THE INFLUENCE OF GROUNDWATER CONDITIONS

ON STREAMBANK STABILITY

IN THE

WET TROPICS

Thesis submitted by

Leonard Brett SANDS BEng (Hons)

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ACKNOWLEDGEMENTS

DEDICATION

This work is dedicated to my family: - Dima (Habibti), Georgia & Fares al Fursan, for their patience, unconditional love and support.

Besos y brazos siempre.

İHasta la victoria siempre!

ABSTRACT

Streams are naturally dynamic, adjusting their form in response to changes in natural processes and human activity. Streambank mass movements (slumps) that affect human utilities such as land-use and infrastructure may occur as part of the natural stream processes, or may be accelerated by flow regulation or encroachment on the stream. Slumping commonly occurs when the subsurface water levels in the bank remain above the falling water levels in the stream. This condition is referred to as 'rapid drawdown', and typically develops when alluvial stream banks, saturated prior to or during flood inundation, are subject to a rapid recession of flood water levels. Rock revetment has been used traditionally in the treatment of bank slumps in order to surcharge the bank as well as to prevent fluvial erosion. Alternative treatments, incorporating subsurface drainage have been used successfully in north Queeensland, Australia, but more needs to be done to fully understand the attributes and mechanisms associated with slumping and to identify performance characteristics of existing drainage treatments. This study will provide practitioners with a better understanding of slumping and improved treatment methods. Subsurface water conditions affecting streambank slumping are a function of stratigraphy, local rainfall, flood infiltration, flood recession and regional water table levels. Pressure, moisture and raingauge instrumentation were installed at a streambank case study site on the Herbert River Anabranch in tropical north Queensland, to monitor subsurface water response to river flooding, site rainfall and regional water table heights. Monitoring results show bank stratigraphy and drainage treatments affect flood infiltration and regional water table inundation of the bank. Furthermore, subsurface water levels within the bank remain elevated during rapid flood recession and continue to be elevated until the regional water table has fallen. Modelling of various streambank and artificial drainage configurations has confirmed the response of subsurface water levels and seepage face progression to flood recession, has demonstrated that subsurface drainage lowers elevated water levels, and identified slumping thresholds associated with typical flood recession rates and bank permeabilities. This research provides an understanding of the attributes and mechanisms of slumping in tropical streams, illustrates the performance of subsurface drainage, and will lead to techniques for better management of slump failures.

LIST OF PUBLICATIONS

Kapitzke, I.R., Pearson, R.G., Smithers, S.G., Crees, M.R., Sands, L.B., (1998). **Streambank Stabilisation and Rehabilitation – Guidelines for North Queensland Streams**, Land & Water Resources Research & Development Corporation and James Cook University.

Sands, L. B. and Kapitzke, I. R. (1998). **Monitoring & Modelling Streambank Subsurface Water Conditions in North Queensland, Australia**, Water Resources Engineering 98: Proceedings of the International Water Resources Engineering Conference, ASCE, Vol. 2, pp. 1882-1887.

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Chapter 1

INTRODUCTION

Streams are naturally dynamic, complex and unstable entities that adjust their form in response to changes in natural processes and human activity. Streams commonly present problems when the stream's natural physical and ecological functions conflict with human use. Streambank mass movements can occur in healthy streams as part of the natural processes, but occur more often and with greater impact when natural processes are accelerated through human overuse (encroachment, catchment landuse). Streambank mass movements exhibit socio-economic problems to stakeholders through loss of land, production and infrastructure and physically to natural stream processes through catastrophic changes in channel planform or regime and degradation of riparian margins. The occurrence of streambank mass movements depends upon the interaction of various factors, but relates principally to gravitational stresses exceeding the strength of soils and/or rock materials, resulting in a new slope configuration that can be maintained by remoulded insitu strengths. The most common cause of streambank mass movement is that by infiltration of water into the slope, which has the effect of both reducing the shear strength of the soil and increasing the gravitational loading on the slope. Streambank mass movements can occur as a result of active streamflow erosion undercutting the toe of a bank triggering the collapse of the upper bank and leading to further collapse once a new cycle of erosion has removed material deposited at the toe.

1.1   STREAMBANK MASS MOVEMENTS

Streambank mass movements (slumping) are site specific events due to the human impacts, local geologic conditions, geotechnical processes and hydraulic interactions involving both groundwater flow and water flowing in the stream. They commonly occur when the subsurface water levels in the bank remain above the falling water levels in the stream. This condition is referred to as 'rapid drawdown', and typically develops when streambanks that have been saturated prior to or during flood inundation are subject to a rapid recession of flood water levels. Depending on the site and insitu conditions, the resulting mode of mass movement may be translational, rotational, retrogressive movements, or tunnelling erosion.

1.2   RESEARCH PROBLEM

The identification and understanding of what causes streambank mass movements has so-far relied on speculation derived from trial and error remediation. The impacts associated with slumping, the inability to predict the location and timing and a lack of understanding of slump attributes has fuelled the need to investigate them in detail. The research problem investigates the attributes of slumping and the effects of subsurface water on streambank mass movements, in relation to flooding, local rainfall and regional groundwater conditions.

1.3   METHODOLOGY

The research problem has been investigated using field monitoring, numerical seepage modelling and rudimentary stability calculations to develop a better understanding of streambank mass movements. Field monitoring investigates streambank subsurface water movements associated with flooding, local rainfall and regional groundwater conditions. This aims to confirm the existence of rapid drawdown conditions whilst identifying its principal saturating mechanism and the effects of subsurface drainage configurations, such as stratigraphy and stabilisation treatments. Numerical seepage modelling investigates subsurface water movements in response to flood hydrograph characteristics such as duration, and rates of rising and falling water levels, using a typical streambank configuration, various soil permeabilities and three drainage configurations. The results from modelling aim to determine the likelihood of flooding saturating a streambank and identify characteristic variations in subsurface water profiles in response to variations in streambank drainage configurations, soil permeabilities and flood hydrograph characteristics. Using the results from the modelling, rudimentary stability calculations have been used to determine stability thresholds for variations in drainage configuration, soil permeability and flood hydrograph characteristics.

1.4   OUTCOMES

The purpose of identifying the factors that influence streambank mass movements is to provide practitioners with a means of identifying the potential of developing streambank mass movements. This in turn allows for choice of the appropriate streambank stabilisation treatment.

Subsurface monitoring results have identified significant subsurface recharge sources which influence rapid drawdown conditions and ultimately stability. Observation of

subsurface water levels has identified the extent of bank saturation during flood events and the influence of stratigraphy on bank saturation.

Modelling results have identified specific performance attributes exhibited by the two subsurface drainage configurations during the flood rise and the flood recession stages. Stability thresholds for each stage of the flood rise, recession and the three bank configurations have been identified, and a correlation between flood recession drawdown ratio and Factor of Safety and minimum soil cohesion to maintain FOS greater than unity have been developed for the three streambank configurations.

Chapter 2

LITERATURE REVIEW

Streambank instabilities (bank scour and slumping) affecting adjoining land and infrastructure are among the most prominent and spectacular problems experienced in streams. Utilities such as buildings, bridge foundations and agricultural land, threatened by bank erosion or bank slumping, have traditionally received high priority remedial action, and will continue to be the focus for streambank stabilisation activities. To deal satisfactorily with these bank instabilities, the practitioner must know the type of instability and mode of failure, and understand the factors that contribute to the instability. This study examines slumping and its interrelationship with subsurface water conditions.

Approaches to understanding subsurface water conditions through monitoring and modelling are investigated. This will provide up to date background information on tools for monitoring and modelling subsurface water conditions associated with streambank instabilities.

2.1   STREAMBANK INSTABILITIES

Instabilities can be broadly classified as either fluvial erosion (scouring) or mass movement (slumping). Fluvial erosion is the direct removal of material by water (rainfall or streamflow) and is closely linked to the processes of sediment transport and deposition. Mass movement is the bulk movement of material, generally as a result of decreased material strength, or increased loading on the stream bank. Fluvial erosion may occur in any of the three zones of the stream cross section: bank, overbank and bed, whereas mass movement is restricted to the stream bank. Mass movement and fluvial erosion in the bank zone are commonly interrelated, as illustrated in Figure 2.1. For example, the slumped material that is deposited at the toe of the bank following mass failure may be removed by scour, potentially leading to further slumping failure. Similarly, scour of material from the toe of the bank by fluvial erosion undermines the upper bank material, which may then fail by slumping, prior to removal by further fluvial erosion.

Mass movements in streambanks can occur in various shapes, sizes and combinations but the influence of water is the major contributing cause. It is widely accepted that the influence of water in a slope decreases stability by:

- increasing the bulk weight of soil that exists in the saturated zone;
- decreasing the apparent cohesion exhibited by unsaturated soils;
- decreasing shear resistance exhibited by soils along the failure surface;
- Increasing seepage pressures which promote failure.

Removal of groundwater reverses these factors and thus improves stability.

Furthermore, streambank mass movements are typically site-specific events caused by localised bank conditions such as groundwater movements, bank configuration and soil properties, and human impacts such as encroachment and clearing of the riparian margin. Groundwater related streambank mass movements commonly occur when the subsurface water levels in the bank remain above the falling water levels in the stream. This condition is referred to as 'rapid drawdown', and typically develops when streambanks that have been saturated prior to or during flood inundation are then subject to a rapid recession of flood water levels.
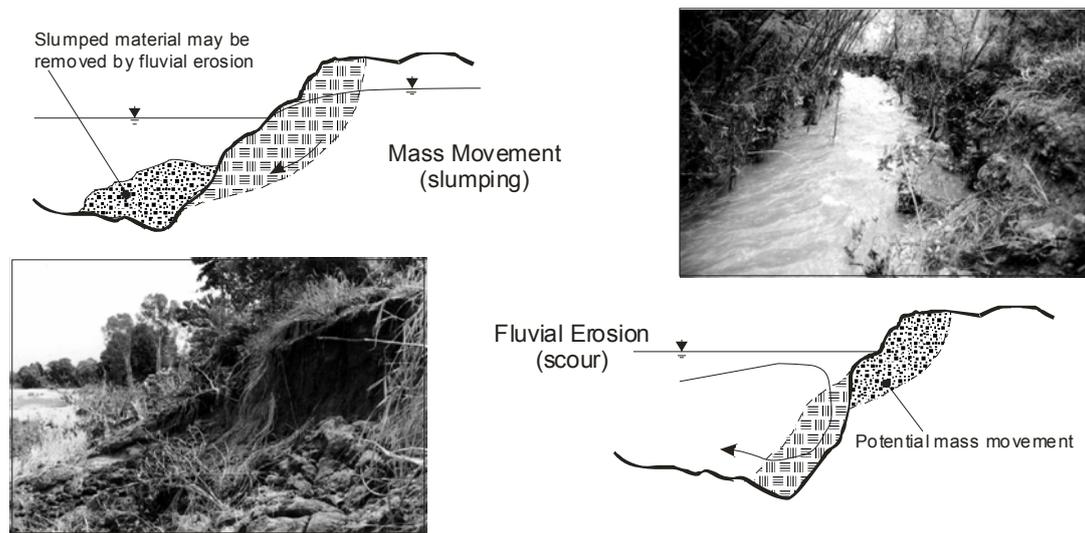
Figure 2.1   Interrelation of mass movement and fluvial bank erosion

2.2   TYPES OF MASS MOVEMENT

According to Varnes (1978) streambank mass movements are a subdivision of slides and flows. In the case of slides, shear failure propagates movement of an intact mass, whereas with flows, failure also propagates from a localised area but opposite in direction to the downward movement. Slide subtypes are classed as rotational and translational and the flow subtype is classed as a retrogressive flow slide. These and an additional type, known as tunnelling erosion, have been described by Eckersley (1995) and Hemphill and Bramley (1989) as slope failure modes possible for alluvial streambanks. Tunnelling erosion will be discussed later, but it is likely that it falls into the category of flows.

Practitioners frequently observe streambank slumping occurring during or immediately after flood recession. This is caused by elevated subsurface water levels, as described above, with the resultant mode of movement dependent on factors such as bank stratigraphy, soil properties and the presence of any existing failure surfaces.

Adapted from work by Varnes (1978) and Eckersley (1995), the basic mechanisms of the four alluvial streambank mass movements are described below.

2.3   FACTORS THAT INFLUENCE MASS MOVEMENT

Seldom, if ever, can a mass movement be attributed to a single definite cause. However, according to Varnes (1978) failure can be as a result of a) the factors that contribute to changes in shear stress and b) the factors that contribute to changes in shear strength. For example, the influence of water on a slope may contribute to both an increase in stress and a decrease in strength. Although water may achieve both of these and is associated with most streambank instabilities, it is useful to identify additional factors which also influence mass movement.

The factors suggested by Varnes (1978) are generic examples which cover conditions beyond to which streambanks are exposed. Therefore, greater context can be gained by modifying the factors suggested by Varnes (1978) to those relating to stream banks. Table 2.1 lists these factors and their major attributes according to their role of either changing shear stresses or shear strengths.
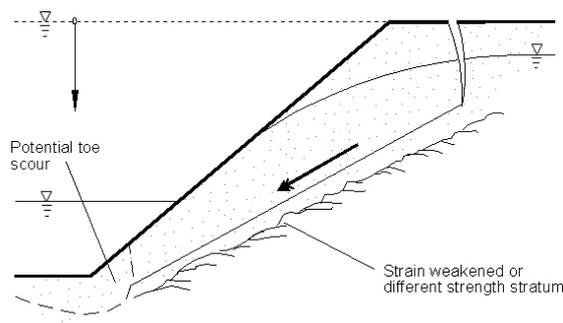
Figure 2.2   Translational slope failure mechanism

Translational movements occur where the failure surface is influenced by an adjacent stratum of significantly different strength, or where significant strain has developed a weakened surface. These types of failures usually occur along a failure surface that is typically planar, sometimes roughly parallel to the slope, and at a relatively shallow depth. Movement occurs soon after a flood has receded, sometimes leaving the distinctive failure surface intact. Compound failures are similar, where the failure surface is defined by curved and planar sections of significantly different strength materials.
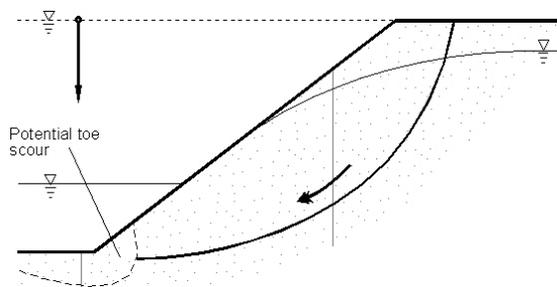
Figure 2.3   Rotational (shallow & deep seated) slope failure mechanism

Rotational bank movements characteristically occur in homogeneous cohesive soils. The failure surface follows a near circular arc that typically passes through a region near the toe of the bank. In deep-seated failures, which commonly occur in cohesive materials, the volume of material involved is relatively large, while in soils with little cohesion, movements are shallower and involve less material (slumping). The mass of moving material rotates during the process, with subsidence near the top of the bank and bulging up near the toe. Non-circular failure surfaces are associated with non-homogeneous soil conditions that have variable strength properties. As for translational slides, this failure mode often occurs immediately after or during flood recession.
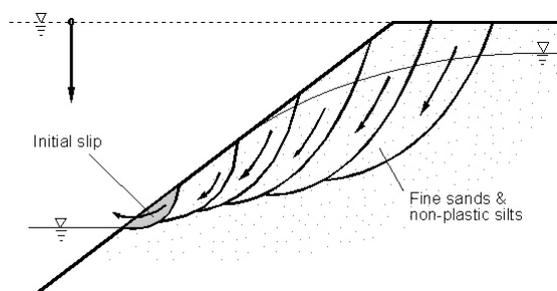
Figure 2.4   Retrogressive slope failure mechanism

Retrogressive bank movement is a variation of shallow rotational failure which can be observed in fine sands and low cohesion silts. As illustrated, the retrogressive failure starts with an initial small rotational failure in the region of the seepage face. This oversteepens the adjacent bank, which then initiates another rotational failure, and so on. This sequence continues until a lower, stable slope is achieved, or until the soil above the most recent slip has sufficient strength/cohesion to inhibit further failure. This mechanism provides one explanation why apparently deep-seated failures have

developed in slopes that otherwise would appear too flat to be unstable.
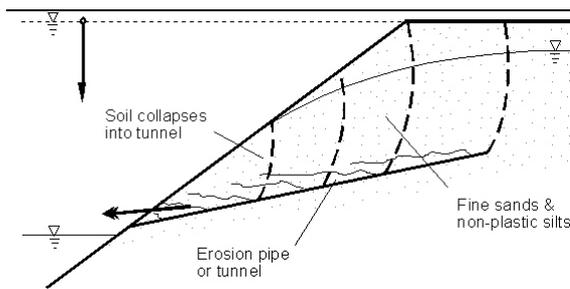
Figure 2.5   Tunnelling Erosion slope failure mechanism

Although tunnelling erosion (piping) is different from the typical mass movements, the processes are closely related and prerequisite conditions are much the same as for retrogressive movements. Movement is initiated when seepage flows wash individual particles from the seepage face, thus causing the seepage face to retreat into the bank, forming a tunnel into which the overlying material eventually collapses. Since the results are similar to retrogressive instabilities it may be difficult to distinguish between the two types unless the process is actually observed, or unless the final condition of the slope preserves part of the earlier tunnel structure. Soils that are susceptible to this type of instability are fine sands, silty sands and non-plastic silts, which have low saturated cohesion and permeabilities that allow significant rapid drawdown conditions to develop or facilitate drainage of a regional groundwater table.

Table 2.1   Factors that influence streambank mass movements

Factor	Major Attribute
Changes in Shear Strength	
Stratigraphy	homogeneity, layering, weak zones
Soil properties	Cohesion, apparent cohesion, internal friction, permeability
Vegetation	restraint, interception, transpiration
Changes in Shear Stress	
Bank configuration	Slope angle, height, tension cracks
Recharge and subsurface drainage	Stratigraphy, configuration, flow capacity
Streamflow	height, duration, rate of recession
Surface drainage	ponded water
Surcharge	infrastructure, machinery
Stream modifications	revetment, subsurface drainage

The factors listed in Table 2.1 are represented in Figure 2.6 and outlined in the following discussion. The effect of many factors is obvious and therefore needs no

lengthy discussion, whereas the remaining factors have been discussed with reference to literature.
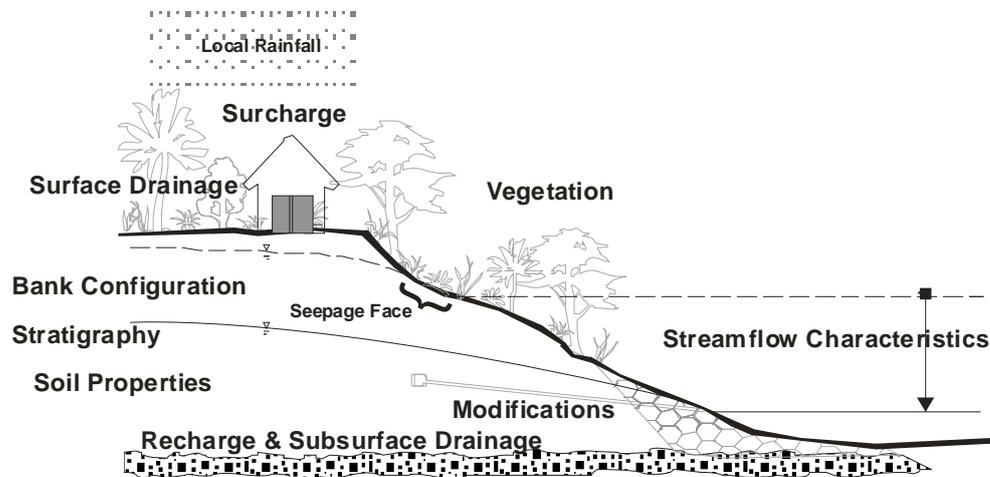
Figure 2.6   Factors that influence mass movement

2.3.1 FACTORS THAT CHANGE SHEAR STRENGTH

Strength factors are intrinsic properties of the stream bank which can be described (somewhat simplistically) by terms such as cohesion and the angle of shearing resistance. These intrinsic properties vary according to the type of material, configuration, and the type of reaction a material has when exposed to drying, weathering or inundation.

Stratigraphy

Stratigraphy is the subsurface soil profile represented in terms layers. A log of subsurface conditions from excavation and/or boreholes is most often used to determine the parameters used in stability analysis or engineering design. Engineering soil classification systems identify layers according to material properties such as grain size, cohesion, colour and wetting characteristics. Preliminary classification of materials is typically performed in the field using visual and rudimentary soil testing methods. Subsequent laboratory testing of samples obtained in the field are performed for classification and strength evaluation purposes.

Stream bed and bank materials are typically fine sedimentary soils developed from the weathering of parent rocks. Residual soils are also observed on stream bed and banks, but at greater depth than sedimentary soils. Often residual soils are observed as a weathered layer of rock typically comprising coarse grain sizes and are less vulnerable to failures.

The sedimentary soils are typically alluvial materials eroded from surrounding elevated land forms. The process of alluvial deposition develops a high degree of longitudinal and lateral variability in bank materials, and in some cases vertical demarcations between materials have been observed (Eckersley 1995; and Hamel 1983). These characteristics are due to the marked episodic changes in sediment regime and channel movement.

Streambanks can be generically classified as cohesive, non-cohesive or layered, i.e. a combination of both. Cohesive banks typically comprise clays that are considered resistant to undercutting but can experience deep seated rotational mass movements. Whereas non-cohesive banks typically comprise silty sands and sands and are more vulnerable to failure modes, such as shallow mass movements and undercutting. Layered streambanks with a combination of cohesive and non-cohesive soils are just as likely to experience typical failure modes, however, the mode would depend on the subsurface layer configuration and their strength. For example, permeable layers in layered banks can act as effective drainage layers, layers of alternating strength can facilitate conditions suitable for translational sliding, and layers with high cohesion can confine the propagation of failure surfaces to zones with lower cohesion.

Soil Properties

Many soil properties play a role in streambank stability. However, for the purpose of analysing stability during rapid drawdown conditions, the following properties are considered significant, namely:

- Soil strength, represented by internal friction and cohesion; and
- Soil permeability and specific weight of soils;

Structural strength of soils is primarily a function of its shear strength, where shear strength refers to the soils ability to resist sliding along internal surfaces within a mass of soil. There are two components of shear strength; *cohesion and friction.* Cohesion is derived from interparticulate forces, Van de Waals, which draws particles together. Cohesion is sensitive to water and porewater chemistry where it is developed quickly to a maximum under small strains and falls away with strain increase. Friction is derived from intergranular contact and is not developed to its maximum value until significant amounts of strain have occurred. Fine grained soils such as clays and silts exhibit "cohesive" dominant properties with course grained soils such as sands and gravels

exhibiting only frictional properties "non-cohesive". Silts have slightly larger particles finer than clays and exhibit little or no interparticulate forces. However, when unsaturated a secondary "apparent cohesion" is often observed as a result of capillary suction. This "apparent cohesion" significantly reduced upon saturation, which is a soil characteristic often influencing streambank stability during rapid drawdown conditions.

The permeability of streambank soils is very important in controlling the extent of soil saturation, and subsequent increase in soil weight, during high flood levels and heavy rainfall. Low permeability soils will take longer to saturate compared to higher permeability soils, which will saturate earlier and provide paths to saturate soils of lower permeability.

The mode of mass movement will depend on the properties of the soil. For example non-cohesive material, such as clean dry sand, is stable regardless of the streambank height, provided the streambank slope angle is equal to less than the angle of internal friction for the sand in a loose state (Terzaghi et al.1996). Whereas cohesive material can withstand a vertical slope at least for short time, provided the height of the slope is somewhat less than four times the ratio of undrained shear strength to total unit weight (Terzaghi et al.1996).

Anecdotal evidence in North Queensland has indicated that the effect of "apparent cohesion" on particular soils has been developed vertical streambank slopes, observed at the Burdekin River Swindley and Herbert River Anabranch Bube sites, failing soon after flood recession.

Vegetation

Riparian vegetation contributes towards stability by mechanically increasing the strength of the soil. The improvement in strength is observed as an increase in apparent cohesion of up to 13 kPa, with little effect on the frictional properties of the soil, (Gray et al. 1980). Further benefits to stability are found as interception and transpiration by vegetation maintains drier soils and delays the onset of soil saturation. Documented evidence on the cause-and-effect relationship between vegetation removal and mass movement has shown that there are 'significant increases in both frequency of slides and size of area affected by slides after logging', (Gray et al. 1980). Accordingly soils permeated by woody roots increase the degree safety required to maintain stability. Furthermore vegetation tends to be self repairing and regenerating, thus allowing adaptation to unfavourable stress conditions. On the other hand,

vegetation also has certain limitations. According to Gray (1976) vegetation is not effective in arresting deep seated mass movements, it is intolerant of certain land uses, susceptible to blight and drought, unable to resist severe scour or wave action, slow to become established, and strong winds can overturn trees (although only aged or diseased trees are normally affected).

The effect of vegetation in improving stability varies between species. For example, root systems range from very fine fibrous systems to systems dominated by a vertical taproot. Individual species of riparian vegetation vary in their rooting behaviour, but soil type and the groundwater regime also strongly influence root development. Roots in well-drained soils extend deeper and exploit a much larger volume of soil than do roots in wet soils, while areas that have a high groundwater table or a layer of densely-compacted soil will force roots to spread laterally. The majority of roots are usually found within 300-400 mm depth in herbaceous vegetation, and up to 3 m deep in vegetation dominated by trees and shrubs (Gray 1976). Although much greater rooting depths are often quoted, the proportion of roots at greater depths is usually very small.

Much of the riparian vegetation along streams in North Queensland has been cleared to the very edge of the bank for the cultivation of sugarcane. Some intact vegetation remains on the slopes of the banks, but much of this is substantially degraded by infestation with exotic grasses which are typically shallow-rooted, and provide an inferior contribution to bank stability compared to that of the often deep-rooted native riverine trees and shrubs. Vegetation surveys undertaken by Skull (1995) in the lower Herbert River have identified native riparian species that may exhibit useful stabilisation characteristics.

2.3.2 FACTORS THAT CHANGE SHEAR STRESS

The second factor to influence stability of stream banks and slopes in general are increases to the stress state. Theoretically total stresses would be increased through bank saturation, which would increase pore pressure and material weight, and effective stresses increased through additional surface loading and/or an increase in localised or average slope angle.

Bank Configuration

Increase in effective stresses as a result of localised or general changes in bank configuration are simplistically represented by the height and angle of a slope. Likely examples of changes in bank configuration may occur as a result of cracks during

drying and wetting periods, or undercutting of a slope, during fast stream flows or manual excavation.

Streambank properties that combined to oppose slope instability include intrinsic material strength and the presence of any binding agents, such as vegetation or man made stabilisation measures.

Cohesive bank materials, such as clays, which exhibit measurable tensile strengths even when wet, are more likely to maintain steeper slope angles, whereas non-cohesive materials, such as sands, can usually support only shallow slope angles. Without any binding agents non-cohesive banks can only maintain stable angles of up to 40°, but in cases with restricted slope heights the presence of an effective agent and cohesive materials, angles close to vertical are often maintained. Some non-cohesive materials, such as silty sands, exhibit a measurable "apparent cohesion" when unsaturated. Apparent cohesion in some cases can maintain moist stable slope angles of greater than 45°. However, upon saturation of the material the apparent cohesion is lost and slope collapses to more stable angles of 40° or less.

Cracks are sometimes found on the surface or tops of banks. They develop as a result of shrinkage caused by soil drying (common in cohesive materials) and/or movement, and can extend up to several metres below the surface. Their effect on stability can be to shorten the failure surface and so decrease the shear resistance, harbour runoff water thus and impose additional hydrostatic loads on the bank, and allow more rapid ingress of water to the profile with subsequent decreases in strength and increases in loading.

Recharge & Subsurface Drainage

Streambank mass movements commonly occur when the subsurface water levels in the bank remain above the falling water levels in the stream. This condition is referred to as 'rapid drawdown', and typically develops when streambanks that have been saturated prior to or during flood rise are then subject to a rapid recession of flood water levels.

Saturation of streambanks by recharge from subsurface water has been identified by many authors (Hamel 1983; Kusakabe et al. 1987; Hooke 1979; and Attanayake 1994). Saturation can occur when water infiltrates from the ground surface as a result of direct rainfall runoff, irrigation, overbank flooding, and flood inundation from the stream.

Recharge typically causes the water table to rise, but the extent of the rise depends on the drainage ability of the bank materials and on the loss of water through evaporation and extraction by vegetation (transpiration). Although evaporation and transpiration generally become negligible at depth and are usually secondary to the drainage characteristics in governing the position of the subsurface water conditions during recharge.

The drainage characteristics of a streambank are governed by the permeability of the material, and the configuration of any drainage pathways through the bank. Streambanks that have drainage layers hydraulically connected with a shallow water table typically discharge water from the slope of the bank. This has been observed at the Burdekin River, Swindley and Herbert River Anabranch, Bube sites, (Eckersley 1993, 1995), where significant discharge from the streambank continues well after rainfall has abated and floodwaters have receded. Ullrich (1986) also observed this characteristic at numerous sites. This characteristic can improve slope stability by lowering the subsurface water levels and faster removal of water from the bank. However, drainage layers can raise subsurface water levels sooner during stream flooding by facilitating faster infiltration of water within the bank. Thus developing greater saturation of the bank and possibly increasing the likelihood of rapid drawdown conditions.

Streamflow

Wolfe et al. (1991), Kusakabe et al. (1987), and Hooke (1979) have observed streambank mass movements associated with certain streamflow characteristics. These streamflow characteristics include the overall height of flooding, flood duration, and the rate of flood recession. Rapid drawdown conditions, for example, are typically associated with high streamflow levels held steady for relatively long durations, followed by a relatively rapid fall in stream flood level. Each stage of the flood directly contributes to the development of rapid drawdown conditions. For example high stream flood levels maintained over long period facilitate the saturation of bank materials. The subsequent rapid fall in high stream flood levels results in subsurface water levels in the stream bank remaining above the stream flood levels. These conditions regularly develop mass movements in fine grained silty sand materials. These materials are particularly susceptible to rapid drawdown conditions due to their ability to sufficiently saturate during high stream flood levels, but remain relatively saturated as stream flood levels rapidly fall. These soil conditions and streamflow characteristics are often found in the Burdekin and Herbert Rivers of North Queensland

where mass movements attributed to rapid drawdown conditions occur regularly (Eckersley 1995).

Surface Drainage

Poor surface drainage can allow water to pond on top of a streambank and in turn influence slope instability. Slope instability influences attributed by ponded water include surcharging, and surface infiltration developing saturated subsurface conditions. Furthermore, subsequent to prolonged high stream flood levels, subsurface conditions are likely to be saturated with ponded water, through infiltration, would maintaining the saturated subsurface conditions. This scenario would promote rapid drawdown conditions to develop during falling stream flood levels.

Surcharge

Surcharge in the context of streambank stability involves any additional load on the bank and their subsequent increase to bank shear stress. Typical streambank surcharges that contribute to instability include structures with shallow foundations; such as buildings, pump stations and stabilisation treatments. Machinery, ponded water and large trees can also contribute to a shear stress increase. Instabilities due to surcharges are most likely where streambank material properties are susceptible to mass movements.

Modern engineered structures are typically designed with criteria that address the likelihood of mass movement, whereas machinery and ponded water can unintentionally initiate mass movement. Consideration should be given to providing surface drainage to minimise excessive ponding, and to limit machinery access whilst bank materials are saturated.

Large trees can present a surcharge instability problem when they are undermined or they are dying and are no longer capable of providing any soil binding effect. The widely believed view that surcharge from the weight of (healthy and stable) trees adversely influences bank stability is not generally correct. According to Gray et al. (1980) the surcharge from trees can actually improve bank stability.

Stream Modifications

Modifications in this context are any stabilisation treatments that have affected bank stability. In some cases stabilisation treatments that have been put in place have actually exacerbated mass movement problems. This usually occurs when poor site investigations fail to identify the potential failure mechanism and its cause, or design

abridgments to a treatment have been implemented with ignorance of potential problems. Poor stabilisation treatments typically fail as a result of interaction with water either flowing in the stream or building up within the bank. An example of a poor stabilisation treatment is where an impermeable structure such as rigid revetment can inhibit subsurface water from draining out of the bank and so develop rapid drawdown conditions.

2.4   METHODS OF STABILITY ANALYSIS

Many different analytical techniques exist which may be used by engineers when assessing whether a particular natural or man-made slope is stable. Numerous geotechnical texts cover the topic of slope stability and provide up to date methods for analysis. Furthermore, specialised computer programs exist which reduce the tedious effort required and allow the user to examine various stability aspects with limited cost in time. This section briefly reviews methods suitable for analysing streambank stability.

By far the most popular methods of slope stability analysis in use today are the limiting equilibrium methods. Of these methods the method of slices used with a circular failure surface is the most popular. However, the method of analysis chosen will broadly follow the observed (or possible) mode of failure, although for some modes there are a large number of different alternatives from which to choose. Furthermore, the stress history and drainage conditions of the soil as well as whether movement will occur along an existing failure surface are important considerations which determine the parameters used in the analysis.

Failure will occur whenever the shear stress imposed on a bank, exceeds the shear strength (resistance) of the bank. Methods of stability analysis use the term 'factor of safety' (F) to indicate whether failure is likely to occur. The factor of safety may be defined as the ratio of shear strength (resistance) over shear stress, where a value of 1.0 indicates failure is probable, while increasing values indicate progressively increasing stability (Thorne et al. 1981). Determination of the minimum factor of safety in slope stability analyses is often an iterative process that evaluates other possible failure surfaces. For this reason the application of computer simulations is often employed.

2.4.1 RAPID DRAWDOWN STABILITY CHARTS

Stability charts were produced, before the advent of readily available computers, to enable the quick assessment of simple slopes, thus avoiding lengthy hand calculations. They are now used for preliminary analyses to allow quick assessment prior to committing a simulation.

Taylor (1948) and Bishop and Morgenstern (1960) developed charts for total stress and effective stress analyses respectively and provided Morgenstern (1963) with a basis to develop charts for homogeneous slopes which took account of rapid drawdown conditions. Although the charts by Morgenstern (1963) are limited to simple slopes and carry many assumptions regarding pore pressure distributions, problem geometry and the unit weight of the embankment material, they provide an excellent basis for rudimentary analysis of streambank stability.

2.4.2 INFINITE SLOPE ANALYSIS

This method of analysis is appropriately used when the potential failure surface is shallow, compared to its length, and parallel to the surface. The slope of infinite length can be analysed in an undrained or drained condition with seepage parallel to the surface by using the same geometry shown in Figure 2.7 below.
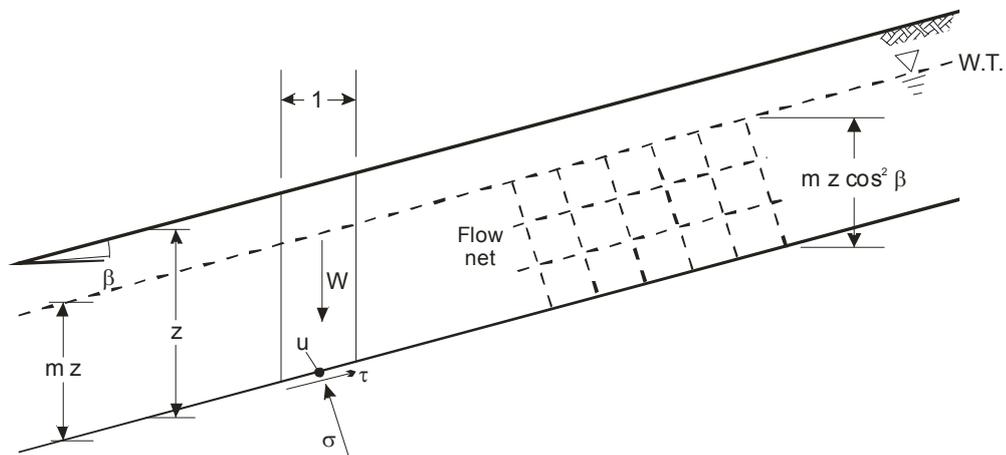
Figure 2.7   Infinite slope analysis (Craig 1992)

According to Craig (1992) the factor of safety is given by

$$F = \frac{c'}{z\gamma_{sat}} \frac{1}{\cos\beta\sin\beta} + \frac{\tan\phi'}{\tan\beta}\left(1 - \frac{r_u}{\cos^2\beta}\right)$$

...........(2.1)

when seepage flow is parallel to the surface r_u is given by

$$r_u = \frac{mz \cos^2 \beta \gamma_w}{z \gamma_{sat}}$$

………(2.2)

In the case when seepage flow is horizontal r_u is given by Bolton (1979)

$$r_u = \frac{m \gamma_w}{\gamma_{sat}}$$

………(2.3)

2.4.3   TRANSLATIONAL SLIDE ANALYSIS (WEDGE)

Translational sliding analysis is used when banks are very steep and the failure surface influenced by an adjacent stratum of significantly different strength, or where significant strain has developed a weakened surface. Translational sliding in soil slopes rarely occurs as a single wedge but often occurs as a two or three wedge slide. The factor of safety for the two wedge system is conveniently derived graphically using the method of force polygons. The reader is referred to Lambe and Whitman (1969) for further discussion of this method.

2.4.4   ROTATIONAL SLIDE ANALYSIS

Rotational slide analyses consider the stability of circular arcs by dividing the segment into a series of slices. This method is often referred to as the Method of Slices, as shown in Figure 2.8. This type of slide may be a base, toe or slope failure depending on where the failure arc intersects the ground surface. The method is readily adapted to include variations in the soil parameters and pore water pressures from one slice to another. There are several forms of solving this method (Bishop, Janbu and Morgenstern and Price), however, the Bishop routine is less conservative than others and is suitable for solution by computer.
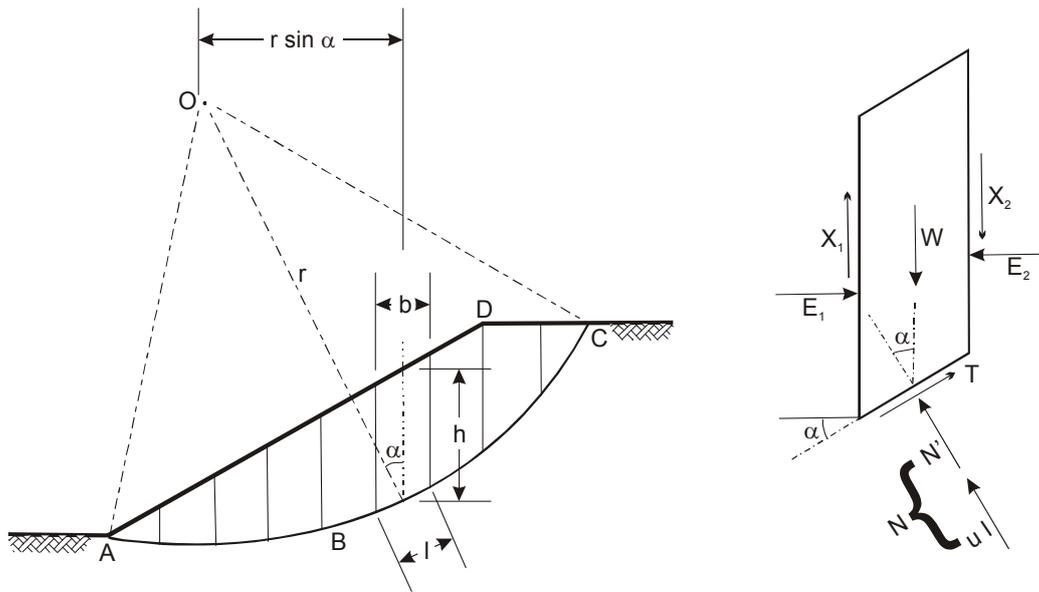
Figure 2.8   Rotational Slide analysis by Method of Slices (Craig 1992)

According to Craig (1992) the factor of safety is given by

$$F = \frac{1}{\sum W \sin \alpha} \sum \left[\{c'b + W(1 - r_u)\tan \phi'\} \frac{\sec \alpha}{1 + \left(\frac{\tan \alpha \tan \phi'}{F}\right)} \right] \qquad (2.4)$$

Where the pore water pressure can be related to the total 'fill pressure' for any slice by means of the dimensionless *pore pressure ratio*, defined as (Craig 1992)

$$r_u = \frac{u}{W/b} \qquad (2.5)$$

2.5   METHODS OF STABILISATION

The various streambank stabilisation treatments can be grouped within a number of stream management strategies. This section describes and illustrates the range of stream management strategies and identifies the treatments suitable for addressing streambank instabilities.   A wide range of literature is available which cover every aspect of stream management, however the reader is referred to Kapitzke et al. (1998) for a background to the stream management approach in North Queensland.

2.5.1   STREAM MANAGEMENT STRATEGIES

Stream management strategies group streambank stabilisation treatments according to similar stabilisation applications. The range of stream management strategies and treatments identified by Kapitzke et al. (1998) are shown in Table 2.2. These stream management strategies typically represent site or reach specific treatments that directly influence the nature of a stream. However strategies such as Catchment Management indirectly influence a stream and are typically implemented at a much larger scale.

Table 2.2   Stream management strategies and their treatments (adapted from Kapitzke et al. 1998)

Strategy	Description	Treatments
Alignment Training	Selectively reinstate sections of an eroded stream to a more stable alignment by providing restraint and facilitating deposition of sediment within the eroded section.	Rock Groynes, Pile Groynes, Retards, Embayments, Fences, Vanes, Bendway Weirs
Bank Protection and Stabilisation	Direct protection of streambank surfaces against fluvial erosion or minimise the risk of streambank mass movements by reducing the stresses imposed on a bank.	Rock Revetment, Rigid Revetment, Bank Battering & Berms, Subsurface Drainage, Bank Chute, Spillway, Rock Mattresses & Gabions, Retaining Wall or Bulkhead, Soil Stabilisation, Geosynthetics
Grade Control	Direct protection of streambed surfaces with revetment structures that dissipate streamflow energy and prevent upstream changes to the bed slope by obstructing an upstream moving headcut.	Bed Chute, Drop Structure
Channel Modifications	Alteration to stream configuration by removing stream blockages such as snags and built up bed material, or adjusting the planform of the stream through cutoffs and channelisation.	Clearing & Desnagging, Channel Excavation, Channelisation, Cutoffs
Native Vegetation	Revegetation of the riparian and instream sections of a stream with native plant species, aiming to improve streambank stability, erosion resistance and internal bank drainage, and improve aesthetic, habitat and conservation values.	
Non Intervention	No stabilisation action taken when apparent stream management problem is merely a natural process that is not affecting human utility	Relocation, Monitoring
Catchment Management	An approach to deal with the causes of the problems in the catchment before they contribute to problems in the stream	Landuse Change, Soil Conservation, Water Conservation, Pollution Control, Stock Control, Revegetation, Rehabilitation
Stream Restoration	Restoring a stream to a naturally-functioning system	Physical Form, Hydro Pattern, Instream Habitat, Riparian Habitat Water Quality

Strategy	Description	Treatments
Flood Mitigation	Addresses flooding issues in urban and agricultural areas	Retention Dams, Diversions, Levees, Floodgates, Rezoning, Flood Proofing, Insurance

Multi-objective projects typically integrate several stream management strategies to effectively address the needs of specific objectives such as physical performance, risk of failure, ecological characteristics and socio-economic factors. For example, Vegetation is often integrated with most strategies to address part of the ecological and failure objectives by improving habitat and stability, and Bank Protection and Stabilisation is typically integrated with Alignment Training to address failure and socio-economic objectives by minimising the effects of fluvial erosion and maintenance costs.

As shown in Table 2.2 the control of streambank instabilities falls within the strategy of Bank Protection and Stabilisation and is only one of many issues covered in stream management.

2.5.2   BANK PROTECTION AND STABILISATION

Bank protection treatments are permeable or impermeable structures that are used as adjuncts to most other treatments and are typically implemented where significant fluvial erosion is likely to occur or has occurred in the past. Bank stabilisation treatments are typically site specific structures that are implemented as a result of significant mass movement that if left untreated could continue and endanger infrastructure.

Appropriate stabilisation treatments include:

- rock revetment
- rigid revetment
- bank battering and berms, and
- subsurface drainage.

Rock revetment and rigid revetment are indirect stabilisation treatments that are frequently used where fluvial erosion commonly undermines the toe of a bank. Bank battering and berms and subsurface drainage are bank stabilisation treatments, where battering and berms are typically used to reinstate a stable profile for revetment works, and subsurface drainage is used in streambanks that suffer from rapid drawdown conditions and is also used in-conjunction with revetment works.

Bank stabilisation treatments are typically perceived as hard engineering solutions because of their inability to satisfy environmental and some human utility objectives such as recreation and conservation values. However, the hard engineering solutions are reliable and can be modified and integrated with more environmentally considerate treatments such as revegetation. An example of this approach can be found at Bube on the Herbert River Anabranch in North Queensland where a section of cleared bank that slumped 1994 has been successfully stabilised with vegetation on the upper bank, subsurface longitudinal drainage near the toe and a relatively thin layer of rock revetment confined to a region around the toe. The layer of rock confined to the toe and the vegetation on the upper bank offer improved habitat characteristics compared to the traditional hard engineering approach of applying rock to the entire bank, and the subsurface drainage as well as the vegetation improve the drainage ability of the bank.

2.6   SURFACE AND SUBSURFACE WATER MONITORING

Water monitoring is by no means a new field. Hydrogeologists, engineers and other professionals have been monitoring surface and subsurface water for decades. The basic and highly reliable methods used in the past are still used today. These methods have been complemented by the advancement in technology which attempt to remove part of the human element.

Surface and subsurface water conditions can be measured in many ways, but for the purpose of this study, the methods of surface and subsurface water level, soil moisture content and rainfall measurements will be reviewed to provide the reader an appropriate background. This can also be achieved by reading an excellent account of monitoring technology by Morrison (1983). Firstly, the approach to monitoring in terms of design and implementation needs introducing.

The first task in designing a subsurface water monitoring system is the selection of the target monitoring zones. These zones are logically selected based on the likelihood that changes in condition will be immediately detected and representative of the surrounding condition. For example, fluctuations in aquifer recharge/ discharge are best measured by placement of sensors within the saturated zone of the aquifer. Furthermore the effects of rainfall infiltration and streamflow inundation are best monitored near the surface, close to the source.

2.6.1   SOIL MOISTURE MEASUREMENT

Field determination of soil moisture can be achieved with minimal cost using an electromagnetic technique. This technique relies upon changes in a soil's electrical properties with changes in moisture content. These changes are measured as a frequency dependent dielectric response using soil moisture blocks. These blocks essentially measure the electrical resistance between two electrodes embedded in a porous material.

Soil moisture blocks are generally individually calibrated in moisture adjusted soil which is typical of in situ conditions. Alternatively, calibration can be done in situ with gravimetric verification. Although this method is inexpensive and simple, sensitivity problems can occur as a result of changes in salt concentration, temperature, sensor integrity, proper soil contact, and pronounced hysteresis during calibration and field use (Morrison 1983).

2.6.2   SOIL PORE PRESSURE MEASUREMENT

Measurement of soil pore pressures within the saturated zone is typically achieved using electric, hydraulic or pneumatic piezometers. The electric piezometers are moderately expensive and typically use a strain gauge diffused on a diaphragm to measure changes in pore pressure. The tension applied to the strain gauge is usually a differential pressure measured between the atmosphere on one side and the water pressure on the other side.

Piezometers are also individually calibrated using an adjustable water column. This method is usually reliable and easily operated, however, problems occur with clogging of inlet tube, fluctuations in temperature, and corrosion of the strain gauge (Morrison 1983).

2.6.3   RAINFALL MEASUREMENT

Methods of rainfall measurement, either electronic or manual, have been widely documented and used for monitoring purposes. The most common and reliable method of electronically measuring rainfall is by use of a monitor sensor tipping bucket rain gauge coupled with a data logger. This method is moderately expensive and can provide ongoing calibration and accuracy checks by measuring the accumulated capture of tipped water.

A relatively new and inexpensive method of rainfall measurement uses a precision dripper to accurately measure rainfall. This method adapts the standard manual raingauge with a sediment settling vessel attached to an electronic counting chamber. This device works by passing rain water through the settling vessel and overflowing into the counting chamber which has two electrodes that send an electrical pulse when water passes between them. The rate at which pulses are sent is proportional to the rate of rainfall (Dataflow Manual 1998).

It appears that regardless of the raingauge type, they all suffer from effects such as wind shear, rain shadowing, and insect infestation.

2.7   SUBSURFACE WATER MODELLING

Numerical methods are among the most powerful tools available for solving problems in subsurface hydrology. Methods range from one to three dimensional finite difference and finite element analyses that yield approximate values of the unknowns at discrete numbers of points. They have been developed because of our need to solve complicated natural hydrologic problems without resorting to simplifications that are mathematically necessary but physically unrealistic. Furthermore, with the aid of the digital computer, these methods have greatly enhanced our capabilities of achieving meaningful solutions to subsurface flow problems

Physical methods were used to solve problems in subsurface hydrology prior to the advent of readily useable numerical methods. The physical methods either relied on full scale monitoring or scaled models to provide fruitful information. These methods often required considerable time and resources to achieve results with limited transferability. Monitoring is still used today but for the purpose of confirming physical processes and as part of determining the geometry and hydraulic characteristics used in numerical applications. Physical modelling has seen limited use since the introduction of computer based numerical methods.

This section describes some of the physical and numerical methods used to solve subsurface flow problems, in particular those for unsaturated/saturated flow.

2.7.1   PHYSICAL MODELLING

The geotechnical centrifuge modelling technique was first used to solve slope stability problems where loading is predominantly due to the ground self-weight (Schofield

1980). Common practice uses a test system attached to a counterbalanced arm that rotates at a desired speed to induce a centrifugal acceleration. The test system is generally a box that houses the test embankment, and has transparent sides so that visual observation can be made whilst rotating.

Seepage flow and streambank failure due to piping have also been modelled using this method Padfield and Schofield 1983; Sutherland and Rechard 1984; and Kusakabe et al. 1987. This requires a controlled supply of water which enters the test system through porous plates. Examination of slope stability involving seepage flow requires a test embankment scaled to Reynolds similitude and appropriately accelerated to ensure Darcian flow. The influence of viscous and seepage forces in this case makes a single scale factor difficult to achieve, consequently partial similitude must be adopted.

2.7.2 FINITE DIFFERENCE MODELLING

L. F. Richardson introduced in 1910 the method of Finite Differences as a method of calculating the solution of partial differential equations. Although Richardson did not explicitly examine transient problems in subsurface flow, he did outline a method of solving the diffusion equation. The solution to the diffusion equation was later applied to steady state subsurface flow problems and incorporated into computer programs for expedient use. The finite difference approach replaces derivates at a point by ratios of the changes in appropriate variables over a small but finite interval. Thus an approximation is made at a finite number of points.

Fluid flow through a saturated soil mass can be described using Darcy's law. Fluid flow through an unsaturated soil mass can be equally described by this law by making the coefficient of permeability a function of matrix suction within the soil, (Richards 1931). This formulation is referred to as Richards equation, and assumes that Darcy's law holds for unsaturated systems. This has been proven to be valid under most conditions of soil water flow, provided the soil can be treated as a continuum. Richard's equation is presented below assuming that gas pressure in the soil is always atmospheric and that the soil has a rigid structure.

$$\frac{\delta\theta}{\delta t} = \frac{\delta}{\delta x} K\left(\frac{\delta\psi}{\delta x} + \frac{\delta z}{\delta x}\right) + s \qquad \qquad \ldots\ldots\ldots(2.6)$$

As available computing power has increased, the numerical solution of the general Richards equation has become feasible. This has facilitated wide use of finite difference and finite element techniques for solving subsurface flow problems. However, numerical problems have been encountered in efficiently solving Richards equation under certain conditions, especially saturated conditions and situations of steep moisture content gradient. Ross (1990a) details a computer model called SWIM that efficiently overcomes most of the problems encountered when solving Richards equation.

SWIM simulates one-dimensional water infiltration and movement in soils using the finite difference method. SWIM allows for runoff, surface storage, surface conductance, and evapotranspiration from up to four different types of vegetation to be included in the analysis, and it allows soil properties to be varied with depth to realistically model actual profiles. SWIM has been used extensively by the CSIRO and in studies at JCU and has proven to be reliable and accurate, although it has limited application due to its one dimensional analysis. This study uses SWIM to calibrate and validate the two dimensional model used to assess streambank subsurface water conditions. The hydraulic conductivity model and numerical methods used in SWIM can be referenced in Ross (1990a and 1990b).

2.7.3   FINITE ELEMENT MODELLING

The finite element method is a versatile numerical method that has been used to solve problems of engineering and mathematical physics. The finite element method was first applied in the 1940s in the field of structural engineering and in the late 1960s in non-structural engineering applications, such as fluid flow and heat conduction. Further extension of the method was made possible by the adaptation of weighted residuals method (Galerkin), which allows the finite element method to be applied directly to any differential equation.

In general, the finite element method models a body as an assemblage of small parts (elements). Each element has properties that emulate in-situ characteristics, and is of simple geometry making it much easier to analyse than the body itself. The body has boundary conditions such as water levels, impermeable surfaces, and flows that emulate the external or internal conditions which force movement. The finite element solution is gained with simultaneously solving linear algebraic equations that have been formulated for each element.

Lam et al. (1987) proposed a two dimensional finite element model to simulate transient seepage for complex groundwater flow systems. The model theory is based on Richards equation (Fredlund 1981) and allows for flow in both saturated and unsaturated zones. A model, called TSEEP, developed at the Centre for Geotechnical Research, Sydney University, by NP Balaam and JR Brooker is based on the work by Lam et al. (1987). TSEEP is used in this study to investigate streambank subsurface water conditions during flood rise and recession.   TSEEP utilises the following governing partial differential flow equation derived on the basis of unsaturated flow theory (Lam et. al 1987).

$$\frac{\delta}{\delta x}\left(k_{xx}\frac{\delta h}{\delta x}+k_{xy}\frac{\delta h}{\delta y}\right)+\frac{\delta}{\delta y}\left(k_{yx}\frac{\delta h}{\delta x}+k_{yy}\frac{\delta h}{\delta y}\right)=\rho_w gm_2^w\frac{\delta h}{\delta t} \qquad \ldots\ldots\ldots\ldots(2.7)$$

where: $k_{xx}=k_1\cos^2\alpha+k_2\sin^2\alpha$,

$k_{yy}=k_1\sin^2\alpha+k_2\cos^2\alpha$ and $k_{xy}=k_{yx}=\left(k_1-k_2\right)$

TSEEP performs a two dimensional finite element seepage analysis of a plane axi-symmetric section through which steady state seepage is occurring. It can accommodate complex geometries with arbitrary degrees of heterogeneity and anisotropy for different soils. Constant head, flux or impermeable boundary conditions as well as sinks and sources can be used to investigate steady state seepage conditions. Enhanced usage of the model can extend its ability to incorporate dynamic boundary conditions, which are useful for emulating transient processes such as a rising or falling river level.

TSEEP defines the relationship between soil-moisture retention and pore pressure by using line segment slopes to interpolate between values of pore pressure, which have been gained from soil suction tests. The hydraulic conductivity soil-water-pressure relationship used in TSEEP is a simple exponential model developed by Gardner (1958). The relationship between *K (hydraulic conductivity)* and *h* the soil water potential is shown in equation (2.8).

$$K\left(h\right)=K_s\exp^{\left(-b|h|\right)} \qquad \ldots\ldots\ldots\ldots(2.8)$$

K_s is the saturated hydraulic conductivity and b is a soil parameter that represents the relative rate of decrease of K with decreasing h. The b parameter is related to the width of the soil pore size distribution, (Russo 1988), and typically ranges between 2 for sands and 25 for clays. Owing to its simplicity, this model may describe the hydraulic conductivity relationship for different soil, but for a limited range of soil water potentials. The reader is referred to Russo (1988) for a useful comparison of the models proposed by Gardner (1958), Brooks and Corey (1964) and van Genuchten (1980).

2.8   SOIL TESTING METHODS

Soil hydraulic properties are required in the computer modelling stage of this study where deterministic models of the physical process of infiltration will use parameters that are based on measurable soil hydraulic properties. The properties that need to be determined are the saturated hydraulic conductivity and the parameters that describe the soil moisture retention relationship.

2.8.1   SOIL SATURATED HYDRAULIC CONDUCTIVITY MEASUREMENT

The saturated hydraulic conductivity can be measured in the laboratory or insitu below the water table or above the water table. Laboratory measurement of saturated hydraulic conductivity is standard practice and has become widely documented. Laboratory measurement can be made using either falling head, (Head 1988) or constant head (Wallace 1974) apparatus for fine and coarse grained materials respectively. The use and reliability of an insitu method for measurement above a water table, the well (borehole) permeameter method, has been widely reported by Talsma and Hallam (1980), Stephens and Neuman (1982), Reynolds and Elrick (1983), Reynolds et al. (1985), Talsma (1987), and Stephens et al. (1987).

Falling and constant permeability test methods

The rate of flow under laminar flow conditions through a unit cross sectional are of porous medium under unit hydraulic gradient is defined as coefficient of permeability. The falling head method of determining permeability is used for soil with low discharge (relatively fine grained material), where as the constant head permeability test is used for coarse-grained soils with a reasonable discharge in a given time. The principle behind the tests is Darcy's law for laminar flow.

The coefficient of permeability for a falling head test is given by:

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

……………………………………(2.9)

Where:

K_s = saturated hydraulic conductivity (cm s^{-1})

a = cross-sectional area of standpipe (cm^2)

L = Length of specimen (cm)

A = Cross-sectional area of specimen in cm^2

t = elapsed time increment (s)

h_1 = height of water at beginning of time increment (cm)

h_2 = height of water at the end of time increment (cm)

The coefficient of permeability for a constant head test is given by:

$$K_s = \frac{qL}{Ah}$$

…………………………………(2.10)

Where:

K_s = saturated hydraulic conductivity (cm s^{-1})

q = discharge (cm^3 s^{-1})

L = Length of specimen (cm)

A = Cross-sectional area of specimen in cm^2

H = Constant head causing flow (cm)

Insitu permeability test method

The borehole permeameter uses a sealed reservoir and a Mariotte tube to maintain a constant head of water in the bottom of the test borehole. The saturated hydraulic conductivity of the material surrounding the wetted depth of the borehole can be calculated from the flow rate required to maintain the constant depth using the equation from Talsma and Hallam (1980).

$$K_s = Q \frac{\{\sinh^{-1}(H/r) - 1\}}{2\pi H^2}$$

....(2.11)

where:

K_s = saturated hydraulic conductivity (m s^{-1})

Q = flow rate required to maintain a constant head in the borehole (m^3 s^{-1})

r = borehole radius (m)

H = wetted depth of borehole (m)

Because this test relies on the flow of water from the borehole to the soil matrix, the ability of the test to accurately measure the hydraulic conductivity of the material depends heavily on the condition of the borehole surface. If there is a significant amount of smearing of the surface during the drilling operation, the test will show conductivities lower than actual. The test is also susceptible to clogging of the pores of the surface which also causes lower values to be calculated. To address the smearing problem as much as possible, the sides of the wetted borehole surface should be scrubbed with a wire brush prior to testing. To reduce the potential for clogging, the borehole should be carefully filled and permeameter placed in the borehole so as to minimise the disturbance of soil.

2.8.2   SOIL MOISTURE RETENTION MEASUREMENT

The relationship between soil water content and the energy status of the soil water can be determined in the laboratory using undisturbed soil cores from the field. The CSIRO at the Davies laboratory readily measure the soil water potential relationship using the hanging water column method. Undisturbed field cores, covered at one end with filter paper and nylon mesh, are placed on a ceramic plate with a hanging water column applying suction. Suctions of 0, 10, 30, 50 and 100 cm are usually applied to cores at weekly intervals to equilibrate measurements. After each interval the core is removed, weighed then replaced on the plate, until after the final suction the bulk density of the soil is determined. From these measurements the volumetric water contents can be determined at each suction stage. Soil water retention relationships can then be obtained to provide parameters useful for modelling unsaturated soil-water behaviour. Section 2.7.3 discusses the different retention models used to numerically characterise the soil-water relationship. When applying a numerical retention model it is appropriate to graph the soil-water retention laboratory test results with plots of the numerical model, thus identifying model parameters which best emulate the soil conditions.

2.9   SOIL WATER CHARACTERISTIC CURVE

The soil water characteristic curve, also referred to as the soil moisture retention curve, depicts the relationship between soil water content and soil water pressure potential. This relationship generally depends on the soil's particle size distribution. In general, sands and gravels lose water very readily upon drainage, thereby increasing the leaching potential, while loams and clays lose much less water upon drainage. In a given soil, this relationship varies, depending on whether the soil is wetting or drying. This discrepancy is referred to as hysteresis. Water content at a given pressure is usually different for a wetting soil than when that soil is drying. This is due mainly to air entrapped in larger pore segments between constrictions.

The measurements of the unsaturated permeability of soil also yield the water-retention relation (water content as a function of matric pressure). At each step in the measurement of the unsaturated permeability and after steady flow has been established, the equilibrium matric pressure in addition to the water content of the sample. This gives a triplet of numbers such that after the set of measurements is complete, one has data for the soil moisture retention relationship.

2.10   SUMMARY

There has been a lack of integrated solutions in the evaluation of streambank instabilities related to stream level rapid drawdown (slumping) to provide a more economical and sustainable solution to failures. The evaluation of streambank slumping has been an "art" of accurately identifying the problem and its appropriate solution. The impacts associated with slumping, the inability to predict the location and timing and a lack of understanding of slump attributes has fuelled the need to investigate them in detail.

A thorough review of literature on streambank failure mechanisms and evaluation of various techniques to model, measure and test have been presented. These techniques allow for the meaningful prediction of the strength and behaviour of soils subject to saturated streambank loading conditions. A review of the groundwater movements and stability modelling of streambanks was covered.

Chapter 3

HERBERT RIVER ANABRANCH BUBE SITE

Streambank slumping has long frustrated the Herbert River Improvement Trust and riparian landholders on the Lower Herbert River. Anecdotal evidence and investigations have identified that slumps predominantly occur in the Lower Herbert River and are typically associated with bank seepage. Treatment of slumps has so far relied on trial and error remediation without a full understanding of the slumping attributes or treatment performance.

This section describes the physiography and human-use characteristics of the Herbert Basin and examines slumping attributes within the lower Herbert River. A case study site is described and its site monitoring program which investigates treatment performance and subsurface water characteristics introduced.

3.1 LOWER HERBERT RIVER

The Herbert River is one of the major tropical river systems along the coast of north-eastern Queensland. It originates in the Wild River near the Wet Tropics town of Herberton on the Atherton Tableland, and follows a course through the Dry Tropics to its debouche near the southern Wet Tropics town of Halifax, refer to Figure 3.1. With a course of over 350 km the Herbert River together with its tributaries and distributaries drains a diverse catchment area of approximately 10,100 km^2.

The Lower Herbert River floodplain downstream of the southern Wet Tropics town of Abergowrie, is a low gradient area that is bounded in the north by the Cardwell Range and the Seaview Range in the west and south, as shown in Figure 3.2. Kapitzke et. al. 1995 geomorphically classified the Herbert River floodplain as a relatively stable environment, in which little change in the configuration of the channel is expected if no significant changes in the catchment occur.

The local climate is tropical, which is characterised by warm humid summers (December to April) and mild dry winters. This seasonal variation facilitates a marked variability in streamflow which peaks during the summer months with monsoonal and

cyclonic activity. The summer period produces high intensity, long duration rainfalls with maximum values of 3,500 mm along the top of the Cardwell Range.

Surface soils that occur on channel benches and levees along the lower Herbert River are typically highly productive *"brown earth with a dark and brown clay loam fine sandy to silty clay loam"*, as described by Wilson & Baker (1990). This soil is referred to as *Macnade* or *Herbert* and forms part of a shallow unconfined and very permeable aquifer referred to as *S4* in Cox's 1979 thesis. The aquifer has a fluctuating water table and is recharged by summer rainfalls once every 6 years in 7 years, (Cox 1979).

Vegetation and agricultural utility in the coastal plain are closely related to the rainfall, soil types and particularly the drainage attributes of those soils. For this reason, the rainforest communities that contribute to the stability of the rich well drained alluvial stream bank soils have been progressively cleared for agricultural uses since settlement. These areas have been subsequently infested with exotic species.

Various flood damage and river management studies undertaken for the trust have reported on the occurrence of bank instabilities in the lower Herbert River. Kapitzke et al. (1995) pursued a research program to examine the causes and attributes of slumping and investigated alternative innovative methods of treatment of slump failures.

3.2 ANABRANCH BUBE SITE

The Bube site is located in the lower Herbert River floodplain on an anabranch connecting the Herbert and Seymour rivers, refer to Figure 3.2 and Figure 3.3. The townships of Halifax and Macnade are located approximately 4 and 2 kilometers east (downstream) of the Bube site respectively.

The Herbert River Anabranch Bube site was identified by the Herbert River Improvement Trust (HRIT) and Kapitzke et al. 1995 as a significant slump site and warranted further investigation to examine the attributes of the slumping failure and to assess the reasons for its occurrence. The studies undertaken at Bube were performed as a collaborative research program between the HRIT and James Cook University of North Queensland.

Slumping at Bube occurred during the February 1994 flood as a result of Cyclone Sadie which maintained a bankfull flood able to inundate the banks for several days.

The saturation of the bank from flood waters as well as runoff and groundwater weakened and increased the bulk mass of the bank material.   This state when unsupported by the flood waters which are receding greater than the permeability of the bank is known as Rapid Drawdown. A state of rapid drawdown was achieved within the river banks at Bube and consequently resulted as intermittent slump failures over an approximate bank length of 300 m (Kapitzke et al. 1995). The failed bank section was confined to a zone of degraded riparian vegetation comprising shallow rooted exotics unable to contribute to bank stability, (Kapitzke et al. 1995). The failure was in the form of single slips, probably rotational, within the upper bank and comprised predominantly cohesive soil (low and medium plasticity sandy clay), Kapitzke et al. 1995.
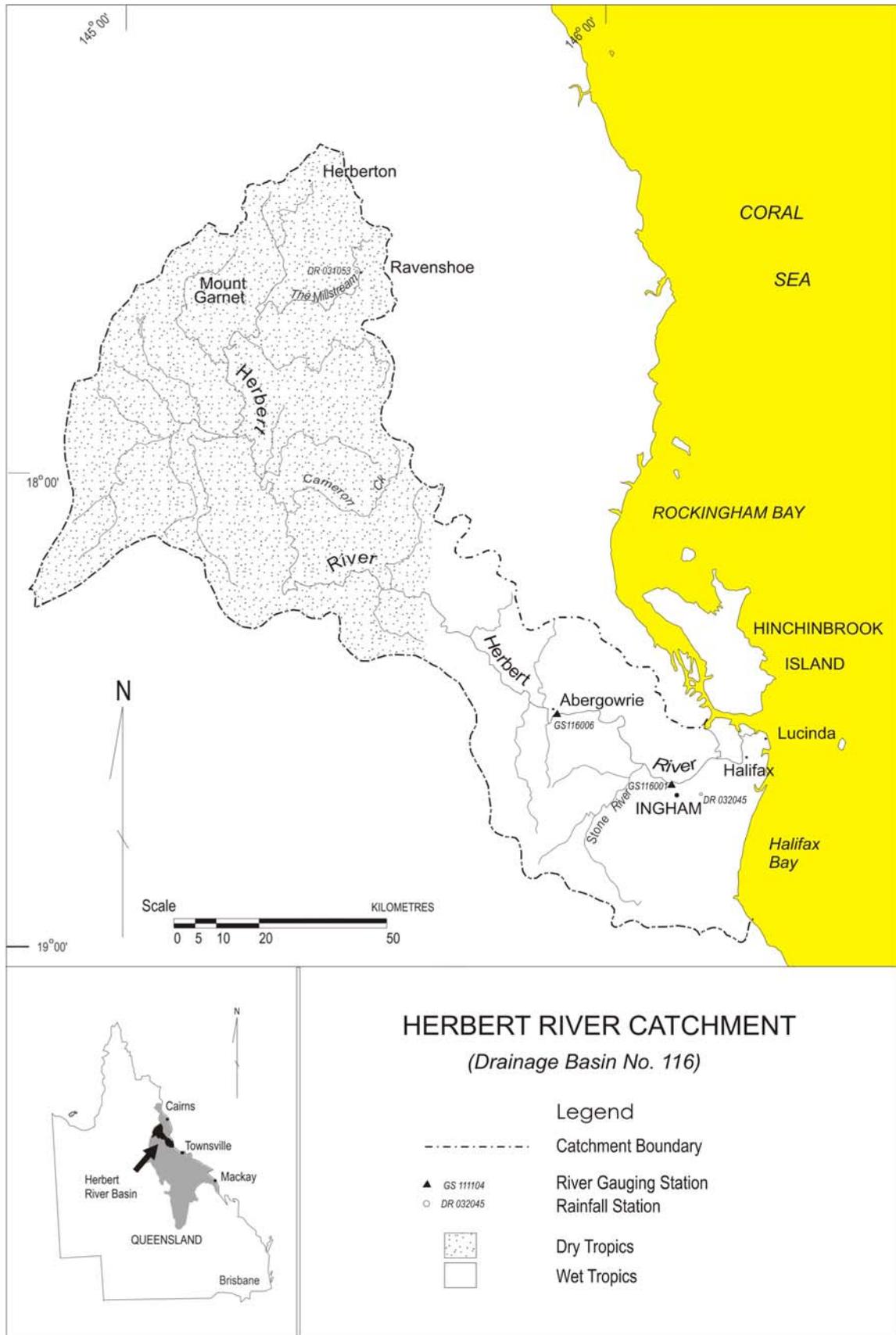
Figure 3.1   Herbert River catchment map

3.3   LOWER HERBERT RIVER BANK INSTABILITIES

Mass movement and fluvial erosion both occur in the lower Herbert River as separate or as interrelated instabilities. For example, the slumped material that is deposited at the toe of the bank following mass movement may be removed by scour, potentially leading to further slumping failure. Similarly, scour of material from the toe of the bank by fluvial erosion undermines the upper bank material, which may then fail by slumping, prior to removal by further fluvial erosion. For this reason the type of bank instability is misconstrued or generically categorised as erosion, without distinguishing the type.

Information on slumping in the lower Herbert River has been obtained from reports to the trust describing historical flood damage. These references are not comprehensive, but provide an overview of common bank instability types and an indication of their attributes. Although a clear indication of their cause is not provided, these references confirm significant historic instabilities and provide a basis for identifying the influence of factors, such as rainfall, streamflow and bank condition, on slumping in the lower Herbert River.

Kapitzke et al. (1995) provides a list of recent bank slump sites compiled from an incomplete data base of problem sites visited by trust officers. Consultant reports provide a description and the general extent of instabilities which occurred prior to their investigations. Table 3.1 gives a list of events compiled from these references, and indicates the location, extent, timing and source with any miscellaneous comments. . Streambank slump sites indicated in Table 3.1 are also shown in Figure 3.2.
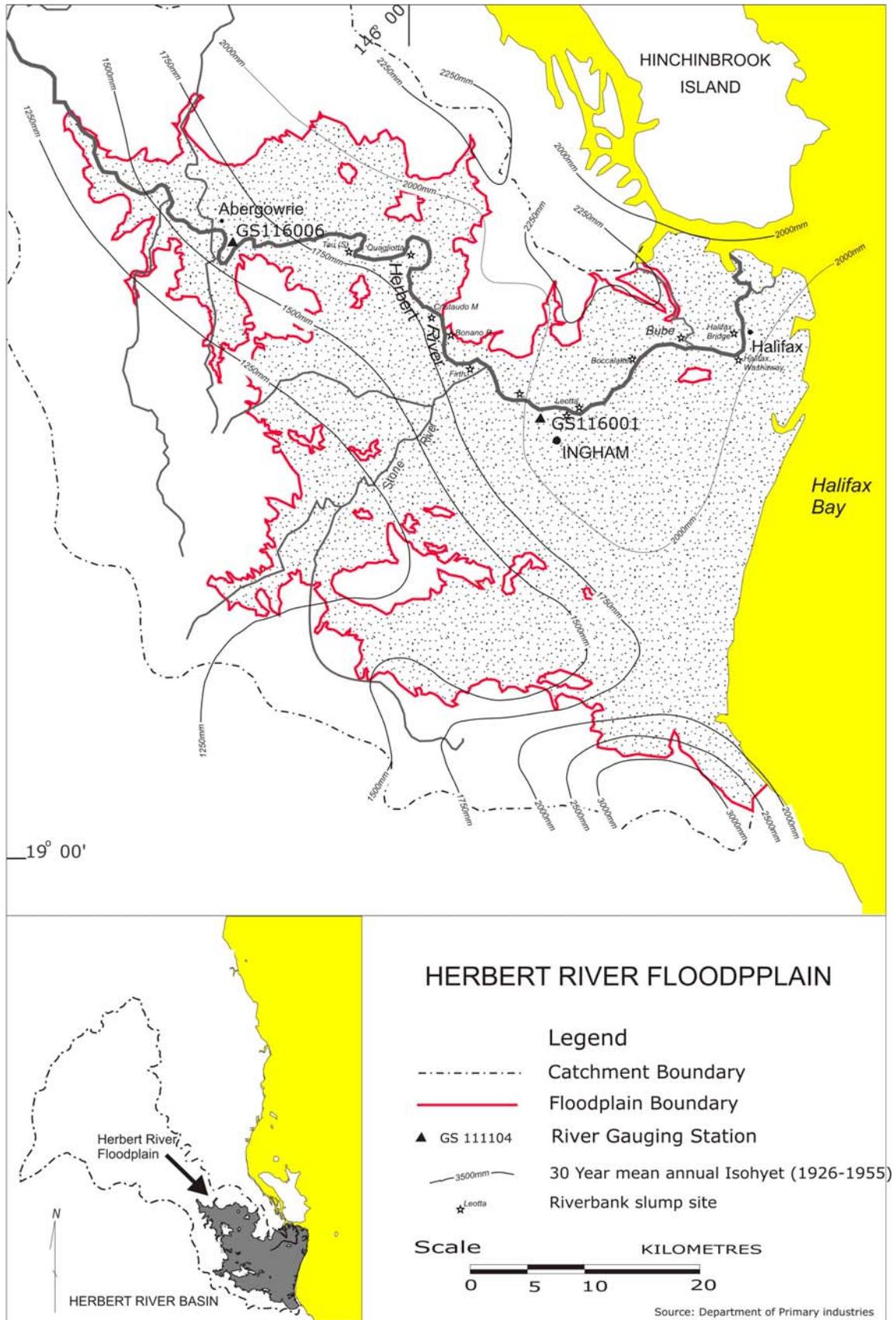
Figure 3.2   **Herbert River floodplain map**

Table 3.1   Bank Slump Sites

Site/Section	Date	Source	Comments (attributes, remedial work, *flooding category*)
Carr P(Marini)	early 1960s	1	minor work continuing, *minor*
lower Herbert River	Mar 1967	3	slumping failure of steep banks along straight sections, *major*
Renaudo	1967	1	fluvial erosion on major bend, slump failure to upper bank, *major*
Halifax Washaway	1967	1	fluvial erosion on major bend, rock spillway, revegetation, *major*
Anabranch Bridge	1967, 1991, 1994	1	1992 - rock revetment, revegetation, fluvial erosion on major bend, *major, moderate, minor*
Halifax Bridge	1967 ?	1	1993 - rock revetment, *major*
Firth	late 1960s, early 1970s	1	fluvial erosion on major bend, slump failure to upper bank
			rock revetment, island removal from channel, *minor*
Renaudo, Firth	Mar 1977	2	slumping induced by groundwater seepage, *major*
lower Herbert River	1993	4	extensive slumping, threat to some assets, *moderate*
Cristaudo M	early 1980s	1	rock revetment, *minor*
Cavallaro	before 1986	1	rock revetment, *minor*
Boccalatte	mid 1980s	1	1992 - rock revetment, JCU monitoring site, *major*
Russo J	1990	1	moderate
Bonano R	1990/1991	1	moderate
Morselli D	1990/1991	1	moderate
Elortegui J	1991, 1995	1	slump failure to upper bank, *moderate, minor*
Tua (Lann)	1991	1	minor
Tua (Sheahan)	1991	1	minor
Leotta	1991	1	1992 - rock revetment, *minor*
Crisafulli	1993	1	minor
Covell	1994	1	1994- revegetation, *minor*
Bube, Anabranch	**1994**	**1**	**1994 - rock revetment, revegetation**
Quagliotta	1994	1	slump failure to upper bank, *minor*
lower Herbert River	to date	5	slumping common at bank seeps and on bends
References	1 Kapitzke et al. (1995) 2 Cameron McNamara (1980)		
	3 Gutteridge Haskins & Davey (1967) 4 Ian Drummond & Associates (1993)		
	5 Dept. Primary Industries (1995a)		

The record of slumping in Table 3.1 is not necessarily complete and there is probably a bias towards the number and significance of slumps recorded during the 90's. For example, Kapitzke et al. (1995) noted that the March 1977 flood was one of the largest on record for the Herbert River, although significant bank slumping is said to have occurred, there is little documented information to confirm this. Also, because fluvial erosion and slumping can be interrelated, subjective bank instability observations are often made misconstruing the principal mode.

Geotechnical investigations by Kapitzke et al. (1995) have identified that slumping commonly occurs as a rotational movement, however, other modes such as translational, retrogressive, and piping also occur. Records show that slumping occurs

during flood events (refer to Table 3.1), is often associated with groundwater discharge from the bank, and is limited to the upper parts of banks upstream of Ingham (to Abergowrie) and both the upper and lower parts of banks downstream of Ingham. The distinction between slumping in upper and lower parts of the banks, up and down stream of Ingham, is associated with the bank configuration and level of groundwater discharge from the bank. This will be discussed further in Section 3.4.

3.4   LOWER HERBERT RIVER SLUMPING ATTRIBUTES

Factors influencing slump failures have been identified in Section 2.3, which include bank configuration, recharge and surface drainage, soil properties, stratigraphy, vegetation, and streamflow characteristics. Each of these factors has attributes that directly influence the extent and occurrence of slumping.

3.4.1   BANK CONFIGURATION (LONGITUDINAL SECTION OF LOWER HERBERT RIVER)

The slump sites shown in Figure 3.2 consistently occur along areas of alluvial streambank deposits, as mapped by Wilson & Baker (1990). These deposits make up the channel benches and levees upstream of Ingham, while downstream they appear principally as levee formations.

Herbert River cross-sections show that streambanks on the outside of bends upstream of Ingham are generally elevated (in excess of 20 m) and steep, whereas downstream of Ingham streambank configuration is less elevated and often not as steep as those upstream. Due to the elevated topography, slumping upstream of Ingham is not always associated with flood inundation, whereas downstream of Ingham the slumped streambanks are regularly associated with inundation during periods of bankfull and overbank flooding. This suggests that regional groundwater conditions are a significant factor influencing slumping upstream and possibly downstream of Ingham.

Although bank configuration and groundwater conditions directly influence slumping, they do not in themselves determine the susceptibility of slumping along a section of streambank.

3.4.2   VEGETATION

Although there has been no detailed study of the riparian vegetation along the lower Herbert River, some studies on the Herbert River have briefly examined this topic.

These studies have predominantly relied on historical information, both documented and anecdotal, as well as aerial photographic coverage dating back to 1943.

Ian Drummond & Associates identified that before European settlement the riparian vegetation was as follows:

- From the mouth of the river to AMTD[1] 7.5, mangroves fringed the river.
- From AMTD 7.5 to approximately the weir (AMTD 30) the riparian vegetation was predominantly riverine rainforest with patches of eucalypts.
- From the weir upstream to Nash's Crossing (AMTD 96) the riparian vegetation was predominantly riverine rainforest.
- Upstream of Nash's Crossing the country becomes progressively drier with fringing vegetation typical of dry open woodland.

As a result of settlement and clearing for forestry and sugar-cane cultivation the riverine rainforest now exists only in narrow remnants. Wilson & Baker (1990) identified that approximately 65 to 60 percent of the floodplain area had been cleared. Most of the riparian vegetation along major tributaries and in mangrove areas has remained reasonably intact, whereas cleared areas have been substantially degraded by the presence of exotic species.

As shown in Figure 3.3 the extent of this degradation is apparent in aerial photography for at least the past forty years. Figure 3.3 also shows the slump sites identified by Kapitzke et al. (1995) and listed in Table 3.1. The slump sites are often adjacent to areas cleared to the top of the bank and cultivated for sugar-cane.

Based on known historical settlement practices which used river passage to access the land, the fertile riparian margin was possibly the first area to be cleared. Therefore, the condition of the riparian margin shown in the 1943 coverage would probably have existed soon after settlement.

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[1] AMTD: Average Middle Thread Distance

Although this historical flood damage is strongly associated with encroachment, recent anecdotal evidence by trust officers indicates that slumping also occurs adjacent to National Park land and other areas where wide riparian buffer zones exist. This recent anecdotal evidence does not detract from the dominant influence of encroachment on slumping, as it is widely accepted that mass movements occur at natural rates as part of the natural stream processes.

3.4.3   STRATIGRAPHY (X-SECTION OF LOWER HERBERT AQUIFERS)

Soil landform mapping of the lower Herbert has been reported by Wilson & Baker (1990) as a low intensity survey which sampled material to a depth of 1.2 m. The Queensland Water Resources Commission has carried out extensive investigations of subsurface hydrology in the Herbert River delta by drilling and sampling material at depth. This has been described in detail by Cox (1979). Geotechnical investigations at problem sites along the banks of the lower Herbert River have also sampled material. The stratigraphy recorded by these investigations show that streambanks, channel benches, levees and terraces are alluvial deposits originating from the surrounding hills.

Surface landform deposits mapped by Wilson & Baker along these areas are mostly fine silty sands to sandy silts (similar to that found along the lower Burdekin River) extending beyond the depth of sampling. This surface material has been described by Cox (1979) as the S4 aquifer landform unit, which characteristically increases in grain size with depth and often overlies a clay to coarse sandy-clay, also described by Cox (1979) as the mud unit M1 landform unit.

S4 is the shallowest and most permeable of the aquifers mapped by Cox (1979). With an extent of only 346 km^2 (refer to Figure 3.2) and an average depth of 7 m (refer to Figure 3.4) this aquifer exhibits sufficient annually rechargeable water (52,000 ML) to make a significant contribution to local water supply.

The silty sands and sandy silts of the S4 are mostly confined to the upper bank upstream of Ingham, but often extend to levels within the lower bank downstream of Ingham. Kapitzke et al (1995) identified that this silty sand/ sandy silt material is vulnerable to slumping as it characteristically loses apparent cohesion when wet.

Cox's M1 unit is often found along the toe of banks downstream of Ingham, but is found with greater elevation upstream of Ingham. A further four units (M2 mud unit and three confined aquifers S1, S2 and S3) were identified by Cox (1979), but lie at depths remote from the bank and exhibit lower yields than the S4 aquifer.

3.4.4 RECHARGE AND SURFACE DRAINAGE

The S4 aquifer is the most accessible and permeable aquifer in the lower Herbert. Cox (1979) identified that recharge to this water table aquifer is direct from rainfall, with its response almost immediate and rate of initial recession extremely high.

During the peak of the dry season (November) water levels in this aquifer are often within 4 m from the surface. Therefore, any depression more than approximately 4 m deep will be fed by groundwater (Cox 1979). However, during this period it is likely that evapotranspiration could be more dominant than discharge into depressions.

In February when the aquifer is fully recharged, water levels rise to within 1.5 m from the surface, thereby increasing the rate and extent of discharge into depressions. Anecdotal evidence and documented observations have identified seepage water discharging from streambanks well after slumping or flooding had occurred, and in some cases seepage water discharges continuously throughout the year. Therefore, streams act as discharge sinks during base flow periods and could act as recharge sources during flooding. Furthermore, given soil moisture is high during the wet season the high rate of initial recession is undoubtedly linked with the extent of discharge into the surface drainage network.

Water levels of the S4 aquifer appear not necessarily associated with the magnitude of the recent rainfall events, but rather the persistence of rainfalls which fill the aquifer to capacity. This is apparent as large magnitude rainfalls during the wet season merely supercharge the aquifer to extremely high temporary levels. Cox (1979) concluded that during the wet season, when soil moisture deficits are minimal, 15% of rainfall infiltrates to become recharge, provided the aquifer is not full. This translates to a one metre rise in levels with each 330 mm of rainfall.
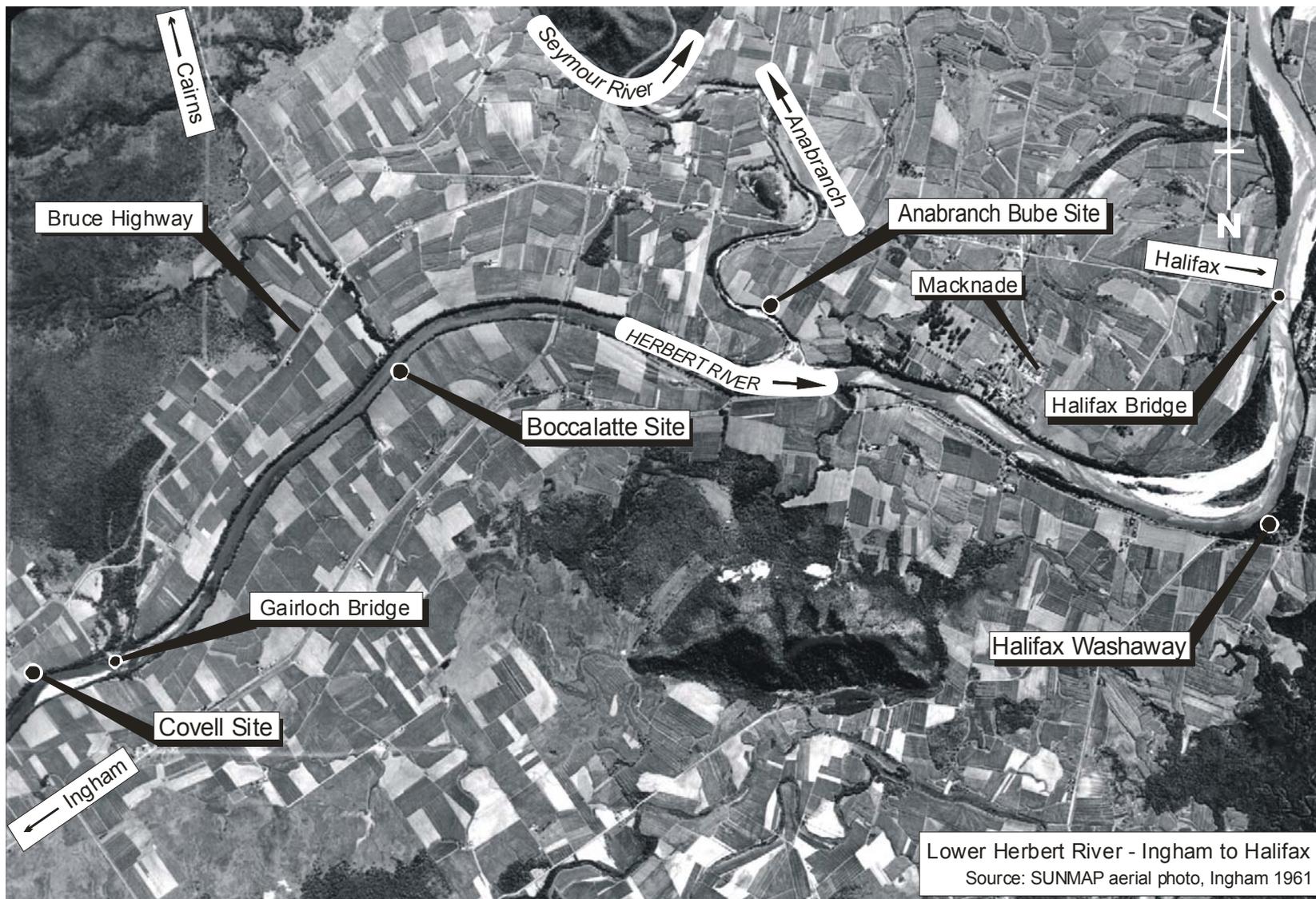
Figure 3.3 **Lower Herbert River aerial photograph (1961)**

Labels on photograph:
- Cairns
- Bruce Highway
- Seymour River
- Anabranch
- Anabranch Bube Site
- Halifax
- Macknade
- HERBERT RIVER
- Boccalatte Site
- Halifax Bridge
- Gairloch Bridge
- Halifax Washaway
- Covell Site
- Ingham
- N

Lower Herbert River - Ingham to Halifax
Source: SUNMAP aerial photo, Ingham 1961
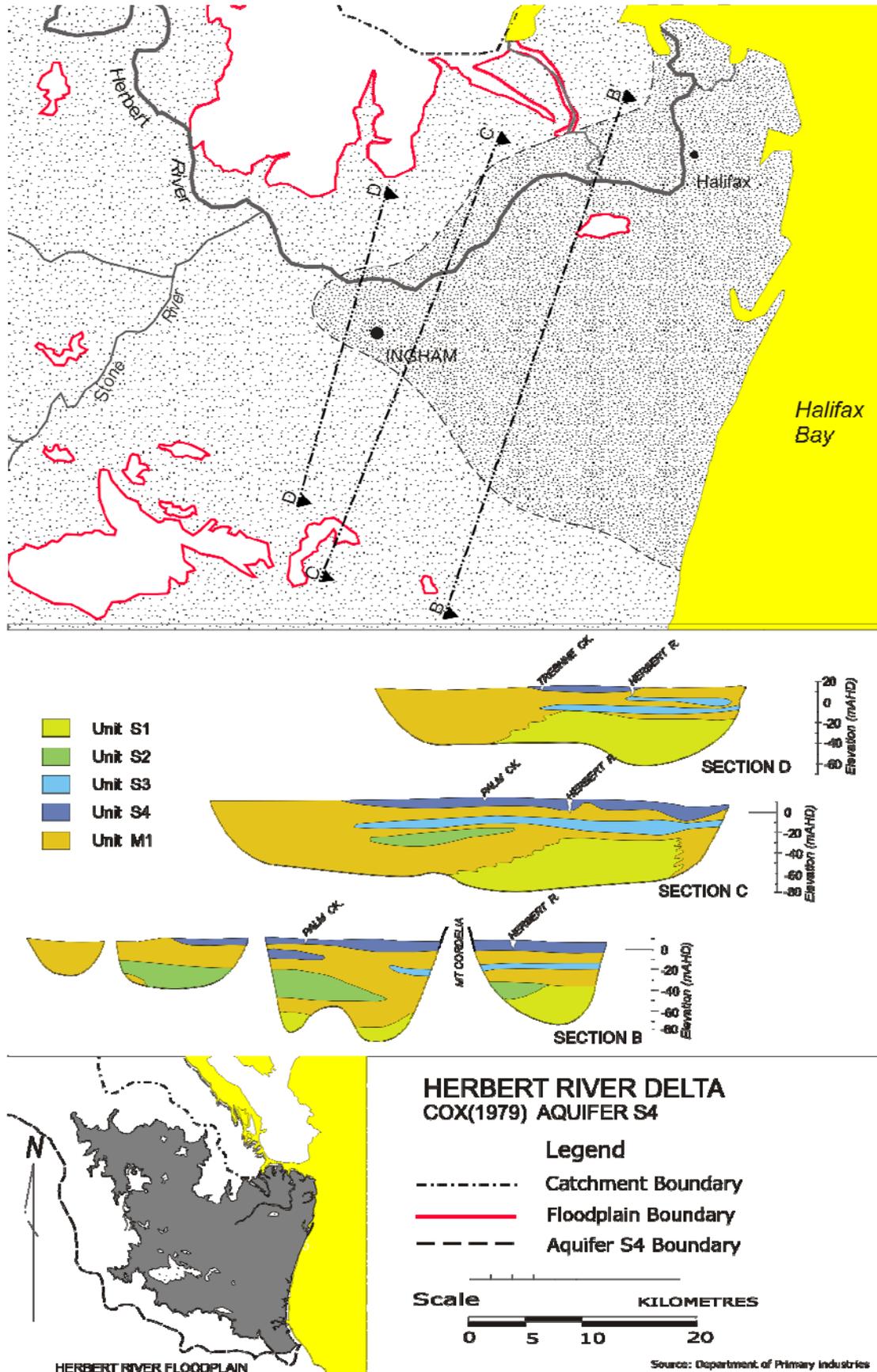
Figure 3.4   Lower Herbert River Cross-sections showing interpretation of Cox (1979) Aquifer S4

In conclusion, the S4 aquifer's characteristic immediate response to rainfall, the hydraulic connection with streambanks, and the occurrence of recharge with flooding make it capable of facilitating rapid drawdown conditions.

