-Sep		634		44		271			572		133		317			571		306		136			537
08-Sep	1	635		44	4	274	1.4E-06	14	586	40	144	7	324	2.78E-06	14	585	40	317	4	139	1.39E-06	14	551
09-Sep	0	635		44	1	275	9.3E-07	1	587		144	2	326	2.31E-06	1	586		317	2	141	1.85E-06	1	552
10-Sep	0	635		44	2	277	1.9E-06	2	589		144	2	328	1.85E-06	2	588		317	2	143	2.31E-06	2	554
11-Sep	0	635	40	55	3	280	3.7E-06	15	604	50	158	4	332	4.63E-06	15	603	60	334	1	144	9.26E-07	16	569
12-Sep	0	635		55	1	281	9.3E-07	3	607		158	2	334	2.78E-06	3	606		334	6	149	6.39E-06	3	572
13-Sep		635		55		281			607		158		334			606		334		149			572
14-Sep		635		55		281			607		158		334			606		334		149			572
15-Sep	0	635		55	30	311	1.2E-05	19	626	65	177	22	357	8.56E-06	19	625	60	350	14	163	5.25E-06	19	591
16-Sep		635		55		311			626		177		357			625		350		163			591
17-Sep	10	645		55	1	311	4.6E-07		626		177	4	360	2.20E-06		625		350	3	166	1.62E-06		591
18-Sep	0	645		55	0	312	2.3E-07	8	634		177	2	362	2.08E-06	8	633		350	1	166	9.26E-07	8	599
19-Sep		645		55		312			634		177		362			633		350		166			599
20-Sep		645		55		312			634		177		362			633		350		166			599
21-Sep		645		55		312			634		177		362			633		350		166			599
22-Sep	27	672		55	3	315	8.7E-07	5	639		177	8	370	2.26E-06	5	638		350	2	168	5.79E-07	5	604
23-Sep		672		55		316			639		177		370			638		350		168			604
24-Sep		672		55		315			639		177		370			638		350		168			604
25-Sep		672		55		315			639		177		370			638		350		168			604
26-Sep	35	707		55	0	315	0.0E+00		639		177	1	371	3.47E-07	0	638		350	0	169	5.79E-08	0	604
27-Sep		707		55		315			639		177		371			638		350		169			604
28-Sep		707		55		315			639		177		371			638		350		169			604
29-Sep		707		55		315			639		177		371			638		350		169			604
30-Sep		707		55		315			639		177		371			638		350		169			604

Sappi Enstra Capping Results; Selected Data and Cumulative Totals

	All	Cum.	Cell1							Cell 2							Cell 3						
	Potent.	Potent.	Runoff	Cum.	Seepage	Cum.	Hydraulic	Equiv.	Cum.	Runoff	Cum.	Seepage	Cum.	Hydraulic	Equiv.	Cum.	Runoff	Cum.	Seepage	Cum.	Hydraulic	Equiv.	Cum.
	Evap	Evap	Sump	Equiv	Flow	Seep.	Conduct.	Precip.	Equiv.		Equiv	Flow	Seep.	Conduct.	Precip.	Equiv.		Equiv	Flow	Seep.	Conduct.	Precip.	Equiv.
Date	mm	mm	mm	Runoff	mm	Flow	cm/s	mm	Precip.	mm	Runoff	mm	Flow	cm/s	mm	Precip.	mm	Runoff	mm	Flow	cm/s	mm	Precip.
1-Aug		435		44		253			457		133		285			422		301		130			422
2-Aug		435		44		253			457		133		285			422		301		130			422
3-Aug		435		44		253			457		133		285			422		301		130			422
4-Aug		435		44		253			457		133		285			422		301		130			422
5-Aug		435		44		253			457		133		285			422		301		130			422
6-Aug	27	462		44	0	253	0.0E+00	13	470		133	3	288	3.29E-07	15	437		301	1	131	7.20E-08	11	433
7-Aug		462		44		253			470		133		288			437		301		131			433
8-Aug	0	462		44		253			470		133		288			437		301		131			433
9-Aug		462		44		253			470		133		288			437		301		131			433
10-Aug		462		44		253			470		133		288			437		301		131			433
11-Aug		462		44	0	253	0.0E+00	12	482		133	0	288	0	8	446		301	0	131	9.26E-08	8	441
12-Aug	30	492		44	0	253	0.0E+00	6	488		133	0	288	0	47	493		301	0	131	0	9	451
13-Aug	6	498		44	1	254	9.3E-07	6	494		133	12	300	1.39E-05	6	499		301	0	131	0	5	456
14-Aug	4	502		44	2	257	2.8E-06	5	499		133	7	307	8.33E-06	0	499		301	0	131	0	5	460
15-Aug		502		44	1	257	9.3E-07	6	505		133	0	308	4.63E-07	0	499		301	0	131	0	4	464
16-Aug		502		44		257			505		133		308			499		301		131			464
17-Aug		502		44		257			505		133		308			499		301		131			464
18-Aug	20	522		44	2	260	9.3E-07	5	511		133	0	308	1.54E-07	4	503		301	0	132	1.54E-07	6	470
19-Aug	4	526		44	0	260	0.0E+00		511		133	0	308	0		503		301	0	132	2.31E-07		470
20-Aug	6	532		44	0	260	0.0E+00	5	515		133	1	309	9.26E-07	6	508	15	306	0	132	0.00E+00		470
21-Aug	8	540		44	0	260	0.0E+00		515		133	1	310	1.02E-06		508		306	1	133	9.26E-07		470
22-Aug	7	547		44	0	260	0.0E+00	7	522		133	1	310	8.33E-07	8	517		306	0	133	0	7	477
23-Aug		547		44		260			522		133		310			517		306		133			477
24-Aug		547		44		260			522		133		310			517		306		133			477
25-Aug	27	574		44	0	260	0.0E+00	9	531		133	1	311	3.09E-07	9	526		306	0	133	0	15	492
26-Aug	7	581		44	0	260	0.0E+00		531		133	1	312	9.26E-07		526		306	0	133	0		492
27-Aug	9	590		44	0	260	4.6E-07	12	543		133	0	312	4.63E-07	12	538		306	0	133	4.63E-07	11	504
28-Aug	4	594		44	1	261	9.3E-07		543		133	0	313	4.63E-07		538		306	0	134	4.63E-07		504
29-Aug	5	599		44	0	261	0.0E+00	8	551		133	0	313	0	8	546		306	0	134	0	8	511
30-Aug		599		44		261			551		133		313			546		306		134			511
31-Aug		599		44		261			551		133		313			546		306		134			511

Sappi Enstra Capping Results: Selected Data and Cumulative Totals

Date	All Potent. Evap mm	Cum. Potent. Evap mm	Cell1 Runoff Sump mm	Cum. Equiv Runoff	Seepage Flow mm	Cum. Seep. Flow	Hydraulic Conduct. cm/s	Equiv. Precip. mm	Cum. Equiv. Precip.	Cell 2 Runoff mm	Cum. Equiv Runoff	Seepage Flow mm	Cum. Seep. Flow	Hydraulic Conduct. cm/s	Equiv. Precip. mm	Cum. Equiv. Precip.	Cell 3 Runoff mm	Cum. Equiv Runoff	Seepage Flow mm	Cum. Seep. Flow	Hydraulic Conduct. cm/s	Equiv. Precip. mm	Cum. Equiv. Precip.
1-Jul		362		44		253			457		133		283			422		301		129			422
2-Jul		362		44		253			457		133		283			422		301		129			422
3-Jul		362		44		253			457		133		283			422		301		129			422
4-Jul		362		44		253			457		133		283			422		301		129			422
5-Jul		362		44		253			457		133		283			422		301		129			422
6-Jul		362		44		253			457		133		283			422		301		129			422
7-Jul	26	388		44	0	253	0.0E+00	0	457		133	0	284	4.59E-08	0	422		301	0	129	2.30E-08	0	422
08-Jul		388		44		253			457		133		284			422		301		129			422
09-Jul	4	392		44	0	253	0.0E+00	0	457		133	0	284	8.04E-08	0	422		301	0	129	0	0	422
10-Jul		392		44		253			457		133		284			422		301		129			422
11-Jul		392		44		253			457		133		284			422		301		129			422
12-Jul		392		44		253			457		133		284			422		301		129			422
13-Jul		392		44		253			457		133		284			422		301		129			422
14-Jul		392		44		253			457		133		284			422		301		129			422
15-Jul		392		44		253			457		133		284			422		301		129			422
16-Jul	11	403		44	0	253	0.0E+00	0	457		133	1	284	9.19E-08	0	422		301	0	130	4.59E-08	0	422
17-Jul		403		44		253			457		133		284			422		301		130			422
18-Jul		403		44		253			457		133		284			422		301		130			422
19-Jul		403		44		253			457		133		284			422		301		130			422
20-Jul		403		44		253			457		133		284			422		301		130			422
21-Jul	15	418		44	0	253	0.0E+00	0	457		133	1	285	1.20E-07	0	422		301	1	130	1.39E-07	0	422
22-Jul		418		44		253			457		133		285			422		301		130			422
23-Jul		418		44		253			457		133		285			422		301		130			422
24-Jul		418		44		253			457		133		285			422		301		130			422
25-Jul	9	427		44	0	253	0.0E+00	0	457		133	0	285	1.39E-07	0	422		301	0	130	4.63E-08	0	42
26-Jul		427		44		253			457		133		285			422		301		130			42
27-Jul		427		44		253			457		133		285			422		301		130			42
28-Jul	8	435		44	0	253	0.0E+00	0	457		133	0	285	9.26E-08	0	422		301	0	130	3.09E-08	0	42
29-Jul		435		44		253			457		133		285			422		301		130			42
30-Jul		435		44		253			457		133		285			422		301		130			42
31-Jul		435		44		253			457		133		285			422		301		130			42

Sappi Enstra Capping Results: Selected Data and Cumulative Totals

	All	Cum.	Cell1							Cell 2							Cell 3						
	Potent.	Potent.	Runoff	Cum.	Seepage	Cum.	Hydraulic	Equiv.	Cum.	Runoff	Cum.	Seepage	Cum.	Hydraulic	Equiv.	Cum.	Runoff	Cum.	Seepage	Cum.	Hydraulic	Equiv.	Cum.
	Evap	Evap	Sump	Equiv	Flow	Seep.	Conduct.	Precip	Equiv.		Equiv	Flow	Seep.	Conduct.	Precip.	Equiv.		Equiv	Flow	Seep.	Conduct.	Precip.	Equiv.
Date	mm	mm	mm	Runoff	mm	Flow	cm/s	mm	Precip.	mm	Runoff	mm	Flow	cm/s	mm	Precip.	mm	Runoff	mm	Flow	cm/s	mm	Precip.
01-Jun		262		44		236			420		133		269			420		301		123			420
02-Jun	11	273	0	44	7	243	2.7E-06	0	420	0	133	5	274	1.93E-06	0	420	0	301	4	127	1.71E-06	0	420
03-Jun	4	277	0	44	1	244	9.6E-07	0	420	0	133	1	274	9.65E-07	0	420	0	301	1	128	1.29E-06	0	420
04-Jun	2	279	0	44	1	244	6.4E-07	0	420	0	133	0	275	3.22E-07	0	420	0	301	0	128	1.61E-07	0	420
05-Jun	4	283	0	44	0	244	0.0E+00	0	420	0	133	2	276	1.93E-06	0	420	0	301	0	129	3.22E-07	0	420
06-Jun	4	287	0	44	0	244	0.0E+00	0	420	0	133	1	277	9.65E-07	0	420	0	301	0	129	6.43E-08	0	420
7-Jun		287		44		244			420		133		277			420		301		129			420
8-Jun		287		44		244			420		133		277			420		301		129			420
9-Jun	9	296	0	44	0	244	0.0E+00	0	420	0	133	1	278	3.32E-07	0	420	0	301	0	129	8.57E-08	0	420
10-Jun	4	300	0	44	0	244	0.0E+00	0	420	0	133	0	276	1.29E-07	0	420	0	301	0	129	0	0	420
11-Jun	2	302	0	44	0	244	0.0E+00	2	122	0	133	0	278	1.61E-07	2	422	0	301	0	129	0	2	422
12-Jun	2	304	0	44	0	244	0.0E+00	0	422	0	133	0	279	3.22E-07	0	422	0	301	0	129	6.43E-08	0	422
13-Jun	3	307	0	44	0	244	0.0E+00	0	422	0	133	0	279	4.82E-07	0	422	0	301	0	129	9.65E-08	0	422
14-Jun		307		44		244			422		133		279			422		301		129			422
15-Jun		307		44		244			422		133		279			422		301		129			422
16-Jun	7	314	0	44	0	244	0.0E+00	0	422	0	133	1	280	4.82E-07	0	422	0	301	0	129	5.36E-08	0	422
17-Jun	3	317	0	44	0	244	0.0E+00	0	422	0	133	0	280	3.22E-07	0	422	0	301	0	129	0	0	422
18-Jun	2	319	0	44	0	244	0.0E+00	0	422	0	133	0	281	3.22E-07	0	422	0	301	0	129	0	0	422
19-Jun	4	323	0	44	0	244	0.0E+00	0	422	0	133	0	281	3.22E-07	0	422	0	301	0	129	0	0	422
20-Jun	4	327	0	44	0	244	0.0E+00	0	422	0	133	1	282	6.43E-07	0	422	0	301	0	129	0	0	422
21-Jun		327		44		244			422		133		282			422		301		129			422
22-Jun		327		44		244			422		133		282			422		301		129			422
23-Jun	9	336	0	44	0	244	0.0E+00	0	422	0	133	0	282	1.07E-07	0	422	0	301	0	129	0	0	422
24-Jun	3	339	0	44	0	244	0.0E+00	0	422	0	133	0	282	3.22E-07	0	422	0	301	0	129	0	0	422
25-Jun	4	343	0	44	0	244	0.0E+00	35	457	0	133	0	282	3.22E-07	0	422	0	301	0	129	0	0	422
26-Jun	3	346	0	44	8	252	8.7E-06	0	457	0	133	0	283	3.22E-07	0	422	0	301	0	129	0	0	422
27-Jun	2	348	0	44	2	253	1.8E-06	0	457	0	133	0	283	3.22E-07	0	422	0	301	0	129	0	0	422
28-Jun		348		44		253			457		133		283			422		301		129			422
29-Jun		348		44		253			457		133		283			422		301		129			422
30-Jun	14	362	0	44	0	253	0.0E+00	0	457	0	133	0	283	1.07E-07	0	422	0	301	0	129	0	0	422