3.4.5 SOIL PROPERTIES

The silty-sand/ sandy-silt soils (S4) along the streams in the lower Herbert vary in colour, cohesiveness and permeability, but are clearly different from the underlying sandy clays (M1).

The S4 soils generally vary from fine grained dark brown to coarse grained light brown material at depth. Very coarse sand and gravel is occasionally found at the base of the S4 unit and is often associated with orange staining and considerable seepage water discharging.

M1 colours are variable with rapid spatial change. However, they are generally white to light grey, very pale brown, reddish yellow and to a lesser extent, pink, (Cox 1979). Mottling is common but near the Herbert River Anabranch the uppermost parts of this unit are grey.

Although the S4 soils exhibit a cohesive characteristic when dry, they are known to loose this characteristic when wet (Kapitzke et al, 1995). Similar soils associated with slumping along the lower Burdekin River have been described and tested by Eckersley et al. (1992) and Evans (1993). In contrast, the M1 sandy clay is genuinely cohesive and is likely to confine slope movement to within the S4 unit.

Research at JCU has provided some insight to the strength and water conveyance relationship exhibited by the silty-sand/ sandy-silt soils. Evans (1993) and Eckersley et al. (1992) performed shear strength and permeability testing of similar S4 soils sampled along the banks of the Burdekin River. Geotechnical investigations that involved describing and testing the S4 and M1 soils performed by Kapitzke et al (1995) on samples from the lower Herbert River; Covell and the Herbert River Anabranch Bube sites. Geotechnical investigations associated with sugar yield studies by the CSIRO sampled seven sites in the Burdekin, Herbert and Tully sugar growing regions in north Queensland. Soil properties such as grading, bulk density, strength, saturated permeability and water retention were determined in the laboratory on disturbed and undisturbed samples. Results from these studies are summarised in Table 3.2 below.

Table 3.2   S4 and similar soil properties

Description	Depth (m) & ref.	Laboratory Test Results								
		%< 425µm	%< 75µm	LL	PI	Soil Class	m/c (%)	ρ_d (t/m^3)	$k_{(sat)}10^{-5}$ (m/s)	$\phi'_{(c'=0)}$ (deg)
Kapitzke et al (1995)-Covell and Anabranch										
Silty SAND	1.5-1.8 C1/blk	96	27			SM?	8.9	1.43	4.6	29
Silty SAND, fine, brown, CL/ML fines	1.7-2.1 A1/D6	98	46	27	6	SM				
Silty SAND, very fine, light brown,	1.6-1.9 A1/blk	100	42	30	6	SM	8.8	1.33	1.5	29
Ford et al. (1995b)-Lower Herbert River										
Clayey LOAM	0.45-0.5 Marbelli new/23a	100♣	57			ML	4.0	1.01	1.4	
Sandy Clayey LOAM	0.45-0.5 Maribelli old/38a	100♣	43			SM/ML	2.5	1.26	3.4	
Evans (1993)-Burdekin River										
Inorganic silt/ very fine sand	Swindley Blk [2]		<50	33	6	SM/ML		1.29		31
Eckersley et al. (1992)-Burdekin River, Swindley										
Sandy SILT	146/92# 1 U50 [2]		55			ML	11.9	1.65	0.2	
Silty SAND/ sandy SILT, light brown	Ant.#1 blk [2]						4.4	1.69	0.8-1.0	
Silty SAND, light brown (med. dense)	156/92# 3 U50 [2]		22			SM	25.7	1.48		38
Sandy SILT, brown, hard	154/92# 4 U50 [2]		85	28	4	ML	6.6	1.37		26.7
Notes:	♣ - %< 2 mm, ? estimate based on available soil data									

Ultimate strength of the saturated silty sand/sandy silt from both Covell and Anabranch sites are similar to that from the Burdekin-Swindley site. When dry, the silty sand/sandy silt material exhibits significant 'cohesion', enabling it to stand in near-vertical slopes two or more metres high. However, when saturated, the same material looses all cohesion, resulting in strength made entirely of frictional resistance and interlocking

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[2] Sample depths for Burdekin River Swindley site are understood to be within the upper bank height.

(dilatancy) behaviour. In some cases the actual magnitude loss of strength, upon saturation, has been in the order of 90% of the original strength.

This strength characteristic is known as apparent cohesion and results from the capillary tension exhibited by thin films of water which hold individual soil grains together. The capillary tensions and thus cohesion are removed upon wetting.

Eckersley et al. (1992) and Evans (1993) found that at relatively low dry densities (below approximately 1.45 t/m^3), the saturated silty-sand/ sandy-silt alluvium is contractant with ϕ' of 27° to 30° (and c'=0), whereas the same material at high dry densities is dilatant with ϕ' of 38° to 40°. Eckersley (1977) identified that during the initial stages of soil movement these materials with low densities will contract, causing the material to lose strength and accelerate movement, so that the slip empties out of the bank. In contrast, the higher density material might be expected to dilate upon movement, resulting in an increase in strength, causing the rate of movement to slow and possibly self-stabilise after some initial movement. Most of the material tested exhibited contractant behaviour at insitu densities.

Limited testing of soil moisture retention has been performed on soils from the Herbert River Floodplain. Ford et. al (1995a) have performed soil moisture retention testing on their Clayey Loam and Sandy Clayey Loam soils. Based on the depth and vicinity of the Ford et. al (1995a) samples to the Bube site and their similar agricultural soil descriptions (vis-à-vis Loam-Silt), the tested soils appear to be similar to the Silty Sand and Sandy Silt soils at the Bube site. The soil moisture retention test results for these soils are presented in Table 3.3 below with an average of three tests.

Table 3.3   Soil moisture retention data (Ford et al., 1995a)

Depth & Ref.	Volumetric Soil Moisture Contents (%) at Suctions:								
	0 cm	10 cm	30 cm	50 cm	100 cm	300 cm	1000 cm	3000 cm	15000 cm
0.45-0.5 m Marbelli new/23a	0.408 (0.416)	0.417 (0.422)	0.405 (0.414)	0.392 (0.405)	0.377 (0.393)	0.338 (0.354)	0.312 (0.328)	0.280 (0.290)	0.191 (0.210)
0.45-0.5 m Maribelli old/38a	0.347 (0.368)	0.351 (0.368)	0.343 (0.353)	0.332 (0.341)	0.317 (0.327)	0.307 (0.314)	0.268 (0.287)	0.249 (0.254)	0.168 (0.183)
Notes:	values in brackets are reported averages from three tests, this includes the reported value.								

3.4.6   STREAMFLOW CHARACTERISTICS (GRAPHS OF FLOOD HYDROGRAPHS AND RATES)

Streamflow in the Herbert River is perennial with pronounced inter-annual and seasonal variability influenced by monsoonal and cyclonic events. Significant flooding typically results from cyclonic rainfall in the upper catchment, whereas heavy rainfall limited to the lower catchment can cause minor flooding of limited duration (Cameron McNamara, 1980). Furthermore, monsoonal and cyclonic rainfall events typically produce sharply rising and falling hydrographs with durations that may exceed six (6) days.

Upper catchment rainfall and river levels are monitored regularly to provide advanced warning of potential flooding. Lower catchment river levels are measured at the Ingham pump station and the Gairloch Bridge gauges (refer to Figure 3.2 and Figure 3.3). Records of water levels have been maintained at the Ingham pump station gauge since 1915, and at Gairloch Bridge since 1956.

Streamflow flood data for the Ingham gauging station (GS 116001) was obtained from the Queensland Department of Primary Industries. Hydrological characteristics have been sourced from various studies undertaken for the trust.

The Bureau of Metrology classifies flood events as *minor*, *moderate* or *major*, according to the maximum gauge levels reached on the Ingham gauge. The lower limit of the bureau's *major* flooding classification corresponds to a flood with a return period of approximately 1 in 3 years.

The Herbert River Basin overall rainfall and runoff characteristics are summarised in Table 3.4.

Table 3.4   Herbert River Basin rainfall and runoff data (Kapitzke et al., 1998)

Area (km^2)	Mean Annual Rainfall (mm)	Mean Annual Runoff Volume (1000 ML)	Runoff Depth / Rainfall (%)
10 130	1331	4991	37

Across the three bio-geographic zones in north Queensland (the wet tropics, the dry tropics, and the moist central coast) the Herbert River Basin has a mean annual runoff volume and basin area second only to the Burdekin.

The Herbert basin runoff/rainfall of 37% is moderate in comparison to the highest of 74% for the Tully Basin (Wet Tropics) and the lowest of 12% for the Burdekin Basin (Dry Tropics), (Kapitzke et al., 1998). The runoff/rainfall percentage inversely indicates the percentage of rainfall infiltration, which in the case of the Lower Herbert River, maintains a relatively shallow regional water table, often observed discharging into water courses through streambanks.

Inter-annual and seasonal distributions of flood flows for the Herbert River at Ingham are illustrated in Figure 3.5 as maximum monthly instantaneous discharges and monthly flow volumes from 1956 to 1995. The Herbert River has a regular pattern of annual flooding. The extreme flood events of *1927, 1946, 1955, 1967 and 1977* shown in Figure 3.6 were associated with significant overbank flow and inundation of the floodplain for several days. During these events subsurface soil conditions would have been fully saturated prior to flood recession.

Six flood events: March 1967, March 1977, February 1991, January 1994, March 1973 and January 1981, have been sampled from Figure 3.5 as groupings of two floods, nominally representing: A (large), B (medium) and C (small) flood categories respectively. These categories have been defined on the basis of 2 year and 20 year average recurrence interval thresholds. Refer to Appendix C for presentation of flood categories. This new flood rating is necessary to avoid difficulties in translating bureau flood categories to periods with different gauging locations. The six Ingham flood height hydrographs are illustrated in Figure 3.6 with rates of rise and fall and flood duration marked on each hydrograph.

The corresponding six flood height hydrographs at Bube are illustrated in Figure 3.7 as an estimate based on the correlation with Ingham levels. The Bube flood hydrographs have been estimated using a height-height correlation as well as a nominal offset in flood peak applied to flood heights at Ingham.   The method used is outlined in Appendix C.

Flood duration at any location along the river depends on many factors. Flood durations, for the purpose of streambank infiltration, are therefore described here in terms of the time of inundation above the lower-third bank height.

Figure 3.8 summaries the rates of rise and fall and lower-third durations for the six flood events at Ingham and Bube.

Rates of flood rise at Ingham range from 108 mm/hr, for the category A flood in 1977, to 686 mm/hr for the category C flood in 1973. An increasing trend in rates of rise, at Ingham, appears to be associated with category C flood events with 'short' durations. This would be hypothesised as cloud-burst rainfall confined within the lower catchment, as discussed earlier. Rates of rise at Bube are different from those at Ingham and follow no definable trend. In terms of streambank infiltration, it is important to appreciate the frequency of streambank overtopping at Bube. From the estimated data overtopping occurs in each of the six flood events. Overtopping at Ingham only occurred in the two category A flood events.
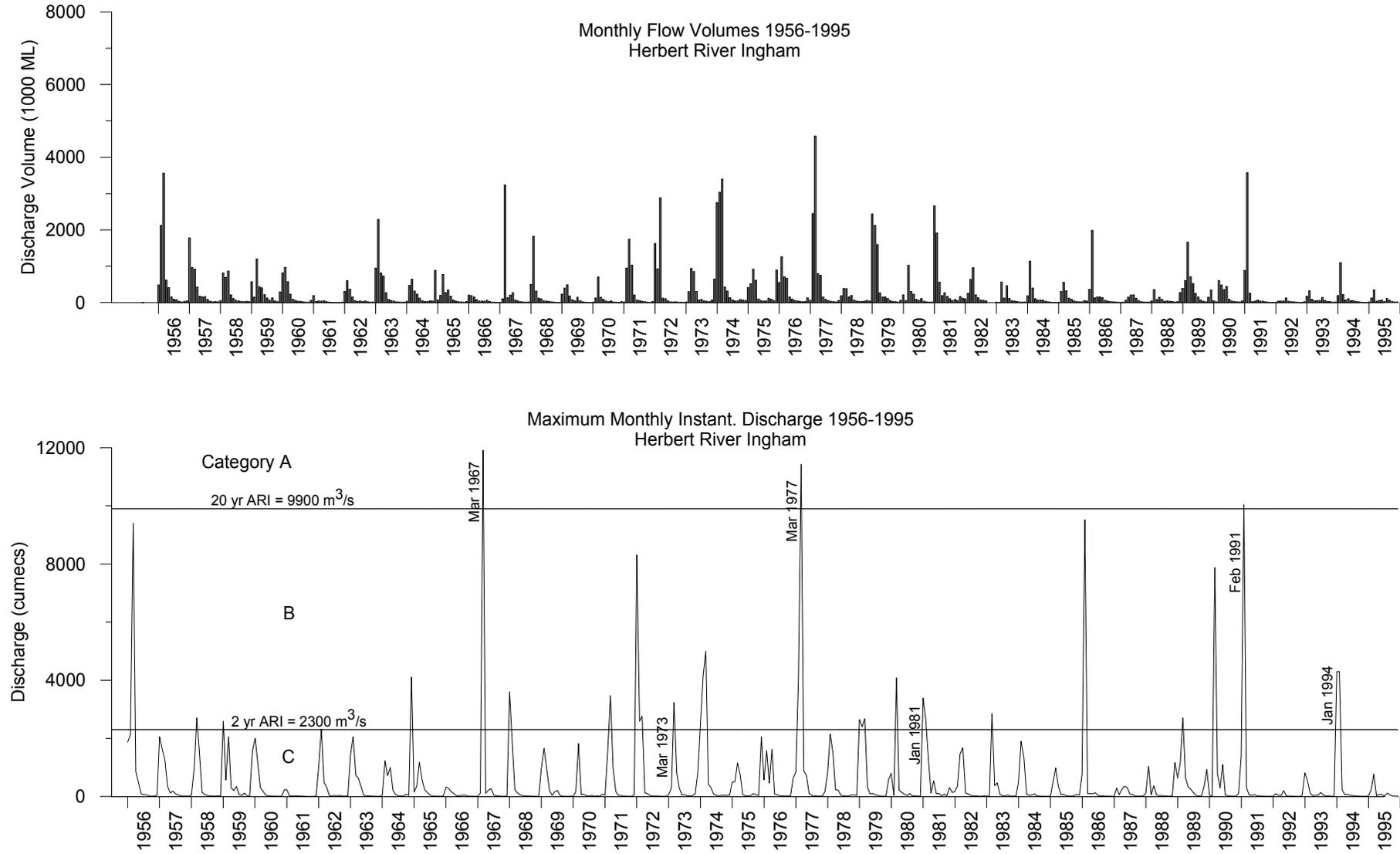
Figure 3.5   Herbert River Ingham stream flood flows (1956 to 1995)

Herbert River Ingham Height Hydrographs
Source: DNR Ayr
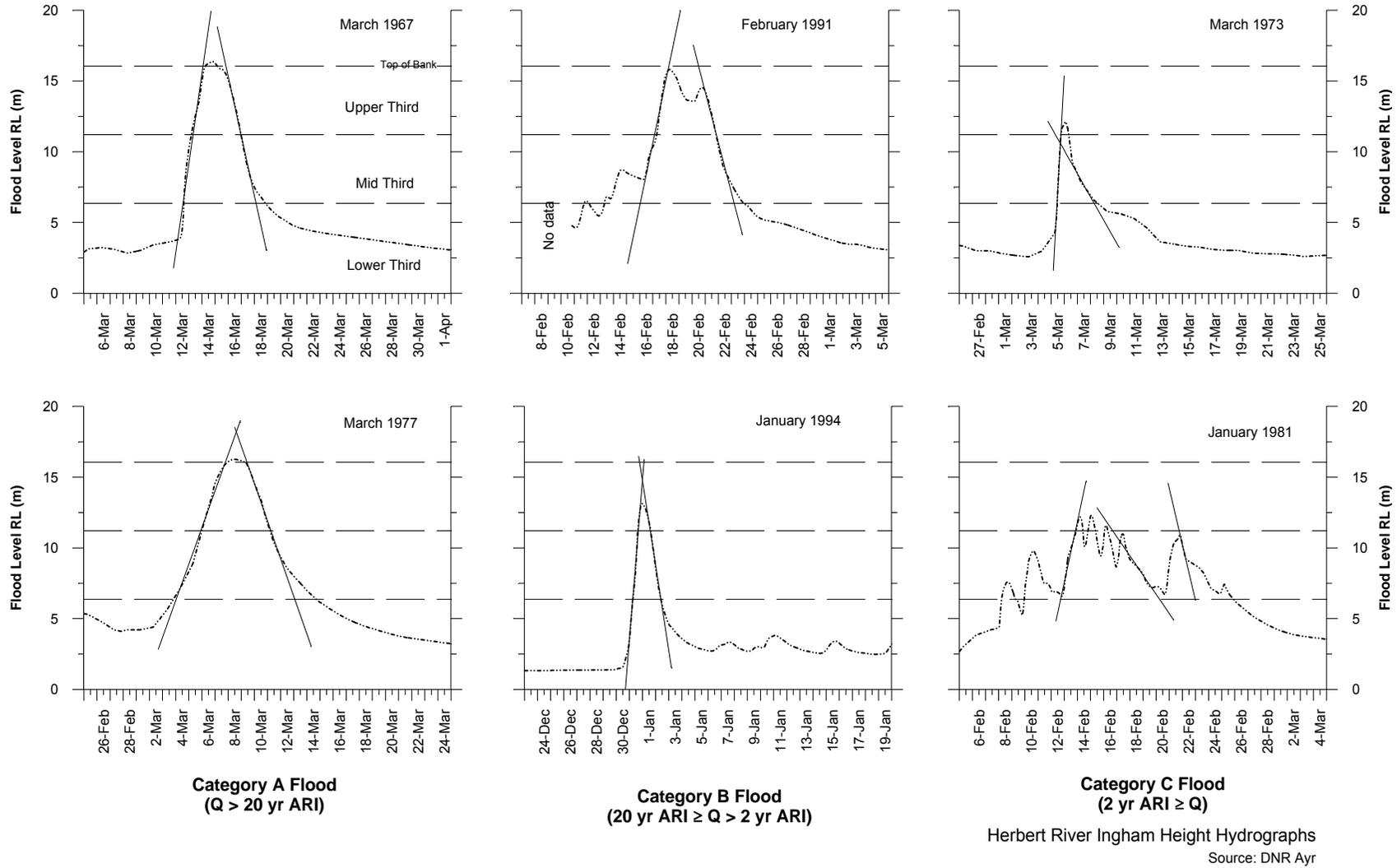
Figure 3.6   Herbert River Ingham flood height hydrographs (March 1967, March 1977, February 1991, January 1994, March 1973 and January 1981)

Figure 3.7 **Annabranch Bube estimated flood height hydrographs (March 1967, March 1977, February 1991, January 1994, March 1973 and January 1981)**

Rates of flood recession at Ingham range from 70 mm/hr, for the category C flood in 1973, to 250 mm/hr for the category B flood in 1994. Apart from the higher recession rates observed with the category B floods, no definable trend exists with this limited data set. However, higher rates of flood rise and recession appear to be associated with 'short' duration flood events. Again consistent with the hypothesis of lower catchment cloud-burst rainfall events. Rates of recession at Bube follow a similar pattern and range from 61 mm/hr, for the category A flood in 1977, to 304 mm/hr for the category B flood in 1991.

Lower-third flood durations are similar at both sites, ranging from 32 hours for the category B flood in 1994 to 172 hours (approx. 7 days) for the category A flood in 1977.

In conclusion, flooding in the lower Herbert River is closely related to the characteristics of rainfall either in the upper or lower catchment. It is likely that flood rates are associated with rainfall rates. Although it would be appropriate to assess the relationship between rates, spatial occurrences and durations of rainfall events and rates and durations of flooding, it is outside the scope of this study.

3.5   SITE DESCRIPTION

Bube is located on the Herbert River Anabranch, a distributary channel of the Herbert River, approximately 9 km west of Halifax and 50 km north-east of Ingham. Refer to Figure 3.2. Slumping of the river bank as a result of flooding in February 1994 established the site as part of a study to identify the characteristic of slumping in the lower Herbert River and alternative treatments of river bank slumping.

Access to the site is available from the Ingham-Halifax Road via two farm headlands. One headland passes through the canelands to the site, whereas the other follows the river bank from the Anabranch Bridge. Refer to Figure 3.3.

Situated in the wet tropical region of North Queensland, the Anabranch drains into the Seymour River which discharges to the north-east corner of the Herbert River basin.
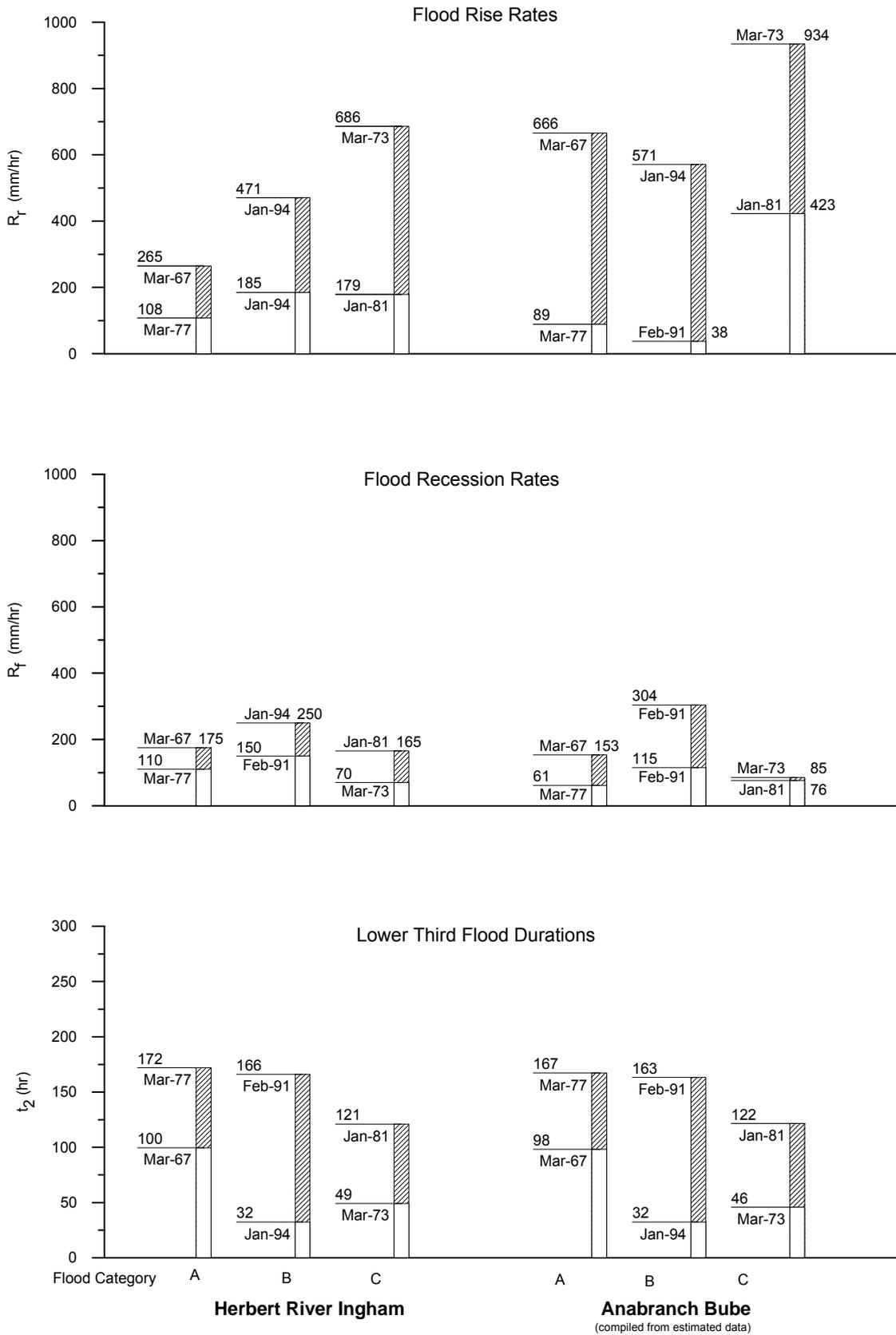
Figure 3.8   **Herbert River Ingham and Annabranch Bube – flood rise and recession rates, and lower third flood height durations**

The Anabranch takes infrequent bank full flood flows as a result of overflow discharge from the Herbert River commonly associated with monsoonal and cyclonic activity during the wet season. Periods other than the wet season see the Anabranch as a tidal channel up to the CSR tram bridge. Above this point the Anabranch and the Bube site experience a dry channel bed.

The site is located on the outside bank of a slight bend approximately 1 km downstream of the Anabranch's junction with the Herbert River. This is shown in Figure 3.9. The site has been established over a total bank length of 300 m and abuts cultivated land. The cultivated land, from survey data, forms a sink which drains the area bounded by the Anabranch, including the site, over a moderate slope to a low point at its centre.

Extensive streambank clearing has been undertaken in the past for sugar cane cultivation, and this has removed all native species from the abutting land and thinned the riparian corridor to a narrow strip no greater than 5 metres. Kapitzke et al (1995) identified exotic species of vegetation dominating the site with moderately intact riparian vegetation present both upstream and downstream of the site. A section of densely regenerating *Melaleuca viminalis* was present at the toe of the bank near the centre of the site. Typical bank heights of eight (8) metres and a varied riparian zone are typical of the site which is abutted by a cane farm owned by Mr Ces Geeson. The slump failures have encroached slightly onto the farm headland.

3.6   PREVIOUS SITE INVESTIGATIONS

Kapitzke et al. (1995) and Ian Drummond and Assoc. (1994) performed studies of the river banks at Bube. Kapitzke et al. (1995) presented the results of collaborative research investigations which: (1) determined the cause and attributes of the common slumping failures on the lower Herbert River; and (2) investigated alternative innovative methods of treatment of slump failures. The results of these objectives would provide a basis for the trust to develop techniques to better manage slump failures in the lower Herbert. The research program by Kapitzke et al. (1995) comprised two parts:

> **Part A - Slump Research**, which has included field investigations, laboratory tests, and office studies on several research sites to assess the reason for, and the attributes of slumping failure in the lower Herbert River.

Part B - Trial Stabilisation Works, in which concepts and inputs to designs have been provided for trial bank stabilisation works which have been undertaken by the Trust as part of the 1994 flood damage restoration works.

The research program has incorporated hydraulic, geomorphic, geotechnical and ecological research tasks, undertaken by JCU personnel involved in the *River Bank Stabilisation* project and these are described in more detail below.

Ian Drummond and Assoc. (1994) were engaged to prepare designs for the trial bank stabilisation works which were implemented by the HRIT at Bube.

3.6.1 HYDROLOGY AND GEOMORPHOLOGY

John Lowry from the Department of Tropical Environment Studies and Geography conducted the hydraulic and geomorphic work, under the direction of Ross Kapitzke and Dr Scott Smithers. This work involved office studies and field investigations to examine the correlation between slump failure and site attributes such as flood hydrology (flood height, duration, rate of rise and fall, local rainfall); local river morphology (river reach, channel configuration); and site topography (bank height, slope). Depending on the available data a temporal analysis of project sites was performed to assess channel change which would indicate likely causes for bank instabilities.

3.6.2 ECOLOGY

Steve Skull of the Australian Centre for Tropical Freshwater Research (ACTFER) conducted a survey of the remnant riparian vegetation at the study sites (both upstream and downstream). This enabled suitable native species to be recommended in the final planting scheme, provided they were available from the Wet Tropics Tree Planting Scheme (WTTPS) nursery. The trial works site was also assessed in terms of exotic invasion, suitability for planting and remnant vegetation retention.
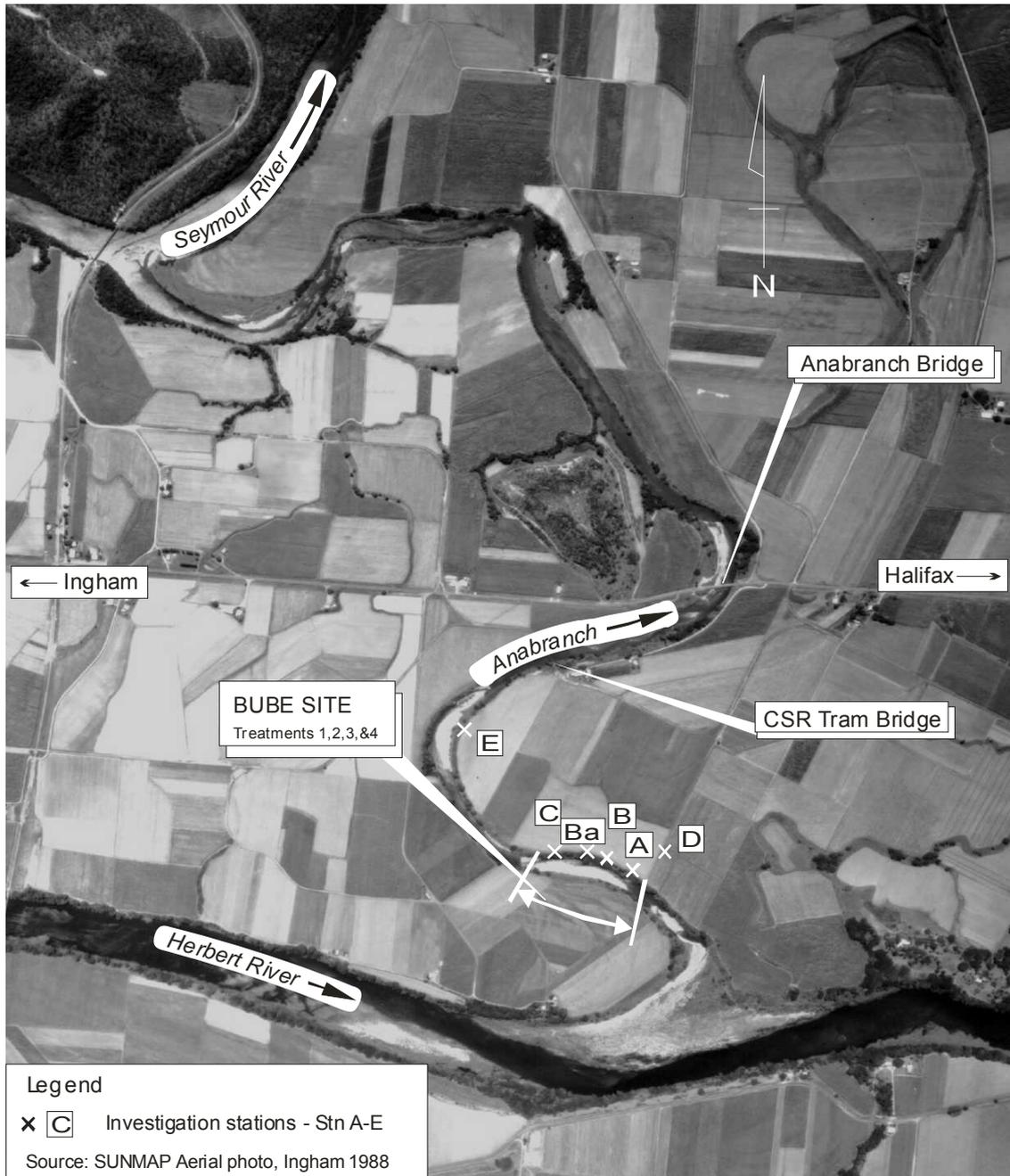
Figure 3.9   Annabranch Bube Site Location Plan

3.6.3 GEOTECHNICAL

A preliminary examination of the geotechnical conditions at Bube was conducted by Dr John Eckersley of the Department of Civil & Environmental Engineering at JCU. This included logging and visual classification of bank materials, laboratory classification and strength testing, and field and laboratory permeability testing, as referred to in Section 3.4. Rudimentary seepage and stability analyses were also performed to estimate the extent of flood water infiltration during the February 1994 flood. This work provided sufficient detail to establish the probable nature of the bank instabilities at the

research sites and determine design parameters for Ian Drummond and Assoc. (1994) to design the engineering components of the trial bank stabilisation treatments at Bube.

Eckersley's geotechnical examination confirmed the mode of bank instability as slumping and revealed that the top 4 to 6 metres of the slumped bank were alluvial soils known as the S4 aquifer of Cox's 1979 thesis. The ability of this unit to influence slumping through streambank inundation was not determined. However, Eckersley proposed that a subsurface monitoring installation would determine this and other influences such as flood rates and soil permeabilities.

The second main objective of the study by Kapitzke et al. (1995) has been to develop innovative bank stabilisation treatments for bank slumping. The Herbert River Improvement Trust have collaborated with JCU to develop trial bank stabilisation works at the Bube site, and these works have been undertaken as part of the 1994 flood damage restoration works for the site.

3.7   TRIAL BANK STABILISATION TREATMENTS

A joint site meeting on Thursday 8 September 1994 included the landholder, JCU personnel, and representatives from the trust and the Wet Tropics Tree Planting Scheme (WTTPS). The site meeting considered conditions which initiated bank failure and developed concepts for trial bank stabilisation treatments. The concepts were later incorporated into designs by Ian Drummond and Associates (1994).

Four alternative trial bank stabilisation treatments (1 to 4) were implemented over an approximate bank length of 300 m. A section of remnant vegetation was retained between treatments 3 and 4 and has been adopted as a control section for comparisons with the trial treatments. This control section suffered minimal damage during the 1994 flood and from observations (Kapitzke et al, 1995) is known to be relatively stable. The extent of and location of each treatment can be seen in Figure 3.10.

Each of the trial treatments have revegetation incorporated into their design. The landholder voluntarily relinquished a ten (10) m buffer zone from cultivation to allow the planting of native species. This work has been performed by the WTTPS of the Hinchinbrook Shire Council and has included removal of exotic species through spraying, using a mixed species for planting, planting in a random manner at an average plant density of 0.5 trees per square metre, fertilising and mulching, and

irrigation and maintenance to restrict competition from exotic species. Each alternative trial treatment is shown in Figure 3.11 as an illustrative cross-section. The following is a description of each treatment in terms of its configuration and role.

Treatment 1

- ~ close replica of current HRIT practice for stabilisation of bank slumps;
- ~ combined toe protection, toe drainage, upper bank earthworks and revegetation;
- ~ rock work at toe to prevent toe retreat and destabilising upper bank;
- ~ rock work placement form access berm;
- ~ longitudinal toe drainage to reduce insitu water levels which could lead to rapid drawdown
- ~ anticipated minimal drainage effect on upper bank material;
- ~ provide berm and batter bank to an even grade; and;
- ~ revegetate upper bank and 10 m beyond top of bank with native species.

Treatment 2

- ~ treatment to minimise disturbance to upper bank;
- ~ combined toe protection, undisturbed upper bank profile and revegetation;
- ~ rock work at toe to prevent toe retreat and destabilising upper bank;
- ~ rock work placement from channel without disturbing the bank and regenerating *Melaleuca viminalis*
- ~ no drainage, to test the ability of deep rooting vegetation in stabilising upper bank;
- ~ no berm and no battering of upper bank;
- ~ retain the regenerating *Melaleuca viminalis* at the toe of the bank; and;
- ~ revegetate upper bank and 10 m beyond top of bank with native species.

Treatment 3

- ~ treatment to minimise disturbance to upper and lower bank;
- ~ undisturbed upper and lower bank profile and revegetation;
- ~ no rock work at toe, to test the ability of deep rooting vegetation in stabilising lower bank;
- ~ no drainage, to test the ability of deep rooting vegetation in stabilising upper bank;
- ~ no berm and battering of upper or lower bank, other than for safety or access; and;
- ~ revegetate upper bank and 10 m beyond top of bank with native species.

Treatment 4

- ~ treatment to provide drainage to upper bank material;
- ~ undisturbed upper and lower bank profile and transverse drainage system;
- ~ no rock work at toe;
- ~ transverse slotted subsurface drainage pipe to reduce insitu water level within upper bank;
- ~ no berm and no battering of upper or lower bank;
- ~ no revegetation of bank to avoid impact of deep rooted trees on drainage pipes; and;
- ~ revegetate 10 m beyond top of bank with native species.
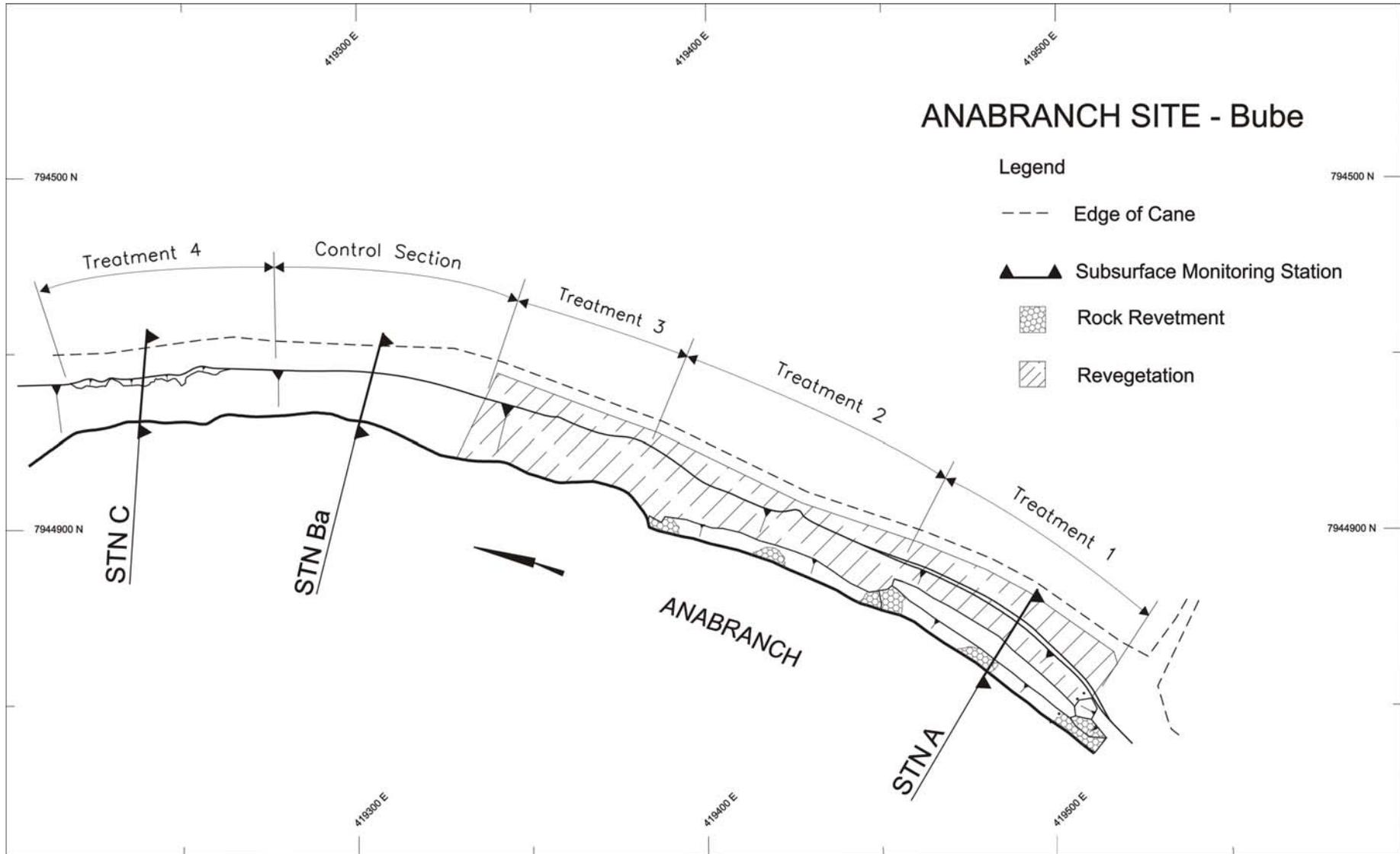
Figure 3.10   Anabranch Bube Site Plan.
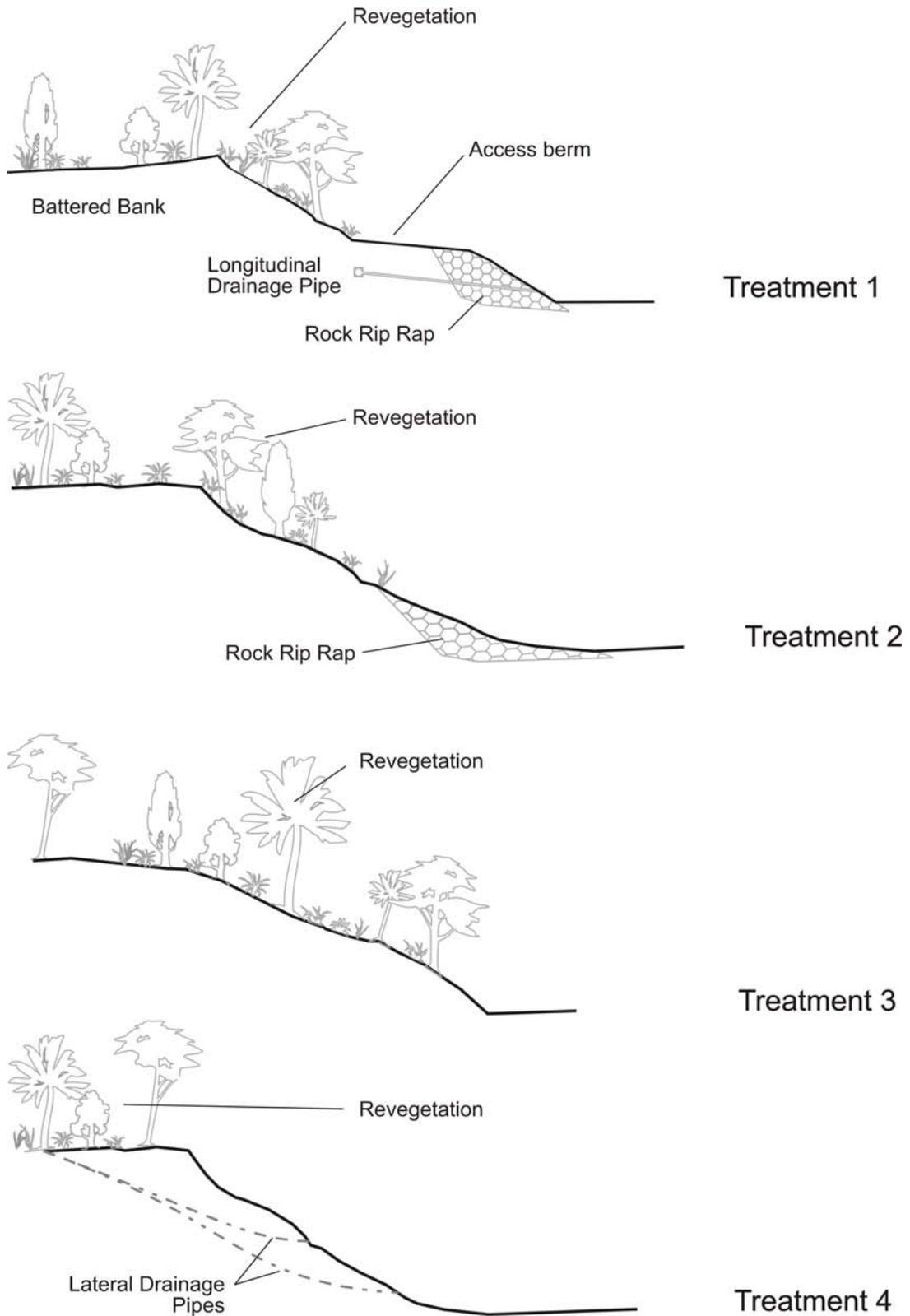
Figure 3.11   Anabranch Bube Trial Treatment Cross-Sections

Treatment 1 is a close replica of bank stabilisation works typically undertaken by the HRIT. This treatment incorporates a technique which provides a collector drain to pick up water flowing through the lower sand lenses. Work necessary for this treatment generally disturb the bank and requires rock to prevent washout at the toe. The longitudinal drainage pipe within the lower bank lowers subsurface water levels adjacent the pipe thus reducing the effects of piping and rapid drawdown conditions.

Treatment 4 is considered as an innovative approach to addressing the rapid drawdown failure mode. Kapitzke et al. (1995) performed rudimentary seepage analyses to establish spacings for the slotted lateral drainage pipes. Pipes of 100 mm diameter installed at 2.5 m centres were adopted as the most economical and functional configuration. Installation of drainage pipes utilised a directional boring system similar to that used by telecommunication companies. This approach places the pipes without the need for drilling or bulk excavation and with minimal disturbance to the streambank. A geotextile sock covers each drainage pipe to prevent material finer than the drainage slots from being washed out.

A continuation of this research program has been undertaken by the HRIT and JCU to develop and implement an ongoing monitoring program for the trial bank stabilisation treatments at Bube.

3.8   SITE MONITORING

A detailed site monitoring program has been included in the collaborative research program (Kapitzke et al. (1995) to provide performance observations on each treatment and the control section. This has included control and topographic surveys, flood height record, photographic and video record, performance observations, quality control and detailed cost record of construction, and subsurface water pressure monitoring. The subsurface water monitoring component is the focus of this investigation where the results will be used in geotechnical analyses which model groundwater movements and assess slope stability of the trial treatments. The results will also be used by the HRIT to further their understanding of groundwater influenced bank failures and the JCU *Improved River Bank Stabilisation Practices* project as one of the six case studies investigating various bank stabilisation techniques and their impacts.

3.8.1   CONTROL AND TOPOGRAPHIC SURVEYS

This work was performed by the HRIT during the initial site meeting to establish reference posts and a preconstruction site profile and post construction to install revetment control survey marks and a as constructed site profile. Spot level contour plots of the site and representative cross section plots of completed treatments have been supplied by the HRIT as part of the program. On request from JCU the HRIT has installed a set of flood gauge boards at the top of treatment 1 and performed a topographic survey to locate subsurface monitoring instrumentation after installation works were completed by JCU.

3.8.2   FLOOD HEIGHT AND RAINFALL RECORD

Flood gauge heights have been recorded manually and by electronic data loggers at various locations. Flood height recordings of the Herbert River have been taken manually at the Gairloch Bridge by the adjacent landholder Mr John Covell and electronically at the Ingham pump station by instrumentation installed for the Bureau of Metrology. Flood heights of the Herbert River Anabranch have been recorded manually by either JCU or the HRIT at the Anabranch Bridge and the Bube gauges. These manual recordings are used for confirmation of electronic measurements of open channel depth logged by subsurface monitoring instrumentation at the site. Site rainfall data has been recorded by an electronic rain-gauge at the site and manually by a Hinchinbrook Shire Council employee approximately 2 km from the site. This site data is supplemented by electronic rainfall readings taken at the Ingham pump station.

3.8.3   PHOTOGRAPHIC AND VIDEO RECORD

Photographic and video record before, during and after each stage of construction has been performed on a regular basis by the HRIT and JCU. This has involved repeat photographs over time from the same locations and photographs of flood events. An emphasis of treatment integration and human construction activities have been captured during each phase.

3.8.4   PERFORMANCE OBSERVATIONS

This component has recorded physical observations of treatment performance and revegetation progress. Control and topographic surveys by the HRIT have assisted in observations of post flood bank movement and disturbance. Species diversity of vegetation compared with original plantings and vegetation performance of treatments with respect to bank characteristics have been observed.

3.8.5 QUALITY CONTROL AND DETAILED COST RECORD OF CONSTRUCTION

Monitoring of activities and material used during the construction phase of each treatment was necessary to record the cost of construction for each treatment and maintain quality standards. Rock size and placement was of particular importance during the construction of toe revetments at treatments 1 & 2. Regenerating *Melaleuca viminalis* were monitored during the construction of toe revetment at treatment 2.

3.8.6 SUBSURFACE WATER MONITORING

The significance of groundwater from either flood water inundation, runoff or the S4 aquifer on the failure mechanism postulated by Kapitzke et al. (1995), is unknown. To optimise the stabilisation techniques used or predict likely hazard zones it is necessary to determine groundwater movements which influence bank instability. Three subsurface monitoring stations have been installed by JCU to remotely monitor insitu pore pressures/water levels and soil moisture conditions at each of the alternative subsurface drainage treatments and in the control section of the site. The three water sources, flooding, aquifer, and rainfall have been instrumented with piezometric pressure sensors and a rainfall gauge respectfully. Automatic data loggers are installed for continuous data recording. The data from the 'source' instrumentation has been coupled with manual recordings to monitor the accuracy. Further instrumentation has been placed within the observed failure zone to detect the extent and magnitude of the 'source' water. Detailed geotechnical investigations have been performed in conjunction with the installation of the instrumentation to guide the design placement. Data from the three subsurface monitoring stations is downloaded every two months and taken back to JCU for analyses. The results of the subsurface monitoring component will further the understanding on groundwater influenced bank failures and provide relative effects of alternative drainage systems on subsurface conditions.

3.9 SUMMARY

The characteristics of the Herbert River catchment have been presented with a focus on the lower Herbert river floodplain, its streambank instabilities, hydrological regime and landform soils. The Bube study site was introduced presenting the history of the site and its streambank instabilities, investigations, treatments and the site monitoring programme. The critical stream flood characteristics were evaluated and established for application in later analysis. The principal landform soil at Bube was found to be the S4 silty-sand/ sandy-silt soil unit identified by Cox (1979) and Kapitzke et al (1995). Soil properties associated with the S4 unit were established from previous laboratory

testing by Eckersley et al. (1992) and Evans (1993), of which will be later used in modelling and stability analysis of generic streambanks.

Chapter 4

PREPARATION & FIELDWORK

This section describes preparation and site activities performed during two geotechnical site investigations for instrumentation installation at Bube.

4.1 GEOTECHNICAL FIELD INVESTIGATIONS

Geotechnical site investigations were undertaken during October and December 1995 to identify site conditions and install instrumentation on site. Field activities in October 1995 were performed by Walker Drilling under the supervision of JCU. Works included insitu testing using the JCU Hogentogler Piezocone Penetrometer (PCPT) at five sites, rotary drilling and sampling (to approximately 8m below ground level), and piezometric pore pressure sensors in drillholes. The fieldworks in December 1995 involved JCU personnel installing, by hand, the remaining instrumentation at shallow depth and above ground level. Samples obtained from drilling and hand excavations were logged onsite in order to identify target depths for instrumentation installation. Further details regarding the geotechnical works and monitoring instrumentation are presented with figures and greater detail later in their respective sections.

Investigations by Eckersley (1995) characterised the geotechnical aspects of the Bube site in sufficient detail to identify that bank instability was initiated by rapid drawdown conditions. Eckersley's investigations were performed using a hydraulic excavator to expose bank materials to depths of 4m to 6m (below ground level) at treatment sites 1, 2 & 3. Eckersley logged and visually classified the bank materials and then performed laboratory classification and strength testing of the Bube soils. Bube soils were classified as being cohesive, although highly variable and containing layers of highly permeable coarse sand and gravel layers around a depth of 4 m bgl. Observations of water seeping from the coarse sand and gravel layers later provided confirmation of Cox's (Cox 1979) S4 aquifer.

The investigation and monitoring works performed as part of this study have used the findings of Eckersley's 1995 study to focus on the subsurface conditions that influence rapid drawdown conditions.

4.1.1   PIEZOCONE PROBING

Before the installation of insitu instrumentation, PCPT probing was undertaken to identify the stratigraphy at each instrumentation location. Identifying the aquifer and phreatic water level at each location was necessary to determine the drilling depths for sampling and instrumentation installation. The speed of probing proved an efficient means of investigating the site prior to instrumentation installation.

PCPTs were successfully performed at a total of six stations, namely; A, B, Ba, C, D and E. The stations were located on headlands adjacent to or nearby the Bube bank stabilisation treatments.   Figure 3.9 illustrates the location of each station. Instrumentation stations, A, Ba & C were later drilled and sampled, providing a means of validating the probing results. Probing at stations D & E was performed to determine the stratigraphy and ground water conditions nearby to the Bube site.

Probing of the Bube soils was performed by Senior Technical Officer Mr Neville K Hines of the Civil & Systems Engineering soils laboratory, JCU. The PCPT equipment, owned by the Queensland Department of Transport, was mounted on Walker's DB1000 drilling rig. Vertical advancement of the PCPT was provided by the rig's hydraulically operated drill head. The hydraulic system advanced an initially saturated instrumented cone, at a standard speed of about 2 cm/s, vertically into the underlying soil. Probing continuously recorded cone measurements of tip resistance, sleeve friction, pore pressure, temperature and inclination by a field computer. During cone advancement measurements were recorded and printed real-time in the field at 5 cm intervals. Verification of cone integrity was performed by electronically measuring the zero load offsets of the three elements (tip, friction & pore pressure) before and after the testing. The purpose of the integrity testing was to verify the load cells within the cone were not over stressed during the test and thus the calibration of the cone remained valid for the current and following tests.

Additional measurements of pore pressure dissipation were performed from time to time when pore pressures became excessive during probe advancement.   Pore pressures were recorded with a fixed load applied to the stationary probe. On two occasions, at stations D & E, probing reached refusal at 10.5 m & 4.25 m (below ground level) respectfully. Refusal at station D was due to the combined probe tip and rod friction, and refusal at station E was due to the probe tip encountering a hard stratum. Site observations indicated that the hard stratum at station E was possibly a basalt formation, as seen at the toe of the adjacent bank.

Two instrumented cones (serial nos. 0351 & 0380) each with a 60° tip producing a 10 cm^2 projected bearing area attached to a 150 cm^2 friction sleeve were used in the investigation. Each cone included a 5 mm thick shoulder filter. Each test was performed by initially saturating the filter with glycerine. This configuration has been proven, through usage by JCU, to be versatile and robust when applied to conditions generally expected within tropical regions.

4.1.2 PIEZOCONE DATA ANALYSIS

Field interpretation of preliminary probing data was required to plan the programme of drilling, sampling and instrumentation installation. Undisturbed samples were recovered from drilling arisings and undisturbed samples were recovered using thin walled stainless steel tubes. Subsurface instrumentation was installed within drillholes penetrating the lower stratum of Cox's S4 aquifer.

Probing data was later processed at JCU soil Laboratory using the proprietary software CONEPLOT and CPTINTRI. Processing incorporated minor calibration corrections to raw data and calculation of cone tip, sleeve friction and pore pressure ratios as well as material classification. The processed data is plotted versus depth and presented in Appendix A.

The interpretation scheme performed by CPTINTRI is given in terms of non-standard soil descriptions. Based on investigations performed by Eckersley (1993) on Burdekin River banks at Swindley, the following non-standard PCPT material descriptions have been correlated with standard soil descriptions. .

Table 4.1   Soil Descriptions Inferred from CPT results (after Eckersley 1993)

Inferred from CPT	Borehole (visual/lab description)
Sand	SW or SP
Sand to silty sand	SP, SM or occasionally, SC; fine, silty or clayey sand
Silty sand to clayey silt	SM or ML; fine sand, low plasticity clay and sandy clay
Sandy silt to clayey silt	CL, CL/ML; low-med plasticity clay and sandy clay
Clayey silt to silty clay	CL, CH; med plasticity clay and sandy clay
Silty clay to clay	CH; med-high plasticity clay
Clay	CH; med-high plasticity

This scheme has been adopted when interpreting PCPT results gathered in this study. Furthermore, this correlation fails to classify the inferred PCPT silty sand to sandy silt description, which appears to be equivalent to SM/ML.

4.1.3 DRILLING INVESTIGATIONS

Three (3) 100 mm diameter rotary drillholes were performed in October 1995 along the headland at stations A, B and C to an approximate depth of 8 m below ground level. Hand auger drillholes were performed in December 1995 to shallow depth on the upper and lower banks at stations A, Ba and C. Drillhole sampling included collection of disturbed drilling arisings and undisturbed U50. All rotary drillholes were initially auger screwed to the water table at which depth the drilling method was changed to rotary wash boring. Drillholes were terminated at instrumentation installation depths as predefined during field processing of PCPT data.

Disturbed samples were recovered at regular intervals during drillhole advancement. Undisturbed standard U50 samples were recovered from within the S4 unit, the material immediately below, and within the zone above the water table. Undisturbed samples were retained and sealed in 50 mm ID stainless steel tubes. All samples were labelled by JCU personnel and transport to the JCU soils laboratory for subsequent classification and testing. Drillholes logs have been prepared for each drillhole presenting in-situ sampling depths and material descriptions based on results of visual classification and laboratory tests. Refer to Appendix A for individual drillhole logs.

4.2 MONITORING INSTRUMENTATION

Instrumentation used to measure and log surface and subsurface water conditions was obtained from Dataflow Systems. All instrumentation, prior to installation, was configured and calibrated at the JCU soil laboratory.

4.2.1 DESIGN CONCEPT

Eckersley (1995) proposed further investigations which would deploy "limited field instrumentation (including piezometers and moisture sensors) to investigate whether rapid drawdown processes are substantial". Through the collaborative efforts of the trust and JCU a significant subsurface monitoring proposal was approved and established during the later half of 1995. JCU devised a configuration of sensors that would examine the rapid drawdown characteristics, and in turn establish the performance and merits of the subsurface drainage treatments, 1 and 4, at Bube.

Three instrumentation stations A, Ba, and C, were chosen adjacent to the corresponding geotechnical investigations introduced in Section 4.1. Stations A and C are located on trial stabilisation treatments 1 and 4 respectively, and station Ba installed as a control station between treatments 3 and 4. The control station is known to be stable, refer to Figure 3.10. Each station was configured to best characterise rapid drawdown conditions and the associated stream bank treatment stabilisation performances.

The extent of stream bank saturation and its timing in relation to flood stages was theoretically evaluated using rudimentary seepage analyses. The analyses provided guidance to positioning sensors within the stream bank. Three stream bank zones were identified, aquifer, bank, and river. Pressure sensors or a combination of pressure and moisture sensors were configured in each zone to measure the subsurface water conditions.

The pressure and moisture sensors were manufactured by Dataflow Systems of Eumundi, Queensland. The pressure sensors employ a piezo-electric strain gauge mechanism and the moisture sensors a dielectric system as discussed in Chapter 2.

Pressure sensors are used in the aquifer zone to monitor local groundwater levels, which are influenced by regional and local rainfall. Measurements from these sensors would indicate the significance and timing of stream bank saturation during rising and falling local groundwater levels.

Sets of pressure and moisture sensor were used in the upper and lower bank zones to monitor the extent of flood waters saturating the stream bank as well as the significance of elevated subsurface water levels during flood recession.

Pressure sensors were used in the river zone to monitor stream flood levels relative to stream bank subsurface water levels. Stream flood levels were also taken at Gairloch Bridge (manual readings) and at Ingham pump station (automated).

Site rainfall is recorded onsite using a 4 inch diameter automated raingauge located at station A. Local rainfall is recorded manually approximately 1 km from the site. The site and local rainfall recordings provide an indication of timing and significance of site

and local rainfall infiltration to site stream bank saturation and rising groundwater levels respectively.

Measurements from each sensor are managed and recorded automatically using a multi-channel data logger at each station. Measurements from each sensor are recorded chronologically in ASCII format. Data is periodically downloaded from each logger onto a Laptop computer for later processing at JCU. Data loggers are reset each time with a fixed sampling sequence. The data loggers are manufactured by Dataflow Systems and feature eight (8) single channels, which can be programmed to manage a variety of sensors and store up to 128 kilobytes of data (approximately six months of half hourly logged data). The data loggers are powered by a single nine (9) volt dry cell battery or a series of 1.5 volt batteries equivalent in voltage to nine (9) volts. The data loggers are housed in a splash proof box, which is secured inside a lockable elevated cabinet on the top of bank at each station.

4.2.2 CONFIGURATION

The as-built plan and cross-sectional Figure 4.1 configuration of each station are presented in, Figure 4.2, and Figure 4.3. The stream zones Aquifer and Bank are each further represented by two areas, Aquifer 1 (below the headland), Aquifer 2 (near the toe of the bank), Bank 1 (top of the bank), and Bank 2 (immediately below top of the bank) as illustrated. Areas Bank 1 and Bank 2 each comprise a single channel pressure and moisture sensor pair measuring the subsurface pore pressure and soil moisture conditions. Area Aquifer 1 has a dual channel temperature and pressure sensor while Aquifer 2 has a single channel pressure sensor. Stream flood levels are measured by a single channel pressure sensor installed at the toe to the stream bank at stations B and C. Sensors are identified using an abbreviation which incorporates station name, zone/area and sensor type. Table 4.2 lists sensor identities to illustrate this scheme.

Table 4.2   Sensor identification

Sensor Identity.	Station	Zone/Area	Sensor Type
AA_1TP	A	Aquifer 1	Temp/Pressure
AB_1P	A	Bank 1	Pressure
AB_1M	A	Bank 1	Moisture
AB_2P	A	Bank 2	Pressure
AB_2M	A	Bank 2	Moisture
AA_2P	A	Aquifer 2	Pressure
ABR	A	Bank	Raingauge
BaA_1P	Ba	Aquifer 1	Temp/Pressure

Sensor Identity.	Station	Zone/Area	Sensor Type
BaB_1P	Ba	Bank 1	Pressure
BaB_1M	Ba	Bank 1	Moisture
BaB_2P	Ba	Bank 2	Pressure
BaB_2M	Ba	Bank 2	Moisture
BaA_2P	Ba	Aquifer 2	Pressure
CRP	Ba	River	Pressure
CA_1P	C	Aquifer 1	Temp/Pressure
CB_1P	C	Bank 1	Pressure
CB_1M	C	Bank 1	Moisture
CB_2P	C	Bank 2	Pressure
CB_2M	C	Bank 2	Moisture
CA_2P	C	Aquifer 2	Pressure
CRP	C	River	Pressure

4.2.3   CALIBRATION

Sensors were calibrated at the JCU soils laboratory prior to site installation works. Sensor calibrations utilised similar data logger configurations employed for site monitoring. Sensor calibrations confirmed the manufacturer's calibration results and provided data specific to conditions anticipated on site. Calibrations were performed in controlled environments (temperature and moisture), which closely emulated conditions anticipated in the field.

Numerous data logger channel-sensor configurations were found unworkable during the initial calibration phase. After discussion with the manufacturer and elimination through trial and error, a single sensor-channel configuration was found workable. This configuration required pressure sensors to be assigned channels preceding those assigned to moisture sensors. The workable data logger sensor-channel configuration is presented in Table 4.3 below.
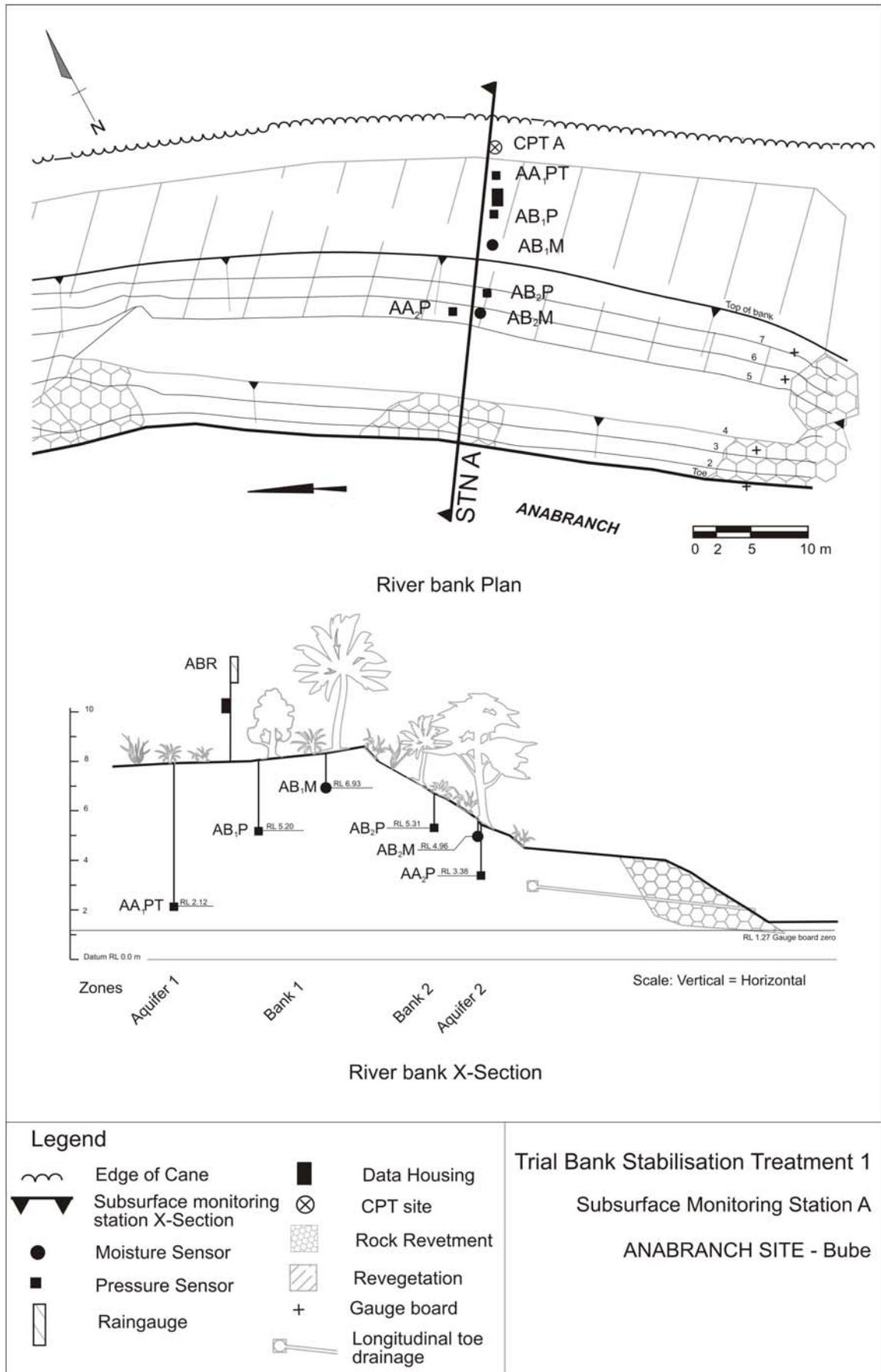
Figure 4.1   Subsurface Monitoring Station A

River bank Plan

River bank X-Section

Legend

∿∿ Edge of Cane

▼▼ Subsurface monitoring
station X-Section

● Moisture Sensor   ▨ Revegetation

■ Pressure Sensor

▮ Data Housing

⊗ CPT site

Trial Bank Stabilisation Control Section

Subsurface Monitoring Station Ba

ANABRANCH SITE - Bube
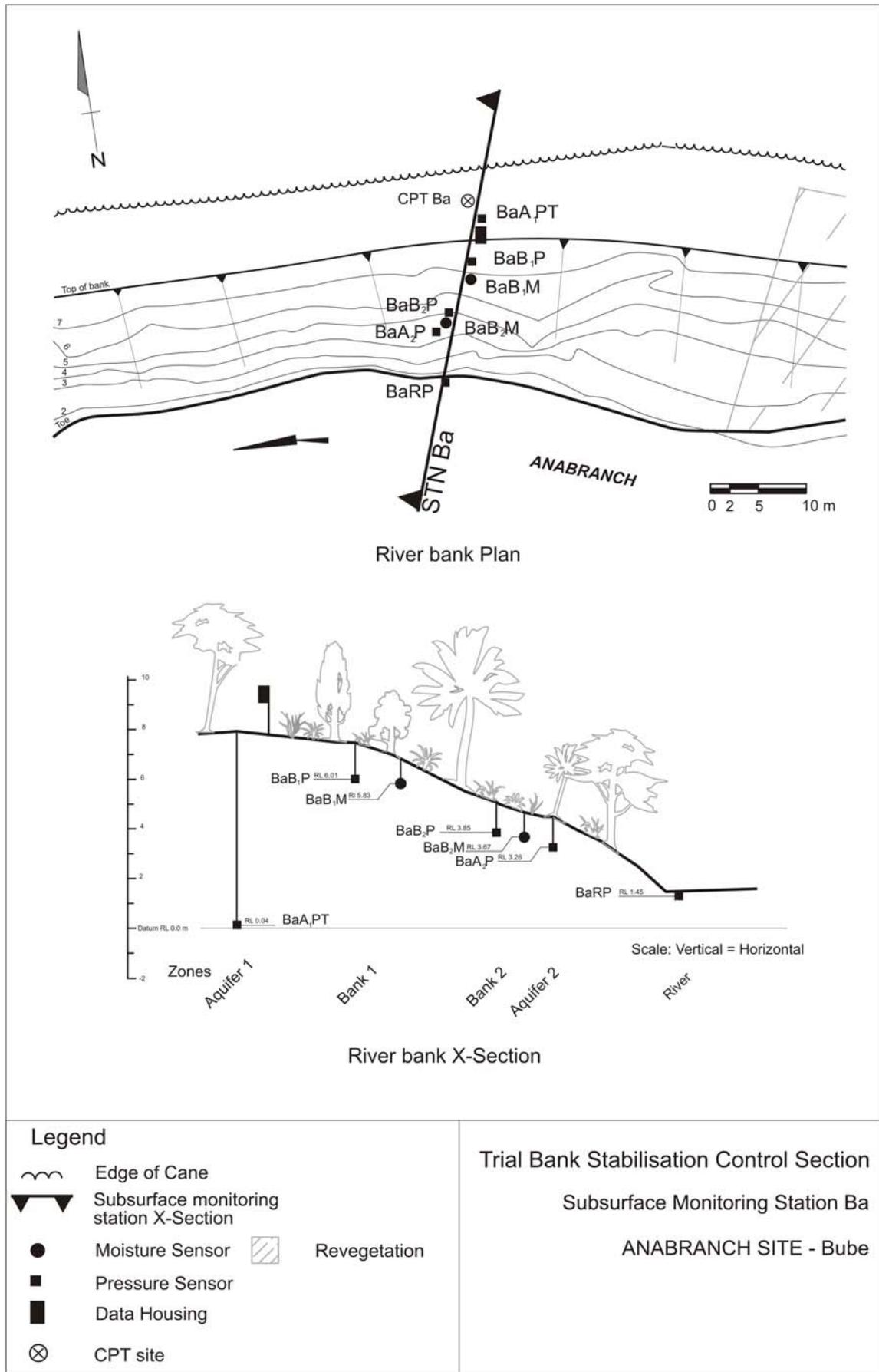
Figure 4.2 Subsurface Monitoring Station Ba.
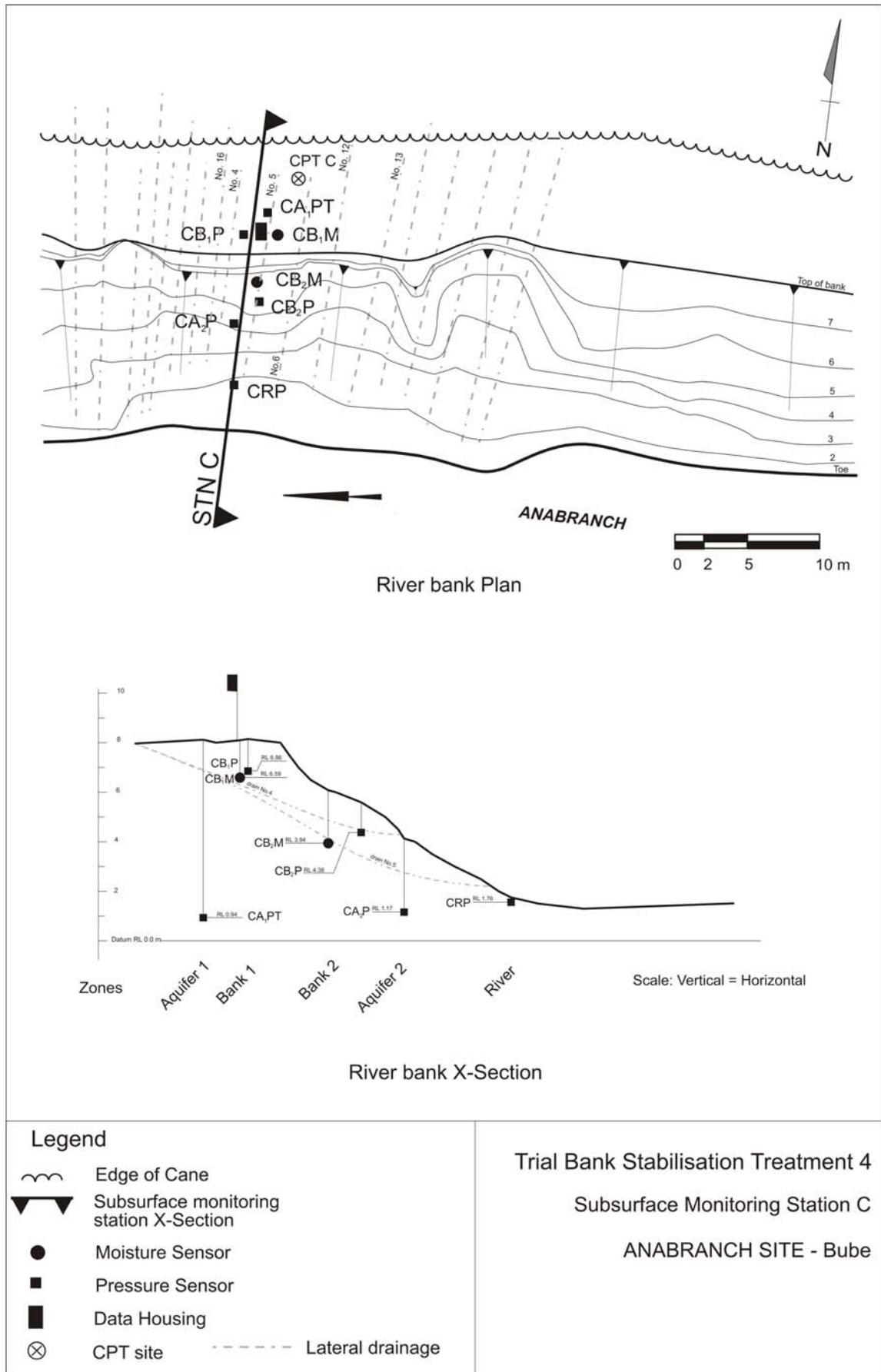
Figure 4.3 Subsurface Monitoring Station C

Table 4.3   Data Logger Sensor-Channel Configuration

Channel	Station A	Station Ba	Station C
1	ABR	BaB_1P	CB_1P
2	AB_1P	BaB_2P	CB_2P
3	AB_2P	BaA_2P	CA_2P
4	AA_2P	BaRP	CRP
5	AB_1M	BaB_1M	CB_1M
6	AB_2M	BaB_2M	CB_2M
7	AA_1T	BaA_1T	CA_1T
8	AA_1P	BaA_1P	CA_1P

Furthermore, data loggers were programmed with single channel pressure sensors (Bank 1, Bank 2, Aquifer 2, and Stream) as frequency devices with internal V/F, whereas the dual channel temperature and pressure sensors (Aquifer 1) were programmed as "dual channel temp/pressure devices". Moisture sensors (Bank1 and Bank2) were setup as "analog converters, 8 bit" devices on each data logger.

A 2.5 m high, 150 mm diameter PVC adjustable water column was used to calibrate pressure sensors. The base of the column was end capped and drilled with six outlet ports to attach pressure sensors. An external piezometer, which scaled the full length of the column, was used to measure the water level within the column. Up to five pressure sensors were simultaneously calibrated with their assigned data logger. This was achieved by adjusting water level within the column at fixed time intervals whilst data loggers recorded sensor measurements. This was typically done in 100 mm increments held for at least 4 minutes, rising and falling the entire height of the column.

Moisture sensor calibrations were performed at the JCU soils laboratory using moisture controlled soil of similar character to that encountered on site.   Initial calibration measurements were influenced by metallic objects and looping of sensor cables, which were found to be unavoidable in the laboratory environment.   Calibrations were subsequently performed outside the laboratory with cables fully stretched and avoiding metallic objects. A block sample retrieved during fieldworks at Bube by Eckersley (1995) was used as the moisture controlled material to calibrate each sensor. Four different moisture contents were mixed thoroughly and tested for moisture content determination.   Each sensor was calibrated in each of the four soil mixes. The calibration arrangement comprised soil and a sensor placed in a 200 mm diameter plastic jug. Each sensor was logged continuously for two hours.

The results of sensor calibrations are presented in Appendix B with equations of best fit. Calibration of pressure sensors proved to be repeatable and stable. Quadratic or

cubic equations were found to best fit the pressure sensor calibration data. Calibration of moisture sensors was erratic and proved difficult to approximate with mathematical equations. The erratic behaviour is assumed to be related to the hysteresis experienced between the wetting up and drying cycles. Observations of wetter or dryer conditions were noted during calibrations as an aid to fully characterise sensor behaviour.

4.2.4 INSTALLATION

Sensor installation was undertaken in phases to meet the drilling programme and the availability of sensors in Australia at the time of placing the order. The first installation consisted of three dual channel temperature/pressure sensors installed at depth in Aquifer 1 zone at each station. The second installation made up the remainder to the sensors and the data loggers.

The exact installation depth of the Aquifer sensors was left for the field analysis of PCPT data and disturbed sampling of material recovered during drilling activities. The installation of bank sensors was predetermined to an approximate depth as the target soil layer was the non-cohesive silty/sand-sand/silt material in the upper 2-3 m. In addition to this, some sensors, such as Bank pressure sensors, not only monitor the groundwater conditions of the non-cohesive soil but the lagging drawdown effect within the saturated bank.

Geotechnical observations indicated that material within the Aquifer zone was generally a coarse sand layer at approximately 5.5 m deep which appeared significant at treatment 1 but tapered towards treatment 3. The location of sensors with respect to bank stratigraphy is presented in Section 5**.**

Installation of pressure sensors varied depending on the depth and the method of drilling, however, the in situ configuration is all similar. The configuration consists of an inverted presaturated pressure sensor covered with a filter and attached to a 25 mm diameter PVC stand pipe, as illustrated in Figure 4.4. The filter offers a barrier to any soil entering the inlet port and the PVC tube houses the sensor cable and acts as a well to allow probing of the water level to confirm calibrated sensor measurements. The PVC tube has perforations adjacent to the sensor for approximately 500 mm of its length. This allows water to enter the tube and form a free surface equivalent in height to the pressure head in the region of the sensor.

Upon termination of each installation drill/auger hole the PVC standpipe was measured to length and cut onsite and the inverted pore water pressure sensor attached to the standpipe. The arrangement was placed centrally in a 100 mm diameter hole so the top of the standpipe was flush with the ground surface. Once in place, uniform grade fine gravel filled the bottom 2 m of the hole, which was then covered with a 0.5 m layer of saturated bentonite. The remainder of the hole was backfilled with excavated material leaving the top 0.5 m of the hole to be filled with saturated bentonite. The bentonite layers were used to seal the hole from rainfall/runoff infiltration.

Moisture sensors were installed using a similar arrangement with the sensor temporarily fixed up-right to the end of a PVC standpipe and the sensor cable passed through the standpipe. The arrangement was installed in a 100 millimetre diameter auger hole drilled 100 mm deeper than the target depth. The bottom 100 mm of the hole was filled with a moisture adjusted soil mix made from excavated material. The moisture sensor was then placed on this material and covered with the remainder of the soil mix. A sample of the soil mix was taken for moisture content determination at the JCU soils laboratory and compared with the initial sensor measurements. The remainder of the hole was filled with excavated material compacted in 200 mm layers. As each layer was compacted the temporary PVC pipe was extracted and sensor cable coiled without looping.

All sensor cables were secured in trenches and connected to a data logger for logging of the initial insitu moisture and pressure conditions.
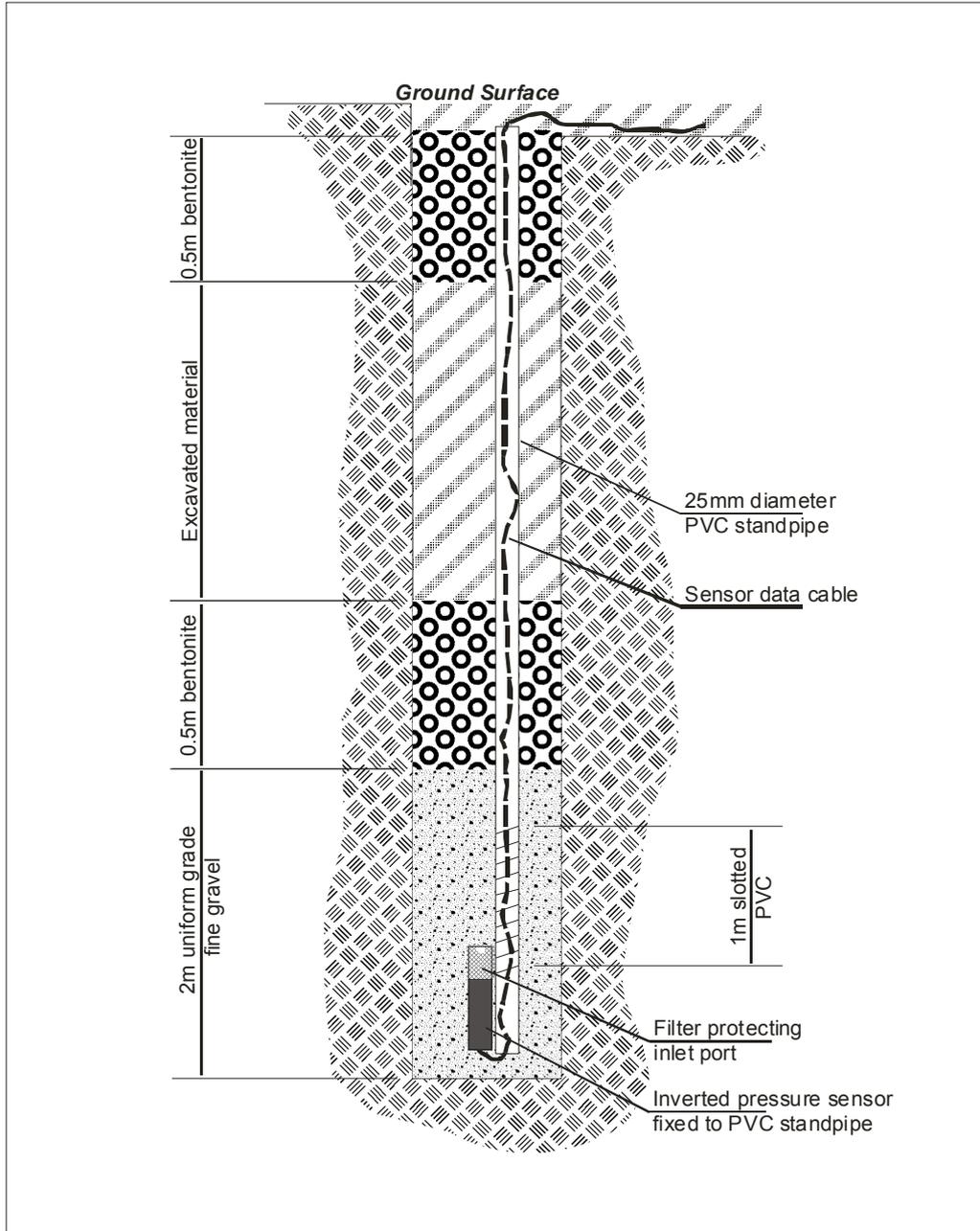
Figure 4.4　Typical pressure sensor installation.

Labels in figure:

- Ground Surface
- 0.5m bentonite
- Excavated material
- 0.5m bentonite
- 2m uniform grade fine gravel
- 25mm diameter PVC standpipe
- Sensor data cable
- 1m slotted PVC
- Filter protecting inlet port
- Inverted pressure sensor fixed to PVC standpipe

Chapter 5

FIELD RESULTS

This section presents test results of laboratory and fieldworks and examines site data related to subsurface conditions, general soil behaviour and subsurface water monitoring

5.1   LABORATORY AND FIELD TESTING

Laboratory testing of soil samples recovered during fieldworks was performed at the JCU soils laboratory. Testing included visual and physical classification of disturbed samples and saturated falling head permeability testing of undisturbed samples. Field testing included in-situ constant head permeability testing of shallow stream bank soils encountered within the upper bank at Station A.

Individual field and laboratory test results are presented in Appendices A and B respectively.

5.1.1   CLASSIFICATION TESTING

Laboratory classification testing included atterberg limits, moisture content and sieving (Grain Size Distribution) tests. Testing was performed on samples recovered during fieldworks in October and December 1995. Australian Standards AS1289 and AS1726 were generally followed, however, sample preparation was slightly modified according to experience in testing tropical soils by Eckersley (1995).

The modified method of sample preparation involved air drying instead of oven drying prior to dry sieving and liquid limit samples were soaked for a minimum of 12 hours prior to testing. Eckersley (1995) utilised air drying to maintain the natural grain sizes rather that oven drying, which was thought to destroy the natural grain sizes and thus change the soil behaviour.

Dry sieving was later replaced by wet sieving and found to be more productive and representative of in-situ soil behaviour. Sieve sizes less than 2.36 mm were generally utilised and considered sufficient for the grain sizes encountered. Sample sizes were generally smaller than specified by the relevant standard, however this was considered

acceptable for the purpose of general classification testing. Laboratory classification test results are summarised in Table 5.1 below.

5.1.2   LABORATORY PERMEABILITY TESTING

Laboratory permeability testing of undisturbed U50 samples was performed using a method adapted from Eckersley (1995) and described by Wallace, Hines and Golding (1977). The authors typically prepared the test arrangement by placing an extruded and cut specimen in a perspex container filled with bentonite slurry to prevent leakage down the sides of the specimen. To avoid sample disturbance the adapted test method retained the sample in the U50 stainless steel sample tube. The sample tube thereby replaces the perspex container and bentonite. Furthermore, a falling head test method was adopted for testing the fine grained material. The falling head test procedure by Head (1994) was adopted for testing.

The testing apparatus included scaled manometer tubes, of various internal diameters, for measuring test water volumes and a water bath to maintain a constant back pressure and sample saturation. The saturated permeability is determined using the following equation presented by Head (1994).

$$k = 3.84 \frac{aL}{At} \log_{10}\left(\frac{h_1}{h_2}\right) \times 10^{-5}$$

…………………..(5.1)

Where:

k = saturated permeability (m/s)

A = cross-sectional area of soil (mm^2)

L = length of specimen (mm)

h_1 = initial height in stand-pipe (mm)

h_2 = final height in stand-pipe (mm)

a = cross-sectional area of stand-pipe (mm^2)

t = time between measurements h_1 and h_2 (minutes)

Preparation of test specimens involved removing all sealing wax and disturbed material from each end of the tube and preparing a roughened planar surface. A sample from each end of the test specimen was retained for determination of pre-test moisture content conditions. The test specimen dimensions and diameter of the U50 tube were then recorded.

Table 5.1   Summary of laboratory classification test results.

Sample No.	Depth (m)	Laboratory Test Results								Description	Falling Head Permeability Test (m/s)
		%< 425μm	%< 75μm	LL	PL	PI	m/c (%)	Soil Class			
Station A											
AA$_1$TP 1	0.5	99	30						SM	Very silty SAND	
AA$_1$TP 3	1.5	97	35						MS	very sandy SILT	
AA$_1$P3	2.0	25	10						SM	slightly gravely, silty SAND	
AA$_1$P5	2.2	50	26						SM	slightly gravely very silty SAND	
AA$_1$P6	2.3	33	18						GM	very silty, very sandy GRAVEL	
AA$_1$TP U50	3.1						23		CS	Silty very sandy CLAY	1.4×10^{-10} / 0.00026
AA$_1$TP 7	3.5	100	55						CS	very sandy CLAY	
AA$_1$TP 9	4.5	100	64						CS	very sandy CLAY	
AA$_1$TP U50	5.45						29		CS	Very sandy CLAY	7.1×10^{-9} / 0.026
AA$_1$TP 11	5.5	100	52						CS	very sandy CLAY	
AA$_1$TP 12	6.0	29	13						SC	clayey, gravely SAND	
AA$_1$TP U50	6.75						35		CS	Very sandy CLAY	2.1×10^{-9} / 0.0071
Station Ba											
BaB$_1$P1	1.3	100	55						MS	very sandy SILT	
BaB$_1$M1	1.3	99	50						MS	very sandy SILT	
BaA$_2$P1	1.4	31	13						SG	silty very gravely SAND	
BaA$_2$P2	1.5	-	44						CS	very sandy CLAY	
BaA$_1$TP4	2.0	100	85						CS	sandy CLAY	
BaA$_1$TP U50	3.2						13		CS	Silty very sandy CLAY	1.5×10^{-9} / 0.0053
BaA$_1$TP9	4.5	92	41						MS	very sandy SILT	
BaA$_1$TP11	5.5	99	38	35	17	19			CS	very sandy CLAY	
BaA$_1$TP U50	7.3	50	16				15		SC	clayey SAND	1.4×10^{-8} / 0.049
BaA$_1$TP U50	7.8	-	40						CS	very sandy CLAY	
BaA$_1$TP U50	8.4								CS	very sandy CLAY	2.8×10^{-9} / 0.01
BaA$_1$TP U50	8.6	50	32						SC	very clayey SAND	
Station C											

Sample No.	Depth (m)	Laboratory Test Results							Description	Falling Head Permeability Test (m/s)
		$\%<$ 425μm	$\%<$ 75μm	LL	PL	PI	m/c (%)	Soil Class		
CaA$_1$TP9	4.5	100	26	28	18	10		SC	very clayey SAND	
CaA$_1$TP13	6.5	99	31	34	17	17		SC	very clayey SAND	
CaA$_1$TP U50	7.2	63	37					CS	very sandy CLAY	
CaA$_v$P6	2.5	85	43					CS	very sandy CLAY	
CaA$_v$P7	3.0	87	43					CS	very sandy CLAY	

A fine gravel filter was placed between two coarse fibreglass discs on each end of the test specimen. The filters minimised any percolation and aeration problems during testing. The test specimen was then sealed with rubber end caps and then placed vertically, half submerged in a water bath. The end caps secured the filters and provided a suitable adaptor to connect flow lines. All test specimens were presaturated and de-aired prior to testing by applying 10 kPa suction, for approximately 4 hours, to the top inlet port of the submerged specimen.

Testing involved firstly recording the time and the height between the initial manometer level and the water bath. Manometer levels were then recorded at regular intervals during the progress of testing. If at any time manometer levels remained constant or appeared abnormally slow, the specimen was again de-aired or a smaller diameter manometer used. The saturated permeability was calculated during the progress of testing to determine if equilibrium conditions had been achieved. Typically after two days of testing the arrangement was disassembled and material extracted for determination of moisture content and material classification. Tests results are presented in Appendix B and summarised in Table 5.2 below.

Table 5.2   Laboratory falling head saturated permeability test results.

Sample location/depth	Visual material description	Permeability (m/s / mm/hr)
AA_1TP - 5.25-5.65 m	very sandy CLAY/SILT	7.1×10^{-9} / 0.026
BaA_1TP - 7.25-7.75 m	clayey SAND	1.4×10^{-8} / 0.049
AA_1TP - 6.50-7.00 m	silty CLAY	2.1×10^{-9} / 0.0071
BaA_1TP - 3.0-3.4 m	silty very sandy CLAY/SILT	1.5×10^{-9} / 0.0053
AA_1TP - 2.9-3.3 m	silty very sandy CLAY/SILT	1.4×10^{-10} / 0.00026
BaA_1TP / 8.25-8.65 m	very sandy CLAY/SILT	2.8×10^{-9} / 0.01

5.1.3 FIELD PERMEABILITY TESTING

In-situ field permeability testing was performed within the top bank at Station A to further assess the saturated permeability of the shallow silty SAND/sandy SILT material. The results are verified with those attained by Eckersley (1995) and utilised in modelling streambank subsurface water conditions.

The test method is described in Section 2.8.1. Testing was performed at four locations within the top of bank at Station A. The test hole was prepared using a 55 millimetre diameter hand auger advanced to a depth of about 300 mm below ground surface. Surfaces of the test hole were brushed to remove any smearing effect from auguring. The test hole was initially filled with water and allowed to develop a saturated test zone for approximately 30 minutes. Testing commenced with filling the test hole with water

and placing a full mariotte bottle within the hole. The mariotte bottle was then adjusted so a 270 mm water height level was maintained in the test hole. Mariotte water levels and corresponding times were recorded until a constant rate had been achieved or the mariotte bottle emptied. This method proved to be easily managed and productive when simultaneously running tests. Test results are presented Appendix A and summarised in Table 5.3 below. Test results compare well with expected values and those obtained by Eckersley (1995).

Table 5.3   Field saturated permeability test results, Station A, Silty Sand.

Test label	Location	Permeability (mm/hr)
StnA2 run1	Edge of vegetation 5 m upstream of StnA	3.8
StnA2 run2	Edge of vegetation 5 m upstream of StnA	15
StnA2 run3	Edge of vegetation 5 m upstream of StnA	16
StnA2 run4	Edge of vegetation 5 m upstream of StnA	17
StnA3 run1	3 m inside vegetation, 8 m upstream of StnA	3
StnA3 run2	3 m inside vegetation, 8 m upstream of StnA	1.5
StnA5 run1	Top of bank 5 m upstream of StnA	4
StnA5 run2	Top of bank 5 m upstream of StnA	3

5.2   STRATIGRAPHY AND SOIL BEHAVIOUR

The stratigraphy and behaviour of the Bube soils have been previously investigated by Eckersley (1995). This examination hypothesised the failure mechanism and provided input to the design of the trial bank stabilisation treatments. This study has undertaken additional investigations to further characterise the stratigraphy and soil behaviour for site monitoring and streambank modelling purposes. This section presents results of these investigations and summarises the overall findings to date on site stratigraphy and behaviour of the Bube soils.

5.2.1   STRATIGRAPHY AND GROUNDWATER

Eckersley (1995) investigated the stratigraphy at treatments 1 and 2 with trial pits and visual observations. Subsurface investigations for the current study included cone penetration tests and drillholes along the adjacent headland and shallow (up to 2 m depth) auger holes traversing the stream bank at each station. Of the excavator pits investigated by Eckersley (1995) only A2 coincides with the current investigations within the upper bank at station A.

The stratigraphy of the Bube site is summarised in Figure 5.1 as a longitudinal section of the riverbank. Figure 5.2, Figure 5.3 and Figure 5.4 present the site stratigraphy in

riverbank cross-sections at each of the subsurface monitoring stations, A Ba and C respectively.   In general the site stratigraphy is characterised by a shallow alluvial silty SAND layer overlying a dominate CLAY/SILT layer classified as a low plasticity CLAY (CL). For the purpose of this investigation these layers have been identified as "Zone 1" and "Zone 2" respectively. The upper Zone 1 layer covers the entire site to a depth of up to 2m. This layer characteristically becomes finer with depth, often emerging as a very sandy SILT at the interface with the Zone 2 layer. Zone 2 extends to a level below the riverbed of about 9m depth below the top of bank. Dispersed within the Zone 2 CLAT/SILT layer appears bands of very sandy SILT and a coarse drainage/aquifer layer (Zone 3) within the upper 4-5 m of the bank. The Zone 3 layer is relatively coarse grained (SPG) and below the groundwater table within trial treatment 1. As this layer extends downstream, towards trial treatment 3, it rises above the groundwater table and becomes finer grained (SMG). Significant water was observed, by Eckersley (1995) and during this investigation, discharging from this layer, notably at trial treatment 1.

Significant longitudinal and lateral variability in site stratigraphy was observed in both investigations. In particular the profile observed at station C (trial treatment 4) which exhibits no drainage/aquifer layer and generally finer grained material.   Lateral variability in soils at each station is likely attributable to collapse material mixing within the lower bank and as a result of formation works during construction of trial stabilisation treatments.

Generally the site materials are cohesive with the clayey sands and silty sands showing significant resistance to disintegrating when soaked. However, the Zone 1 silts and sands, when air-dried, showed less resistance to disintegration when soaked. The silty clays are generally dispersed with orange and mottled grey. Small lumps of organics were observed in the lower depths of the bank. The ground water level was observed between relative levels 3.5 m and 4.0 m AHD.

The CPT results shown in Appendix A are presented as plots with soil interpretation according to Fellenius and Eslami (2000), Plates A3.1 to A3.6, and profile parameterisation with soil interpretation according to Robertson and Campanella (1983), Plates A4.1 to A4.6.   The CPT results generally compare well with material tested from adjacent boreholes.   Furthermore, the CPT results provide greater stratigraphic detail compared with the conventional disturbed and undisturbed sampling. The inferred "sensitive fine grained" inferred by Robertson and Campanella (1983) consistently coincides with the SILT/CLAY (Zone 2) material. In some instances

CPT pore pressure readings peaked in this material, making it necessary to undertake dissipation tests. This generally indicates the presents of a low permeability-fine grained material. CPT probings at stations D and E show a similar profile to those at stations A, B, Ba, and C. Probing at both stations encountered refusal on a dense coarse layer.

5.2.2   BASIC SOIL BEHAVIOUR

Field permeability tests performed within the Zone 1 material at station A show a saturated permeability ranging between 3 and 15 mm/hr. Permeability data appears presents to two distinctive sets, indicating variation in the fines content and presence of micro pores from roots.

Laboratory permeability tests were performed on six undisturbed U50 tube samples taken from stations A and Ba. The samples tested were taken from low permeability materials such as sandy SILT and SILT/CLAY. Material classification was typically determined when each tube was cut and examined after testing. Results from theses tests show that this material generally has a saturated permeability between 0.6 to less than 0.0036 mm/hr.

Classification tests performed on the Zone 1 material shows it has a moderate dry strength and that it rapidly disintegrates when immersed in water. Material in the other zones appears to have greater dry strength and resistance to disintegration upon wetting.

5.3   MONITORING & ANALYSIS

The purpose of the subsurface monitoring installation has been to investigate the response of subsurface water pressures and soil moistures to rainfall and fluctuations in groundwater and flood water levels, and to observe the relative effects of the alternative drainage systems on these subsurface conditions. This will ultimately identify the mechanisms that saturate bank materials and develop rapid drawdown conditions.
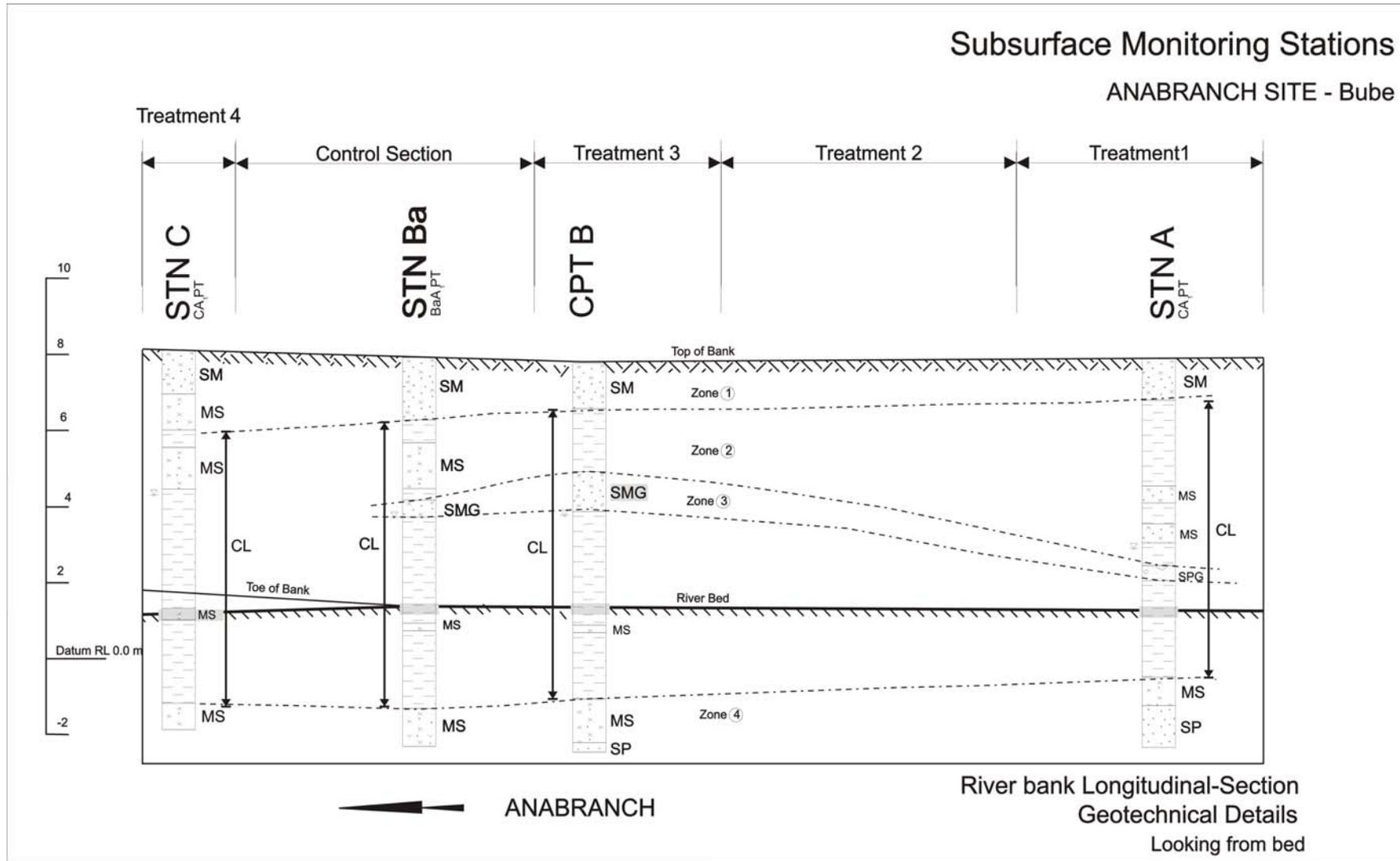
Figure 5.1   Anabranch Bube geotechnical longitudinal section.
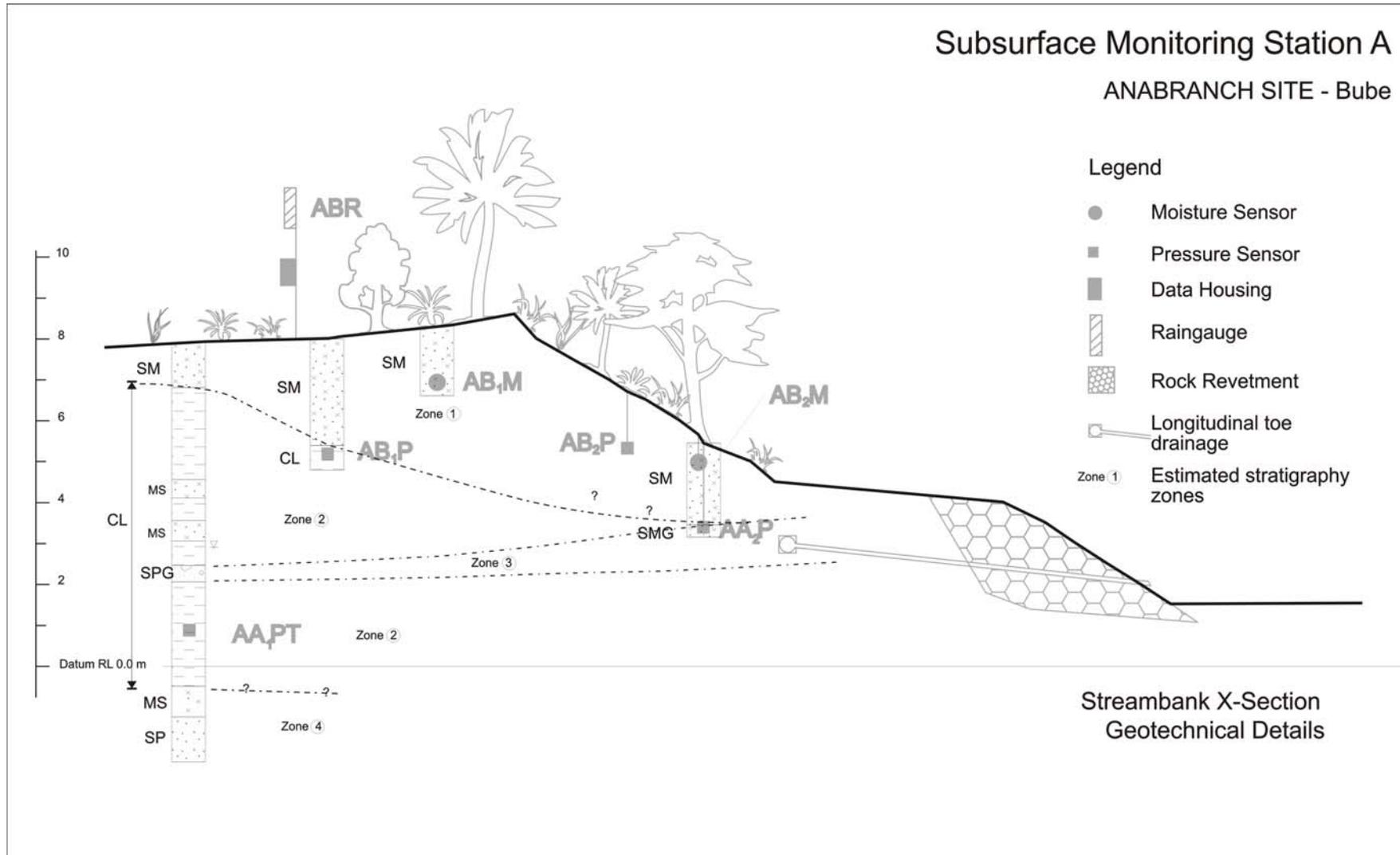
Figure 5.2   Anabranch Bube Subsurface Monitoring Station A - geotechnical streambank cross-section.
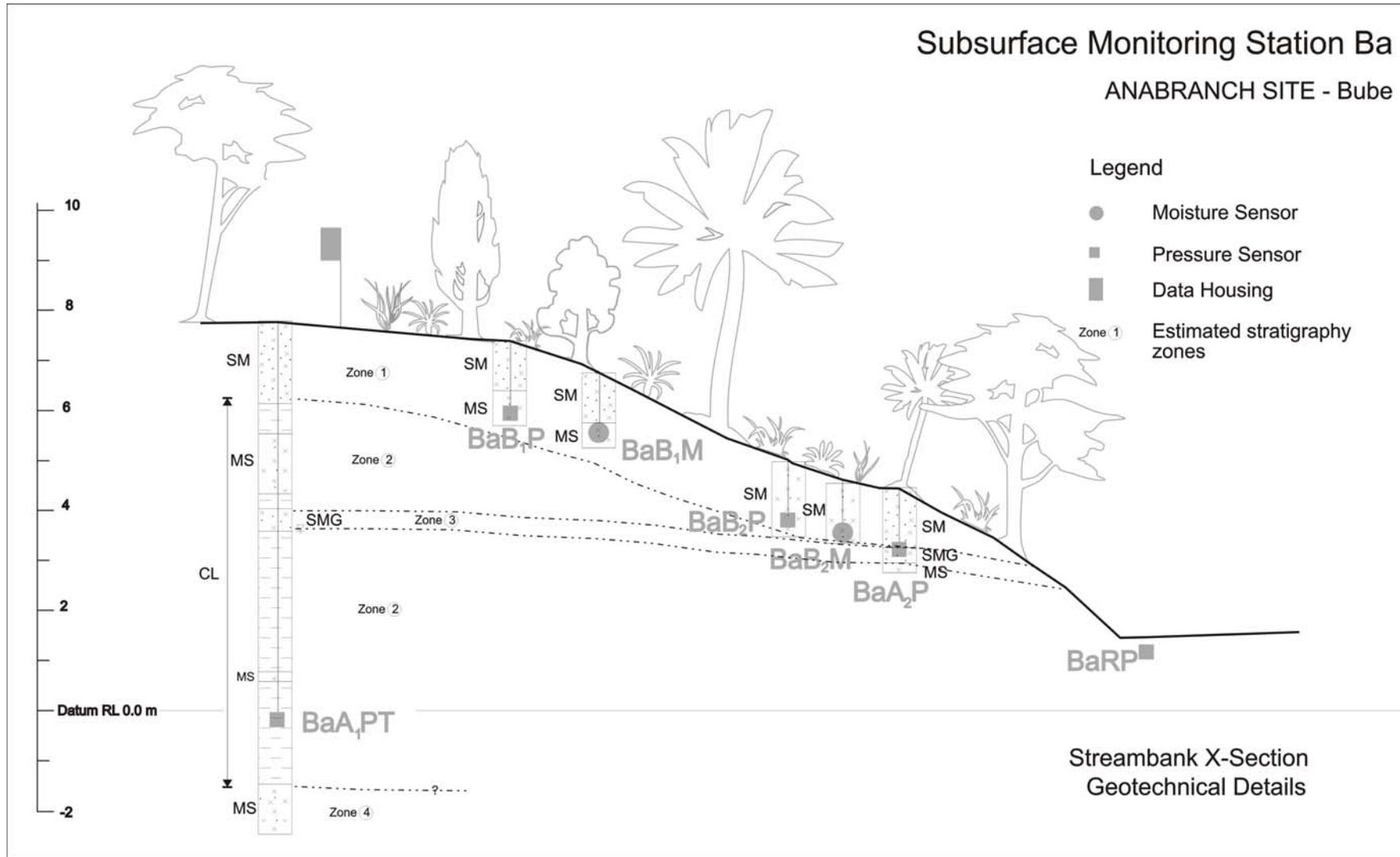
Figure 5.3   Anabranch Bube Subsurface Monitoring Station Ba - geotechnical streambank cross-section.
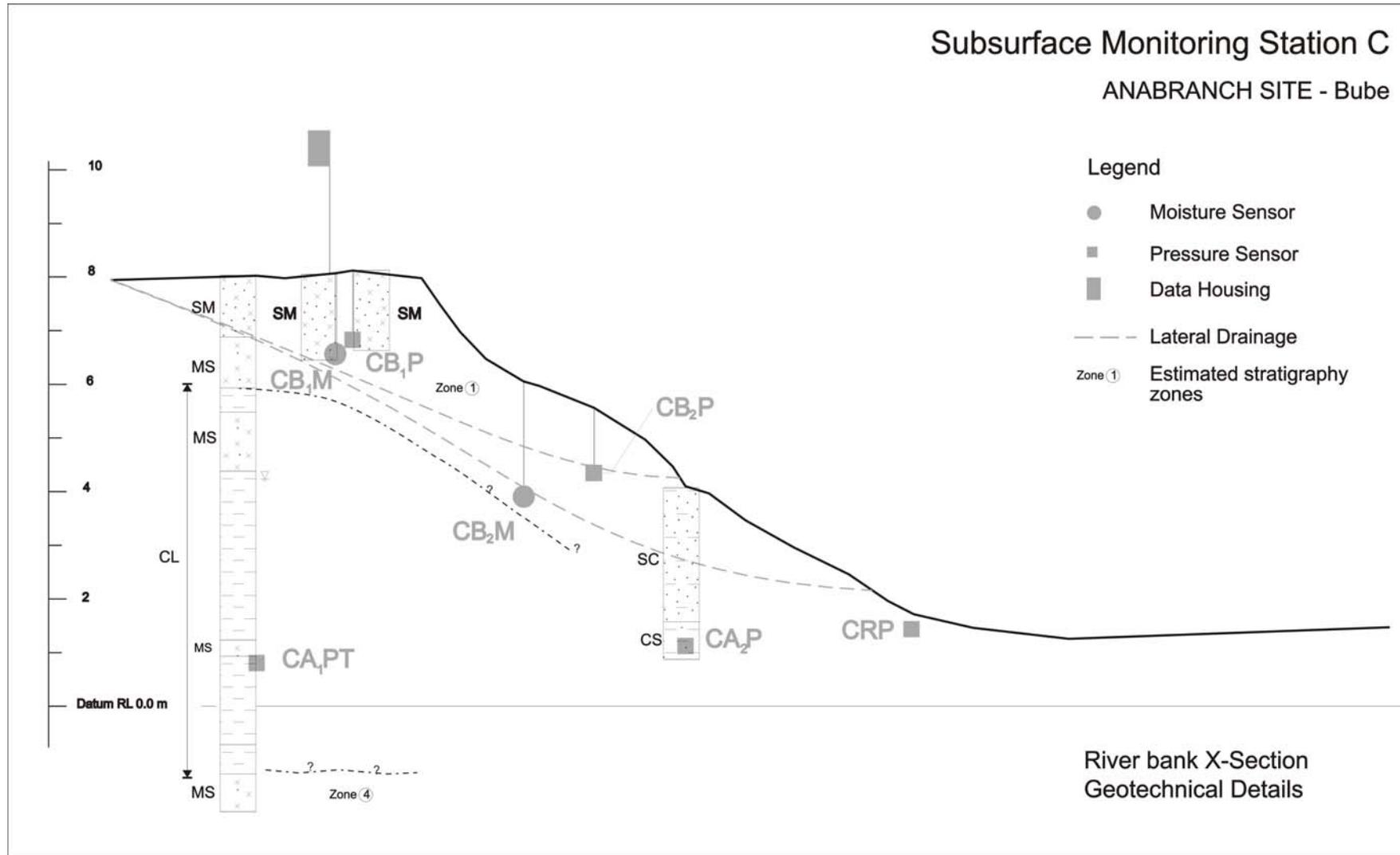
Figure 5.4   Anabranch Bube Subsurface Monitoring Station C - geotechnical streambank cross-section.

This section documents the methodology applied to the various data gathering tasks and presents an interpretation of data from two flood events in March 1996 and February 1997. Furthermore an evaluation of the results will develop an understanding of the in-situ mechanisms involved.

5.3.1   ACQUISITION OF FIELD DATA

Subsurface monitoring at Bube commenced on 14 December 1995 and logged continuously until mid 1997. Within this period one minor event in March 1996 has been successfully recorded while a second event in February 1997 has only been vaguely recorded by station A. Also during this period a close watch has been kept on any meteorological activity that would lead to significant discharges in the Herbert River. The flood alert system monitored by the Hinchinbrook Shire council has also provided early warning for travelling to the Bube site and monitor instrumentation and physically record flood characteristics. Daily rainfall totals near the Macnade school, approximately 5 km from Bube, have been recorded by a council worker and provided a calibration to automated measurement taken at the site. Flood hydrographs at the Ingham Pump station and Gairloch Bridge have been recorded by instrumentation and a landholder respectively. These additional recordings provide a backup and a means of validating the data recorded by site instrumentation.

Monitoring data was typically downloaded every two to three months and data loggers reset and charged with new batteries. On two occasions the battery supply to a data logger had failed leaving a period of no data. The first failure occurred during a period without flooding, however, the second occurred at station Ba immediately before the February 1997 flood event. Consequently no data was recorded at this station during the flood event. Furthermore, continual instrumentation problems at station C resulted in data being only recorded at station A for this event. This data is, however, proved difficult to interpret due to the deterioration of in-situ sensors. Data covering the March 1996 flood event was downloaded in two stages, which included measurements up to the flood peak and those after the peak. This event was successfully recorded by stations A and Ba whereas station C proved to be erratic due to in-situ sensor failure. Data covering the two flood events was transferred to JCU and corrected using calibration data recorded for each sensor. Data from pressure sensors is represented as piezometric heads (RL AHD) while data from moisture sensors is represented as a fluctuation over the preflood average, and site rainfall as cumulative millimetres of rain fallen during the measured interval (30 minutes). Data from moisture sensors has

been presented in a dimensionless form (i.e. relative to a preflood average) to alleviate the hysteresis experienced in field data and not encountered when calibrating. The dimensionless moisture sensor data is presented on time based plots in Appendix C, Plates C2.1 to C2.3 respectfully.

Measurements and observations of groundwater discharge from drainage pipes have been recorded at trial treatments 1 and 4 in May 1996. These measurements were performed to establish the performance characteristics of the subsurface drainage treatments. Outflow measurements were taken near the subsurface monitoring station A at trial treatment 1 and from lateral drainage pipes at the downstream end of trial treatment 4. Outflow rates were measured four to five times at each pipe using a measuring flask and stop watch.

5.3.2   SURFACE MONITORING DATA

The March 1996 flood height hydrographs at the Ingham pump station, Gairloch Bridge, Bube and Anabranch Bridge are shown in Figure 5.5. Flood heights shown at Bube are from the river pressure sensors CRP and BaRP and manual gauge board readings taken approximately 300 m upstream of sensor BaRP. Height differences between river sensors and gauge board readings can be attributed to the flood slope between locations. This flood event achieved a minor flood ranking and peaked at 2.4 m below the top of the bank at Bube, as shown in Plate 5.1. Consequently the upper 2 m of the silty sand-sandy silty material, known to be vulnerable to slumping, escaped from being inundated. Furthermore the flood duration and recession rate appears marginal compared to the 1994 floods presented in Chapter 3. Sensor CRP exhibits a noticeable change in flood height after data was downloaded around the flood peak. Data recorded before downloading appears to be influenced by a blocked vent, which provides atmospheric pressure compensation to the differential sensor membrane.
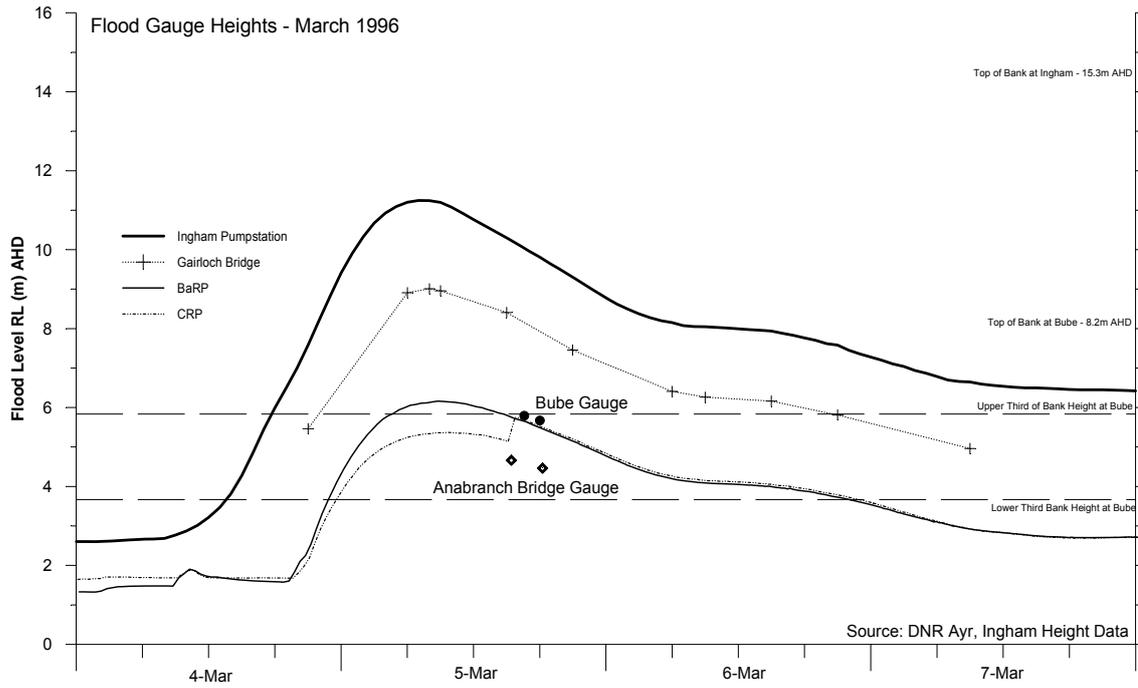
Figure 5.5   March 1996 Herbert River and Anabranch Flood Height Hydrographs

Plate 5.1   March 1996 flood peak at Bube (looking downstream from treatment 1).

The February 1997 flood height hydrograph data, shown in Figure 5.6, was only obtained for the Ingham pump station. Subsurface monitoring Instrumentation failure prevented any instream flood levels from being recorded at the Bube site. However, anecdotal evidence indicates that flood levels were over the bank at Bube for three days. An indication of this is shown by the extrapolated flood height hydrograph at Bube shown in Figure 5.6. Refer to Appendix C, Plate C for method of Bube flood height extrapolation. The flat stage of the Bube hydrograph indicates the duration of over bank flows. Site conditions prevented safe access to the site for two weeks after the flood. Monitoring data was downloaded and site conditions recorded. A small slump failure, shown in Plate 5.2, was observed within the upper bank at trial treatment 3 during flood recession. Closer inspection identified that at the time of the failure the flood level was approximately two metres below the top of bank (as indicated by the demarcation of the flood washed slumped material). Furthermore slumping was confined to the upper bank where revegetation had locally deteriorated. Numerous small roots and macro pores were observed throughout the scarp face and groundwater was seeping abundantly from the lower bank below the scarp. Seepage indicated subsurface water levels remain elevated well after flooding. Minor scour holes around the rock revetment at treatment 2 and numerous flattened trees were also observed as a result of flooding. Plate 5.3 shows the fluvial undercutting of the toe at Trial Treatment 4. Minimal damage was observed where vegetation was well established at treatment 1.
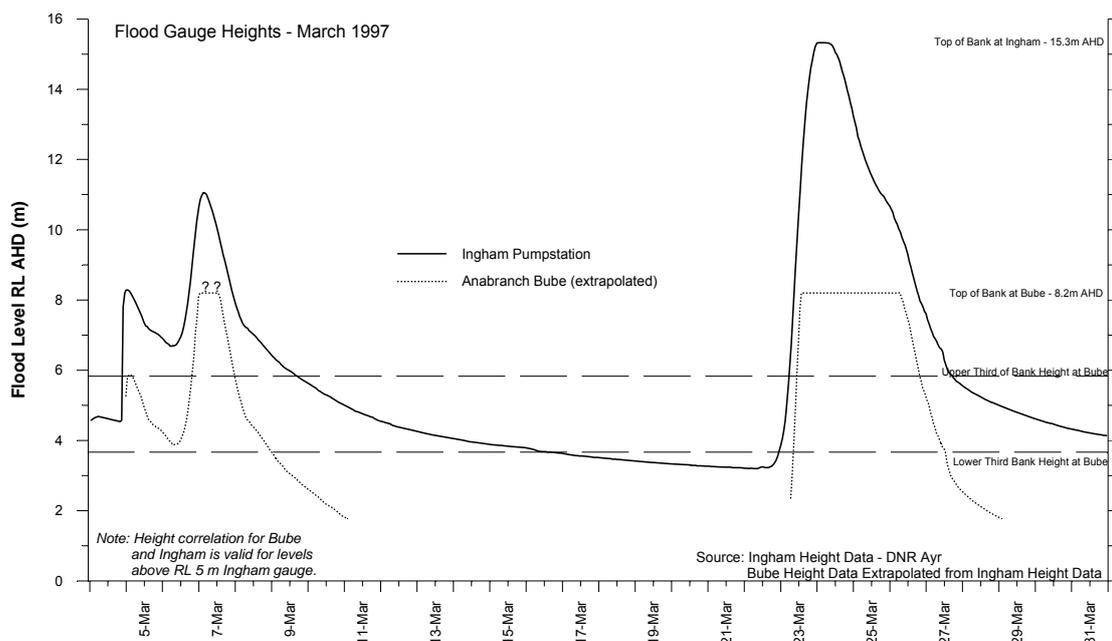
Figure 5.6   **March 1997 Herbert River and Anabranch Flood Height Hydrographs**

Plate 5.2   **March 1997 minor slump at Bube (looking downstream from treatment 3).**

Plate 5.3   **March 1997 fluvial undercutting of the toe and in-situ drainage pipes at Trial Treatment 4 (looking upstream)**

Table 5.4 summaries hydrograph characteristics of the major and moderate February 1994 floods, the minor March 1996 and major March 1997 floods recorded at Ingham

pump station. Peak gauge heights, maximum recession rates and flood durations are greatest for the 1994 and 1997 floods. Also shown is the dry portion of the bank at Bube. This is critical at Bube since the material most likely to slump is the upper 2-3 m of alluvial Sandy/Silt-Silty/Sand. The flood duration for the first February 1994 flood is comparable to the March 1996 event. However, the 1994 event remained above the 1996 flood peak for 3 days, indicating that the bank was completely saturated once flood levels started to recede.   Furthermore bank saturation would be maintained during flood recession due to the influence of regional elevated groundwater levels. The flood recession rates shown are for the upper two-third height of the bank at Bube. Comparison of this rate is useful for validating slope stability analyses, as it provides an indication of rapid drawdown rates required to slump a fully saturated bank.

Table 5.4   February 1994, March 1996, and February 1997 Flood Characteristics

Flood Event	Peak Gauge[1] Height-Ingham (metres)	Max. Recession Rate (mm/hr)	Flood Duration[2] (days)	Streambank failure (location)
1 February 1994	12.9 *(0.0)*	312	4.5	extensive upper bank
22 February 1994	9.1(0.0)	166	8	extensive poss. from prev. flood
5 March 1996	6.5 (2.4)	118	4	none
24 March 1997	14.1(0.0)	126	4[3]	local minor upper bank
Notes	1 values shown in brackets *(2.4)* indicate dry bank height above flood peak at Bube			
	2 approximate only			
	3 Overbank or bank full pre-flooding at Bube saturates bank materials			

5.3.3   SUBSURFACE MONITORING DATA

March 1996 subsurface monitoring data recorded at stations A, Ba and C is shown in Appendix C, Plates C2.1 to C2.3 respectfully. March 1997 data recorded at station A is shown in Appendix C, Plate C2.4.   The data is presented as temporal plots of subsurface pressure heads (Relative Levels-Australian Height Datum) and soil moisture fluctuations (relative to preflood conditions).   Site rainfall in each figure is recorded at station A as half-hourly totals and daily totals recorded manually near Macknade Mill.   Pressure sensor zeros as well as top and toe of bank levels are marked and labelled on the piezometric head scale.   The subsurface monitoring data for March 1996 has been interpreted and presented in Figure 5.7 to Figure 5.12 as flood rise and recession cross-sections showing levels within the bank and the stream.

March 1996 data from stations A and Ba show response times and magnitudes compare well to instream flood levels (BaRP). Most data recorded at station C for the

same event exhibits erratic responses compared to instream flood levels. This behaviour shows no plausible trend and is likely attributable to instrumentation failure or blocked ventilation tubes. The moisture sensors at all stations appear to be influenced by hysteresis, which was encountered during calibration. Consultation with instrumentation supplier did not provide any solution to resolving this problem. Therefore, moisture sensor measurements are plotted as dimensionless values relative to an average of preflood measurements. The preflood average is indicated by the zero baseline. Although no quantifiable information is available form these sensors, the data provides an indication at a point in the bank when changes occur in in-situ soil moisture state, i.e. switches indicating when subsurface water levels are at/above/or below the sensor. Site rainfall logged at station A shows expected trends when compared with subsurface and instream sensor responses. However, the daily totals when compared with those recorded manually nearby at Macknade Mill show little correlation. The lack of correlation is possibly due to wind shear experienced by the elevated gauge at Bube and sensor clogging.

March 1997 subsurface monitoring data at station A was only recorded up to 11th March excluding the major flood event on 22nd and 23rd March. Subsurface responses show similar patterns as recorded in the March 1996 event. Although no in stream flood levels where recorded, the subsurface pressures recorded by sensor AA2P provide a reasonably accurate indication of the instream level. This is based on the proximity of the sensor to the treatment in-situ drainage pipes, which not only aid drainage from the bank but also aid bank infiltration. Accordingly, the response from this sensor shows a peak level below the top of bank and below the upper two metres of silt sand material. Therefore the extrapolated flood levels at Bube shown in Figure 5.7 should only be used as an approximation. As recorded in March 1996 the 1997 data shows the characteristic preflood response within the aquifer (sensor AA1TP) and the delay in recession of subsurface pressures compared with falling instream flood levels.

Flood Rise
Subsurface Pressures
Station A March 1996
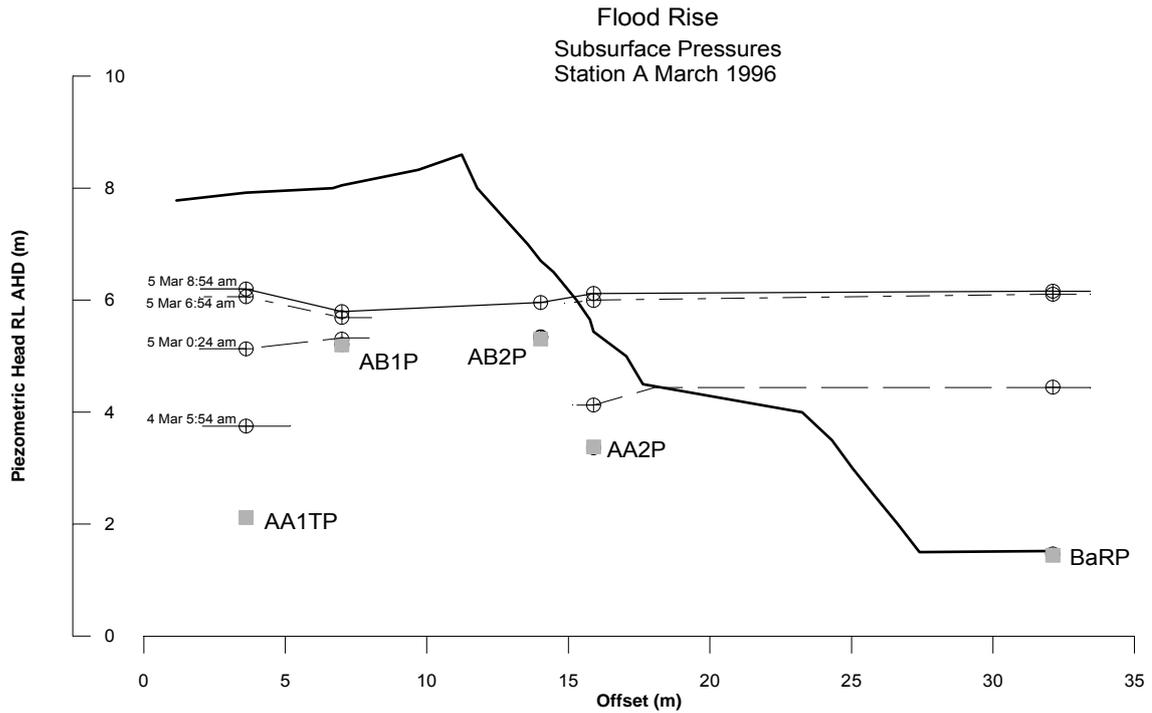
Figure 5.7   Interpretation of Herbert River Anabranch Bube Subsurface Pressures Flood Rise Station A – March 1996

Flood Recession
Subsurface Pressures
Station A March 1996
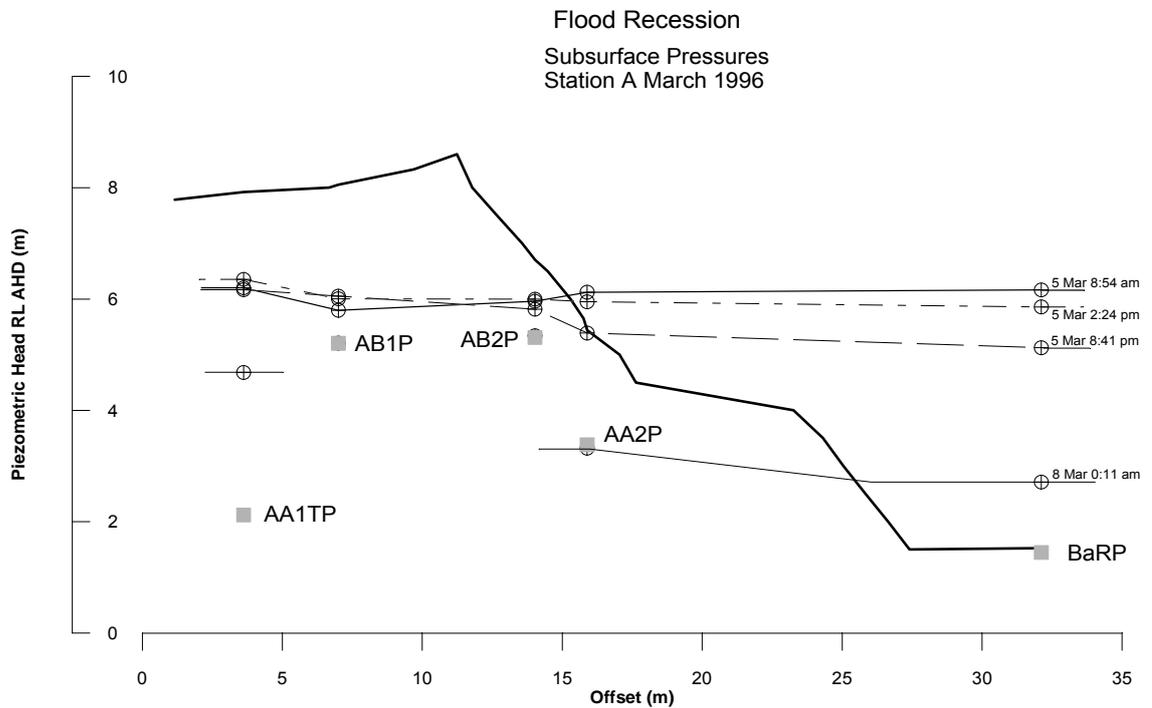
Figure 5.8   Interpretation of Herbert River Anabranch Bube Subsurface Pressures Flood Recession Station A – March 1996
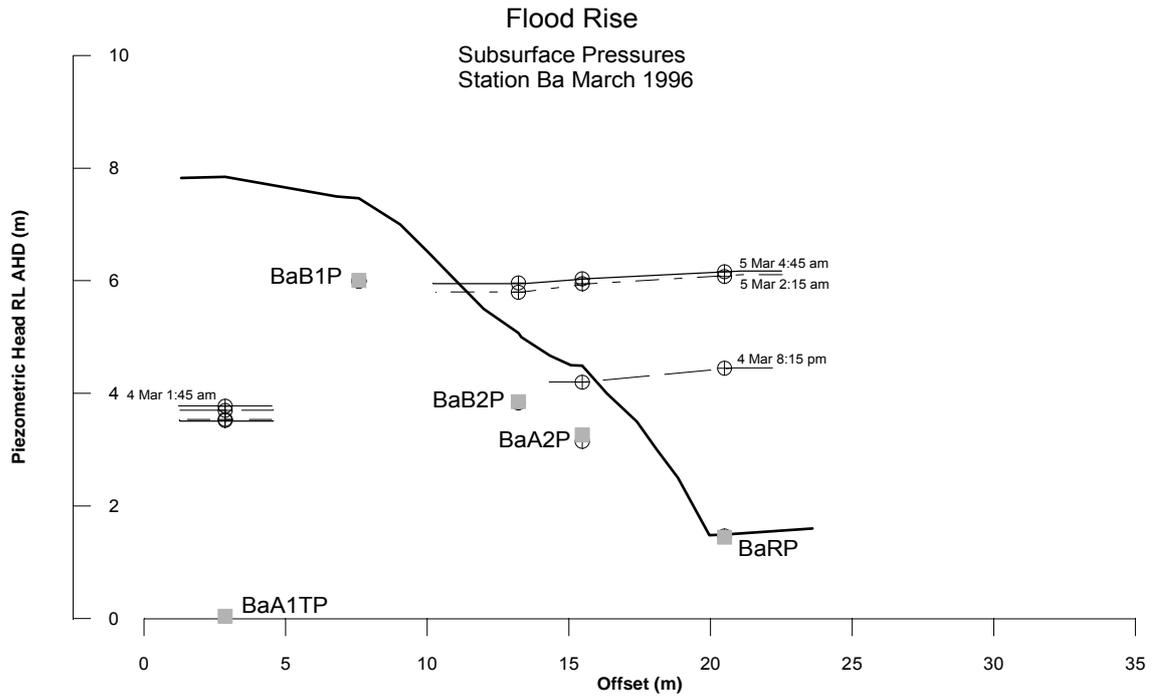
Figure 5.9   **Interpretation of Herbert River Anabranch Bube Subsurface Pressures Flood Rise Station Ba – March 1996**
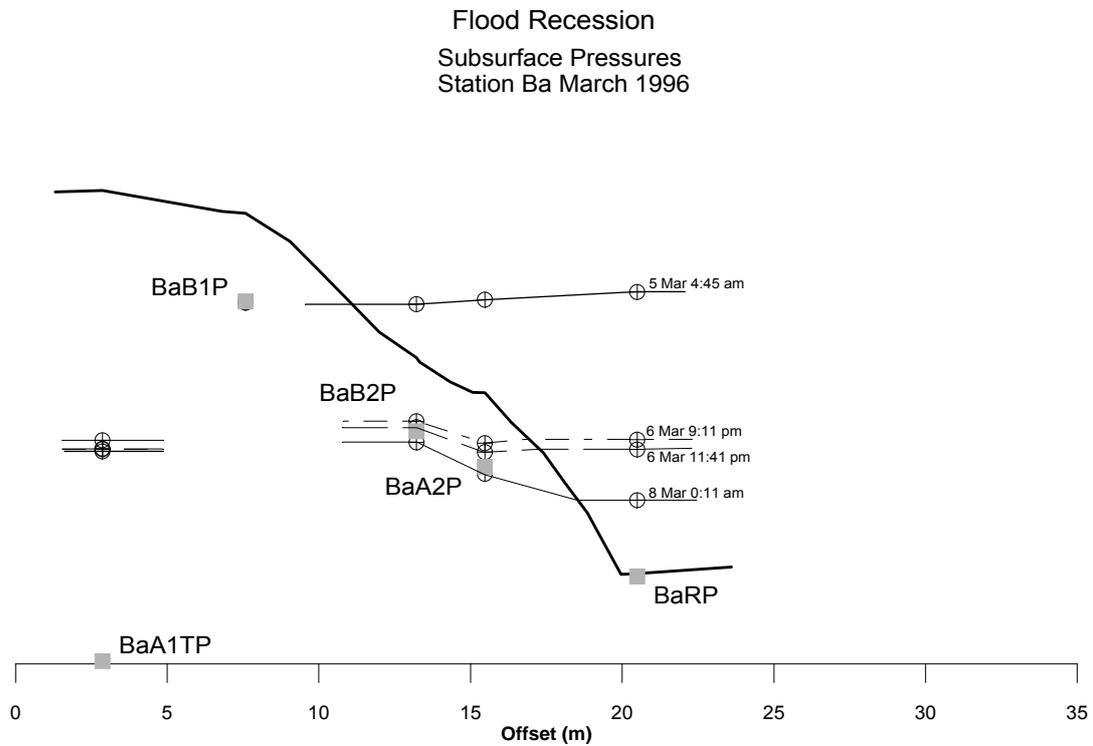
Figure 5.10   **Interpretation of Herbert River Anabranch Bube Subsurface Pressures Flood Recession Station Ba – March 1996**
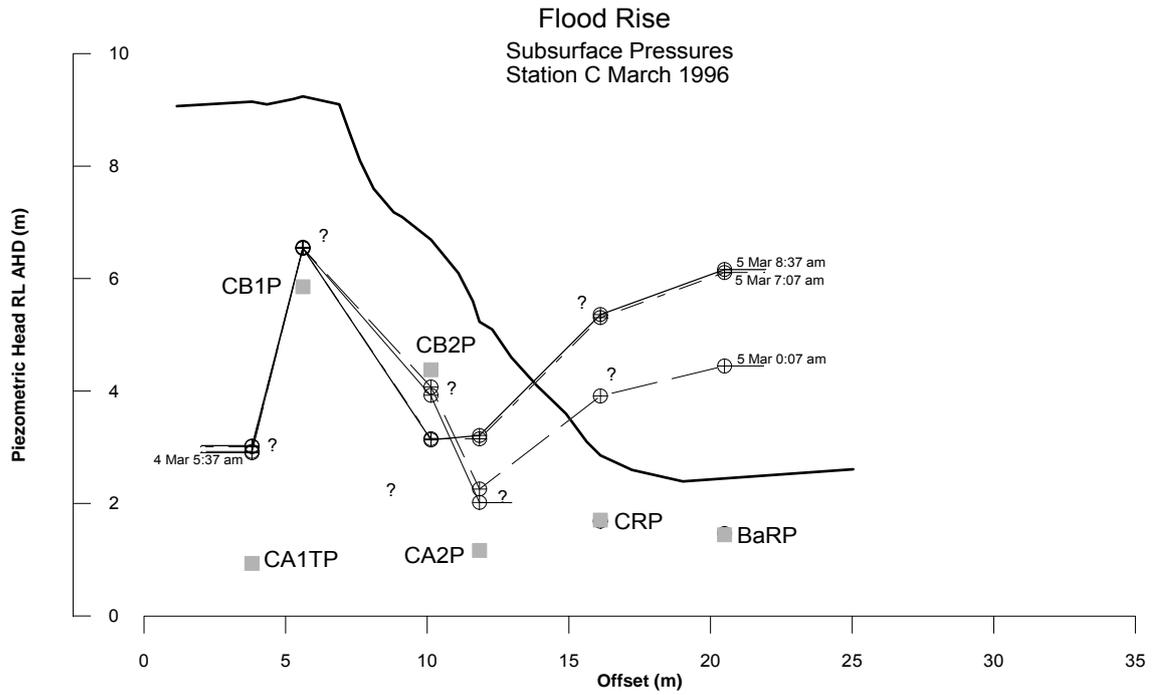
Figure 5.11 **Interpretation of Herbert River Anabranch Bube Subsurface Pressures Flood Rise Station C – March 1996**
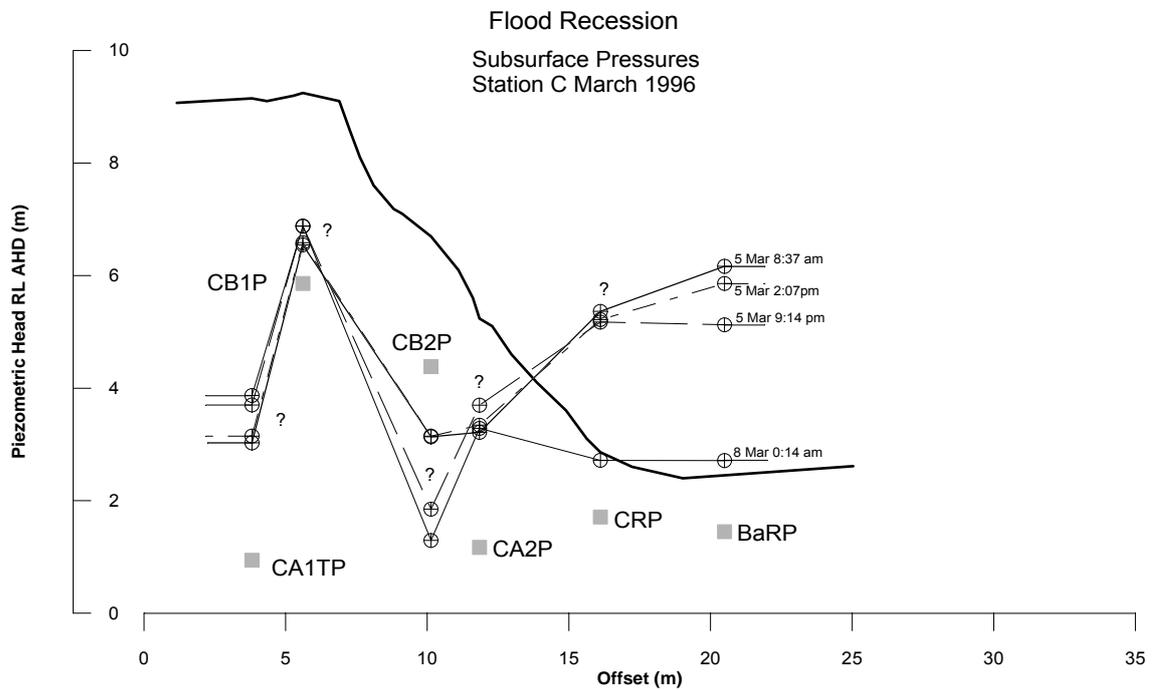
Figure 5.12 **Interpretation of Herbert River Anabranch Bube Subsurface Pressures Flood Recession Station C – March 1996**

5.3.4 SUBSURFACE DRAINAGE MONITORING DATA

Significant ground water seepage was observed by Kapitzke et al. (1995) when a porous drainage layer was exposed at Bube during preliminary geotechnical site investigations by Eckersley (1995). Eckersley (1995) identified the drainage layer as the S4 aquifer of Cox's 1979 thesis, refer Section 3. Design of the in-situ drainage pipes at Trial Treatments 1 and 4 (refer to Figure 3.10 and Figure 3.11) is to locally drain groundwater from the S4 aquifer (refer to Section 3.4.5), thereby locally lowering subsurface water levels in the lower bank. It was proposed that the groundwater seepage was recharged by flood water levels infiltrating through the river banks. However, periods of no flooding have exhibited a steady seepage released through the drainage systems. Therefore the groundwater recharge source is probably local floodplain rainfall infiltration raising the S4 aquifer water table, refer Chapter 3.

Trial Treatment 1 construction works were performed prior to subsurface monitoring works, however, construction works at Trial Treatment 4 were observed as part of the subsurface monitoring works. Prior to installation of in-situ drainage pipes at treatment 4, the lower bank condition appeared saturated and swollen with groundwater pressures. The wetting fringe of this groundwater was observed in the vertical face of the upper bank, approximately 3.5 from the top of bank. The lateral in-situ drainage pipes were installed at 1 metre centres from the top of the bank in semi-circle arcs. The in-situ drainage pipe outlets appear at various heights within 4 metres above the toe of the bank. The installation of each pipe generally resulted in groundwater being released through its outlet and accompanied by a noticeable reduction in bank swelling. This was more evident from drainage pipes closer to the toe. Initial outflow measurements from lower drainage pipes were undertaken by the contractor and found to be approximately 60 litres per hour. The variability in outflow observed between upper and lower drainage outlets is likely due to greater water pressures and soil hydraulic conductivities nearer to the toe of the bank.

Further measurements of subsurface water drainage outflows were made in May 1996 at trial treatments 1 and 4. The results of these measurements are presented in Table 5.5. Measurements at trial treatment 1 were taken from four drainage outlets between station A and trial treatment 2. Measurements at trial treatment 4 were taken from four drainage outlets, one coincident with station C and the remainder from the last three pipes at the downstream end of the treatment.

Table 5.5   Drainage outflow rates 7 May 1996

Trial Treatment	Drainage Pipe	Outflow Rate (Litres/hour/metre of bank)
1	adj. to Stn A	18.9
1	3 rd last downstream	245.4
1	2nd last	228.3
1	last	232.8
4	adj. to Stn C	1.2
4	3 rd last downstream	66.3
4	2nd last	0.0
4	last	45.3

Measurements at trial treatment 4 were taken from outlets closest to the toe as upper outlets exhibited no flow. Ponding of fresh water at the toe was observed at both sites and found to contain live small fish.

Outflow rates at treatment 1 appear to be greatest and more consistent closer to trial treatment 2. Measurements of sensor water levels were performed, coincident with outflow measurements, with a scaled water level probe dipped in the sensor's perforated stand pipe. These measurements recorded water levels only in the aquifer 1 sensors AA_1PT and CA_1PT. Outflow rates recorded at station C were smaller in magnitude and varied greatly depending on slight variations in outlet height.

5.4   EVALUATION OF SUBSURFACE WATER CONDITIONS

Although instrumentation failure plagued the subsurface monitoring program, what has been recorded can provide a valuable insight to the mechanisms involved in rapid drawdown bank instabilities. In-particular the questions:

- what influence does streamflow inundation have on saturating bank materials;
- what influence does a shallow water table have on saturating bank materials;
- what influence does site rainfall have on saturating bank materials;
- how significant is the lag between subsurface and streamflow water levels during flood recession;
- what rates of flood recession develop a lag between subsurface and streamflow water levels;
- how significant is the influence each factor, introduced in Chapter 2, has on developing or eliminating rapid drawdown bank instabilities may be addressed by the results so far obtained at Bube.

The following evaluation will be principally based on the more reliable March 1996 data by addressing the factors that appear to influence the subsurface water condition.

5.4.1 RAINFALL

During the March 1996 event the Macanade rain gauge recorded 113 millimetres prior to any response from any pressure sensor and 230 millimetres prior to the flood peak. Site rainfall shown in Appendix C, Plates C2.1 to C2.3 provides an excellent indication of the distribution of falls throughout the event. During the initial stages station A Bank 1 moisture and pressure sensors appear to respond to rainfall that precedes any rise of instream levels. This response seems more rapid with moisture sensors and appears to be short lived once the rainfall stops. The timing of these responses and the lack of a response from station A bank 2 and station Ba and C sensors, indicate rainfall/runoff has infiltrated through the relatively disturbed installation holes. Furthermore, bentonite plugs diverting or slowing the infiltration process have likely caused the delayed response experienced by pressure sensors. Overall the influence of rainfall/runoff infiltration saturating bank materials appears to be minor compared to streamflow and shallow watertable inundation. However, the pre-saturation affect of rainfall/runoff must not be discounted, as it may increase the hydraulic conductivity of the material, thus aiding inundation from streamflow and the shallow watertable.

5.4.2 STRATIGRAPHY

Stratigraphy can play an important role in controlling how or if bank materials become saturated. Stratigraphy at the site varies greatly, but can be broadly described by three zones, such as, the Silty Sand "Zone 1" material that overlies a less permeable SILT/CLAY "Zone 2" material, which includes a permeable drainage/aquifer coarse layer "Zone 3" material, as shown in Figure 5.1. The Zone 3 layer has sufficient hydraulic conductivity to allow movement of water through the bank during flood rise and rising groundwater levels. The Zone 2 material exhibits a saturated permeability that is likely to prevent any significant movement of water that would otherwise lead to rapid drawdown conditions. However the Zone 2 layer has several moderately permeable very sandy SILT layers which will greatly influence saturation. The absence of these and the drainage/aquifer layers at station C provide a basis for limited response in subsurface water levels at this area of the site.

5.4.3 SHALLOW WATERTABLE INUNDATION

The shallow watertable was initially observed during geotechnical investigations along the headland, between 3 to 5 metres below the ground surface. Similar investigations only observed wet material at the base of sensor AA2P installation hole, approximately the same level as the adjacent headland observation. These levels are essentially

maintained during non-flood periods and rise during flood events. Levels recorded by sensor AA1TP during the March 1996 and 1997 events show a rise well before water levels rise in the Anabranch. Cyclic small rises in instream levels are observed prior flooding as a result of tide levels being pushed from the mouth of the river. The characteristic rapid drawdown configuration of subsurface water levels is only observed at station A, where the aquifer influence is most prominent.

During both events the rising aquifer levels at station A appear independent to instream levels. The aquifer levels peak higher and remain high well after instream levels have fallen. In both flood events, aquifer levels peak after the instream flood peak. Pressures recorded within the upper bank at sensor AB1P appear to be influenced largely by aquifer levels rather than instream levels. This is indicated by the rise and fall rates similar to those recorded by the AA1TP sensor. Furthermore, the rise recorded by the AB1P sensor occurs before instream levels reach the height of the sensor. These observations indicate that the shallow watertable at station A has a significant influence on inundating bank materials and thus facilitating rapid drawdown conditions. This influence is less towards the toe, as the longitudinal drainage system tends to equalise the levels in this area to those in the stream.

Pressures recorded at sensor BaA1TP are also independent to instream levels and those recorded by upper and lower bank sensors. Furthermore pressures at sensor BaA1TP do not reach the same magnitudes as instream levels or even of those recorded at station A. This would indicate that aquifer water levels do not influence subsurface water levels at station Ba, as confirmed by the absence of any water seeping from the bank during non-flood periods. Pressures at other sensors generally match with instream levels.

5.4.4 STREAM INUNDATION AND STREAMFLOW

Stream inundation is the only saturating mechanism observed at station Ba. The responses recorded by sensors AA2P and BaA2P match instream levels. This is due to the influence of the longitudinal drainage system at station A and the more permeable material at station Ba. The flood rise response recorded by lower bank sensors (BaB2P and AB2P) also appears to match instream levels. However, the flood recession response lags the fall of instream levels indicating the development of rapid drawdown conditions.

In March 1996 the instream levels generally fall at a slow rate (118mm/hr) developing a maximum lag of 1.4 metres with subsurface levels recorded at sensor AB2P.   The great lag in subsurface levels recorded at station Ba was approximately 0.2 metres above instream levels. As a result of the low flood peak and duration (prevent full bank saturation) no bank failures were recorded on site.   However, the March 1997 flood event (22nd to 23rd March) exposed the site to significant overbank flooding for three days proceeded by a moderate rate of flood recession (126mm/hr) resulted in minor flooding within the upper bank. These observations indicate that stream inundation is the primary source of bank saturation at station Ba and that without the influence of an aquifer or significant overbank flooding, rapid drawdown conditions are unlikely to develop.

5.4.5   SUBSURFACE DRAINAGE

The longitudinal drainage system installed at trial treatment 1 (station A) appears to assist the inundation of lower bank materials during flood rise and reduces the lag of subsurface level within the lower bank to instream levels. The longitudinal drainage system appears to effectively reduce the local subsurface water levels as a result of the elevated aquifer levels.   However, the drainage system doesn't appear to influence water levels within the upper bank where aquifer levels appear to dominate the conditions.

Chapter 6

SUBSURFACE WATER MODELLING

Two-dimensional finite element modelling of transient seepage flows through a streambank cross-section has been undertaken to parametrically determine the instream infiltration and drainage conditions that develop rapid drawdown conditions. A generic bank cross-section with a 1 in 2 slope has been used as the model. Soil properties representing the instability prone Bube silty SAND (Zone 1) material have been used as the principal medium, to which transient boundary conditions, emulating various flood rise and recession conditions, have been applied. The parametric study deals exclusively with homogeneous isotropic soils, with particular consideration given to three streambank drainage conditions:

- homogeneous drainage conditions;
- drainage layer through the toe; and
- longitudinal drainage pipe.

All drainage conditions are subjected to flood recession-saturated permeability ratios ranging between 20 and 0.33. Results from flood rise modelling will examine the extent of instream infiltration whilst flood recession modelling will examine the development of rapid drawdown conditions. The results obtained through the modelling do not constitute a full analysis of streambank instabilities, but must be combined with an appropriate assessment of slope stability examined in Chapter 7.

Sensitivity of the modelling approach has been examined by comparing tests that vary individual parameters such as the saturated permeability, time steps and flood increments. Results are presented as snap shots of subsurface water level profiles. Outcomes from modelling will lead to possible enhancements in drainage systems as well as identify a likely rapid drawdown relationship between flood characteristics and soil properties.

6.1   SOLUTION TECHNIQUES, SATURATED-UNSATURATED METHODS

6.1.1   FLOWNETS

The flownet solution results in two families of curves, referred to as flow lines and equipotential lines. The flownet solution has been used extensively to analyse problems involving seepage through saturated soils, and is explained in most soil mechanics textbooks. There is an inherent problem with applying the flownet technique to saturated-unsaturated flow. Freeze (1971) stated that, "..the boundary conditions that are satisfied on the free surface specify that the pressure head must be atmospheric and the surface must be a streamline. Whereas the first of these conditions is true the second is not.". Typically what is done in saturated-unsaturated flow systems is to construct the free surface using empirical methods that neglect flow in the unsaturated zone.

6.1.2   MODELLING

Numerical methods are among the most powerful tools available for solving problems in subsurface hydrology. Methods range from one to three dimensional finite difference and finite element analyses. Development of these models has been required to solve complicated natural hydrologic problems without resorting to simplifications that are mathematically necessary but physically unrealistic. Furthermore, with the aid of the digital computer, these methods have greatly enhanced capabilities of achieving meaningful solutions to subsurface flow problems

Physical methods were used to solve problems in subsurface hydrology prior to the advent of readily useable numerical methods. The physical methods either relied on full scale monitoring or scaled models to provide fruitful information. These methods often required considerable time and resources to achieve results with limited transferability. Monitoring is still used today but for the purpose of confirming physical processes and as part of determining the geometry and hydraulic characteristics used in numerical applications. Physical modelling has seen limited use since the introduction of computer based numerical methods.

This section describes some of the physical and numerical methods used to solve subsurface flow problems, in particular those for unsaturated/saturated flow.

6.1.3 PHYSICAL MODELLING

The geotechnical centrifuge modelling technique was first used to solve slope stability problems where loading is predominantly due to the ground self-weight, (Schofield 1980). Common practice uses a test system attached to a counterbalanced arm that rotates at a desired speed to induce a centrifugal acceleration. The test system is generally a box that houses the test embankment, and has transparent sides so that visual observation can be made whilst rotating.

Seepage flow and streambank failure due to piping have also been modelled using this method, (Padfield and Schofield 1983; Sutherland and Rechard 1984; and Kusakabe et al. 1987). This requires a controlled supply of water which enters the test system through porous plates. Examination of slope stability involving seepage flow requires a test embankment scaled to reynolds similitude and appropriately accelerated to ensure darcian flow. The influence of viscous and seepage forces in this case makes a single scale factor difficult to achieve, consequently partial similitude must be adopted.

6.1.4 FINITE DIFFERENCE MODELLING

L. F. Richardson introduced in 1910 the method of Finite Differences as a method of calculating the solution of partial differential equations. Although Richardson did not explicitly examine transient problems in subsurface flow, he did outline a method of solving the diffusion equation. The solution to the diffusion equation was later applied to steady state subsurface flow problems and incorporated into computer programs for expedient use. The finite difference approach replaces derivates at a point by ratios of the changes in appropriate variables over a small but finite interval. Thus an approximation is made at a finite number of points.

Fluid flow through a saturated soil mass can be described using Darcy's law. Fluid flow through an unsaturated soil mass can be equally described by this law by making the coefficient of permeability a function of matrix suction within the soil, (Richards 1931). This formulation is referred to as Richards equation, and assumes that Darcy's law holds for unsaturated systems. This has been proven to be valid under most conditions of soil water flow, provided the soil can be treated as a continuum.

As available computing power has increased, the numerical solution of the general Richards equation has become feasible. This has facilitated wide use of finite difference and finite element techniques for solving subsurface flow problems. However, numerical problems have been encountered in efficiently solving Richards

equation (Section 2.7.2, page 25) under certain conditions, especially saturated conditions and situations of steep moisture content gradient. Ross (1990a) details a computer model called SWIM that efficiently overcomes most of the problems encountered when solving Richards equation.

A model, called SWIM, developed at CSIRO Davies Laboratories by Ross (1990a) has been used to validate TSEEP. SWIM is a finite difference model that solves Richard's equation for one dimensional unsaturated flow. SWIM simulates one-dimensional water infiltration and movement in soils using the finite difference method. SWIM allows for runoff, surface storage, surface conductance, and evapotranspiration from up to four different types of vegetation to be included in the analysis, and it allows soil properties to be varied with depth to realistically model actual profiles. SWIM has been used extensively by the CSIRO and in studies at JCU and has proven to be reliable and accurate but is limited by its one dimensional analysis. This study uses SWIM to calibrate and validate the processing of soil-water conditions by TSEEP. The hydraulic conductivity model and numerical methods used in SWIM can be referenced in Ross (1990a) and (1990b).

6.1.5 FINITE ELEMENT MODELLING

The finite element method is a versatile numerical method that has been used to solve problems of engineering and mathematical physics. The finite element method was first applied in the 1940s in the field of structural engineering and in the late 1960s in non-structural engineering applications, such as fluid flow and heat conduction. Further extension of the method was made possible by the adaptation of weighted residuals method (Galerkin), which allows the finite element method to be applied directly to any differential equation.

In general, the finite element method models a body as an assemblage of small parts (elements). Each element has properties that emulate in-situ characteristics, and is of simple geometry making it much easier to analyse than the body itself. The body has boundary conditions such as water levels, impermeable surfaces, and flows that emulate the external or internal conditions which force movement. The finite element solution is gained with simultaneously solving linear algebraic equations that have been formulated for each element.

Lam et al. (1987) proposed a two dimensional finite element model to simulate transient seepage for complex groundwater flow systems. The model theory is based

on Richards equation, (Fredlund 1981), and allows for flow in both saturated and unsaturated zones. A model, called TSEEP, developed at the Centre for Geotechnical Research, Sydney University, by NP Balaam and JR Brooker is based on the work by Lam et al. (1987). TSEEP is used in this study to investigate streambank subsurface water conditions during flood rise and recession. The governing partial differential equation used in TSEEP in presented in Section 2.7.3, page 26.

TSEEP for Transient SEEPage, solves a governing partial differential flow equation based on Fredlund (1981) unsaturated flow theory used to describe continuous flow in saturated-unsaturated soil systems. TSEEP performs a 2-dimensional finite element seepage analysis of a plane or axi-symmetric section through which steady state seepage is occurring. It can accommodate complex geometries with arbitrary degrees of heterogeneity and anisotropy for different soils. Constant total head, flux or impermeable boundary conditions are used to investigate steady state seepage conditions. Enhanced usage of the model can extend its ability to incorporate dynamic boundary conditions, which are useful for emulating transient processes such as a rising or falling river level.

The relationship between moisture retention and pore pressure is defined in TSEEP by specifying pore pressure values and the rate at which moisture retention varies between the pore pressure points. TSEEP does not incorporate hysteresis into this relationship. The hydraulic conductivity soil-water-pressure relationship used in TSEEP is a simple exponential model developed by Gardner (1958). The relationship between *K (hydraulic conductivity)* and *h* the soil water potential is shown in equation (6.1).

$$K(h) = K_s \exp^{(-b|h|)}$$

$$\text{.........................(6.1)}$$

Where K_s is the saturated hydraulic conductivity and *b* is a soil parameter that represents the relative rate of decrease of *K* with decreasing *h*. The *b* parameter is related to the width of the soil pore size distribution, (Russo 1988), and typically ranges between 2 for sands and 25 for clays. Owing to its simplicity, this model may describe the hydraulic conductivity relationship for different soil, but for a limited range of soil water potentials. The reader is referred to Russo (1988) for a useful comparison of the models proposed by Gardner (1958), Brooks and Corey (1964) and van Genuchten (1980). TSEEP applies a linear suction profile above the watertable with zero suction at the water surface and suctions above increasing proportionally to the height.

The results of the modelling can be used to identify the seepage face progression during flood recession, the effects of subsurface drainage on reducing elevated subsurface water levels and degree of streambank infiltration during flood rise.

6.2   MODELLING APPROACH

Streambank rapid drawdown conditions develop when the subsurface water levels in the bank remain above the falling water levels in the stream. This typically develops when streambanks that have been inundated prior to or during flood rise are then subject to a rapid recession of flood water levels. Inundation develops from either or a combination of instream conditions, rainfall runoff infiltration or a rising groundwater. The difference between subsurface water levels in the bank and water levels in the stream imparts a stress-strength imbalance that can lead to collapse of the bank.

The approach taken to model rapid drawdown conditions has involved analysing the stages of flood rise and recession separately. The influences of instream rise and recession are only examined as it is considered those influences from rainfall runoff and rising watertable will only aid the rapid drawdown process. Furthermore, it is uncertain whether instream conditions alone can develop a rapid drawdown condition.

Of the factors that influence streambank stability, presented in Chapter 2, those of subsurface drainage, instream characteristics, soil properties, stratigraphy and bank configuration, predominantly influence, to some degree, the rapid drawdown process. The later factors of stratigraphy and bank configuration are maintained constant throughout the modelling while the remaining factors are used to parametrically examine instream infiltration and rapid drawdown drainage processes. The reasoning behind this approach is justified by the necessity to simplify the model. This is achieved by only examining the material that is susceptible to slumping and which is in a bank configuration that is typical of field profiles.

A simplified eight metre high bank cross-section with a 1 in 2 slope has been used as the model that best represents a typical streambank configuration. The 1 in 2 slope (26°) is considered an average angle of repose for the sandy silt material tested by Eckersley et. al (1992) (refer to Table 3.2) and cohesionless material (non-plastic silt) in Lambe and Whitman (1969).   Three subsurface bank drainage configurations, homogeneous, drainage layer through the toe, and longitudinal drainage pipe, as shown in Figure 6.1, are separately incorporated into the model. The performance of

these drainage configurations is examined by applying the same instream rise and recession boundary conditions.
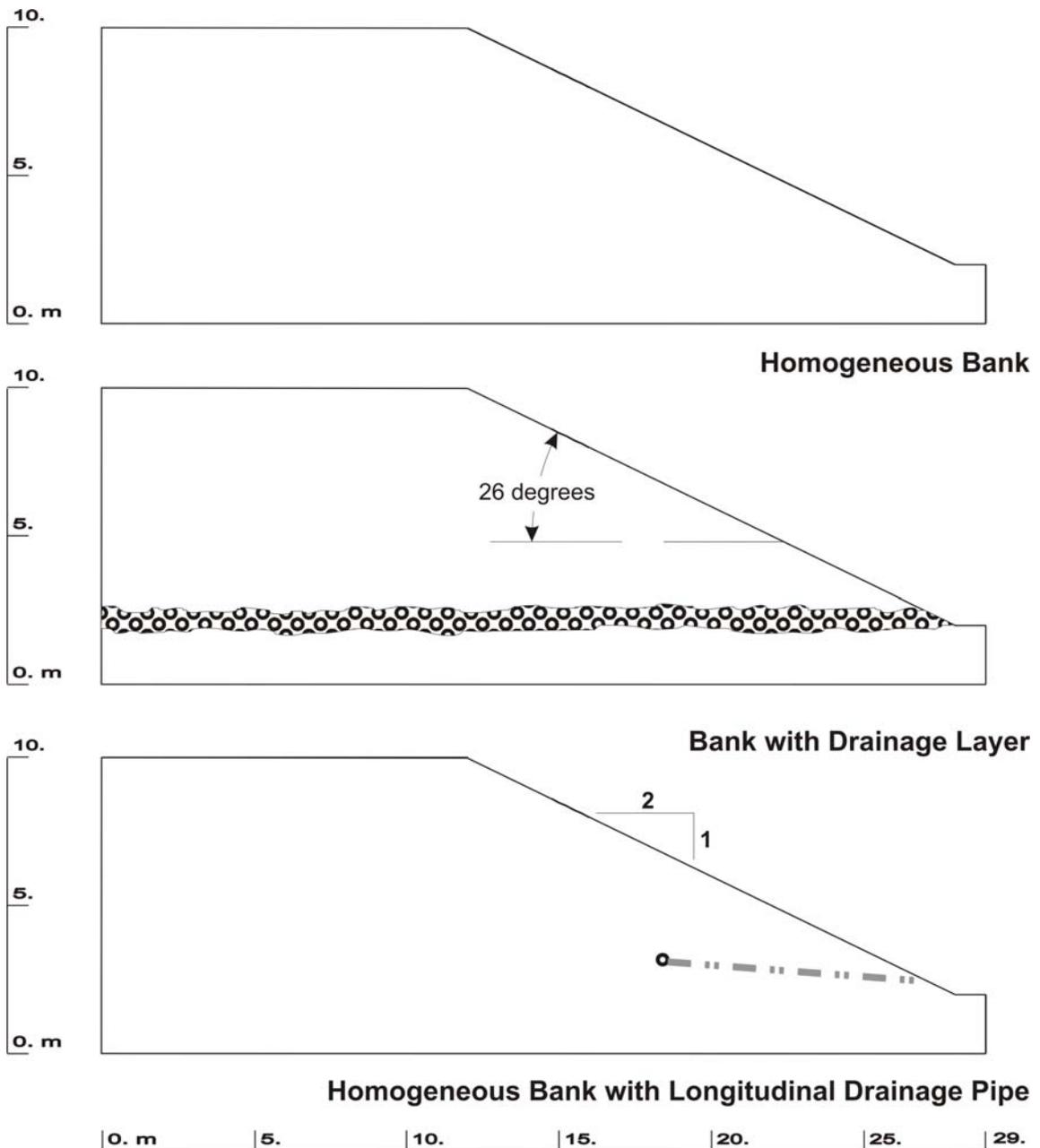
Figure 6.1   Generic Groundwater Models

6.2.1 MESH SIZE

The streambank cross-section is represented by a finite element mesh shown in Appendix D, Plate D1.1. The mesh generated is made up of 882 elements and 998 nodes. Rectangular elements have been predominantly used with some triangular elements along the 1 in 2 face. Over half of the elements are meshed adjacent to the 1 in 2 slope. Concentrating elements in this region allows the variable and important

transient process to be modelled accurately. Larger elements are used adjacent to the left boundary.

6.2.2 INITIAL MOISTURE CONDITIONS

Initial moisture conditions in TSEEP are calculated by specifying the water level height and whether the pore pressure distribution above the water level is set to zero or is negative and increasing linearly above. This can be manually entered into the data file or TSEEP can use output from the previous simulation to perform a "hot start". The initial instream water level for flood recession is set level with the top of the bank while for flood rise the water level is at the toe of the bank. In both cases the modelled flood rate is started at the initial water level.

6.2.3 BOUNDARY CONDITIONS

Impermeable boundary conditions have been used on the bottom and left faces of the model. The top face has a boundary condition emulating atmospheric conditions and the 1 in 2 slope has a transient flood rise and recession boundary condition. The left impermeable face emulates a condition that prevents any water from draining outward. This drainage condition is adequate during saturated bank flood recession when assuming symmetrical drainage either side of the face. However, during unsaturated bank flood rise, this boundary condition becomes inadequate once water accumulates at this face. It would be more realistic to extend the left face beyond the extent of flood rise infiltration. Although the model may not represent field conditions during flood rise, it does indicate how a longitudinal drainage pipe and a drainage layer influence the flood rise infiltration process.

Flood rise and recession transient boundary conditions are emulated by applying, in the form of a total head condition, a stepwise linear hydrograph along the 1 in 2 face of the model. This is achieved by raising or lowering a hydrostatic water level at fixed increments along this face. The rate at which increments are moved is equivalent to the flood rate modelled. In the case of the longitudinal drainage configuration, this transient boundary condition is also applied as a sink or source at the internal drainage point. The modelled flood rates have been based on the hydrological data examined in Chapter 3 and range from 5 to 300 mm/hr for flood recession and 300 and 600 mm/hr for flood rise. The sensitivity of varying flood increment size is examined to determine what influence these transient boundary conditions have. The sensitivity of varying the time steps set in the model is also examined.

6.2.4 SOIL MOISTURE CHARACTERISTICS

Parameters describing the unsaturated and saturated soil moisture characteristics have been taken from results of field permeability tests and of suction tests performed by CSIRO. The relationship between the matric suction (negative pressure head of an unsaturated soil) and the moisture content and the relationship between the permeability and the moisture content are the two basic soil moisture characteristics required for simulating unsaturated soil-water flow. Results from field permeability tests are summarised in Table 3.2 and from suction tests in Table 3.3. Classification test results on a material tested by CSIRO are shown in Table 3.2. The relationships between matric suction and moisture content used in the TSEEP models are summarised in Table 6.1. The four matric suction - moisture content models have been labelled with abbreviated names as follows: MRPP1 to MRPP4.

Table 6.1   **Modelled soil moisture retention and pore pressure relationships**

MRPP1		MRPP2		MRPP3		MRPP4	
Pore Pressure	Retention	Pore Pressure	Retention	Pore Pressure	Retention	Pore Pressure	Retention 2x VARM2
(kPa)	(1/kPa)	(kPa)	(1/kPa)	(kPa)	(1/kPa)	(kPa)	(1/kPa)
	0.0001		1.0000*		1.0000*		1.0000*
-1471.500		-1471.500		-1471.500		-1471.500	
	0.0001		1.0000*		1.0000*		1.0000*
-294.300		-294.300		-294.300		-294.300	
	0.0002		1.0000*		1.0000*		1.0000*
-98.100		-98.100		-98.100		-98.100	
	0.0004		1.0000*		1.0000*		1.0000*
-29.430		-68.670		-68.670		-68.670	
	0.0020		0.0004		1.0000		0.0008
-9.810		-29.430		-29.430		-29.430	
	0.0025		0.0020		1.0000		0.0040
-4.905		-9.810		-9.810		-9.810	
	0.0046		0.0025		1.0000		0.0050
-2.934		-4.905		-4.905		-4.905	
	0.0041		0.0046		0.7000		0..0092
-0.981		-2.934		-2.934		-2.934	
	0.0001		0.0041		0.0100		0.0082
0.000		-0.981		-0.981		-0.981	
	0.0001		0.0001		0.0100		0.0002
10.000		0.000		0.000		0.000	
	0.0001		0.0001		0.0001		0.0002
1000.000		10.000		10.000		10.000	
	0.0001		0.0001		0.0001		0.0002

* These numbers are superfluous since ψ > -68.670 kPa i.e. 7m of suction head

The relationships shown in Table 6.1 have been used in various tests to validate and examine the sensitivity of modelling subsurface water conditions. TSEEP b values that

describe the variation of permeability when pore pressure is in suction have been determined from comparisons with the Laliberte et al. (1966) expression used by Wallace and Leonardi (1976) in THEWET. This approach was necessary, as available information was insufficient to facilitate direct application of b values. It also provided an opportunity to scrutinise the relationship by Gardner (1958) against the proven and reliable relationship by Laliberte et al. (1966). According to Wallace and Leonardi (1976) the Laliberte et al. (1966) relationship for silty/sands-sandy/silts can be appropriately represented by parameters shown in Table 6.2. Plate D2.1 presents the comparison between THEWET and TSEEP permeability-pore pressure relationships. Also shown in Plate D2.1 is the "window" defining the range of permeabilities utilised in the generic streambank model. TSEEP b values that best represent the Laliberte, Corey and Brooks (1964) relationship appear to range between 0.015-0.03. The influence of TSEEP b values will be assessed later in a sensitivity analysis. The saturated permeabilities used in the TSEEP model have been 4.167×10^{-6} and 1.389×10^{-5} m/s (15 and 50 mm/hr).

Table 6.2   **Parameters used to represent the silty/sand-sandy/silt material when using the Laliberte et al. (1966) relationship**

Parameter	Value
θ_{sat} (saturated volumetric moisture content)	0.42 (%)
$\theta_r = \theta_{sat} - 0.05$ (volumetric moisture content of resaturated soil) #	0.37 (%)
θ_{res} (residual volumetric moisture content) #	0.1 (%)
n (unsaturated hydraulic conductivity index) #	4
K_r (resaturated hydraulic conductivity)	2.22×10^{-6} (m/s)
# Wallace and Leonardi (1976)	

A summary of model parameters used in this study are presented in Appendix D, Plates D3.1 and D4.1, along with typical examples of input files on Plates D5.1 to D5.25.

6.3   TSEEP VALIDATION

TSEEP has been used to solve several classical problems of seepage through a dam, (per com. Nigel Balaam). Examples of these problems are presented in Fredlund & Rahardjo (1993). The examples range from the inundation of an isotropic dam with a horizontal drain through the toe to the development of a seepage face on the downstream side of the dam. It was found that results from TSEEP compared well with the analytical and empirical solutions offered by other researchers.

6.4   BACKGROUND TO TRANSIENT INFILTRATION AND DRAINAGE

It is of considerable importance to develop an understanding of the infiltration, redistribution and drainage processes involved in streambank transient subsurface water movements. The processes of streambank infiltration and drainage can occur as a result of, individually or in combination with, rainfall-runoff, watertable fluctuations, or a rising or falling stream flood level. Only the processes associated with a rising or falling stream flood level will be examined in this research.

This section will examine the infiltration of water from a rising stream flood level into a homogeneous soil, the subsequent redistribution of the infiltrated water, and the drainage of the infiltrated water during a receding stream flood level. This will provide a generalised physical description of transient subsurface water movements.

6.4.1   INFILTRATION

Infiltration is the term applied to the process of water entry into the soil, while soil infiltrability, is the infiltration rate which the soil profile can absorb without ponding over the surface, or trickle downslope as runoff. Hillel (1971) distinguishes between flux and profile controlled infiltration. Flux controlled infiltration refers to the situation when the rate of water supply to the surface is smaller than the soil infiltrability, thus the supply rate determines the infiltration rate. Whereas Profile controlled infiltration occurs once the supply rate exceeds soil infiltrability and the soil infiltrability determines the infiltration rate. Profile controlled infiltration would appear to be the mode that occurs during stream flood rise. It is generally accepted (Hillel, 1971) that soil infiltrability is initially high and tends to decrease to a steady state infiltrability with time due chiefly to a decrease in matric suction gradient.

Bouwer (1969) reviews much of the theory on seepage from open channels, including the transient rising watertable after the water level in the channel is raised. Theory for this case defines the transient seepage per unit length of channel and is only applicable when the soil in which the channel is imbedded is uniform and underlain by less permeable material. Bouwer (1969) noted that for this case the effect of channel shape on seepage is minor. As will be found with the available drainage theory the transient water level profile isn't defined.

Eckersley (1977) using the modified Green and Ampt model (Wallace 1974), described in general terms the process of rainfall infiltration into stockpiled coal. Using the Green and Ampt suction gradient equation (6.2) with an initially ponded surface water

condition, Eckersley (1977) demonstrated the influence of decreasing matric suction on soil infiltrability.

$$\frac{1}{\beta} = \frac{h_o - h_c}{L_f}$$ ……………………………………..(6.2)

where:

β = the degree of wetting;

h_o= pressure head above soil surface;

h_c= soil matric suction;

L_f= distance to the wetting front.

Wallace (1974) notes that for $\beta \geq 4.0$, gravity flow predominates, with absorption and/or boundary pressure forces most significant for $\beta \leq 0.5$. Therefore, for large h_c and assuming h_o is constant, $L_f \leq \approx 0.5 h_c$ infiltration will be driven by boundary pressure forces. Alternatively, the infiltration process will be driven by the boundary pressure forces if the pressure head h_c changes at rate greater than twice the rate at which the wetting front moves, such as experienced with a rising stream flood level. Assuming the wetting front moves at an average rate less than the saturated permeability, stream flood levels would have to rise at a rate greater than 30 mm/hr for boundary pressure forces to predominate the infiltration of the Bube silty/sand-sandy/silt material. From the rates of flood rise shown in Chapter 3 and the rates of 300 and 600 mm/hr used in the numerical model, it is highly likely that infiltration from rising stream flood levels is driven by the boundary pressure forces.

6.4.2   REDISTRIBUTION

According to Hillel (1971) redistribution is a post-infiltration movement of subsurface water where the soil remains unsaturated below the level at which the water is draining. In the case of subsurface water movements, post flood rise infiltration, water tends to internally drain to a steady state position or flood recession starts subsequently influencing the redistribution process. Therefore redistribution is probably negligible given the predominance to flood rise and recession boundary pressures.

6.4.3   DRAINAGE

Hillel (1971) refers to drainage as a saturated process involving flow within the saturated zone. The recession of stream flood levels cause a mound of subsurface water to develop, which typically drains laterally through a seepage face and into the

adjacent land.   With rapid flood level recession, seepage faces as well as the differences in stream and subsurface water levels become large (rapid drawdown). Van Schilfgaarde (1974a) and Van Schilfgaarde (1974b) review much of the steady and non-steady state drainage theory respectively.   Although the steady state theory addresses seepage face development and non-steady state theory the transient drawdown of a mounded watertable, they fail to address the transient progression of a seepage face and/or the transient drawdown of the channel/stream water level.

Eckersley (1995) developed a simple transient seepage model that approximates the relationship between soil permeability and the rate of flood recession required to develop a rapid drawdown condition.

6.5   SENSITIVITY ANALYSIS

This section seeks to determine how various modelling parameters influence the infiltration and drainage processes.   The sensitivity of soil parameters such as b_{TSEEP}, and matric suction-moisture content relationship are examined as well as the sensitivity of varying time steps and flood increment. The analyses will exclusively use the homogeneous streambank drainage condition, as shown in Figure 6.1, subject to instantaneous flood rise and recession rates, except when analysing the sensitivity of flood increment.

In particular this section will define what mechanisms that control the infiltration and drainage processes. In general, the results showed good agreement with the infiltration and drainage processes examined in Section 6.4. A summary of model parameters is presented in Appendix D, Plate D3.1.

6.5.1   B$_{TSEEP}$

TSEEP uses a *b* parameter to represent the relative rate of decrease of soil hydraulic conductivity with decreasing soil matric suction. The *b* parameter is related to the width of the soil pore size distribution, and typically ranges between 2 for sands and 25 for clays. Limited data is available to fully guide the selection of *b* values, therefore the values identified in Section 6.2 are most appropriate.