Sappi Enstra Capping Results: Selected Data and Cumulative Totals

	All	Cum.	Cell1							Cell 2							Cell 3						
	Potent.	Potent.	Runoff	Cum.	Seepage	Cum.	Hydraulic	Equiv.	Cum.	Runoff	Cum.	Seepage	Cum.	Hydraulic	Equiv.	Cum.	Runoff	Cum.	Seepage	Cum.	Hydraulic	Equiv.	Cum.
	Evap	Evap	Sump	Equiv	Flow	Seep.	Conduct.	Precip.	Equiv.		Equiv	Flow	Seep.	Conduct.	Precip.	Equiv.		Equiv	Flow	Seep.	Conduct.	Precip.	Equiv.
Date	mm	mm	mm	Runoff	mm	Flow	cm/s	mm	Precip	mm	Runoff	mm	Flow	cm/s	mm	Precip.	mm	Runoff	mm	Flow	cm/s	mm	Precip.
1-May		175		44		136			302		92		191			302		239		65			302
2-May	7	182	0	44	0	136	0.0E+00	0	302	0	92	0	191	6.43E-08	0	302	0	239	0	65	1.61E-07	0	302
3-May		182		44		136			302		92		191			302		239		65			302
4-May		182		44		136			302		92		191			302		239		65			302
5-May	13	195	0	44	0	136	0.0E+00	1	303	0	92	4	196	1.61E-06	1	303	0	239	2	67	6.43E-07	1	303
6-May	3	198	0	44	0	136	0.0E+00	0	303	0	92	0	196	0	0	303	0	239	0	67	0	0	303
7-May	5	203	0	44	0	136	0.0E+00	0	303	0	92	0	196	0	0	303	0	239	0	67	0	0	303
8-May	4	207	0	44	0	136	0.0E+00	0	303	0	92	0	196	0	0	303	0	239	0	67	0	0	303
9-May	3	210	0	44	0	136	0.0E+00	0	303	0	92	0	196	0	0	303	0	239	0	67	0	0	303
10-May		210		44		136			303		92		196			303		239		67			303
11-May		210		44		136			303		92		196			303		239		67			303
12-May	8	218	0	44	0	136	0.0E+00	0	303	0	92	4	200	1.61E-06	0	303	0	239	0	67	5.36E-08	0	303
13-May	6	224	0	44	0	136	0.0E+00	0	303	0	92	0	200	0	0	303	0	239	0	67	0	0	303
14-May	4	228	0	44	0	136	0.0E+00	0	303	0	92	0	200	1.61E-07	0	303	0	239	0	67	1.61E-07	0	303
15-May	2	230	0	44	0	136	0.0E+00	0	303	0	92	0	200	0	0	303	0	239	0	67	0	0	303
16-May	2	232	0	44	0	136	0.0E+00	0	303	0	92	0	200	0	0	303	0	239	0	67	0	0	303
17-May		232		44		136			303		92		200			303		239		67			303
18-May		232		44		136			303		92		200			303		239		67			303
19-May	13	245	0	44	0	136	0.0E+00	0	303	0	92	4	204	1.71E-06	0	303	0	239	0	67	0	0	303
20-May	4	249	0	44	0	136	0.0E+00	0	303	0	92	0	204	0	0	303	0	239	0	67	0	0	303
21-May	4	253	0	44	0	136	0.0E+00	0	303	0	92	0	204	0	0	303	0	239	0	67	0	0	303
22-May	3	256	0	44	0	136	0.0E+00	0	303	0	92	0	204	0	0	303	0	239	0	67	0	0	303
23-May	2	258	0	44	0	136	0.0E+00	0	303	0	92	0	204	0	0	303	0	239	0	67	0	0	303
24-May		258		44		136			303		92		204			303		239		67			303
25-May		258		44		136			303		92		204			303		239		67			303
26-May	0	258	0	44	28	164	1.1E-05	85	388	120	116	27	232	1.05E-05	85	388	180	274	23	90	9.00E-06	85	388
27-May	0	258	0	44	28	192	3.2E-05	18	406	60	127	17	249	1.96E-05	18	406	120	298	17	107	1.93E-05	18	406
28-May	0	258	0	44	28	219	3.2E-05	14	420	30	133	9	258	1.09E-05	14	420	20	301	11	117	1.22E-05	14	420
29-May	1	259	0	44	11	230	1.3E-05	0	420	0	133	7	265	7.72E-06	0	420	0	301	3	120	3.54E-06	0	420
30-May	3	262	0	44	6	236	7.1E-06	0	420	0	133	4	269	4.60E-06	0	420	0	301	2	123	2.57E-06	0	420
31-May		262		44		236			420		133		269			420		301		123			420