Four models (VARB1, VARB2, VARK1, and VARK2) simulate the *b* value influence on a seven metre instantaneous flood recession, while two models (VARB4 and VARB5) examine the same influence but for a seven metre instantaneous flood rise.   The

"VARB" series have saturated permeabilities of 15 mm/hr while the "VARK" series have saturated permeabilities of 50 mm/hr. Series 1 and 4, 2 and 5 have *b* values of 0.015 and 0.040 respectively. The same soil-moisture-retention relationship, MRPP1 shown in Table 6.1, has been used in each model. The time/cycle data used in flood recession models consisted of 5 cycles with 200 steps per cycle started at 80 seconds per step and factored by 4 after each cycle. The flood rise time/cycle data is the same but factored by unity. This provides a drainage duration of approximately 63 days and an infiltration duration of less than 1 day. The subsurface water conditions where exported to a file every 50 steps. The difference between the two models is assessed by comparing the difference in pore pressures at reference nodes 20 and 248, refer to Figure 6.2 to Figure 6.4. As shown in Plate D1.1 these nodes are positioned along the bottom boundary of each model, where pore pressure at node 20 represents the water levels adjacent to the left boundary and node 248 water levels below the top of the 1 in 2 sloping boundary.
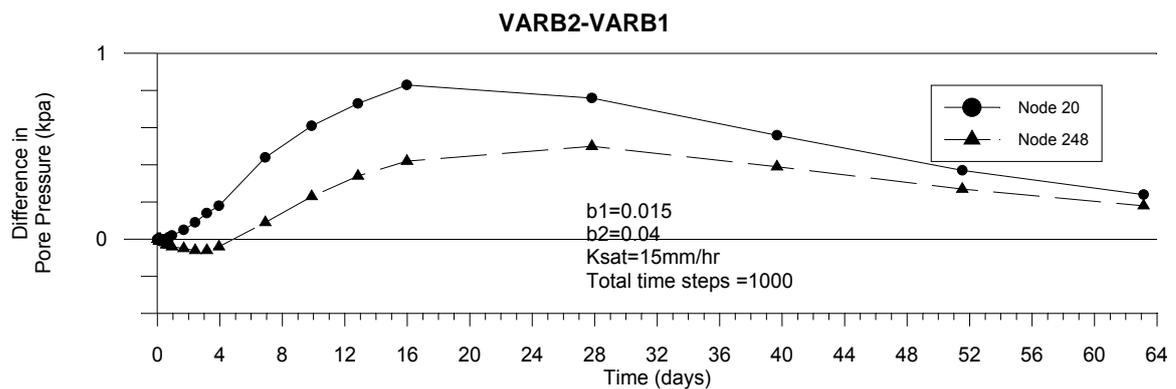
Figure 6.2   **Sensitivity of b_{TSEEP}, pore pressure difference between flood recession models VARB1 and VARB2.**
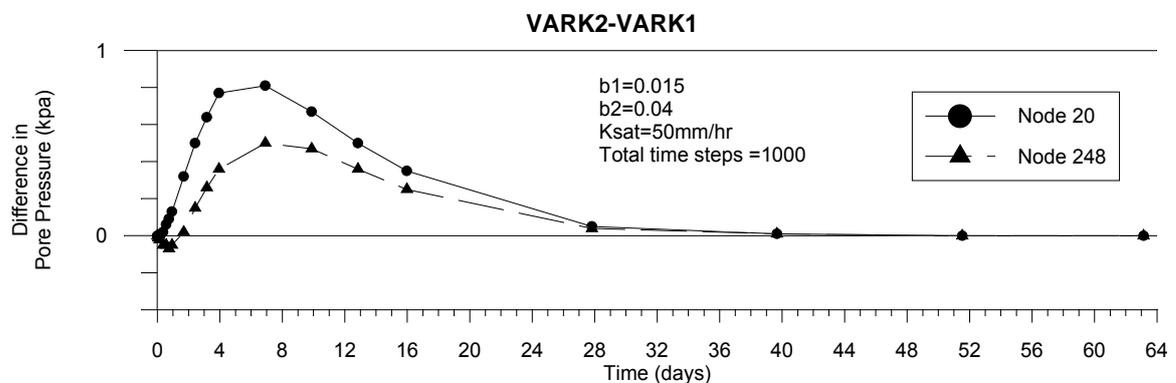
Figure 6.3   **Sensitivity of b_{TSEEP}, pore pressure difference between instantaneous flood recession models VARK1 and VARK2.**
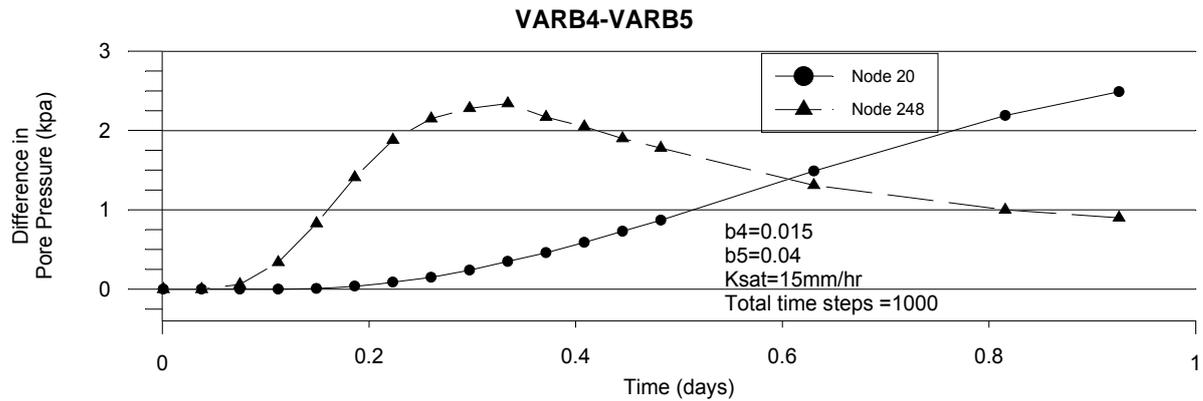
Figure 6.4   Sensitivity of b_{TSEEP}, pore pressure difference between instantaneous flood rise models VARB4 and VARB5.

Results from flood recession models show a maximum difference in pore pressures of approximately 0.8 kPa (80 mm) at node 20 and approximately 0.4 kPa (40 mm) at node 248. The "VARK" series models appear to have the same drainage profile but at an accelerated rate compared to the "VARB" series models. In both flood recession models the simulations with b values of 0.04 appear to drain slightly slower than the simulations with b values of 0.015. Although this delay in drainage is consistent with higher b values, it is apparent that choosing a b value within the range 0.015-0.04 has minimal influence on the rapid flood recession drainage process. This confirms the saturated nature of drainage process discussed in Section 6.4.

Results from the flood rise models show a greater difference in pore pressure, up to 2.5 kPa (250 mm) at node 248. Unlike the flood recession models the flood rise models appear to have either different processes occurring between nodes 20 and 248 or the process is the same but only delayed at node 20. The later explanation is more probable due to the naturally rapid redistribution of pore pressures in a saturated soil profile, conversely for an unsaturated profile. The greater difference experienced with the flood rise infiltration suggests a dependency on unsaturated soil properties during this process. Infiltration response appears to be quicker with the VARB4 model. This is generally expected given the slightly higher unsaturated permeabilities associated with the lower b value, refer to Plate D2.1.

6.5.2   MATRIC SUCTION (ψ)-MOISTURE CONTENT (θ) RELATIONSHIP

The matric suction -moisture content relationship is graphically represented by a curve known as the *soil-moisture-retention curve*.   TSEEP uses this experimentally determined curve to partly characterise the unsaturated nature of fluid flow through soils.   Contrary to experience with TSEEP *b* values, enough data is available to successfully define the soil-moisture-retention curve, however, it is unknown what influence this relationship has on the modelled transient infiltration and drainage processes.

Three models (VARB1, VARM2, and VARM5) simulate a seven metre instantaneous flood recession using a saturated permeability of 15 mm/hr, a 0.015 *b* value, and the soil-moisture-retention relationships (MRPP1, MRPP2, and MRPP4) shown in Table 6.2. Three models (VARB4, VARM3 and VARM4) simulate a seven metre instantaneous flood rise using the same saturated permeability and *b* value, but different soil-moisture-retention relationships, namely MRPP1, MRPP3, and MRPP4 respectively.

Comparison of the flood recession models VARB1 and VARM2 will determine the effects of changing the soil-moisture-retention relationship outside the feasible range of matric suctions, i.e. changing retention slopes for suctions greater than 68.67 kPa (7 metres). Whereas comparison of the flood recession models VARB1 and VARM5 will determine the effects of changing the soil-moisture-retention slopes within the feasible range of matric suctions.

As with the flood recession models the two models VARM3 and VARM4 will be compared with VARB4. The comparison with VARM3 will determine the effects of doubling the retention slopes for the entire range of pressures and suctions. While the comparison with VARM3 will determine the effects of further increasing the retention slopes.

The same time/cycle data used in evaluating the sensitivity of b_{TSEEP} has been used in these models. Again, comparisons will be made on the difference in nodal pore pressures (nos. 20 and 248) between models. Figure 6.5 and Figure 6.6 show the results of models VARM2 and VARM5 respectively. While Figure 6.7 and Figure 6.8 show the results of models VARM3 and VARM4 respectively.

VARM2-VARB1

b1=0.015
M2=0.015
Ksat=15mm/hr
Total time steps=1000

Node 20
Node 248
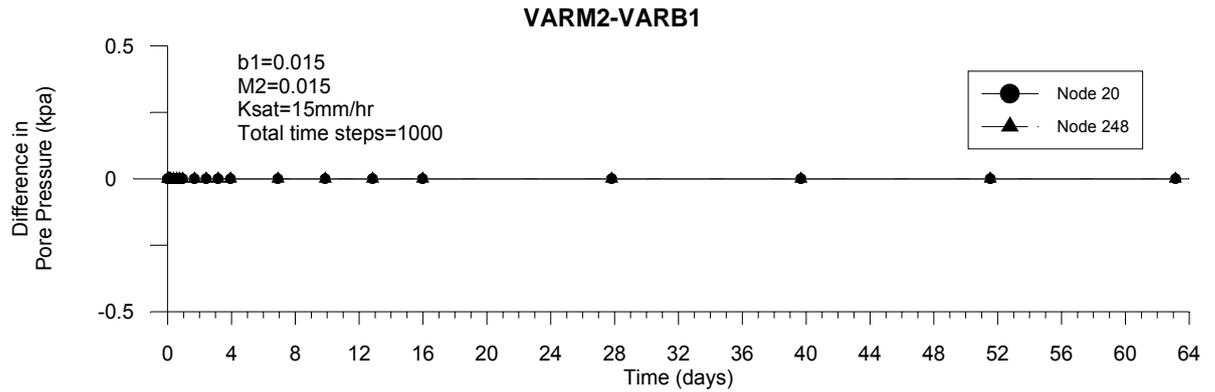
Figure 6.5   **Sensitivity of soil-moisture-retention relationship; pore pressure difference between instantaneous flood recession models VARB1 and VARM2.**

VARM5-VARB1

b=0.015
Ksat=15mm/hr
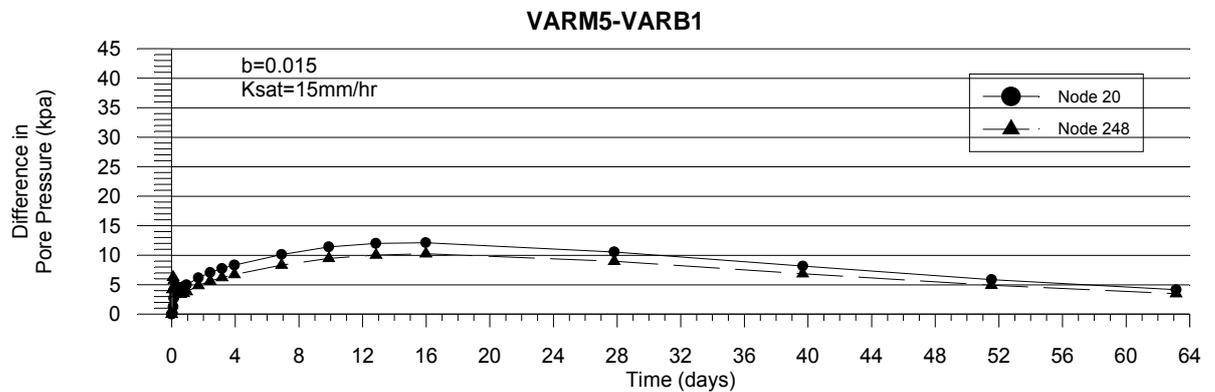
Node 20
Node 248

Figure 6.6   **Sensitivity of soil-moisture-retention relationship; pore pressure difference between instantaneous flood recession models VARB1 and VARM5.**

Node 20

b=0.015
Ksat=15mm/hr

VARB4-VARM3
VARB4-VARM4
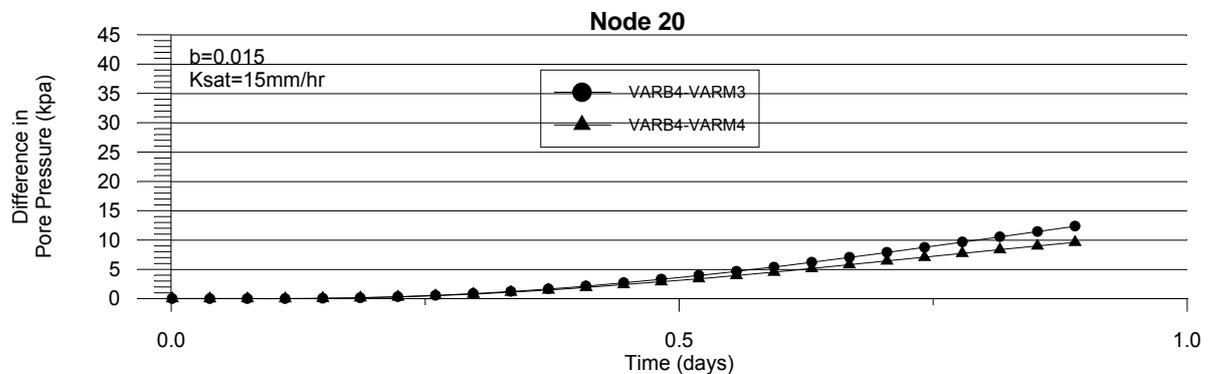
Figure 6.7   **Sensitivity of soil-moisture-retention relationship at node 20; pore pressure difference between instantaneous flood recession models VARB4/VARM3 and VARB4/VARM4.**
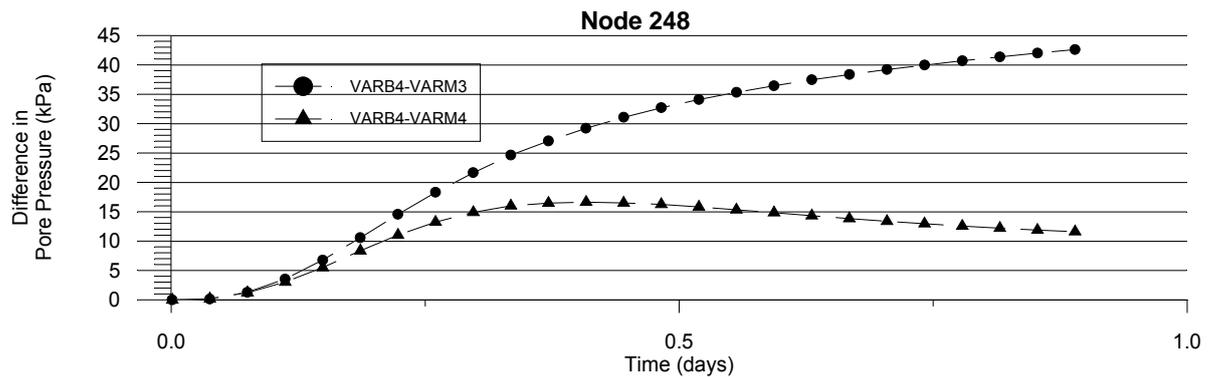
Figure 6.8   Sensitivity of soil-moisture-retention relationship at node 248; pore pressure difference between instantaneous flood recession models VARB4/VARM3 and VARB4/VARM4.

As expected, results show that any change to the soil-moisture-retention relationship outside the feasible range of matric suctions has no effect on the flood recession drainage process. This would also apply for the flood rise infiltration process. However, changes to the relationship within the feasible range of matric suctions has a significant effect on the infiltration and drainage processes. Results in Figure 6.10 to Figure 6.12 show differences at node 248 of up to 13 kPa (130mm) during drainage and 43 kPa (430mm) during infiltration. Both the drainage and infiltration processes experienced a delay with increased retention slopes. This is attributed to the increased retention slopes emulating a material with large voids that require a greater volume of water to drain and fill. The higher "permeabilities" experienced during the flood recession drainage process are likely to facilitate greater movement of water compared to the flood rise infiltration process, hence the difference in effect experienced by the two processes.

6.5.3   TIME STEPS

Time steps in TSEEP control the intervals at which transient subsurface water movements are calculated. Increasing the number of time steps in a simulation will generally improve the solution accuracy. However, this comes at the expense of greater computer processing time and limited improvement in accuracy. TSEEP uses a factored time/cycle approach that provides detail with closer time steps initially when subsurface water movements are greatest and lessens during the later stages of simulation when movements are least. This is achieved by defining the number of cycle and time steps per cycle, the initial time interval per step as well as the factor by which the time interval is to be increased at the end the cycle. Generally, the time/cycle

data is specified so processing time is reasonable and specific model times are simulated for analysis purposes. Therefore, numerous time/cycle combinations can be applied without understanding what influence it has on solution accuracy.

Two models (VARB1 and VARB3) are used to examine the influence of changing time steps when simulating a seven metre instantaneous flood recession. Soil parameters used in both models include a saturated permeability of 50 mm/hr, TSEEP *b* value of 0.015, and soil-moisture-retention values defined by MRPP1. For model VARB1 the number of time cycles has been specified as 5, the number of time steps per cycle is 200 and the initial time interval taken as 80 seconds. Model VARB3 has the number of time cycles specified as 5, the number of steps per cycle as 100 and the initial time interval taken as 160 seconds. For both models the factor used to increase the previous time interval at the end of each cycle is 4. These models simulate the same drainage duration of approximately 64 days but model VARB3 has only a total of 500 time steps compared to 1000 for VARB1. The difference between the two models is again assessed by comparing the difference in pore pressures at nodes 20 and 248, refer to Figure 6.10.

Results show that for instantaneous flood recession, changing the total time steps by half has no effect on solution accuracy. This would also apply to instantaneous flood rise or step wise linear hydrograph models.
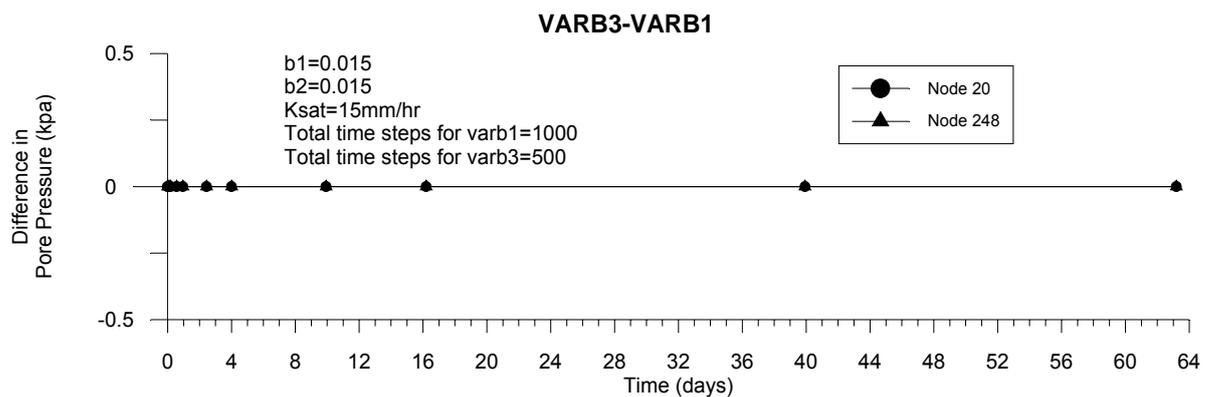
Figure 6.9   Sensitivity of time steps; pore pressure difference between instantaneous flood recession models VARB1 and VARM3.

6.5.4   FLOOD INCREMENT

Flood increment is defined as the vertical (height) interval by which the transient flood rise or recession stepwise linear hydrograph boundary condition is moved. Progressively smaller flood increments will ultimately converge to a seamlessly linear rate of rise or recession.   However, this accuracy becomes labour and processing intensive and can probably be sufficiently approximated with larger more manageable flood increments.

Four models (GEN1, GEN13, and GEN15) simulate a stepwise linear hydrograph flood recession rate of 300 mm/hr using flood increments of 0.5, 1.0, and 2.0 metres respectively. Using a saturated permeability ratio of 15 mm/hr provides for a flood rate-saturated permeability ratio (r/K_{sat}) of 20.   A *b* value of 0.02 and moisture-retention relationship MRPP1 has been used in each model.   Table 6.3 summarises the time/cycle parameters used for each model.

Table 6.3   Flood increment time/cycle parameters for each model.

Model	Flood increment (m)	No. cycles	No. steps/cycle	Initial Δt (sec)	Factor	Steps / output
GEN1	0.5	3	100	100	2	100
GEN13	1.0	6	100	60	10	200
GEN15	2.0	8	50	60	100	400

Results from the GEN1 model are schematically shown in Figure 6.11 at selected drawdown profiles.   The development of a seepage face and a rapid drawdown condition is evident in this figure. The influence of flood increment size between the three models is assessed by examining the difference in pore pressures with respect to the GEN1 model.   This approach is based on the assumption that out of the three models GEN1 provides the most accurate emulation. The differences in pore pressures at nodes 20 and 248 are shown in Figure 6.12 and Figure 6.13 respectively. In each case pore pressures from models GEN13 and GEN15 are subtracted from pore pressures at corresponding intervals in GEN1.

Homogeneous Bank
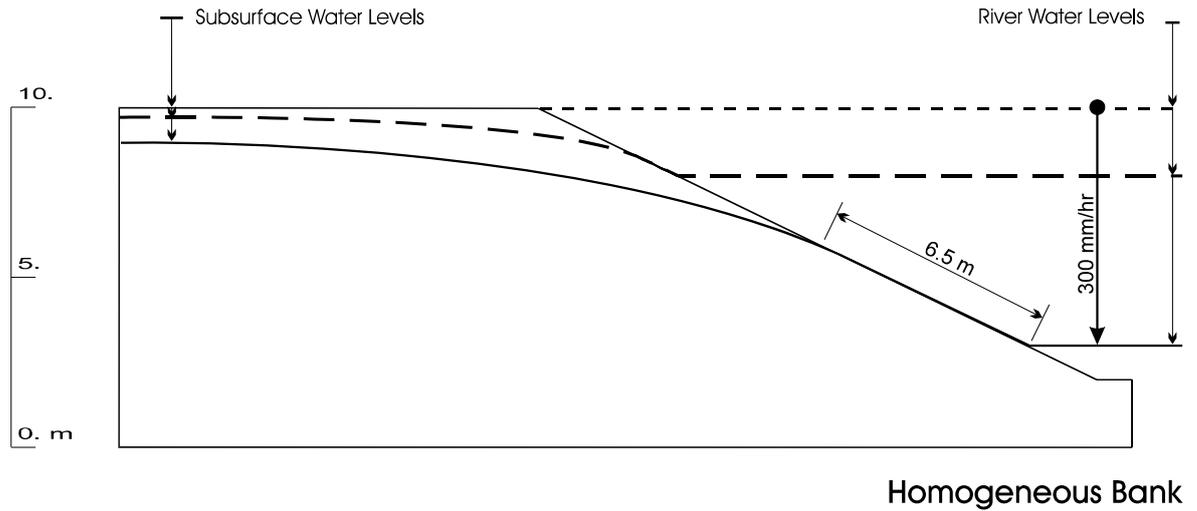
Figure 6.10   Stepwise flood recession model GEN1; selected drawdown profiles from a series of 0.5 m flood increments.

The maximum difference in pore pressures is approximately 1.8 kPa or 180 mm difference in water levels. The results show that lesser pore pressures are experienced with greater flood increments. It is interesting to note that the difference in pore pressure with respect to GEN1 appears proportional to the difference in flood increment size, i.e. the difference between flood increments 0.5 and 1.0 metres is approximately half the difference between flood increments 0.5 and 2.0 metres. This trend would be attributed to the increasing drainage gradients experienced with increasing flood increments. Therefore it may be possible to estimate that the 0.5 metre flood increment is approximately no greater than 1 kPa less than the true solution or 100 mm below the true phreatic surface. Based on the model height of 8m, a 100mm resolution (1.25%) is considered acceptable for the purpose of this generic examination.
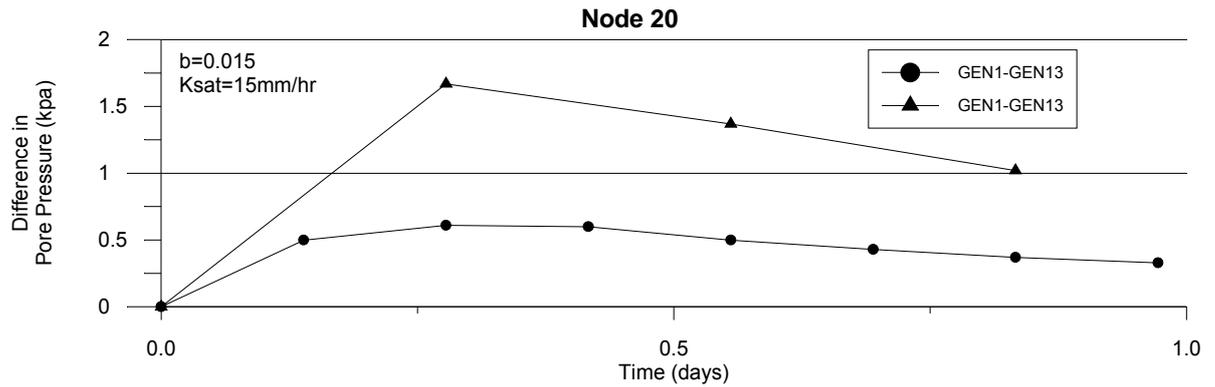
Figure 6.11   Sensitivity of flood increment at node 20; pore pressure difference between stepwise flood recession models GEN1/GEN13 and GEN1/GEN15.
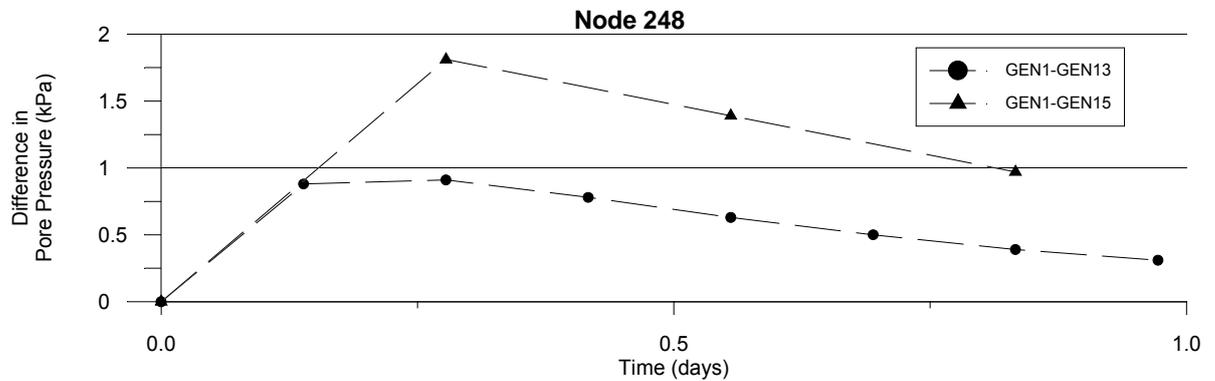
Figure 6.12   Sensitivity of flood increment at node 248; pore pressure difference between stepwise flood recession models GEN1/GEN13 and GEN1/GEN15.

6.5.5   SUMMARY

From the parameters examined, a number of clear trends emerge concerning their influence on flood rise infiltration and flood recession drainage processes. The influence of the TSEEP *b* value is clearly different to that of the soil-moisture-retention relationship. It was shown that the *b* value has minimal influence on the rapid flood recession drainage process and while the influence on the infiltration processes are greater, however, it can also be considered as minimal. In contrast, changes to the soil-moisture-retention relationship within the feasible range of matric suctions have a significant effect on the infiltration and drainage processes. It was also found that changing the soil-moisture-retention relationship outside the feasible range of matric suctions has no effect on the drainage process. Reducing the total number of time steps by half appears to have no influence on flood recession drainage. Whereas, it was found that increasing the flood increment size used in the stepwise transient

boundary condition successively lowered the water level profile and that a flood increment of 0.5 metres appeared acceptable to model a linear flood rise or recession rate. Therefore the following examination of transient flood rise infiltration and recession drainage processes can be successfully achieved by using a *b* value of 0.02, saturated permeability of 15 or 50 mm/hr, soil-moisture-retention relationships MRPP1 or MRPP2, and a flood increment of 0.5 metres.

6.6   TRANSIENT FLOOD RISE INFILTRATION

In this section, results of finite element simulations of flood rise infiltration will be presented with the aim of identifying the extent of infiltration and the influence of three subsurface drainage configurations. The analyses will deal with the three streambank drainage configurations shown in 6.2.1, with particular consideration given to flood rise rate of 300 mm/hr and a saturated permeability of 15 mm/hr (r/Ksat = 20).

In particular this section will seek to determine whether flood rise infiltrates a sufficient proportion of a streambank to instigate a rapid drawdown condition during the subsequent flood recession stage. Also, determine to what extent the internal drainage configurations (longitudinal drainage pipe and drainage layer through the toe) aid the infiltration process.

The flood rise events are started from the toe of the bank and raised to the top in increments of 0.5 metres. Each increment will be maintained for a simulated duration of 100 minutes (i.e. 300 mm/hr). A final increment of 100 mm will be maintained above the top of the bank to emulate overbank outflow. This will illustrate accelerated infiltration once stream levels overtop the bank. The overbank outflow will be maintained until the entire streambank is saturated, thereby identifying and approximate duration of overbank outflow to establish full streambank saturation.

Details of computer analyses are given in Appendix D. In particular the Summary of Groundwater Modelling parameters, shown in Table D3.1, provide a basis for comparison of the various groundwater models employed.

6.6.1   RESULTS

Only partial saturation of bank materials are achieved immediately after bank overtopping

- In each case, only the area below the slope face is saturated at the time of

reaching top of bank flood level

- The bank configuration with the drainage layer is saturated marginally quicker than the longitudinal drainage pipe and the homogeneous bank configurations.

- After approximately 11 hours of flood levels remaining above the top of bank the unsaturated areas range from 20% to 40% for the drainage layer and homogeneous bank configurations respectively

- Full bank saturation is achieved after flood levels overtopping the bank for approximately 0.8 days and 1.5 days for the drainage layer and the homogeneous bank configurations respectively.

- Maximum insitu velocities were approximately 67mm/hr for the drainage pipe and homogenous bank configurations and approximately 131mm/hr for the drainage layer configuration. The maximum velocities for the drainage pipe and homogenous configurations were observed within the slope face immediately before reaching top of bank flood levels while the maximum velocity for the drainage layer was observed within the more permeable drainage layer at the time of flood levels reaching the top of bank.

6.7   TRANSIENT FLOOD RECESSION DRAINAGE

In this section, results of finite element simulations of flood recession drainage are be presented with the aim of identifying the development of the seepage face and elevated subsurface water levels and the performance of three subsurface drainage configurations during stream flood recession. The analyses will deal with the three streambank drainage configurations shown in Figure 6.1, with particular consideration given to flood recession rates of 300 and 50 mm/hr in combination with a saturated permeability of 15 mm/hr (r/Ksat = 20 and 3.33).

In particular this section will seek to determine if saturated streambank conditions can develop elevated subsurface water levels and seepage face conditions sufficient to instigate a rapid drawdown conditions. Also, determine to what extent and how the internal drainage configurations (longitudinal drainage pipe and drainage layer through the toe) aid the drainage process.

Each model is started with subsurface and stream water levels at the top of the bank. Stream levels are lowered to the toe of the bank in increments of 0.5 metres, simulating flood recession rates of 300 and 50 mm/hr. Each increment is maintained for simulated durations of 100 and 600 minutes respectively (i.e. 300 and 50 mm/hr). The

final stream level increment is maintained at the toe of the bank until the subsurface levels have obtained equilibrium with the stream level.
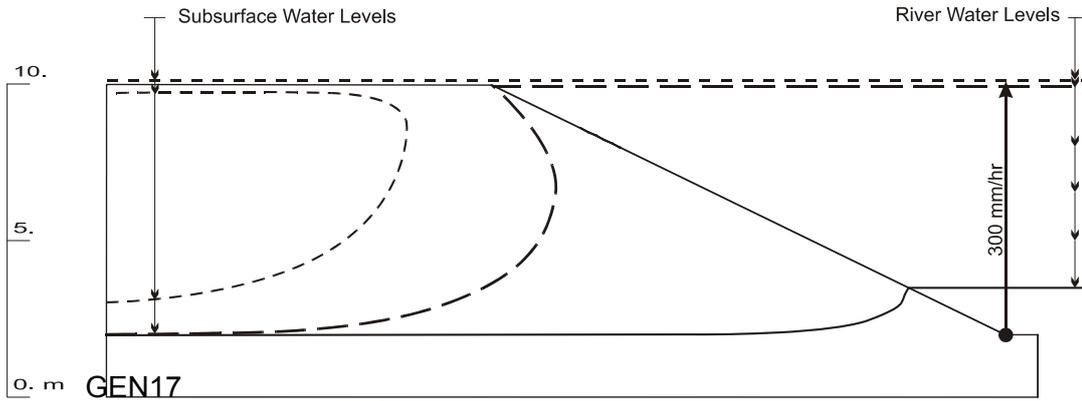
Homogeneous Bank
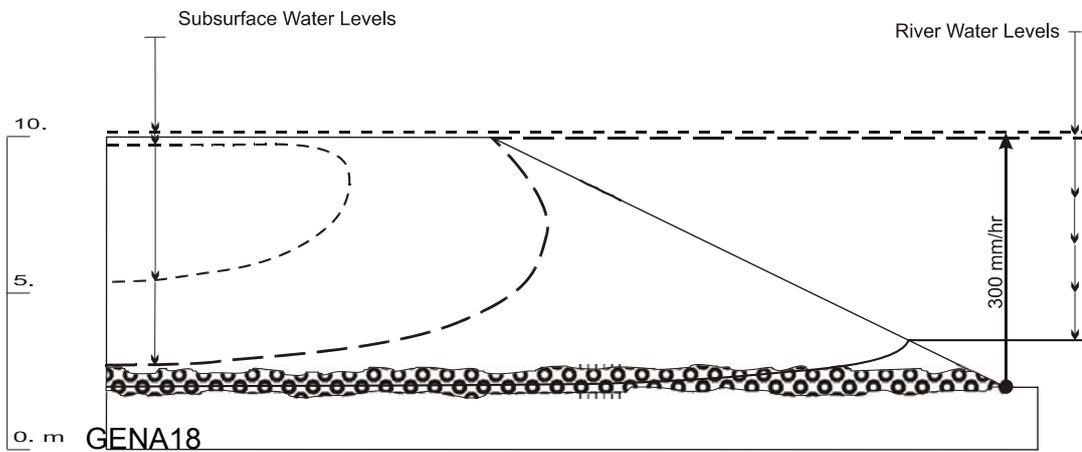
Bank with Drainage Layer
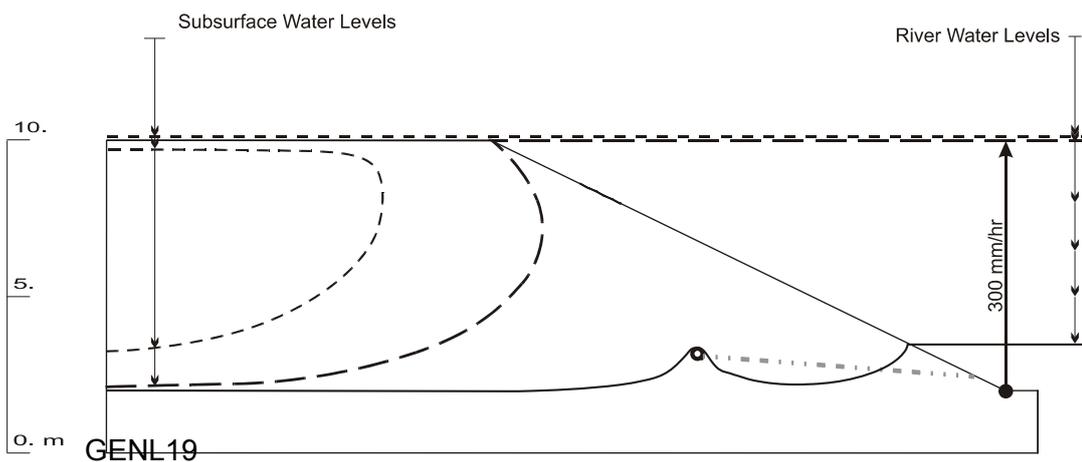
Longitudinal Drainage Pipe

Flood Rise: r=300 mm/hr, Ksat=15 mm/hr

Figure 6.13   Schematic results of flood rise at selected stages.

Details of computer analyses are given in Appendix D. In particular the Summary of Groundwater Modelling parameters, shown in Table D3.1, provide a basis for comparison of the various groundwater models employed.

6.7.1 RESULTS

The homogeneous bank configuration develops superior rapid drawdown conditions compared to the drainage layer configuration followed by the longitudinal drainage configuration.

- After a flood recession height of seven (7) meters the homogenous bank develops maximum seepage face lengths of 6.5 and 3 meters respectively for the flood recession rates of 300 and 50 mm/hr.

- In comparison, the drainage layer configuration develops maximum seepage face lengths of three (3) and less than one (1) meters for the two flood recession rates respectively.

- The drainage pipe configuration develops seepage face lengths of one and half (1.5) and 0.3 meters respectively for the same flood recession rates.

- The homogeneous bank develops a seepage approximately proportional in size to the recession height of flood water levels. Whereas the drainage layer and drainage pipe configurations only develop seepage faces proportional to the recession height of water levels up to flood levels of 3.5 meters below the top of bank.

- The drainage layer and drainage pipe configurations develop a break point level at 3.5m below top of bank (approximately 50% of bank height), at which point the rate of development of their seepage faces drastically reduces or decays as internal flow becomes dominated by internal drainage.

- In the case of the drainage pipe configuration the maximum seepage face length is developed at the break point level. With the drainage layer configuration the seepage face continues to develop up to the third-quarter flood recession level.

- Modelled internal drainage flows in the homogeneous bank show flow concentrations through the seepage face and in directions aligned with potential shallow failure surfaces.

- In the case of the drainage layer and drainage pipe configurations, flows are concentrated in the areas of internal drainage. Furthermore, as the flood levels progressively recede, flow directions diverge from the seepage face in directions towards the areas of internal drainage and not principally aligned with potential

failure surfaces.

- The internal drainage provided by the drainage pipe and drainage layer configurations distinctively provide a stabilising influence in terms of rapid drawdown development influencing slope stability.

- Maximum insitu velocities were approximately 10mm/hr for the homogenous bank configuration, approximately 151mm/hr for the drainage layer and approximately 43mm/hr for the drainage pipe configuration.

- The maximum velocities for the homogenous bank were observed within the slope face during maximum seepage face development, while the maximum velocities for the drainage layer configuration were observed within the more permeable drainage layer, and for the drainage pipe configuration at the point of internal drainage.

6.8   DISCUSSION

Results of the two transient subsurface flood models (rise infiltration and recession drainage) have been analysed with various primary model parameters of soil permeability, flood rise and fall rates and internal drainage configurations, and secondary model parameters of soil matrix suction, transient flood height increments, and modelling time steps. The results of the models provide valuable insight into the development of saturated streambank conditions during flood stream level rise and the development of rapid drawdown conditions during flood stream level recession.

It has been demonstrated that streambanks are capable of becoming saturated during stream flood level rise durations and heights equivalent to a category B event. The internal bank drainage configuration of a longitudinal drainage pipe and a drainage layer (aquifer) facilitate a greater saturation of the bank materials during the earlier stream flood levels, but appear to not drastically influence the saturation of the entire stream bank during the later stage of stream flood levels.

The flood recession modelling has provided the most valuable insight to drainage of subsurface water levels during stream flood recession. Based on an initially saturated streambank, the modelling has demonstrated that the homogeneous bank develops seepage face lengths approximately in proportion to the rate of falling stream flood levels. Whereas the drainage layer and drainage pipe bank configurations develop proportional seepage face lengths up to a break point height in stream flood level, at which point the development of seepage faces drastically changes to either a decay or slower rate. The break point is associated with stream flood heights around the mid

level between the top of bank and the internal drainage point. In this case a stream flood level of approximately 3.5 meters below the top of bank defines the break point in development of seepage face length. Further evaluation of recession models reveals subsurface drainage flows for the homogenous bank are concentrated within the seepage face with directions either parallel or exiting to the seepage face. However the influence of the internal drainage configurations appears to draw the drainage flows towards the point of internal drainage thereby minimising velocities exiting the seepage face and flow directions likely to be aligned with potential shallow slope failure surfaces. In summary the internal drainage configurations are likely to aid the stability of stream bank slopes compared to homogenous stream bank.

Flood Recession: r=300 mm/hr, Ksat=15 mm/hr

Figure 6.14   Schematic results of flood recession at selected stages (r=300mm/hr).
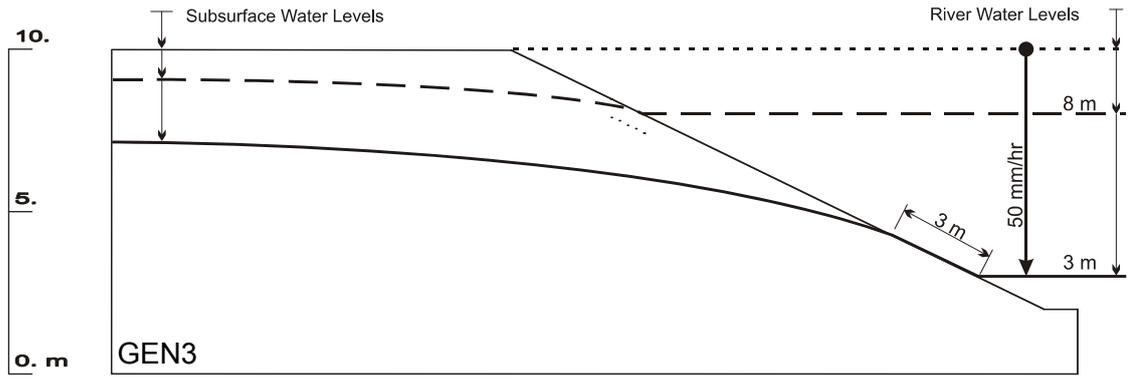
GEN3

Homogeneous Bank

GENA9

Bank with Drainage Layer

GENL11
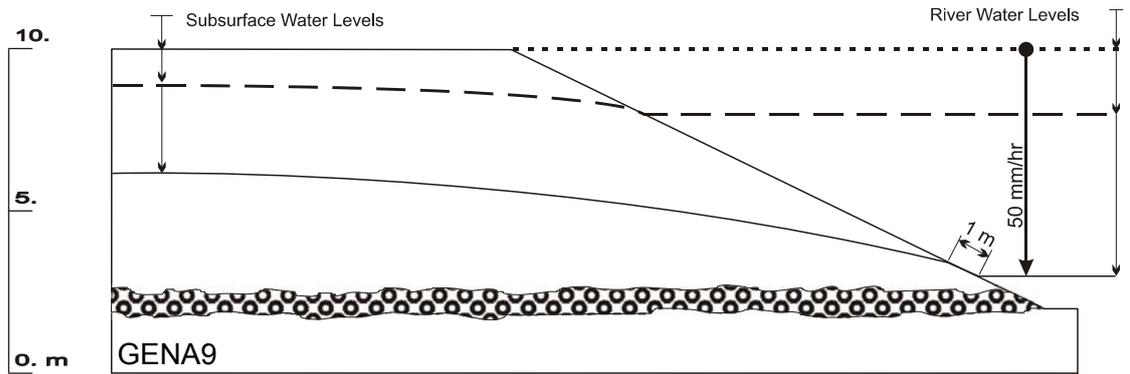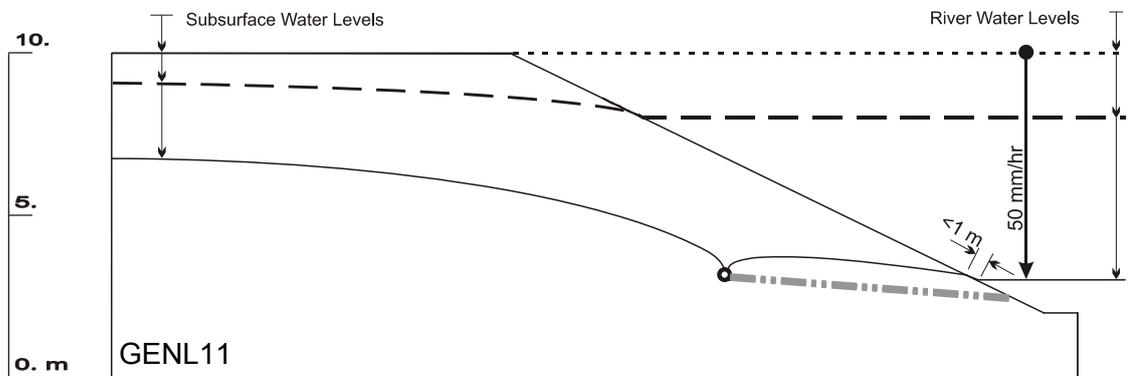
Longitudinal Drainage Pipe

Flood Recession: r = 50 mm/hr, Ksat = 15mm/hr

Figure 6.15   Schematic results of flood recession at selected stages (r=50mm/hr).

Homogeneous Bank

Bank with Drainage Layer

Longitudinal Drainage Pipe
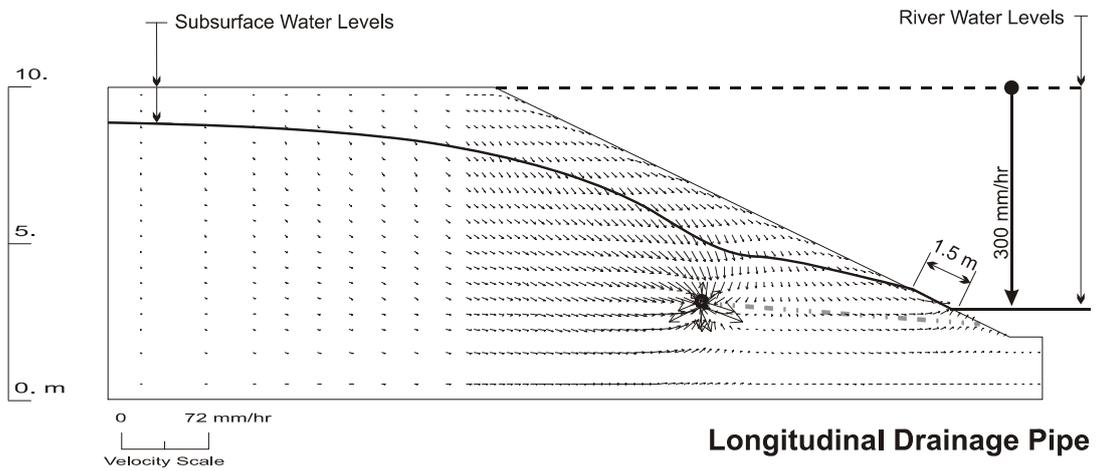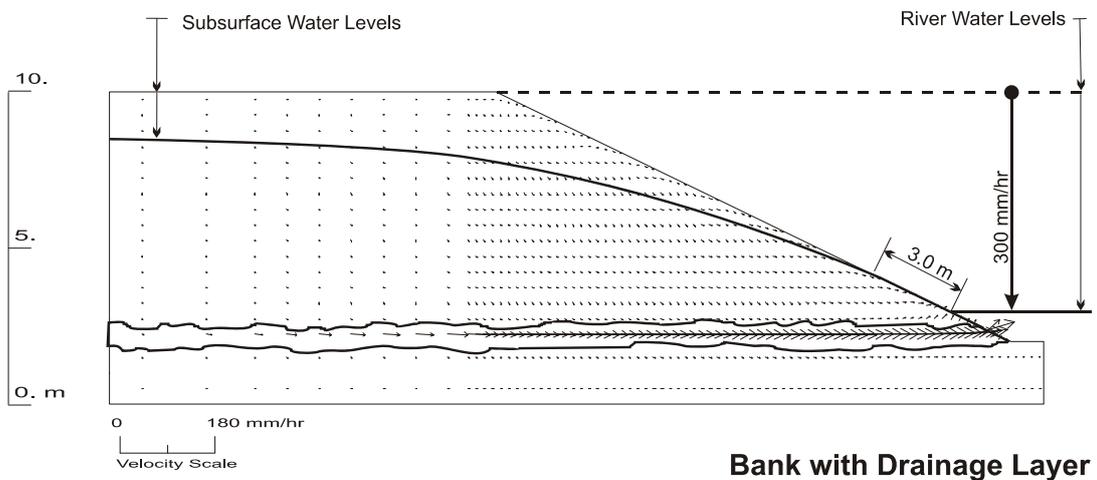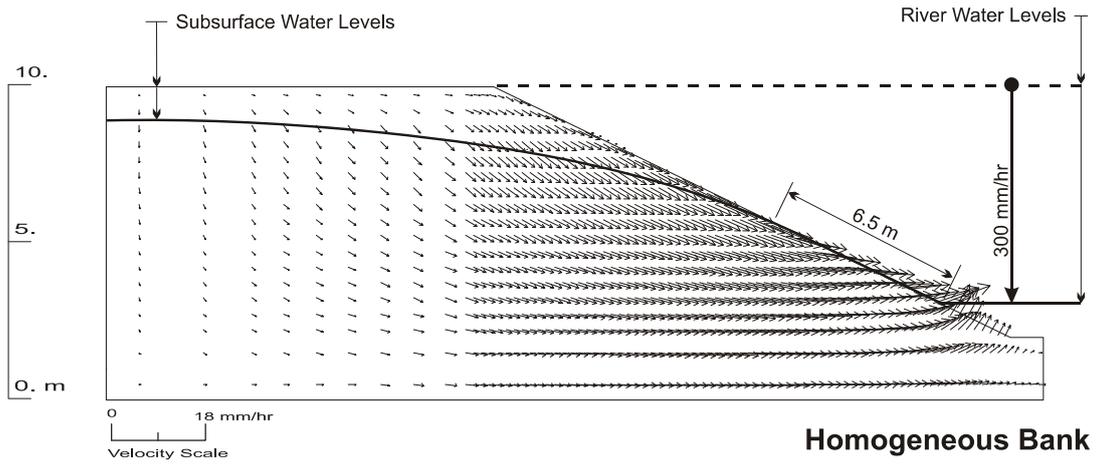
Flood Recession: r=300 mm/hr, Ksat=15 mm/hr

Figure 6.16   Schematic results of flood recession in-situ velocities (r=300mm/hr).
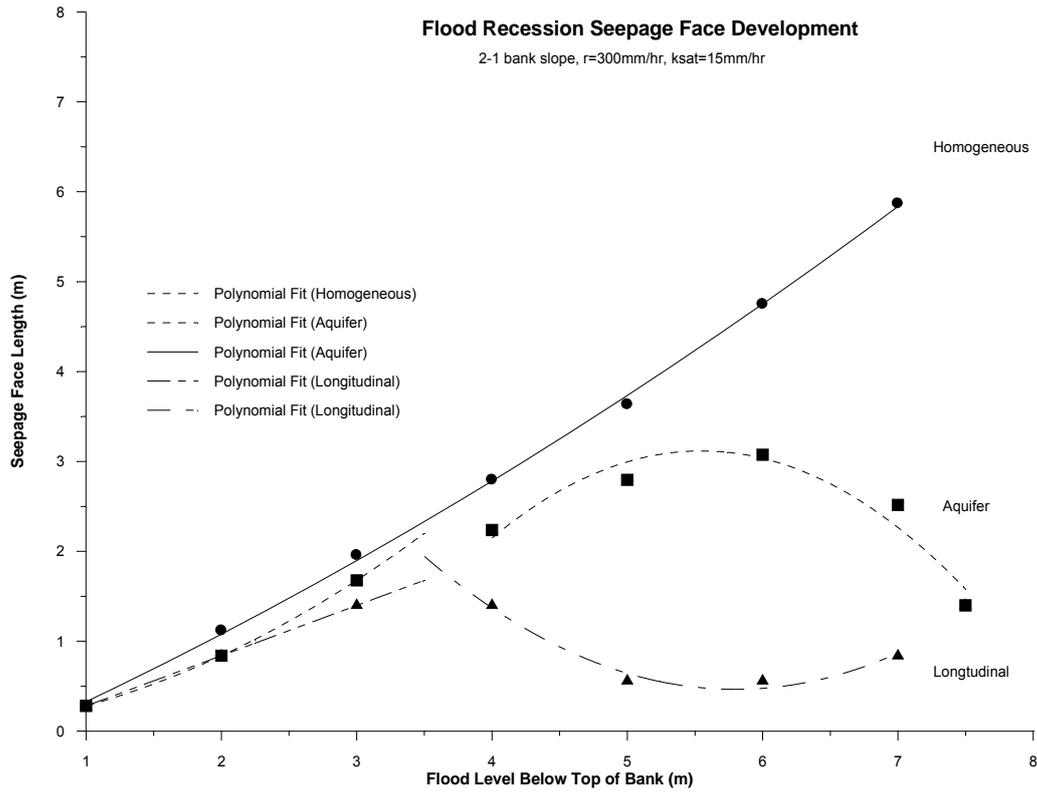
Figure 6.17   Flood recession levels versus seepage face development (r=300mm/hr).
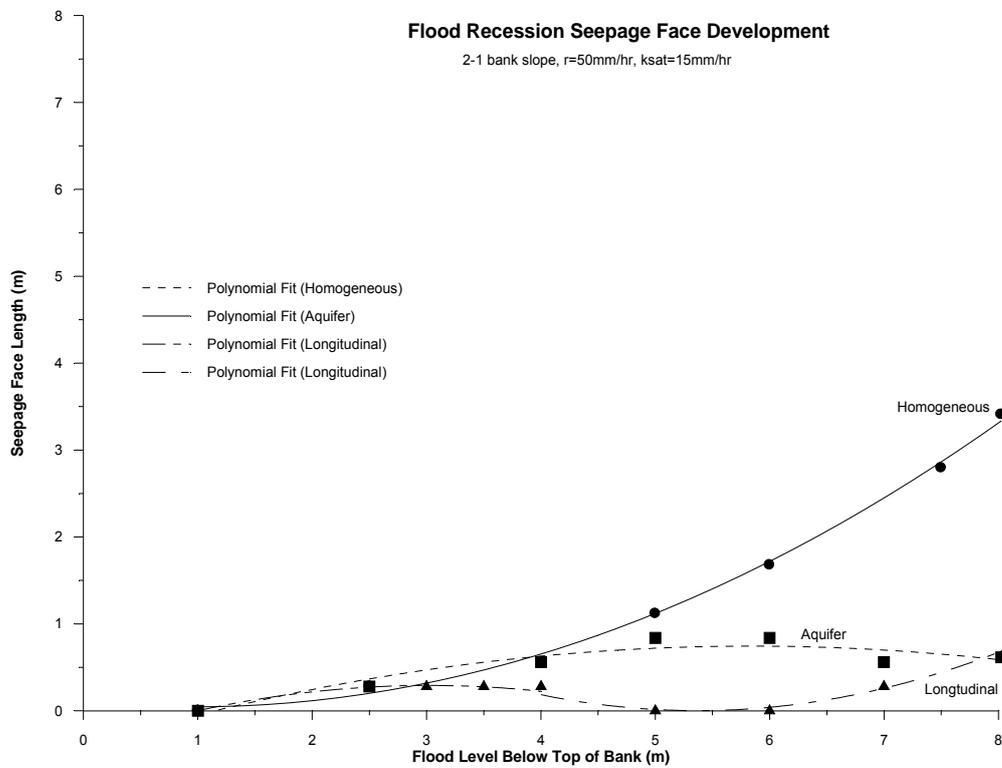
Figure 6.18   Flood recession levels versus seepage face development (r=50mm/hr).

Chapter 7

SLOPE STABILITY ANALYSIS

Two-dimensional limit equilibrium slope stability analyses of a generic streambank have been performed to evaluate the rapid drawdown conditions developed in Chapter 6. A generic bank cross-section with a 1 in 2 slope has been used as the model. Soil properties representing the instability prone Bube silty SAND (Zone 1) material have been used as the principal medium, to which various piezometric lines have been applied to emulate various rapid drawdown stages. The analyses deal exclusively with a homogeneous isotropic soil, with piezometric lines derived from the two flood recession rates of 300mm/hr and 50mm/hr and the three streambank drainage conditions:

- homogeneous drainage conditions;
- drainage layer through the toe; and
- longitudinal drainage pipe.

Results are presented as flood recession snap shots of streambank slope stability contours for factors of safety less than one (1). Results from the analyses will lead to the evaluation of the susceptibility of streambank slope instability at various stages rapid drawdown. The influences of the various drainage conditions on streambank instability are also evaluated.

7.1   ANALYSIS APPROACH

A student version of SLOPE/W as provided in GeoStudio 2004 ^{TM} has been utilised for the stability analysis of the generic streambank. The student version of the software is limited to analysis of:

- Maximum of two (2) materials
- Only Mohr-Coulomb, no strength (water) and bedrock soil models can be used
- No advanced soil properties
- Only the Bishop, Janbu, Ordinary, Spencer, Morgenstern-Price, and GLE methods can be used
- Only the constant and half-sine interslice force functions can be used

- Only the Grid and Radius slip surface and Entry and Exit options can be used

- No user specified axis point

- Allows slip surface optimization, but no auto locate

- Allows detail force file for the critical and the optimized slip surfaces only

- A maximum of 1 piezometric line can be specified

- No external loading

7.1.1   STREAMBANK MODEL

A simplified eight metre high bank cross-section with a 1 in 2 slope has been used as the model that best represents a typical streambank configuration. The 1 in 2 slope (26°) is considered an average angle of repose for the sandy silt material tested by Eckersley et al. (1992) (refer to Table 3.2).   Three subsurface bank drainage configurations, homogeneous, drainage layer through the toe, and longitudinal drainage pipe, as previously shown in Figure 6.1, are separately incorporated into the model through utilising the piezometric lines derived from the rapid drawdown analysis of each model.   The transient rapid drawdown models used in the stability analyses are:

- GEN1 (homogeneous bank, 300mm/hr)

- GENA8 (Drainage layer, 300mm/hr)

- GENL10 (Longitudinal drainage pipe, 300mm/hr)

- GEN3 (homogeneous bank, 50mm/hr)

- GENA9 (Drainage layer, 50mm/hr)

- GENL11 (Longitudinal drainage pipe, 50mm/hr)

7.1.2   MATERIAL PROPERTIES

Two materials are used in each analysis; Mohr-Coulomb silty-sand and Water.   The Mohr-Coulomb material makes up the entire streambank material while the Water is used in stream.   The water is defined with zero strength properties and a unit weight of 9.81kN/m^3.   The streambank material is considered to be in a worst case; dilatant and completely saturated state.   Although some form of cohesion may exist in the soil due bonding by vegetation or residual apparent cohesion.   The properties adopted for the saturated Mohr-Coulomb silty-sand are:

Table 7.1   **Ultimate effective strength parameters used to represent the saturated silty/sand-sandy/silt material**

Parameter	Cohesion less
γ Unit weight (kN/m^3)	15.0
ϕ' Friction angle (deg)	30.0
c' cohesion (kPa)	0.0 (8.6*)
Refer to Section 3.3 Soil Properties, * apparent cohesion whilst dry	

7.1.3   PIEZOMETRIC LINES

Piezometric lines are defined in each stability analysis from the results of the transient rapid drawdown seepage analyses derived in Chapter 6.   Selective piezometric lines are chosen to evaluate slope instability for the two stream recession rates (300mm/hr and 50mm/hr) and the three streambank drainage configurations. The principal stream recession levels analysed in each case are of 2m, 4m and 7m below top of bank. Additional stream levels are analysed for the generic homogeneous bank configuration. The piezometric lines are drawn in each analysis by importing and tracing a scaled image of the various piezometric lines derived in TSEEP. The piezometric line extends into the stream at the same height as the receded stream level.

7.1.4   SLIP SURFACES

Entry and Exit ground surface ranges have been used in the analyses to specify the limits of where the slip surfaces can enter and exit the slope.   The transition point between the slip surface entry and exit ranges was chosen to the mid point of the seepage face for each piezometric line. The outer extents of each exit and entry range were generally chosen as the ground surface limits of the model.   The slip movement direction was predefined as left to right, i.e. out of the bank and towards the stream. Ten (10) slip surface increments were chosen over both the entry and exit ranges with slip surface radius increments set at one hundred (100) for each of the ten (10) slip surface increments.   The resulting number of slip surfaces analysed for each model was approximately ten thousand (10,000) with an additional two thousand (2000) iterations to optimise the critical slip surfaces.

7.1.5   ANALYSIS METHOD

The four (4) limit equilibrium analysis methods of Bishop, Ordinary, Janbu and Spencer were selected for each stability analysis. The Ordinary method sets both the normal and shear interslice forces to zero whereas the Bishop and Janbu methods consider normal forces but not shear forces between the slices. The Bishop method satisfies

only moment equilibrium, and the Janbu method satisfies only force equilibrium. The factor of safety generated by Janbu does not include Janbu's empirical correction factor, fo. The Spencer method satisfies both force and moment equilibrium and is restricted to a constant interslice force function. SLOPE/W uses the "Rapid Solver" technique to compute the lambda value that results in the same factor of safety for both moment and force equilibrium. The lower factor of safety derived from the analysis using the four methods have been reported as the final factor of safety.

7.2   ANALYSIS

In this section, results of the slope stability analyses are be presented with the aim of identifying the extent of slope instability at each stage of stream level rapid drawdown for the three (3) streambank drainage conditions shown in Figure 6.1.

In particular this section will seek to determine the influence of the streambank drainage conditions on slope instability and identify zones of slope instabilities. Slope instability is evaluated against the two flood recession rates of 300mm/hr and 50mm/hr and the results of Morgenstern (1963) are used as a comparative. The minimum factor of safety is evaluated for selected stream levels (2, 4 & 7m blow top of bank) and the minimum soil cohesion is evaluated which would maintain slope stability (i.e. FOS>1).

Each analysis utilises the piezometric lines derived from the transient rapid drawdown analyses presented in Chapter 6. In each case the piezometric lines are snap shots of the ground water conditions as derived from an initially saturated streambank and stream water levels falling from the top of the bank. Results are presented as coloured contours of factors of safety less than one. The analysis of the minimum cohesion required to maintain slope stability is performed iteratively in each case by intuitively guessing a value of cohesion until a FOS of one or greater is achieved. Details of computer analyses are given in Appendix E.

7.3   RESULTS

As observed in the groundwater modelling results the stability analysis shows that under the same rapid drawdown conditions the homogeneous bank configuration experiences slope instabilities greater than the drainage layer configuration followed by the longitudinal drainage configuration.

- Results indicate that the saturated generic 1in2 (27°) streambank with stream levels at the top of the bank (i.e. no drawdown of stream levels) exhibits a minimum

factor of safety of 1.15, indicating a material and slope state close to failure (ϕ=30°, C=0kPa). This confirms that cohesionless saturated stream banks steeper than the saturated friction angle would theoretically fail independent of the stream drawdown rate. However, any presence of reinforcement by vegetation, internal drainage or stabilisation works would improve bank stability.

- Results are presented in Figure 7.1 and in Appendix E are cross sections of slope failure surfaces with FOS less than one. Each series of cross sections are for specific stream drawdown levels.

- All three drainage configurations experience similar degrees of slope instability during the initial one (1) metre of stream level drawdown. For the three drainage cases minimum factors of safety of 0.74 and 0.88 were experienced after the initial one metre drawdown in stream level for the 300 and 50mm/hr recession rates respectively.

- Development of slope failure surfaces appear to start with the lowest factors of safety nearest the seepage face and as shallow infinite slope forms. As rapid drawdown progresses the slope failure surfaces extend to above and blow the seepage face but still maintain the critical surface within the seepage face. It is likely that the slope failures would progress retrogressively as the slope oversteepens with each failure.

- Analyses using the Janbu method presented deeper failure surfaces in comparison to the failures surfaces derived from the Bishop method. Furthermore, the Janbu method produced slightly lower factors of safety for the same analysis.

- The results have been interpreted in plots as minimum factor of safety (Figure 7.2) versus the dimensionless drawdown ratio (L/H) utilised by Morgenstern (1963). The dimensionless parameter provide for scaling of results. Furthermore, a comparison of a Morgenstern (1963) drawdown case is presented in each plot.

- A convergence to a minimum factor of safety of 0.38 was experienced by all drainage cases after seven metres of stream level rapid drawdown. The same converganece was experienced for both the 300m/hr and 50mm/hr drawdown rates (refer to Figure 7.2).

- The convergence possibly indicates a limitation in the analysis when evaluating factors of safety less than one.

- In order to avoid the convergence limitation in the analysis an approach using the minimum soil cohesion required to maintain slope stability (i.e. FOS≥1) was evaluated iteratively for each drainage case.

- Figure 7.3 presents the results of evaluating the minimum cohesion required to

- In the homogeneous case, the progression of stream level drawdown appears to be linearly associated with an increasing cohesion required to maintain stability.

In contrary, the internal drainage cases present a parabolic relationship which reaches a maximum cohesion with stream levels around mid to two-thirds bank height and a lesser cohesion upon reaching the maximum stream drawdown level. This relationship is associated with the proximity of the internal drainage system to the falling stream level. For example, as the stream level draws to a level nearer the level of the internal drainage system the influence of reducing the seepage face becomes greater. Of the two internal drainage cases, the longitudinal drainage case clearly reduces the development of the seepage face below mid bank height. Cohesions of 0.5kPa and 2.5kPa were required after seven meters of stream level drawdown to maintain stability with drawdown rates of 50mm/hr and 300mm/hr respectively. For the Bube soils, the interparticle bonding (apparent cohesion) plays an important role in stabilising the bank slopes, and steeper stable slopes can be achieved than in the non-cohesive soils presented in this analysis. When a seepage face develops due to rapid drawdown or local groundwater discharge, the banks become less stable, and failure is likely to occur in shallow slips.

7.4   DISCUSSION

Results of the stability analyses clearly show that the internal drainage systems influence slope stability positively. In both cases the influence appears after stream levels fall below approximately mid bank height. The longitudinal drainage pipe has the greatest influence by reducing the cohesion required to maintain stability by 2.5kPa compared to a streambank without internal drainage. The reduction in the required cohesion appears to be the same irrespective of the stream drawdown rate (300mm/hr or 50mm/hr). The influence by the streambank with an aquifer appears to be slightly greater than 1kPa.

The stabilising influence of the internal drainage systems is brought about by the reduction in the size of the seepage face and thus the quantity of excess water in the

region of the slope face. This reduces the excess weight on the bank charged by the subsurface water.

In all cases the failure surfaces appear with greatest probability at the seepage face and radiate out from the seepage face with lesser probability. The failure surfaces are not deep seated forms but perhaps shallow infinite slope forms which reflect the absence of cohesion in the soil.

It was observed that analysing stability in terms of Factor of Safety (FOS) was not feasible as a limitation in the analysis was discovered due to low Factors of Safety. Given critical soils conditions (dilatant and loss of apparent cohesion) slope instabilities are predicated for the 2in1 streambank even at stream drawdown rates of 50mm/hr.

Figure 7.1   Slope stability analysis of homogeneous streambank model GEN1 (300mm/hr).
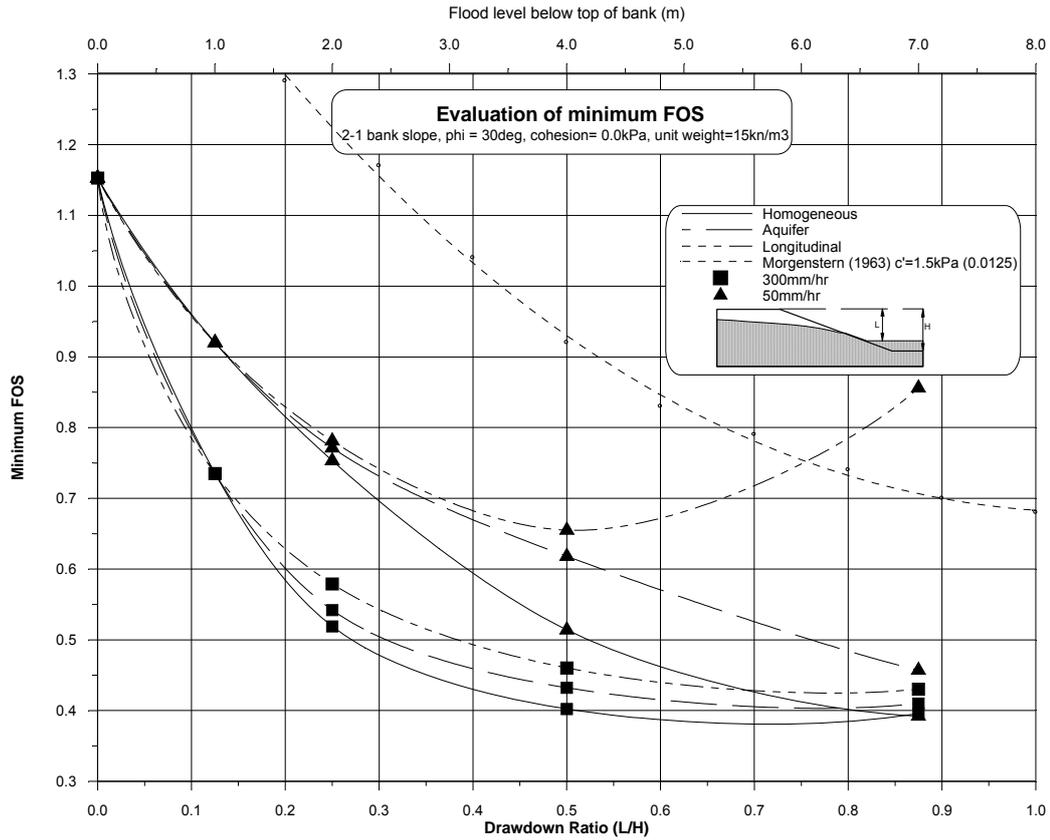
Figure 7.2   **Minimum factor of safety for slope stability of various drainage models**
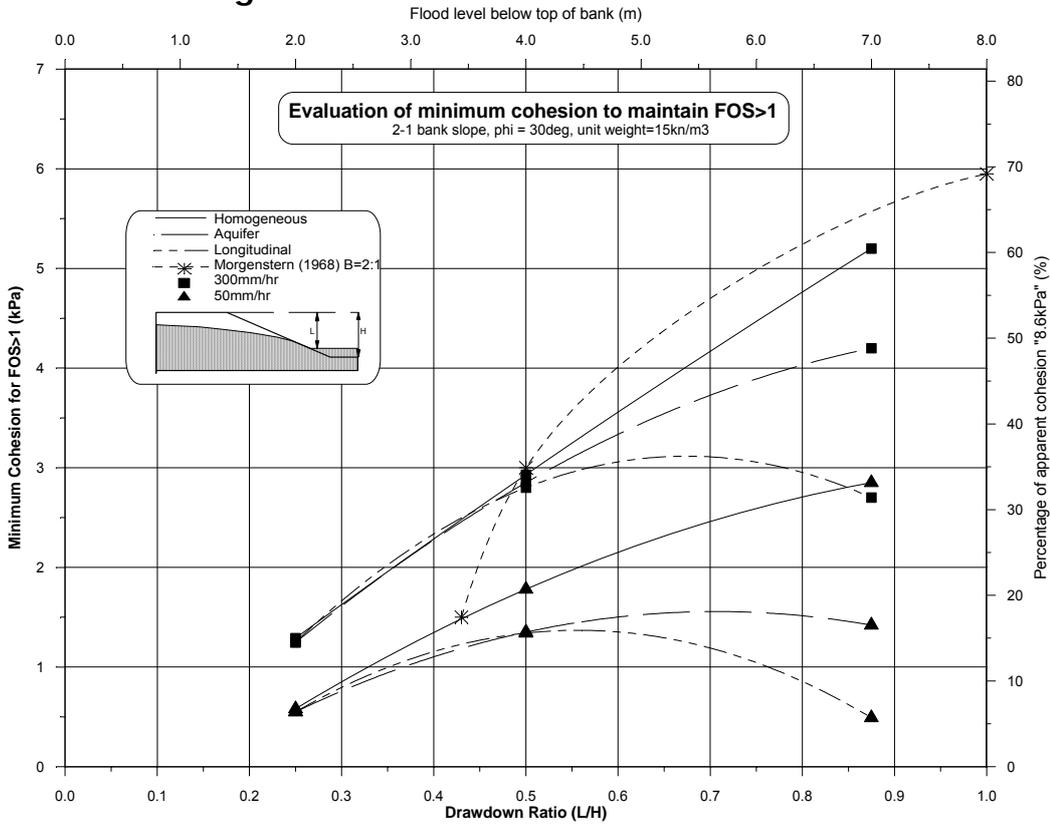
Figure 7.3   **Minimum cohesion to maintain factor of safety for slope stability greater than 1.0**

Chapter 8

SUMMARY & CONCLUSIONS

This chapter presents the summary and conclusions of the investigation and analysis of into streambank instabilities influenced by rapid drawdown of stream water levels. The results of the physical investigation at Bube, analyses of the subsurface water modelling along with the resultant slope instabilities analysed at each phase of rapid stream level drawdown are summarised and conclusions presented.

8.1   SUMMARY

Streambank slumping has long frustrated the Herbert River Improvement Trust and riparian landholders on the Lower Herbert River.   Anecdotal evidence and investigations have identified that slumps predominantly occur in the Lower Herbert River and are typically associated with bank seepage. Treatment of slumps has so far relied on trial and error remediation without a full understanding of the slumping attributes or treatment performance.   The impacts associated with slumping, the inability to predict the location and timing and a lack of understanding of slump attributes has fuelled the need to investigate them in detail.   This thesis investigates the attributes of slumping and the effects of subsurface water on streambank mass movements, in relation to flooding, local rainfall and regional groundwater conditions

The thesis has performed investigations using field monitoring, numerical seepage modelling and rudimentary stability calculations to develop a better understanding of streambank mass movements.   The field monitoring investigated streambank subsurface water movements associated with site conditions such as; stream flood levels, local rainfall and regional groundwater conditions. The monitoring confirmed the existence of rapid drawdown conditions associated with stream water levels and local groundwater conditions.   The monitoring identified the principal streambank saturating mechanisms and the positive drainage effects of subsurface drainage configurations.   The numerical seepage modelling investigated subsurface water movements in response to stream flood characteristics such as duration, and rates of rise and fall.   The stream bank soil parameters included in the numerical modelling were as identified onsite and incorporated three drainage configurations (homogeneous, drainage layer and longitudinal drainage pipe..   The results of the

modelling determined the likelihood of stream flood levels saturating bank soils and identified the characteristic variations in subsurface water profiles in response to variations in streambank drainage configurations, soil permeabilities and stream flood hydrograph characteristics. The results of the numerical modelling were used to determine streambank stability thresholds for variations in subsurface drainage configuration, soil strength and stream flood level characteristics.

8.2   CONCLUSIONS

The conclusions drawn from the research are broken down into sections corresponding to the chapters of this thesis.

8.2.1   LOWER HERBERT RIVER

Generic factors effecting streambank slumping have been researched and found principally to influence either changes in shear strength or shear stress of a streambank. Methods of streambank stabilisation were reviewed and the geographical distribution of streambank failures in the lower Herbert River was identified from various sources. In particular it was identified by Kapitzke et al. (1995) that the streambank soils in the lower Herbert are susceptible to a rapid drawdown type failure, since they are permeable enough to allow saturation from river flood waters and local rainfall, and yet retain an elevated water table after flooding due to poor drainage capacity and the tropical flood characteristics that exhibited during rapid drawdown of flood levels after the flood peak. The physiography and human-use characteristics of the Herbert Basin have been investigated and attributes of slumping failures within the lower Herbert River have been characterised.

As part of a collaborative research investigation between the Bube case study site was investigated and instrumented as part of a site monitoring program which investigated streambank treatment performance and associated subsurface water characteristics. The results of the site monitoring program proved that infrequent bank full flood flows as a result of overflow discharge from the Herbert River (commonly associated with monsoonal and cyclonic activity during the wet season) and the recharge of the regional aquifer S4 contribute to the rapid drawdown induced slump failures at Bube. Furthermore, the extensive streambank clearing undertaken in the past for sugar cane cultivation and invasion of exotic species of vegetation further contribute to the degradation of streambank shear strength and streambank slumping.

Six Herbert River flood events: March 1967, March 1977, February 1991, January 1994, March 1973 and January 1981, were selected to analyse the hydrographic characteristics of three flood categories: A (large), B (medium) and C (small). These categories were defined on the basis of 2 year and 20 year average recurrence interval thresholds. Flood hydrograph characteristics such as rate of rise and recession and lower third bank height duration were analysed for the six flood events. In conclusion, flooding in the lower Herbert River is closely related to the characteristics of rainfall either in the upper or lower catchment. Flood rise rate of 300mm/hr and flood recession rates of 300 and 50 mm/hr were chosen as the basis for modelling subsurface water conditions.

8.2.2   STREAMBANK MONITORING

Subsurface monitoring data was recorded at the Bube site for the March 1996 flood event. Although instrumentation failure plagued the subsurface monitoring program, what was recorded provided a valuable insight to the mechanisms involved in rapid drawdown bank instabilities.

The shallow watertable was observed to be independent to the stream flood levels. In particular at station A the watertable when compared to stream flood levels; peaked higher and remained high well after. Unlike in other monitoring stations the shallow watertable at station A has a significant influence on inundating bank materials and thus facilitating rapid drawdown conditions. This influence was less towards the toe of the bank as the longitudinal subsurface drainage system effectively lowers the subsurface water levels equivalent to those of the stream.

Stream inundation was the only saturating mechanism observed at station Ba, where the shallow watertable did not have the same influence as in station A. The subsurface water levels recorded during flood recession lagged the instream levels indicating the development of rapid drawdown conditions, but only locally near the streambank slope face. These observations indicate that stream inundation is the primary source of bank saturation at station Ba and that without the influence of an aquifer or significant overbank flooding, rapid drawdown conditions would unlikely develop.

The longitudinal drainage system installed at trial treatment 1 (station A) was observed to effectively assist the inundation of lower bank materials during flood rise and reduce the lag of subsurface level within the lower bank to instream levels. The longitudinal drainage system appears to effectively reduce the local subsurface water levels as a

result of the elevated aquifer levels. However, the drainage system doesn't appear to influence water levels within the upper bank where aquifer levels appear to dominate the conditions in station A.

8.2.3   STREAMBANK SUBSURFACE MODELLING

Results of the two transient subsurface flood models (rise infiltration and recession drainage) were analysed with various primary model parameters of soil permeability, flood rise and fall rates and internal drainage configurations, and secondary model parameters of soil matrix suction, transient flood height increments, and modelling time steps.

It was demonstrated that streambanks are capable of becoming saturated during stream flood level rise durations and heights equivalent to a category B event. The internal bank drainage configuration of a longitudinal drainage pipe and a drainage layer (aquifer) facilitate a greater saturation of the bank materials during the earlier stream flood levels, but appear to not drastically influence the saturation of the entire stream bank during the later stage of stream flood levels.

The flood recession modelling has provided the most valuable insight to drainage of subsurface water levels during stream flood recession. Based on an initially saturated streambank, the modelling has demonstrated that the homogeneous bank develops seepage face lengths approximately in proportion to the rate of falling stream flood levels. Whereas the drainage layer and drainage pipe bank configurations develop proportional seepage face lengths up to a break point height in stream flood level, at which point the development of seepage faces drastically changes to either a decay or slower rate. The break point is associated with stream flood heights around the mid level between the top of bank and the internal drainage point. In this case a stream flood level of approximately 3.5 meters below the top of bank defines the break point in development of seepage face length. Further evaluation of recession models reveals subsurface drainage flows for the homogenous bank are concentrated within the seepage face with directions either parallel or exiting to the seepage face. However the influence of the internal drainage configurations appears to draw the drainage flows towards the point of internal drainage thereby minimising velocities exiting the seepage face and flow directions likely to be aligned with potential shallow slope failure surfaces. In summary the internal drainage configurations are likely to aid the stability of stream bank slopes compared to homogenous stream bank.

8.2.4 STREAMBANK STABILITY ANALYSES

Results of the stability analyses clearly show that the internal drainage systems influence slope stability positively. In both cases the influence appears after stream levels fall below approximately mid bank height. The longitudinal drainage pipe has the greatest influence by reducing the cohesion required to maintain stability by 2.5kPa compared to a streambank without internal drainage. The reduction in the required cohesion appears to be the same irrespective of the stream drawdown rate (300mm/hr or 50mm/hr). The influence by the streambank with an aquifer appears to be slightly greater than 1kPa.

The stabilising influence of the internal drainage systems is brought about by the reduction in the size of the seepage face and thus the quantity of excess water in the region of the slope face. This reduces the excess weight on the bank charged by the subsurface water.

In all cases the failure surfaces appear with greatest probability at the seepage face and radiate out from the seepage face with lesser probability. The failure surfaces are not deep seated forms but perhaps shallow infinite slope forms which reflect the absence of cohesion in the soil.

It was observed that analysing stability in terms of Factor of Safety (FOS) was not feasible as a limitation in the analysis was discovered due to low Factors of Safety. Given critical soils conditions (dilatant and loss of apparent cohesion) slope instabilities are predicated for the 2in1 streambank even at stream drawdown rates of 50mm/hr.

8.3   RECOMMENDATIONS

* Investigate the relationship between rates, spatial occurrences and durations of rainfall events and rates and durations of flooding, it is outside the scope of this study
* Increase database on slumping occurance and streambank stratigraphy and soil type
* Investigate and trial alternative subsurface drainage systems
* Investigate the occurance of streambank slumping in high river bank upstream of Ingham

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APPENDIX A

GEOTECHNICAL FIELD DATA

SYMBOL LEGEND FOR GEOTECHNICAL LOGS

SOIL TYPES:

MADE GROUND

BOULDERS & COBBLES

GRAVEL
- Poorly graded
- Well graded

SAND
- Poorly graded
- Well graded

SILT
- High plasticity
- Low plasticity

CLAY
- High plasticity
- Low plasticity

PEAT/ ORGANIC CLAY

Composite soil types: Signified by combined symbols; eg. Silty SAND
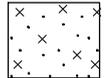
Additional Secondary Terms: Shelly   Gypsiferous
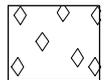
ROCK TYPES:

Sedimentary:

CLAYSTONE/ MUDSTONE

SILTSTONE

SANDSTONE

CONGLOMERATE

BRECCIA

LIMESTONE

CHALK

Carb. CLAYSTONE/ CALCILUTITE

Carb. SILTSTONE/ CALCISILTITE

Carb. SANDSTONE/ CALCARENITE

Carb. CONGLOMATE/ CALCIRUDITE

Evaporite:

GYPSUM/ HALITE

Igneous:

Coarse Grained
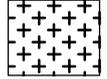
Medium Grained
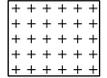
Fine Grained

Metamorphic:

Coarse Grained
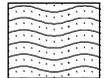
Medium Grained
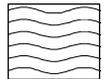
Fine Grained

SAMPLE TYPES:

Bulk/ disturbed   Shelby/ undisturbed   Standard Penetration Test (SPT)   No Recovery (SPT)   Rock Core

JAMES COOK UNIVERSITY
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Borehole: **A**

Equipment: Walker's DB100	**Start Date:** 18/10/1995	**Coordinates:**	
Method: Rotary Auger/ Wash Boring/ PCPT	**Bore Diameter (mm):** 100	**E** 419493.3	**N** 7944880.2
Fluid Flush: Water	**Core Diameter (mm):** N/A	**Surface Elevation:** +7.9 mAHD	

Date	Casing Depth (m)	Water Depth (m)	Graphic Symbol	Depth (m)	Strata Description	Sample No.	Sample/ Test Records	Sample Type & Depth (m)	TCR	SCR	RQD
18/10/1995					Medium dense, olive brown to brown, slightly silty to silty, fine SAND, dry, compacted layer (<0.8m) {SM}	B1		0.30 / 0.70			
				1 — 6.8	Firm to stiff, light grey stained, reddish brown, CLAY/SILT, interbedded with lenses/bands (<0.4m) of silty SAND, moist becoming wet {CL}	B2		1.30 / 1.70			
				2		B3		2.30 / 2.70			
				3 — 4.6		U1		2.90 / 3.30			
					[3.35 to 3.80]....silty SAND {SM} — 4.1	B4		3.30 / 3.70			
				4 — 3.6	[4.35 to 4.85]....very sandy SILT, moist {SM} — 3.1	B5		4.30 / 4.70			
				5	▽... becoming firm — 2.5	U2		5.30 / 5.70			
					Medium dense, SAND, some gravel?, (Aquifer?), wet {SPG} — 2.1						
				6	Soft, CLAY/SILT, wet {CL}	B6		5.70 / 6.30			
						U3		6.50 / 7.00			
18/10/1995 17/10/1995	7.0	5.00		7	Borehole Terminated at 7.0m Depth [7.0m] ..Electric temperature/pressure sensor {AA¹TP}						
				8 — -0.5	Loose, sandy to very sandy CLAY/SILT, wet {MS}						
				9 — -1.3	Loose to medium dense, slightly silt SAND, wet {SP}						
				10 — -2.1							

Remarks: Log developed from combination of bulk sampling and adjacent PCPT data. Located on Annabranch river bank treatment. Borehole terminated at 7.0m and PCPT terminated at 10.25m.

Project:	**Bube Subsurface Monitoring Program**
Location:	**Herbert River Annabranch**
Client:	**JCU/HRIT**
Job No.:	**Sands (2005)**

Logged by: Lsd

Checked by:

Plate No.: A2.1.1

Sheet 1 of 2

JAMES COOK UNIVERSITY
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Borehole: A

Equipment: Walker's DB100   **Start Date:**   18/10/1995   **Coordinates:**

Method: Rotary Auger/ Wash Boring/ PCPT **Bore Diameter (mm):** 100   **E** 419493.3   **N** 7944880.2

Fluid Flush: Water   **Core Diameter (mm):** N/A   **Surface Elevation:** +7.9 mAHD

Borehole Progress			Graphic Symbol	Depth (m)	Strata Description	Sample No.	Sample/ Test Records	Sample Type & Depth (m)	Rock Core Quality		
Date	Casing Depth (m)	Water Depth (m)							TCR	SCR	RQD
17/10/1995		5.00			[SAND as above] -2.4						
				11							
				12							
				13							
				14							
				15							
				16							
				17							
				18							
				19							
				20							

Remarks: Log developed from combination of bulk sampling and adjacent PCPT data. Located on Annabranch river bank treatment. Borehole terminated at 7.0m and PCPT terminated at 10.25m.

Project: **Bube Subsurface Monitoring Program**

Location: **Herbert River Annabranch**

Client: **JCU/HRIT**

Job No.: **Sands (2005)**

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Logged by: Lsd

Checked by:

Plate No.: A2.1.2

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Borehole: AA2P

Equipment: Hand Auger 100mm   **Start Date:** 12/11/1995   **Coordinates:**

Method: Rotary Auger Boring   **Bore Diameter (mm):** 100   **E** 419487.5   **N** 7944871.5

Fluid Flush: N/A   **Core Diameter (mm):** N/A   **Surface Elevation:** +5.4 mAHD

Borehole Progress			Graphic Symbol	Depth (m)	Strata Description	Sample No.	Sample/ Test Records	Sample Type & Depth (m)	Rock Core Quality		
Date	Casing Depth (m)	Water Depth (m)							TCR	SCR	RQD
12/11/1995					Olive light brown, slightly silty to silty, fine SAND, dry becoming moist, {SM}	B1		0.30			
				1							
				2	3.4						
12/11/1995					Light grey, slightly gravelly, silty, fine to coarse SAND becoming very gravelly, wet, (Aquifer?), {SMG} 3.1	B2 B3 B4		2.00 2.10 2.20			
					Borehole Terminated at 2.6m Depth						
				3							
				4							
				5							
				6							
				7							
				8							
				9							
				10							

Remarks: Borehole located on Annabranch streamwork slope at Treatment 1. Electric pressure sensor installed at 2.1m below existing ground level.

Project: **Bube Subsurface Monitoring Program**

Location: **Herbert River Annabranch**

Client: **JCU/HRIT**

Job No.: **Sands (2005)**

Logged by: Lsd

Checked by:

Plate No.: A2.4.1

Sheet 1 of 1

JAMES COOK UNIVERSITY
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Borehole: AB1P

Equipment: Hand Auger 100mm	**Start Date:** 12/11/1995	**Coordinates:**
Method: Rotary Auger Boring	**Bore Diameter (mm):** 100	**E** 419491.5 **N** 7944877.3
Fluid Flush: N/A	**Core Diameter (mm):** N/A	**Surface Elevation:** +8.1 mAHD

Borehole Progress			Graphic Symbol	Depth (m)	Strata Description	Sample No.	Sample/ Test Records	Sample Type & Depth (m)	Rock Core Quality		
Date	Casing Depth (m)	Water Depth (m)							TCR	SCR	RQD
12/11/1995					Olive brown, slightly silty to silty, fine SAND, dry {SM}						
						B1		0.30			
				1		B2		1.00			
				2							
							5.5				
					Brown, SILT/CLAY, dry {CL}	B3		2.60			
12/11/1995				3	Borehole Terminated at 3.2m Depth 4.9			3.20			
				4							
				5							
				6							
				7							
				8							
				9							
				10							

Remarks: Borehole located on top of Annabranch streambank within Treatment 1. Electric pressure sensor installed at 3.0m below existing ground surface.	Project: **Bube Subsurface Monitoring Program**		Logged by: Lsd
	Location: **Herbert River Annabranch**		Checked by:
	Client: **JCU/HRIT**		
	Job No.: **Sands (2005)**	Sheet 1 of 1	Plate No.: A2.2.1

JAMES COOK UNIVERSITY
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Borehole: AB2P

Equipment: Hand Auger 100mm **Start Date:** 12/11/1995 **Coordinates:**

Method: Rotary Auger Boring **Bore Diameter (mm):** 100 **E** 419490 **N** 7944875

Fluid Flush: N/A **Core Diameter (mm):** N/A **Surface Elevation:** +8.3 mAHD

Borehole Progress			Graphic Symbol	Depth (m)	Strata Description	Sample No.	Sample/ Test Records	Sample Type & Depth (m)	Rock Core Quality		
Date	Casing Depth (m)	Water Depth (m)							TCR	SCR	RQD
12/11/1995					Olive brown, slightly silty to silty, fine SAND, dry, {SM}						
						B1		0.30			
				1							
12/11/1995					Borehole Terminated at 1.7m Depth 6.6	B2		1.40			
				2							
				3							
				4							
				5							
				6							
				7							
				8							
				9							
				10							

Remarks: Borehole located on top of Annabranch streambank within Treatment 1. Electric moisture sensor installed at 1.7m below existing ground level.