Sappi Enstra Capping Results: Selected Data and Cumulative Totals

	All	Cum.	Cell1							Cell 2							Cell 3						
	Potent.	Potent.	Runoff	Cum.	Seepage	Cum.	Hydraulic	Equiv.	Cum.	Runoff	Cum.	Seepage	Cum.	Hydraulic	Equiv.	Cum.	Runoff	Cum.	Seepage	Cum.	Hydraulic	Equiv.	Cum.
	Evap	Evap	Sump	Equiv	Flow	Seep.	Conduct.	Precip.	Equiv.		Equiv	Flow	Seep.	Conduct.	Precip.	Equiv.		Equiv	Flow	Seep.	Conduct.	Precip.	Equiv.
Date	mm	mm	mm	Runoff	mm	Flow	cm/s	mm	Precip.	mm	Runoff	mm	Flow	cm/s	mm	Precip.	mm	Runoff	mm	Flow	cm/s	mm	Precip.
01-Apr	12	59	0	44	7	129	4.2E-06	1	279	0	92	11	167	6.6E-06	1	279	0	239	1	61	6.4E-07	1	279
02-Apr	5	64	0	44	8	136	8.7E-06	0	279	0	92	3	160	3.2E-06	0	279	0	239	0	61	3.9E-07	0	279
03-Apr	5	69	0	44	0	136	1.9E-07	0	279	0	92	2	162	2.6E-06	0	279	0	239	0	61	2.6E-07	0	279
04-Apr	8	77	0	44	0	136	9.6E-08	0	279		92	1	164	1.6E-06	0	279		239	0	62	3.2E-07	0	279
05-Apr		77		44		136			279		92		164			279		239		62			279
06-Apr		77		44		136			279	0	92		164			279	0	239		62			279
07-Apr	7	84	0	44	0	136	0.0E+00	7	286	0	92	8	172	4.7E-06	7	286	0	239	0	62	1.1E-07	7	286
08-Apr	2	86	0	44	0	136	0.0E+00	0	286	0	92	0	172	1.6E-07	0	286	0	239	0	62	0.0E+00	0	286
09-Apr	4	90	0	44	0	136	0.0E+00	0	286	0	92	1	173	6.4E-07	0	286	0	239	0	62	4.8E-07	0	286
10-Apr	5	95	0	44	0	136	0.0E+00	0	286	0	92	0	173	3.2E-07	0	286	0	239	0	62	1.6E-07	0	286
11-Apr	4	99	0	44	0	136	0.0E+00	0	286		92	1	174	6.4E-07	0	286		239	0	62	6.4E-08	0	286
12-Apr		99		44		136			286		92		174			286		239		62			286
13-Apr		99		44		136			286	0	92		174			286	0	239		62			286
14-Apr	16	115	0	44	0	136	0.0E+00	0	286	0	92	11	184	6.1E-06	0	286	0	239	0	63	6.6E-08	0	286
15-Apr	0	115	0	44	0	136	0.0E+00	0	286	0	92	0	184	2.6E-07	0	286	0	239	0	63	6.4E-08	0	286
16-Apr	6	121	0	44	0	136	0.0E+00	0	286	0	92	0	185	3.2E-07	0	286	0	239	0	63	1.9E-07	0	286
17-Apr	9	130	0	44	0	136	0.0E+00	0	286	0	92	0	185	4.5E-07	0	286	0	239	0	63	2.3E-07	0	286
18-Apr	0	130	0	44	0	136	0.0E+00	0	286		92	0	185	2.6E-07	0	286		239	0	63	1.6E-07	0	286
19-Apr		130		44		136			286		92		185			286		239		63			286
20-Apr		130		44		136			286		92		185			286		239		63			286
21-Apr	8	136	0	44	0	136	0.0E+00	8	294	0	92	2	187	9.6E-07	8	294	0	239	0	63	1.1E-07	8	294
22-Apr	4	142	0	44	0	136	0.0E+00	0	294	0	92	1	187	5.8E-07	0	294	0	239	0	63	0.0E+00	0	294
23-Apr	2	144	0	44	0	136	0.0E+00	2	296	0	92	0	187	6.4E-08	2	296	0	239	0	64	1.3E-07	2	296
24-Apr	4	148	0	44	0	136	0.0E+00	6	302	0	92	1	188	6.4E-07	6	302	0	239	0	64	1.3E-07	6	302
25-Apr	8	156	0	44	0	136	0.0E+00	0	302	0	92	0	188	1.3E-07	0	302	0	239	0	64	6.4E-08	0	302
26-Apr		156		44		136			302		92		188			302		239		64			302
27-Apr		156		44		136			302		92		188			302		239		64			302
28-Apr		156		44		136			302		92		188			302		239		64			302
29-Apr	17	173	0	44	0	136	0.0E+00	0	302	0	92	3	191	9.0E-07	0	302	0	239	1	64	1.9E-07	0	302
30-Apr	2	175	0	44	0	136	0.0E+00	0	302	0	92	0	191	1.3E-07	0	302	0	239	0	65	1.9E-07	0	302

Sappi Enstra Capping Results: Selected Data and Cumulative Totals

	All	Cum.	Cell1							Cell 2							Cell 3						
	Potent.	Potent.	Runoff	Cum.	Seepage	Cum.	Hydraulic	Equiv.	Cum.	Runoff	Cum.	Seepage	Cum.	Hydraulic	Equiv.	Cum.	Runoff	Cum.	Seepage	Cum.	Hydraulic	Equiv.	Cum.
	Evap	Evap	Sump	Equiv	Flow	Seep.	Conduct.	Precip.	Equiv.		Equiv	Flow	Seep.	Conduct.	Precip.	Equiv.		Equiv	Flow	Seep.	Conduct.	Precip.	Equiv.
Date	mm	mm	mm	Runoff	mm	Flow	cm/s	mm	Precip.	mm	Runoff	mm	Flow	cm/s	mm	Precip.	mm	Runoff	mm	Flow	cm/s	mm	Precip.
1-Mar	12	12	0	0						0	0						0	0					
2-Mar	3	15		0							0							0					
3-Mar	2	17	0	0	0	0	0.0E+00	1	1	0	0	0	0	6.4E-08	1	1	0	0	0	0	8.0E-08	1	1
4-Mar		17	0	0	0	0	0.0E+00	4	5	0	0	0	0		4	5	0	0	0	0	6.4E-08	4	5
5-Mar	0	17	50	10	28	28	3.2E-05	70	75	150	29	25	25	2.9E-05	70	75	350	68	22	22	2.5E-05	70	75
6-Mar		17	50	19	28	56	3.2E-05	35	110	130	54	26	51	3.1E-05	35	110	230	113	14	36	1.6E-05	35	110
7-Mar		17	20	23	28	83	3.2E-05	25	135	115	77	20	71	2.3E-05	25	135	210	154	7	43	7.6E-06	25	135
8-Mar	13	30		23		83			135		77		71			135		154		43			135
9-Mar	0	30		23		83			135		77		71			135		154		43			135
10-Mar	2	32	0	23	9	93	3.6E-06	5	140	0	77	15	86	5.8E-06	5	140	0	154	3	46	1.1E-06	5	140
11-Mar	1	33	0	23	1	94	9.6E-07	6	146	0	77	10	97	1.2E-05	6	146	0	154	3	49	3.9E-06	6	146
12-Mar		33	0	23	0	94	0.0E+00	0	146	0	77	1	98	1.6E-06	0	146	0	154	0	49	3.2E-07	0	146
13-Mar		33		23		94			146		77		98			146		154		49			146
14-Mar		33	10	25	0	94	0.0E+00	11	157	10	79	5	103	3.8E-06	11	157	0	154	1	51	6.0E-07	11	157
15-Mar	14	47		25		94			157		79		103			157		154		51			157
16-Mar	0	47		25		94			157		79		103			157		154		51			157
17-Mar	0	47	0	25	0	94	1.1E-07	0	157	0	79	4	107	4.2E-06	0	157	0	154	1	52	3.2E-07	0	157
18-Mar		47	0	25	0	94	0.0E+00	10	167	0	79	1	108	5.8E-07	10	167	0	154	0	52	3.2E-07	10	167
19-Mar		47	5	26	0	94	0.0E+00	1	168	0	79	1	109	1.2E-06	1	168	10	156	1	52	6.4E-07	1	168
20-Mar		47	10	28	0	94	0.0E+00	3	171	0	79	2	111	1.9E-06	3	171	20	159	1	53	6.4E-07	3	171
21-Mar	0	47		28		94			171		79		111			171		159		53			171
22-Mar		47		28		94			171		79		111			171		159		63			171
23-Mar		47		28		94			171		79		111			171		159		53			171
24-Mar		47	0	28	0	94	0.0E+00	10	181	0	79	8	118	2.9E-06	10	181	0	159	2	65	6.4E-07	10	181
25-Mar		47	0	28	0	94	0.0E+00	6	187	0	79	0	119	5.5E-07	6	187	0	159	0	55	3.2E-07	6	187
26-Mar		47	20	32	0	94	0.0E+00	6	193	40	87	1	119	9.8E-07	6	193	20	163	0	55	3.2E-07	6	193
27-Mar		47		32		94			193		87		119			193		163		55			193
28-Mar		47		32		94			193		87		119			193		163		55			193
29-Mar		47		32		94			193		87		119			193		163		55			193
30-Mar		47	60	44	28	121	8.0E-06	85	278	30	92	27	146	7.7E-06	85	278	390	239	4	60	1.3E-06	85	278
31 Mar		47		44		121			278	0	92		146			278	0	239		60			278