Project: **Bube Subsurface Monitoring Program**

Location: **Herbert River Annabranch**

Client: **JCU/HRIT**

Job No.: **Sands (2005)**

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Logged by: Lsd

Checked by:

Plate No.: A2.3.1

JAMES COOK UNIVERSITY
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Borehole: Ba

Equipment: Walker's DB100	**Start Date:** 18/10/1995
Method: Rotary Auger/ Wash Boring/ PCPT	**Bore Diameter (mm):** 100
Fluid Flush: Water	**Core Diameter (mm):** N/A

Coordinates:
E 419307.3 **N** 7944946.8
Surface Elevation: +7.8 mAHD

Borehole Progress			Graphic Symbol	Depth (m)	Strata Description	Sample No.	Sample/ Test Records	Sample Type & Depth (m)	Rock Core Quality		
Date	Casing Depth (m)	Water Depth (m)							TCR	SCR	RQD
18/10/1995					Medium dense, olive brown to brown, slightly silty becoming silty, fine SAND , dry, compacted layer {SM}	B1		0.30 / 0.70			
				1							
					6.2						
				2	Stiff, reddish brown to brown, slightly sandy SILT/CLAY, dry. {CL}	B2		1.80 / 2.20			
					5.6						
				3	Medium dense, very sandy becoming sandy CLAY/SILT {MS}	U1		3.00 / 3.40			
					4.4						
					Firm, slighty sandy CLAY/SILT {CL} 4.1						
				4	Medium dense, slightly silty, SAND, some gravel?, (Aquifer?) {SMG} 3.6						
					Soft to firm, grey, CLAY/SILT {CL}	B3		4.30 / 4.70			
				5							
						B4		5.30 / 5.70			
				6							
						B5		6.30 / 6.70			
				7	0.8						
					[7.0 to 7.2] .... loose, sandy CLAY/SILT {MS} 0.6	U2		7.30 / 7.80			
				8	[8.0m] ..Electric temperature/pressure sensor {BaA¹TP}						
18/10/1995	8.7	4.20				U3		8.25 / 8.65			
17/10/1995					Borehole Terminated at 8.7m Depth						
				9							
					-1.5						
					Medium dense, very sandy CLAY/SILT {MS}						
				10	-2.2						

Remarks: Log developed from combination of bulk sampling and adjacent PCPT data. Located on Annabranch river bank treatment. Borehole terminated at 8.7m and PCPT terminated at 10.25m.

Project:	**Bube Subsurface Monitoring Program**
Location:	**Herbert River Annabranch**
Client:	**JCU/HRIT**
Job No.:	**Sands (2005)**

Logged by: Lsd
Checked by:
Plate No.: A2.6.1
Sheet 1 of 2

JAMES COOK UNIVERSITY
School of Engineering - Civil & Environmental

Borehole: Ba

Equipment: Walker's DB100   **Start Date:** 18/10/1995   **Coordinates:**

Method: Rotary Auger/ Wash Boring/ PCPT   **Bore Diameter (mm):** 100   **E** 419307.3   **N** 7944946.8

Fluid Flush: Water   **Core Diameter (mm):** N/A   **Surface Elevation:** +7.8 mAHD

Borehole Progress			Graphic Symbol	Depth (m)	Strata Description	Sample No.	Sample/ Test Records	Sample Type & Depth (m)	Rock Core Quality		
Date	Casing Depth (m)	Water Depth (m)							TCR	SCR	RQD
17/10/1995		4.20			[very sandy CLAY/SILT as above] -2.5						
				11							
				12							
				13							
				14							
				15							
				16							
				17							
				18							
				19							
				20							

Remarks: Log developed from combination of bulk sampling and adjacent PCPT data. Located on Annabranch river bank treatment. Borehole terminated at 8.7m and PCPT terminated at 10.25m.

Project: **Bube Subsurface Monitoring Program**

Location: **Herbert River Annabranch**

Client: **JCU/HRIT**

Job No.: **Sands (2005)**

Logged by: Lsd

Checked by:

Sheet 2 of 2

Plate No.: A2.6.2

JAMES COOK UNIVERSITY
School of Engineering - Civil & Environmental

Borehole: BaA2P

Equipment: Hand Auger 100mm	**Start Date:** 12/11/1995	**Coordinates:**
Method: Rotary Auger Boring	**Bore Diameter (mm):** 100	**E** 419300.7 **N** 7944935.8
Fluid Flush: N/A	**Core Diameter (mm):** N/A	**Surface Elevation:** +4.5 mAHD

Borehole Progress			Graphic Symbol	Depth (m)	Strata Description	Sample No.	Sample/ Test Records	Sample Type & Depth (m)	Rock Core Quality		
Date	Casing Depth (m)	Water Depth (m)							TCR	SCR	RQD
12/11/1995					Olive brown, slightly silty to silty, fine SAND, dry {SM}						
				1							
					3.3			1.20			
					Silty, very gravelly fine to coarse SAND, moist, (Aquifer?) {SMG} 3.0	B1		1.50			
12/11/1995					Borehole Terminated at 1.7m Depth 2.8 Very sandy CLAY/SILT, moist {MS}	B2					
				2							
				3							
				4							
				5							
				6							
				7							
				8							
				9							
				10							

Remarks: Borehole located on top of Annabranch streambank slope within control station. Electric pressure sensor installed at 1.4m below existing ground surface.	**Project:** **Bube Subsurface Monitoring Program** **Location:** **Herbert River Annabranch** **Client:** **JCU/HRIT** **Job No.:** **Sands (2005)** Sheet 1 of 1

Logged by: Lsd
Checked by:
Plate No.: A2.11.1

JAMES COOK UNIVERSITY
School of Engineering - Civil & Environmental

Borehole: BaB1M

Equipment: Hand Auger 100mm **Start Date:** 12/11/1995 **Coordinates:**

Method: Rotary Auger Boring **Bore Diameter (mm):** 100 **E** 419305.1 **N** 7944940.7

Fluid Flush: N/A **Core Diameter (mm):** N/A **Surface Elevation:** +7.1 mAHD

Borehole Progress			Graphic Symbol	Depth (m)	Strata Description	Sample No.	Sample/ Test Records	Sample Type & Depth (m)	Rock Core Quality		
Date	Casing Depth (m)	Water Depth (m)							TCR	SCR	RQD
12/11/1995					Olive brown, silty to very silty, fine SAND, dry {SM}						
				1	6.1						
					Olive brown, very sandy SILT, dry {MS}	B1		1.10			
12/11/1995					Borehole Terminated at 1.5m Depth 5.6			1.50			
				2							
				3							
				4							
				5							
				6							
				7							
				8							
				9							
				10							

Remarks: Borehole located on top of Annabranch streambank within control station. Electric moisture sensor installed at 1.5m below existing ground surface.

Project: **Bube Subsurface Monitoring Program**

Location: **Herbert River Annabranch**

Client: **JCU/HRIT**

Job No.: **Sands (2005)**

Sheet 1 of 1

Logged by: Lsd

Checked by:

Plate No.: A2.8.1

JAMES COOK UNIVERSITY
School of Engineering - Civil & Environmental

Borehole: BaB1P

Equipment: Hand Auger 100mm	**Start Date:** 12/11/1995	**Coordinates:**
Method: Rotary Auger Boring	**Bore Diameter (mm):** 100	**E** 419305.7 **N** 7944942.5
Fluid Flush: N/A	**Core Diameter (mm):** N/A	**Surface Elevation:** +7.5 mAHD

Borehole Progress			Graphic Symbol	Depth (m)	Strata Description	Sample No.	Sample/ Test Records	Sample Type & Depth (m)	Rock Core Quality		
Date	Casing Depth (m)	Water Depth (m)							TCR	SCR	RQD
12/11/1995					Olive brown, silty to very silty, fine SAND, dry {SM}						
				1	6.5						
					Olive brown, very sandy SILT, dry {MS}	B1		1.00 1.40			
12/11/1995					Borehole Terminated at 1.7m Depth 5.8						
				2							
				3							
				4							
				5							
				6							
				7							
				8							
				9							
				10							

Remarks: Borehole located on top of Annabranch streambank within control section. Electric pressure sensor installed at 1.5m below existing ground level.

Project: **Bube Subsurface Monitoring Program**	Logged by: Lsd
Location: **Herbert River Annabranch**	Checked by:
Client: **JCU/HRIT**	
Job No.: **Sands (2005)**	Plate No.: A2.7.1

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JAMES COOK UNIVERSITY
School of Engineering - Civil & Environmental

Borehole: BaB2M

Equipment: Hand Auger 100mm

Method: Rotary Auger Boring

Fluid Flush: N/A

Start Date: 12/11/1995

Bore Diameter (mm): 100

Core Diameter (mm): N/A

Coordinates:

E 419301.9 **N** 7944936.6

Surface Elevation: +4.7 mAHD

Borehole Progress			Graphic Symbol	Depth (m)	Strata Description	Sample No.	Sample/ Test Records	Sample Type & Depth (m)	Rock Core Quality		
Date	Casing Depth (m)	Water Depth (m)							TCR	SCR	RQD
12/11/1995					Olive brown, very sandy SILT, dry {MS}						
12/11/1995				1	Borehole Terminated at 1.2m Depth 3.5	B1		0.90			
				2							
				3							
				4							
				5							
				6							
				7							
				8							
				9							
				10							

Remarks: Borehole located on top of Annabranch streambank slope within control station. Electric moisture sensor installed at 1.2m below existing ground level.

Project: **Bube Subsurface Monitoring Program**

Location: **Herbert River Annabranch**

Client: **JCU/HRIT**

Job No.: **Sands (2005)**

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Logged by: Lsd

Checked by:

Plate No.: A2.10.1

JAMES COOK UNIVERSITY
School of Engineering - Civil & Environmental

Borehole: BaB2P

Equipment: Hand Auger 100mm	**Start Date:** 12/11/1995	**Coordinates:**	
Method: Rotary Auger Boring	**Bore Diameter (mm):** 100	**E** 419302.3	**N** 7944937.6
Fluid Flush: N/A	**Core Diameter (mm):** N/A	**Surface Elevation:** +5.1 mAHD	

Borehole Progress			Graphic Symbol	Depth (m)	Strata Description	Sample No.	Sample/ Test Records	Sample Type & Depth (m)	Rock Core Quality		
Date	Casing Depth (m)	Water Depth (m)							TCR	SCR	RQD
12/11/1995					Olive brown, very sandy SILT, dry {MS}						
				1		B1		0.90			
12/11/1995					Borehole Terminated at 1.5m Depth 3.6						
				2							
				3							
				4							
				5							
				6							
				7							
				8							
				9							
				10							

Remarks: Borehole located on top of Annabranch streambank slope within control station. Electric pressure sensor installed at 1.3m below existing ground surface.

Project:	**Bube Subsurface Monitoring Program**
Location:	**Herbert River Annabranch**
Client:	**JCU/HRIT**
Job No.:	**Sands (2005)**

Logged by: Lsd

Checked by:

Plate No.: A2.9.1

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JAMES COOK UNIVERSITY
School of Engineering - Civil & Environmental

Borehole: C

Equipment: Walker's DB100	**Start Date:** 17/10/1995	**Coordinates:**
Method: Rotary Auger/ Wash Boring/ PCPT	**Bore Diameter (mm):** 100	**E** 419239.5 **N** 7944946.4
Fluid Flush: Water	**Core Diameter (mm):** N/A	**Surface Elevation:** +7.8 mAHD

Borehole Progress			Graphic Symbol	Depth (m)	Strata Description	Sample No.	Sample/ Test Records	Sample Type & Depth (m)	Rock Core Quality		
Date	Casing Depth (m)	Water Depth (m)							TCR	SCR	RQD
18/10/1995					Medium dense, olive brown to brown, slightly silty fine SAND, dry compacted layer (<0.5m) {SM}	B1		0.30 / 0.70			
				1							
					Medium dense, sandy SILT {MS} 6.7	B2		1.30 / 1.70			
				2							
					Stiff to very stiff, SILT/CLAY, dry {CL} 5.7	B3		2.30 / 2.70			
					Medium dense, brown, very sandy CLAY/SILT {MS} 5.3						
				3							
					4.2	B4		3.30 / 3.70			
					Soft to firm, brown mottled grey, SILT/CLAY, interbedded with bands of very clayey/silty sand {MH/CL}						
				4		U1		4.00 / 4.40			
						B5		4.40 / 4.80			
				5							
						B6		5.30 / 5.70			
				6							
						B7		6.30 / 6.70			
					1.0						
				7	[6.80 to 7.10]....very sandy SILT/CLAY {MS} 0.7						
						U2		7.20			
				8							
						U3		8.40 / 8.80			
18/10/1995	8.4	3.80			Borehole Terminated at 8.8m Depth -1.0						
17/10/1995					Firm to stiff, SILT/CLAY {CL} [8.8m] ..Electric temperature/pressure sensor {CA¹TP}						
				9							
					-1.5						
					Medium dense, sandy to very sandy SILT {MS}						
17/10/1995		3.80		10	-2.2						

Remarks: Log developed from combination of bulk sampling and adjacent PCPT data. Located on Annabranch river bank treatment. Borehole terminated at 8.8m and PCPT terminated at 10m.

Project: **Bube Subsurface Monitoring Program**	Logged by: Lsd
Location: **Herbert River Annabranch**	Checked by:
Client: **JCU/HRIT**	
Job No.: **Sands (2005)**	Plate No.: A2.12.1

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JAMES COOK UNIVERSITY
School of Engineering - Civil & Environmental

Borehole: CA2P

Equipment: Hand Auger 100mm **Start Date:** 12/11/1995 **Coordinates:**

Method: Rotary Auger Boring **Bore Diameter (mm):** 100 **E** 419239.8 **N** 7944940

Fluid Flush: N/A **Core Diameter (mm):** N/A **Surface Elevation:** +4.1 mAHD

Borehole Progress			Graphic Symbol	Depth (m)	Strata Description	Sample No.	Sample/ Test Records	Sample Type & Depth (m)	Rock Core Quality		
Date	Casing Depth (m)	Water Depth (m)							TCR	SCR	RQD
12/11/1995					Brown mottled grey, very clayey SAND with bands of very sandy clay, moist becoming wet. {SC}						
						B1		0.50			
				1							
				2							
						1.6					
					Light grey mottled brown, very sandy CLAY, wet {CS}	B2		2.50			
12/11/1995				3	Borehole Terminated at 3.2m Depth 0.9	B3		2.90			
				4							
				5							
				6							
				7							
				8							
				9							
				10							

Remarks: Borehole located on Annabranch stream bank slope at Treatment 4. Electric pressure sensor installed at 3.0m below existing ground level.

Project:	**Bube Subsurface Monitoring Program**
Location:	**Herbert River Annabranch**
Client:	**JCU/HRIT**
Job No.:	**Sands (2005)**

Logged by: Lsd

Checked by:

Plate No.: A2.15.1

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JAMES COOK UNIVERSITY
School of Engineering - Civil & Environmental

Borehole: CB1M

Equipment: Hand Auger 100mm   **Start Date:** 12/11/1995   **Coordinates:**

Method: Rotary Auger Boring   **Bore Diameter (mm):** 100   **E** 419240.6   **N** 7944944.9

Fluid Flush: N/A   **Core Diameter (mm):** N/A   **Surface Elevation:** +8.1 mAHD

Borehole Progress			Graphic Symbol	Depth (m)	Strata Description	Sample No.	Sample/ Test Records	Sample Type & Depth (m)	Rock Core Quality		
Date	Casing Depth (m)	Water Depth (m)							TCR	SCR	RQD
12/11/1995					Brown, silty fine SAND, dry {SM}						
				1		B1		0.70			
12/11/1995					Borehole Terminated at 1.6m Depth 6.5	B2		1.30			
				2							
				3							
				4							
				5							
				6							
				7							
				8							
				9							
				10							

Remarks: Borehole located on Annabranch riverbank within Treatment 4. Electric moisture sensor installed at 1.5m below existing ground level.

Project:	**Bube Subsurface Monitoring Program**
Location:	**Herbert River Annabranch**
Client:	**JCU/HRIT**
Job No.:	**Sands (2005)**

Logged by: Lsd

Checked by:

Plate No.: A2.14.1

Sheet 1 of 1

JAMES COOK UNIVERSITY
School of Engineering - Civil & Environmental

Borehole: CB1P

Equipment: Hand Auger 100mm　　**Start Date:** 12/11/1995　　**Coordinates:**

Method: Rotary Auger Boring　　**Bore Diameter (mm):** 100　　**E** 419238.1　　**N** 7944944.6

Fluid Flush: N/A　　**Core Diameter (mm):** N/A　　**Surface Elevation:** +8.1 mAHD

Borehole Progress			Graphic Symbol	Depth (m)	Strata Description	Sample No.	Sample/ Test Records	Sample Type & Depth (m)	Rock Core Quality		
Date	Casing Depth (m)	Water Depth (m)							TCR	SCR	RQD
12/11/1995					Brown, slightly silty fine SAND, dry {SM}						
				1		B1		0.70			
12/11/1995					Borehole Terminated at 1.5m Depth　　6.6						
				2							
				3							
				4							
				5							
				6							
				7							
				8							
				9							
				10							

Remarks: Borehole located on top of Annabranch river bank within Treatment 4. Electric pressure sensor installed at 1.4m below existing ground level.

Project:　**Bube Subsurface Monitoring Program**

Location:　**Herbert River Annabranch**

Client:　**JCU/HRIT**

Job No.:　**Sands (2005)**

Sheet 1 of 1

Logged by: Lsd

Checked by:

Plate No.: A2.13.1

Soil Classification
Eslami & Fellenius (1997)

Depth	Classification
0.00	sandyGRAVEL / SAND
0.35	sandySILT / siltySAND
0.90	siltyCLAY / claySILT
1.10	SILT / CLAY
2.50	siltyCLAY / claySILT
3.35	sandySILT / siltySAND
3.80	siltyCLAY / claySILT
4.35	sandySILT / siltySAND
4.85	SILT / CLAY
5.10	siltyCLAY / claySILT
5.20	SILT / CLAY
5.45	sandyGRAVEL / SAND
5.80	sandySILT / siltySAND
5.90	SILT / CLAY
8.40	sandySILT / siltySAND
9.15	sandyGRAVEL / SAND
9.75	sandySILT / siltySAND
9.78	sandyGRAVEL / SAND
9.90	sandySILT / siltySAND
10.15	sandyGRAVEL / SAND

STNA

STATION A HEADLAND

HERBERT RIVER ANNABRANCH - BUBE SITE

Elevation [mAHD]

Friction Ratio Rf, [%]

Pore Pressure, U₂ [MPa]

Cone Resistance, q_c [MPa]

Sleeve Friction, f_s [MPa]

Depth Below Ground Level [m]

Date of Testing :	16/10/1995 14:55
Ground Elevation :	+ 7.70 [mAHD]
Coordinates (m) :	E 419494.4
	N 7944882.5
Engineer :	L. SANDS
Cone Type :	HOGT351,10T,U2
Cone Base Area [mm²] :	1000

Soil Classification
Eslami & Fellenius (1997)

Elevation [mAHD]	Classification
0.00 sandySILT / siltySAND	
0.15 sandyGRAVEL / SAND	
0.70 sandySILT / siltySAND	
1.20 siltyCLAY / claySILT	
2.80 sandySILT / siltySAND	
2.95 sandyGRAVEL / SAND	
3.85 sandySILT / siltySAND	
4.10 siltyCLAY / claySILT	
4.30 SILT / CLAY	
8.45 siltyCLAY / claySILT	
8.85 sandySILT / siltySAND	
9.85 siltyCLAY / claySILT	
9.95 sandySILT / siltySAND	
10.15 sandyGRAVEL / SAND	

Friction Ratio Rf, [%]

Pore Pressure, U_2 [MPa]

Cone Base Area [mm^2] :1000

Cone Resistance, q_c [MPa]

Sleeve Friction, f_s [MPa]

Depth Below Ground Level [m]

STNB

STATION B HEADLAND
HERBERT RIVER ANNABRANCH - BUBE SITE

Date of Testing :	17/10/1995 07:50
Ground Elevation :	+ 7.80 [mAHD]
Coordinates (m) :	E 419351.3
	N 7944942.0
Engineer :	L. SANDS
Cone Type :	HOGT351,10T,U2

Soil Classification
Eslami & Fellenius (1997)

Friction Ratio Rf, [%]

Pore Pressure, U$_2$ [MPa]

Elevation [mAHD]

7

6

5

4

3

2

1

0

-1

-2

-3

0.00 sandyGRAVEL / SAND
0.45 sandySILT / siltySAND
0.70 sandyGRAVEL / SAND
1.10 sandySILT / siltySAND
1.60 siltyCLAY / claySILT
2.30 sandySILT / siltySAND
3.45 siltyCLAY / claySILT
3.70 sandySILT / siltySAND
3.80 sandyGRAVEL / SAND
4.00 sandySILT / siltySAND
4.20 SILT / CLAY
7.00 sandySILT / siltySAND
7.25 SILT / CLAY
8.95 siltyCLAY / claySILT
9.25 sandySILT / siltySAND
10.30sandyGRAVEL / SAND

6

4

2

0

0.4

0.3

0.2

0.1

0.0

-0.1

Cone Resistance, q$_c$[MPa]
Sleeve Friction, f$_s$ [MPa]

24   0.60
22   0.55
20   0.50
18   0.45
16   0.40
14   0.35
12   0.30
10   0.25
8   0.20
6   0.15
4   0.10
2   0.05
0   0.00

0
1
2
3
4
5
6
7
8
9
10
11

Depth Below Ground Level [m]

STNBa

STATION Ba HEADLAND
HERBERT RIVER ANNABRANCH - BUBE SITE

Cone Base Area [mm^2] :1000

Date of Testing   : 17/10/1995 09:30
Ground Elevation : + 7.80   [mAHD]
Coordinates (m)   : E 419306.2

Engineer   :   L. SANDS
Cone Type :   HOGT380,10T,U2
                   N 7944949.0

Soil Classification
Eslami & Fellenius (1997)

Depth	Classification
0.00	sandySILT / siltySAND
0.20	sandyGRAVEL / SAND
1.15	sandySILT / siltySAND
1.95	siltyCLAY / claySILT
2.15	SILT / CLAY
2.40	siltyCLAY / claySILT
2.55	sandySILT / siltySAND
3.65	SILT / CLAY
4.00	siltyCLAY / claySILT
4.25	SILT / CLAY
4.45	siltyCLAY / claySILT
4.55	SILT / CLAY
8.90	siltyCLAY / claySILT
9.30	sandySILT / siltySAND

Elevation [mAHD]

Friction Ratio Rf, [%]

Pore Pressure, U$_2$ [MPa]

Cone Resistance, q$_c$ [MPa]
Sleeve Friction, f$_s$ [MPa]

Depth Below Ground Level [m]

STNC

STATION C HEADLAND
HERBERT RIVER ANNABRANCH - BUBE SITE

Cone Base Area [mm^2] : 1000

Date of Testing : 17/10/1995 11:03
Ground Elevation : + 7.80 [mAHD]
Coordinates (m) : E 419241.4

Engineer : L. SANDS
Cone Type : HOGT380,10T,U2
N 7944949.0

Soil Classification
Eslami & Fellenius (1997)

Elevation [mAHD]

6 5 4 3 2 1 0 -1 -2 -3 -4

0.00 sandyGRAVEL / SAND
0.35 sandySILT / siltySAND
1.50 siltyCLAY / claySILT
1.90 SILT / CLAY
2.95 siltyCLAY / siltySAND
3.00 sandyGRAVEL / siltySAND
3.35 siltyCLAY / claySILT
3.60 SILT / CLAY

8.95 sandySILT / siltySAND
9.25 SILT / CLAY
9.45 sandyGRAVEL / siltySAND
9.80 sandySILT / siltySAND
9.95 sandyGRAVEL / SAND

Friction Ratio Rf, [%]

0 2 4 6

Pore Pressure, U₂ [MPa]

-0.1 0.0 0.1 0.2 0.3 0.4

Cone Resistance, q_c [MPa]

Sleeve Friction, f_s [MPa]

0 2 4 6 8 10 12 14 16 18 20 22 24

0.00 0.05 0.10 0.15 0.20 0.25 0.30 0.35 0.40 0.45 0.50 0.55 0.60

Depth Below Ground Level [m]

0 1 2 3 4 5 6 7 8 9 10 11

STATION D FIELD (MANGO)
HERBERT RIVER ANNABRANCH - BUBE SITE

Cone Base Area [mm²] : 1000

Engineer : L. SANDS
Cone Type : HOGT380,10T,U2

Date of Testing : 17/10/1995 15:15
Ground Elevation : + 6.80 [mAHD]
Coordinates (m) : E 419702.5   N 7945206.5

Soil Classification
Eslami & Fellenius (1997)

0.00 sandySILT / siltySAND
0.10 sandyGRAVEL / SAND
0.30 sandySILT / siltySAND

2.30 sandyGRAVEL / SAND

4.30 sandySILT / siltySAND

Elevation [mAHD]

Friction Ratio Rf, [%]

Pore Pressure, U_2 [MPa]

Cone Resistance, q_c [MPa]

Sleeve Friction, f_s [MPa]

Depth Below Ground Level [m]

STNE

STATION E HEADLAND
HERBERT RIVER ANNABRANCH - BUBE SITE

Date of Testing :	17/10/1995 15:15
Ground Elevation :	+ 6.50 [mAHD]
Coordinates (m) :	E 418943.1
	N 7945295.5

Engineer : L. SANDS
Cone Type : HOGT380,10T,U2

Cone Base Area [mm^2] :1000

GEOMECHANICS JAMES COOK UNIVERSITY

Operator	: N.K.HINES		Engineer	: L.B.SANDS
On Site Loc	: Herbert River Anabranch		CPT Date	:10/16/95 14:56
Hole No.	: STNA HEADLAND		Cone Used	:0351
Tot. Unit Wt. (avg)	: 15 kN/m^3		Water table (meters) : 5	

DEPTH	Qc (avg)	Fs (avg)	Rf (avg)	SIGV'	SOIL BEHAVIOUR TYPE	Eq - Dr	PHI	SPT	Su
(meters)	(MN/m^2)	(kN/m^2)	(%)	(kPa)		(%)	deg.	N	kpa
0.25	13.06	147.92	1.13	1.88	sand to silty sand	>90	>48	33	UNDEFINED
0.50	9.46	116.84	1.24	5.63	sand to silty sand	>90	>48	24	UNDEFINED
0.75	3.04	36.16	1.19	9.38	silty sand to sandy silt	70-80	46-48	10	UNDEFINED
1.00	1.55	27.20	1.75	13.13	clayey silt to silty clay	UNDFND	UNDFD	8	102.4
1.25	1.24	40.18	3.24	16.88	silty clay to clay	UNDFND	UNDFD	8	81.6
1.50	1.01	43.30	4.30	20.64	clay	UNDFND	UNDFD	10	65.8
1.75	1.03	44.16	4.30	24.39	clay	UNDFND	UNDFD	10	66.9
2.00	1.15	40.46	3.53	28.14	silty clay to clay	UNDFND	UNDFD	8	74.5
2.25	1.13	42.08	3.71	31.89	clay	UNDFND	UNDFD	11	73.4
2.50	1.30	43.60	3.35	35.65	silty clay to clay	UNDFND	UNDFD	9	84.2
2.75	1.58	47.02	2.98	39.40	clayey silt to silty clay	UNDFND	UNDFD	8	102.4
3.00	1.97	67.40	3.43	43.15	clayey silt to silty clay	UNDFND	UNDFD	10	128.1
3.25	2.03	66.44	3.27	46.90	clayey silt to silty clay	UNDFND	UNDFD	10	132.2
3.50	3.68	37.50	1.02	50.65	silty sand to sandy silt	40-50	38-40	12	UNDEFINED
3.75	5.36	49.10	0.92	54.41	silty sand to sandy silt	50-60	40-42	18	UNDEFINED
4.00	1.50	28.84	1.92	58.16	clayey silt to silty clay	UNDFND	UNDFD	8	96.1
4.25	1.32	19.74	1.50	61.91	clayey silt to silty clay	UNDFND	UNDFD	7	83.8
4.50	2.80	21.44	0.77	65.66	silty sand to sandy silt	<40	36-38	9	UNDEFINED
4.75	1.72	14.06	0.82	69.42	sandy silt to clayey silt	UNDFND	UNDFD	7	110
5.00	0.95	7.54	0.80	73.17	clayey silt to silty clay	UNDFND	UNDFD	5	58.1
5.25	0.95	7.50	0.79	75.69	sandy silt to clayey silt	UNDFND	UNDFD	4	58.4
5.50	2.99	2.60	0.09	76.99	silty sand to sandy silt	<40	36-38	10	UNDEFINED
5.75	7.80	11.72	0.15	78.29	sand	60-70	40-42	16	UNDEFINED
6.00	1.62	22.42	1.38	79.59	sandy silt to clayey silt	UNDFND	UNDFD	6	102.2
6.25	0.55	0.82	0.15	80.89	sensitive fine grained	UNDFND	UNDFD	3	30.6
6.50	0.60	5.90	0.98	82.18	sensitive fine grained	UNDFND	UNDFD	3	33.7
6.75	0.61	6.94	1.14	83.48	sensitive fine grained	UNDFND	UNDFD	3	34
7.00	0.59	2.84	0.48	84.78	sensitive fine grained	UNDFND	UNDFD	3	32.5
7.25	0.83	9.68	1.16	86.08	clayey silt to silty clay	UNDFND	UNDFD	4	48.4
7.50	0.73	7.36	1.00	87.38	sensitive fine grained	UNDFND	UNDFD	4	41.5
7.75	0.59	5.64	0.96	88.68	sensitive fine grained	UNDFND	UNDFD	3	31.5
8.00	0.61	5.96	0.98	89.97	sensitive fine grained	UNDFND	UNDFD	3	32.6
8.25	0.60	4.50	0.75	91.27	sensitive fine grained	UNDFND	UNDFD	3	31.7
8.50	1.24	10.30	0.83	92.57	sandy silt to clayey silt	UNDFND	UNDFD	5	74.4
8.75	2.73	15.92	0.58	93.87	silty sand to sandy silt	<40	34-36	9	UNDEFINED
9.00	2.67	9.10	0.34	95.17	silty sand to sandy silt	<40	34-36	9	UNDEFINED
9.25	1.95	5.10	0.26	96.47	silty sand to sandy silt	<40	30-32	6	UNDEFINED
9.50	2.21	6.08	0.28	97.76	silty sand to sandy silt	<40	32-34	7	UNDEFINED
9.75	2.20	6.28	0.29	99.06	silty sand to sandy silt	<40	32-34	7	UNDEFINED
10.00	5.83	49.96	0.86	100.36	sand to silty sand	40-50	38-40	15	UNDEFINED
10.25	12.30	149.80	1.22	101.66	sand to silty sand	70-80	40-42	31	UNDEFINED

Dr - Ticino sand (Bellotti et al. 1985)	PHI - Robertson and Campanella 1983	Su: Nk= 15

GEOMECHANICS JAMES COOK UNIVERSITY

Operator	: N.K.HINES		Engineer	: L.B.SANDS	
On Site Loc	: Herbert River Anabranch		CPT Date	: 17/10/95 @ 7:50 am	
Hole No.	: STNB HEADLAND		Cone Used	:0351	
Tot. Unit Wt. (avg)	: 15 kN/m^3		Water table (meters) : 5		

DEPTH	Qc (avg)	Fs (avg)	Rf (avg)	SIGV'	SOIL BEHAVIOUR TYPE	Eq - Dr	PHI	SPT	Su
(meters)	(MN/m^2)	(kN/m^2)	(%)	(kPa)		(%)	deg.	N	kpa
0.25	8.14	38.86	0.48	1.88	sand to silty sand	>90	>48	20	UNDEFINED
0.50	14.14	83.56	0.59	5.63	sand	>90	>48	28	UNDEFINED
0.75	4.71	23.00	0.49	9.38	sand to silty sand	>90	46-48	12	UNDEFINED
1.00	2.84	33.44	1.18	13.13	sandy silt to clayey silt	UNDFND	UNDFD	11	188.1
1.25	1.97	38.28	1.94	16.88	sandy silt to clayey silt	UNDFND	UNDFD	8	130.2
1.50	2.00	55.52	2.78	20.64	clayey silt to silty clay	UNDFND	UNDFD	10	131.9
1.75	1.97	60.20	3.06	24.39	clayey silt to silty clay	UNDFND	UNDFD	10	129.4
2.00	1.70	52.86	3.11	28.14	clayey silt to silty clay	UNDFND	UNDFD	9	111.5
2.25	1.70	36.96	2.17	31.89	clayey silt to silty clay	UNDFND	UNDFD	9	111.3
2.50	1.83	42.76	2.34	35.65	clayey silt to silty clay	UNDFND	UNDFD	9	119.3
2.75	2.30	57.82	2.51	39.40	clayey silt to silty clay	UNDFND	UNDFD	12	150.8
3.00	3.34	27.10	0.81	43.15	silty sand to sandy silt	40-50	38-40	11	UNDEFINED
3.25	3.85	6.88	0.18	46.90	sand to silty sand	40-50	40-42	10	UNDEFINED
3.50	4.58	10.36	0.23	50.65	sand to silty sand	50-60	40-42	11	UNDEFINED
3.75	4.54	10.88	0.24	54.41	sand to silty sand	50-60	40-42	11	UNDEFINED
4.00	2.77	12.10	0.44	58.16	silty sand to sandy silt	<40	36-38	9	UNDEFINED
4.25	1.12	11.32	1.01	61.91	sandy silt to clayey silt	UNDFND	UNDFD	4	70.2
4.50	0.87	8.66	0.99	65.66	clayey silt to silty clay	UNDFND	UNDFD	4	53.8
4.75	0.71	4.52	0.64	69.42	sensitive fine grained	UNDFND	UNDFD	4	42.4
5.00	0.69	0.46	0.07	73.17	sensitive fine grained	UNDFND	UNDFD	3	40.8
5.25	0.65	4.94	0.76	75.69	sensitive fine grained	UNDFND	UNDFD	3	38.3
5.50	0.93	9.46	1.02	76.99	clayey silt to silty clay	UNDFND	UNDFD	5	56.3
5.75	0.66	3.88	0.59	78.29	sensitive fine grained	UNDFND	UNDFD	3	38.3
6.00	0.74	5.06	0.69	79.59	sensitive fine grained	UNDFND	UNDFD	4	43.1
6.25	0.66	9.72	1.47	80.89	undefined	UNDFND	UNDFD	UDF	UNDEFINED
6.50	0.71	1.28	0.18	82.18	sensitive fine grained	UNDFND	UNDFD	4	40.6
6.75	1.26	0.00	0.00	83.48	undefined	UNDFND	UNDFD	UDF	UNDEFINED
7.00	1.71	0.42	0.02	84.78	silty sand to sandy silt	<40	30-32	6	UNDEFINED
7.25	1.22	0.00	0.00	86.08	undefined	UNDFND	UNDFD	UDF	UNDEFINED
7.50	0.57	6.50	1.14	87.38	sensitive fine grained	UNDFND	UNDFD	3	30.6
7.75	0.61	10.16	1.65	88.68	silty clay to clay	UNDFND	UNDFD	4	33.3
8.00	0.65	8.98	1.39	89.97	sensitive fine grained	UNDFND	UNDFD	3	35.3
8.25	0.72	23.92	3.32	91.27	clay	UNDFND	UNDFD	7	39.8
8.50	1.56	58.10	3.72	92.57	silty clay to clay	UNDFND	UNDFD	10	95.6
8.75	2.45	89.32	3.64	93.87	clayey silt to silty clay	UNDFND	UNDFD	12	154.9
9.00	3.31	85.44	2.58	95.17	sandy silt to clayey silt	UNDFND	UNDFD	13	211.6
9.25	2.48	48.52	1.96	96.47	sandy silt to clayey silt	UNDFND	UNDFD	10	156.2
9.50	3.01	44.96	1.49	97.76	sandy silt to clayey silt	UNDFND	UNDFD	12	191.1

Dr - Ticino sand (Bellotti et al. 1985) PHI - Robertson and Campanella 1983 Su: Nk= 15

PLOTTED CPT PROFILE should be used with the TABULATED OUTPUT from CPTINTR1 (v 3.04) ****

GEOMECHANICS JAMES COOK UNIVERSITY

Operator	: N.K.HINES					Engineer	: L.B.SANDS		
On Site Loc	: Herbert River Anabranch					CPT Date	: 17/10/95 @ 9:30 am		
Hole No.	: STN BA HEADLAND					Cone Used	: 0380		
Tot. Unit Wt. (avg)	: 15 kN/m^3					Water table (meters) : 5			

DEPTH	Qc (avg)	Fs (avg)	Rf (avg)	SIGV'	SOIL BEHAVIOUR TYPE	Eq - Dr	PHI	SPT	Su
(meters)	(MN/m^2)	(kN/m^2)	(%)	(kPa)		(%)	deg.	N	kpa
0.25	12.98	107.16	0.83	1.88	sand to silty sand	>90	>48	32	UNDEFINED
0.50	14.95	141.60	0.95	5.63	sand	>90	>48	30	UNDEFINED
0.75	7.21	53.40	0.74	9.38	sand to silty sand	>90	>48	18	UNDEFINED
1.00	4.97	21.58	0.43	13.13	sand to silty sand	80-90	46-48	12	UNDEFINED
1.25	3.88	19.18	0.49	16.88	silty sand to sandy silt	60-70	44-46	13	UNDEFINED
1.50	3.22	29.54	0.92	20.64	silty sand to sandy silt	50-60	42-44	11	UNDEFINED
1.75	2.96	87.00	2.94	24.39	clayey silt to silty clay	UNDFND	UNDFD	15	195.5
2.00	2.60	107.72	4.15	28.14	silty clay to clay	UNDFND	UNDFD	17	171.1
2.25	2.44	101.92	4.18	31.89	silty clay to clay	UNDFND	UNDFD	16	160.2
2.50	3.67	60.34	1.65	35.65	sandy silt to clayey silt	UNDFND	UNDFD	15	242
2.75	4.19	56.08	1.34	39.40	silty sand to sandy silt	50-60	40-42	14	UNDEFINED
3.00	4.16	113.50	2.73	43.15	sandy silt to clayey silt	UNDFND	UNDFD	17	274.1
3.25	5.48	127.28	2.32	46.90	sandy silt to clayey silt	UNDFND	UNDFD	22	362
3.50	4.78	151.18	3.16	50.65	sandy silt to clayey silt	UNDFND	UNDFD	19	315.1
3.75	2.90	76.10	2.62	54.41	sandy silt to clayey silt	UNDFND	UNDFD	12	189.8
4.00	5.44	22.56	0.41	58.16	sand to silty sand	50-60	40-42	14	UNDEFINED
4.25	2.59	29.58	1.14	61.91	sandy silt to clayey silt	UNDFND	UNDFD	10	168.5
4.50	0.54	11.10	2.04	65.66	silty clay to clay	UNDFND	UNDFD	4	31.8
4.75	0.71	13.40	1.88	69.42	silty clay to clay	UNDFND	UNDFD	5	42.8
5.00	0.51	6.06	1.20	73.17	sensitive fine grained	UNDFND	UNDFD	3	28.8
5.25	0.71	9.66	1.37	75.69	clayey silt to silty clay	UNDFND	UNDFD	4	41.9
5.50	0.87	16.42	1.88	76.99	clayey silt to silty clay	UNDFND	UNDFD	4	52.8
5.75	0.57	6.28	1.11	78.29	sensitive fine grained	UNDFND	UNDFD	3	32.2
6.00	0.71	6.88	0.96	79.59	sensitive fine grained	UNDFND	UNDFD	4	41.7
6.25	0.72	16.16	2.24	80.89	silty clay to clay	UNDFND	UNDFD	5	41.8
6.50	0.78	13.92	1.79	82.18	clayey silt to silty clay	UNDFND	UNDFD	4	45.3
6.75	0.88	4.18	0.47	83.48	undefined	UNDFND	UNDFD	UDF	UNDEFINED
7.00	0.78	4.02	0.51	84.78	sensitive fine grained	UNDFND	UNDFD	4	45.2
7.25	1.49	3.08	0.21	86.08	sandy silt to clayey silt	UNDFND	UNDFD	6	92.3
7.50	0.45	3.42	0.75	87.38	sensitive fine grained	UNDFND	UNDFD	2	22.8
7.75	0.47	12.80	2.74	88.68	clay	UNDFND	UNDFD	5	23.5
8.00	0.45	11.90	2.63	89.97	clay	UNDFND	UNDFD	5	22.2
8.25	0.58	13.68	2.35	91.27	silty clay to clay	UNDFND	UNDFD	4	30.6
8.50	0.85	19.58	2.31	92.57	silty clay to clay	UNDFND	UNDFD	6	48
8.75	1.13	50.62	4.50	93.87	clay	UNDFND	UNDFD	11	66.4
9.00	1.42	70.30	4.96	95.17	clay	UNDFND	UNDFD	14	85.5
9.25	1.84	48.08	2.61	96.47	clayey silt to silty clay	UNDFND	UNDFD	9	113.6
9.50	4.23	110.38	2.61	97.76	sandy silt to clayey silt	UNDFND	UNDFD	17	272.8
9.75	5.85	135.10	2.31	99.06	sandy silt to clayey silt	UNDFND	UNDFD	23	380.3
10.00	5.56	134.86	2.43	100.36	sandy silt to clayey silt	UNDFND	UNDFD	22	360.6
10.25	9.16	298.22	3.25	101.66	sandy silt to clayey silt	UNDFND	UNDFD	37	600.6

Dr - Ticino sand (Bellotti et al. 1985)	PHI - Robertson and Campanella 1983	Su: Nk= 15

GEOMECHANICS JAMES COOK UNIVERSITY

Operator	: N.K.HINES	Engineer	: L.B.SANDS
On Site Loc	: Herbert River Anabranch	CPT Date	: 17/10/95 @ 11:03 am
Hole No.	: STN C HEADLAND	Cone Used	: 0380
Tot. Unit Wt. (avg)	: 15 kN/m^3	Water table (meters)	: 5

DEPTH (meters)	Qc (avg) (MN/m^2)	Fs (avg) (kN/m^2)	Rf (avg) (%)	SIGV' (kPa)	SOIL BEHAVIOUR TYPE	Eq - Dr (%)	PHI deg.	SPT N	Su kpa
0.25	9.61	77.12	0.80	1.88	sand to silty sand	>90	>48	24	UNDEFINED
0.50	8.21	59.80	0.73	5.63	sand to silty sand	>90	>48	21	UNDEFINED
0.75	5.99	35.48	0.59	9.38	sand to silty sand	>90	>48	15	UNDEFINED
1.00	5.48	21.78	0.40	13.13	sand to silty sand	80-90	46-48	14	UNDEFINED
1.25	5.87	43.90	0.75	16.88	sand to silty sand	80-90	46-48	15	UNDEFINED
1.50	4.77	89.28	1.87	20.64	silty sand to sandy silt	70-80	44-46	16	UNDEFINED
1.75	2.95	35.84	1.21	24.39	silty sand to sandy silt	50-60	40-42	10	UNDEFINED
2.00	2.08	41.16	1.98	28.14	sandy silt to clayey silt	UNDFND	UNDFD	8	136.5
2.25	1.46	56.02	3.83	31.89	silty clay to clay	UNDFND	UNDFD	10	95.3
2.50	1.64	52.98	3.24	35.65	clayey silt to silty clay	UNDFND	UNDFD	8	106.6
2.75	2.52	23.40	0.93	39.40	silty sand to sandy silt	<40	38-40	8	UNDEFINED
3.00	3.03	23.82	0.79	43.15	silty sand to sandy silt	40-50	38-40	10	UNDEFINED
3.25	3.83	18.14	0.47	46.90	silty sand to sandy silt	40-50	40-42	13	UNDEFINED
3.50	3.18	18.64	0.59	50.65	silty sand to sandy silt	<40	38-40	11	UNDEFINED
3.75	0.92	12.36	1.34	54.41	clayey silt to silty clay	UNDFND	UNDFD	5	57.7
4.00	0.91	10.52	1.16	58.16	clayey silt to silty clay	UNDFND	UNDFD	5	56.6
4.25	0.95	11.26	1.18	61.91	clayey silt to silty clay	UNDFND	UNDFD	5	59.3
4.50	1.08	14.32	1.32	65.66	clayey silt to silty clay	UNDFND	UNDFD	5	67.8
4.75	0.99	10.06	1.02	69.42	clayey silt to silty clay	UNDFND	UNDFD	5	61.2
5.00	0.77	4.60	0.60	73.17	sensitive fine grained	UNDFND	UNDFD	4	46.1
5.25	0.93	14.46	1.55	75.69	clayey silt to silty clay	UNDFND	UNDFD	5	56.8
5.50	0.77	5.14	0.67	76.99	sensitive fine grained	UNDFND	UNDFD	4	45.8
5.75	0.57	2.18	0.38	78.29	sensitive fine grained	UNDFND	UNDFD	3	32.3
6.00	0.55	2.06	0.37	79.59	sensitive fine grained	UNDFND	UNDFD	3	31
6.25	0.60	6.62	1.11	80.89	sensitive fine grained	UNDFND	UNDFD	3	33.7
6.50	0.52	3.92	0.76	82.18	sensitive fine grained	UNDFND	UNDFD	3	28.1
6.75	1.41	0.76	0.05	83.48	sandy silt to clayey silt	UNDFND	UNDFD	6	87.1
7.00	0.83	0.44	0.05	84.78	sensitive fine grained	UNDFND	UNDFD	4	48.1
7.25	0.67	6.70	0.99	86.08	sensitive fine grained	UNDFND	UNDFD	3	37.8
7.50	0.80	10.50	1.32	87.38	clayey silt to silty clay	UNDFND	UNDFD	4	45.8
7.75	0.70	3.04	0.43	88.68	sensitive fine grained	UNDFND	UNDFD	4	39.1
8.00	0.46	0.34	0.07	89.97	sensitive fine grained	UNDFND	UNDFD	2	22.6
8.25	0.54	0.78	0.14	91.27	sensitive fine grained	UNDFND	UNDFD	3	28.1
8.50	0.79	15.98	2.02	92.57	silty clay to clay	UNDFND	UNDFD	5	44.2
8.75	1.17	49.98	4.28	93.87	clay	UNDFND	UNDFD	12	69.2
9.00	2.04	74.64	3.67	95.17	silty clay to clay	UNDFND	UNDFD	14	126.8
9.25	3.56	128.46	3.60	96.47	clayey silt to silty clay	UNDFND	UNDFD	18	228.4
9.50	4.02	98.94	2.46	97.76	sandy silt to clayey silt	UNDFND	UNDFD	16	258.6
9.75	5.06	132.50	2.62	99.06	sandy silt to clayey silt	UNDFND	UNDFD	20	327.9
10.00	8.11	118.74	1.46	100.36	silty sand to sandy silt	60-70	40-42	27	UNDEFINED

Dr - Ticino sand (Bellotti et al. 1985)   PHI - Robertson and Campanella 1983   Su: Nk= 15

PLOTTED CPT PROFILE should be used with the TABULATED OUTPUT from CPTINTR1 (v 3.04) ****

GEOMECHANICS JAMES COOK UNIVERSITY

Operator	: N.K.HINES					Engineer	: L.B.SANDS		
On Site Loc	: Herbert River Anabranch					CPT Date	: 17/10/95 @ 3:16 pm		
Hole No.	: STN D MANGO					Cone Used	: 0380		
Tot. Unit Wt. (avg)	: 15 kN/m^3					Water table (meters) : 5			

DEPTH	Qc (avg)	Fs (avg)	Rf (avg)	SIGV'	SOIL BEHAVIOUR TYPE	Eq - Dr	PHI	SPT	Su
(meters)	(MN/m^2)	(kN/m^2)	(%)	(kPa)		(%)	deg.	N	kpa
0.25	7.60	49.14	0.65	1.88	sand to silty sand	>90	>48	19	UNDEFINED
0.50	6.48	68.18	1.05	5.63	silty sand to sandy silt	>90	>48	22	UNDEFINED
0.75	5.14	91.56	1.78	9.38	silty sand to sandy silt	>90	>48	17	UNDEFINED
1.00	4.63	152.62	3.29	13.13	clayey silt to silty clay	UNDFND	UNDFD	23	307.9
1.25	5.01	216.90	4.33	16.88	silty clay to clay	UNDFND	UNDFD	33	333.1
1.50	4.83	203.80	4.22	20.64	clayey silt to silty clay	UNDFND	UNDFD	24	320.8
1.75	3.27	135.32	4.14	24.39	silty clay to clay	UNDFND	UNDFD	22	216.3
2.00	1.49	57.74	3.86	28.14	silty clay to clay	UNDFND	UNDFD	10	97.7
2.25	1.02	27.54	2.69	31.89	silty clay to clay	UNDFND	UNDFD	7	66
2.50	0.96	11.98	1.25	35.65	clayey silt to silty clay	UNDFND	UNDFD	5	61.3
2.75	0.96	15.92	1.65	39.40	clayey silt to silty clay	UNDFND	UNDFD	5	61.5
3.00	2.88	23.28	0.81	43.15	silty sand to sandy silt	<40	38-40	10	UNDEFINED
3.25	5.08	76.26	1.50	46.90	silty sand to sandy silt	50-60	40-42	17	UNDEFINED
3.50	1.95	36.90	1.89	50.65	sandy silt to clayey silt	UNDFND	UNDFD	8	126.4
3.75	0.77	9.14	1.19	54.41	clayey silt to silty clay	UNDFND	UNDFD	4	47.4
4.00	0.60	10.58	1.77	58.16	silty clay to clay	UNDFND	UNDFD	4	35.9
4.25	0.60	8.74	1.47	61.91	sensitive fine grained	UNDFND	UNDFD	3	35.6
4.50	0.57	8.44	1.48	65.66	sensitive fine grained	UNDFND	UNDFD	3	33.6
4.75	0.62	11.22	1.80	69.42	silty clay to clay	UNDFND	UNDFD	4	36.9
5.00	0.95	26.82	2.81	73.17	silty clay to clay	UNDFND	UNDFD	6	58.7
5.25	0.88	20.34	2.32	75.69	silty clay to clay	UNDFND	UNDFD	6	53.2
5.50	0.43	5.36	1.24	76.99	sensitive fine grained	UNDFND	UNDFD	2	23.5
5.75	0.59	6.22	1.05	78.29	sensitive fine grained	UNDFND	UNDFD	3	33.8
6.00	0.56	8.96	1.61	79.59	sensitive fine grained	UNDFND	UNDFD	3	31.1
6.25	0.54	6.72	1.25	80.89	sensitive fine grained	UNDFND	UNDFD	3	29.7
6.50	0.52	6.50	1.25	82.18	sensitive fine grained	UNDFND	UNDFD	3	28.2
6.75	0.75	12.48	1.66	83.48	clayey silt to silty clay	UNDFND	UNDFD	4	43.6
7.00	0.56	8.30	1.49	84.78	sensitive fine grained	UNDFND	UNDFD	3	30.3
7.25	0.61	8.76	1.44	86.08	sensitive fine grained	UNDFND	UNDFD	3	33.4
7.50	0.58	6.60	1.13	87.38	sensitive fine grained	UNDFND	UNDFD	3	31.5
7.75	0.62	6.80	1.09	88.68	sensitive fine grained	UNDFND	UNDFD	3	33.9
8.00	0.64	7.92	1.25	89.97	sensitive fine grained	UNDFND	UNDFD	3	34.5
8.25	0.62	6.72	1.09	91.27	sensitive fine grained	UNDFND	UNDFD	3	32.9
8.50	0.76	9.24	1.22	92.57	clayey silt to silty clay	UNDFND	UNDFD	4	42.2
8.75	1.01	13.42	1.33	93.87	clayey silt to silty clay	UNDFND	UNDFD	5	58.5
9.00	1.46	15.08	1.03	95.17	sandy silt to clayey silt	UNDFND	UNDFD	6	88.3
9.25	3.24	26.02	0.80	96.47	silty sand to sandy silt	<40	34-36	11	UNDEFINED
9.50	3.19	10.72	0.34	97.76	silty sand to sandy silt	<40	34-36	11	UNDEFINED
9.75	9.83	23.24	0.24	99.06	sand	60-70	40-42	20	UNDEFINED
10.00	5.49	45.98	0.84	100.36	silty sand to sandy silt	40-50	38-40	18	UNDEFINED
10.25	8.98	16.04	0.18	101.66	sand	60-70	40-42	18	UNDEFINED
10.50	8.22	23.20	0.28	102.96	sand to silty sand	50-60	40-42	21	UNDEFINED

GEOMECHANICS JAMES COOK UNIVERSITY

Operator   : N.K.HINES   Engineer   : L.B.SANDS
On Site Loc   : Herbert River Anabranch   CPT Date   : 17/10/95 @ 3:17 pm
Hole No.   : STN E HEADLAND   Cone Used   : 0380
Tot. Unit Wt. (avg) : 15 kN/m^3   Water table (meters) : 5

DEPTH	Qc (avg)	Fs (avg)	Rf (avg)	SIGV'	SOIL BEHAVIOUR TYPE	Eq - Dr	PHI	SPT	Su
(meters)	(MN/m^2)	(kN/m^2)	(%)	(kPa)		(%)	deg.	N	kpa
0.25	6.72	63.90	0.95	1.88	sand to silty sand	>90	>48	17	UNDEFINED
0.50	4.74	34.58	0.73	5.63	silty sand to sandy silt	>90	>48	16	UNDEFINED
0.75	1.76	8.88	0.51	9.38	sandy silt to clayey silt	UNDFND	UNDFD	7	116.5
1.00	1.40	4.68	0.34	13.13	sandy silt to clayey silt	UNDFND	UNDFD	6	92.1
1.25	1.58	4.60	0.29	16.88	sandy silt to clayey silt	UNDFND	UNDFD	6	104
1.50	2.38	9.74	0.41	20.64	silty sand to sandy silt	40-50	40-42	8	UNDEFINED
1.75	3.23	13.06	0.40	24.39	silty sand to sandy silt	50-60	42-44	11	UNDEFINED
2.00	4.05	20.44	0.50	28.14	silty sand to sandy silt	60-70	42-44	14	UNDEFINED
2.25	8.29	144.36	1.74	31.89	silty sand to sandy silt	80-90	44-46	28	UNDEFINED
2.50	12.06	64.42	0.53	35.65	sand	>90	46-48	24	UNDEFINED
2.75	12.01	112.94	0.94	39.40	sand to silty sand	>90	44-46	30	UNDEFINED
3.00	12.27	101.08	0.82	43.15	sand to silty sand	>90	44-46	31	UNDEFINED
3.25	18.88	149.48	0.79	46.90	sand	>90	46-48	38	UNDEFINED
3.50	16.41	138.54	0.84	50.65	sand	>90	46-48	33	UNDEFINED
3.75	21.78	233.28	1.07	54.41	sand	>90	46-48	44	UNDEFINED
4.00	15.88	216.04	1.36	58.16	sand to silty sand	>90	44-46	40	UNDEFINED
4.25	16.37	104.46	0.64	61.91	sand	>90	44-46	33	UNDEFINED

Dr - Ticino sand (Bellotti et al. 1985)   PHI - Robertson and Campanella 1983   Su: Nk= 15

PLOTTED CPT PROFILE should be used with the TABULATED OUTPUT from CPTINTR1 (v 3.04) ****

Insitu Constant Head Permeability Test

Test Label:	**StnA 2 RUN 1**
Mariotte Bottle:	CSIRO 3
X-sectional area:	907.250 (mm^2)
Hole Diameter:	55.000 (mm
Height of Water:	270.000 (mm)
H/r:	9.818 (mm/mm)
Depth of Hole :	420.000 (mm)
Location of Test:	Edge of vegetation 5 m upstream of Stn A
Date & Time:	21/8/96 @ 2pm
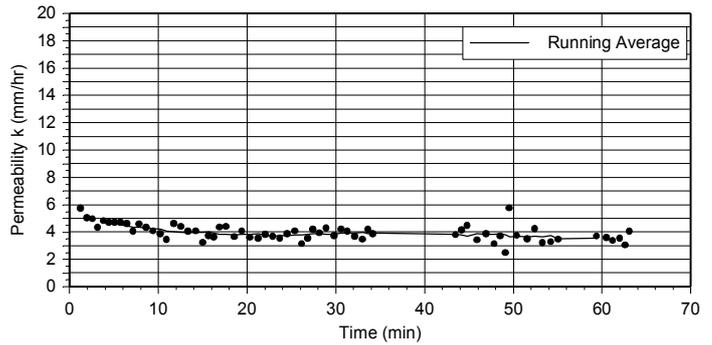
Time (hr : min : sec)			Mariotte reading (mm)	Flowrate Q (m^3/s)	Permeability k (m/s)	Time (hr : min : sec)			Mariotte reading (mm)	Flowrate Q (m^3/s)	Permeability k (m/s)
		0	276				23	42	698	2.268E-07	9.804E-07
		38	290	3.343E-07	1.445E-06		24	33	712	2.490E-07	1.077E-06
	1	15	305	3.678E-07	1.590E-06		25	25	727	2.617E-07	1.131E-06
	1	57	320	3.240E-07	1.401E-06		26	10	737	2.016E-07	8.715E-07
	2	34	333	3.188E-07	1.378E-06		26	50	747	2.268E-07	9.804E-07
	3	10	344	2.772E-07	1.198E-06		27	27	758	2.697E-07	1.166E-06
	3	48	357	3.104E-07	1.342E-06		28	10	770	2.532E-07	1.094E-06
	4	27	370	3.024E-07	1.307E-06		28	56	784	2.761E-07	1.194E-06
	5	6	383	3.024E-07	1.307E-06		29	49	798	2.397E-07	1.036E-06
	5	45	396	3.024E-07	1.307E-06		30	36	812	2.702E-07	1.168E-06
	6	28	410	2.954E-07	1.277E-06		31	18	824	2.592E-07	1.120E-06
	7	10	422	2.592E-07	1.120E-06		32	8	837	2.359E-07	1.020E-06
	7	50	435	2.949E-07	1.275E-06		33	1	850	2.225E-07	9.619E-07
	8	39	450	2.777E-07	1.201E-06		33	38	861	2.697E-07	1.166E-06
	9	24	463	2.621E-07	1.133E-06		34	11	870	2.474E-07	1.070E-06
	10	15	477	2.490E-07	1.077E-06		43	30	1020	2.434E-07	1.052E-06
	10	56	487	2.213E-07	9.565E-07		44	11	1032	2.655E-07	1.148E-06
	11	45	503	2.962E-07	1.281E-06		44	49	1044	2.865E-07	1.238E-06
	12	33	518	2.835E-07	1.226E-06		45	55	1060	2.199E-07	9.507E-07
	13	22	532	2.592E-07	1.120E-06		46	57	1077	2.488E-07	1.075E-06
	14	14	547	2.617E-07	1.131E-06		47	51	1089	2.016E-07	8.715E-07
	15	2	558	2.079E-07	8.987E-07		48	33	1100	2.376E-07	1.027E-06
	15	40	568	2.388E-07	1.032E-06		49	7	1106	1.601E-07	6.921E-07
	16	15	577	2.333E-07	1.008E-06		49	34	1117	3.696E-07	1.598E-06
	16	54	589	2.792E-07	1.207E-06		50	23	1130	2.407E-07	1.040E-06
	17	39	603	2.823E-07	1.220E-06		51	36	1148	2.237E-07	9.670E-07
	18	33	617	2.352E-07	1.017E-06		52	26	1163	2.722E-07	1.177E-06
	19	25	632	2.617E-07	1.131E-06		53	19	1175	2.054E-07	8.879E-07
	20	20	646	2.309E-07	9.983E-07		54	15	1188	2.106E-07	9.104E-07
	21	16	660	2.268E-07	9.804E-07		55	4	1200	2.222E-07	9.604E-07
	22	4	673	2.457E-07	1.062E-06		59	24	1268	2.373E-07	1.026E-06
	22	54	686	2.359E-07	1.020E-06	1		31	1285	2.302E-07	9.951E-07
						1	1	13	1295	2.160E-07	9.337E-07
						1	2	1	1307	2.268E-07	9.804E-07
						1	2	38	1315	1.962E-07	8.479E-07
						1	3	6	1323	2.592E-07	1.120E-06

Average =   1.112E-06

Insitu Constant Head Permeability Test

Test Label:	**StnA 2 RUN 2**
Mariotte Bottle:	CSIRO 3
X-sectional area:	907.250 (mm^2)
Hole Diameter:	55.000 (mm
Height of Water:	270.000 (mm)
H/r:	9.818 (mm/mm)
Depth of Hole :	420.000 (mm)
Location of Test:	Edge of vegetation 5 m upstream of Stn A
Date & Time:	21/8/96 @ 3:40pm
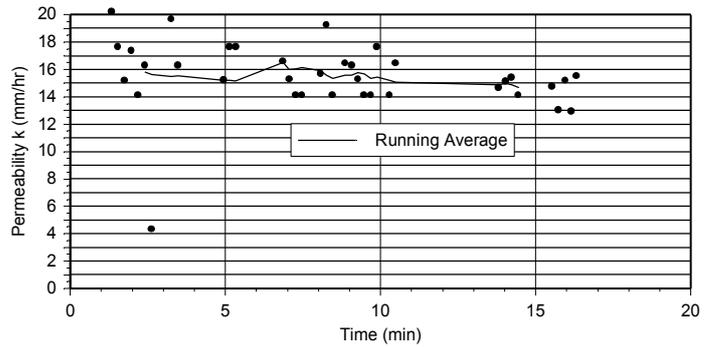
Time (hr : min : sec)			Mariotte reading (mm)	Flowrate Q (m^3/s)	Permeability k (m/s)
		0	215		
		36	242	6.804E-07	2.941E-06
	1	20	305	1.299E-06	5.615E-06
	1	32	320	1.134E-06	4.902E-06
	1	45	334	9.770E-07	4.223E-06
	1	58	350	1.117E-06	4.827E-06
	2	11	363	9.073E-07	3.922E-06
	2	24	378	1.047E-06	4.525E-06
	2	37	382	2.792E-07	1.207E-06
	3	15	435	1.265E-06	5.470E-06
	3	28	450	1.047E-06	4.525E-06
	4	56	545	9.794E-07	4.234E-06
	5	8	560	1.134E-06	4.902E-06
	5	20	575	1.134E-06	4.902E-06
	6	51	682	1.067E-06	4.611E-06
	7	3	695	9.829E-07	4.249E-06
	7	16	708	9.073E-07	3.922E-06
	7	28	720	9.072E-07	3.922E-06
	8	4	760	1.008E-06	4.357E-06
	8	15	775	1.237E-06	5.348E-06
	8	27	787	9.073E-07	3.922E-06
	8	51	815	1.058E-06	4.575E-06
	9	4	830	1.047E-06	4.525E-06
	9	16	843	9.829E-07	4.249E-06
	9	28	855	9.073E-07	3.922E-06
	9	41	868	9.073E-07	3.922E-06
	9	53	883	1.134E-06	4.902E-06
	10	17	907	9.072E-07	3.922E-06
	10	29	921	1.058E-06	4.575E-06
	13	48	1128	9.437E-07	4.079E-06
	14	2	1143	9.721E-07	4.202E-06
	14	13	1155	9.897E-07	4.278E-06
	14	26	1168	9.073E-07	3.922E-06
	15	31	1236	9.491E-07	4.103E-06
	15	44	1248	8.375E-07	3.620E-06
	15	57	1262	9.770E-07	4.223E-06
	16	9	1273	8.316E-07	3.595E-06
	16	19	1284	9.980E-07	4.314E-06

Average =   4.26E-06

Insitu Constant Head Permeability Test

Test Label:	**StnA 2 RUN 3**
Mariotte Bottle:	CSIRO 3
X-sectional area:	907.250 (mm^2)
Hole Diameter:	55.000 (mm
Height of Water:	270.000 (mm)
H/r:	9.818 (mm/mm)
Depth of Hole :	420.000 (mm)
Location of Test:	Edge of vegetation 5 m upstream of Stn A
Date & Time:	21/8/96 @ 3:20pm
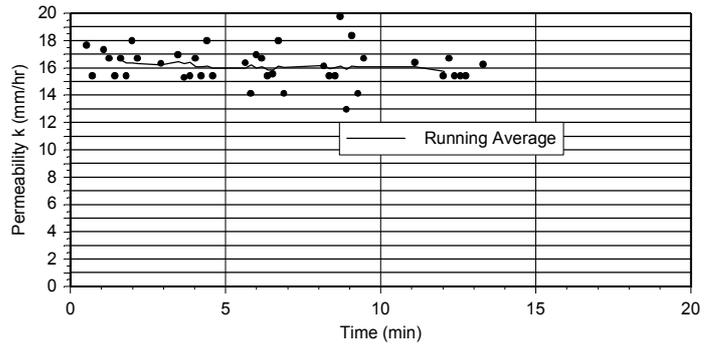
Time (hr : min : sec)			Mariotte reading (mm)	Flowrate Q (m^3/s)	Permeability k (m/s)	Time (hr : min : sec)			Mariotte reading (mm)	Flowrate Q (m^3/s)	Permeability k (m/s)
		0	370				4	35	691	9.897E-07	4.278E-06
		11	383	1.072E-06	4.635E-06		5	38	764	1.051E-06	4.544E-06
		31	408	1.134E-06	4.902E-06		5	49	775	9.072E-07	3.922E-06
		42	420	9.897E-07	4.278E-06		5	59	787	1.089E-06	4.706E-06
	1	4	447	1.113E-06	4.813E-06		6	10	800	1.072E-06	4.635E-06
	1	15	460	1.072E-06	4.635E-06		6	21	812	9.897E-07	4.278E-06
	1	26	472	9.897E-07	4.278E-06		6	31	823	9.980E-07	4.314E-06
	1	37	485	1.072E-06	4.635E-06		6	42	837	1.155E-06	4.991E-06
	1	48	497	9.897E-07	4.278E-06		6	53	848	9.073E-07	3.922E-06
	1	59	511	1.155E-06	4.991E-06		8	10	936	1.037E-06	4.482E-06
	2	10	524	1.072E-06	4.635E-06		8	21	948	9.897E-07	4.278E-06
	2	55	576	1.048E-06	4.532E-06		8	32	960	9.897E-07	4.278E-06
	3	6	579	2.474E-07	1.070E-06		8	42	974	1.270E-06	5.490E-06
	3	18	603	1.815E-06	7.843E-06		8	54	985	8.316E-07	3.595E-06
	3	28	615	1.089E-06	4.706E-06		9	4	998	1.179E-06	5.098E-06
	3	40	628	9.829E-07	4.249E-06		9	16	1010	9.072E-07	3.922E-06
	3	51	640	9.897E-07	4.278E-06		9	27	1023	1.072E-06	4.635E-06
	4	2	653	1.072E-06	4.635E-06		11	6	1138	1.054E-06	4.556E-06
	4	13	665	9.897E-07	4.278E-06		12	1	1198	9.897E-07	4.278E-06
	4	24	679	1.155E-06	4.991E-06		12	12	1211	1.072E-06	4.635E-06
							12	23	1223	9.897E-07	4.278E-06
							12	34	1235	9.897E-07	4.278E-06
							12	45	1247	9.897E-07	4.278E-06
							13	18	1285	1.045E-06	4.516E-06

Average =   4.49E-06

Insitu Constant Head Permeability Test

Test Label:	**StnA 2 RUN 4**
Mariotte Bottle:	CSIRO 3
X-sectional area:	907.250 (mm^2)
Hole Diameter:	55.000 (mm
Height of Water:	270.000 (mm)
H/r:	9.818 (mm/mm)
Depth of Hole :	420.000 (mm)
Location of Test:	Edge of vegetation 5 m upstream of Stn A
Date & Time:	21/8/96 @ 4:29pm
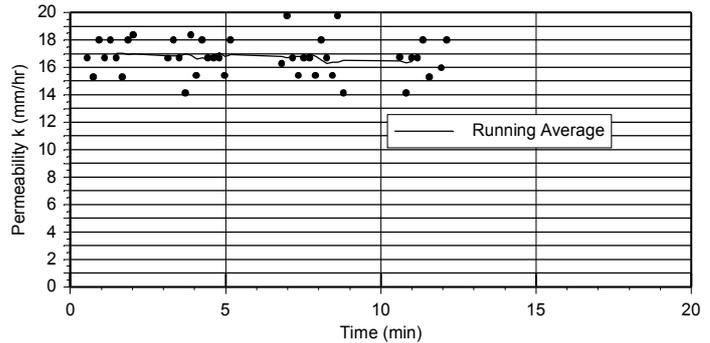
Time (hr : min : sec)			Mariotte reading (mm)	Flowrate Q (m^3/s)	Permeability k (m/s)	Time (hr : min : sec)			Mariotte reading (mm)	Flowrate Q (m^3/s)	Permeability k (m/s)
		0	460				4	48	803	1.072E-06	4.635E-06
		22	487	1.113E-06	4.813E-06		4	59	815	9.897E-07	4.278E-06
		33	500	1.072E-06	4.635E-06		5	10	829	1.155E-06	4.991E-06
		45	513	9.829E-07	4.249E-06		6	49	943	1.045E-06	4.516E-06
		56	527	1.155E-06	4.991E-06		6	59	957	1.270E-06	5.490E-06
	1	7	540	1.072E-06	4.635E-06		7	10	970	1.072E-06	4.635E-06
	1	18	554	1.155E-06	4.991E-06		7	21	982	9.897E-07	4.278E-06
	1	29	567	1.072E-06	4.635E-06		7	32	995	1.072E-06	4.635E-06
	1	41	580	9.829E-07	4.249E-06		7	43	1008	1.072E-06	4.635E-06
	1	52	594	1.155E-06	4.991E-06		7	54	1020	9.897E-07	4.278E-06
	2	2	607	1.179E-06	5.098E-06		8	5	1034	1.155E-06	4.991E-06
	3	9	686	1.070E-06	4.624E-06		8	16	1047	1.072E-06	4.635E-06
	3	20	700	1.155E-06	4.991E-06		8	27	1059	9.897E-07	4.278E-06
	3	31	713	1.072E-06	4.635E-06		8	37	1073	1.270E-06	5.490E-06
	3	43	725	9.072E-07	3.922E-06		8	48	1084	9.072E-07	3.922E-06
	3	53	738	1.179E-06	5.098E-06		10	37	1213	1.074E-06	4.641E-06
	4	4	750	9.897E-07	4.278E-06		10	49	1225	9.073E-07	3.922E-06
	4	15	764	1.155E-06	4.991E-06		11	0	1238	1.072E-06	4.635E-06
	4	26	777	1.072E-06	4.635E-06		11	11	1251	1.072E-06	4.635E-06
	4	37	790	1.072E-06	4.635E-06		11	22	1265	1.155E-06	4.991E-06
							11	34	1278	9.829E-07	4.249E-06
							11	57	1304	1.026E-06	4.433E-06
							12	8	1318	1.155E-06	4.991E-06

Average =   4.653E-06

Insitu Constant Head Permeability Test

Test Label:	**StnA 3 RUN 1**
Mariotte Bottle:	CSIRO 2
X-sectional area:	901.700 (mm^2)
Hole Diameter:	60.000 (mm
Height of Water:	300.000 (mm)
H/r:	10.000 (mm/mm)
Depth of Hole :	420.000 (mm)
Location of Test:	3 m in from veg, 8 m upstream of StnA
Date & Time:	
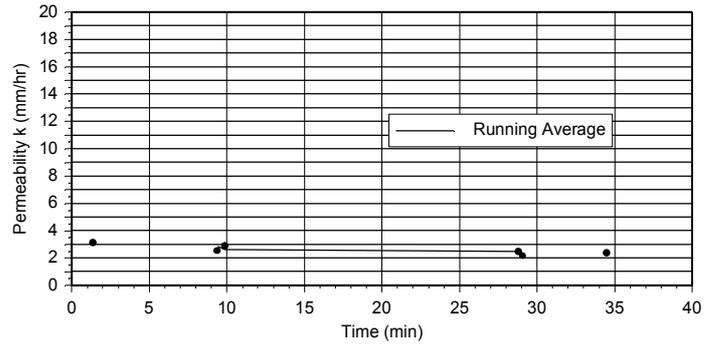
Time (hr : min : sec)			Mariotte reading (mm)	Flowrate Q (m^3/s)	Permeability k (m/s)
		0	234		
		49	245	2.024E-07	7.153E-07
	1	22	254	2.459E-07	8.690E-07
	9	24	360	1.983E-07	7.007E-07
	9	52	367	2.254E-07	7.966E-07
	28	49	610	1.927E-07	6.810E-07
	29	5	613	1.691E-07	5.974E-07
	34	30	680	1.859E-07	6.569E-07

Average =   7.17E-07

Insitu Constant Head Permeability Test

Test Label:	**StnA 3 RUN 2**	
Mariotte Bottle:	CSIRO 2	
X-sectional area:	901.700 (mm^2)	
Hole Diameter:	60.000 (mm	
Height of Water:	300.000 (mm)	
H/r:	10.000 (mm/mm)	
Depth of Hole :	420.000 (mm)	
Location of Test:	3 m from edge of vegetation 8 m upstream of Stn A	
Date & Time:	22/8/96 @ 12:00pm	
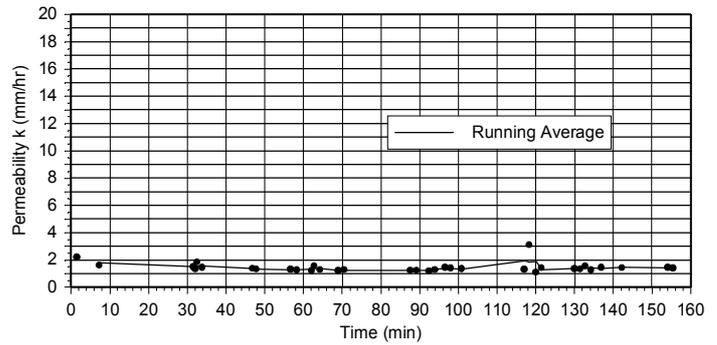
Time (hr : min : sec)			Mariotte reading (mm)	Flowrate Q (m^3/s)	Permeability k (m/s)
			180		
	1	13	190	1.235E-07	4.365E-07
	1	34	194	1.718E-07	6.069E-07
	7	15	242	1.269E-07	4.485E-07
	31	32	432	1.176E-07	4.155E-07
	32	6	436	1.061E-07	3.749E-07
	32	31	440	1.443E-07	5.098E-07
	33	50	450	1.141E-07	4.033E-07
	46	49	543	1.076E-07	3.804E-07
	47	50	550	1.035E-07	3.656E-07
	56	43	610	1.015E-07	3.587E-07
	58	15	620	9.801E-08	3.463E-07
1	2	10	645	9.593E-08	3.390E-07
1	2	47	650	1.219E-07	4.306E-07
1	4	17	660	1.002E-07	3.540E-07
1	9	3	690	9.458E-08	3.342E-07
1	10	33	700	1.002E-07	3.540E-07
1	27	38	810	9.677E-08	3.419E-07
1	29	11	820	9.696E-08	3.426E-07
1	32	26	840	9.248E-08	3.268E-07
1	33	56	850	1.002E-07	3.540E-07
1	36	36	870	1.127E-07	3.983E-07
1	37	59	880	1.086E-07	3.839E-07
1	40	50	900	1.055E-07	3.727E-07
1	57	5	1010	1.017E-07	3.595E-07
1	58	19	1030	2.437E-07	8.612E-07
2	0	5	1040	8.507E-08	3.006E-07
2	1	26	1050	1.113E-07	3.934E-07
2	10	2	1110	1.048E-07	3.705E-07
2	11	29	1120	1.036E-07	3.662E-07
2	12	43	1130	1.219E-07	4.306E-07
2	14	15	1140	9.801E-08	3.463E-07
2	16	54	1160	1.134E-07	4.008E-07
2	22	16	1200	1.120E-07	3.958E-07
2	34	8	1290	1.140E-07	4.028E-07
2	35	30	1300	1.100E-07	3.886E-07
				Average =	**4.0E-07**

Insitu Constant Head Permeability Test

Test Label:	**StnA 5 RUN 1**
Mariotte Bottle:	CSIRO 3
X-sectional area:	907.250 (mm^2)
Hole Diameter:	58 (mm
Height of Water:	300 (mm)
H/r:	10.345 (mm/mm)
Depth of Hole :	520 (mm)
Location of Test:	Top of bank 5 m upstream of Stn A
Date & Time:	22/8/96 @ 1:00 pm
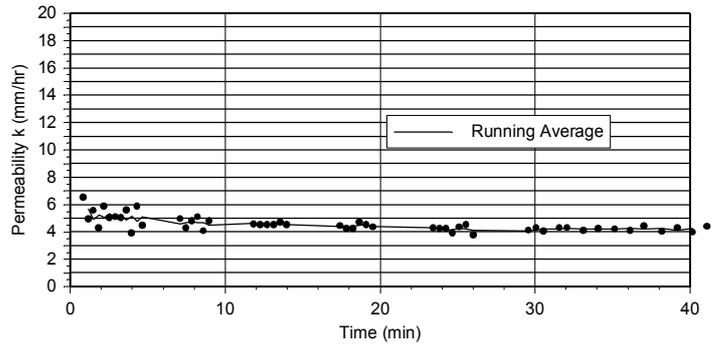
Time (hr : min : sec)			Mariotte reading (mm)	Flowrate Q (m^3/s)	Permeability k (m/s)	Time (hr : min : sec)		Mariotte reading (mm)	Flowrate Q (m^3/s)	Permeability k (m/s)
		0	335			13	59	681	3.489E-07	1.254E-06
		33	350	4.124E-07	1.482E-06	17	25	759	3.435E-07	1.234E-06
		51	360	5.040E-07	1.811E-06	17	50	768	3.266E-07	1.174E-06
	1	10	368	3.820E-07	1.373E-06	18	15	777	3.266E-07	1.174E-06
	1	29	377	4.298E-07	1.544E-06	18	40	787	3.629E-07	1.304E-06
	1	51	385	3.299E-07	1.185E-06	19	6	797	3.489E-07	1.254E-06
	2	11	395	4.536E-07	1.630E-06	19	33	807	3.360E-07	1.207E-06
	2	32	404	3.888E-07	1.397E-06	23	26	892	3.310E-07	1.189E-06
	2	55	414	3.945E-07	1.417E-06	23	51	901	3.266E-07	1.174E-06
	3	16	423	3.888E-07	1.397E-06	24	16	910	3.266E-07	1.174E-06
	3	37	433	4.320E-07	1.552E-06	24	40	918	3.024E-07	1.087E-06
	3	58	440	3.024E-07	1.087E-06	25	7	928	3.360E-07	1.207E-06
	4	18	450	4.536E-07	1.630E-06	25	33	938	3.489E-07	1.254E-06
	4	39	458	3.456E-07	1.242E-06	26	1	947	2.916E-07	1.048E-06
	7	6	520	3.826E-07	1.375E-06	29	35	1022	3.180E-07	1.143E-06
	7	28	528	3.299E-07	1.185E-06	30	5	1033	3.327E-07	1.195E-06
	7	50	537	3.711E-07	1.334E-06	30	34	1043	3.128E-07	1.124E-06
	8	13	547	3.945E-07	1.417E-06	31	34	1065	3.327E-07	1.195E-06
	8	36	555	3.156E-07	1.134E-06	32	4	1076	3.327E-07	1.195E-06
	8	58	564	3.711E-07	1.334E-06	33	7	1098	3.168E-07	1.138E-06
	11	50	631	3.534E-07	1.270E-06	34	5	1119	3.285E-07	1.180E-06
	12	16	641	3.489E-07	1.254E-06	35	9	1142	3.260E-07	1.172E-06
	12	42	651	3.489E-07	1.254E-06	36	9	1163	3.175E-07	1.141E-06
	13	8	661	3.489E-07	1.254E-06	37	2	1183	3.424E-07	1.230E-06
	13	33	671	3.629E-07	1.304E-06	38	12	1207	3.111E-07	1.118E-06
						39	12	1229	3.327E-07	1.195E-06
						40	11	1249	3.075E-07	1.105E-06
						41	7	1270	3.402E-07	1.223E-06

Average =   1.3E-06

Insitu Constant Head Permeability Test

Test Label:	**StnA 5 RUN 2**
Mariotte Bottle:	CSIRO 3
X-sectional area:	907.250 (mm^2)
Hole Diameter:	58 (mm
Height of Water:	300 (mm)
H/r:	10.345 (mm/mm)
Depth of Hole :	520 (mm)
Location of Test:	Top of bank 5 m upstream of Stn A
Date & Time:	22/8/96 @ 2:00 pm
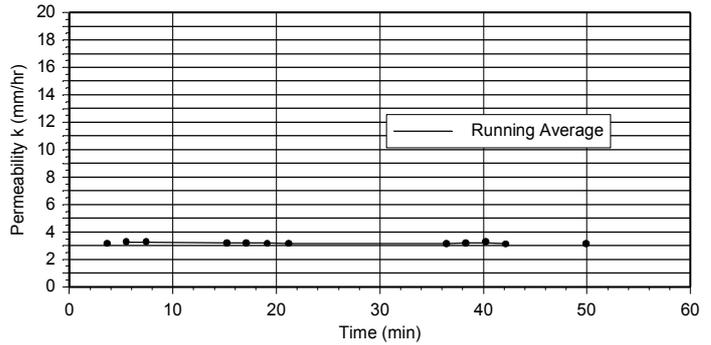
Time (hr : min : sec)			Mariotte reading (mm)	Flowrate Q (m^3/s)	Permeability k (m/s)
			246		
	1	52	328	6.642E-07	2.387E-06
	3	40	357	2.436E-07	8.754E-07
	5	31	388	2.534E-07	9.105E-07
	7	26	420	2.525E-07	9.071E-07
	15	14	547	2.462E-07	8.847E-07
	17	8	578	2.467E-07	8.865E-07
	19	7	610	2.440E-07	8.766E-07
	21	13	644	2.448E-07	8.797E-07
	36	28	888	2.419E-07	8.693E-07
	38	19	918	2.452E-07	8.811E-07
	40	14	950	2.525E-07	9.071E-07
	42	11	981	2.404E-07	8.638E-07
	49	56	1105	2.419E-07	8.693E-07

Average =   1.0E-06

APPENDIX B

LABORATORY DATA

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Department of Civil & Systems Engineering
POSTAL ADDRESS: TELEPHONE   FACSIMILE:
   James Cook University, QLD 4811   (077) 81 4112   (077) 75 1184
   AUSTRALIA

ATTERBERG LIMITS

Project	JCU/HRIT Bube subsurface monitoring			
Sample No. BaA1 TP 11 @ 5.5 m		**Lab No.** JCU		**Sample Date:** 14/11/95

Test Procedure:

Dry & wet sieving according to AS 1289

Sample Description:

very sandy CLAY (SC)

		Liquid Limit				Plastic Limit	
Tin No.	A82	A72	A101	A97		A61	
Wt. tin & wet soil (g)	27.796	27.902	27.029	38.326		23.391	
Wt. tin & dry soil (g)	25.375	25.217	24.644	32.813		22.620	
Wt. tin (g)	18.001	17.305	18.020	18.106		18.050	
Wt. dry soil (g)	7.374	7.912	6.624	14.707		4.570	
Moisture loss (g)	2.421	2.685	2.385	5.513		0.771	
Moisture Content (%)	32.8	33.9	36.0	37.5		16.9	
Cone penetration (mm)	15.65 16.00	18.25 17.80	21.40 20.80	23.95 23.60			
Ave.:	**15.83**	**18.03**	**21.10**	**23.80**			

Liquid Limit LL	(%)	35.4
Plastic Limit PL	(%)	16.9
Plastic Index PI = LL - PL	(%)	18.5

LINEAR SHRINKAGE TEST

Mould No.	
Linear shrinkage (%)	

Tested by:	L Sands	Checked by:	L Sands
Date:	16/11/95	Date:	26/07/01

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ATTERBERG LIMITS

Project	JCU/HRIT Bube subsurface monitoring			
Sample No. CA1 TP 9 @ 4.5 m		**Lab No.** JCU		**Sample Date:** 14/11/95

Test Procedure:	Sample Description:
Dry & wet sieving according to AS 1289	very clayey fine SAND (SC)

		Liquid Limit				Plastic Limit	
Tin No.	A91	A35	A84	A67		A66	A24
Wt. tin & wet soil (g)	31.212	33.075	34.255	45.851		24.115	28.691
Wt. tin & dry soil (g)	28.481	30.162	30.625	39.454		23.115	27.974
Wt. tin (g)	18.169	19.580	18.073	18.170		17.566	23.924
Wt. dry soil (g)	10.312	10.582	12.552	21.284		5.549	4.050
Moisture loss (g)	2.731	2.913	3.630	6.397		1.000	0.717
Moisture Content (%)	26.5	27.5	29.0	30.0		18.0	17.7
Cone penetration (mm)	16.80 16.05	18.60 18.60	21.20 21.80	24.30 23.90			**17.9**
Ave.:	**16.4**	**18.6**	**21.5**	**24.1**			

Liquid Limit LL (%)	28.3
Plastic Limit PL (%)	17.9
Plastic Index PI = LL - PL (%)	10.4

LINEAR SHRINKAGE TEST

Mould No.	
Linear shrinkage (%)	

Tested by:	L Sands	Checked by:	L Sands
Date:	16/11/95	Date:	26/07/01

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POSTAL ADDRESS:
James Cook University, QLD 4811
AUSTRALIA

TELEPHONE
(077) 81 4112

FACSIMILE:
(077) 75 1184

ATTERBERG LIMITS

Project	JCU/HRIT Bube subsurface monitoring			
Sample No. CA1 TP 13 @ 6.5 m		**Lab No.** JCU		**Sample Date:** 14/11/95
Test Procedure:		**Sample Description:**		
Dry & wet sieving according to AS 1289		very clayey fine SAND (SC)		

		Liquid Limit				Plastic Limit	
Tin No.	A92	A74	A33	A94		A93	A38
Wt. tin & wet soil (g)	29.998	31.025	31.199	35.603		25.892	25.036
Wt. tin & dry soil (g)	27.283	27.736	28.207	30.754		24.949	24.280
Wt. tin (g)	18.538	17.733	19.609	17.469		19.391	19.829
Wt. dry soil (g)	8.745	10.003	8.598	13.285		5.558	4.451
Moisture loss (g)	2.715	3.289	2.992	4.849		0.943	0.756
Moisture Content (%)	31.0	33.0	35.0	36.5		17.0	17.0
Cone penetration (mm)	15.30 14.70	18.60 17.60	21.20 20.50	23.60 24.30			**17.0**
Ave.:	**15.0**	**18.1**	**20.9**	**24.0**			

Liquid Limit LL (%)	34.4
Plastic Limit PL (%)	17.0
Plastic Index PI = LL - PL (%)	17.4

LINEAR SHRINKAGE TEST

Mould No.	
Linear shrinkage (%)	

Tested by:	L Sands	Checked by:	L Sands
Date:	16/11/95	Date:	26/07/01

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MOISTURE CONTENT

Project	JCU/HRIT Bube subsurface monitoring					
Sample No.		**Lab No.**	JCU	**Sample Date:**	11/12/96	
Test Procedure: as per AS1289 & AS1726		**Sample Description:** Field installation of moisture sensors, prepared moisture sample				

Station	A	A	Ba	Ba	C	C
Zone	Bank 1 moisture	Bank 2 moisture	Bank 1 moisture	Bank 2 moisture	Bank 1 moisture	Bank 2 moisture
Depth wrt ground (m)	1.40-1.73	0.59-0.74	1.24-1.40	1.00-1.13	1.5-1.6	2.14-2.20
Tin No.	B59	B37	B11	B2	B58	B34
Wt. tin (g)	39.303	27.066	42.149	40.397	38.971	27.427
Wt tin & wet soil (g) W1	186.832	184.585	102.767	145.152	203.692	63.383
Wt. tin & dry soil (g) W2	154.087	152.576	86.831	116.894	165.221	54.597
Wt. dry soil (g) W3	114.784	125.510	44.682	76.497	126.250	27.170
Moisture Content (%) (W1-W2)/W3	**28.5**	**25.5**	**35.7**	**36.9**	**30.5**	**32.3**

Tested by: L Sands

Date: 01/01/96

Checked by: L Sands

Date: 26/07/01

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GRAIN SIZE DISTRIBUTION

Project	JCU/HRIT Bube subsurface monitoring

Sample No. StnA aquifer 1	**Lab No.** JCU	**Sample Date:** 14/11/95

Test Procedure:	**Sample Description:**
Dry sieving according to AS 1289	Refer to sieve data for classification

AS sieve size - millimetres: 0.075, 0.15, 0.3, 0.425, 0.6, 1.18, 2.36, 4.75, 6.7, 9.5, 13.2, 19, 26.5, 37.5, 53, 75, 150

percentage finer than size

grain size - millimetres

Legend:
- AA₁ TP 1 @ 0.5 m (dry)
- AA₁ TP 3 @ 1.5 m (dry)
- AA₁ TP 7 @ 3.5 m (dry)
- AA₁ TP 9 @ 4.5 m (dry)
- AA₁ TP 11 @ 5.5 m (dry)

	0.002			0.075			2.36			63
Clay	Silt			Sand			Gravel			Cobbles
	fine	medium	coarse	fine	medium	coarse	fine	medium	coarse	

0.006   0.02   0.2   0.6   6   20

Sample:	
liquid limit	%
plastic limit	%
plasticity index	%
linear shrinkage	%
particle density	t/m³
natural moisture	%
classification:	

Plasticity index vs Liquid limit chart (U-line, A-line, CH, CI, MH, CL-ML, CL, ML)

Tested by: L Sands	Checked by: L Sands
Date: 16/11/95	Date: 26/07/01

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GRAIN SIZE DISTRIBUTION

Project	JCU/HRIT Bube subsurface monitoring			
Sample No.	StnA aquifer 1 & 2	**Lab No.** JCU	**Sample Date:**	14/11/95

Test Procedure:	Sample Description:
Dry & wet sieving according to AS 1289	Refer to sieve data for classification

AS sieve size - millimetres: 0.075 0.15 0.3 0.425 0.6 1.18 2.36 4.75 6.7 9.5 13.2 19 26.5 37.5 53 75 150

percentage finer than size vs grain size - millimetres

Legend:
- AA$_1$TP 12 @ 6.0 m (dry)
- AA$_2$P 3 @ 2.0 m (wet)
- AA$_2$P 5 @ 2.2 m (wet)
- AA$_2$P 6 @2.3 m (wet)

Clay	Silt			Sand			Gravel			Cobbles
	fine	medium	coarse	fine	medium	coarse	fine	medium	coarse	

0.002 — 0.075 — 2.36 — 63
0.006 0.02 — 0.2 0.6 — 6 20

Sample:	
liquid limit	%
plastic limit	%
plasticity index	%
linear shrinkage	%
particle density	t/m^3
natural moisture	%
classification:	

Plasticity index vs Liquid limit chart (U-line, A-line, CH, CI, MH, CL-ML, CL, ML)

Tested by:	L Sands	Checked by:	L Sands
Date:	16/11/95	Date:	26/07/01

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GRAIN SIZE DISTRIBUTION

Project	JCU/HRIT Bube subsurface monitoring

Sample No.	StnBa aquifer 1	**Lab No.**	JCU	**Sample Date:**	14/11/95

Test Procedure:	**Sample Description:**
Dry & wet sieving according to AS 1289	Refer to sieve data for classification

AS sieve size - millimetres: 0.075 0.15 0.3 0.425 0.6 1.18 2.36 4.75 6.7 9.5 13.2 19 26.5 37.5 53 75 150

percentage finer than size

grain size - millimetres

Legend:
- BaA₁TP 4 @ 2.0 m (wet)
- BaA₁TP 9 @ 4.5 m (dry)
- BaA₁TP 11 @ 5.5 m (dry)
- BaA₁TP U50 @ 7.25 m (wet)
- BaA₁TP U50 @ 7.75 m (wet)

	0.002		0.075		2.36		63

Clay	Silt			Sand			Gravel			Cobbles
	fine	medium	coarse	fine	medium	coarse	fine	medium	coarse	

0.006   0.02   0.2   0.6   6   20

Sample:	BaA₁TP1
liquid limit %	35.4
plastic limit %	16.9
plasticity index %	18.5
linear shrinkage %	
particle density t/m³	
natural moisture %	
classification:	BaA₁TP11: CLAY, very sandy

Plasticity index vs Liquid limit chart:
BaA₁TP 11 @ 5.5 m (dry), U - line, A - line, CH, CI, MH, CL-ML, CL, ML

Tested by:	L Sands	Checked by:	L Sands
Date:	16/11/95	Date:	26/07/01

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GRAIN SIZE DISTRIBUTION

Project	JCU/HRIT Bube subsurface monitoring			
Sample No.	StnBa	Lab No.	JCU	Sample Date: 14/11/95

Test Procedure:	Sample Description:
Dry & wet sieving according to AS 1289	Refer to sieve data for classification

AS sieve size - millimetres: 0.075, 0.15, 0.3, 0.425, 0.6, 1.18, 2.36, 4.75, 6.7, 9.5, 13.2, 19, 26.5, 37.5, 53, 75, 150

percentage finer than size vs *grain size - millimetres*

Legend:
- ● BaA$_1$ TP U50 @ 8.6 m (wet)
- ■ BaB$_1$ P 1 @ 1.3 m (wet)
- ▲ BaB$_1$ M 1 @ 1.25 m (wet)
- ⊕ BaA$_2$ P 1 @ 1.4 m (wet)
- ✕ BaA$_2$ P 2 @ 1.5 m (wet)

	0.002		0.075			2.36			63
Clay	Silt			Sand			Gravel		Cobbles
	fine	medium	coarse	fine	medium	coarse	fine	medium	coarse	

0.006   0.02   0.2   0.6   6   20

Sample:	
liquid limit	%
plastic limit	%
plasticity index	%
linear shrinkage	%
particle density	t/m^3
natural moisture	%
classification:	

Plasticity chart: Plasticity index vs Liquid limit — U-line, A-line, CH, CI, MH, CL, CL-ML, ML

Tested by: L Sands

Date: 16/11/95

Checked by: L Sands

Date: 26/07/01

Department of Civil & Systems Engineering

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James Cook University, QLD 4811 (077) 81 4112 (077) 75 1184

AUSTRALIA

GRAIN SIZE DISTRIBUTION

Project	JCU/HRIT Bube subsurface monitoring		
Sample No. StnC	**Lab No.** JCU	**Sample Date:** 14/11/95

Test Procedure:	Sample Description:
Dry & wet sieving according to AS 1289	Refer to sieve data for classification

AS sieve size - millimetres

0.075 0.15 0.3 0.425 0.6 1.18 2.36 4.75 6.7 9.5 13.2 19 26.5 37.5 53 75 150

percentage finer than size

grain size - millimetres

Legend:
- CA₁TP 9 @ 4.5 m (dry)
- CA₁TP 13 @ 6.5 m (dry)
- CA₁TP U50 @ 7.2 m (wet)
- CA₂P 6 @ 2.5 m (wet)
- CA₂P 7 @ 3.0 m (wet)

0.002			0.075			2.36			63
Clay	Silt			Sand			Gravel			Cobbles
	fine	medium	coarse	fine	medium	coarse	fine	medium	coarse	

0.006 0.02 0.2 0.6 6 20
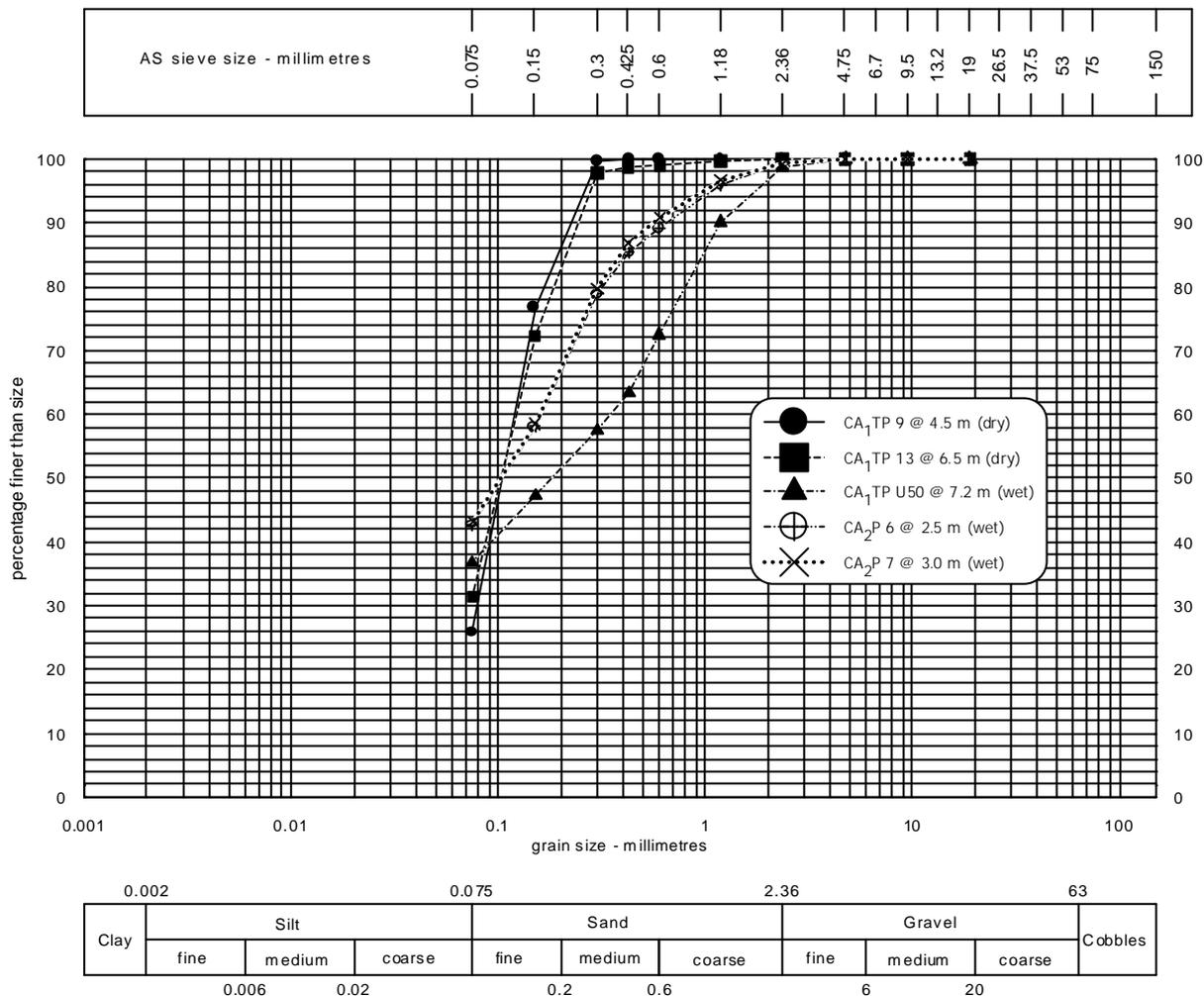
Sample:		CA₁TP9	CA₁TP13
liquid limit	%	28.3	34.4
plastic limit	%	17.9	17.0
plasticity index	%	10.4	17.4
linear shrinkage	%		
particle density	t/m³		
natural moisture	%		
classification:	CA₁TP9: fine SAND, very clayey		
	CA₁TP13: fine SAND, very clayey		

Plasticity index chart (Liquid limit vs Plasticity index) showing CL-ML, CL, CI, MH, CH, ML regions with A-line and U-line.