SAPPI ENSTRA
LANDFILL CAPPING FIELD TEST RESULTS

Month	Nov 97						Cell 1											Cell 2											Cell 3									
	Precipitation			Evaporation			Runoff		Seepage		Equiv	Hydraulic	Irrigation			Total	Runoff		Seepage		Equiv	Hydraulic	Irrigation			Total	Runoff		Seepage		Equiv	Hydraulic	Irrigation			Total
	Road	Left	Nett	Road	Left	Nett	Road	Left	Read	Left	Flow	Conduct	Read	Left	Equiv	P	Road	Left	Road	Left	Flow	Conduct	Read	Left	Equiv	P	Road	Left	Read	Left	Flow	Conduct	Read	Left	Equiv	P
Date	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	cm/s	m3	m3	mm	mm	mm	mm	mm	mm	mm	cm/s	m3	m3	mm	mm	mm	mm	mm	mm	mm	cm/s	m3	m3	mm	mm
01-Nov																0.0										0.0										0.0
02-Nov																0.0										0.0										0.0
03-Nov																0.0										0.0										0.0
04-Nov																0.0										0.0										0.0
05-Nov	0	0	0	82	237	13	0	0	0	0	0.0	0.0E+00				0.0	0	0	580	580	0.6	6.7E-06				0.0	0	0	110	110	0.8	2.3E-07				0.0
06-Nov	2	0	2	234	234	3	0	0	0	0	0.0	0.0E+00				2.0	0	0	587	587	0.3	8.1E-08				2.0	0	0	112	112	0.1	2.3E-08				2.0
07-Nov	3	0	3	225	225	0										3.0			600	600	0.6	1.5E-07				3.0			116	116	0.2	4.6E-08				3.0
08-Nov																0.0										0.0										0.0
09-Nov																0.0										0.0										0.0
10-Nov	2	0	2	200	200	25	0	0	0	0	0.0	0.0E+00				2.0	0	0	623	623	0.9	2.7E-07				2.0	0	0	128	128	0.5	1.4E-07				2.0
11-Nov	0	0	0	180	190	10	0	0	0	0	0.0	0.0E+00				0.0	0	0	628	628	0.2	6.8E-08				0.0	0	0	128	128	0.0	0.0E+00				0.0
12-Nov	0	0	0	187	187	3	0	0	0	0	0.0	0.0E+00				0.0	0	0	631	631	0.1	3.5E-08				0.0	0	0	130	130	0.1	2.3E-08				0.0
13-Nov	34	0	34	216	216	0	80	0	100	100	4.0	1.2E-06				34.0	90	0	940	940	12.4	3.6E-06				34.0	80	0	610	610	19.2	5.6E-06				34.0
14-Nov	0	0	0	203	203	13	0	0	110	110	0.4	1.2E-07				0.0	0	0	950	950	0.4	1.2E-07				0.0	0	0	620	620	0.4	1.2E-07				0.0
15-Nov																0.0										0.0										0.0
16-Nov																0.0										0.0										0.0
17-Nov	9	0	9	105	195	0	30	0	90	90	0.0	0.0E+00				9.0	30	0	1010	830	2.4	6.8E-07				9.0	25	0	680	680	2.4	6.9E-07				9.0
18-Nov	0	0	0	180	180	16	0	0	95	95	0.2	5.8E-08				0.0	0	0	840	840	0.4	1.2E-07				0.0	[illegible]	0	880	880	8.0	2.3E-06				0.0
19-Nov	0	0	0	169	169	11	0	0	95	95	0.0	0.0E+00				0.0	0	0	840	840	0.0	0.0E+00				0.0	[illegible]	0	770	770	0.0	0.0E+00				0.0
20-Nov	0	0	0	181	181	8	0	0	80	80	0.0	0.0E+00				0.0	0	0	845	845	0.2	5.0E-08				0.0	0	0	730	730	0.0	0.0E+00				0.0
21-Nov	0	0	0	150	150	11	0	0	80	80	0.0	0.0E+00				0.0	0	0	840	840	0.0	0.0E+00				0.0	0	0	685	685	0.0	0.0E+00				0.0
22-Nov																0.0										0.0										0.0
23-Nov																0.0										0.0										0.0
24-Nov	0	0	0	114	114	36	0	0	78	78	0.0	0.0E+00				0.0	0	0	820	820	0.0	0.0E+00				0.0	0	0	705	705	0.8	2.3E-07				0.0
25-Nov																0.0										0.0										0.0
26-Nov	1	0	1	110	110	4	0	0	75	76	0.0	0.0E+00				1.0	0	0	830	830	0.4	1.2E-07				1.0	0	0	705	705	0.0	0.0E+00				1.0
27-Nov	20	0	20	116	116	0	60	0	72	72	0.0	0.0E+00				20.0	60	0	920	920	3.[illegible]	1.0E-06				20.0	50	0	730	730	1.0	2.0E-07				20.0
28-Nov	8	0	8	120	120	0	20	0	70	70	0.7	4.6E-08				8.0	10	0	940	940	0.8	2.3E-07				8.0	30	0	760	760	0.8	2.3E-07				8.0
29-Nov	55	0	55	178	175	0	130	0	1000	1000	37.0	1.1E-05				55.0	120	0	970	970	1.2	3.5E-07				55.0	135	0	1100	1100	14.0	4.1E-06				55.0
30-Nov																0.0										0.0										0.0
			134			169					41.7	1.6E-06		31%	0.0	134.0					21.5	9.1E-07		18%	0.0	134.0					47.3	1.8E-06		35%	0.0	134.0

SAPPI ENSTRA
LANDFILL CAPPING FIELD TEST RESULTS

Month: Oct-97

	Precipitation			Evaporation			Cell1 Runoff		Seepage		Equiv	Hydraulic	Irrigation			Tot..
	Road	Left	Nett	Road	Left	Nett	Road	Left	Road	Left	Flow	Conduct	Road	Left	Equiv	P
Date	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	cm/s	m3	m3	mm	mm
01-Oct																0.0
02-Oct				126	260	44			830	0	0.0	0.0E+00				0.0
03-Oct				241	241	9			0	0	0.0	0.0E+00				0.0
04-Oct																0.0
05-Oct																0.0
06-Oct				218	218	23			10	10	0.4	1.2E-07				0.0
07-Oct				209	209	9			10	10	0.0	0.0E+00				0.0
08-Oct				199	199	10			15	15	0.2	5.8E-08				0.0
09-Oct	10	0	10	194	194	5	10	0	20	20	0.2	5.8E-08				10.0
10-Oct				196	190	0			20	20	0.0	0.0E+00				0.0
11-Oct																0.0
12-Oct																0.0
13-Oct	5	0	5	180	180	16			20	20	0.0	0.0E+00				5.0
14-Oct				174	174	0			20	20	0.0	0.0E+00				0.0
15-Oct	5	0	5	170	170	0			20	20	0.0	0.0E+00				5.0
16-Oct	3	0	3	178	178	0			20	20	0.0	0.0E+00				3.0
17-Oct				165	165	13			20	20	0.0	0.0E+00				0.0
18-Oct																0.0
19-Oct																0.0
20-Oct				160	160	18			20	20	0.0	0.0E+00				0.0
21-Oct				142	143	7			20	20	0.0	0.0E+00				0.0
22-Oct				140	140	3			20	20	0.0	0.0E+00				0.0
23-Oct				129	129	11			20	20	0.0	0.0E+00				0.0
24-Oct				118	118	11			20	20	0.0	0.0E+00				0.0
25-Oct																0.0
26-Oct																0.0
27-Oct	14	0	14	100	100	18	20	0	10	10	0.0	0.0E+00				14.0
28-Oct				94	94	6			10	10	0.0	0.0E+00				0.0
29-Oct				86	80	8			10	10	0.0	0.0E+00				0.0
30-Oct				75	75	11			10	10	0.0	0.0E+00				0.0
31-Oct																
			37			225					0.4	1.6E-08		1%	0.0	37.0

	Cell 2 Runoff		Seepage		Equiv	Hydraulic	Irrigation			Total
	Road	Left	Road	Left	Flow	Conduct	Road	Left	Equiv	P
Date	mm	mm	mm	mm	mm	cm/s	m3	m3	mm	mm
01-Oct										0.0
02-Oct			935	0	0.0	0.0E+00				0.0
03-Oct			10	10	0.4	1.2E-07				0.0
04-Oct										0.0
05-Oct										0.0
06-Oct			50	50	1.6	4.6E-07				0.0
07-Oct			50	50	0.0	0.0E+00				0.0
08-Oct			50	50	0.0	0.0E+00				0.0
09-Oct	40	0	55	55	0.2	5.8E-08				10.0
10-Oct			65	65	0.4	1.2E-07				0.0
11-Oct										0.0
12-Oct										0.0
13-Oct			200	200	6.4	1.6E-06				5.0
14-Oct			240	240	1.6	4.6E-07				0.0
15-Oct			285	285	1.8	5.2E-07				5.0
16-Oct	20	0	355	355	2.8	8.1E-07				3.0
17-Oct										0.0
18-Oct										0.0
19-Oct										0.0
20-Oct			380	380	1.0	2.9E-07				0.0
21-Oct			380	380	0.0	0.0E+00				0.0
22-Oct			390	390	0.4	1.2E-07				0.0
23-Oct			410	410	0.8	2.3E-07				0.0
24-Oct										0.0
25-Oct										0.0
26-Oct										0.0
27-Oct	30	0	550	550	5.8	1.6E-06				14.0
28-Oct			560	560	0.4	1.2E-07				0.0
29-Oct			565	565	0.2	5.8E-08				0.0
30-Oct			565	565	0.0	0.0E+00				0.0
31-Oct										0.0
					20.6	7.9E-07		50%	0.0	37.0

	Cell 3 Runoff		Seepage		Equiv	Hydraulic	Irrigation			Total
	Road	Left	Road	Left	Flow	Conduct	Road	Left	Equiv	P
Date	mm	mm	mm	mm	mm	cm/s	m3	m3	mm	mm
01-Oct										0.0
02-Oct			530	0	1.8	5.2E-07				0.0
03-Oct			0	0	0.0	0.0E+00				0.0
04-Oct										0.0
05-Oct										0.0
06-Oct			30	30	1.2	3.5E-07				0.0
07-Oct			30	30	0.0	0.0E+00				0.0
08-Oct			35	35	0.2	5.8E-08				0.0
09-Oct	30	0	40	40	0.2	5.8E-08				10.0
10-Oct			40	40	0.0	0.0E+00				0.0
11-Oct										0.0
12-Oct										0.0
13-Oct			40	40	0.0	0.0E+00				5.0
14-Oct			40	40	0.0	0.0E+00				0.0
15-Oct			50	50	0.4	1.2E-07				5.0
16-Oct	20	0	50	50	0.0	0.0E+00				2.0
17-Oct										0.0
18-Oct										0.0
19-Oct										0.0
20-Oct			55	55	0.2	5.8E-08				0.0
21-Oct			55	55	0.0	0.0E+00				0.0
22-Oct			70	70	0.6	1.7E-07				0.0
23-Oct			80	80	0.4	1.2E-07				0.0
24-Oct										0.0
25-Oct										0.0
26-Oct			90	90	0.8	2.3E-07				0.0
27-Oct	20	0	90	90	0.0	0.0E+00				14.0
28-Oct			90	90	0.0	0.0E+00				0.0
29-Oct			90	90	0.0	0.0E+00				0.0
30-Oct										0.0
31-Oct										0.0
					2.0	1.1E-07		8%	0.0	37.0