Tested by:	L Sands	Checked by:	L Sands
Date:	16/11/95	Date:	26/07/01

JAMES COOK UNIVERSITY

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Department of Civil & Systems Engineering

GRAIN SIZE DATA

Project	JCU/HRIT Bube subsurface monitoring		
Sample No. Stn A aquifer 1		**Lab No.** JCU	**Sample Date:** 14/11/95

Test Procedure:	Sample Description:
Dry & wet sieving according to AS 1289	Refer to sieve data for classification

Sample No.	AA₁TP 1 @ 0.5 m (dry)		
Sieve Size (mm)	Mass Retained (g)	% Retained	% Passing
19.0	0.000	0.0	100.0
9.5	0.000	0.0	100.0
4.75	0.000	0.0	100.0
2.36	0.000	0.0	100.0
1.18	0.025	0.0	100.0
0.600	0.352	0.4	99.6
0.425	0.941	0.9	98.7
0.300	8.230	8.2	90.4
0.150	27.904	28.0	62.5
0.075	32.862	32.9	29.5
Pan	29.472	Sample Description	
Total (Mₛ)	99.786	very silty, fine SAND	
Intial (Mₛ)	100.389		

Sample No.	AA₁TP 3 @ 1.5 m (dry)		
Sieve Size (mm)	Mass Retained (g)	% Retained	% Passing
19.0	0.000	0.0	100.0
9.5	0.000	0.0	100.0
4.75	0.000	0.0	100.0
2.36	0.000	0.0	100.0
1.18	0.227	0.4	99.6
0.600	0.689	1.2	98.4
0.425	0.909	1.6	96.8
0.300	2.685	4.7	92.2
0.150	14.059	24.4	67.7
0.075	18.586	32.3	35.4
Pan	20.355	Sample Description	
Total (Mₛ)	57.51	very sandy, SILT/SAND	
Intial (Mₛ)	58.034		

Notes: Dry or Washed soil, passing 19 mm sieve, is used.

1. *% Retained = 100 x Mass Retained / Mₛ.*
2. *% Passing = 100 x Mass Passed / Mₛ*
3. The procedure is simplified here. See AS 1289 for the standard procedure.

Sample No.	AA₁TP 7 @3.5 m (dry)		
Sieve Size (mm)	Mass Retained (g)	% Retained	% Passing
19.0	0.000	0.0	100.0
9.5	0.000	0.0	100.0
4.75	0.000	0.0	100.0
2.36	0.000	0.0	100.0
1.18	0.319	0.2	99.8
0.600	0.076	0.0	99.8
0.425	0.115	0.1	99.7
0.300	0.227	0.1	99.6
0.150	2.432	1.4	98.2
0.075	78.293	43.8	54.5
Pan	97.416	Sample Description	
Total (Mₛ)	178.878	very sandy Clay	
Intial (Mₛ)			

Sample No.	AA₁TP 9 @ 4.5 m (dry)		
Sieve Size (mm)	Mass Retained (g)	% Retained	% Passing
19.0	0.000	0.0	100.0
9.5	0.000	0.0	100.0
4.75	0.000	0.0	100.0
2.36	0.000	0.0	100.0
1.18	0.153	0.2	99.8
0.600	0.124	0.1	99.7
0.425	0.153	0.2	99.5
0.300	0.276	0.3	99.2
0.150	3.456	3.9	95.3
0.075	27.912	31.7	63.6
Pan	56.113	Sample Description	
Total (Mₛ)	88.187	very sandy CLAY	
Intial (Mₛ)			

Tested by:	L Sands	Checked by:	L Sands
Date:	16/11/95	Date:	26/07/01

GRAIN SIZE DATA

Project	JCU/HRIT Bube subsurface monitoring			
Sample No.	Stn A aquifer 1 & 2	**Lab No.**	JCU	**Sample Date:** 14/11/95
Test Procedure:		**Sample Description:**		
Dry & wet sieving according to AS 1289		Refer to sieve data for classification		

Sample No.	AA$_1$TP 11 @ 5.5 m (dry)		
Sieve Size (mm)	Mass Retained (g)	% Retained	% Passing
19.0	0.000	0.0	100.0
9.5	0.000	0.0	100.0
4.75	0.000	0.0	100.0
2.36	0.000	0.0	100.0
1.18	0.000	0.0	100.0
0.600	0.000	0.0	100.0
0.425	0.000	0.0	100.0
0.300	0.000	0.0	100.0
0.150	9.330	8.2	91.8
0.075	44.921	39.4	52.4
Pan	59.713	Sample Description	
Total (M$_s$)	113.964	very sandy CLAY	
Intial (M$_s$)			

Sample No.	AA$_1$TP 12 @ 6.0 m (dry)		
Sieve Size (mm)	Mass Retained (g)	% Retained	% Passing
19.0	0.000	0.0	100.0
9.5	0.000	0.0	100.0
4.75	0.000	0.0	100.0
2.36	6.117	18.8	81.2
1.18	12.349	38.0	43.2
0.600	3.370	10.4	32.9
0.425	1.345	4.1	28.7
0.300	1.214	3.7	25.0
0.150	1.009	3.1	21.9
0.075	2.934	9.0	12.9
Pan	4.186	Sample Description	
Total (M$_s$)	32.524	clayey, gravelly, coarse SAND	
Intial (M$_s$)			

Notes: Dry or Washed soil, passing 19 mm sieve, is used.

1. *% Retained = 100 x Mass Retained / M$_s$.*
2. *% Passing = 100 x Mass Passed / M$_s$*
3. The procedure is simplified here. See AS 1289 for the standard procedure.

Sample No.	AA$_2$P 3 @ 2.0 m (wet)		
Sieve Size (mm)	Mass Retained (g)	% Retained	% Passing
19.0	0.000	0.0	100.0
9.5	4.091	2.9	97.1
4.75	0.232	0.2	96.9
2.36	1.072	0.8	96.1
1.18	26.318	19.0	77.2
0.600	59.719	43.0	34.2
0.425	12.136	8.7	25.4
0.300	5.584	4.0	21.4
0.150	9.682	7.0	14.4
0.075	5.727	4.1	10.3
Pan	14.303	Sample Description	
Before (M$_s$)	138.864	slightly gravelly, silty, coarse SAND	
After (M$_s$)	138.864		

Sample No.	AA$_2$P 5 @ 2.2 m (wet)		
Sieve Size (mm)	Mass Retained (g)	% Retained	% Passing
19.0	0.000	0.0	100.0
9.5	0.000	0.0	100.0
4.75	3.112	4.7	95.3
2.36	10.422	15.6	79.8
1.18	10.496	15.7	64.1
0.600	7.327	11.0	53.1
0.425	2.278	3.4	49.7
0.300	2.104	3.1	46.5
0.150	5.685	8.5	38.0
0.075	8.215	12.3	25.7
Pan	17.204	Sample Description	
Before (M$_s$)	66.843	slightly gravelly, very silty, fine to coarse SAND	
After (M$_s$)	66.843		

Tested by: L Sands

Date: 16/11/95

Checked by: L Sands

Date: 26/07/01

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POSTAL ADDRESS: TELEPHONE   FACSIMILE:
James Cook University, QLD 4811   (077) 81 4112   (077) 75 1184
AUSTRALIA

GRAIN SIZE DATA

Project	JCU/HRIT Bube subsurface monitoring			
Sample No.	Stn A aquifer 2	**Lab No.**	JCU	**Sample Date:** 14/11/95

Test Procedure:	Sample Description:
Dry & wet sieving according to AS 1289	Refer to sieve data for classification

Sample No.	AA$_2$P 6 @ 2.3 m (wet)		
Sieve Size (mm)	Mass Retained (g)	% Retained	% Passing
19.0	98.160	39.1	60.9
9.5	11.648	4.6	56.3
4.75	4.612	1.8	54.4
2.36	13.053	5.2	49.2
1.18	19.437	7.7	41.5
0.600	15.428	6.1	35.3
0.425	7.215	2.9	32.5
0.300	7.658	3.1	29.4
0.150	14.797	5.9	23.5
0.075	13.388	5.3	18.2
Pan	45.637	Sample Description	
Before (M$_s$)	251.033	very silty, very sandy, coarse GRAVEL	
After (M$_s$)	251.033		

Notes: Dry or Washed soil, passing 19 mm sieve, is used.

1. *% Retained = 100 x Mass Retained / M$_s$.*
2. *% Passing = 100 x Mass Passed / M$_s$*
3. The procedure is simplified here. See AS 1289 for the standard procedure.

Tested by: L Sands   Checked by: L Sands

Date: 16/11/95   Date: 26/07/01

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POSTAL ADDRESS:	TELEPHONE	FACSIMILE:
James Cook University, QLD 4811	(077) 81 4112	(077) 75 1184
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GRAIN SIZE DATA

Project	JCU/HRIT Bube subsurface monitoring		

Sample No.	Stn Ba aquifer 1	**Lab No.**	JCU	**Sample Date:**	14/11/95

Test Procedure:	**Sample Description:**
Dry & wet sieving according to AS 1289	Refer to sieve data for classification

Sample No.	BaA$_1$TP 4 (wet) @ 2.0 m		
Sieve Size (mm)	Mass Retained (g)	% Retained	% Passing
19.0	0.000	0.0	100.0
9.5	0.000	0.0	100.0
4.75	0.000	0.0	100.0
2.36	0.000	0.0	100.0
1.18	0.000	0.0	100.0
0.600	0.000	0.0	100.0
0.425	0.645	0.4	99.6
0.300			
0.150	7.147	3.9	95.7
0.075	19.660	10.8	84.9
Pan	153.993	Sample Description	
Total (M$_s$)	181.445	**sandy CLAY**	
Intial (M$_s$)			

Sample No.	BaA$_1$TP 9 (dry) @ 4.5 m		
Sieve Size (mm)	Mass Retained (g)	% Retained	% Passing
19.0	0.000	0.0	100.0
9.5	0.000	0.0	100.0
4.75	0.000	0.0	100.0
2.36	0.000	0.0	100.0
1.18	0.035	0.0	100.0
0.600	1.537	2.0	97.9
0.425	4.372	5.8	92.2
0.300	7.248	9.6	82.6
0.150	14.055	18.5	64.1
0.075	17.261	22.8	41.3
Pan	31.347	Sample Description	
Total (M$_s$)	75.855	**very sandy SILT**	
Intial (M$_s$)			

Notes: Dry or Washed soil, passing 19 mm sieve, is used.

1. *% Retained = 100 x Mass Retained / M$_s$.*
2. *% Passing = 100 x Mass Passed / M$_s$*
3. The procedure is simplified here. See AS 1289 for the standard procedure.

Sample No.	BaA$_1$TP 11 (dry) @ 5.5 m		
Sieve Size (mm)	Mass Retained (g)	% Retained	% Passing
19.0	0.000	0.0	100.0
9.5	0.000	0.0	100.0
4.75	0.000	0.0	100.0
2.36	0.000	0.0	100.0
1.18	0.000	0.0	100.0
0.600	0.497	0.2	99.8
0.425	1.416	0.6	99.2
0.300	1.770	0.8	98.4
0.150	23.748	10.3	88.1
0.075	116.001	50.5	37.6
Pan	86.448	Sample Description	
Total (M$_s$)	229.880	**very sandy CLAY**	
Intial (M$_s$)			

Sample No.	BaA$_1$TP U50 (wet) @ 7.25 m		
Sieve Size (mm)	Mass Retained (g)	% Retained	% Passing
19.0	0.000	0.0	100.0
9.5	0.000	0.0	100.0
4.75	0.000	0.0	100.0
2.36	0.472	0.6	99.4
1.18	4.825	6.2	93.2
0.600	19.749	25.2	68.1
0.425	14.194	18.1	50.0
0.300	8.276	10.5	39.4
0.150	12.432	15.8	23.6
0.075	5.606	7.1	16.4
Pan	12.898	Sample Description	
Total (M$_s$)	78.452	**clayey, fine to coarse SAND**	
Intial (M$_s$)			

Tested by:	L Sands	Checked by:	L Sands
Date:	16/11/95	Date:	26/07/01

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Department of Civil & Systems Engineering

POSTAL ADDRESS:
James Cook University, QLD 4811
AUSTRALIA

TELEPHONE
(077) 81 4112

FACSIMILE:
(077) 75 1184

GRAIN SIZE DATA

Project	JCU/HRIT Bube subsurface monitoring			
Sample No.	Stn Ba refer to data	**Lab No.**	JCU	**Sample Date:** 14/11/95
Test Procedure: Dry & wet sieving according to AS 1289			**Sample Description:** Refer to sieve data for classification	

Sample No.	BaA$_1$TP U50 (wet) @ 7.75 m		
Sieve Size (mm)	Mass Retained (g)	% Retained	% Passing
19.0			
9.5			
4.75			
2.36			
1.18			
0.600			
0.425			
0.300			
0.150			
0.075		60.5	39.5
Pan	11.821	Sample Description	
Total (M$_s$)	29.955	**very sandy CLAY**	
Intial (M$_s$)			

Sample No.	BaA$_1$TP U50 (wet) @ 8.60 m		
Sieve Size (mm)	Mass Retained (g)	% Retained	% Passing
19.0	0.000	0.0	100.0
9.5	0.000	0.0	100.0
4.75	0.000	0.0	100.0
2.36	4.627	5.9	94.1
1.18	11.406	14.5	79.7
0.600	16.012	20.3	59.4
0.425	7.045	8.9	50.4
0.300	4.490	5.7	44.7
0.150	6.637	8.4	36.3
0.075	3.493	4.4	31.9
Pan	25.142	Sample Description	
Total (M$_s$)	78.852	**very clayey SAND**	
Intial (M$_s$)			

Notes: Dry or Washed soil, passing 19 mm sieve, is used.

1. *% Retained = 100 x Mass Retained / M$_s$.*
2. *% Passing = 100 x Mass Passed / M$_s$*
3. The procedure is simplified here. See AS 1289 for the standard procedure.

Sample No.	BaB$_1$P 1 (wet) @ 1.3 m		
Sieve Size (mm)	Mass Retained (g)	% Retained	% Passing
19.0	0.000	0.0	100.0
9.5	0.000	0.0	100.0
4.75	0.000	0.0	100.0
2.36	0.000	0.0	100.0
1.18	0.000	0.0	100.0
0.600	0.000	0.0	100.0
0.425	0.788	0.5	99.6
0.300			
0.150	29.999	17.8	81.8
0.075	44.993	26.7	55.1
Pan	92.801	Sample Description	
Before (M$_s$)	168.504	**very sandy SILT**	
After (M$_s$)			

Sample No.	BaB$_1$M 1 (wet) @ 1.25 m		
Sieve Size (mm)	Mass Retained (g)	% Retained	% Passing
19.0	0.000	0.0	100.0
9.5	0.000	0.0	100.0
4.75	0.000	0.0	100.0
2.36	0.095	0.0	100.0
1.18	0.147	0.1	99.9
0.600	0.313	0.1	99.8
0.425	0.797	0.4	99.4
0.300	4.931	2.2	97.3
0.150	51.254	22.5	74.7
0.075	56.783	25.0	49.7
Pan	113.073	Sample Description	
Before (M$_s$)	227.344	**very sandy SILT**	
After (M$_s$)			

Tested by:	L Sands	Checked by:	L Sands
Date:	16/11/95	Date:	26/07/01

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James Cook University, QLD 4811   (077) 81 4112   (077) 75 1184
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GRAIN SIZE DATA

Project	JCU/HRIT Bube subsurface monitoring				
Sample No.	Stn Ba refer to data	**Lab No.**	JCU	**Sample Date:**	14/11/95

Test Procedure:	Sample Description:
Dry & wet sieving according to AS 1289	Refer to sieve data for classification

Sample No.	BaA$_2$P 1 (wet) @ 1.4 m		
Sieve Size (mm)	Mass Retained (g)	% Retained	% Passing
19.0	0.000	0.0	100.0
9.5	3.637	1.5	98.5
4.75	20.257	8.5	90.0
2.36	49.624	20.8	69.1
1.18	56.629	23.8	45.4
0.600	31.368	13.2	32.2
0.425	2.081	0.9	31.3
0.300	2.660	1.1	30.2
0.150	20.475	8.6	21.6
0.075	20.319	8.5	13.1
Pan	31.138	Sample Description	
Before (M$_s$)	238.188	silty, very gravelly, fine to coarse SAND	
After (M$_s$)			

Sample No.	BaA$_2$P 2 (wet) @ 1.5 m		
Sieve Size (mm)	Mass Retained (g)	% Retained	% Passing
19.0	0.000	0.0	100.0
9.5	0.000	0.0	100.0
4.75	0.000	0.0	100.0
2.36	1.912	0.9	99.1
1.18	8.536	4.1	95.0
0.600	20.658	10.0	85.0
0.425			
0.300	24.690	11.9	73.1
0.150	33.505	16.1	57.0
0.075	27.541	13.3	43.7
Pan	90.715	Sample Description	
Before (M$_s$)	207.557	very sandy CLAY	
After (M$_s$)			

Notes: Dry or Washed soil, passing 19 mm sieve, is used.

1. *% Retained = 100 x Mass Retained / M$_s$.*
2. *% Passing = 100 x Mass Passed / M$_s$*
3. The procedure is simplified here. See AS 1289 for the standard procedure.

Tested by: L Sands   Checked by: L Sands

Date: 16/11/95   Date: 26/07/01

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GRAIN SIZE DATA

Project	JCU/HRIT Bube subsurface monitoring		
Sample No. Stn C aquifer 1 & 2		**Lab No.** JCU	**Sample Date:** 14/11/95

Test Procedure:	Sample Description:
Dry & wet sieving according to AS 1289	Refer to sieve data for classification

Sample No.	CA$_1$TP 9 (dry) @ 4.5 m		
Sieve Size (mm)	Mass Retained (g)	% Retained	% Passing
19.0	0.000	0.0	100.0
9.5	0.000	0.0	100.0
4.75	0.000	0.0	100.0
2.36	0.000	0.0	100.0
1.18	0.000	0.0	100.0
0.600	0.093	0.0	100.0
0.425	0.169	0.1	99.9
0.300	0.472	0.2	99.7
0.150	58.724	22.9	76.8
0.075	130.049	50.8	26.0
Pan	66.493	Sample Description	
Total (M$_s$)	256	very clayey, fine SAND	
Intial (M$_s$)			

Sample No.	CA$_1$TP 13 (dry) @ 6.5 m		
Sieve Size (mm)	Mass Retained (g)	% Retained	% Passing
19.0	0.000	0.0	100.0
9.5	0.000	0.0	100.0
4.75	0.000	0.0	100.0
2.36	0.000	0.0	100.0
1.18	0.899	0.4	99.6
0.600	1.374	0.6	99.0
0.425	0.856	0.4	98.7
0.300	2.049	0.9	97.8
0.150	60.988	25.5	72.3
0.075	97.949	41.0	31.3
Pan	74.835	Sample Description	
Total (M$_s$)	238.95	very clayey, fine SAND	
Intial (M$_s$)			

Notes: Dry or Washed soil, passing 19 mm sieve, is used.

1. *% Retained = 100 x Mass Retained / M$_s$*
2. *% Passing = 100 x Mass Passed / M$_s$*
3. The procedure is simplified here. See AS 1289 for the standard procedure.

Sample No.	CA$_1$TP U50 (wet) @ 7.2 m		
Sieve Size (mm)	Mass Retained (g)	% Retained	% Passing
19.0	0.000	0.0	100.0
9.5	0.000	0.0	100.0
4.75	0.000	0.0	100.0
2.36	0.207	1.3	98.7
1.18	1.354	8.5	90.1
0.600	2.806	17.7	72.4
0.425	1.435	9.1	63.4
0.300	0.925	5.8	57.5
0.150	1.623	10.2	47.3
0.075	1.672	10.6	36.7
Pan	5.822	Sample Description	
Total (M$_s$)	15.844	very sandy CLAY	
Intial (M$_s$)			

Sample No.	CA$_2$P 6 (wet) @ 2.5 m		
Sieve Size (mm)	Mass Retained (g)	% Retained	% Passing
19.0	0.000	0.0	100.0
9.5	0.000	0.0	100.0
4.75	0.000	0.0	100.0
2.36	0.577	0.6	99.4
1.18	3.128	3.5	95.9
0.600	6.134	6.8	89.1
0.425	3.471	3.8	85.3
0.300	5.894	6.5	78.8
0.150	18.784	20.7	58.1
0.075	13.947	15.4	42.7
Pan	38.703	Sample Description	
Total (M$_s$)	90.638	very sandy CLAY	
Intial (M$_s$)			

Tested by: L Sands		Checked by: L Sands
Date: 16/11/95		Date: 26/07/01

GRAIN SIZE DATA

Project	JCU/HRIT Bube subsurface monitoring			
Sample No.	Stn C aquifer 2	**Lab No.**	JCU	**Sample Date:** 14/11/95

Test Procedure:	**Sample Description:**
Dry & wet sieving according to AS 1289	Refer to sieve data for classification

Sample No.	CA$_2$P 7 (wet) @ 3.0 m		
Sieve Size (mm)	Mass Retained (g)	% Retained	% Passing
19.0	0.000	0.0	100.0
9.5	0.000	0.0	100.0
4.75	0.000	0.0	100.0
2.36	1.486	0.7	99.3
1.18	5.394	2.6	96.7
0.600	12.338	5.9	90.8
0.425	8.291	4.0	86.9
0.300	14.931	7.1	79.7
0.150	44.301	21.2	58.5
0.075	32.255	15.4	43.1
Pan	90.265	Sample Description	
Total (M$_s$)	209.261	**very sandy CLAY**	
Intial (M$_s$)			

Notes: Dry or Washed soil, passing 19 mm sieve, is used.

1. *% Retained = 100 x Mass Retained / M$_s$*
2. *% Passing = 100 x Mass Passed / M$_s$*
3. The procedure is simplified here. See AS 1289 for the standard procedure.

Tested by:	L Sands	Checked by:	L Sands
Date:	16/11/95	Date:	26/07/01

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Department of Civil & Systems Engineering

POSTAL ADDRESS: TELEPHONE FACSIMILE:
James Cook University, QLD 4811 (077) 81 4112 (077) 75 1184

FALLING HEAD PERMEABILITY

Test No. 1				Bube- AA$_1$TP (U50) 5.25-5.65 m	
Weight: sample + tube (g)	Pre: 1937	Post: 1938	Sample Dia. **D** (mm)	Top:48	Bot: 48
Length of tube **L$_3$** (mm)		411	Top recess **L$_1$** (mm)		36
Length of sample **L** (mm)		338	Bot. recess **L$_2$** (mm)		37
Sample description		Light grey stained orange, very sandy CLAY, coarse sand at end of tube			
Manometer size **d**(mm)	3.4	Orientation of test:	Vertical - Partially submerged		
Saturation method		-10 kPa vacuum whilst partially submerged			

Date/Time (hr:min:sec)	Reading **h** (mm)	Remarks	Permeability (eqn A1) k(m/s)
0:00:00	987	water temp in tub= 21.1°c	
1:27:00	873	21.0°c	3.93x10^{-8}
18:10:00	471	removed air lock and restarted	1.70x10^{-8}
0:00:00	987		
4:04:00	816		2.17x10^{-8}
5:59:00	779	21.7°c	1.12x10^{-8}
21:12:00	575	21.8°c	9.19x10^{-9}
27:25:00	520	22.0°c	7.67x10^{-9}
45:52:00	392	22.2°c	6.95x10^{-9}
48:00:00	379	22.2°c	7.12x10^{-9}
50:44:00	364		6.65x10^{-9}
		Reported value(@22°c):	**7.1x10^{-9} m/s** **0.026 mm/hr**

Pre & Post Test Moisture Content Evaluation

	Pre		Post	
	Top	Bottom	Top	Bottom
Tin No.	A82	A9	A24	A9
Wt. tin & wet soil (g)	52.9	50.8	48.7	45.2
Wt. tin (g)	18.0	19.3	23.9	19.3
Wt. tin & dry soil	44.8	43.9	42.6	39.5
Wt. dry soil	26.8	24.6	18.6	20.2
Moisture content (%)	30.3	28.1	32.8	28.4
Constant Reference height **h$_r$** (mm)=			120.6	
Datum (mm)=			100	
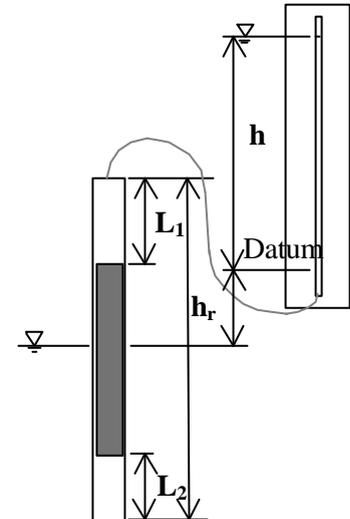
$$k(m/s) = \frac{d^2 L}{D^2 \, 60 \times 10^3 (t_2 - t_1)} \log_e\left(\frac{h_1}{h_2}\right) \qquad \text{eqn A1}$$

d = manometer internal diameter (mm)

D = sample diameter (mm)

t = time (minutes)

L = length of sample (mm)

$h_1 = h_x + h_r - Datum$ (mm)

$h_2 = h_{x+1} + h_r - Datum$ (mm)

Permeability k (mm/hr) vs Time (min) — Running Average

Tested by:	L Sands	Checked by:	L Sands
Date:	11/02/96	Date:	26/07/01

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Department of Civil & Systems Engineering

POSTAL ADDRESS:
James Cook University, QLD 4811

TELEPHONE
(077) 81 4112

FACSIMILE:
(077) 75 1184
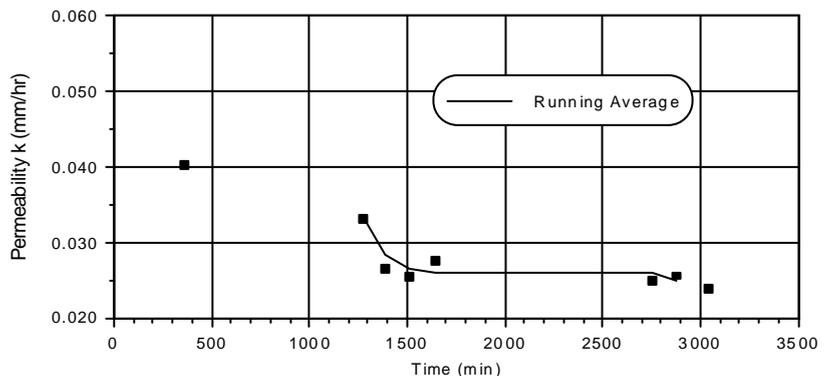
FALLING HEAD PERMEABILITY

Test No. 2			Bube- BaA$_1$TP (U50) 7.25-7.75 m		
Weight: sample + tube (g)	Pre: 1946	Post: 1961	Sample Dia. **D** (mm)	Top:48	Bot: 48
Length of tube **L$_3$** (mm)		401	Top recess **L$_1$** (mm)		49
Length of sample **L** (mm)		328	Bot. recess **L$_2$** (mm)		24
Sample description		Dark grey stained orange very sandy CLAY, dense, some organics			
Manometer size **d** (mm)	3.4	Orientation of test:		Vertical - Partially submerged	
Saturation method		-10 kPa vacuum whilst partially submerged			

Date/Time (hr:min:sec)	Reading **h** (mm)	Remarks			Permeability (eqn A1) k(m/s)
0:00:00	938	water temp in tub= 20.6°c			
1:39:00	889	21.1°c			1.46x10^{-8}
3:34:00	841	21.3°c			1.30x10^{-8}
4:47:00	808	21.4°c			1.48x10^{-8}
22:25:00	497	20.8°c			1.23x10^{-8}
		Reported value (@21°c):			**1.4x10^{-8} m/s** **0.049 mm/hr**

Pre & Post Test Moisture Content Evaluation

	Pre		Post	
	Top	Bottom	Top	Bottom
Tin No.	A9	A82	A91	A24
Wt. tin & wet soil (g)	34.9	38.5	51.9	50.8
Wt. tin (g)	19.3	18.0	18.2	23.9
Wt. tin & dry soil	33.2	35.3	46.9	46.0
Wt. dry soil	13.9	17.3	28.7	22.2
Moisture content (%)	12.5	18.0	16.3	21.4
Constant Reference height **h$_r$** (mm)=			120.9	
Datum (mm)=			100	

$$k(m/s) = \frac{d^2 L}{D^2 60 \times 10^3 (t_2 - t_1)} \log_e\left(\frac{h_1}{h_2}\right) \qquad \text{eqn A1}$$
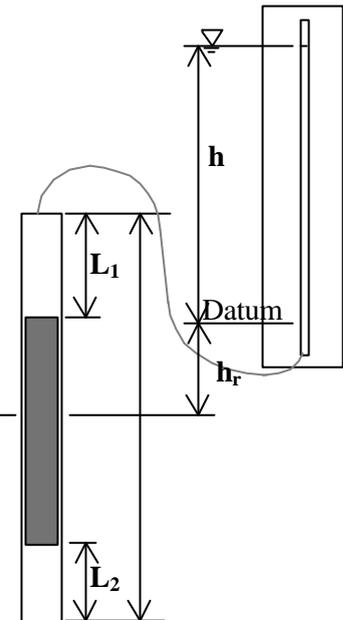
d = manometer internal diameter (mm)

D = sample diameter (mm)

t = time (minutes)

L = length of sample (mm)

$h_1 = h_x + h_r - Datum$ (mm)

$h_2 = h_{x+1} + h_r - Datum$ (mm)

Tested by:	L Sands	Checked by:	L Sands
Date:	11/02/96	Date:	26/07/01

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Department of Civil & Systems Engineering

POSTAL ADDRESS:	TELEPHONE	FACSIMILE:
James Cook University, QLD 4811	(077) 81 4112	(077) 75 1184
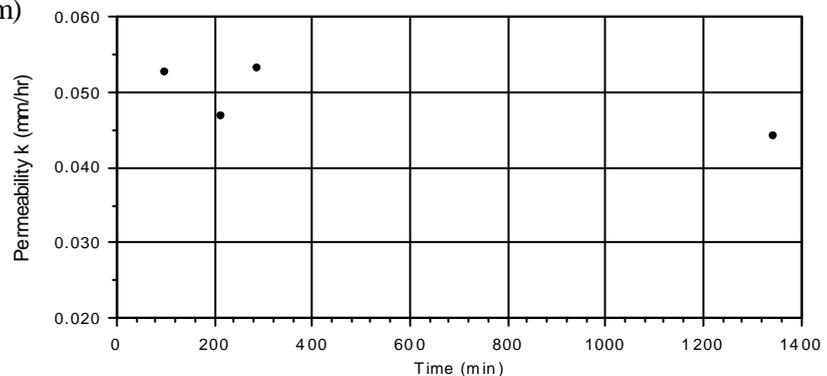
FALLING HEAD PERMEABILITY

Test No. 3	Bube- AA$_1$TP (U50) 6.50-7.00 m

Weight: sample + tube (g)	Pre: 1884	Post: 1887	Sample Dia. **D** (mm)	Top:48	Bot: 48
Length of tube **L$_3$** (mm)		415	Top recess **L$_1$** (mm)		38
Length of sample **L** (mm)		338	Bot. recess **L$_2$** (mm)		39
Sample description			light grey stained orange, very sandy CLAY		
Manometer size **d** (mm)	3.4		Orientation of test:	Vertical - Partially submerged	
Saturation method			-10 kPa vacuum whilst partially submerged		

Date/Time (hr:min:sec)	Reading **h** (mm)	Remarks	Permeability (eqn A1) k(m/s)
0:00:00	975	water temp in tub= 23.2°c	
0:37:00	963		9.33×10^{-9}
30:57:00	759	23.8°c	3.64×10^{-9}
44:52:00	700	21.8°c	2.68×10^{-9}
47:26:00	692	21.5°c	2.19×10^{-9}
49:29:00	685	21.8°c	2.12×10^{-9}
52:02:00	677	21.9°c	2.12×10^{-9}
68:02:00	629	21.2°c	2.11×10^{-9}
71:09:00	624	21.4°c	1.29×10^{-9}
		Reported value(@21°c):	**2.1x10^{-9} m/s** **0.0071mm/hr**

Pre & Post Test Moisture Content Evaluation

	Pre		Post	
	Top	Bottom	Top	Bottom
Tin No.	A9	A82		
Wt. tin & wet soil (g)	41.3	43.2		
Wt. tin (g)	19.3	18.0		
Wt. tin & dry soil	35.6	36.7		
Wt. dry soil	16.3	18.7		
Moisture content (%)	35.6	35.3		
Constant Reference height **h$_r$** (mm)=			120.6	
Datum (mm)=			100	

$$k(m/s) = \frac{d^2 L}{D^2 \, 60 \times 10^3 (t_2 - t_1)} \log_e \left(\frac{h_1}{h_2} \right) \qquad \text{eqn A1}$$

d = manometer internal diameter (mm)

D = sample diameter (mm)

t = time (minutes)

L = length of sample (mm)

$h_1 = h_x + h_r - Datum$ (mm)

$h_2 = h_{x+1} + h_r - Datum$ (mm)
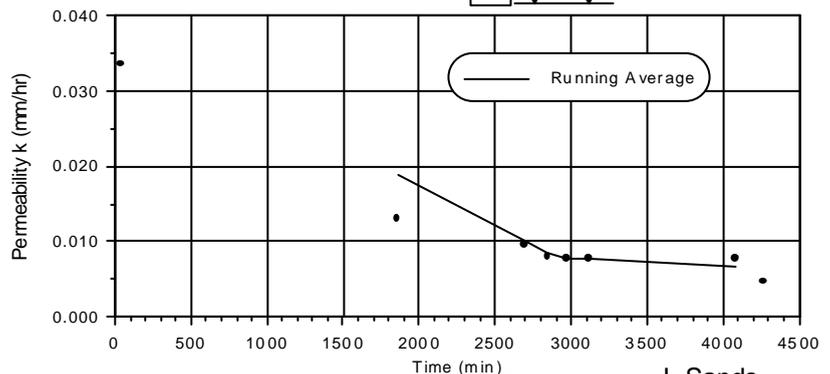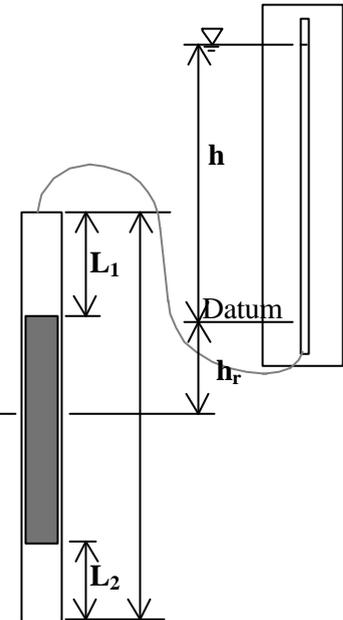
Tested by:	L Sands	Checked by:	L Sands
Date:	11/02/96	Date:	26/07/01

FALLING HEAD PERMEABILITY

Test No. 4			Bube- BaA₁TP (U50) 3.0-3.4 m		

Weight: sample + tube (g)	Pre:	Post: 1133	Sample Dia. **D** (mm)	Top:48	Bot: 48
Length of tube **L₃** (mm)		285	Top recess **L₁** (mm)		84
Length of sample **L** (mm)		164	Bot. recess **L₂** (mm)		37
Sample description		Brownish grey, slightly cemted lumps, silty very sandy CLAY			
Manometer size **d** (mm)	6.8	Orientation of test:		Vertical - Partially submerged	
Saturation method		-10 kPa vacuum whilst partially submerged			

Date/Time (hr:min:sec)	Reading **h** (mm)	Remarks			Permeability (eqn A1) k(m/s)
0:00:00	991	water temp in tub=			
24:54:00	834				6.28×10^{-9}
49:31:00	796				1.71×10^{-9}
53:04:00	792				1.28×10^{-9}
67:48:00	774	23.3°c			1.41×10^{-9}
		Reported value(@23°c):			**1.5×10^{-9} m/s** **0.0053 mm/hr**

Pre & Post Test Moisture Content Evaluation

	Pre		Post	
	Top	Bottom	Top	Bottom
Tin No.	A91	A82	A82	A76
Wt. tin & wet soil (g)	35.0	32.2	56.7	38.3
Wt. tin (g)	18.2	18.0	18.0	18.1
Wt. tin & dry soil	32.9	30.7	47.0	33.8
Wt. dry soil	14.8	12.7	29.0	15.6
Moisture content (%)	14.2	12.4	33.0	29.2
Constant Reference height **h_r** (mm)=			120.6	
Datum (mm)=			100	

$$k(m/s) = \frac{d^2 L}{D^2 \, 60\times10^3 (t_2 - t_1)} \log_e\left(\frac{h_1}{h_2}\right) \qquad \text{eqn A1}$$

d = manometer internal diameter (mm)

D = sample diameter (mm)

t = time (minutes)

L = length of sample (mm)

$h_1 = h_x + h_r - Datum$ (mm)

$h_2 = h_{x+1} + h_r - Datum$ (mm)
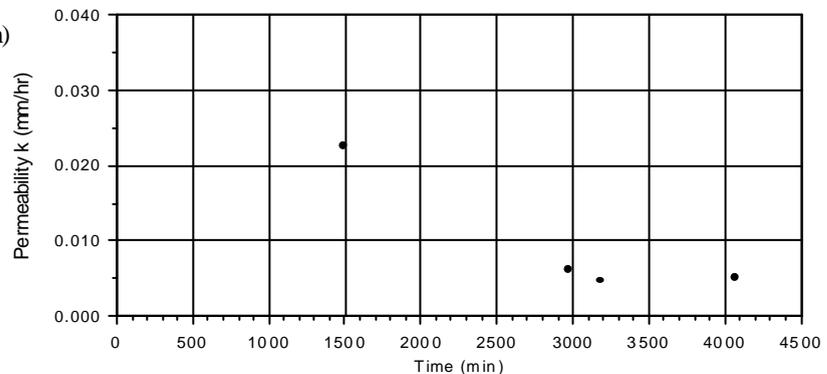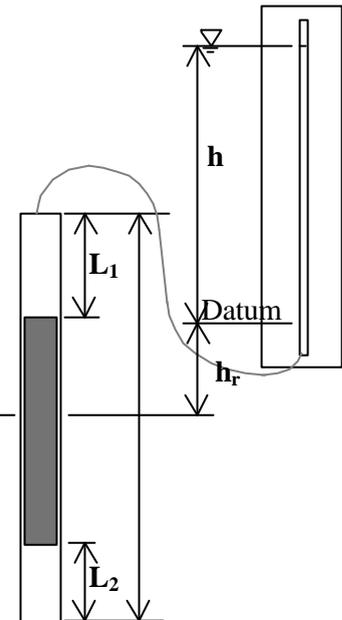
Tested by:	L Sands	Checked by:	L Sands
Date:	11/02/96	Date:	26/07/01

FALLING HEAD PERMEABILITY

Test No. 5

Bube- AA₁TP (U50), 2.9-3.3 m

Weight: sample + tube (g)	Pre: 1538	Post: 1553	Sample Dia. **D** (mm)	Top:48	Bot: 48
Length of tube **L₃** (mm)		344	Top recess **L₁** (mm)		75
Length of sample **L** (mm)		253	Bot. recess **L₂** (mm)		18
Sample description			light grey stained orange, silty very sandy CLAY		
Manometer size **d** (mm)	3.4		Orientation of test:	Vertical - Partially submerged	
Saturation method		immersed in bucket and capped both ends, removed from bucket and transferred to tank with valves shut, then applied -10 kPa vacuum whilst partially submerged			

Date/Time (hr:min:sec)	Reading **h** (mm)	Remarks	Permeability (eqn A1) k(m/s)
0:00:00	995		
1:07:50	967		8.85x10⁻⁹
3:52:16	967		6.61x10⁻¹¹
30:15:00	964		3.44x10⁻¹¹
48:54:00	949		2.94x10⁻¹⁰
76:50:00	938		1.46x10⁻¹⁰
100:58:00	927		1.71x10⁻¹⁰
121:38:00	919		1.47x10⁻¹⁰
		Reported value(@22°c):	**1.4x10⁻¹⁰ m/s** **0.00052 mm/hr**

Pre & Post Test Moisture Content Evaluation

	Pre		Post	
	Top	Bottom	Top	Bottom
Tin No.	A91	A82	A76	A107
Wt. tin & wet soil (g)	50.0	36.0	18.2	17.8
Wt. tin (g)	18.2	18.0	48.5	42.4
Wt. tin & dry soil	44.0	32.7	41.6	36.2
Wt. dry soil	25.9	14.6	23.5	18.4
Moisture content (%)	23.1	22.7	29.1	33.4
Constant Reference height **h_r** (mm)=			123.1	
Datum (mm)=			100	

$$k(m/s) = \frac{d^2 L}{D^2 \, 60 \times 10^3 (t_2 - t_1)} \log_e\left(\frac{h_1}{h_2}\right) \qquad \text{eqn A1}$$

d = manometer internal diameter (mm)

D = sample diameter (mm)

t = time (minutes)

L = length of sample (mm)

$h_1 = h_x + h_r - Datum$ (mm)

$h_2 = h_{x+1} + h_r - Datum$ (mm)

Tested by:	L Sands	Checked by:	L Sands
Date:	11/02/96	Date:	26/07/01

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James Cook University, QLD 4811	(077) 81 4112	(077) 75 1184
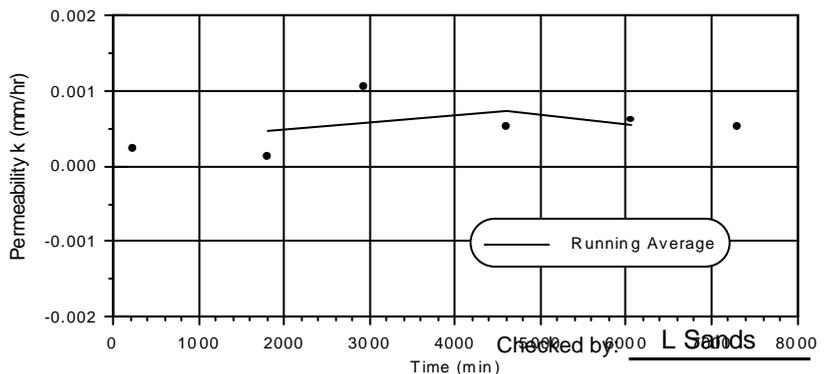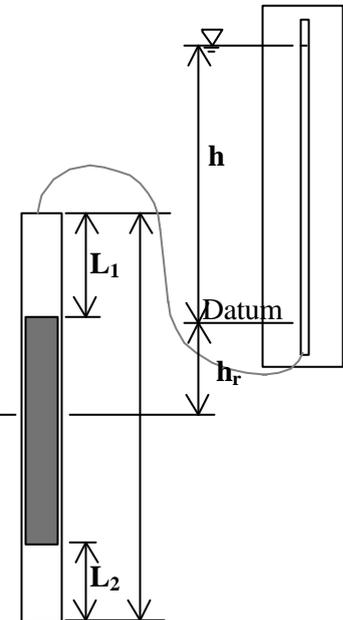
FALLING HEAD PERMEABILITY

Test No. 6				Bube- BaA₁TP (U50), 8.25-8.65 m	

Weight: sample + tube (g)	Pre:	Post: 1978	Sample Dia. **D** (mm)	Top:48	Bot: 48
Length of tube **L₃** (mm)		448	Top recess L₁ (mm)		104
Length of sample **L** (mm)		320	Bot. recess **L₂** (mm)		24
Sample description			light grey very sandy CLAY, some white concretions		
Manometer size **d** (mm)	3.4		Orientation of test:	Vertical - Partially submerged	
Saturation method			-10 kPa vacuum whilst partially submerged		

Date/Time (hr:min:sec)	Reading **h** (mm)	Remarks		Permeability (eqn A1) k(m/s)
0:00:00	951	water temp in tub= 22.9°c		
63:33:00	656		19.4°c	2.55×10^{-9}
65:30:00	658		20.4	
69:58:00	652		21.6	
72:01:30	650		21.75, restarted	6.48×10^{-10}
0:00:00	870	restarted 21.75°c		
23:17:00	738		21.75°c	3.09×10^{-8}
		Reported value:		**2.8×10^{-9} m/s** **0.010 mm/hr**

Pre & Post Test Moisture Content Evaluation

	Pre		Post	
	Top	Bottom	Top	Bottom
Tin No.			A91	A24
Wt. tin & wet soil (g)			33.3	38.5
Wt. tin (g)			18.2	23.9
Wt. tin & dry soil			30.6	36.4
Wt. dry soil			12.4	12.4
Moisture content (%)			21.8	17.2
Constant Reference height **h_r** (mm)=			123.4	
Datum (mm)=			100	

$$k(m/s) = \frac{d^2 L}{D^2\, 60 \times 10^3 (t_2 - t_1)} \log_e\left(\frac{h_1}{h_2}\right) \qquad \text{eqn A1}$$
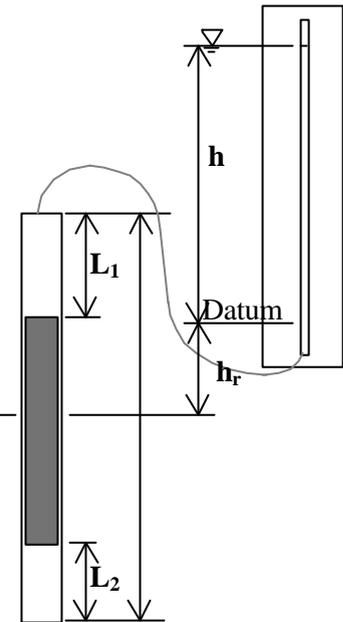
d = manometer internal diameter (mm)

D = sample diameter (mm)

t = time (minutes)

L = length of sample (mm)

$h_1 = h_x + h_r - Datum$ (mm)

$h_2 = h_{x+1} + h_r - Datum$ (mm)
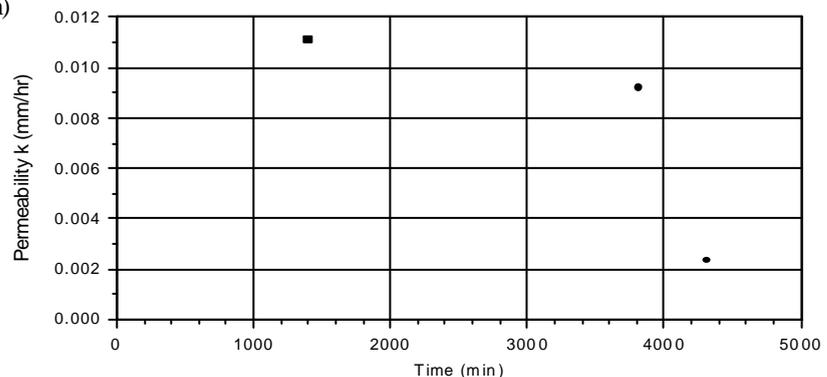
Tested by:	L Sands	Checked by:	L Sands
Date:	11/02/96	Date:	26/07/01

APPENDIX C

HYDROLOGICAL DATA

Flood Categories

Flood Frequency Curve
Herbert River Ingham
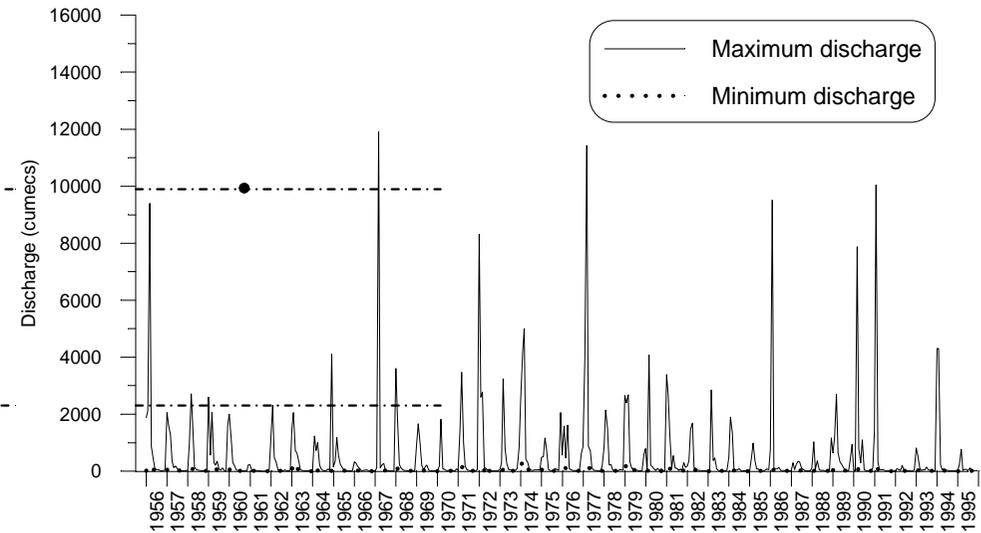
Monthly Instant. Discharge 1956-1995
Herbert River Ingham

Plate C1   Herbert River Ingham Flood Frequency Categories
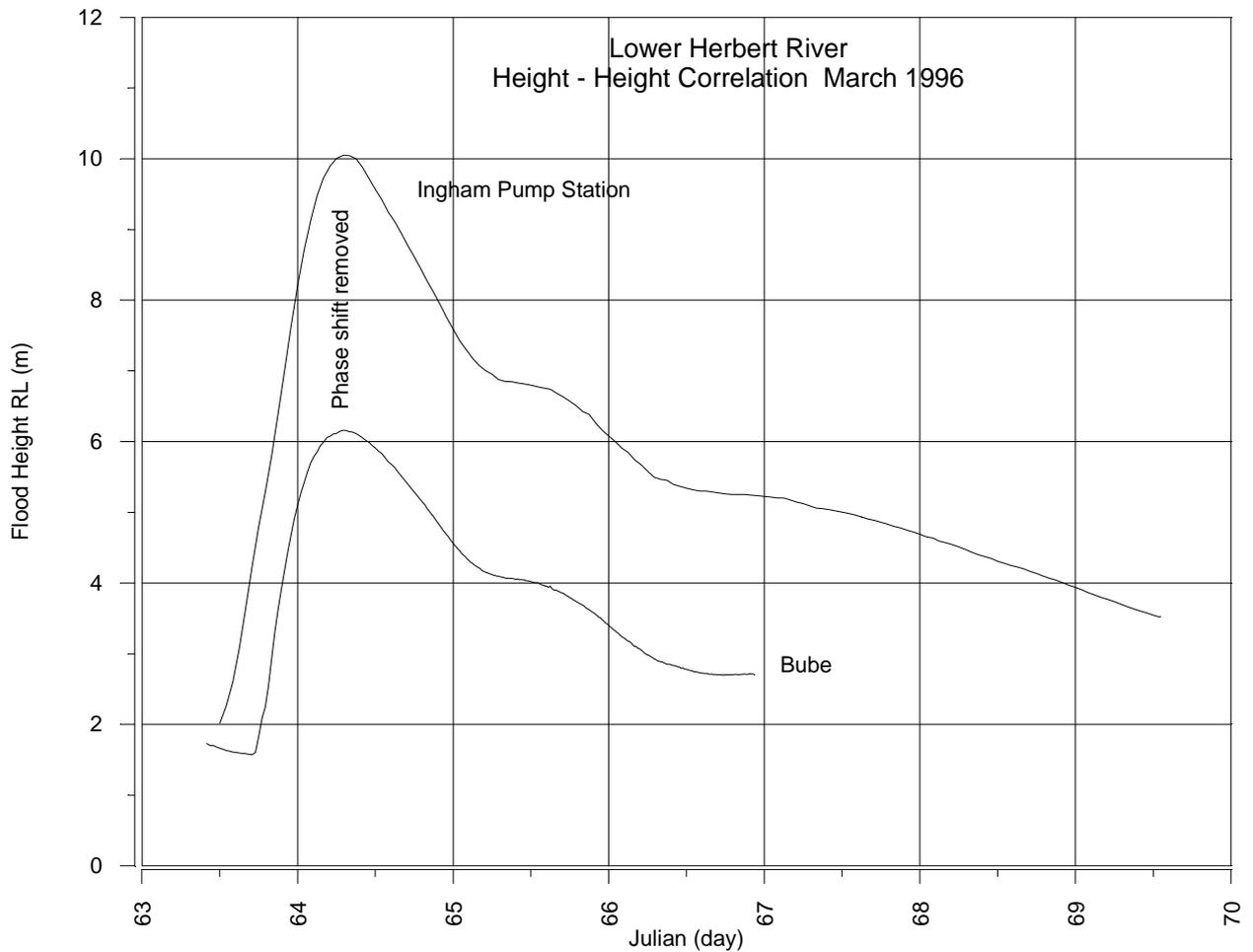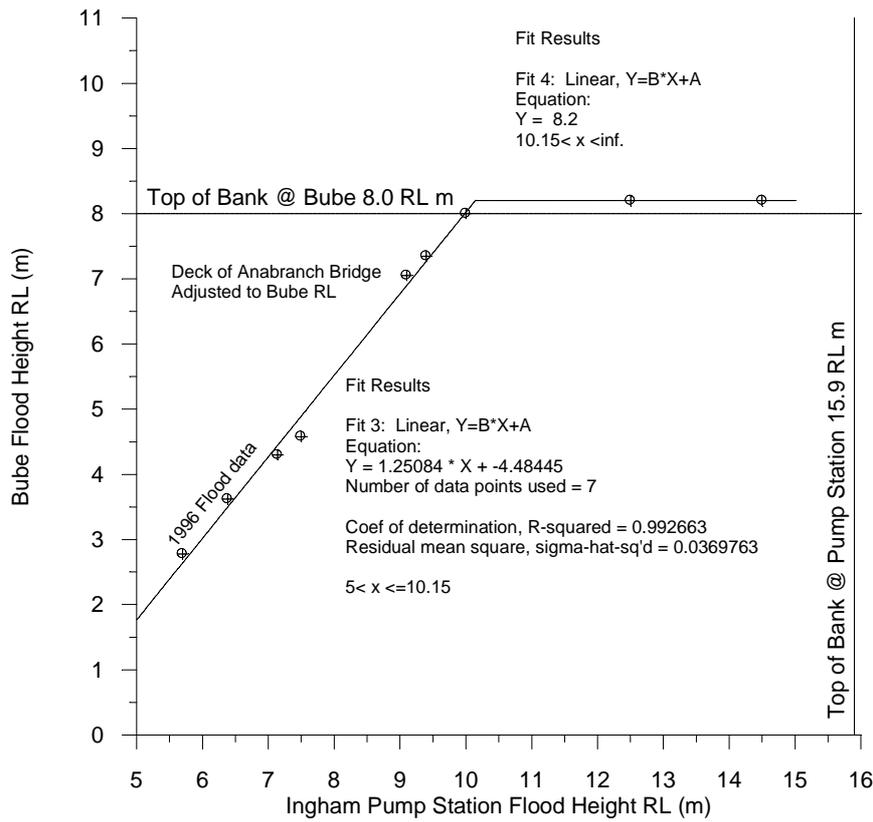
Plate C2   Herbert River Ingham and Anabranch Bube Flood Height-Height Correlation

Herbert River Pump Station X-Section 116001E (1992 - to date)
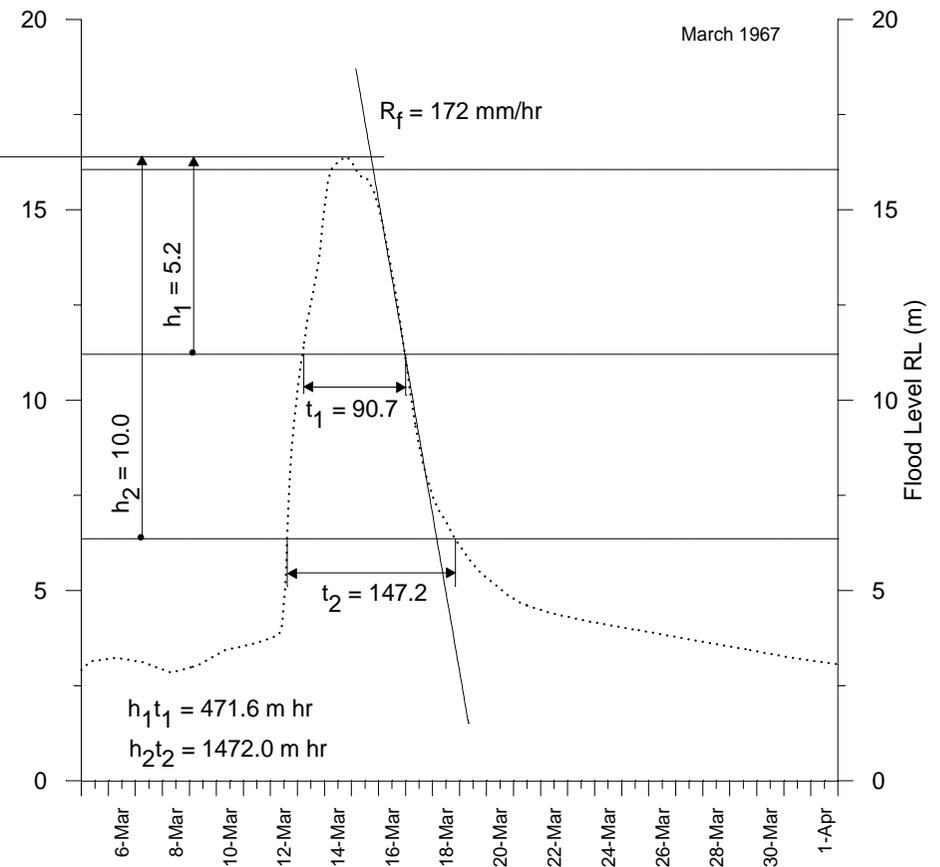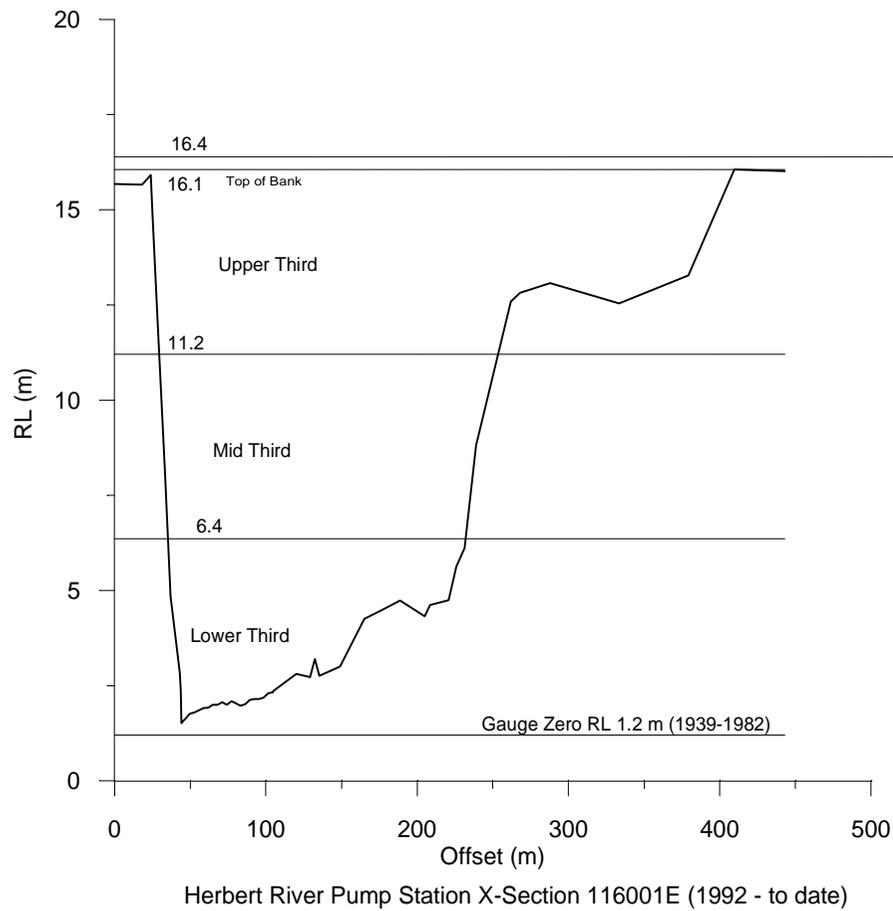
Category A Flood
(Q > 20 yr ARI)

Bank Zones and Inundation
Herbert River Ingham 1967 Flood
Source: DNR Ayr

Plate C3   Herbert River Ingham Bank Zones and Inundation
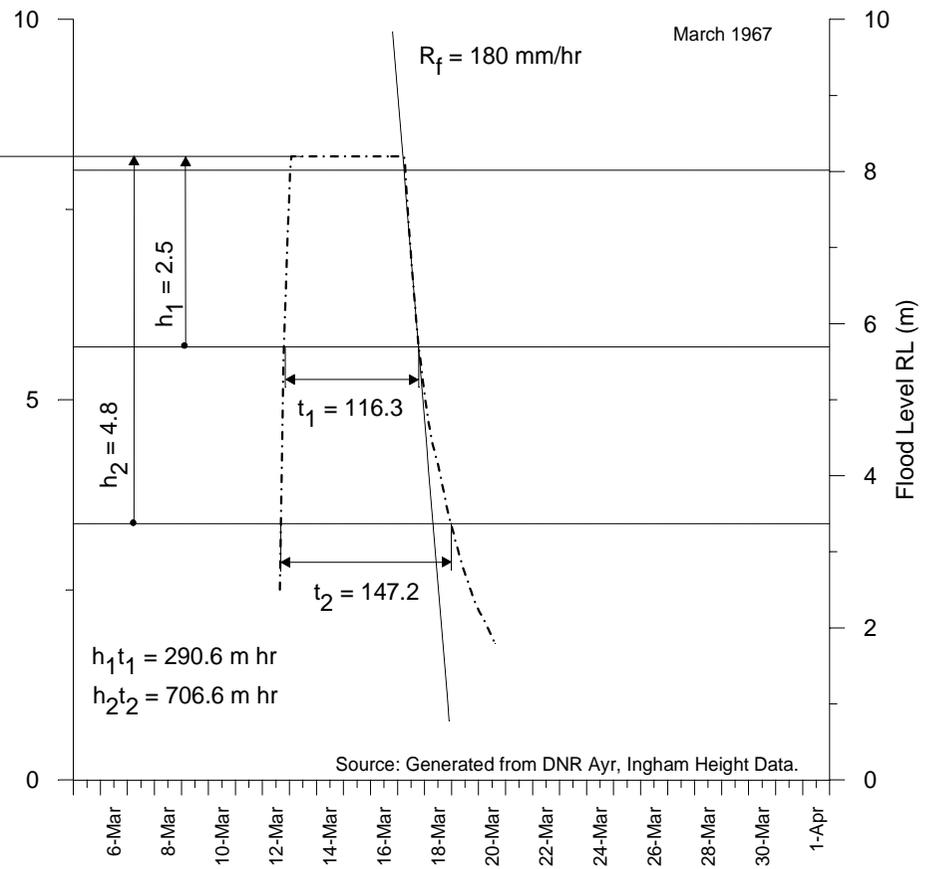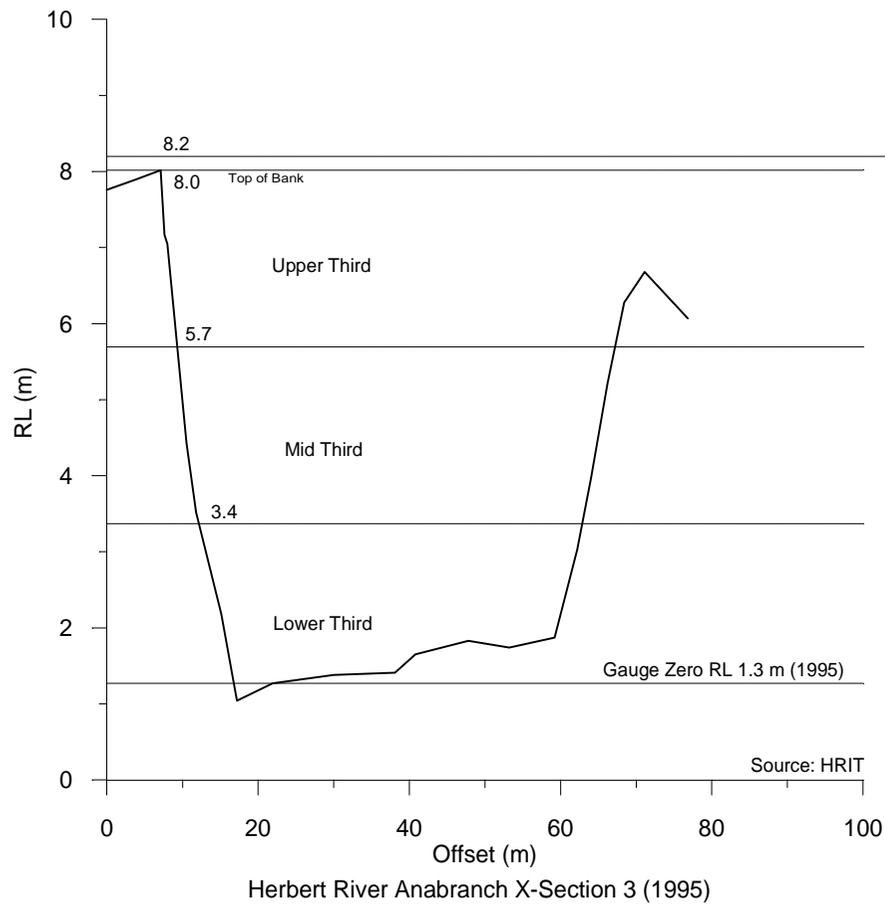
Herbert River Anabranch X-Section 3 (1995)

Category A Flood
(Q > 20 yr ARI)

Bank Zones and Inundation
Herbert River Anabranch Bube 1967 Flood

Plate C4   Anabranch Bube Bank Zones and Inundation
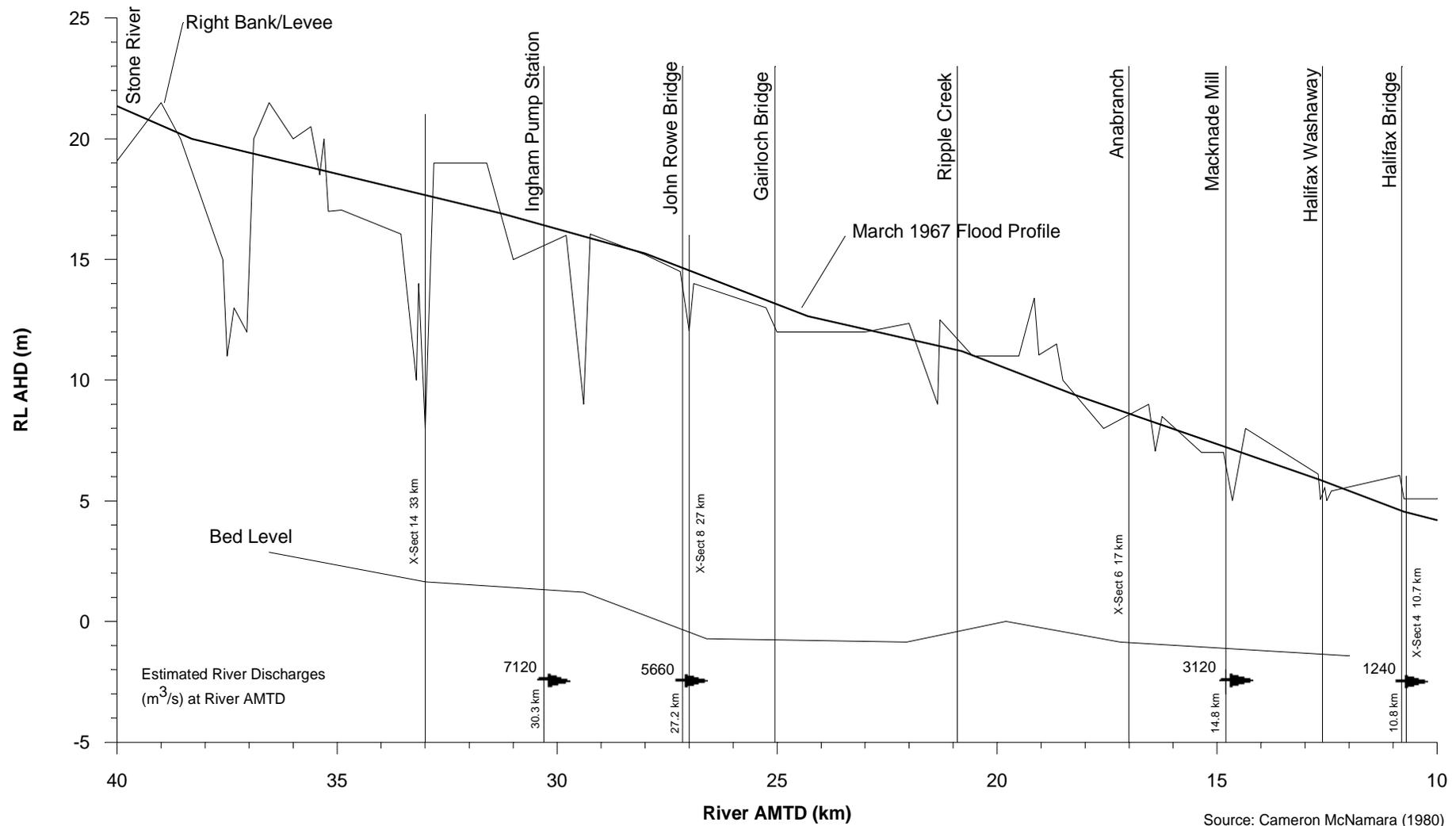
Herbert River Longitudinal Section

Plate C5   Lower Herbert River Longitudinal Section – March 1967 Flood Height Levels

APPENDIX D

GROUNDWATER MODELLING DATA

Generic Groundwater Modelling Grid

Evaluation of b TSEEP

Trying to match Kw(TSEEP) with Kw(SWIM)					
over two ranges. This is achieved by adjusting					
b(TSEEP) for each range until the difference between Kw(TSEEP)					
& Kw(SWIM) is negilable or balanced for each range.					
The fitting of Kw(TSEEP) has been divided into two ranges to compensate					
for TSEEP's Kw equation which poorly fits laboratory data.					
Each range has a b(TSEEP) value which suits the application for "wetting up" or "drying out".					

From CSIRO	$\ln(\psi) = \ln(\psi e\ \theta sat^b) - b\ln(\theta)$		This gives θsat when ψ vs θ is known
Kw(SWIM) =	Ksat (q / qsat)^ (bn) + Km (q / qsat) ^ (bm)		
	For the purpose of TSEEP assume Km (macro pore perm.)=0		
Kw(TSEEP) =	Ksat exp^ (-b(TSEEP) y (kpa)} where Ksat is the y intercept and -b controls the slope.		

ψ =	Suction Head or Pressure (matric potential)
θ (%)=	Volumetric Water Content
Wet=	b value which gives Kw values used for flood recession in TSEEP
Dry=	b value which gives Kw values used for flood rise in TSEEP
ψe=	air entry potential
θsat=	Saturation water content
b(SWIM)=	slope of lny vs lnq
b(TSEEP)=	defines the slope of Kw(TSEEP)

Ksat (m/s) =	1.00E-05

Core 1 JCU/Weipa

ψ (cm)	ψ (kpa)	θ (%)	Kw(SWIM)	Drying out Kw(TSEEP)	Wetting up Kw(TSEEP)
0	0	0.456	3.21511E-06	1.00E-05	1.00E-05
50	-4.905	0.323	2.04206E-09	8.99E-09	4.04E-06
100	-9.81	0.271	4.81551E-11	8.08E-12	1.63E-06
1000	-98.1	0.206	1.38055E-13		1.31E-13
15000	-1471.5	0.176	4.79533E-15		
				Drying out	**Wetting up**
			b(TSEEP)=	1.43	0.185
	b(SWIM)=	9.174			
	ψe (cm)=	1.298			
	BD (g/cm^3)=	1.12			
	θsat=	0.4809			
	n=2+3/b(SWIM)=	2.3270			

95 =Depth (cm)

Core 2 JCU/Weipa

ψ (cm)	ψ (kpa)	θ (%)	Kw(SWIM)	Kw(TSEEP) Drying out	Kw(TSEEP) Wetting up
0	0	0.489	1.42883E-05	1.00E-05	1.00E-05
50	-4.905	0.356	1.62918E-08	3.38E-08	3.94E-06
100	-9.81	0.289	1.90047E-10	1.1426E-10	1.55E-06
1000	-98.1	0.201	8.1704E-14		8.04E-14
15000	-1471.5	0.18	7.74767E-15		
				Drying out	**Wetting up**
			b(TSEEP)=	1.16	0.19
	b(SWIM)=	7.678			
	ψe (cm)=	2.759			
	BD (g/cm^3)=	1.053			
	θsat=	0.5192			
	n=2+3/b(SWIM)=	2.3907			

65 =Depth (cm)

Core 7 JCU/Weipa

ψ (cm)	ψ (kpa)	θ (%)	Kw(SWIM)	Kw(TSEEP) Drying out	Kw(TSEEP) Wetting up
0	0	0.441	1.57431E-06	1.00E-05	1.00E-05
50	-4.905	0.393	1.34495E-07	3.23E-07	5.29E-06
100	-9.81	0.355	1.53422E-08	1.04E-08	2.79E-06
1000	-98.1	0.262	2.34158E-11		2.89E-11
15000	-1471.5	0.238	3.01147E-12		
				Drying out	**Wetting up**
			b(TSEEP)=	0.7	0.13
	b(SWIM)=	10.304			
	ψe (cm)=	11.683			
	BD (g/cm^3)=	1.251			
	θsat=	0.4526			
	n=2+3/b(SWIM)=	2.2911			

45 =Depth (cm)

Core 8 JCU/Weipa

ψ (cm)	ψ (kpa)	θ (%)	Kw(SWIM)	Kw(TSEEP) Drying out	Kw(TSEEP) Wetting up
0	0	0.424	6.80174E-07	1.00E-05	1.00E-05
50	-4.905	0.381	6.93746E-08	3.23E-07	5.83E-06
100	-9.81	0.355	1.53422E-08	1.04E-08	3.40E-06
1000	-98.1	0.292	2.36923E-10		2.06E-10
15000	-1471.5	0.269	4.11117E-11		
				Drying out	**Wetting up**
			b(TSEEP)=	0.7	0.11
	b(SWIM)=	15.383			
	ψe (cm)=	7.294			
	BD (g/cm^3)=	1.337			
	θsat=	0.4318			
	n=2+3/b(SWIM)=	2.1950			

20 =Depth (cm)

Model	K_{sat} (m/s)	b_{TSEEP}	r (mm/hr)	r/K_{sat} (%)	Flood Increment (m)	N°. cycles	N°. steps/cycle	Initial Δt (sec)	Factor	Into (steps)	ψ v Θ model	Comments
GEN1	4.167×10^{-6}	0.02	300	20	-0.5	3	100	100	2	100	MRPP1	Flood Recession
GEN12	4.167×10^{-6}	0.02	50	3.333	-0.5	1	100	360	1	100	MRPP1	Flood Recession
GEN13	4.167×10^{-6}	0.02	300	20	-1.0	6	100	60	10	200	MRPP1	Sensitivity of flood increment
GEN14	4.167×10^{-6}	0.02	50	3.333	-1.0	1	200	360	1	200	MRPP1	Sensitivity of flood increment
GEN15	4.167×10^{-6}	0.02	300	20	-2.0	1	400	60	100	400	MRPP1	Sensitivity of flood increment
GEN16	4.167×10^{-6}	0.02	50	3.333	-2.0	1	400	360	1	400	MRPP1	Sensitivity of flood increment
GEN17	4.167×10^{-6}	0.02	300	20	0.5	1	100	60	1	100	MRPP1	Extent of flood inundation
GEN2	4.167×10^{-6}	0.02	100	6.667	-0.5	1	180	100	1	100	MRPP1	Flood Recession
GEN3	4.167×10^{-6}	0.02	5	0.333	-0.5	1	200	1800	1	100	MRPP1	Flood Recession
GEN4	4.167×10^{-6}	0.02	15	1	-0.5	1	100	1200	1	100	MRPP1	Flood Recession
GEN5	1.389×10^{-5}	0.02	50	1	-0.5	1	100	360	1	100	MRPP1	Flood Recession
GEN6	1.389×10^{-5}	0.02	100	2	-0.5	1	100	180	1	100	MRPP1	Flood Recession
GEN7	1.389×10^{-5}	0.02	250	5	-0.5	1	100	72	1	100	MRPP1	Flood Recession
GENA18	4.167×10^{-6}	0.02	300	20	0.5	1	100	60	1	100	MRPP1	Extent of flood inundation, $K_{sat(Aquifer)}$=300 mm/hr
GENA8	4.167×10^{-6}	0.02	300	20	-0.5	1	100	60	1	100	MRPP1	Flood Recession, Drainage Layer: K_{sat}=300
GENA9	4.167×10^{-6}	0.02	50	3.333	-0.5	1	100	360	1	100	MRPP1	Flood Recession, Drainage Layer: K_{sat}=300
GENL10	4.167×10^{-6}	0.02	300	20	-0.5	1	100	60	1	100	MRPP1	Flood Recession Longitudinal drainage
GENL11	4.167×10^{-6}	0.02	50	3.333	-0.5	1	100	360	1	100	MRPP1	Flood Recession Longitudinal drainage
GENL19	4.167×10^{-6}	0.02	300	20	0.5	1	100	60	1	100	MRPP1	Extent of flood inundation Longitudinal drainage
VARB1	4.167×10^{-6}	0.015	Instant.	N/A	-8	5	200	80	4	50	MRPP1	Flood Recession, Sensitivity of b_{TSEEP} / Change
VARB2	4.167×10^{-6}	0.04	Instant.	N/A	-8	5	200	80	4	50	MRPP1	Flood Recession, Sensitivity of b_{TSEEP}
VARB3	4.167×10^{-6}	0.015	Instant.	N/A	-8	5	100	160	4		MRPP1	Flood Recession, Sensitivity of time steps
VARB4	4.167×10^{-6}	0.015	Instant.	N/A	8	5	200	80	4	50	MRPP1	Flood Rise, Sensitivity of b_{TSEEP}
VARB5	4.167×10^{-6}	0.04	Instant.	N/A	8	5	200	80	4	50	MRPP1	Flood Rise, Sensitivity of b_{TSEEP}
VARK1	1.389×10^{-5}	0.015	Instant.	N/A	-8	5	200	80	4	50	MRPP1	Flood Recession, Sensitivity of K_{sat}
VARK2	1.389×10^{-5}	0.04	Instant.	N/A	-8	5	200	80	4	50	MRPP1	Flood Recession, Sensitivity of K_{sat}
VARM2	4.167×10^{-6}	0.015	Instant.	N/A	-8	5	200	80	4	50	MRPP2	Flood Recession, Sensitivity of ψ v Θ
VARM3	4.167×10^{-6}	0.015	Instant.	N/A	8	5	200	80	4	50	MRPP3	Flood Rise, Sensitivity of ψ v Θ
VARM4	4.167×10^{-6}	0.015	Instant.	N/A	8	5	200	80	1	50	MRPP4	Flood Rise, Sensitivity of ψ v Θ
VARM5	4.167×10^{-6}	0.015	Instant.	N/A	-8	5	200	80	4	50	MRPP4	Flood Recession, Sensitivity of ψ v Θ
Notes:	Model Abbreviations: GEN (Generic), A (Aquifer), L (Longitudinal drainage), VAR (Sensitivity anaylsis), Instant. (Instantaneous flood rise or fall)											

Summary of TSEEP validation parameters

Model	K_{sat} (m/s)	b_{TSEEP}	r (mm/hr)	r/K_{sat} (%)	Flood Increment (m)	N°. cycles	N°. steps/cycle	Initial ∂t (sec)	Factor	Into (steps)	Plot (file name)	Comments VARB1 retention data
COLSWR3	4.167×10^{-6}	0.015	Instant.	N/A	1	2	200	600	6	10	TPSCLF.GRF	Flood rise
COLSWR5	4.167×10^{-6}	0.015	Instant.	N/A	3	4	225	120	4	25		Flood rise
COLSWF5	4.167×10^{-6}	0.015	Instant.	N/A	-5	4	225	120	4	25	TPSCLF.GRF	Flood recession
COLSWF8	4.167×10^{-6}	0.015	Instant.	N/A	-2	4	225	120	5	25	TPSCLF.GRF	Flood recession

Summary of SWIM validation parameters

Model	K_{sat} (cm/hr)	b_{SWIM}	n	θ_{sat} (%)	ψ_e (cm)	Flood Increment (cm)	Start Time (hr)	Finish Time (hr)	Water Increment (cm)	Print Interval (hr)	Plot (file name)	Comments
TSPCLR3	1.5	14.380	0.487	0.419	-28.55	100	0	4 & 160	2	0.2 & 1.2	TPSCLF.GRF	Flood rise
TSPCLF5	1.5	14.380	0.487	0.419	-28.55	-500	0	100	2	0.2	TPSCLF.GRF	Flood recession
TSPCLF8	1.5	14.380	0.487	0.419	-28.55	-200	0	192	2	1.2	TPSCLF.GRF	Flood recession

GEN1-Generic Subsurface Drawdown @ 300mm/hr

NODES	NUMEL	NMAT	NFHD	NFLO	KOUT	MAXP	KREST	INTO
998	914	1	36	0	2	11	1	101

KEYNODE
20

UNITW - Unit weight of water
9.810

NODE	X(NODE)	Y(NODE)
1	0.000	0.000
2	0.000	1.000
3	0.000	2.000
4	0.000	2.500
5	0.000	3.000
6	0.000	3.500
7	0.000	4.000
8	0.000	4.500
9	0.000	5.000
10	0.000	5.500
11	0.000	6.000
12	0.000	6.500
13	0.000	7.000
14	0.000	7.500
15	0.000	8.000
16	0.000	8.500
17	0.000	9.000
18	0.000	9.500
19	0.000	10.000
20	2.000	0.000
21	2.000	1.000
22	2.000	2.000
23	2.000	2.500
24	2.000	3.000
25	2.000	3.500
26	2.000	4.000
27	2.000	4.500
28	2.000	5.000
29	2.000	5.500
30	2.000	6.000
31	2.000	6.500
32	2.000	7.000
33	2.000	7.500
34	2.000	8.000
35	2.000	8.500
36	2.000	9.000
37	2.000	9.500
38	2.000	10.000
39	4.000	0.000
40	4.000	1.000
41	4.000	2.000
42	4.000	2.500
43	4.000	3.000
44	4.000	3.500
45	4.000	4.000
46	4.000	4.500
47	4.000	5.000
48	4.000	5.500
49	4.000	6.000
50	4.000	6.500
51	4.000	7.000
52	4.000	7.500
53	4.000	8.000
54	4.000	8.500
55	4.000	9.000
56	4.000	9.500
57	4.000	10.000
58	5.000	0.000
59	5.000	1.000
60	5.000	2.000
61	5.000	2.500
62	5.000	3.000
63	5.000	3.500
64	5.000	4.000
65	5.000	4.500
66	5.000	5.000
67	5.000	5.500
68	5.000	6.000
69	5.000	6.500
70	5.000	7.000

71	5.000	7.500
72	5.000	8.000
73	5.000	8.500
74	5.000	9.000
75	5.000	9.500
76	5.000	10.000
77	6.000	0.000
78	6.000	1.000
79	6.000	2.000
80	6.000	2.500
81	6.000	3.000
82	6.000	3.500
83	6.000	4.000
84	6.000	4.500
85	6.000	5.000
86	6.000	5.500
87	6.000	6.000
88	6.000	6.500
89	6.000	7.000
90	6.000	7.500
91	6.000	8.000
92	6.000	8.500
93	6.000	9.000
94	6.000	9.500
95	6.000	10.000
96	7.000	0.000
97	7.000	1.000
98	7.000	2.000
99	7.000	2.500
100	7.000	3.000
101	7.000	3.500
102	7.000	4.000
103	7.000	4.500
104	7.000	5.000
105	7.000	5.500
106	7.000	6.000
107	7.000	6.500
108	7.000	7.000
109	7.000	7.500
110	7.000	8.000
111	7.000	8.500
112	7.000	9.000
113	7.000	9.500
114	7.000	10.000
115	8.000	0.000
116	8.000	1.000
117	8.000	2.000
118	8.000	2.500
119	8.000	3.000
120	8.000	3.500
121	8.000	4.000
122	8.000	4.500
123	8.000	5.000
124	8.000	5.500
125	8.000	6.000
126	8.000	6.500
127	8.000	7.000
128	8.000	7.500
129	8.000	8.000
130	8.000	8.500
131	8.000	9.000
132	8.000	9.500
133	8.000	10.000
134	9.000	0.000
135	9.000	1.000
136	9.000	2.000
137	9.000	2.500
138	9.000	3.000
139	9.000	3.500
140	9.000	4.000
141	9.000	4.500
142	9.000	5.000
143	9.000	5.500
144	9.000	6.000
145	9.000	6.500
146	9.000	7.000
147	9.000	7.500
148	9.000	8.000
149	9.000	8.500
150	9.000	9.000
151	9.000	9.500
152	9.000	10.000

153	10.000	0.000
154	10.000	1.000
155	10.000	2.000
156	10.000	2.500
157	10.000	3.000
158	10.000	3.500
159	10.000	4.000
160	10.000	4.500
161	10.000	5.000
162	10.000	5.500
163	10.000	6.000
164	10.000	6.500
165	10.000	7.000
166	10.000	7.500
167	10.000	8.000
168	10.000	8.500
169	10.000	9.000
170	10.000	9.500
171	10.000	10.000
172	11.000	0.000
173	11.000	1.000
174	11.000	2.000
175	11.000	2.500
176	11.000	3.000
177	11.000	3.500
178	11.000	4.000
179	11.000	4.500
180	11.000	5.000
181	11.000	5.500
182	11.000	6.000
183	11.000	6.500
184	11.000	7.000
185	11.000	7.500
186	11.000	8.000
187	11.000	8.500
188	11.000	9.000
189	11.000	9.500
190	11.000	10.000
191	11.250	0.000
192	11.250	1.000
193	11.250	2.000
194	11.250	2.500
195	11.250	3.000
196	11.250	3.500
197	11.250	4.000
198	11.250	4.500
199	11.250	5.000
200	11.250	5.500
201	11.250	6.000
202	11.250	6.500
203	11.250	7.000
204	11.250	7.500
205	11.250	8.000
206	11.250	8.500
207	11.250	9.000
208	11.250	9.500
209	11.250	10.000
210	11.500	0.000
211	11.500	1.000
212	11.500	2.000
213	11.500	2.500
214	11.500	3.000
215	11.500	3.500
216	11.500	4.000
217	11.500	4.500
218	11.500	5.000
219	11.500	5.500
220	11.500	6.000
221	11.500	6.500
222	11.500	7.000
223	11.500	7.500
224	11.500	8.000
225	11.500	8.500
226	11.500	9.000
227	11.500	9.500
228	11.500	10.000
229	11.750	0.000
230	11.750	1.000
231	11.750	2.000
232	11.750	2.500
233	11.750	3.000
234	11.750	3.500

235	11.750	4.000
236	11.750	4.500
237	11.750	5.000
238	11.750	5.500
239	11.750	6.000
240	11.750	6.500
241	11.750	7.000
242	11.750	7.500
243	11.750	8.000
244	11.750	8.500
245	11.750	9.000
246	11.750	9.500
247	11.750	10.000
248	12.000	0.000
249	12.000	1.000
250	12.000	2.000
251	12.000	2.500
252	12.000	3.000
253	12.000	3.500
254	12.000	4.000
255	12.000	4.500
256	12.000	5.000
257	12.000	5.500
258	12.000	6.000
259	12.000	6.500
260	12.000	7.000
261	12.000	7.500
262	12.000	8.000
263	12.000	8.500
264	12.000	9.000
265	12.000	9.500
266	12.000	10.000
267	12.250	0.000
268	12.250	1.000
269	12.250	2.000
270	12.250	2.500
271	12.250	3.000
272	12.250	3.500
273	12.250	4.000
274	12.250	4.500
275	12.250	5.000
276	12.250	5.500
277	12.250	6.000
278	12.250	6.500
279	12.250	7.000
280	12.250	7.500
281	12.250	8.000
282	12.250	8.500
283	12.250	9.000
284	12.250	9.500
285	12.250	9.875
286	12.500	0.000
287	12.500	1.000
288	12.500	2.000
289	12.500	2.500
290	12.500	3.000
291	12.500	3.500
292	12.500	4.000
293	12.500	4.500
294	12.500	5.000
295	12.500	5.500
296	12.500	6.000
297	12.500	6.500
298	12.500	7.000
299	12.500	7.500
300	12.500	8.000
301	12.500	8.500
302	12.500	9.000
303	12.500	9.500
304	12.500	9.750
305	12.750	0.000
306	12.750	1.000
307	12.750	2.000
308	12.750	2.500
309	12.750	3.000
310	12.750	3.500
311	12.750	4.000
312	12.750	4.500
313	12.750	5.000
314	12.750	5.500
315	12.750	6.000
316	12.750	6.500

317	12.750	7.000
318	12.750	7.500
319	12.750	8.000
320	12.750	8.500
321	12.750	9.000
322	12.750	9.500
323	12.750	9.625
324	13.000	0.000
325	13.000	1.000
326	13.000	2.000
327	13.000	2.500
328	13.000	3.000
329	13.000	3.500
330	13.000	4.000
331	13.000	4.500
332	13.000	5.000
333	13.000	5.500
334	13.000	6.000
335	13.000	6.500
336	13.000	7.000
337	13.000	7.500
338	13.000	8.000
339	13.000	8.500
340	13.000	9.000
341	13.000	9.500
342	13.250	0.000
343	13.250	1.000
344	13.250	2.000
345	13.250	2.500
346	13.250	3.000
347	13.250	3.500
348	13.250	4.000
349	13.250	4.500
350	13.250	5.000
351	13.250	5.500
352	13.250	6.000
353	13.250	6.500
354	13.250	7.000
355	13.250	7.500
356	13.250	8.000
357	13.250	8.500
358	13.250	9.000
359	13.250	9.375
360	13.500	0.000
361	13.500	1.000
362	13.500	2.000
363	13.500	2.500
364	13.500	3.000
365	13.500	3.500
366	13.500	4.000
367	13.500	4.500
368	13.500	5.000
369	13.500	5.500
370	13.500	6.000
371	13.500	6.500
372	13.500	7.000
373	13.500	7.500
374	13.500	8.000
375	13.500	8.500
376	13.500	9.000
377	13.500	9.250
378	13.750	0.000
379	13.750	1.000
380	13.750	2.000
381	13.750	2.500
382	13.750	3.000
383	13.750	3.500
384	13.750	4.000
385	13.750	4.500
386	13.750	5.000
387	13.750	5.500
388	13.750	6.000
389	13.750	6.500
390	13.750	7.000
391	13.750	7.500
392	13.750	8.000
393	13.750	8.500
394	13.750	9.000
395	13.750	9.125
396	14.000	0.000
397	14.000	1.000
398	14.000	2.000

399	14.000	2.500
400	14.000	3.000
401	14.000	3.500
402	14.000	4.000
403	14.000	4.500
404	14.000	5.000
405	14.000	5.500
406	14.000	6.000
407	14.000	6.500
408	14.000	7.000
409	14.000	7.500
410	14.000	8.000
411	14.000	8.500
412	14.000	9.000
413	14.250	0.000
414	14.250	1.000
415	14.250	2.000
416	14.250	2.500
417	14.250	3.000
418	14.250	3.500
419	14.250	4.000
420	14.250	4.500
421	14.250	5.000
422	14.250	5.500
423	14.250	6.000
424	14.250	6.500
425	14.250	7.000
426	14.250	7.500
427	14.250	8.000
428	14.250	8.500
429	14.250	8.875
430	14.500	0.000
431	14.500	1.000
432	14.500	2.000
433	14.500	2.500
434	14.500	3.000
435	14.500	3.500
436	14.500	4.000
437	14.500	4.500
438	14.500	5.000
439	14.500	5.500
440	14.500	6.000
441	14.500	6.500
442	14.500	7.000
443	14.500	7.500
444	14.500	8.000
445	14.500	8.500
446	14.500	8.750
447	14.750	0.000
448	14.750	1.000
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463	14.750	8.625
464	15.000	0.000
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613	17.250	6.500
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666	18.250	5.500
667	18.250	6.000
668	18.250	6.500
669	18.250	6.875
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693	18.750	6.000
694	18.750	6.500
695	18.750	6.625
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714	19.250	4.000
715	19.250	4.500
716	19.250	5.000
717	19.250	5.500
718	19.250	6.000
719	19.250	6.375
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722	19.500	2.000
723	19.500	2.500
724	19.500	3.000
725	19.500	3.500
726	19.500	4.000

727	19.500	4.500
728	19.500	5.000
729	19.500	5.500
730	19.500	6.000
731	19.500	6.250
732	19.750	0.000
733	19.750	1.000
734	19.750	2.000
735	19.750	2.500
736	19.750	3.000
737	19.750	3.500
738	19.750	4.000
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740	19.750	5.000
741	19.750	5.500
742	19.750	6.000
743	19.750	6.125
744	20.000	0.000
745	20.000	1.000
746	20.000	2.000
747	20.000	2.500
748	20.000	3.000
749	20.000	3.500
750	20.000	4.000
751	20.000	4.500
752	20.000	5.000
753	20.000	5.500
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757	20.250	2.000
758	20.250	2.500
759	20.250	3.000
760	20.250	3.500
761	20.250	4.000
762	20.250	4.500
763	20.250	5.000
764	20.250	5.500
765	20.250	5.875
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767	20.500	1.000
768	20.500	2.000
769	20.500	2.500
770	20.500	3.000
771	20.500	3.500
772	20.500	4.000
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774	20.500	5.000
775	20.500	5.500
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777	20.750	0.000
778	20.750	1.000
779	20.750	2.000
780	20.750	2.500
781	20.750	3.000
782	20.750	3.500
783	20.750	4.000
784	20.750	4.500
785	20.750	5.000
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787	20.750	5.625
788	21.000	0.000
789	21.000	1.000
790	21.000	2.000
791	21.000	2.500
792	21.000	3.000
793	21.000	3.500
794	21.000	4.000
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801	21.250	2.500
802	21.250	3.000
803	21.250	3.500
804	21.250	4.000
805	21.250	4.500
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807	21.250	5.375
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810	21.500	2.000
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812	21.500	3.000
813	21.500	3.500
814	21.500	4.000
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818	21.750	0.000
819	21.750	1.000
820	21.750	2.000
821	21.750	2.500
822	21.750	3.000
823	21.750	3.500
824	21.750	4.000
825	21.750	4.500
826	21.750	5.000
827	21.750	5.125
828	22.000	0.000
829	22.000	1.000
830	22.000	2.000
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832	22.000	3.000
833	22.000	3.500
834	22.000	4.000
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836	22.000	5.000
837	22.250	0.000
838	22.250	1.000
839	22.250	2.000
840	22.250	2.500
841	22.250	3.000
842	22.250	3.500
843	22.250	4.000
844	22.250	4.500
845	22.250	4.875
846	22.500	0.000
847	22.500	1.000
848	22.500	2.000
849	22.500	2.500
850	22.500	3.000
851	22.500	3.500
852	22.500	4.000
853	22.500	4.500
854	22.500	4.750
855	22.750	0.000
856	22.750	1.000
857	22.750	2.000
858	22.750	2.500
859	22.750	3.000
860	22.750	3.500
861	22.750	4.000
862	22.750	4.500
863	22.750	4.625
864	23.000	0.000
865	23.000	1.000
866	23.000	2.000
867	23.000	2.500
868	23.000	3.000
869	23.000	3.500
870	23.000	4.000
871	23.000	4.500
872	23.250	0.000
873	23.250	1.000
874	23.250	2.000
875	23.250	2.500
876	23.250	3.000
877	23.250	3.500
878	23.250	4.000
879	23.250	4.375
880	23.500	0.000
881	23.500	1.000
882	23.500	2.000
883	23.500	2.500
884	23.500	3.000
885	23.500	3.500
886	23.500	4.000
887	23.500	4.250
888	23.750	0.000
889	23.750	1.000
890	23.750	2.000

891	23.750	2.500
892	23.750	3.000
893	23.750	3.500
894	23.750	4.000
895	23.750	4.125
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898	24.000	2.000
899	24.000	2.500
900	24.000	3.000
901	24.000	3.500
902	24.000	4.000
903	24.250	0.000
904	24.250	1.000
905	24.250	2.000
906	24.250	2.500
907	24.250	3.000
908	24.250	3.500
909	24.250	3.875
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911	24.500	1.000
912	24.500	2.000
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914	24.500	3.000
915	24.500	3.500
916	24.500	3.750
917	24.750	0.000
918	24.750	1.000
919	24.750	2.000
920	24.750	2.500
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922	24.750	3.500
923	24.750	3.625
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925	25.000	1.000
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930	25.250	0.000
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932	25.250	2.000
933	25.250	2.500
934	25.250	3.000
935	25.250	3.375
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937	25.500	1.000
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940	25.500	3.000
941	25.500	3.250
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945	25.750	2.500
946	25.750	3.000
947	25.750	3.125
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949	26.000	1.000
950	26.000	2.000
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952	26.000	3.000
953	26.250	0.000
954	26.250	1.000
955	26.250	2.000
956	26.250	2.500
957	26.250	2.875
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959	26.500	1.000
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962	26.500	2.750
963	26.750	0.000
964	26.750	1.000
965	26.750	2.000
966	26.750	2.500
967	26.750	2.625
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969	27.000	1.000
970	27.000	2.000
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972	27.250	0.000

973	27.250	1.000
974	27.250	2.000
975	27.250	2.375
976	27.500	0.000
977	27.500	1.000
978	27.500	2.000
979	27.500	2.250
980	27.750	0.000
981	27.750	1.000
982	27.750	2.000
983	27.750	2.125
984	28.000	0.000
985	28.000	1.000
986	28.000	2.000
987	28.250	0.000
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989	28.250	2.000
990	28.500	0.000
991	28.500	1.000
992	28.500	2.000
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995	28.750	2.000
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998	29.000	2.000

ELEM	MAT	N1	N2	N3	N4
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6	1	6	25	26	7
7	1	7	26	27	8
8	1	8	27	28	9
9	1	9	28	29	10
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11	1	11	30	31	12
12	1	12	31	32	13
13	1	13	32	33	14
14	1	14	33	34	15
15	1	15	34	35	16
16	1	16	35	36	17
17	1	17	36	37	18
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26	1	27	46	47	28
27	1	28	47	48	29
28	1	29	48	49	30
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46	1	48	67	68	49
47	1	49	68	69	50
48	1	50	69	70	51
49	1	51	70	71	52
50	1	52	71	72	53
51	1	53	72	73	54
52	1	54	73	74	55
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54	1	56	75	76	57

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71    1    74    93    94    75
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77    1    81    100   101   82
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92    1    97    116   117   98
93    1    98    117   118   99
94    1    99    118   119   100
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96    1    101   120   121   102
97    1    102   121   122   103
98    1    103   122   123   104
99    1    104   123   124   105
100   1    105   124   125   106
101   1    106   125   126   107
102   1    107   126   127   108
103   1    108   127   128   109
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106   1    111   130   131   112
107   1    112   131   132   113
108   1    113   132   133   114
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110   1    116   135   136   117
111   1    117   136   137   118
112   1    118   137   138   119
113   1    119   138   139   120
114   1    120   139   140   121
115   1    121   140   141   122
116   1    122   141   142   123
117   1    123   142   143   124
118   1    124   143   144   125
119   1    125   144   145   126
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122   1    128   147   148   129
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124   1    130   149   150   131
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126   1    132   151   152   133
127   1    134   153   154   135
128   1    135   154   155   136
129   1    136   155   156   137
130   1    137   156   157   138
131   1    138   157   158   139
132   1    139   158   159   140
133   1    140   159   160   141
134   1    141   160   161   142
135   1    142   161   162   143
136   1    143   162   163   144
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142  1  149  168  169  150
143  1  150  169  170  151
144  1  151  170  171  152
145  1  153  172  173  154
146  1  154  173  174  155
147  1  155  174  175  156
148  1  156  175  176  157
149  1  157  176  177  158
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761  1  812  822  823  813
762  1  813  823  824  814
763  1  814  824  825  815
764  1  815  825  826  816
765  1  816  826  827  817
766  1  828  829  819  818
767  1  829  830  820  819
768  1  830  831  821  820
769  1  831  832  822  821
770  1  832  833  823  822
771  1  833  834  824  823
772  1  834  835  825  824
773  1  835  836  826  825
774  1  836  827  826   0
775  1  828  837  838  829
776  1  829  838  839  830
777  1  830  839  840  831
778  1  831  840  841  832
779  1  832  841  842  833
780  1  833  842  843  834
781  1  834  843  844  835
782  1  835  844  845  836
783  1  837  846  847  838
784  1  838  847  848  839
785  1  839  848  849  840
786  1  840  849  850  841
787  1  841  850  851  842
788  1  842  851  852  843
789  1  843  852  853  844
790  1  844  853  854  845
791  1  846  855  856  847
792  1  847  856  857  848
```

```
793  1  848  857  858  849
794  1  849  858  859  850
795  1  850  859  860  851
796  1  851  860  861  852
797  1  852  861  862  853
798  1  853  862  863  854
799  1  864  865  856  855
800  1  865  866  857  856
801  1  866  867  858  857
802  1  867  868  859  858
803  1  868  869  860  859
804  1  869  870  861  860
805  1  870  871  862  861
806  1  871  863  862   0
807  1  864  872  873  865
808  1  865  873  874  866
809  1  866  874  875  867
810  1  867  875  876  868
811  1  868  876  877  869
812  1  869  877  878  870
813  1  870  878  879  871
814  1  872  880  881  873
815  1  873  881  882  874
816  1  874  882  883  875
817  1  875  883  884  876
818  1  876  884  885  877
819  1  877  885  886  878
820  1  878  886  887  879
821  1  880  888  889  881
822  1  881  889  890  882
823  1  882  890  891  883
824  1  883  891  892  884
825  1  884  892  893  885
826  1  885  893  894  886
827  1  886  894  895  887
828  1  896  897  889  888
829  1  897  898  890  889
830  1  898  899  891  890
831  1  899  900  892  891
832  1  900  901  893  892
833  1  901  902  894  893
834  1  902  895  894   0
835  1  896  903  904  897
836  1  897  904  905  898
837  1  898  905  906  899
838  1  899  906  907  900
839  1  900  907  908  901
840  1  901  908  909  902
841  1  903  910  911  904
842  1  904  911  912  905
843  1  905  912  913  906
844  1  906  913  914  907
845  1  907  914  915  908
846  1  908  915  916  909
847  1  910  917  918  911
848  1  911  918  919  912
849  1  912  919  920  913
850  1  913  920  921  914
851  1  914  921  922  915
852  1  915  922  923  916
853  1  924  925  918  917
854  1  925  926  919  918
855  1  926  927  920  919
856  1  927  928  921  920
857  1  928  929  922  921
858  1  929  923  922   0
859  1  924  930  931  925
860  1  925  931  932  926
861  1  926  932  933  927
862  1  927  933  934  928
863  1  928  934  935  929
864  1  930  936  937  931
865  1  931  937  938  932
866  1  932  938  939  933
867  1  933  939  940  934
868  1  934  940  941  935
869  1  936  942  943  937
870  1  937  943  944  938
871  1  938  944  945  939
872  1  939  945  946  940
873  1  940  946  947  941
874  1  948  949  943  942
```

```
875   1  949  950  944  943
876   1  950  951  945  944
877   1  951  952  946  945
878   1  952  947  946    0
879   1  948  953  954  949
880   1  949  954  955  950
881   1  950  955  956  951
882   1  951  956  957  952
883   1  953  958  959  954
884   1  954  959  960  955
885   1  955  960  961  956
886   1  956  961  962  957
887   1  958  963  964  959
888   1  959  964  965  960
889   1  960  965  966  961
890   1  961  966  967  962
891   1  968  969  964  963
892   1  969  970  965  964
893   1  970  971  966  965
894   1  971  967  966    0
895   1  968  972  973  969
896   1  969  973  974  970
897   1  970  974  975  971
898   1  972  976  977  973
899   1  973  977  978  974
900   1  974  978  979  975
901   1  976  980  981  977
902   1  977  981  982  978
903   1  978  982  983  979
904   1  984  985  981  980
905   1  985  986  982  981
906   1  986  983  982    0
907   1  984  987  988  985
908   1  985  988  989  986
909   1  987  990  991  988
910   1  988  991  992  989
911   1  990  993  994  991
912   1  991  994  995  992
913   1  993  996  997  994
914   1  994  997  998  995
```

(NFHD) NODES WITH FIXED HEAD

```
787    5.625
797    5.500
807    5.375
817    5.250
827    5.125
836    5.000
845    4.875
854    4.750
863    4.625
871    4.500
879    4.375
887    4.250
895    4.125
902    4.000
909    3.875
916    3.750
923    3.625
929    3.500
935    3.375
941    3.250
947    3.125
952    3.000
957    2.875
962    2.750
967    2.625
971    2.500
975    2.375
979    2.250
983    2.125
986    2.000
989    2.000
992    2.000
995    2.000
998    2.000
997    2.000
996    2.000
```

[NADD] - No. nodes that can be added to boundary conditions

```
  0
```

[NADD : NODES] - Nodes that can be added (10 per line)

[NDEL] - No. nodes that can be deleted from boundary conditions
  28

[NDEL : NODES] - Nodes that can be deleted (10 per line)
 787 797 807 817 836 845 854 863 871 879
 887 895 902 909 916 923 929 935 941 947
 952 957 962 967 971 975 979 983

[WLEVEL] - Water Level - i.e. initial pore pressures
  10.000

[KZERO] - Initial p.p. above W.T. (=0) Zero (=-1) Negative
  -1

[DATUM] - Datum level for calculating Total Head
  0.000

[TIME] No.Cycles, No. steps per Cycle, Initial d(t), Factor
  3 100 100.000   2.000

[PROPS] Mat k(x)   k(y)   k(1)   b   k(2)/k(1) alpha
  1 4.167E-06 4.167E-06 4.167E-06 0.020000   1.000   0.000

[RETAINED MOISTURE vs P.P.] Mat, NPRM (No. points on functions)
  1   11

[PORE PRESSURES] - Mat No., then NPRM values (5 per line)
  1
 -1471.500 -294.300 -98.100 -29.430   -9.810
   -4.905   -2.934   -0.981   0.000   10.000
  1000.000

[SLOPES] Mat No., then (NPRM + 1) points
  1
  0.0001   0.0001   0.0002   0.0004   0.0020
  0.0025   0.0046   0.0041   0.0001   0.0001
  0.0001   0.0001

```
**********************************************************
*                PROGRAM   TSEEP                 *
*                                                 *
* Finite Element Analysis of Transient Seepage    *
*     Through Saturated-Unsaturated Soil          *
**********************************************************
```

Data File : gen1.dat
Output File : gen1.ou9
First Plotting File : gen1.600

****
* TITLE *
****

GEN1-Generic Subsurface Drawdown @ 300mm/hr

****
* UNIT WEIGHT OF WATER *
****

Unit weight of water =   9.810

****
* MESH DETAILS *
****

 NUMBER OF NODES = 998

NODE	X-COORD	Y-COORD	NODE	X-COORD	Y-COORD
1	0.000	0.000	2	0.000	1.000
3	0.000	2.000	4	0.000	2.500
5	0.000	3.000	6	0.000	3.500
7	0.000	4.000	8	0.000	4.500
9	0.000	5.000	10	0.000	5.500
11	0.000	6.000	12	0.000	6.500
13	0.000	7.000	14	0.000	7.500
15	0.000	8.000	16	0.000	8.500
17	0.000	9.000	18	0.000	9.500
19	0.000	10.000	20	2.000	0.000
21	2.000	1.000	22	2.000	2.000
23	2.000	2.500	24	2.000	3.000
25	2.000	3.500	26	2.000	4.000
27	2.000	4.500	28	2.000	5.000
29	2.000	5.500	30	2.000	6.000
31	2.000	6.500	32	2.000	7.000
33	2.000	7.500	34	2.000	8.000
35	2.000	8.500	36	2.000	9.000
37	2.000	9.500	38	2.000	10.000
39	4.000	0.000	40	4.000	1.000
41	4.000	2.000	42	4.000	2.500
43	4.000	3.000	44	4.000	3.500
45	4.000	4.000	46	4.000	4.500
47	4.000	5.000	48	4.000	5.500
49	4.000	6.000	50	4.000	6.500
51	4.000	7.000	52	4.000	7.500
53	4.000	8.000	54	4.000	8.500
55	4.000	9.000	56	4.000	9.500
57	4.000	10.000	58	5.000	0.000
59	5.000	1.000	60	5.000	2.000
61	5.000	2.500	62	5.000	3.000
63	5.000	3.500	64	5.000	4.000
65	5.000	4.500	66	5.000	5.000
67	5.000	5.500	68	5.000	6.000
69	5.000	6.500	70	5.000	7.000
71	5.000	7.500	72	5.000	8.000
73	5.000	8.500	74	5.000	9.000
75	5.000	9.500	76	5.000	10.000
77	6.000	0.000	78	6.000	1.000
79	6.000	2.000	80	6.000	2.500
81	6.000	3.000	82	6.000	3.500
83	6.000	4.000	84	6.000	4.500
85	6.000	5.000	86	6.000	5.500
87	6.000	6.000	88	6.000	6.500
89	6.000	7.000	90	6.000	7.500
91	6.000	8.000	92	6.000	8.500
93	6.000	9.000	94	6.000	9.500

```

| | | | | | |
|---|---|---|---|---|---|
| 95 | 6.000 | 10.000 | 96 | 7.000 | 0.000 |
| 97 | 7.000 | 1.000 | 98 | 7.000 | 2.000 |
| 99 | 7.000 | 2.500 | 100 | 7.000 | 3.000 |
| 101 | 7.000 | 3.500 | 102 | 7.000 | 4.000 |
| 103 | 7.000 | 4.500 | 104 | 7.000 | 5.000 |
| 105 | 7.000 | 5.500 | 106 | 7.000 | 6.000 |
| 107 | 7.000 | 6.500 | 108 | 7.000 | 7.000 |
| 109 | 7.000 | 7.500 | 110 | 7.000 | 8.000 |
| 111 | 7.000 | 8.500 | 112 | 7.000 | 9.000 |
| 113 | 7.000 | 9.500 | 114 | 7.000 | 10.000 |
| 115 | 8.000 | 0.000 | 116 | 8.000 | 1.000 |
| 117 | 8.000 | 2.000 | 118 | 8.000 | 2.500 |
| 119 | 8.000 | 3.000 | 120 | 8.000 | 3.500 |
| 121 | 8.000 | 4.000 | 122 | 8.000 | 4.500 |
| 123 | 8.000 | 5.000 | 124 | 8.000 | 5.500 |
| 125 | 8.000 | 6.000 | 126 | 8.000 | 6.500 |
| 127 | 8.000 | 7.000 | 128 | 8.000 | 7.500 |
| 129 | 8.000 | 8.000 | 130 | 8.000 | 8.500 |
| 131 | 8.000 | 9.000 | 132 | 8.000 | 9.500 |
| 133 | 8.000 | 10.000 | 134 | 9.000 | 0.000 |
| 135 | 9.000 | 1.000 | 136 | 9.000 | 2.000 |
| 137 | 9.000 | 2.500 | 138 | 9.000 | 3.000 |
| 139 | 9.000 | 3.500 | 140 | 9.000 | 4.000 |
| 141 | 9.000 | 4.500 | 142 | 9.000 | 5.000 |
| 143 | 9.000 | 5.500 | 144 | 9.000 | 6.000 |
| 145 | 9.000 | 6.500 | 146 | 9.000 | 7.000 |
| 147 | 9.000 | 7.500 | 148 | 9.000 | 8.000 |
| 149 | 9.000 | 8.500 | 150 | 9.000 | 9.000 |
| 151 | 9.000 | 9.500 | 152 | 9.000 | 10.000 |
| 153 | 10.000 | 0.000 | 154 | 10.000 | 1.000 |
| 155 | 10.000 | 2.000 | 156 | 10.000 | 2.500 |
| 157 | 10.000 | 3.000 | 158 | 10.000 | 3.500 |
| 159 | 10.000 | 4.000 | 160 | 10.000 | 4.500 |
| 161 | 10.000 | 5.000 | 162 | 10.000 | 5.500 |
| 163 | 10.000 | 6.000 | 164 | 10.000 | 6.500 |
| 165 | 10.000 | 7.000 | 166 | 10.000 | 7.500 |
| 167 | 10.000 | 8.000 | 168 | 10.000 | 8.500 |
| 169 | 10.000 | 9.000 | 170 | 10.000 | 9.500 |
| 171 | 10.000 | 10.000 | 172 | 11.000 | 0.000 |
| 173 | 11.000 | 1.000 | 174 | 11.000 | 2.000 |
| 175 | 11.000 | 2.500 | 176 | 11.000 | 3.000 |
| 177 | 11.000 | 3.500 | 178 | 11.000 | 4.000 |
| 179 | 11.000 | 4.500 | 180 | 11.000 | 5.000 |
| 181 | 11.000 | 5.500 | 182 | 11.000 | 6.000 |
| 183 | 11.000 | 6.500 | 184 | 11.000 | 7.000 |
| 185 | 11.000 | 7.500 | 186 | 11.000 | 8.000 |
| 187 | 11.000 | 8.500 | 188 | 11.000 | 9.000 |
| 189 | 11.000 | 9.500 | 190 | 11.000 | 10.000 |
| 191 | 11.250 | 0.000 | 192 | 11.250 | 1.000 |
| 193 | 11.250 | 2.000 | 194 | 11.250 | 2.500 |
| 195 | 11.250 | 3.000 | 196 | 11.250 | 3.500 |
| 197 | 11.250 | 4.000 | 198 | 11.250 | 4.500 |
| 199 | 11.250 | 5.000 | 200 | 11.250 | 5.500 |
| 201 | 11.250 | 6.000 | 202 | 11.250 | 6.500 |
| 203 | 11.250 | 7.000 | 204 | 11.250 | 7.500 |
| 205 | 11.250 | 8.000 | 206 | 11.250 | 8.500 |
| 207 | 11.250 | 9.000 | 208 | 11.250 | 9.500 |
| 209 | 11.250 | 10.000 | 210 | 11.500 | 0.000 |
| 211 | 11.500 | 1.000 | 212 | 11.500 | 2.000 |
| 213 | 11.500 | 2.500 | 214 | 11.500 | 3.000 |
| 215 | 11.500 | 3.500 | 216 | 11.500 | 4.000 |
| 217 | 11.500 | 4.500 | 218 | 11.500 | 5.000 |
| 219 | 11.500 | 5.500 | 220 | 11.500 | 6.000 |
| 221 | 11.500 | 6.500 | 222 | 11.500 | 7.000 |
| 223 | 11.500 | 7.500 | 224 | 11.500 | 8.000 |
| 225 | 11.500 | 8.500 | 226 | 11.500 | 9.000 |
| 227 | 11.500 | 9.500 | 228 | 11.500 | 10.000 |
| 229 | 11.750 | 0.000 | 230 | 11.750 | 1.000 |
| 231 | 11.750 | 2.000 | 232 | 11.750 | 2.500 |
| 233 | 11.750 | 3.000 | 234 | 11.750 | 3.500 |
| 235 | 11.750 | 4.000 | 236 | 11.750 | 4.500 |
| 237 | 11.750 | 5.000 | 238 | 11.750 | 5.500 |
| 239 | 11.750 | 6.000 | 240 | 11.750 | 6.500 |
| 241 | 11.750 | 7.000 | 242 | 11.750 | 7.500 |
| 243 | 11.750 | 8.000 | 244 | 11.750 | 8.500 |
| 245 | 11.750 | 9.000 | 246 | 11.750 | 9.500 |
| 247 | 11.750 | 10.000 | 248 | 12.000 | 0.000 |
| 249 | 12.000 | 1.000 | 250 | 12.000 | 2.000 |
| 251 | 12.000 | 2.500 | 252 | 12.000 | 3.000 |
| 253 | 12.000 | 3.500 | 254 | 12.000 | 4.000 |
| 255 | 12.000 | 4.500 | 256 | 12.000 | 5.000 |
| 257 | 12.000 | 5.500 | 258 | 12.000 | 6.000 |

| 259 | 12.000 | 6.500 | 260 | 12.000 | 7.000 |
|---|---|---|---|---|---|
| 261 | 12.000 | 7.500 | 262 | 12.000 | 8.000 |
| 263 | 12.000 | 8.500 | 264 | 12.000 | 9.000 |
| 265 | 12.000 | 9.500 | 266 | 12.000 | 10.000 |
| 267 | 12.250 | 0.000 | 268 | 12.250 | 1.000 |
| 269 | 12.250 | 2.000 | 270 | 12.250 | 2.500 |
| 271 | 12.250 | 3.000 | 272 | 12.250 | 3.500 |
| 273 | 12.250 | 4.000 | 274 | 12.250 | 4.500 |
| 275 | 12.250 | 5.000 | 276 | 12.250 | 5.500 |
| 277 | 12.250 | 6.000 | 278 | 12.250 | 6.500 |
| 279 | 12.250 | 7.000 | 280 | 12.250 | 7.500 |
| 281 | 12.250 | 8.000 | 282 | 12.250 | 8.500 |
| 283 | 12.250 | 9.000 | 284 | 12.250 | 9.500 |
| 285 | 12.250 | 9.875 | 286 | 12.500 | 0.000 |
| 287 | 12.500 | 1.000 | 288 | 12.500 | 2.000 |
| 289 | 12.500 | 2.500 | 290 | 12.500 | 3.000 |
| 291 | 12.500 | 3.500 | 292 | 12.500 | 4.000 |
| 293 | 12.500 | 4.500 | 294 | 12.500 | 5.000 |
| 295 | 12.500 | 5.500 | 296 | 12.500 | 6.000 |
| 297 | 12.500 | 6.500 | 298 | 12.500 | 7.000 |
| 299 | 12.500 | 7.500 | 300 | 12.500 | 8.000 |
| 301 | 12.500 | 8.500 | 302 | 12.500 | 9.000 |
| 303 | 12.500 | 9.500 | 304 | 12.500 | 9.750 |
| 305 | 12.750 | 0.000 | 306 | 12.750 | 1.000 |
| 307 | 12.750 | 2.000 | 308 | 12.750 | 2.500 |
| 309 | 12.750 | 3.000 | 310 | 12.750 | 3.500 |
| 311 | 12.750 | 4.000 | 312 | 12.750 | 4.500 |
| 313 | 12.750 | 5.000 | 314 | 12.750 | 5.500 |
| 315 | 12.750 | 6.000 | 316 | 12.750 | 6.500 |
| 317 | 12.750 | 7.000 | 318 | 12.750 | 7.500 |
| 319 | 12.750 | 8.000 | 320 | 12.750 | 8.500 |
| 321 | 12.750 | 9.000 | 322 | 12.750 | 9.500 |
| 323 | 12.750 | 9.625 | 324 | 13.000 | 0.000 |
| 325 | 13.000 | 1.000 | 326 | 13.000 | 2.000 |
| 327 | 13.000 | 2.500 | 328 | 13.000 | 3.000 |
| 329 | 13.000 | 3.500 | 330 | 13.000 | 4.000 |
| 331 | 13.000 | 4.500 | 332 | 13.000 | 5.000 |
| 333 | 13.000 | 5.500 | 334 | 13.000 | 6.000 |
| 335 | 13.000 | 6.500 | 336 | 13.000 | 7.000 |
| 337 | 13.000 | 7.500 | 338 | 13.000 | 8.000 |
| 339 | 13.000 | 8.500 | 340 | 13.000 | 9.000 |
| 341 | 13.000 | 9.500 | 342 | 13.250 | 0.000 |
| 343 | 13.250 | 1.000 | 344 | 13.250 | 2.000 |
| 345 | 13.250 | 2.500 | 346 | 13.250 | 3.000 |
| 347 | 13.250 | 3.500 | 348 | 13.250 | 4.000 |
| 349 | 13.250 | 4.500 | 350 | 13.250 | 5.000 |
| 351 | 13.250 | 5.500 | 352 | 13.250 | 6.000 |
| 353 | 13.250 | 6.500 | 354 | 13.250 | 7.000 |
| 355 | 13.250 | 7.500 | 356 | 13.250 | 8.000 |
| 357 | 13.250 | 8.500 | 358 | 13.250 | 9.000 |
| 359 | 13.250 | 9.375 | 360 | 13.500 | 0.000 |
| 361 | 13.500 | 1.000 | 362 | 13.500 | 2.000 |
| 363 | 13.500 | 2.500 | 364 | 13.500 | 3.000 |
| 365 | 13.500 | 3.500 | 366 | 13.500 | 4.000 |
| 367 | 13.500 | 4.500 | 368 | 13.500 | 5.000 |
| 369 | 13.500 | 5.500 | 370 | 13.500 | 6.000 |
| 371 | 13.500 | 6.500 | 372 | 13.500 | 7.000 |
| 373 | 13.500 | 7.500 | 374 | 13.500 | 8.000 |
| 375 | 13.500 | 8.500 | 376 | 13.500 | 9.000 |
| 377 | 13.500 | 9.250 | 378 | 13.750 | 0.000 |
| 379 | 13.750 | 1.000 | 380 | 13.750 | 2.000 |
| 381 | 13.750 | 2.500 | 382 | 13.750 | 3.000 |
| 383 | 13.750 | 3.500 | 384 | 13.750 | 4.000 |
| 385 | 13.750 | 4.500 | 386 | 13.750 | 5.000 |
| 387 | 13.750 | 5.500 | 388 | 13.750 | 6.000 |
| 389 | 13.750 | 6.500 | 390 | 13.750 | 7.000 |
| 391 | 13.750 | 7.500 | 392 | 13.750 | 8.000 |
| 393 | 13.750 | 8.500 | 394 | 13.750 | 9.000 |
| 395 | 13.750 | 9.125 | 396 | 14.000 | 0.000 |
| 397 | 14.000 | 1.000 | 398 | 14.000 | 2.000 |
| 399 | 14.000 | 2.500 | 400 | 14.000 | 3.000 |
| 401 | 14.000 | 3.500 | 402 | 14.000 | 4.000 |
| 403 | 14.000 | 4.500 | 404 | 14.000 | 5.000 |
| 405 | 14.000 | 5.500 | 406 | 14.000 | 6.000 |
| 407 | 14.000 | 6.500 | 408 | 14.000 | 7.000 |
| 409 | 14.000 | 7.500 | 410 | 14.000 | 8.000 |
| 411 | 14.000 | 8.500 | 412 | 14.000 | 9.000 |
| 413 | 14.250 | 0.000 | 414 | 14.250 | 1.000 |
| 415 | 14.250 | 2.000 | 416 | 14.250 | 2.500 |
| 417 | 14.250 | 3.000 | 418 | 14.250 | 3.500 |
| 419 | 14.250 | 4.000 | 420 | 14.250 | 4.500 |
| 421 | 14.250 | 5.000 | 422 | 14.250 | 5.500 |

| | | | | | |
|---|---|---|---|---|---|
| 423 | 14.250 | 6.000 | 424 | 14.250 | 6.500 |
| 425 | 14.250 | 7.000 | 426 | 14.250 | 7.500 |
| 427 | 14.250 | 8.000 | 428 | 14.250 | 8.500 |
| 429 | 14.250 | 8.875 | 430 | 14.500 | 0.000 |
| 431 | 14.500 | 1.000 | 432 | 14.500 | 2.000 |
| 433 | 14.500 | 2.500 | 434 | 14.500 | 3.000 |
| 435 | 14.500 | 3.500 | 436 | 14.500 | 4.000 |
| 437 | 14.500 | 4.500 | 438 | 14.500 | 5.000 |
| 439 | 14.500 | 5.500 | 440 | 14.500 | 6.000 |
| 441 | 14.500 | 6.500 | 442 | 14.500 | 7.000 |
| 443 | 14.500 | 7.500 | 444 | 14.500 | 8.000 |
| 445 | 14.500 | 8.500 | 446 | 14.500 | 8.750 |
| 447 | 14.750 | 0.000 | 448 | 14.750 | 1.000 |
| 449 | 14.750 | 2.000 | 450 | 14.750 | 2.500 |
| 451 | 14.750 | 3.000 | 452 | 14.750 | 3.500 |
| 453 | 14.750 | 4.000 | 454 | 14.750 | 4.500 |
| 455 | 14.750 | 5.000 | 456 | 14.750 | 5.500 |
| 457 | 14.750 | 6.000 | 458 | 14.750 | 6.500 |
| 459 | 14.750 | 7.000 | 460 | 14.750 | 7.500 |
| 461 | 14.750 | 8.000 | 462 | 14.750 | 8.500 |
| 463 | 14.750 | 8.625 | 464 | 15.000 | 0.000 |
| 465 | 15.000 | 1.000 | 466 | 15.000 | 2.000 |
| 467 | 15.000 | 2.500 | 468 | 15.000 | 3.000 |
| 469 | 15.000 | 3.500 | 470 | 15.000 | 4.000 |
| 471 | 15.000 | 4.500 | 472 | 15.000 | 5.000 |
| 473 | 15.000 | 5.500 | 474 | 15.000 | 6.000 |
| 475 | 15.000 | 6.500 | 476 | 15.000 | 7.000 |
| 477 | 15.000 | 7.500 | 478 | 15.000 | 8.000 |
| 479 | 15.000 | 8.500 | 480 | 15.250 | 0.000 |
| 481 | 15.250 | 1.000 | 482 | 15.250 | 2.000 |
| 483 | 15.250 | 2.500 | 484 | 15.250 | 3.000 |
| 485 | 15.250 | 3.500 | 486 | 15.250 | 4.000 |
| 487 | 15.250 | 4.500 | 488 | 15.250 | 5.000 |
| 489 | 15.250 | 5.500 | 490 | 15.250 | 6.000 |
| 491 | 15.250 | 6.500 | 492 | 15.250 | 7.000 |
| 493 | 15.250 | 7.500 | 494 | 15.250 | 8.000 |
| 495 | 15.250 | 8.375 | 496 | 15.500 | 0.000 |
| 497 | 15.500 | 1.000 | 498 | 15.500 | 2.000 |
| 499 | 15.500 | 2.500 | 500 | 15.500 | 3.000 |
| 501 | 15.500 | 3.500 | 502 | 15.500 | 4.000 |
| 503 | 15.500 | 4.500 | 504 | 15.500 | 5.000 |
| 505 | 15.500 | 5.500 | 506 | 15.500 | 6.000 |
| 507 | 15.500 | 6.500 | 508 | 15.500 | 7.000 |
| 509 | 15.500 | 7.500 | 510 | 15.500 | 8.000 |
| 511 | 15.500 | 8.250 | 512 | 15.750 | 0.000 |
| 513 | 15.750 | 1.000 | 514 | 15.750 | 2.000 |
| 515 | 15.750 | 2.500 | 516 | 15.750 | 3.000 |
| 517 | 15.750 | 3.500 | 518 | 15.750 | 4.000 |
| 519 | 15.750 | 4.500 | 520 | 15.750 | 5.000 |
| 521 | 15.750 | 5.500 | 522 | 15.750 | 6.000 |
| 523 | 15.750 | 6.500 | 524 | 15.750 | 7.000 |
| 525 | 15.750 | 7.500 | 526 | 15.750 | 8.000 |
| 527 | 15.750 | 8.125 | 528 | 16.000 | 0.000 |
| 529 | 16.000 | 1.000 | 530 | 16.000 | 2.000 |
| 531 | 16.000 | 2.500 | 532 | 16.000 | 3.000 |
| 533 | 16.000 | 3.500 | 534 | 16.000 | 4.000 |
| 535 | 16.000 | 4.500 | 536 | 16.000 | 5.000 |
| 537 | 16.000 | 5.500 | 538 | 16.000 | 6.000 |
| 539 | 16.000 | 6.500 | 540 | 16.000 | 7.000 |
| 541 | 16.000 | 7.500 | 542 | 16.000 | 8.000 |
| 543 | 16.250 | 0.000 | 544 | 16.250 | 1.000 |
| 545 | 16.250 | 2.000 | 546 | 16.250 | 2.500 |
| 547 | 16.250 | 3.000 | 548 | 16.250 | 3.500 |
| 549 | 16.250 | 4.000 | 550 | 16.250 | 4.500 |
| 551 | 16.250 | 5.000 | 552 | 16.250 | 5.500 |
| 553 | 16.250 | 6.000 | 554 | 16.250 | 6.500 |
| 555 | 16.250 | 7.000 | 556 | 16.250 | 7.500 |
| 557 | 16.250 | 7.875 | 558 | 16.500 | 0.000 |
| 559 | 16.500 | 1.000 | 560 | 16.500 | 2.000 |
| 561 | 16.500 | 2.500 | 562 | 16.500 | 3.000 |
| 563 | 16.500 | 3.500 | 564 | 16.500 | 4.000 |
| 565 | 16.500 | 4.500 | 566 | 16.500 | 5.000 |
| 567 | 16.500 | 5.500 | 568 | 16.500 | 6.000 |
| 569 | 16.500 | 6.500 | 570 | 16.500 | 7.000 |
| 571 | 16.500 | 7.500 | 572 | 16.500 | 7.750 |
| 573 | 16.750 | 0.000 | 574 | 16.750 | 1.000 |
| 575 | 16.750 | 2.000 | 576 | 16.750 | 2.500 |
| 577 | 16.750 | 3.000 | 578 | 16.750 | 3.500 |
| 579 | 16.750 | 4.000 | 580 | 16.750 | 4.500 |
| 581 | 16.750 | 5.000 | 582 | 16.750 | 5.500 |
| 583 | 16.750 | 6.000 | 584 | 16.750 | 6.500 |
| 585 | 16.750 | 7.000 | 586 | 16.750 | 7.500 |

| | | | | | |
|---|---|---|---|---|---|
| 587 | 16.750 | 7.625 | 588 | 17.000 | 0.000 |
| 589 | 17.000 | 1.000 | 590 | 17.000 | 2.000 |
| 591 | 17.000 | 2.500 | 592 | 17.000 | 3.000 |
| 593 | 17.000 | 3.500 | 594 | 17.000 | 4.000 |
| 595 | 17.000 | 4.500 | 596 | 17.000 | 5.000 |
| 597 | 17.000 | 5.500 | 598 | 17.000 | 6.000 |
| 599 | 17.000 | 6.500 | 600 | 17.000 | 7.000 |
| 601 | 17.000 | 7.500 | 602 | 17.250 | 0.000 |
| 603 | 17.250 | 1.000 | 604 | 17.250 | 2.000 |
| 605 | 17.250 | 2.500 | 606 | 17.250 | 3.000 |
| 607 | 17.250 | 3.500 | 608 | 17.250 | 4.000 |
| 609 | 17.250 | 4.500 | 610 | 17.250 | 5.000 |
| 611 | 17.250 | 5.500 | 612 | 17.250 | 6.000 |
| 613 | 17.250 | 6.500 | 614 | 17.250 | 7.000 |
| 615 | 17.250 | 7.375 | 616 | 17.500 | 0.000 |
| 617 | 17.500 | 1.000 | 618 | 17.500 | 2.000 |
| 619 | 17.500 | 2.500 | 620 | 17.500 | 3.000 |
| 621 | 17.500 | 3.500 | 622 | 17.500 | 4.000 |
| 623 | 17.500 | 4.500 | 624 | 17.500 | 5.000 |
| 625 | 17.500 | 5.500 | 626 | 17.500 | 6.000 |
| 627 | 17.500 | 6.500 | 628 | 17.500 | 7.000 |
| 629 | 17.500 | 7.250 | 630 | 17.750 | 0.000 |
| 631 | 17.750 | 1.000 | 632 | 17.750 | 2.000 |
| 633 | 17.750 | 2.500 | 634 | 17.750 | 3.000 |
| 635 | 17.750 | 3.500 | 636 | 17.750 | 4.000 |
| 637 | 17.750 | 4.500 | 638 | 17.750 | 5.000 |
| 639 | 17.750 | 5.500 | 640 | 17.750 | 6.000 |
| 641 | 17.750 | 6.500 | 642 | 17.750 | 7.000 |
| 643 | 17.750 | 7.125 | 644 | 18.000 | 0.000 |
| 645 | 18.000 | 1.000 | 646 | 18.000 | 2.000 |
| 647 | 18.000 | 2.500 | 648 | 18.000 | 3.000 |
| 649 | 18.000 | 3.500 | 650 | 18.000 | 4.000 |
| 651 | 18.000 | 4.500 | 652 | 18.000 | 5.000 |
| 653 | 18.000 | 5.500 | 654 | 18.000 | 6.000 |
| 655 | 18.000 | 6.500 | 656 | 18.000 | 7.000 |
| 657 | 18.250 | 0.000 | 658 | 18.250 | 1.000 |
| 659 | 18.250 | 2.000 | 660 | 18.250 | 2.500 |
| 661 | 18.250 | 3.000 | 662 | 18.250 | 3.500 |
| 663 | 18.250 | 4.000 | 664 | 18.250 | 4.500 |
| 665 | 18.250 | 5.000 | 666 | 18.250 | 5.500 |
| 667 | 18.250 | 6.000 | 668 | 18.250 | 6.500 |
| 669 | 18.250 | 6.875 | 670 | 18.500 | 0.000 |
| 671 | 18.500 | 1.000 | 672 | 18.500 | 2.000 |
| 673 | 18.500 | 2.500 | 674 | 18.500 | 3.000 |
| 675 | 18.500 | 3.500 | 676 | 18.500 | 4.000 |
| 677 | 18.500 | 4.500 | 678 | 18.500 | 5.000 |
| 679 | 18.500 | 5.500 | 680 | 18.500 | 6.000 |
| 681 | 18.500 | 6.500 | 682 | 18.500 | 6.750 |
| 683 | 18.750 | 0.000 | 684 | 18.750 | 1.000 |
| 685 | 18.750 | 2.000 | 686 | 18.750 | 2.500 |
| 687 | 18.750 | 3.000 | 688 | 18.750 | 3.500 |
| 689 | 18.750 | 4.000 | 690 | 18.750 | 4.500 |
| 691 | 18.750 | 5.000 | 692 | 18.750 | 5.500 |
| 693 | 18.750 | 6.000 | 694 | 18.750 | 6.500 |
| 695 | 18.750 | 6.625 | 696 | 19.000 | 0.000 |
| 697 | 19.000 | 1.000 | 698 | 19.000 | 2.000 |
| 699 | 19.000 | 2.500 | 700 | 19.000 | 3.000 |
| 701 | 19.000 | 3.500 | 702 | 19.000 | 4.000 |
| 703 | 19.000 | 4.500 | 704 | 19.000 | 5.000 |
| 705 | 19.000 | 5.500 | 706 | 19.000 | 6.000 |
| 707 | 19.000 | 6.500 | 708 | 19.250 | 0.000 |
| 709 | 19.250 | 1.000 | 710 | 19.250 | 2.000 |
| 711 | 19.250 | 2.500 | 712 | 19.250 | 3.000 |
| 713 | 19.250 | 3.500 | 714 | 19.250 | 4.000 |
| 715 | 19.250 | 4.500 | 716 | 19.250 | 5.000 |
| 717 | 19.250 | 5.500 | 718 | 19.250 | 6.000 |
| 719 | 19.250 | 6.375 | 720 | 19.500 | 0.000 |
| 721 | 19.500 | 1.000 | 722 | 19.500 | 2.000 |
| 723 | 19.500 | 2.500 | 724 | 19.500 | 3.000 |
| 725 | 19.500 | 3.500 | 726 | 19.500 | 4.000 |
| 727 | 19.500 | 4.500 | 728 | 19.500 | 5.000 |
| 729 | 19.500 | 5.500 | 730 | 19.500 | 6.000 |
| 731 | 19.500 | 6.250 | 732 | 19.750 | 0.000 |
| 733 | 19.750 | 1.000 | 734 | 19.750 | 2.000 |
| 735 | 19.750 | 2.500 | 736 | 19.750 | 3.000 |
| 737 | 19.750 | 3.500 | 738 | 19.750 | 4.000 |
| 739 | 19.750 | 4.500 | 740 | 19.750 | 5.000 |
| 741 | 19.750 | 5.500 | 742 | 19.750 | 6.000 |
| 743 | 19.750 | 6.125 | 744 | 20.000 | 0.000 |
| 745 | 20.000 | 1.000 | 746 | 20.000 | 2.000 |
| 747 | 20.000 | 2.500 | 748 | 20.000 | 3.000 |
| 749 | 20.000 | 3.500 | 750 | 20.000 | 4.000 |

| | | | | | |
|---|---|---|---|---|---|
| 751 | 20.000 | 4.500 | 752 | 20.000 | 5.000 |
| 753 | 20.000 | 5.500 | 754 | 20.000 | 6.000 |
| 755 | 20.250 | 0.000 | 756 | 20.250 | 1.000 |
| 757 | 20.250 | 2.000 | 758 | 20.250 | 2.500 |
| 759 | 20.250 | 3.000 | 760 | 20.250 | 3.500 |
| 761 | 20.250 | 4.000 | 762 | 20.250 | 4.500 |
| 763 | 20.250 | 5.000 | 764 | 20.250 | 5.500 |
| 765 | 20.250 | 5.875 | 766 | 20.500 | 0.000 |
| 767 | 20.500 | 1.000 | 768 | 20.500 | 2.000 |
| 769 | 20.500 | 2.500 | 770 | 20.500 | 3.000 |
| 771 | 20.500 | 3.500 | 772 | 20.500 | 4.000 |
| 773 | 20.500 | 4.500 | 774 | 20.500 | 5.000 |
| 775 | 20.500 | 5.500 | 776 | 20.500 | 5.750 |
| 777 | 20.750 | 0.000 | 778 | 20.750 | 1.000 |
| 779 | 20.750 | 2.000 | 780 | 20.750 | 2.500 |
| 781 | 20.750 | 3.000 | 782 | 20.750 | 3.500 |
| 783 | 20.750 | 4.000 | 784 | 20.750 | 4.500 |
| 785 | 20.750 | 5.000 | 786 | 20.750 | 5.500 |
| 787 | 20.750 | 5.625 | 788 | 21.000 | 0.000 |
| 789 | 21.000 | 1.000 | 790 | 21.000 | 2.000 |
| 791 | 21.000 | 2.500 | 792 | 21.000 | 3.000 |
| 793 | 21.000 | 3.500 | 794 | 21.000 | 4.000 |
| 795 | 21.000 | 4.500 | 796 | 21.000 | 5.000 |
| 797 | 21.000 | 5.500 | 798 | 21.250 | 0.000 |
| 799 | 21.250 | 1.000 | 800 | 21.250 | 2.000 |
| 801 | 21.250 | 2.500 | 802 | 21.250 | 3.000 |
| 803 | 21.250 | 3.500 | 804 | 21.250 | 4.000 |
| 805 | 21.250 | 4.500 | 806 | 21.250 | 5.000 |
| 807 | 21.250 | 5.375 | 808 | 21.500 | 0.000 |
| 809 | 21.500 | 1.000 | 810 | 21.500 | 2.000 |
| 811 | 21.500 | 2.500 | 812 | 21.500 | 3.000 |
| 813 | 21.500 | 3.500 | 814 | 21.500 | 4.000 |
| 815 | 21.500 | 4.500 | 816 | 21.500 | 5.000 |
| 817 | 21.500 | 5.250 | 818 | 21.750 | 0.000 |
| 819 | 21.750 | 1.000 | 820 | 21.750 | 2.000 |
| 821 | 21.750 | 2.500 | 822 | 21.750 | 3.000 |
| 823 | 21.750 | 3.500 | 824 | 21.750 | 4.000 |
| 825 | 21.750 | 4.500 | 826 | 21.750 | 5.000 |
| 827 | 21.750 | 5.125 | 828 | 22.000 | 0.000 |
| 829 | 22.000 | 1.000 | 830 | 22.000 | 2.000 |
| 831 | 22.000 | 2.500 | 832 | 22.000 | 3.000 |
| 833 | 22.000 | 3.500 | 834 | 22.000 | 4.000 |
| 835 | 22.000 | 4.500 | 836 | 22.000 | 5.000 |
| 837 | 22.250 | 0.000 | 838 | 22.250 | 1.000 |
| 839 | 22.250 | 2.000 | 840 | 22.250 | 2.500 |
| 841 | 22.250 | 3.000 | 842 | 22.250 | 3.500 |
| 843 | 22.250 | 4.000 | 844 | 22.250 | 4.500 |
| 845 | 22.250 | 4.875 | 846 | 22.500 | 0.000 |
| 847 | 22.500 | 1.000 | 848 | 22.500 | 2.000 |
| 849 | 22.500 | 2.500 | 850 | 22.500 | 3.000 |
| 851 | 22.500 | 3.500 | 852 | 22.500 | 4.000 |
| 853 | 22.500 | 4.500 | 854 | 22.500 | 4.750 |
| 855 | 22.750 | 0.000 | 856 | 22.750 | 1.000 |
| 857 | 22.750 | 2.000 | 858 | 22.750 | 2.500 |
| 859 | 22.750 | 3.000 | 860 | 22.750 | 3.500 |
| 861 | 22.750 | 4.000 | 862 | 22.750 | 4.500 |
| 863 | 22.750 | 4.625 | 864 | 23.000 | 0.000 |
| 865 | 23.000 | 1.000 | 866 | 23.000 | 2.000 |
| 867 | 23.000 | 2.500 | 868 | 23.000 | 3.000 |
| 869 | 23.000 | 3.500 | 870 | 23.000 | 4.000 |
| 871 | 23.000 | 4.500 | 872 | 23.250 | 0.000 |
| 873 | 23.250 | 1.000 | 874 | 23.250 | 2.000 |
| 875 | 23.250 | 2.500 | 876 | 23.250 | 3.000 |
| 877 | 23.250 | 3.500 | 878 | 23.250 | 4.000 |
| 879 | 23.250 | 4.375 | 880 | 23.500 | 0.000 |
| 881 | 23.500 | 1.000 | 882 | 23.500 | 2.000 |
| 883 | 23.500 | 2.500 | 884 | 23.500 | 3.000 |
| 885 | 23.500 | 3.500 | 886 | 23.500 | 4.000 |
| 887 | 23.500 | 4.250 | 888 | 23.750 | 0.000 |
| 889 | 23.750 | 1.000 | 890 | 23.750 | 2.000 |
| 891 | 23.750 | 2.500 | 892 | 23.750 | 3.000 |
| 893 | 23.750 | 3.500 | 894 | 23.750 | 4.000 |
| 895 | 23.750 | 4.125 | 896 | 24.000 | 0.000 |
| 897 | 24.000 | 1.000 | 898 | 24.000 | 2.000 |
| 899 | 24.000 | 2.500 | 900 | 24.000 | 3.000 |
| 901 | 24.000 | 3.500 | 902 | 24.000 | 4.000 |
| 903 | 24.250 | 0.000 | 904 | 24.250 | 1.000 |
| 905 | 24.250 | 2.000 | 906 | 24.250 | 2.500 |
| 907 | 24.250 | 3.000 | 908 | 24.250 | 3.500 |
| 909 | 24.250 | 3.875 | 910 | 24.500 | 0.000 |
| 911 | 24.500 | 1.000 | 912 | 24.500 | 2.000 |
| 913 | 24.500 | 2.500 | 914 | 24.500 | 3.000 |

```
915   24.500   3.500   916   24.500   3.750
917   24.750   0.000   918   24.750   1.000
919   24.750   2.000   920   24.750   2.500
921   24.750   3.000   922   24.750   3.500
923   24.750   3.625   924   25.000   0.000
925   25.000   1.000   926   25.000   2.000
927   25.000   2.500   928   25.000   3.000
929   25.000   3.500   930   25.250   0.000
931   25.250   1.000   932   25.250   2.000
933   25.250   2.500   934   25.250   3.000
935   25.250   3.375   936   25.500   0.000
937   25.500   1.000   938   25.500   2.000
939   25.500   2.500   940   25.500   3.000
941   25.500   3.250   942   25.750   0.000
943   25.750   1.000   944   25.750   2.000
945   25.750   2.500   946   25.750   3.000
947   25.750   3.125   948   26.000   0.000
949   26.000   1.000   950   26.000   2.000
951   26.000   2.500   952   26.000   3.000
953   26.250   0.000   954   26.250   1.000
955   26.250   2.000   956   26.250   2.500
957   26.250   2.875   958   26.500   0.000
959   26.500   1.000   960   26.500   2.000
961   26.500   2.500   962   26.500   2.750
963   26.750   0.000   964   26.750   1.000
965   26.750   2.000   966   26.750   2.500
967   26.750   2.625   968   27.000   0.000
969   27.000   1.000   970   27.000   2.000
971   27.000   2.500   972   27.250   0.000
973   27.250   1.000   974   27.250   2.000
975   27.250   2.375   976   27.500   0.000
977   27.500   1.000   978   27.500   2.000
979   27.500   2.250   980   27.750   0.000
981   27.750   1.000   982   27.750   2.000
983   27.750   2.125   984   28.000   0.000
985   28.000   1.000   986   28.000   2.000
987   28.250   0.000   988   28.250   1.000
989   28.250   2.000   990   28.500   0.000
991   28.500   1.000   992   28.500   2.000
993   28.750   0.000   994   28.750   1.000
995   28.750   2.000   996   29.000   0.000
997   29.000   1.000   998   29.000   2.000
```

NUMBER OF ELEMENTS =  914

```
         MAT   NODE  NODE  NODE  NODE
ELEMENT No.     1     2     3     4
-----------------------------------------------------------
   1     1    1    20    21     2
   2     1    2    21    22     3
   3     1    3    22    23     4
   4     1    4    23    24     5
   5     1    5    24    25     6
   6     1    6    25    26     7
   7     1    7    26    27     8
   8     1    8    27    28     9
   9     1    9    28    29    10
  10     1   10    29    30    11
  11     1   11    30    31    12
  12     1   12    31    32    13
  13     1   13    32    33    14
  14     1   14    33    34    15
  15     1   15    34    35    16
  16     1   16    35    36    17
  17     1   17    36    37    18
  18     1   18    37    38    19
  19     1   20    39    40    21
  20     1   21    40    41    22
  21     1   22    41    42    23
  22     1   23    42    43    24
  23     1   24    43    44    25
  24     1   25    44    45    26
  25     1   26    45    46    27
  26     1   27    46    47    28
  27     1   28    47    48    29
  28     1   29    48    49    30
  29     1   30    49    50    31
  30     1   31    50    51    32
  31     1   32    51    52    33
  32     1   33    52    53    34
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33    1    34    53    54    35
34    1    35    54    55    36
35    1    36    55    56    37
36    1    37    56    57    38
37    1    39    58    59    40
38    1    40    59    60    41
39    1    41    60    61    42
40    1    42    61    62    43
41    1    43    62    63    44
42    1    44    63    64    45
43    1    45    64    65    46
44    1    46    65    66    47
45    1    47    66    67    48
46    1    48    67    68    49
47    1    49    68    69    50
48    1    50    69    70    51
49    1    51    70    71    52
50    1    52    71    72    53
51    1    53    72    73    54
52    1    54    73    74    55
53    1    55    74    75    56
54    1    56    75    76    57
55    1    58    77    78    59
56    1    59    78    79    60
57    1    60    79    80    61
58    1    61    80    81    62
59    1    62    81    82    63
60    1    63    82    83    64
61    1    64    83    84    65
62    1    65    84    85    66
63    1    66    85    86    67
64    1    67    86    87    68
65    1    68    87    88    69
66    1    69    88    89    70
67    1    70    89    90    71
68    1    71    90    91    72
69    1    72    91    92    73
70    1    73    92    93    74
71    1    74    93    94    75
72    1    75    94    95    76
73    1    77    96    97    78
74    1    78    97    98    79
75    1    79    98    99    80
76    1    80    99    100   81
77    1    81    100   101   82
78    1    82    101   102   83
79    1    83    102   103   84
80    1    84    103   104   85
81    1    85    104   105   86
82    1    86    105   106   87
83    1    87    106   107   88
84    1    88    107   108   89
85    1    89    108   109   90
86    1    90    109   110   91
87    1    91    110   111   92
88    1    92    111   112   93
89    1    93    112   113   94
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709	1	755	766	767	756
710	1	756	767	768	757
711	1	757	768	769	758
712	1	758	769	770	759
713	1	759	770	771	760
714	1	760	771	772	761
715	1	761	772	773	762
716	1	762	773	774	763
717	1	763	774	775	764
718	1	764	775	776	765
719	1	766	777	778	767
720	1	767	778	779	768
721	1	768	779	780	769
722	1	769	780	781	770
723	1	770	781	782	771
724	1	771	782	783	772
725	1	772	783	784	773
726	1	773	784	785	774
727	1	774	785	786	775
728	1	775	786	787	776
729	1	788	789	778	777
730	1	789	790	779	778
731	1	790	791	780	779
732	1	791	792	781	780
733	1	792	793	782	781
734	1	793	794	783	782
735	1	794	795	784	783
736	1	795	796	785	784
737	1	796	797	786	785
738	1	797	787	786	0
739	1	788	798	799	789
740	1	789	799	800	790
741	1	790	800	801	791
742	1	791	801	802	792
743	1	792	802	803	793
744	1	793	803	804	794
745	1	794	804	805	795
746	1	795	805	806	796
747	1	796	806	807	797
748	1	798	808	809	799
749	1	799	809	810	800
750	1	800	810	811	801
751	1	801	811	812	802
752	1	802	812	813	803
753	1	803	813	814	804
754	1	804	814	815	805
755	1	805	815	816	806
756	1	806	816	817	807
757	1	808	818	819	809
758	1	809	819	820	810
759	1	810	820	821	811
760	1	811	821	822	812
761	1	812	822	823	813
762	1	813	823	824	814
763	1	814	824	825	815
764	1	815	825	826	816
765	1	816	826	827	817
766	1	828	829	819	818
767	1	829	830	820	819
768	1	830	831	821	820
769	1	831	832	822	821
770	1	832	833	823	822

771	1	833	834	824	823
772	1	834	835	825	824
773	1	835	836	826	825
774	1	836	827	826	0
775	1	828	837	838	829
776	1	829	838	839	830
777	1	830	839	840	831
778	1	831	840	841	832
779	1	832	841	842	833
780	1	833	842	843	834
781	1	834	843	844	835
782	1	835	844	845	836
783	1	837	846	847	838
784	1	838	847	848	839
785	1	839	848	849	840
786	1	840	849	850	841
787	1	841	850	851	842
788	1	842	851	852	843
789	1	843	852	853	844
790	1	844	853	854	845
791	1	846	855	856	847
792	1	847	856	857	848
793	1	848	857	858	849
794	1	849	858	859	850
795	1	850	859	860	851
796	1	851	860	861	852
797	1	852	861	862	853
798	1	853	862	863	854
799	1	864	865	856	855
800	1	865	866	857	856
801	1	866	867	858	857
802	1	867	868	859	858
803	1	868	869	860	859
804	1	869	870	861	860
805	1	870	871	862	861
806	1	871	863	862	0
807	1	864	872	873	865
808	1	865	873	874	866
809	1	866	874	875	867
810	1	867	875	876	868
811	1	868	876	877	869
812	1	869	877	878	870
813	1	870	878	879	871
814	1	872	880	881	873
815	1	873	881	882	874
816	1	874	882	883	875
817	1	875	883	884	876
818	1	876	884	885	877
819	1	877	885	886	878
820	1	878	886	887	879
821	1	880	888	889	881
822	1	881	889	890	882
823	1	882	890	891	883
824	1	883	891	892	884
825	1	884	892	893	885
826	1	885	893	894	886
827	1	886	894	895	887
828	1	896	897	889	888
829	1	897	898	890	889
830	1	898	899	891	890
831	1	899	900	892	891
832	1	900	901	893	892
833	1	901	902	894	893
834	1	902	895	894	0
835	1	896	903	904	897
836	1	897	904	905	898
837	1	898	905	906	899
838	1	899	906	907	900
839	1	900	907	908	901
840	1	901	908	909	902
841	1	903	910	911	904
842	1	904	911	912	905
843	1	905	912	913	906
844	1	906	913	914	907
845	1	907	914	915	908
846	1	908	915	916	909
847	1	910	917	918	911
848	1	911	918	919	912
849	1	912	919	920	913
850	1	913	920	921	914
851	1	914	921	922	915
852	1	915	922	923	916

```
853   1   924   925   918   917
854   1   925   926   919   918
855   1   926   927   920   919
856   1   927   928   921   920
857   1   928   929   922   921
858   1   929   923   922    0
859   1   924   930   931   925
860   1   925   931   932   926
861   1   926   932   933   927
862   1   927   933   934   928
863   1   928   934   935   929
864   1   930   936   937   931
865   1   931   937   938   932
866   1   932   938   939   933
867   1   933   939   940   934
868   1   934   940   941   935
869   1   936   942   943   937
870   1   937   943   944   938
871   1   938   944   945   939
872   1   939   945   946   940
873   1   940   946   947   941
874   1   948   949   943   942
875   1   949   950   944   943
876   1   950   951   945   944
877   1   951   952   946   945
878   1   952   947   946    0
879   1   948   953   954   949
880   1   949   954   955   950
881   1   950   955   956   951
882   1   951   956   957   952
883   1   953   958   959   954
884   1   954   959   960   955
885   1   955   960   961   956
886   1   956   961   962   957
887   1   958   963   964   959
888   1   959   964   965   960
889   1   960   965   966   961
890   1   961   966   967   962
891   1   968   969   964   963
892   1   969   970   965   964
893   1   970   971   966   965
894   1   971   967   966    0
895   1   968   972   973   969
896   1   969   973   974   970
897   1   970   974   975   971
898   1   972   976   977   973
899   1   973   977   978   974
900   1   974   978   979   975
901   1   976   980   981   977
902   1   977   981   982   978
903   1   978   982   983   979
904   1   984   985   981   980
905   1   985   986   982   981
906   1   986   983   982    0
907   1   984   987   988   985
908   1   985   988   989   986
909   1   987   990   991   988
910   1   988   991   992   989
911   1   990   993   994   991
912   1   991   994   995   992
913   1   993   996   997   994
914   1   994   997   998   995
```

****
* BOUNDARY CONDITIONS *
****

NUMBER OF BOUNDARY CONDITIONS = 51

NODES WITH A PRESCRIBED HEAD

NODE	HEAD	NODE	HEAD	NODE	HEAD
601	7.50	615	7.38	629	7.25
643	7.13	656	7.00	669	6.88
682	6.75	695	6.63	707	6.50
719	6.38	731	6.25	743	6.13
754	6.00	765	5.88	776	5.75
787	5.63	797	5.50	807	5.50
817	5.50	827	5.50	836	5.50
845	5.50	854	5.50	863	5.50

```
871      5.50      879      5.50      887      5.50
895      5.50      902      5.50      909      5.50
916      5.50      923      5.50      929      5.50
935      5.50      941      5.50      947      5.50
952      5.50      957      5.50      962      5.50
967      5.50      971      5.50      975      5.50
979      5.50      983      5.50      986      5.50
989      5.50      992      5.50      995      5.50
998      5.50      997      5.50      996      5.50
```

NUMBER OF NODES WHICH CAN BE ADDED TO THE BOUNDARY CONDITIONS = 0

NUMBER OF NODES WHICH CAN BE DELETED FROM THE BOUNDARY CONDITIONS = 16

THE NODES ARE:

 601 615 629 643 656 669 682 695 707 719
 731 743 754 765 776 787

****
* WATER LEVEL *
****

Water level used to calculate initial pore pressures =   10.00

****
* INITIAL PORE PRESSURE PROFILE ABOVE WATER LEVEL *
****

Pore pressures set to :
Pore Pressure = (WLEVEL - Y) * UNITW

****
* DATUM *
****

Datum used to calculate Total Head is located at (y) =   0.00

****
* TIME INCREMENTS *
****

Number of time cycles =   1
Number of time intervals/cycle =   75
Initial time increment between solutions =   8.0000E+01
Factor time increment is multiplied by each time cycle = 1.0000E+00

****
* UNSATURATED SOIL DATA *
****

Number of different material types = 1

MATERIAL TYPE NUMBER 1

        Permeability in (x) direction   k(x) = 4.1670E-06
        Permeability in (y) direction   k(y) = 4.1670E-06

        Permeability Function:
        k1 = ko * exp[-b*|pore press|] when unsaturated
          = ko   when saturated

        where:

        k1 is the major principal permeability coefficient
          for unsaturated flow conditions
        ko is the major principal permeability coefficient
          for saturated flow conditions

        and:

        ko .... = 4.1670E-06
        b .... = 2.00000E-02
```

Ratio of major to minor principal
  permeability coefficient .... =   1.0000E+00
Angle between x axis and major
  principal direction .... =   0.0000E+00

Number of intervals defining moisture
content-pore pressure curve ...... =   11

Limits for pore-pressure ranges:
 -1.4715E+03
 -2.9430E+02
 -9.8100E+01
 -2.9430E+01
 -9.8100E+00
 -4.9050E+00
 -2.9340E+00
 -9.8100E-01
  0.0000E+00
  1.0000E+01
  1.0000E+03

Gradient of moisture-pore pressure curve:
  1.0000E-04
  1.0000E-04
  2.0000E-04
  4.0000E-04
  2.0000E-03
  2.5000E-03
  4.6000E-03
  4.1000E-03
  1.0000E-04
  1.0000E-04
  1.0000E-04
  1.0000E-04

****
* TABLES OF RESULTS *
****

INITIAL VALUES OF TOTAL HEAD   TIME =   4.800E+04
(1) 9.142   (2) 9.145   (3) 9.155   (4) 9.163
(5) 9.172   (6) 9.183   (7) 9.196   (8) 9.210
(9) 9.226   (10) 9.243   (11) 9.262   (12) 9.282
(13) 9.303   (14) 9.326   (15) 9.351   (16) 9.376
(17) 9.402   (18) 9.430   (19) 9.445   (20) 9.119
(21) 9.123   (22) 9.133   (23) 9.141   (24) 9.151
(25) 9.162   (26) 9.175   (27) 9.189   (28) 9.206
(29) 9.223   (30) 9.243   (31) 9.263   (32) 9.286
(33) 9.309   (34) 9.334   (35) 9.361   (36) 9.388
(37) 9.417   (38) 9.434   (39) 9.051   (40) 9.055
(41) 9.066   (42) 9.075   (43) 9.085   (44) 9.097
(45) 9.111   (46) 9.127   (47) 9.144   (48) 9.164
(49) 9.184   (50) 9.207   (51) 9.231   (52) 9.256
(53) 9.283   (54) 9.312   (55) 9.341   (56) 9.373
(57) 9.390   (58) 8.999   (59) 9.003   (60) 9.015
(61) 9.024   (62) 9.035   (63) 9.048   (64) 9.063
(65) 9.079   (66) 9.098   (67) 9.118   (68) 9.140
(69) 9.164   (70) 9.189   (71) 9.216   (72) 9.245
(73) 9.274   (74) 9.304   (75) 9.334   (76) 9.348
(77) 8.935   (78) 8.939   (79) 8.952   (80) 8.961
(81) 8.973   (82) 8.986   (83) 9.002   (84) 9.020
(85) 9.039   (86) 9.061   (87) 9.085   (88) 9.110
(89) 9.138   (90) 9.167   (91) 9.198   (92) 9.230
(93) 9.263   (94) 9.296   (95) 9.308   (96) 8.857
(97) 8.862   (98) 8.875   (99) 8.885   (100) 8.897
(101) 8.912   (102) 8.928   (103) 8.947   (104) 8.969
(105) 8.992   (106) 9.018   (107) 9.045   (108) 9.075
(109) 9.107   (110) 9.141   (111) 9.177   (112) 9.216
(113) 9.254   (114) 9.265   (115) 8.766   (116) 8.771
(117) 8.785   (118) 8.796   (119) 8.809   (120) 8.824
(121) 8.842   (122) 8.862   (123) 8.885   (124) 8.910
(125) 8.938   (126) 8.968   (127) 9.001   (128) 9.036
(129) 9.073   (130) 9.112   (131) 9.155   (132) 9.196
(133) 9.209   (134) 8.661   (135) 8.665   (136) 8.680
(137) 8.691   (138) 8.705   (139) 8.721   (140) 8.740
(141) 8.762   (142) 8.787   (143) 8.814   (144) 8.844
(145) 8.877   (146) 8.912   (147) 8.950   (148) 8.991
(149) 9.035   (150) 9.079   (151) 9.125   (152) 9.138
(153) 8.540   (154) 8.545   (155) 8.560   (156) 8.572
(157) 8.586   (158) 8.603   (159) 8.623   (160) 8.646
(161) 8.672   (162) 8.702   (163) 8.734   (164) 8.770

(165) 8.809   (166) 8.851   (167) 8.896   (168) 8.945
(169) 8.995   (170) 9.038   (171) 9.051   (172) 8.404
(173) 8.409   (174) 8.425   (175) 8.437   (176) 8.451
(177) 8.469   (178) 8.489   (179) 8.513   (180) 8.541
(181) 8.572   (182) 8.607   (183) 8.646   (184) 8.688
(185) 8.735   (186) 8.785   (187) 8.840   (188) 8.898
(189) 8.942   (190) 8.954   (191) 8.368   (192) 8.373
(193) 8.388   (194) 8.400   (195) 8.415   (196) 8.432
(197) 8.453   (198) 8.477   (199) 8.505   (200) 8.537
(201) 8.572   (202) 8.611   (203) 8.655   (204) 8.703
(205) 8.755   (206) 8.811   (207) 8.870   (208) 8.915
(209) 8.928   (210) 8.331   (211) 8.336   (212) 8.351
(213) 8.363   (214) 8.377   (215) 8.395   (216) 8.416
(217) 8.440   (218) 8.468   (219) 8.500   (220) 8.536
(221) 8.576   (222) 8.620   (223) 8.669   (224) 8.723
(225) 8.781   (226) 8.841   (227) 8.886   (228) 8.901
(229) 8.292   (230) 8.297   (231) 8.312   (232) 8.324
(233) 8.338   (234) 8.356   (235) 8.377   (236) 8.402
(237) 8.430   (238) 8.462   (239) 8.498   (240) 8.539
(241) 8.585   (242) 8.635   (243) 8.690   (244) 8.750
(245) 8.813   (246) 8.858   (247) 8.875   (248) 8.253
(249) 8.258   (250) 8.273   (251) 8.284   (252) 8.299
(253) 8.316   (254) 8.337   (255) 8.362   (256) 8.390
(257) 8.422   (258) 8.459   (259) 8.501   (260) 8.547
(261) 8.598   (262) 8.655   (263) 8.717   (264) 8.784
(265) 8.828   (266) 8.852   (267) 8.213   (268) 8.218
(269) 8.232   (270) 8.244   (271) 8.258   (272) 8.275
(273) 8.296   (274) 8.321   (275) 8.349   (276) 8.382
(277) 8.419   (278) 8.461   (279) 8.508   (280) 8.561
(281) 8.619   (282) 8.683   (283) 8.752   (284) 8.798
(285) 8.822   (286) 8.172   (287) 8.176   (288) 8.191
(289) 8.202   (290) 8.216   (291) 8.233   (292) 8.254
(293) 8.278   (294) 8.307   (295) 8.340   (296) 8.377
(297) 8.420   (298) 8.468   (299) 8.521   (300) 8.581
(301) 8.646   (302) 8.717   (303) 8.765   (304) 8.783
(305) 8.130   (306) 8.134   (307) 8.148   (308) 8.159
(309) 8.173   (310) 8.190   (311) 8.210   (312) 8.235
(313) 8.263   (314) 8.296   (315) 8.334   (316) 8.377
(317) 8.425   (318) 8.480   (319) 8.540   (320) 8.608
(321) 8.680   (322) 8.729   (323) 8.738   (324) 8.087
(325) 8.091   (326) 8.105   (327) 8.115   (328) 8.129
(329) 8.145   (330) 8.166   (331) 8.190   (332) 8.218
(333) 8.251   (334) 8.289   (335) 8.332   (336) 8.382
(337) 8.437   (338) 8.499   (339) 8.567   (340) 8.639
(341) 8.690   (342) 8.043   (343) 8.047   (344) 8.060
(345) 8.070   (346) 8.083   (347) 8.100   (348) 8.120
(349) 8.143   (350) 8.171   (351) 8.204   (352) 8.243
(353) 8.286   (354) 8.336   (355) 8.392   (356) 8.455
(357) 8.524   (358) 8.597   (359) 8.635   (360) 7.998
(361) 8.002   (362) 8.014   (363) 8.024   (364) 8.037
(365) 8.053   (366) 8.072   (367) 8.096   (368) 8.123
(369) 8.156   (370) 8.194   (371) 8.238   (372) 8.289
(373) 8.345   (374) 8.409   (375) 8.481   (376) 8.551
(377) 8.577   (378) 7.952   (379) 7.956   (380) 7.968
(381) 7.977   (382) 7.989   (383) 8.005   (384) 8.024
(385) 8.046   (386) 8.074   (387) 8.106   (388) 8.145
(389) 8.188   (390) 8.239   (391) 8.296   (392) 8.361
(393) 8.435   (394) 8.503   (395) 8.516   (396) 7.906
(397) 7.909   (398) 7.920   (399) 7.929   (400) 7.941
(401) 7.955   (402) 7.974   (403) 7.996   (404) 8.023
(405) 8.055   (406) 8.093   (407) 8.137   (408) 8.188
(409) 8.246   (410) 8.311   (411) 8.385   (412) 8.452
(413) 7.859   (414) 7.862   (415) 7.872   (416) 7.880
(417) 7.891   (418) 7.905   (419) 7.922   (420) 7.944
(421) 7.970   (422) 8.002   (423) 8.039   (424) 8.083
(425) 8.134   (426) 8.193   (427) 8.259   (428) 8.333
(429) 8.382   (430) 7.811   (431) 7.814   (432) 7.823
(433) 7.830   (434) 7.840   (435) 7.853   (436) 7.870
(437) 7.890   (438) 7.916   (439) 7.947   (440) 7.984
(441) 8.028   (442) 8.079   (443) 8.137   (444) 8.204
(445) 8.279   (446) 8.310   (447) 7.762   (448) 7.764
(449) 7.772   (450) 7.779   (451) 7.788   (452) 7.800
(453) 7.816   (454) 7.835   (455) 7.860   (456) 7.890
(457) 7.927   (458) 7.970   (459) 8.021   (460) 8.080
(461) 8.147   (462) 8.221   (463) 8.237   (464) 7.713
(465) 7.715   (466) 7.721   (467) 7.727   (468) 7.735
(469) 7.746   (470) 7.760   (471) 7.779   (472) 7.802
(473) 7.831   (474) 7.867   (475) 7.910   (476) 7.961
(477) 8.020   (478) 8.087   (479) 8.160   (480) 7.663
(481) 7.664   (482) 7.670   (483) 7.675   (484) 7.681
(485) 7.691   (486) 7.704   (487) 7.721   (488) 7.743
(489) 7.771   (490) 7.806   (491) 7.848   (492) 7.899

(493)	7.958	(494)	8.025	(495)	8.078	(496)	7.612
(497)	7.613	(498)	7.617	(499)	7.621	(500)	7.627
(501)	7.635	(502)	7.646	(503)	7.661	(504)	7.682
(505)	7.708	(506)	7.742	(507)	7.784	(508)	7.835
(509)	7.894	(510)	7.961	(511)	7.996	(512)	7.561
(513)	7.562	(514)	7.564	(515)	7.567	(516)	7.571
(517)	7.577	(518)	7.587	(519)	7.600	(520)	7.619
(521)	7.644	(522)	7.676	(523)	7.718	(524)	7.768
(525)	7.828	(526)	7.895	(527)	7.912	(528)	7.510
(529)	7.510	(530)	7.511	(531)	7.512	(532)	7.514
(533)	7.519	(534)	7.526	(535)	7.537	(536)	7.554
(537)	7.577	(538)	7.608	(539)	7.649	(540)	7.699
(541)	7.759	(542)	7.827	(543)	7.458	(544)	7.458
(545)	7.456	(546)	7.456	(547)	7.457	(548)	7.459
(549)	7.464	(550)	7.473	(551)	7.487	(552)	7.508
(553)	7.537	(554)	7.577	(555)	7.628	(556)	7.689
(557)	7.740	(558)	7.407	(559)	7.405	(560)	7.402
(561)	7.400	(562)	7.399	(563)	7.399	(564)	7.401
(565)	7.407	(566)	7.418	(567)	7.436	(568)	7.464
(569)	7.502	(570)	7.553	(571)	7.616	(572)	7.651
(573)	7.355	(574)	7.353	(575)	7.347	(576)	7.343
(577)	7.340	(578)	7.338	(579)	7.337	(580)	7.340
(581)	7.348	(582)	7.363	(583)	7.387	(584)	7.424
(585)	7.475	(586)	7.541	(587)	7.560	(588)	7.303
(589)	7.300	(590)	7.292	(591)	7.287	(592)	7.281
(593)	7.276	(594)	7.272	(595)	7.271	(596)	7.275
(597)	7.286	(598)	7.307	(599)	7.342	(600)	7.393
(601)	7.500	(602)	7.251	(603)	7.247	(604)	7.237
(605)	7.229	(606)	7.221	(607)	7.213	(608)	7.206
(609)	7.201	(610)	7.201	(611)	7.207	(612)	7.224
(613)	7.255	(614)	7.306	(615)	7.375	(616)	7.199
(617)	7.194	(618)	7.181	(619)	7.172	(620)	7.162
(621)	7.150	(622)	7.139	(623)	7.130	(624)	7.124
(625)	7.125	(626)	7.137	(627)	7.164	(628)	7.213
(629)	7.250	(630)	7.147	(631)	7.142	(632)	7.126
(633)	7.115	(634)	7.102	(635)	7.087	(636)	7.072
(637)	7.057	(638)	7.046	(639)	7.041	(640)	7.046
(641)	7.067	(642)	7.111	(643)	7.125	(644)	7.096
(645)	7.090	(646)	7.072	(647)	7.058	(648)	7.042
(649)	7.024	(650)	7.004	(651)	6.984	(652)	6.966
(653)	6.954	(654)	6.951	(655)	6.965	(656)	7.000
(657)	7.045	(658)	7.038	(659)	7.017	(660)	7.002
(661)	6.983	(662)	6.961	(663)	6.936	(664)	6.910
(665)	6.885	(666)	6.864	(667)	6.852	(668)	6.858
(669)	6.875	(670)	6.995	(671)	6.987	(672)	6.963
(673)	6.946	(674)	6.924	(675)	6.898	(676)	6.868
(677)	6.836	(678)	6.802	(679)	6.771	(680)	6.749
(681)	6.745	(682)	6.750	(683)	6.945	(684)	6.937
(685)	6.910	(686)	6.890	(687)	6.866	(688)	6.836
(689)	6.801	(690)	6.762	(691)	6.719	(692)	6.676
(693)	6.642	(694)	6.626	(695)	6.625	(696)	6.896
(697)	6.887	(698)	6.858	(699)	6.836	(700)	6.809
(701)	6.775	(702)	6.735	(703)	6.689	(704)	6.636
(705)	6.580	(706)	6.529	(707)	6.500	(708)	6.849
(709)	6.838	(710)	6.807	(711)	6.783	(712)	6.753
(713)	6.715	(714)	6.671	(715)	6.617	(716)	6.554
(717)	6.482	(718)	6.412	(719)	6.375	(720)	6.802
(721)	6.791	(722)	6.757	(723)	6.731	(724)	6.698
(725)	6.658	(726)	6.608	(727)	6.548	(728)	6.474
(729)	6.384	(730)	6.288	(731)	6.250	(732)	6.756
(733)	6.744	(734)	6.709	(735)	6.681	(736)	6.646
(737)	6.602	(738)	6.548	(739)	6.482	(740)	6.400
(741)	6.290	(742)	6.156	(743)	6.125	(744)	6.711
(745)	6.699	(746)	6.662	(747)	6.632	(748)	6.595
(749)	6.548	(750)	6.491	(751)	6.420	(752)	6.329
(753)	6.213	(754)	6.000	(755)	6.668	(756)	6.655
(757)	6.616	(758)	6.585	(759)	6.546	(760)	6.498
(761)	6.437	(762)	6.362	(763)	6.267	(764)	6.137
(765)	5.875	(766)	6.626	(767)	6.613	(768)	6.572
(769)	6.540	(770)	6.500	(771)	6.449	(772)	6.387
(773)	6.309	(774)	6.210	(775)	6.080	(776)	5.750
(777)	6.585	(778)	6.572	(779)	6.530	(780)	6.497
(781)	6.456	(782)	6.404	(783)	6.340	(784)	6.261
(785)	6.162	(786)	6.036	(787)	5.625	(788)	6.546
(789)	6.532	(790)	6.490	(791)	6.456	(792)	6.414
(793)	6.362	(794)	6.297	(795)	6.217	(796)	6.120
(797)	5.500	(798)	6.508	(799)	6.494	(800)	6.451
(801)	6.418	(802)	6.375	(803)	6.322	(804)	6.257
(805)	6.178	(806)	6.083	(807)	5.500	(808)	6.472
(809)	6.458	(810)	6.415	(811)	6.381	(812)	6.338
(813)	6.285	(814)	6.221	(815)	6.144	(816)	6.052
(817)	5.500	(818)	6.438	(819)	6.423	(820)	6.380

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(821)  6.346    (822)  6.303    (823)  6.251    (824)  6.188
(825)  6.113    (826)  6.024    (827)  5.500    (828)  6.404
(829)  6.390    (830)  6.347    (831)  6.313    (832)  6.271
(833)  6.220    (834)  6.158    (835)  6.085    (836)  5.500
(837)  6.373    (838)  6.359    (839)  6.316    (840)  6.283
(841)  6.241    (842)  6.191    (843)  6.130    (844)  6.060
(845)  5.500    (846)  6.343    (847)  6.329    (848)  6.287
(849)  6.254    (850)  6.213    (851)  6.164    (852)  6.105
(853)  6.037    (854)  5.500    (855)  6.315    (856)  6.301
(857)  6.259    (858)  6.227    (859)  6.187    (860)  6.139
(861)  6.083    (862)  6.018    (863)  5.500    (864)  6.288
(865)  6.274    (866)  6.233    (867)  6.202    (868)  6.164
(869)  6.117    (870)  6.063    (871)  5.500    (872)  6.263
(873)  6.249    (874)  6.209    (875)  6.179    (876)  6.142
(877)  6.097    (878)  6.044    (879)  5.500    (880)  6.239
(881)  6.226    (882)  6.187    (883)  6.158    (884)  6.121
(885)  6.078    (886)  6.028    (887)  5.500    (888)  6.216
(889)  6.204    (890)  6.166    (891)  6.138    (892)  6.103
(893)  6.061    (894)  6.013    (895)  5.500    (896)  6.195
(897)  6.183    (898)  6.147    (899)  6.120    (900)  6.086
(901)  6.046    (902)  5.500    (903)  6.176    (904)  6.164
(905)  6.129    (906)  6.103    (907)  6.071    (908)  6.032
(909)  5.500    (910)  6.158    (911)  6.147    (912)  6.113
(913)  6.088    (914)  6.057    (915)  6.020    (916)  5.500
(917)  6.141    (918)  6.130    (919)  6.098    (920)  6.074
(921)  6.044    (922)  6.009    (923)  5.500    (924)  6.125
(925)  6.115    (926)  6.084    (927)  6.061    (928)  6.033
(929)  5.500    (930)  6.111    (931)  6.101    (932)  6.072
(933)  6.050    (934)  6.023    (935)  5.500    (936)  6.098
(937)  6.088    (938)  6.061    (939)  6.040    (940)  6.014
(941)  5.500    (942)  6.086    (943)  6.077    (944)  6.050
(945)  6.031    (946)  6.007    (947)  5.500    (948)  6.075
(949)  6.066    (950)  6.041    (951)  6.023    (952)  5.500
(953)  6.064    (954)  6.057    (955)  6.033    (956)  6.016
(957)  5.500    (958)  6.055    (959)  6.048    (960)  6.026
(961)  6.010    (962)  5.500    (963)  6.047    (964)  6.040
(965)  6.020    (966)  6.004    (967)  5.500    (968)  6.040
(969)  6.033    (970)  6.014    (971)  5.500    (972)  6.033
(973)  6.027    (974)  6.010    (975)  5.500    (976)  6.027
(977)  6.022    (978)  6.006    (979)  5.500    (980)  6.021
(981)  6.017    (982)  6.003    (983)  5.500    (984)  6.016
(985)  6.013    (986)  5.500    (987)  6.012    (988)  6.009
(989)  5.500    (990)  6.008    (991)  6.006    (992)  5.500
(993)  6.004    (994)  6.003    (995)  5.500    (996)  5.500
(997)  5.500    (998)  5.500    (
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Time step : **   TIME =   4.8080E+04