SAPPI ENSTRA
LANDFILL CAPPING FIELD TEST RESULTS

Month	Sep-97						Cell 1										Cell 2										Cell 3									
	Precipitation			Evaporation			Runoff		Seepage		Equiv	Hydraulic	Irrigation			Total	Runoff		Seepage		Equiv	Hydraulic	Irrigation			Total	Runoff		Seepage		Equiv	Hydraulic	Irrigation			Total
	Read	Left		Read	Left		Read	Left	Read	Left	Flow	Conduct.	Read	Left	Equiv	P	Read	Left	Read	Left	Flow	Conduct	Read	Left	Equiv	P	Read	Left	Read	Left	Flow	Conduct	Read	Left	Equiv	P
Date	mm	mm		mm	mm		mm	mm	mm	mm	mm	cm/s	m3	m3	mm	mm	mm	mm	mm	mm	mm	cm/s	m3	m3	mm	mm	mm	mm	mm	mm	mm	cm/s	m3	m3	mm	mm
01-Sep	5	0	5	115	115	5			680	680	4.0	1.5E-07	13.292	13.479	7.5	12.5			160	160	1.6	6.2E-07	13.056	13.292	9.4	14.4			250	250	0.4	1.5E-07	1[illegible].7745	13.0557	11.2	16.2
02-Sep				110	110	5																														
03-Sep				105	105	5			680	680	4.0	2.3E-06	13.479	13.701	8.9	8.9			200	200	1.6	9.3E-07	13.701	13.975	10.9	10.9			270	270	0.6	4.8E-07	13.9746	14.2162	9.7	9.7
04-Sep																																				
05-Sep				65	225	20			720	720	1.6	9.3E-07							230	230	1.2	6.9E-07	14.862	14.976		0.0			290	290	0.6	4.6E-07	14.7494	14.8616		0.0
06-Sep																																				
07-Sep																																				
08-Sep	14	0	14	224	224	1			810	810	3.6	1.4E-06				14.0	40	0	410	410	7.2	2.8E-06				14.0	40	0	380	380	3.6	1.4E-06				14.0
09-Sep	1	0	1	227	227	0			830	830	0.8	9.3E-07				1.0			460	460	2.0	2.3E-06				1.0			420	420	1.6	1.9E-06				1.0
10-Sep	2	0	2	229	229	0			870	870	1.6	1.9E-06				2.0			500	500	1.6	1.9E-06				2.0			470	470	2.0	2.3E-06				2.0
11-Sep	15	0	15	235	235	0	40	0	950	950	3.2	3.7E-06				15.0	50	0	600	600	4.0	4.6E-06				15.0	60	0	490	490	0.8	9.3E-07				15.0
12-Sep	3	0	3	237	237	0			970	0	0.8	9.3E-07				3.0			600	0	2.4	2.8E-06				3.0			670	0	6.5	8.4E-06				3.0
13-Sep																																				
14-Sep																																				
15-Sep	19	0	19	239	239	0			750	750	30.0	1.2E-05				19.0	65	0	565	565	22.2	8.8E-06				19.0	60	0	340	340	13.6	6.2E-06				19.0
16-Sep																																				
17-Sep				229	229	10			770	770	0.8	4.6E-07							650	650	3.8	2.2E-06							410	410	2.8	1.0E-06				
18-Sep	8	0	8	232	232	0			775	775	0.2	2.3E-07				8.0			695	695	1.8	2.1E-06				8.0			430	430	0.8	9.3E-07				8.0
19-Sep																																				
20-Sep																																				
21-Sep																																				
22-Sep	6	0	6	205	205	27			850	850	3.0	8.7E-07				6.0			890	890	7.8	2.3E-06				6.0			460	460	2.0	5.8E-07				6.0
23-Sep																																				
24-Sep																																				
25-Sep																																				
26-Sep				170	170	35			850	850	0.0	0.0E+00							920	920	1.2	3.5E-07				0.0			485	485	0.2	5.8E-08				0.0
27-Sep																																				
28-Sep																																				
29-Sep																																				
30-Sep																																				
			72			108					44.0	1.7E-06		50%	16.4	88.4					64.0	2.1E-06		58%	20.4	92.4					32.9	1.3E-06		35%	20.9	92.9

SAPPI ENSTRA
LANDFILL CAPPING FIELD TEST RESULTS

Month:	Aug-97						Cell1										Cell 2										Cell 3									
	Precipitation			Evaporation			Runoff		Seepage		Equiv	Hydraulic	Irrigation			Total	Runoff		Seepage		Equiv	Hydraulic	Irrigation			Total	Runoff		Seepage		Equiv	Hydraulic	Irrigation			Total
	Read	Left		Read	Left		Read	Left	Read	Left	Flow	Conduct.	Read	Left	Equiv	P	Read	Left	Read	Left	Flow	Conduct.	Read	Left	Equiv	P	Read	Left	Read	Left	Flow	Conduct.	Read	Left	Equiv	P
Date	mm	mm		mm	mm		mm	mm	mm	mm	mm	cm/s	m3	m3	mm	mm	mm	mm	mm	mm	mm	cm/s	m3	m3	mm	mm	mm	mm	mm	mm	mm	cm/s	m3	m3	mm	mm
01-Aug																																				
02-Aug																																				
03-Aug																																				
04-Aug																																				
05-Aug																																				
06-Aug				60	250	27			300	300	0.0	0.0E+00	0.3217	0.658	13.4	13.4			440	440	2.6	3.3E-07	0.656	1.0433	15.5	15.5			80	80	0.6	7.2E-08	1.0433	1.3234	11.2	11.2
07-Aug																																				
08-Aug				250	250	0																														
09-Aug																																				
10-Aug																																				
11-Aug									300	300	0.0	0.0E+00	1.9168	2.2182	12.1	12.1			440	440	0.0	0.0E+00	2.2182	2.4208	8.1	8.1			90	90	0.4	9.3E-08	2.4208	2.6213	8.0	8.1
12-Aug				220	220	30			300	300	0.0	0.0E+00	4.0328	4.183	6.0	6.0			440	440	0.0	0.0E+00	2.856	4.0328	47.1	47.1			90	90	0.0	0.0E+00	2.6218	2.856	0.4	9.
13-Aug				214	214	8			320	320	0.8	9.3E-07	4.183	4.3316	5.9	5.9			740	740	12.0	1.4E-05	4.3316	4.4837	6.1	6.1			90	90	0.0	0.0E+00	4.4837	4.6071	4.0	4.
14-Aug				210	210	4			380	380	2.4	2.0E-06	4.7308	4.8618	5.2	5.2			920	920	7.2	8.3E-06	0	0	0.0	0.0			90	90	0.0	0.0E+00	4.6074	4.7306	4.0	4.
15-Aug									400	400	0.8	9.3E-07	4.8618	5.0151	6.1	6.1			930	540	0.4	4.6E-07	0	0	0.0	0.0			90	90	0.0	0.0E+00	5.0151	5.1104	3.8	3.
16-Aug																																				
17-Aug																																				
18-Aug				190	190	20			460	460	2.4	9.3E-07	5.7012	5.8346	5.3	5.3			940	940	0.4	1.6E-07	5.6043	5.7012	3.9	3.9			100	100	0.4	1.6E-07	5.4613	5.6041	5.7	6.
19-Aug				186	186	4			460	460	0.0	0.0E+00							940	0	0.0	0.0E+00							105	0	0.2	2.3E-07				
20-Aug				180	180	6			460	460	0.0	0.0E+00	8.3436	8.4623	4.7	4.7			20	20	0.8	9.3E-07	8.4625	8.6070	5.8	5.8	15	0	0	200	0.0	0.0E+00			0.0	
21-Aug				172	172	8			460	460	0.0	0.0E+00							42	42	0.9	1.0E-06							220	220	0.8	9.3E-07				
22-Aug				165	165	7			460	460	0.0	0.0E+00	8.8339	8.9978	6.6	6.6			60	60	0.7	9.3E-07	8.6252	8.8339	8.3	8.3			220	220	0.0	0.0E+00	8.9979	9.1786	7.2	7
23-Aug																																				
24-Aug																																				
25-Aug				145	145	27			450	450	0.0	0.0E+00	9.2411	9.477	9.4	9.4			80	80	0.8	3.1E-07	9.477	9.7051	9.1	9.1			220	220	0.0	0.0E+00	9.7051	10.081	16.0	16
26-Aug				138	138	7			450	450	0.0	0.0E+00							100	100	0.8	9.3E-07							220	220	0.0	0.0E+00				
27-Aug				129	129	9			460	460	0.4	4.6E-07	10.874	10.926	12.1	12.1			110	110	0.4	4.6E-07	10.327	10.624	11.9	11.9			230	230	0.4	4.6E-07	10.0452	10.3285	11.3	11
28-Aug				125	129	4			480	480	0.8	9.3E-07							120	120	0.4	4.6E-07							240	240	0.4	4.6E-07				
29-Aug				120	120	5			480	480	0.0	0.0E+00	11.735	11.923	7.5	7.5			120	120	0.0	0.0E+00	11.921	12.123	8.1	8.1			240	240	0.0	0.0E+00	12.1231	12.3208	7.9	7
30-Aug																																				
31-Aug																																				
						164					7.6	2.8E-07		8%	94.5	94.5					27.4	1.0E-06		22%	123.0	123.0					3.2	1.2E-07		4%	89.4	89

internal
correspondence

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REF: ABK/jd/0697

DATE: 20 August, 1997

FROM: A. B. KUMALO
MILL LAB

TO: N.P. LEHOKO
R. SNYMAN

ANALYSIS OF THREE SAMPLES

	CELL 1	CELL 2	CELL 3
pH	8.60	7.66	7.92
Conductivity (µS/m)	67.4	225	143
Total Alkalinity	262.5	1303.3	844.2
Total Hardness	320	1385	646
Sulphate as SO_4	63	25	11
Chloride as Cl	60	165	110
Potassium as K	13	50	42
Sodium as Na	95	135	135
COD	16	2088	168
Nitrogen - NH_3	0.03	4.54	0.46
- NO_3	0.6	2.0	0.2
Calcium as Ca	126.6	367.3	169.6
Magnesium as Mg	27.30	113.42	84.20
Manganese as Mn	0.019	0.35	0.60
Iron as Fe	0.022	4.84	0.37
Aluminium as Al	Nil	Nil	Nil

NB:

All results expressed in ppm except for conductivity and pH.

A. B. KUMALO
SENIOR CHEMIST.

APPENDIX 5

WATER QUALITY ANALYSES ON SEEPAGE SAMPLES

Sappi Enstra Capping Results: Selected Data and Cumulative Totals

	All	Cum.	Cell1							Cell 2							Cell 3						
	Potent.	Potent.	Runoff	Cum.	Seepage	Cum.	Hydraulic	Equiv.	Cum.	Runoff	Cum.	Seepage	Cum.	Hydraulic	Equiv.	Cum.	Runoff	Cum.	Seepage	Cum.	Hydraulic	Equiv.	Cum.
	Evap	Evap	Sump	Equiv	Flow	Seep.	Conduct.	Precip.	Equiv.		Equiv	Flow	Seep.	Conduct	Precip.	Equiv.		Equiv	Flow	Seep.	Conduct.	Precip.	Equiv.
Date	mm	mm	mm	Runoff	mm	Flow	cm/s	mm	Precip.	mm	Runoff	mm	Flow	cm/s	mm	Precip.	mm	Runoff	mm	Flow	cm/s	mm	Precip.
01-Nov		932		63		315		0	676		202		394		0	675		370		174		0	641
02-Nov		932		63		315		0	676		202		394		0	675		370		174		0	641
03-Nov		932		63		315		0	676		202		394		0	675		370		174		0	641
04-Nov		932		63		315		0	676		202		394		0	675		370		174		0	641
05-Nov	13	945	0	63	0	315	0.0E+00	0	676	0	202	1	394	6.7E-06	0	675	0	370	1	175	2.3E-07	0	641
06-Nov	3	948	0	63	0	315	0.0E+00	2	678	0	202	0	395	8.1E-08	2	677	0	370	0	175	2.3E-08	2	643
07-Nov	9	957		63		315		3	681		202	1	395	1.5E-07	3	680		370	0	175	4.6E-08	3	646
08-Nov		957		63		315		0	681		202		395		0	680		370		175		0	646
09-Nov		957		63		315		0	681		202		395		0	680		370		175		0	646
10-Nov	25	982	0	63	0	315	0.0E+00	2	683	0	202	1	396	2.7E-07	2	682	0	370	0	176	1.4E-07	2	648
11-Nov	10	992	0	63	0	315	0.0E+00	0	683	0	202	0	396	5.8E-08	0	682	0	370	0	176	0.0E+00	0	648
12-Nov	3	995	0	63	0	315	0.0E+00	0	683	0	202	0	396	3.5E-08	0	682	0	370	0	176	2.3E-08	0	648
13-Nov	0	995	80	86	4	319	1.2E-06	34	717	96	229	12	409	3.6E-06	34	716	80	392	19	195	5.6E-06	34	682
14-Nov	13	1008	0	86	0	320	1.2E-07	0	717	0	229	0	409	1.2E-07	0	716	0	392	0	196	1.2E-07	0	682
15-Nov		1008		86		320		0	717		229		409		0	716		392		196		0	682
16-Nov		1008		86		320		0	717		229		409		0	716		392		196		0	682
17-Nov	8	1016	30	94	0	320	0.0E+00	9	726	30	237	2	412	6.9E-07	9	725	25	399	2	198	6.9E-07	9	691
18-Nov	15	1031	0	94	0	320	5.8E-08	0	726	0	237	0	412	1.2E-07	0	725	0	399	8	206	2.3E-06	0	691
19-Nov	11	1042	[illegible]	94	0	320	0.0E+00	0	726	0	237	0	412	0.0E+00	0	726	0	399	0	206	0.0E+00	0	691
20-Nov	8	1050	0	94	0	320	0.0E+00	0	726	0	237	0	412	5.8E-08	0	725	0	399	0	206	0.0E+00	0	691
21-Nov	11	1061	0	94	0	320	0.0E+00	0	726	0	237	0	412	0.0E+00	0	725	0	399	0	206	0.0E+00	0	691
22-Nov		1061		94		320		0	726		237		412		0	725		399		206		0	691
23-Nov		1061		94		320		0	726		237		412		0	725		399		206		0	691
24-Nov	36	1097	0	94	0	320	0.0E+00	0	726	0	237	0	412	0.0E+00	0	725	0	399	1	207	2.3E-07	0	691
25-Nov		1097		94		320		0	726		237		412		0	725		399		207		0	691
26-Nov	4	1101	0	94	0	320	0.0E+00	1	727	0	237	0	413	1.2E-07	1	726	0	399	0	207	0.0E+00	1	692
27-Nov	0	1101	60	111	0	320	0.0E+00	20	747	60	254	4	416	1.0E-06	20	746	50	413	1	208	2.9E-07	20	712
28-Nov	0	1101	20	117	0	320	4.6E-08	8	755	30	262	1	417	2.3E-07	8	754	30	422	1	209	2.3E-07	8	720
29-Nov	0	1101	130	153	37	357	1.1E-05	55	810	120	296	1	418	3.5E-07	55	809	135	460	14	223	4.1E-06	55	775
30-Nov		1101		153		357		0	810		296		418		0	809		460		223		0	775

Author: Brown, Riva Anne.
Name of thesis: Determination of the suitability of the primary and secondary sludge produced by Sappi Enstra as landfill capping material.

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