TOTAL HEAD = ELEVATION HEAD + PRESSURE HEAD

```
(  1)  9.140    (  2)  9.144    (  3)  9.154    (  4)  9.162
(  5)  9.171    (  6)  9.182    (  7)  9.194    (  8)  9.209
(  9)  9.224    ( 10)  9.242    ( 11)  9.260    ( 12)  9.281
( 13)  9.302    ( 14)  9.325    ( 15)  9.349    ( 16)  9.375
( 17)  9.401    ( 18)  9.429    ( 19)  9.444    ( 20)  9.118
( 21)  9.121    ( 22)  9.132    ( 23)  9.140    ( 24)  9.149
( 25)  9.161    ( 26)  9.173    ( 27)  9.188    ( 28)  9.204
( 29)  9.222    ( 30)  9.241    ( 31)  9.262    ( 32)  9.284
( 33)  9.308    ( 34)  9.333    ( 35)  9.359    ( 36)  9.387
( 37)  9.416    ( 38)  9.433    ( 39)  9.050    ( 40)  9.054
( 41)  9.065    ( 42)  9.073    ( 43)  9.084    ( 44)  9.096
( 45)  9.110    ( 46)  9.126    ( 47)  9.143    ( 48)  9.162
( 49)  9.183    ( 50)  9.206    ( 51)  9.230    ( 52)  9.255
( 53)  9.282    ( 54)  9.310    ( 55)  9.340    ( 56)  9.371
( 57)  9.389    ( 58)  8.998    ( 59)  9.002    ( 60)  9.014
( 61)  9.023    ( 62)  9.033    ( 63)  9.046    ( 64)  9.061
( 65)  9.078    ( 66)  9.096    ( 67)  9.117    ( 68)  9.139
( 69)  9.163    ( 70)  9.188    ( 71)  9.215    ( 72)  9.243
( 73)  9.273    ( 74)  9.303    ( 75)  9.333    ( 76)  9.346
( 77)  8.933    ( 78)  8.938    ( 79)  8.950    ( 80)  8.960
( 81)  8.971    ( 82)  8.985    ( 83)  9.000    ( 84)  9.018
( 85)  9.038    ( 86)  9.060    ( 87)  9.083    ( 88)  9.109
( 89)  9.136    ( 90)  9.166    ( 91)  9.196    ( 92)  9.229
( 93)  9.262    ( 94)  9.295    ( 95)  9.307    ( 96)  8.856
( 97)  8.860    ( 98)  8.874    ( 99)  8.884    (100)  8.896
(101)  8.910    (102)  8.927    (103)  8.946    (104)  8.967
(105)  8.991    (106)  9.016    (107)  9.044    (108)  9.074
(109)  9.106    (110)  9.140    (111)  9.176    (112)  9.215
(113)  9.253    (114)  9.264    (115)  8.765    (116)  8.769
(117)  8.783    (118)  8.794    (119)  8.807    (120)  8.822
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(121)	8.840	(122)	8.860	(123)	8.883	(124)	8.909
(125)	8.936	(126)	8.966	(127)	8.999	(128)	9.034
(129)	9.071	(130)	9.111	(131)	9.153	(132)	9.195
(133)	9.208	(134)	8.659	(135)	8.664	(136)	8.679
(137)	8.690	(138)	8.703	(139)	8.720	(140)	8.739
(141)	8.760	(142)	8.785	(143)	8.812	(144)	8.842
(145)	8.875	(146)	8.911	(147)	8.949	(148)	8.990
(149)	9.033	(150)	9.078	(151)	9.123	(152)	9.137
(153)	8.538	(154)	8.543	(155)	8.559	(156)	8.570
(157)	8.585	(158)	8.602	(159)	8.622	(160)	8.645
(161)	8.671	(162)	8.700	(163)	8.733	(164)	8.768
(165)	8.807	(166)	8.850	(167)	8.895	(168)	8.943
(169)	8.994	(170)	9.037	(171)	9.050	(172)	8.403
(173)	8.408	(174)	8.423	(175)	8.435	(176)	8.449
(177)	8.467	(178)	8.488	(179)	8.512	(180)	8.539
(181)	8.570	(182)	8.605	(183)	8.644	(184)	8.687
(185)	8.733	(186)	8.784	(187)	8.838	(188)	8.897
(189)	8.941	(190)	8.953	(191)	8.366	(192)	8.371
(193)	8.387	(194)	8.398	(195)	8.413	(196)	8.431
(197)	8.451	(198)	8.476	(199)	8.503	(200)	8.535
(201)	8.570	(202)	8.610	(203)	8.653	(204)	8.701
(205)	8.753	(206)	8.810	(207)	8.869	(208)	8.914
(209)	8.927	(210)	8.329	(211)	8.334	(212)	8.349
(213)	8.361	(214)	8.375	(215)	8.393	(216)	8.414
(217)	8.438	(218)	8.466	(219)	8.498	(220)	8.534
(221)	8.574	(222)	8.619	(223)	8.668	(224)	8.722
(225)	8.780	(226)	8.840	(227)	8.885	(228)	8.900
(229)	8.290	(230)	8.295	(231)	8.311	(232)	8.322
(233)	8.337	(234)	8.354	(235)	8.375	(236)	8.400
(237)	8.428	(238)	8.460	(239)	8.497	(240)	8.538
(241)	8.583	(242)	8.633	(243)	8.688	(244)	8.749
(245)	8.812	(246)	8.856	(247)	8.873	(248)	8.251
(249)	8.256	(250)	8.271	(251)	8.283	(252)	8.297
(253)	8.315	(254)	8.336	(255)	8.360	(256)	8.388
(257)	8.421	(258)	8.458	(259)	8.499	(260)	8.546
(261)	8.597	(262)	8.654	(263)	8.716	(264)	8.783
(265)	8.827	(266)	8.850	(267)	8.211	(268)	8.216
(269)	8.230	(270)	8.242	(271)	8.256	(272)	8.274
(273)	8.294	(274)	8.319	(275)	8.348	(276)	8.380
(277)	8.418	(278)	8.460	(279)	8.507	(280)	8.559
(281)	8.617	(282)	8.682	(283)	8.751	(284)	8.796
(285)	8.820	(286)	8.170	(287)	8.174	(288)	8.189
(289)	8.200	(290)	8.214	(291)	8.232	(292)	8.252
(293)	8.277	(294)	8.305	(295)	8.338	(296)	8.376
(297)	8.418	(298)	8.466	(299)	8.520	(300)	8.579
(301)	8.645	(302)	8.716	(303)	8.763	(304)	8.781
(305)	8.128	(306)	8.132	(307)	8.146	(308)	8.157
(309)	8.171	(310)	8.188	(311)	8.209	(312)	8.233
(313)	8.262	(314)	8.295	(315)	8.332	(316)	8.376
(317)	8.424	(318)	8.479	(319)	8.539	(320)	8.606
(321)	8.678	(322)	8.727	(323)	8.737	(324)	8.085
(325)	8.089	(326)	8.103	(327)	8.113	(328)	8.127
(329)	8.144	(330)	8.164	(331)	8.188	(332)	8.216
(333)	8.250	(334)	8.288	(335)	8.331	(336)	8.380
(337)	8.436	(338)	8.497	(339)	8.566	(340)	8.638
(341)	8.688	(342)	8.041	(343)	8.045	(344)	8.058
(345)	8.068	(346)	8.082	(347)	8.098	(348)	8.118
(349)	8.142	(350)	8.170	(351)	8.203	(352)	8.241
(353)	8.285	(354)	8.335	(355)	8.391	(356)	8.454
(357)	8.523	(358)	8.596	(359)	8.633	(360)	7.996
(361)	8.000	(362)	8.013	(363)	8.022	(364)	8.035
(365)	8.051	(366)	8.071	(367)	8.094	(368)	8.122
(369)	8.155	(370)	8.193	(371)	8.237	(372)	8.287
(373)	8.344	(374)	8.408	(375)	8.480	(376)	8.550
(377)	8.575	(378)	7.950	(379)	7.954	(380)	7.966
(381)	7.975	(382)	7.988	(383)	8.003	(384)	8.022
(385)	8.045	(386)	8.072	(387)	8.105	(388)	8.143
(389)	8.187	(390)	8.238	(391)	8.295	(392)	8.360
(393)	8.433	(394)	8.502	(395)	8.514	(396)	7.904
(397)	7.907	(398)	7.919	(399)	7.927	(400)	7.939
(401)	7.954	(402)	7.972	(403)	7.994	(404)	8.021
(405)	8.053	(406)	8.091	(407)	8.136	(408)	8.186
(409)	8.244	(410)	8.310	(411)	8.384	(412)	8.451
(413)	7.857	(414)	7.860	(415)	7.870	(416)	7.878
(417)	7.889	(418)	7.903	(419)	7.921	(420)	7.942
(421)	7.969	(422)	8.000	(423)	8.038	(424)	8.082
(425)	8.133	(426)	8.191	(427)	8.258	(428)	8.331
(429)	8.381	(430)	7.809	(431)	7.812	(432)	7.821
(433)	7.828	(434)	7.838	(435)	7.852	(436)	7.868
(437)	7.889	(438)	7.914	(439)	7.945	(440)	7.983
(441)	8.026	(442)	8.078	(443)	8.136	(444)	8.203
(445)	8.278	(446)	8.309	(447)	7.760	(448)	7.763

(449)	7.771	(450)	7.777	(451)	7.787	(452)	7.799
(453)	7.814	(454)	7.834	(455)	7.858	(456)	7.889
(457)	7.925	(458)	7.969	(459)	8.020	(460)	8.079
(461)	8.146	(462)	8.220	(463)	8.235	(464)	7.711
(465)	7.713	(466)	7.720	(467)	7.726	(468)	7.734
(469)	7.745	(470)	7.759	(471)	7.777	(472)	7.801
(473)	7.830	(474)	7.866	(475)	7.909	(476)	7.960
(477)	8.019	(478)	8.086	(479)	8.158	(480)	7.661
(481)	7.662	(482)	7.668	(483)	7.673	(484)	7.680
(485)	7.689	(486)	7.702	(487)	7.719	(488)	7.741
(489)	7.770	(490)	7.805	(491)	7.848	(492)	7.899
(493)	7.957	(494)	8.024	(495)	8.077	(496)	7.610
(497)	7.612	(498)	7.616	(499)	7.619	(500)	7.625
(501)	7.633	(502)	7.644	(503)	7.660	(504)	7.680
(505)	7.707	(506)	7.741	(507)	7.784	(508)	7.835
(509)	7.894	(510)	7.960	(511)	7.995	(512)	7.560
(513)	7.560	(514)	7.562	(515)	7.565	(516)	7.569
(517)	7.576	(518)	7.585	(519)	7.599	(520)	7.617
(521)	7.643	(522)	7.676	(523)	7.717	(524)	7.768
(525)	7.828	(526)	7.894	(527)	7.911	(528)	7.508
(529)	7.508	(530)	7.509	(531)	7.510	(532)	7.513
(533)	7.517	(534)	7.525	(535)	7.536	(536)	7.553
(537)	7.576	(538)	7.607	(539)	7.649	(540)	7.700
(541)	7.760	(542)	7.827	(543)	7.457	(544)	7.456
(545)	7.455	(546)	7.455	(547)	7.455	(548)	7.458
(549)	7.463	(550)	7.472	(551)	7.486	(552)	7.507
(553)	7.537	(554)	7.577	(555)	7.630	(556)	7.692
(557)	7.742	(558)	7.405	(559)	7.403	(560)	7.400
(561)	7.398	(562)	7.397	(563)	7.397	(564)	7.400
(565)	7.406	(566)	7.417	(567)	7.436	(568)	7.463
(569)	7.503	(570)	7.557	(571)	7.623	(572)	7.657
(573)	7.353	(574)	7.351	(575)	7.345	(576)	7.342
(577)	7.339	(578)	7.336	(579)	7.336	(580)	7.339
(581)	7.347	(582)	7.362	(583)	7.387	(584)	7.425
(585)	7.481	(586)	7.556	(587)	7.572	(588)	7.301
(589)	7.298	(590)	7.290	(591)	7.285	(592)	7.279
(593)	7.274	(594)	7.271	(595)	7.270	(596)	7.274
(597)	7.285	(598)	7.307	(599)	7.343	(600)	7.397
(601)	7.500	(602)	7.249	(603)	7.245	(604)	7.235
(605)	7.228	(606)	7.220	(607)	7.212	(608)	7.205
(609)	7.200	(610)	7.200	(611)	7.206	(612)	7.224
(613)	7.256	(614)	7.311	(615)	7.375	(616)	7.197
(617)	7.193	(618)	7.180	(619)	7.171	(620)	7.160
(621)	7.149	(622)	7.138	(623)	7.128	(624)	7.123
(625)	7.124	(626)	7.137	(627)	7.164	(628)	7.215
(629)	7.250	(630)	7.145	(631)	7.140	(632)	7.125
(633)	7.113	(634)	7.100	(635)	7.085	(636)	7.070
(637)	7.056	(638)	7.045	(639)	7.040	(640)	7.046
(641)	7.067	(642)	7.111	(643)	7.125	(644)	7.094
(645)	7.088	(646)	7.070	(647)	7.056	(648)	7.040
(649)	7.022	(650)	7.002	(651)	6.982	(652)	6.964
(653)	6.952	(654)	6.951	(655)	6.965	(656)	7.000
(657)	7.043	(658)	7.036	(659)	7.016	(660)	7.000
(661)	6.981	(662)	6.959	(663)	6.934	(664)	6.908
(665)	6.882	(666)	6.862	(667)	6.851	(668)	6.857
(669)	6.875	(670)	6.993	(671)	6.985	(672)	6.962
(673)	6.944	(674)	6.922	(675)	6.896	(676)	6.866
(677)	6.833	(678)	6.799	(679)	6.769	(680)	6.748
(681)	6.744	(682)	6.750	(683)	6.944	(684)	6.935
(685)	6.909	(686)	6.889	(687)	6.864	(688)	6.833
(689)	6.798	(690)	6.758	(691)	6.714	(692)	6.673
(693)	6.640	(694)	6.626	(695)	6.625	(696)	6.895
(697)	6.886	(698)	6.857	(699)	6.834	(700)	6.806
(701)	6.772	(702)	6.731	(703)	6.683	(704)	6.629
(705)	6.574	(706)	6.527	(707)	6.500	(708)	6.847
(709)	6.837	(710)	6.806	(711)	6.781	(712)	6.750
(713)	6.712	(714)	6.665	(715)	6.608	(716)	6.542
(717)	6.472	(718)	6.408	(719)	6.375	(720)	6.800
(721)	6.789	(722)	6.756	(723)	6.729	(724)	6.695
(725)	6.653	(726)	6.600	(727)	6.534	(728)	6.455
(729)	6.366	(730)	6.283	(731)	6.250	(732)	6.755
(733)	6.743	(734)	6.707	(735)	6.679	(736)	6.642
(737)	6.596	(738)	6.537	(739)	6.462	(740)	6.368
(741)	6.256	(742)	6.148	(743)	6.125	(744)	6.710
(745)	6.698	(746)	6.660	(747)	6.630	(748)	6.590
(749)	6.540	(750)	6.475	(751)	6.390	(752)	6.279
(753)	6.140	(754)	6.000	(755)	6.667	(756)	6.654
(757)	6.614	(758)	6.582	(759)	6.541	(760)	6.487
(761)	6.416	(762)	6.320	(763)	6.188	(764)	6.016
(765)	5.875	(766)	6.625	(767)	6.611	(768)	6.570
(769)	6.537	(770)	6.493	(771)	6.436	(772)	6.359
(773)	6.251	(774)	6.094	(775)	5.875	(776)	5.750

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(777) 6.584    (778) 6.570    (779) 6.527    (780) 6.493
(781) 6.447    (782) 6.387    (783) 6.304    (784) 6.185
(785) 5.996    (786) 5.709    (787) 5.625    (788) 6.545
(789) 6.531    (790) 6.487    (791) 6.451    (792) 6.404
(793) 6.340    (794) 6.251    (795) 6.118    (796) 5.904
(797) 5.500    (798) 6.507    (799) 6.493    (800) 6.448
(801) 6.411    (802) 6.362    (803) 6.295    (804) 6.199
(805) 6.054    (806) 5.801    (807) 5.500    (808) 6.471
(809) 6.457    (810) 6.411    (811) 6.373    (812) 6.322
(813) 6.252    (814) 6.149    (815) 5.987    (816) 5.707
(817) 5.500    (818) 6.436    (819) 6.422    (820) 6.375
(821) 6.337    (822) 6.284    (823) 6.211    (824) 6.100
(825) 5.919    (826) 5.607    (827) 5.500    (828) 6.403
(829) 6.389    (830) 6.342    (831) 6.302    (832) 6.248
(833) 6.170    (834) 6.050    (835) 5.846    (836) 5.500
(837) 6.372    (838) 6.357    (839) 6.310    (840) 6.270
(841) 6.213    (842) 6.130    (843) 5.999    (844) 5.769
(845) 5.500    (846) 6.342    (847) 6.327    (848) 6.279
(849) 6.238    (850) 6.179    (851) 6.090    (852) 5.946
(853) 5.690    (854) 5.500    (855) 6.313    (856) 6.299
(857) 6.250    (858) 6.208    (859) 6.146    (860) 6.050
(861) 5.887    (862) 5.600    (863) 5.500    (864) 6.286
(865) 6.272    (866) 6.223    (867) 6.179    (868) 6.114
(869) 6.008    (870) 5.823    (871) 5.500    (872) 6.261
(873) 6.246    (874) 6.197    (875) 6.151    (876) 6.081
(877) 5.965    (878) 5.753    (879) 5.500    (880) 6.237
(881) 6.223    (882) 6.172    (883) 6.124    (884) 6.048
(885) 5.918    (886) 5.680    (887) 5.500    (888) 6.215
(889) 6.200    (890) 6.148    (891) 6.097    (892) 6.013
(893) 5.866    (894) 5.595    (895) 5.500    (896) 6.193
(897) 6.179    (898) 6.125    (899) 6.070    (900) 5.978
(901) 5.806    (902) 5.500    (903) 6.174    (904) 6.159
(905) 6.102    (906) 6.043    (907) 5.939    (908) 5.741
(909) 5.500    (910) 6.155    (911) 6.140    (912) 6.080
(913) 6.015    (914) 5.897    (915) 5.672    (916) 5.500
(917) 6.138    (918) 6.122    (919) 6.058    (920) 5.985
(921) 5.849    (922) 5.591    (923) 5.500    (924) 6.122
(925) 6.106    (926) 6.036    (927) 5.953    (928) 5.794
(929) 5.500    (930) 6.107    (931) 6.090    (932) 6.013
(933) 5.919    (934) 5.732    (935) 5.500    (936) 6.092
(937) 6.075    (938) 5.989    (939) 5.880    (940) 5.667
(941) 5.500    (942) 6.079    (943) 6.060    (944) 5.963
(945) 5.836    (946) 5.589    (947) 5.500    (948) 6.066
(949) 6.046    (950) 5.935    (951) 5.784    (952) 5.500
(953) 6.054    (954) 6.031    (955) 5.904    (956) 5.725
(957) 5.500    (958) 6.042    (959) 6.016    (960) 5.869
(961) 5.662    (962) 5.500    (963) 6.029    (964) 6.001
(965) 5.827    (966) 5.587    (967) 5.500    (968) 6.015
(969) 5.984    (970) 5.778    (971) 5.500    (972) 5.999
(973) 5.965    (974) 5.722    (975) 5.500    (976) 5.980
(977) 5.941    (978) 5.660    (979) 5.500    (980) 5.954
(981) 5.911    (982) 5.585    (983) 5.500    (984) 5.917
(985) 5.874    (986) 5.500    (987) 5.869    (988) 5.815
(989) 5.500    (990) 5.790    (991) 5.744    (992) 5.500
(993) 5.669    (994) 5.643    (995) 5.500    (996) 5.500
(997) 5.500    (998) 5.500    (
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PORE PRESSURE

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( 1) 89.67    ( 2) 79.89    ( 3) 70.18    ( 4) 65.35
( 5) 60.54    ( 6) 55.74    ( 7) 50.96    ( 8) 46.19
( 9) 41.44    ( 10) 36.71   ( 11) 31.98   ( 12) 27.28
( 13) 22.58   ( 14) 17.91   ( 15) 13.24   ( 16) 8.582
( 17) 3.937   ( 18) -0.6998 ( 19) -5.457  ( 20) 89.45
( 21) 79.67   ( 22) 69.96   ( 23) 65.14   ( 24) 60.32
( 25) 55.53   ( 26) 50.75   ( 27) 45.99   ( 28) 41.24
( 29) 36.51   ( 30) 31.80   ( 31) 27.10   ( 32) 22.41
( 33) 17.74   ( 34) 13.08   ( 35) 8.431   ( 36) 3.798
( 37) -0.8219 ( 38) -5.565  ( 39) 88.78   ( 40) 79.00
( 41) 69.31   ( 42) 64.48   ( 43) 59.68   ( 44) 54.89
( 45) 50.13   ( 46) 45.38   ( 47) 40.64   ( 48) 35.93
( 49) 31.23   ( 50) 26.54   ( 51) 21.87   ( 52) 17.22
( 53) 12.58   ( 54) 7.949   ( 55) 3.335   ( 56) -1.261
( 57) -5.998  ( 58) 88.27   ( 59) 78.50   ( 60) 68.80
( 61) 63.99   ( 62) 59.19   ( 63) 54.41   ( 64) 49.65
( 65) 44.91   ( 66) 40.18   ( 67) 35.48   ( 68) 30.79
( 69) 26.12   ( 70) 21.47   ( 71) 16.83   ( 72) 12.20
( 73) 7.582   ( 74) 2.970   ( 75) -1.643  ( 76) -6.413
( 77) 87.64   ( 78) 77.87   ( 79) 68.18   ( 80) 63.37
( 81) 58.58   ( 82) 53.80   ( 83) 49.05   ( 84) 44.32
( 85) 39.61   ( 86) 34.92   ( 87) 30.25   ( 88) 25.59
( 89) 20.96   ( 90) 16.34   ( 91) 11.74   ( 92) 7.149
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( 93)  2.571      ( 94)  -2.012     ( 95)  -6.799     ( 96)  86.88
( 97)  77.11      ( 98)  67.43      ( 99)  62.62      (100)  57.84
(101)  53.07      (102)  48.33      (103)  43.61      (104)  38.92
(105)  34.24      (106)  29.59      (107)  24.96      (108)  20.34
(109)  15.75      (110)  11.18      (111)  6.632      (112)  2.105
(113)  -2.426     (114)  -7.223     (115)  85.98      (116)  76.22
(117)  66.54      (118)  61.74      (119)  56.97      (120)  52.21
(121)  47.48      (122)  42.78      (123)  38.09      (124)  33.44
(125)  28.80      (126)  24.20      (127)  19.61      (128)  15.05
(129)  10.51      (130)  5.996      (131)  1.505      (132)  -2.990
(133)  -7.769     (134)  84.94      (135)  75.18      (136)  65.52
(137)  60.72      (138)  55.95      (139)  51.21      (140)  46.49
(141)  41.79      (142)  37.13      (143)  32.49      (144)  27.88
(145)  23.30      (146)  18.74      (147)  14.22      (148)  9.713
(149)  5.231      (150)  0.7663     (151)  -3.695     (152)  -8.466
(153)  83.76      (154)  74.00      (155)  64.34      (156)  59.55
(157)  54.78      (158)  50.05      (159)  45.34      (160)  40.66
(161)  36.01      (162)  31.39      (163)  26.81      (164)  22.25
(165)  17.73      (166)  13.24      (167)  8.780      (168)  4.349
(169) -5.6932E-02 (170)  -4.546     (171)  -9.324     (172)  82.43
(173)  72.67      (174)  63.01      (175)  58.22      (176)  53.46
(177)  48.73      (178)  44.02      (179)  39.36      (180)  34.72
(181)  30.12      (182)  25.56      (183)  21.03      (184)  16.55
(185)  12.10      (186)  7.692      (187)  3.321      (188)  -1.010
(189)  -5.487     (190)  -10.27     (191)  82.07      (192)  72.31
(193)  62.65      (194)  57.86      (195)  53.10      (196)  48.37
(197)  43.67      (198)  39.00      (199)  34.37      (200)  29.77
(201)  25.22      (202)  20.70      (203)  16.22      (204)  11.79
(205)  7.392      (206)  3.037      (207)  -1.285     (208)  -5.752
(209)  -10.53     (210)  81.71      (211)  71.94      (212)  62.28
(213)  57.49      (214)  52.73      (215)  48.00      (216)  43.30
(217)  38.64      (218)  34.01      (219)  29.41      (220)  24.86
(221)  20.35      (222)  15.88      (223)  11.46      (224)  7.079
(225)  2.743      (226)  -1.567     (227)  -6.034     (228)  -10.79
(229)  81.33      (230)  71.57      (231)  61.91      (232)  57.12
(233)  52.35      (234)  47.62      (235)  42.92      (236)  38.26
(237)  33.63      (238)  29.04      (239)  24.49      (240)  19.99
(241)  15.53      (242)  11.12      (243)  6.753      (244)  2.438
(245)  -1.847     (246)  -6.314     (247)  -11.05     (248)  80.94
(249)  71.18      (250)  61.52      (251)  56.73      (252)  51.96
(253)  47.23      (254)  42.53      (255)  37.87      (256)  33.24
(257)  28.65      (258)  24.11      (259)  19.61      (260)  15.16
(261)  10.76      (262)  6.412      (263)  2.119      (264)  -2.133
(265)  -6.602     (266)  -11.28     (267)  80.55      (268)  70.79
(269)  61.12      (270)  56.33      (271)  51.56      (272)  46.83
(273)  42.13      (274)  37.46      (275)  32.84      (276)  28.26
(277)  23.72      (278)  19.22      (279)  14.78      (280)  10.39
(281)  6.056      (282)  1.781      (283)  -2.447     (284)  -6.904
(285)  -10.35     (286)  80.15      (287)  70.38      (288)  60.71
(289)  55.92      (290)  51.15      (291)  46.42      (292)  41.71
(293)  37.05      (294)  32.42      (295)  27.84      (296)  23.31
(297)  18.82      (298)  14.38      (299)  10.00      (300)  5.682
(301)  1.423      (302)  -2.788     (303)  -7.227     (304)  -9.501
(305)  79.73      (306)  69.97      (307)  60.30      (308)  55.50
(309)  50.73      (310)  45.99      (311)  41.29      (312)  36.62
(313)  32.00      (314)  27.42      (315)  22.88      (316)  18.40
(317)  13.97      (318)  9.600      (319)  5.290      (320)  1.044
(321)  -3.155     (322)  -7.580     (323)  -8.710     (324)  79.31
(325)  69.54      (326)  59.87      (327)  55.07      (328)  50.30
(329)  45.55      (330)  40.85      (331)  36.18      (332)  31.55
(333)  26.97      (334)  22.44      (335)  17.96      (336)  13.54
(337)  9.178      (338)  4.880      (339)  0.6447     (340)  -3.549
(341)  -7.964     (342)  78.88      (343)  69.11      (344)  59.43
(345)  54.63      (346)  49.85      (347)  45.11      (348)  40.40
(349)  35.73      (350)  31.10      (351)  26.52      (352)  21.99
(353)  17.51      (354)  13.09      (355)  8.738      (356)  4.451
(357)  0.2294     (358)  -3.968     (359)  -7.276     (360)  78.44
(361)  68.67      (362)  58.98      (363)  54.18      (364)  49.40
(365)  44.65      (366)  39.93      (367)  35.26      (368)  30.63
(369)  26.04      (370)  21.51      (371)  17.04      (372)  12.63
(373)  8.280      (374)  4.002      (375)  -0.1969    (376)  -4.416
(377)  -6.618     (378)  77.99      (379)  68.22      (380)  58.53
(381)  53.71      (382)  48.93      (383)  44.17      (384)  39.46
(385)  34.78      (386)  30.14      (387)  25.55      (388)  21.02
(389)  16.55      (390)  12.14      (391)  7.801      (392)  3.532
(393)  -0.6527    (394)  -4.889     (395)  -5.990     (396)  77.54
(397)  67.76      (398)  58.06      (399)  53.24      (400)  48.45
(401)  43.69      (402)  38.96      (403)  34.28      (404)  29.64
(405)  25.05      (406)  20.52      (407)  16.04      (408)  11.64
(409)  7.302      (410)  3.041      (411)  -1.140     (412)  -5.385
(413)  77.07      (414)  67.30      (415)  57.59      (416)  52.76
(417)  47.96      (418)  43.20      (419)  38.46      (420)  33.77
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(421)   29.12   (422)   24.53   (423)   19.99   (424)   15.52
(425)   11.11   (426)   6.782   (427)   2.528   (428)  -1.653
(429)  -4.844   (430)   76.60   (431)   66.82   (432)   57.10
(433)   52.27   (434)   47.47   (435)   42.69   (436)   37.95
(437)   33.24   (438)   28.59   (439)   23.99   (440)   19.45
(441)   14.97   (442)   10.57   (443)   6.241   (444)   1.992
(445)  -2.182   (446)  -4.324   (447)   76.13   (448)   66.34
(449)   56.61   (450)   51.77   (451)   46.96   (452)   42.17
(453)   37.42   (454)   32.70   (455)   28.04   (456)   23.43
(457)   18.89   (458)   14.41   (459)   10.01   (460)   5.678
(461)   1.430   (462)  -2.751   (463)  -3.822   (464)   75.64
(465)   65.85   (466)   56.11   (467)   51.26   (468)   46.44
(469)   41.64   (470)   36.87   (471)   32.15   (472)   27.48
(473)   22.86   (474)   18.31   (475)   13.83   (476)   9.421
(477)   5.093   (478)   0.8445  (479)  -3.351   (480)   75.15
(481)   65.36   (482)   55.60   (483)   50.75   (484)   45.91
(485)   41.10   (486)   36.32   (487)   31.58   (488)   26.89
(489)   22.26   (490)   17.70   (491)   13.22   (492)   8.814
(493)   4.487   (494)   0.2360  (495)  -2.921   (496)   74.66
(497)   64.86   (498)   55.09   (499)   50.22   (500)   45.37
(501)   40.55   (502)   35.75   (503)   31.00   (504)   26.29
(505)   21.65   (506)   17.08   (507)   12.59   (508)   8.187
(509)   3.861   (510)  -0.3931  (511)  -2.502   (512)   74.16
(513)   64.35   (514)   54.57   (515)   49.69   (516)   44.82
(517)   39.98   (518)   35.17   (519)   30.40   (520)   25.68
(521)   21.02   (522)   16.44   (523)   11.94   (524)   7.538
(525)   3.216   (526)  -1.037   (527)  -2.096   (528)   73.66
(529)   63.85   (530)   54.04   (531)   49.15   (532)   44.27
(533)   39.41   (534)   34.58   (535)   29.78   (536)   25.04
(537)   20.36   (538)   15.77   (539)   11.27   (540)   6.868
(541)   2.554   (542)  -1.700   (543)   73.15   (544)   63.33
(545)   53.51   (546)   48.60   (547)   43.71   (548)   38.83
(549)   33.97   (550)   29.15   (551)   24.39   (552)   19.69
(553)   15.08   (554)   10.57   (555)   6.177   (556)   1.881
(557)  -1.306   (558)   72.64   (559)   62.82   (560)   52.98
(561)   48.05   (562)   43.14   (563)   38.23   (564)   33.35
(565)   28.51   (566)   23.71   (567)   18.99   (568)   14.35
(569)   9.838   (570)   5.464   (571)   1.203   (572)  -0.9154
(573)   72.13   (574)   62.30   (575)   52.44   (576)   47.50
(577)   42.56   (578)   37.63   (579)   32.72   (580)   27.85
(581)   23.02   (582)   18.26   (583)   13.60   (584)   9.070
(585)   4.721   (586)   0.5445  (587)  -0.5201  (588)   71.62
(589)   61.78   (590)   51.90   (591)   46.94   (592)   41.98
(593)   37.03   (594)   32.09   (595)   27.17   (596)   22.31
(597)   17.51   (598)   12.82   (599)   8.269   (600)   3.892
(601)   0.0000  (602)   71.11   (603)   61.27   (604)   51.35
(605)   46.38   (606)   41.40   (607)   36.41   (608)   31.44
(609)   26.49   (610)   21.58   (611)   16.74   (612)   12.00
(613)   7.414   (614)   3.049   (615)   0.0000  (616)   70.60
(617)   60.75   (618)   50.81   (619)   45.82   (620)   40.81
(621)   35.79   (622)   30.78   (623)   25.79   (624)   20.83
(625)   15.94   (626)   11.15   (627)   6.516   (628)   2.106
(629)   0.0000  (630)   70.10   (631)   60.23   (632)   50.27
(633)   45.26   (634)   40.22   (635)   35.17   (636)   30.12
(637)   25.07   (638)   20.06   (639)   15.10   (640)   10.26
(641)   5.564   (642)   1.087   (643)   0.0000  (644)   69.59
(645)   59.72   (646)   49.74   (647)   44.70   (648)   39.64
(649)   34.55   (650)   29.45   (651)   24.35   (652)   19.27
(653)   14.25   (654)   9.325   (655)   4.559   (656)   0.0000
(657)   69.10   (658)   59.22   (659)   49.20   (660)   44.14
(661)   39.05   (662)   33.93   (663)   28.78   (664)   23.62
(665)   18.47   (666)   13.36   (667)   8.352   (668)   3.505
(669)   0.0000  (670)   68.60   (671)   58.72   (672)   48.68
(673)   43.59   (674)   38.47   (675)   33.31   (676)   28.11
(677)   22.89   (678)   17.65   (679)   12.45   (680)   7.338
(681)   2.396   (682)   0.0000  (683)   68.12   (684)   58.22
(685)   48.16   (686)   43.05   (687)   37.90   (688)   32.70
(689)   27.45   (690)   22.15   (691)   16.82   (692)   11.50
(693)   6.277   (694)   1.232   (695)   0.0000  (696)   67.64
(697)   57.74   (698)   47.64   (699)   42.52   (700)   37.34
(701)   32.10   (702)   26.79   (703)   21.41   (704)   15.98
(705)   10.53   (706)   5.166   (707)   0.0000  (708)   67.17
(709)   57.26   (710)   47.14   (711)   42.00   (712)   36.79
(713)   31.51   (714)   26.14   (715)   20.68   (716)   15.13
(717)   9.532   (718)   4.004   (719)   0.0000  (720)   66.71
(721)   56.79   (722)   46.65   (723)   41.49   (724)   36.25
(725)   30.93   (726)   25.50   (727)   19.96   (728)   14.28
(729)   8.497   (730)   2.773   (731)   0.0000  (732)   66.26
(733)   56.34   (734)   46.17   (735)   40.99   (736)   35.73
(737)   30.37   (738)   24.88   (739)   19.24   (740)   13.42
(741)   7.419   (742)   1.455   (743)   0.0000  (744)   65.83
(745)   55.90   (746)   45.71   (747)   40.51   (748)   35.22
```

```
(749)  29.82    (750)  24.28    (751)  18.54    (752)  12.55
(753)  6.283    (754)  0.0000   (755)  65.40    (756)  55.46
(757)  45.26    (758)  40.05    (759)  34.73    (760)  29.30
(761)  23.70    (762)  17.85    (763)  11.66    (764)  5.058
(765)  0.0000   (766)  64.99    (767)  55.05    (768)  44.83
(769)  39.60    (770)  34.27    (771)  28.80    (772)  23.14
(773)  17.18    (774)  10.73    (775)  3.683    (776)  0.0000
(777)  64.59    (778)  54.65    (779)  44.41    (780)  39.17
(781)  33.82    (782)  28.32    (783)  22.60    (784)  16.53
(785)  9.775    (786)  2.055    (787)  0.0000   (788)  64.21
(789)  54.26    (790)  44.01    (791)  38.76    (792)  33.39
(793)  27.86    (794)  22.08    (795)  15.87    (796)  8.871
(797)  0.0000   (798)  63.84    (799)  53.89    (800)  43.63
(801)  38.37    (802)  32.98    (803)  27.42    (804)  21.58
(805)  15.24    (806)  7.861    (807)  1.226    (808)  63.48
(809)  53.53    (810)  43.27    (811)  38.00    (812)  32.59
(813)  27.00    (814)  21.08    (815)  14.59    (816)  6.933
(817)  2.453    (818)  63.14    (819)  53.19    (820)  42.92
(821)  37.64    (822)  32.22    (823)  26.59    (824)  20.60
(825)  13.92    (826)  5.952    (827)  3.679    (828)  62.82
(829)  52.86    (830)  42.59    (831)  37.30    (832)  31.86
(833)  26.19    (834)  20.11    (835)  13.20    (836)  4.905
(837)  62.51    (838)  52.55    (839)  42.28    (840)  36.98
(841)  31.52    (842)  25.80    (843)  19.61    (844)  12.45
(845)  6.131    (846)  62.21    (847)  52.26    (848)  41.98
(849)  36.67    (850)  31.19    (851)  25.41    (852)  19.09
(853)  11.67    (854)  7.357    (855)  61.93    (856)  51.98
(857)  41.70    (858)  36.38    (859)  30.87    (860)  25.01
(861)  18.52    (862)  10.79    (863)  8.584    (864)  61.67
(865)  51.72    (866)  41.43    (867)  36.09    (868)  30.55
(869)  24.61    (870)  17.88    (871)  9.810    (872)  61.42
(873)  51.47    (874)  41.17    (875)  35.82    (876)  30.23
(877)  24.18    (878)  17.20    (879)  11.04    (880)  61.19
(881)  51.23    (882)  40.93    (883)  35.55    (884)  29.90
(885)  23.72    (886)  16.48    (887)  12.26    (888)  60.97
(889)  51.01    (890)  40.69    (891)  35.29    (892)  29.56
(893)  23.21    (894)  15.65    (895)  13.49    (896)  60.76
(897)  50.80    (898)  40.46    (899)  35.02    (900)  29.21
(901)  22.63    (902)  14.71    (903)  60.56    (904)  50.61
(905)  40.24    (906)  34.75    (907)  28.83    (908)  21.99
(909)  15.94    (910)  60.38    (911)  50.42    (912)  40.03
(913)  34.48    (914)  28.42    (915)  21.31    (916)  17.17
(917)  60.21    (918)  50.25    (919)  39.81    (920)  34.19
(921)  27.95    (922)  20.52    (923)  18.39    (924)  60.05
(925)  50.09    (926)  39.59    (927)  33.88    (928)  27.40
(929)  19.62    (930)  59.91    (931)  49.93    (932)  39.37
(933)  33.54    (934)  26.80    (935)  20.85    (936)  59.77
(937)  49.78    (938)  39.13    (939)  33.16    (940)  26.16
(941)  22.07    (942)  59.63    (943)  49.64    (944)  38.88
(945)  32.72    (946)  25.40    (947)  23.30    (948)  59.51
(949)  49.50    (950)  38.61    (951)  32.21    (952)  24.53
(953)  59.39    (954)  49.35    (955)  38.30    (956)  31.64
(957)  25.75    (958)  59.27    (959)  49.21    (960)  37.95
(961)  31.02    (962)  26.98    (963)  59.14    (964)  49.06
(965)  37.55    (966)  30.28    (967)  28.20    (968)  59.01
(969)  48.89    (970)  37.06    (971)  29.43    (972)  58.85
(973)  48.70    (974)  36.52    (975)  30.66    (976)  58.66
(977)  48.47    (978)  35.91    (979)  31.88    (980)  58.41
(981)  48.17    (982)  35.17    (983)  33.11    (984)  58.05
(985)  47.82    (986)  34.34    (987)  57.58    (988)  47.23
(989)  34.34    (990)  56.80    (991)  46.54    (992)  34.34
(993)  55.62    (994)  45.55    (995)  34.34    (996)  53.96
(997)  44.15    (998)  34.34    (
```

NODAL FLOWS

```
(601)  1.7065E-07  (615) -6.3694E-09  (629) -5.7703E-08  (643) -9.8261E-08
(656) -1.3608E-07  (669) -1.7942E-07  (682) -2.1595E-07  (695) -2.5213E-07
(707) -2.9158E-07  (719) -3.4759E-07  (731) -4.0630E-07  (743) -4.7418E-07
(754) -5.4813E-07  (765) -6.7707E-07  (776) -8.4143E-07  (787) -1.0497E-06
(797) -1.4115E-06  (807) -1.0575E-06  (817) -1.0628E-06  (827) -1.0980E-06
(836) -9.5873E-07  (845) -9.1625E-07  (854) -9.6186E-07  (863) -1.0175E-06
(871) -8.9062E-07  (879) -8.5770E-07  (887) -9.0865E-07  (895) -9.6829E-07
(902) -8.4490E-07  (909) -8.1556E-07  (916) -8.6905E-07  (923) -9.3084E-07
(929) -8.0956E-07  (935) -7.8263E-07  (941) -8.3798E-07  (947) -9.0153E-07
(952) -7.8222E-07  (957) -7.5764E-07  (962) -8.1514E-07  (967) -8.8101E-07
(971) -7.6476E-07  (975) -7.4424E-07  (979) -8.0412E-07  (983) -8.6532E-07
(986) -8.6726E-07  (989) -2.9569E-07  (992) -1.6385E-07  (995) -2.5822E-08
(998) -4.2168E-07  (997) -2.0374E-06  (996) -1.3326E-06  (
```

TOTAL INFLOW = 1.7065E-07
TOTAL OUTFLOW = -3.6042E-05

The following nodes have been deleted from the boundary conditions

601

Time step : **   TIME = 4.8160E+04

The following nodes have been deleted from the boundary conditions

615

Time step : **   TIME = 4.8240E+04

Time step : **   TIME = 4.8320E+04

Time step : **   TIME = 4.8400E+04

Time step : **   TIME = 4.8480E+04

Time step : **   TIME = 4.8560E+04

Time step : **   TIME = 4.8640E+04

Time step : **   TIME = 4.8720E+04

Time step : **   TIME = 4.8800E+04

Time step : **   TIME = 4.8880E+04

Time step : **   TIME = 4.8960E+04

The following nodes have been deleted from the boundary conditions

629

Time step : **   TIME = 4.9040E+04

Time step : **   TIME = 4.9120E+04

Time step : **   TIME = 4.9200E+04

Time step : **   TIME = 4.9280E+04

Time step : **   TIME = 4.9360E+04

Time step : ** TIME =   4.9440E+04

Time step : ** TIME =   4.9520E+04

Time step : ** TIME =   4.9600E+04

Time step : ** TIME =   4.9680E+04

Time step : ** TIME =   4.9760E+04

Time step : ** TIME =   4.9840E+04

Time step : ** TIME =   4.9920E+04

Time step : ** TIME =   5.0000E+04

Time step : ** TIME =   5.0080E+04

Time step : ** TIME =   5.0160E+04

Time step : ** TIME =   5.0240E+04

Time step : ** TIME =   5.0320E+04

Time step : ** TIME =   5.0400E+04

Time step : ** TIME =   5.0480E+04

Time step : ** TIME =   5.0560E+04

Time step : ** TIME =   5.0640E+04

Time step : ** TIME =   5.0720E+04

Time step : ** TIME =   5.0800E+04

Time step : ** TIME =   5.0880E+04

Time step : ** TIME =   5.0960E+04

Time step : ** TIME =   5.1040E+04

The following nodes have been deleted from the boundary conditions

 643

Time step : **   TIME = 5.1120E+04

Time step : **   TIME = 5.1200E+04

Time step : **   TIME = 5.1280E+04

Time step : **   TIME = 5.1360E+04

Time step : **   TIME = 5.1440E+04

Time step : **   TIME = 5.1520E+04

Time step : **   TIME = 5.1600E+04

Time step : **   TIME = 5.1680E+04

Time step : **   TIME = 5.1760E+04

Time step : **   TIME = 5.1840E+04

Time step : **   TIME = 5.1920E+04

Time step : **   TIME = 5.2000E+04

Time step : **   TIME = 5.2080E+04

Time step : **   TIME = 5.2160E+04

Time step : **   TIME = 5.2240E+04

Time step : **   TIME = 5.2320E+04

Time step : **   TIME = 5.2400E+04

Time step : **   TIME = 5.2480E+04

Time step : **   TIME = 5.2560E+04

Time step : **   TIME =   5.2640E+04

Time step : **   TIME =   5.2720E+04

Time step : **   TIME =   5.2800E+04

Time step : **   TIME =   5.2880E+04

Time step : **   TIME =   5.2960E+04

Time step : **   TIME =   5.3040E+04

Time step : **   TIME =   5.3120E+04

Time step : **   TIME =   5.3200E+04

Time step : **   TIME =   5.3280E+04

Time step : **   TIME =   5.3360E+04

Time step : **   TIME =   5.3440E+04

Time step : **   TIME =   5.3520E+04

The following nodes have been deleted from the boundary conditions

 656

Time step : **   TIME =   5.3600E+04

Time step : **   TIME =   5.3680E+04

Time step : **   TIME =   5.3760E+04

Time step : **   TIME =   5.3840E+04

Time step : **   TIME =   5.3920E+04

Time step : **   TIME =   5.4000E+04

TOTAL HEAD = ELEVATION HEAD + PRESSURE HEAD

(1)   9.036   (2)   9.040   (3)   9.051   (4)   9.059
(5)   9.069   (6)   9.081   (7)   9.095   (8)   9.110
(9)   9.127   (10)   9.146   (11)   9.166   (12)   9.188
(13)   9.211   (14)   9.235   (15)   9.261   (16)   9.288
(17)   9.317   (18)   9.347   (19)   9.361   (20)   9.013
(21)   9.016   (22)   9.028   (23)   9.037   (24)   9.047

```
( 25)  9.059   ( 26)  9.073   ( 27)  9.089   ( 28)  9.107
( 29)  9.126   ( 30)  9.147   ( 31)  9.169   ( 32)  9.193
( 33)  9.218   ( 34)  9.244   ( 35)  9.271   ( 36)  9.299
( 37)  9.327   ( 38)  9.341   ( 39)  8.942   ( 40)  8.946
( 41)  8.958   ( 42)  8.968   ( 43)  8.979   ( 44)  8.992
( 45)  9.007   ( 46)  9.025   ( 47)  9.044   ( 48)  9.064
( 49)  9.087   ( 50)  9.112   ( 51)  9.138   ( 52)  9.165
( 53)  9.194   ( 54)  9.225   ( 55)  9.257   ( 56)  9.288
( 57)  9.297   ( 58)  8.888   ( 59)  8.892   ( 60)  8.905
( 61)  8.915   ( 62)  8.927   ( 63)  8.941   ( 64)  8.957
( 65)  8.975   ( 66)  8.995   ( 67)  9.018   ( 68)  9.042
( 69)  9.068   ( 70)  9.096   ( 71)  9.125   ( 72)  9.157
( 73)  9.190   ( 74)  9.225   ( 75)  9.259   ( 76)  9.270
( 77)  8.821   ( 78)  8.825   ( 79)  8.839   ( 80)  8.850
( 81)  8.862   ( 82)  8.877   ( 83)  8.894   ( 84)  8.914
( 85)  8.935   ( 86)  8.959   ( 87)  8.985   ( 88)  9.013
( 89)  9.043   ( 90)  9.075   ( 91)  9.109   ( 92)  9.145
( 93)  9.183   ( 94)  9.220   ( 95)  9.231   ( 96)  8.740
( 97)  8.745   ( 98)  8.760   ( 99)  8.771   (100)  8.784
(101)  8.800   (102)  8.819   (103)  8.839   (104)  8.862
(105)  8.888   (106)  8.916   (107)  8.946   (108)  8.978
(109)  9.013   (110)  9.049   (111)  9.088   (112)  9.129
(113)  9.169   (114)  9.181   (115)  8.646   (116)  8.651
(117)  8.666   (118)  8.678   (119)  8.692   (120)  8.709
(121)  8.729   (122)  8.751   (123)  8.776   (124)  8.803
(125)  8.834   (126)  8.866   (127)  8.901   (128)  8.938
(129)  8.978   (130)  9.019   (131)  9.062   (132)  9.104
(133)  9.117   (134)  8.536   (135)  8.541   (136)  8.558
(137)  8.570   (138)  8.585   (139)  8.604   (140)  8.625
(141)  8.648   (142)  8.675   (143)  8.705   (144)  8.737
(145)  8.773   (146)  8.811   (147)  8.852   (148)  8.895
(149)  8.941   (150)  8.989   (151)  9.029   (152)  9.041
(153)  8.410   (154)  8.416   (155)  8.433   (156)  8.447
(157)  8.463   (158)  8.482   (159)  8.504   (160)  8.530
(161)  8.558   (162)  8.590   (163)  8.625   (164)  8.664
(165)  8.706   (166)  8.751   (167)  8.799   (168)  8.849
(169)  8.903   (170)  8.944   (171)  8.955   (172)  8.269
(173)  8.275   (174)  8.293   (175)  8.306   (176)  8.323
(177)  8.343   (178)  8.367   (179)  8.394   (180)  8.424
(181)  8.458   (182)  8.496   (183)  8.538   (184)  8.584
(185)  8.634   (186)  8.687   (187)  8.744   (188)  8.802
(189)  8.840   (190)  8.852   (191)  8.231   (192)  8.237
(193)  8.255   (194)  8.268   (195)  8.285   (196)  8.306
(197)  8.329   (198)  8.357   (199)  8.388   (200)  8.422
(201)  8.461   (202)  8.504   (203)  8.551   (204)  8.601
(205)  8.656   (206)  8.716   (207)  8.777   (208)  8.813
(209)  8.826   (210)  8.192   (211)  8.198   (212)  8.216
(213)  8.230   (214)  8.247   (215)  8.267   (216)  8.291
(217)  8.319   (218)  8.350   (219)  8.385   (220)  8.425
(221)  8.468   (222)  8.516   (223)  8.568   (224)  8.625
(225)  8.686   (226)  8.749   (227)  8.787   (228)  8.800
(229)  8.152   (230)  8.158   (231)  8.176   (232)  8.190
(233)  8.207   (234)  8.227   (235)  8.251   (236)  8.279
(237)  8.311   (238)  8.347   (239)  8.387   (240)  8.431
(241)  8.480   (242)  8.533   (243)  8.591   (244)  8.654
(245)  8.720   (246)  8.759   (247)  8.774   (248)  8.110
(249)  8.116   (250)  8.135   (251)  8.148   (252)  8.166
(253)  8.186   (254)  8.211   (255)  8.239   (256)  8.271
(257)  8.307   (258)  8.348   (259)  8.393   (260)  8.443
(261)  8.497   (262)  8.557   (263)  8.621   (264)  8.689
(265)  8.731   (266)  8.752   (267)  8.068   (268)  8.074
(269)  8.092   (270)  8.106   (271)  8.123   (272)  8.144
(273)  8.168   (274)  8.197   (275)  8.229   (276)  8.266
(277)  8.307   (278)  8.353   (279)  8.404   (280)  8.460
(281)  8.521   (282)  8.587   (283)  8.656   (284)  8.700
(285)  8.722   (286)  8.025   (287)  8.031   (288)  8.049
(289)  8.063   (290)  8.080   (291)  8.101   (292)  8.125
(293)  8.154   (294)  8.186   (295)  8.223   (296)  8.265
(297)  8.312   (298)  8.363   (299)  8.420   (300)  8.483
(301)  8.550   (302)  8.621   (303)  8.667   (304)  8.684
(305)  7.981   (306)  7.987   (307)  8.004   (308)  8.018
(309)  8.035   (310)  8.056   (311)  8.081   (312)  8.109
(313)  8.142   (314)  8.180   (315)  8.222   (316)  8.269
(317)  8.322   (318)  8.380   (319)  8.444   (320)  8.513
(321)  8.583   (322)  8.631   (323)  8.641   (324)  7.935
(325)  7.941   (326)  7.959   (327)  7.972   (328)  7.989
(329)  8.010   (330)  8.035   (331)  8.063   (332)  8.096
(333)  8.134   (334)  8.177   (335)  8.225   (336)  8.278
(337)  8.337   (338)  8.402   (339)  8.475   (340)  8.543
(341)  8.592   (342)  7.889   (343)  7.895   (344)  7.912
(345)  7.926   (346)  7.942   (347)  7.963   (348)  7.987
(349)  8.016   (350)  8.049   (351)  8.087   (352)  8.130
```

(353)	8.179	(354)	8.233	(355)	8.293	(356)	8.360
(357)	8.434	(358)	8.501	(359)	8.537	(360)	7.842
(361)	7.847	(362)	7.864	(363)	7.878	(364)	7.894
(365)	7.915	(366)	7.939	(367)	7.968	(368)	8.001
(369)	8.039	(370)	8.082	(371)	8.131	(372)	8.186
(373)	8.247	(374)	8.315	(375)	8.389	(376)	8.456
(377)	8.481	(378)	7.793	(379)	7.799	(380)	7.815
(381)	7.828	(382)	7.845	(383)	7.865	(384)	7.889
(385)	7.918	(386)	7.951	(387)	7.989	(388)	8.033
(389)	8.082	(390)	8.137	(391)	8.199	(392)	8.268
(393)	8.343	(394)	8.408	(395)	8.421	(396)	7.744
(397)	7.749	(398)	7.765	(399)	7.778	(400)	7.794
(401)	7.814	(402)	7.838	(403)	7.866	(404)	7.899
(405)	7.937	(406)	7.981	(407)	8.031	(408)	8.087
(409)	8.149	(410)	8.219	(411)	8.296	(412)	8.357
(413)	7.693	(414)	7.698	(415)	7.714	(416)	7.727
(417)	7.742	(418)	7.762	(419)	7.785	(420)	7.813
(421)	7.846	(422)	7.884	(423)	7.928	(424)	7.978
(425)	8.035	(426)	8.098	(427)	8.168	(428)	8.245
(429)	8.289	(430)	7.642	(431)	7.647	(432)	7.662
(433)	7.674	(434)	7.689	(435)	7.708	(436)	7.731
(437)	7.759	(438)	7.791	(439)	7.829	(440)	7.873
(441)	7.924	(442)	7.980	(443)	8.044	(444)	8.114
(445)	8.190	(446)	8.221	(447)	7.590	(448)	7.595
(449)	7.609	(450)	7.620	(451)	7.635	(452)	7.653
(453)	7.676	(454)	7.703	(455)	7.735	(456)	7.773
(457)	7.817	(458)	7.867	(459)	7.924	(460)	7.988
(461)	8.058	(462)	8.133	(463)	8.149	(464)	7.537
(465)	7.541	(466)	7.555	(467)	7.565	(468)	7.579
(469)	7.597	(470)	7.619	(471)	7.645	(472)	7.677
(473)	7.715	(474)	7.758	(475)	7.809	(476)	7.866
(477)	7.930	(478)	8.001	(479)	8.074	(480)	7.483
(481)	7.487	(482)	7.499	(483)	7.510	(484)	7.523
(485)	7.540	(486)	7.560	(487)	7.586	(488)	7.617
(489)	7.654	(490)	7.698	(491)	7.749	(492)	7.806
(493)	7.871	(494)	7.942	(495)	7.995	(496)	7.428
(497)	7.432	(498)	7.443	(499)	7.453	(500)	7.465
(501)	7.481	(502)	7.501	(503)	7.526	(504)	7.556
(505)	7.593	(506)	7.636	(507)	7.686	(508)	7.744
(509)	7.809	(510)	7.880	(511)	7.915	(512)	7.373
(513)	7.376	(514)	7.386	(515)	7.395	(516)	7.406
(517)	7.421	(518)	7.439	(519)	7.463	(520)	7.493
(521)	7.529	(522)	7.572	(523)	7.622	(524)	7.680
(525)	7.746	(526)	7.817	(527)	7.834	(528)	7.317
(529)	7.319	(530)	7.328	(531)	7.336	(532)	7.346
(533)	7.359	(534)	7.377	(535)	7.399	(536)	7.428
(537)	7.463	(538)	7.505	(539)	7.556	(540)	7.614
(541)	7.681	(542)	7.753	(543)	7.260	(544)	7.262
(545)	7.269	(546)	7.276	(547)	7.285	(548)	7.297
(549)	7.313	(550)	7.334	(551)	7.361	(552)	7.395
(553)	7.437	(554)	7.487	(555)	7.546	(556)	7.613
(557)	7.668	(558)	7.203	(559)	7.204	(560)	7.210
(561)	7.215	(562)	7.222	(563)	7.233	(564)	7.247
(565)	7.266	(566)	7.292	(567)	7.325	(568)	7.366
(569)	7.416	(570)	7.476	(571)	7.544	(572)	7.580
(573)	7.145	(574)	7.146	(575)	7.150	(576)	7.153
(577)	7.159	(578)	7.167	(579)	7.180	(580)	7.197
(581)	7.221	(582)	7.252	(583)	7.293	(584)	7.343
(585)	7.403	(586)	7.472	(587)	7.490	(588)	7.087
(589)	7.087	(590)	7.089	(591)	7.091	(592)	7.095
(593)	7.101	(594)	7.111	(595)	7.126	(596)	7.148
(597)	7.177	(598)	7.216	(599)	7.267	(600)	7.328
(601)	7.399	(602)	7.029	(603)	7.028	(604)	7.027
(605)	7.028	(606)	7.030	(607)	7.034	(608)	7.041
(609)	7.053	(610)	7.072	(611)	7.100	(612)	7.137
(613)	7.188	(614)	7.251	(615)	7.306	(616)	6.970
(617)	6.969	(618)	6.966	(619)	6.964	(620)	6.964
(621)	6.965	(622)	6.970	(623)	6.979	(624)	6.995
(625)	7.019	(626)	7.055	(627)	7.105	(628)	7.171
(629)	7.209	(630)	6.912	(631)	6.909	(632)	6.903
(633)	6.900	(634)	6.897	(635)	6.896	(636)	6.897
(637)	6.903	(638)	6.915	(639)	6.936	(640)	6.969
(641)	7.018	(642)	7.087	(643)	7.108	(644)	6.853
(645)	6.850	(646)	6.841	(647)	6.836	(648)	6.830
(649)	6.825	(650)	6.823	(651)	6.825	(652)	6.832
(653)	6.850	(654)	6.879	(655)	6.925	(656)	6.998
(657)	6.794	(658)	6.790	(659)	6.779	(660)	6.771
(661)	6.762	(662)	6.754	(663)	6.748	(664)	6.745
(665)	6.748	(666)	6.760	(667)	6.785	(668)	6.828
(669)	6.875	(670)	6.736	(671)	6.731	(672)	6.716
(673)	6.706	(674)	6.695	(675)	6.683	(676)	6.671
(677)	6.663	(678)	6.661	(679)	6.667	(680)	6.687

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(681)  6.724   (682)  6.750   (683)  6.678   (684)  6.672
(685)  6.654   (686)  6.642   (687)  6.627   (688)  6.610
(689)  6.594   (690)  6.580   (691)  6.571   (692)  6.571
(693)  6.584   (694)  6.615   (695)  6.625   (696)  6.621
(697)  6.614   (698)  6.593   (699)  6.577   (700)  6.559
(701)  6.538   (702)  6.517   (703)  6.496   (704)  6.479
(705)  6.471   (706)  6.477   (707)  6.500   (708)  6.564
(709)  6.556   (710)  6.532   (711)  6.514   (712)  6.492
(713)  6.466   (714)  6.438   (715)  6.410   (716)  6.385
(717)  6.368   (718)  6.366   (719)  6.375   (720)  6.508
(721)  6.499   (722)  6.472   (723)  6.451   (724)  6.425
(725)  6.395   (726)  6.360   (727)  6.324   (728)  6.289
(729)  6.262   (730)  6.249   (731)  6.250   (732)  6.454
(733)  6.443   (734)  6.412   (735)  6.389   (736)  6.359
(737)  6.324   (738)  6.283   (739)  6.238   (740)  6.191
(741)  6.151   (742)  6.128   (743)  6.125   (744)  6.400
(745)  6.388   (746)  6.354   (747)  6.328   (748)  6.295
(749)  6.255   (750)  6.207   (751)  6.151   (752)  6.092
(753)  6.036   (754)  6.000   (755)  6.347   (756)  6.335
(757)  6.297   (758)  6.269   (759)  6.232   (760)  6.187
(761)  6.132   (762)  6.067   (763)  5.991   (764)  5.917
(765)  5.875   (766)  6.295   (767)  6.282   (768)  6.242
(769)  6.211   (770)  6.171   (771)  6.122   (772)  6.060
(773)  5.985   (774)  5.891   (775)  5.791   (776)  5.750
(777)  6.245   (778)  6.231   (779)  6.189   (780)  6.155
(781)  6.113   (782)  6.059   (783)  5.992   (784)  5.908
(785)  5.795   (786)  5.657   (787)  5.625   (788)  6.197
(789)  6.182   (790)  6.137   (791)  6.102   (792)  6.057
(793)  6.000   (794)  5.928   (795)  5.835   (796)  5.717
(797)  5.500   (798)  6.150   (799)  6.135   (800)  6.088
(801)  6.051   (802)  6.003   (803)  5.944   (804)  5.868
(805)  5.771   (806)  5.639   (807)  5.500   (808)  6.104
(809)  6.089   (810)  6.040   (811)  6.002   (812)  5.953
(813)  5.891   (814)  5.813   (815)  5.714   (816)  5.581
(817)  5.500   (818)  6.061   (819)  6.045   (820)  5.995
(821)  5.956   (822)  5.906   (823)  5.843   (824)  5.764
(825)  5.664   (826)  5.536   (827)  5.500   (828)  6.019
(829)  6.003   (830)  5.952   (831)  5.913   (832)  5.862
(833)  5.798   (834)  5.719   (835)  5.621   (836)  5.500
(837)  5.979   (838)  5.962   (839)  5.912   (840)  5.872
(841)  5.821   (842)  5.758   (843)  5.680   (844)  5.584
(845)  5.500   (846)  5.941   (847)  5.924   (848)  5.873
(849)  5.834   (850)  5.783   (851)  5.720   (852)  5.644
(853)  5.552   (854)  5.500   (855)  5.905   (856)  5.888
(857)  5.837   (858)  5.798   (859)  5.748   (860)  5.687
(861)  5.612   (862)  5.524   (863)  5.500   (864)  5.870
(865)  5.854   (866)  5.804   (867)  5.765   (868)  5.716
(869)  5.656   (870)  5.584   (871)  5.500   (872)  5.838
(873)  5.822   (874)  5.772   (875)  5.734   (876)  5.686
(877)  5.628   (878)  5.559   (879)  5.500   (880)  5.807
(881)  5.791   (882)  5.743   (883)  5.706   (884)  5.659
(885)  5.603   (886)  5.537   (887)  5.500   (888)  5.778
(889)  5.763   (890)  5.716   (891)  5.680   (892)  5.635
(893)  5.581   (894)  5.517   (895)  5.500   (896)  5.752
(897)  5.737   (898)  5.691   (899)  5.656   (900)  5.612
(901)  5.561   (902)  5.500   (903)  5.726   (904)  5.712
(905)  5.668   (906)  5.634   (907)  5.592   (908)  5.542
(909)  5.500   (910)  5.703   (911)  5.689   (912)  5.646
(913)  5.614   (914)  5.574   (915)  5.526   (916)  5.500
(917)  5.681   (918)  5.668   (919)  5.627   (920)  5.596
(921)  5.558   (922)  5.512   (923)  5.500   (924)  5.661
(925)  5.648   (926)  5.609   (927)  5.579   (928)  5.543
(929)  5.500   (930)  5.643   (931)  5.630   (932)  5.593
(933)  5.565   (934)  5.530   (935)  5.500   (936)  5.626
(937)  5.614   (938)  5.578   (939)  5.551   (940)  5.518
(941)  5.500   (942)  5.610   (943)  5.599   (944)  5.565
(945)  5.540   (946)  5.508   (947)  5.500   (948)  5.596
(949)  5.585   (950)  5.553   (951)  5.529   (952)  5.500
(953)  5.583   (954)  5.573   (955)  5.543   (956)  5.520
(957)  5.500   (958)  5.571   (959)  5.562   (960)  5.533
(961)  5.512   (962)  5.500   (963)  5.560   (964)  5.552
(965)  5.525   (966)  5.506   (967)  5.500   (968)  5.551
(969)  5.543   (970)  5.518   (971)  5.500   (972)  5.542
(973)  5.535   (974)  5.512   (975)  5.500   (976)  5.535
(977)  5.528   (978)  5.507   (979)  5.500   (980)  5.528
(981)  5.522   (982)  5.503   (983)  5.500   (984)  5.521
(985)  5.517   (986)  5.500   (987)  5.515   (988)  5.512
(989)  5.500   (990)  5.510   (991)  5.508   (992)  5.500
(993)  5.505   (994)  5.504   (995)  5.500   (996)  5.500
(997)  5.500   (998)  5.500   (
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PORE PRESSURE

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(  1)  88.64    (  2)  78.87    (  3)  69.17    (  4)  64.35
(  5)  59.54    (  6)  54.75    (  7)  49.98    (  8)  45.23
(  9)  40.49    ( 10)  35.77    ( 11)  31.06    ( 12)  26.37
( 13)  21.69    ( 14)  17.02    ( 15)  12.37    ( 16)  7.732
( 17)  3.108    ( 18)  -1.498   ( 19)  -6.265   ( 20)  88.41
( 21)  78.64    ( 22)  68.94    ( 23)  64.12    ( 24)  59.32
( 25)  54.54    ( 26)  49.77    ( 27)  45.02    ( 28)  40.29
( 29)  35.57    ( 30)  30.87    ( 31)  26.18    ( 32)  21.51
( 33)  16.85    ( 34)  12.20    ( 35)  7.564    ( 36)  2.932
( 37)  -1.693   ( 38)  -6.462   ( 39)  87.72    ( 40)  77.95
( 41)  68.26    ( 42)  63.45    ( 43)  58.65    ( 44)  53.88
( 45)  49.12    ( 46)  44.39    ( 47)  39.67    ( 48)  34.97
( 49)  30.29    ( 50)  25.62    ( 51)  20.97    ( 52)  16.34
( 53)  11.72    ( 54)  7.112    ( 55)  2.521    ( 56)  -2.084
( 57)  -6.899   ( 58)  87.19    ( 59)  77.42    ( 60)  67.74
( 61)  62.93    ( 62)  58.14    ( 63)  53.38    ( 64)  48.63
( 65)  43.90    ( 66)  39.19    ( 67)  34.51    ( 68)  29.84
( 69)  25.19    ( 70)  20.56    ( 71)  15.94    ( 72)  11.35
( 73)  6.767    ( 74)  2.206    ( 75)  -2.363   ( 76)  -7.166
( 77)  86.53    ( 78)  76.77    ( 79)  67.09    ( 80)  62.29
( 81)  57.51    ( 82)  52.75    ( 83)  48.01    ( 84)  43.30
( 85)  38.60    ( 86)  33.93    ( 87)  29.28    ( 88)  24.65
( 89)  20.04    ( 90)  15.45    ( 91)  10.87    ( 92)  6.323
( 93)  1.791    ( 94)  -2.747   ( 95)  -7.540   ( 96)  85.74
( 97)  75.98    ( 98)  66.31    ( 99)  61.52    (100)  56.74
(101)  52.00    (102)  47.27    (103)  42.57    (104)  37.89
(105)  33.23    (106)  28.60    (107)  23.99    (108)  19.40
(109)  14.84    (110)  10.29    (111)  5.765    (112)  1.261
(113)  -3.246   (114)  -8.030   (115)  84.81    (116)  75.05
(117)  65.40    (118)  60.61    (119)  55.84    (120)  51.10
(121)  46.39    (122)  41.70    (123)  37.04    (124)  32.41
(125)  27.80    (126)  23.21    (127)  18.65    (128)  14.11
(129)  9.593    (130)  5.095    (131)  0.6081   (132)  -3.884
(133)  -8.661   (134)  83.74    (135)  73.98    (136)  64.33
(137)  59.55    (138)  54.79    (139)  50.07    (140)  45.37
(141)  40.70    (142)  36.05    (143)  31.44    (144)  26.85
(145)  22.29    (146)  17.76    (147)  13.26    (148)  8.779
(149)  4.323    (150) -0.1106   (151)  -4.625   (152)  -9.412
(153)  82.51    (154)  72.75    (155)  63.11    (156)  58.34
(157)  53.59    (158)  48.87    (159)  44.19    (160)  39.53
(161)  34.91    (162)  30.32    (163)  25.76    (164)  21.23
(165)  16.73    (166)  12.27    (167)  7.834    (168)  3.426
(169) -0.9499   (170)  -5.457   (171)  -10.25   (172)  81.12
(173)  71.36    (174)  61.73    (175)  56.96    (176)  52.22
(177)  47.51    (178)  42.84    (179)  38.20    (180)  33.59
(181)  29.02    (182)  24.49    (183)  19.99    (184)  15.54
(185)  11.12    (186)  6.740    (187)  2.394    (188)  -1.943
(189)  -6.475   (190)  -11.26   (191)  80.74    (192)  70.99
(193)  61.36    (194)  56.59    (195)  51.85    (196)  47.14
(197)  42.47    (198)  37.83    (199)  33.23    (200)  28.67
(201)  24.14    (202)  19.66    (203)  15.21    (204)  10.81
(205)  6.440    (206)  2.115    (207)  -2.189   (208)  -6.735
(209)  -11.52   (210)  80.36    (211)  70.61    (212)  60.98
(213)  56.21    (214)  51.47    (215)  46.76    (216)  42.09
(217)  37.46    (218)  32.86    (219)  28.30    (220)  23.79
(221)  19.31    (222)  14.87    (223)  10.48    (224)  6.127
(225)  1.822    (226)  -2.459   (227)  -6.997   (228)  -11.78
(229)  79.97    (230)  70.22    (231)  60.58    (232)  55.81
(233)  51.08    (234)  46.37    (235)  41.71    (236)  37.07
(237)  32.48    (238)  27.93    (239)  23.41    (240)  18.94
(241)  14.52    (242)  10.14    (243)  5.801    (244)  1.514
(245)  -2.747   (246)  -7.265   (247)  -12.03   (248)  79.56
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(253)  45.97    (254)  41.31    (255)  36.68    (256)  32.09
(257)  27.54    (258)  23.03    (259)  18.57    (260)  14.15
(261)  9.782    (262)  5.461    (263)  1.189    (264)  -3.053
(265)  -7.548   (266)  -12.24   (267)  79.15    (268)  69.40
(269)  59.77    (270)  55.00    (271)  50.26    (272)  45.56
(273)  40.89    (274)  36.27    (275)  31.68    (276)  27.13
(277)  22.63    (278)  18.18    (279)  13.77    (280)  9.413
(281)  5.106    (282)  0.8495   (283)  -3.377   (284)  -7.850
(285)  -11.31   (286)  78.73    (287)  68.97    (288)  59.34
(289)  54.57    (290)  49.83    (291)  45.13    (292)  40.47
(293)  35.84    (294)  31.26    (295)  26.72    (296)  22.22
(297)  17.77    (298)  13.38    (299)  9.029    (300)  4.737
(301)  0.4944   (302)  -3.722   (303)  -8.173   (304)  -10.45
(305)  78.29    (306)  68.54    (307)  58.90    (308)  54.13
(309)  49.40    (310)  44.69    (311)  40.03    (312)  35.41
(313)  30.82    (314)  26.29    (315)  21.80    (316)  17.35
(317)  12.97    (318)  8.630    (319)  4.352    (320)  0.1287
(321)  -4.093   (322)  -8.528   (323)  -9.657   (324)  77.85
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(329)  44.24    (330)  39.58    (331)  34.96    (332)  30.38
(333)  25.84    (334)  21.36    (335)  16.92    (336)  12.54
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(341)  -8.912   (342)  77.39    (343)  67.64    (344)  58.00
(345)  53.22    (346)  48.49    (347)  43.78    (348)  39.12
(349)  34.49    (350)  29.91    (351)  25.38    (352)  20.90
(353)  16.47    (354)  12.10    (355)   7.780   (356)   3.527
(357) -0.6521   (358)  -4.894   (359)  -8.216   (360)  76.93
(361)  67.17    (362)  57.53    (363)  52.75    (364)  48.01
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(369)  24.91    (370)  20.43    (371)  16.00    (372)  11.64
(373)   7.329   (374)   3.087   (375)  -1.086   (376)  -5.334
(377)  -7.546   (378)  76.45    (379)  66.69    (380)  57.05
(381)  52.27    (382)  47.53    (383)  42.82    (384)  38.15
(385)  33.53    (386)  28.95    (387)  24.42    (388)  19.94
(389)  15.52    (390)  11.16    (391)   6.859   (392)   2.628
(393)  -1.540   (394)  -5.809   (395)  -6.909   (396)  75.97
(397)  66.21    (398)  56.56    (399)  51.78    (400)  47.03
(401)  42.32    (402)  37.65    (403)  33.02    (404)  28.44
(405)  23.91    (406)  19.44    (407)  15.02    (408)  10.66
(409)   6.370   (410)   2.149   (411)  -2.005   (412)  -6.312
(413)  75.47    (414)  65.71    (415)  56.06    (416)  51.27
(417)  46.52    (418)  41.81    (419)  37.13    (420)  32.50
(421)  27.92    (422)  23.39    (423)  18.92    (424)  14.50
(425)  10.15    (426)   5.862   (427)   1.646   (428)  -2.505
(429)  -5.745   (430)  74.97    (431)  65.21    (432)  55.54
(433)  50.76    (434)  46.00    (435)  41.28    (436)  36.60
(437)  31.97    (438)  27.38    (439)  22.85    (440)  18.38
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(445)  -3.039   (446)  -5.187   (447)  74.46    (448)  64.69
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(453)  36.06    (454)  31.42    (455)  26.83    (456)  22.30
(457)  17.82    (458)  13.41    (459)   9.066   (460)   4.787
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(465)  64.17    (466)  54.49    (467)  49.69    (468)  44.92
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(473)  21.73    (474)  17.25    (475)  12.84    (476)   8.497
(477)   4.221   (478) 9.0695E-03 (479) -4.183   (480)  73.41
(481)  63.64    (482)  53.95    (483)  49.14    (484)  44.37
(485)  39.63    (486)  34.93    (487)  30.28    (488)  25.68
(489)  21.14    (490)  16.66    (491)  12.25    (492)   7.909
(493)   3.635   (494) -0.5678   (495)  -3.730   (496)  72.87
(497)  63.10    (498)  53.40    (499)  48.58    (500)  43.80
(501)  39.05    (502)  34.34    (503)  29.68    (504)  25.07
(505)  20.53    (506)  16.05    (507)  11.64    (508)   7.301
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(525)   2.413   (526)  -1.791   (527)  -2.854   (528)  71.78
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(545)  51.69    (546)  46.85    (547)  42.03    (548)  37.24
(549)  32.50    (550)  27.80    (551)  23.16    (552)  18.59
(553)  14.09    (554)   9.685   (555)   5.358   (556)   1.112
(557)  -2.033   (558)  70.66    (559)  60.86    (560)  51.11
(561)  46.25    (562)  41.42    (563)  36.62    (564)  31.85
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(577)  40.80    (578)  35.98    (579)  31.19    (580)  26.46
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(589)  59.72    (590)  49.92    (591)  45.04    (592)  40.17
(593)  35.33    (594)  30.52    (595)  25.76    (596)  21.07
(597)  16.45    (598)  11.93    (599)   7.523   (600)   3.221
(601) -0.9931   (602)  68.95    (603)  59.14    (604)  49.32
(605)  44.42    (606)  39.53    (607)  34.67    (608)  29.83
(609)  25.05    (610)  20.33    (611)  15.69    (612)  11.16
(613)   6.746   (614)   2.463   (615) -0.6786   (616)  68.38
(617)  58.55    (618)  48.71    (619)  43.79    (620)  38.88
(621)  33.99    (622)  29.13    (623)  24.32    (624)  19.57
(625)  14.90    (626)  10.35    (627)   5.934   (628)   1.676
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(633)  43.16    (634)  38.23    (635)  33.31    (636)  28.42
(637)  23.57    (638)  18.78    (639)  14.09    (640)   9.506
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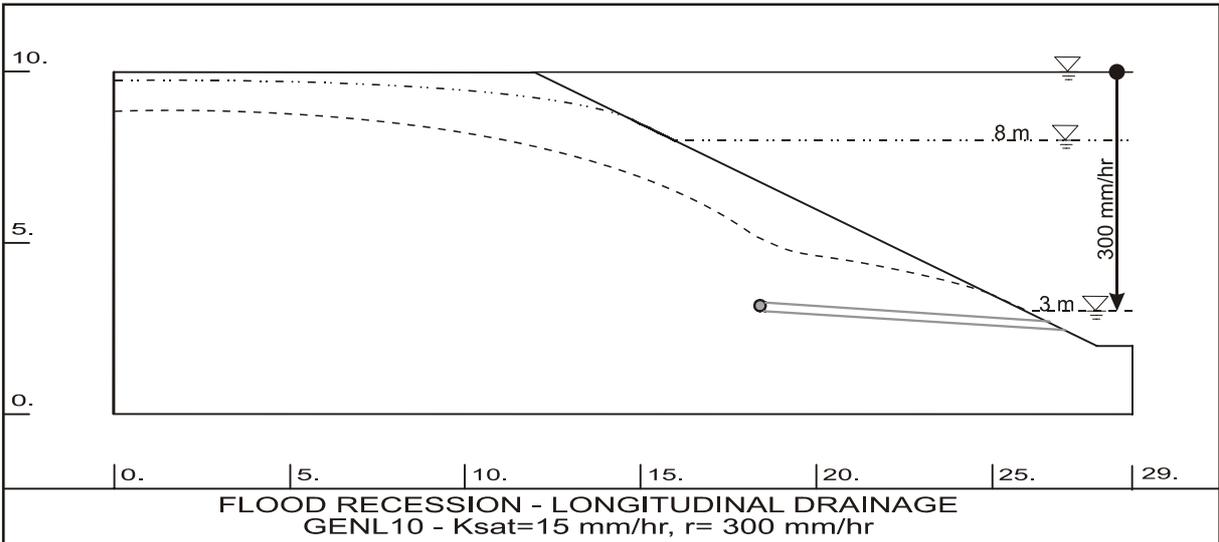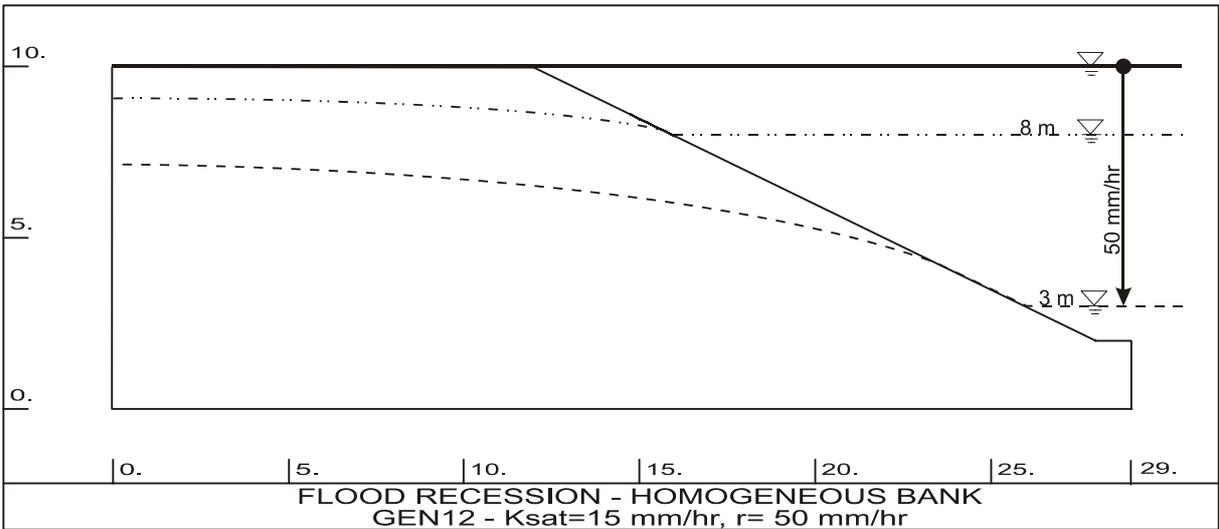
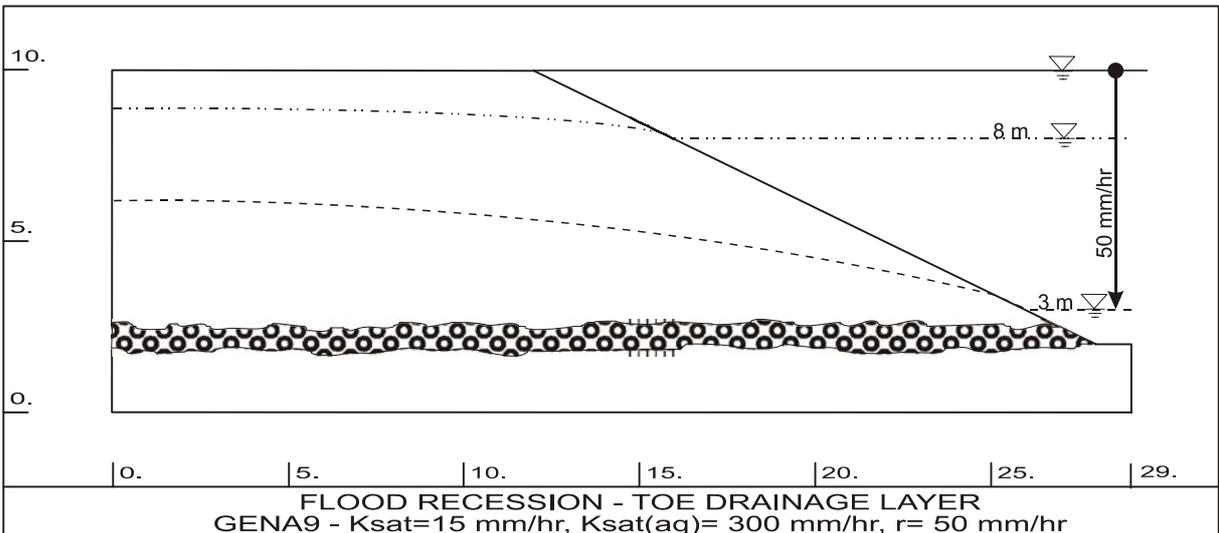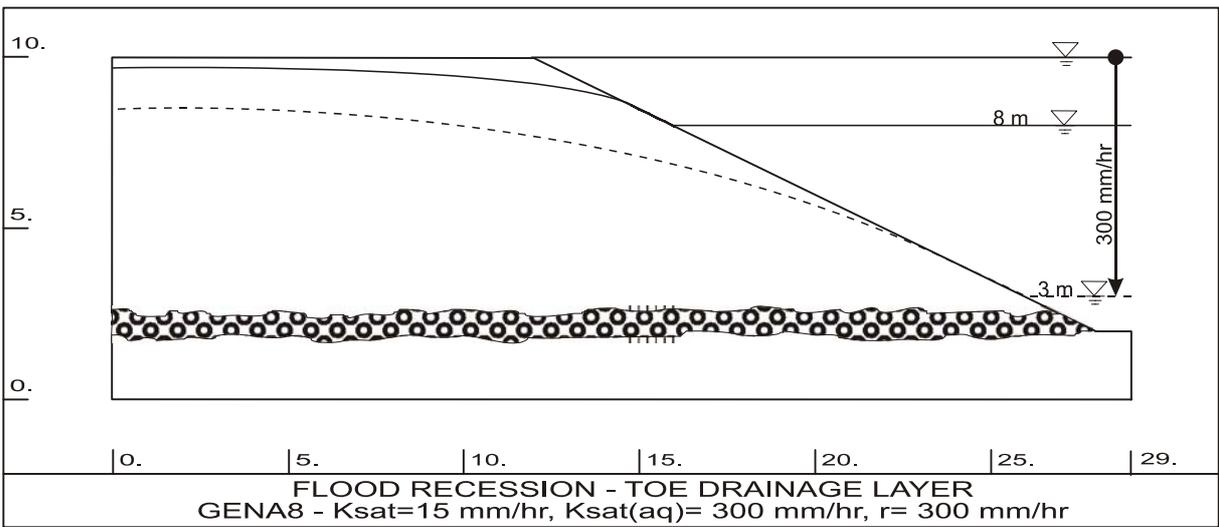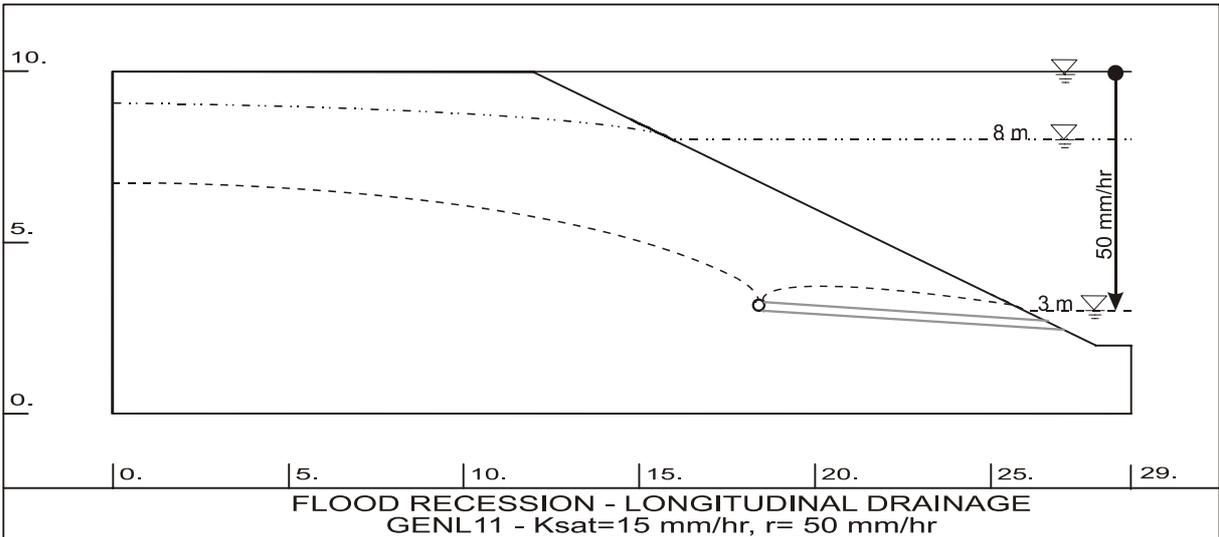|			
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(657) 66.65	(658) 56.80	(659) 46.88	(660) 41.90
(661) 36.91	(662) 31.92	(663) 26.95	(664) 22.02
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(669) 0.0000	(670) 66.08	(671) 56.22	(672) 46.27
(673) 41.26	(674) 36.24	(675) 31.22	(676) 26.21
(677) 21.22	(678) 16.29	(679) 11.45	(680) 6.738
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(685) 45.66	(686) 40.63	(687) 35.58	(688) 30.51
(689) 25.45	(690) 20.41	(691) 15.41	(692) 10.51
(693) 5.730	(694) 1.126	(695) 0.0000	(696) 64.95
(697) 55.07	(698) 45.06	(699) 40.00	(700) 34.91
(701) 29.81	(702) 24.69	(703) 19.58	(704) 14.51
(705) 9.530	(706) 4.678	(707) 0.0000	(708) 64.40
(709) 54.51	(710) 44.46	(711) 39.37	(712) 34.25
(713) 29.10	(714) 23.92	(715) 18.74	(716) 13.59
(717) 8.519	(718) 3.586	(719) 0.0000	(720) 63.85
(721) 53.95	(722) 43.87	(723) 38.75	(724) 33.60
(725) 28.40	(726) 23.16	(727) 17.89	(728) 12.65
(729) 7.473	(730) 2.446	(731) 0.0000	(732) 63.31
(733) 53.40	(734) 43.28	(735) 38.15	(736) 32.95
(737) 27.70	(738) 22.40	(739) 17.04	(740) 11.68
(741) 6.388	(742) 1.255	(743) 0.0000	(744) 62.78
(745) 52.86	(746) 42.71	(747) 37.55	(748) 32.32
(749) 27.02	(750) 21.65	(751) 16.20	(752) 10.71
(753) 5.260	(754) 0.0000	(755) 62.26	(756) 52.33
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(761) 20.92	(762) 15.37	(763) 9.722	(764) 4.089
(765) 0.0000	(766) 61.76	(767) 51.82	(768) 41.62
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(789) 50.84	(790) 40.59	(791) 35.34	(792) 29.99
(793) 24.52	(794) 18.91	(795) 13.10	(796) 7.033
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(817) 2.453	(818) 59.46	(819) 49.49	(820) 39.19
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(825) 11.42	(826) 5.259	(827) 3.679	(828) 59.04
(829) 49.08	(830) 38.77	(831) 33.48	(832) 28.08
(833) 22.55	(834) 16.87	(835) 11.00	(836) 4.905
(837) 58.65	(838) 48.68	(839) 38.37	(840) 33.08
(841) 27.67	(842) 22.15	(843) 16.48	(844) 10.63
(845) 6.131	(846) 58.28	(847) 48.31	(848) 38.00
(849) 32.70	(850) 27.30	(851) 21.78	(852) 16.13
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(865) 47.62	(866) 37.31	(867) 32.03	(868) 26.64
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(873) 47.30	(874) 37.01	(875) 31.73	(876) 26.35
(877) 20.88	(878) 15.29	(879) 11.04	(880) 56.97
(881) 47.00	(882) 36.72	(883) 31.45	(884) 26.09
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(889) 46.73	(890) 36.45	(891) 31.19	(892) 25.85
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(909) 15.94	(910) 55.95	(911) 46.00	(912) 35.77
(913) 30.55	(914) 25.25	(915) 19.88	(916) 17.17
(917) 55.73	(918) 45.79	(919) 35.58	(920) 30.37
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(925) 45.60	(926) 35.40	(927) 30.21	(928) 24.95
(929) 19.62	(930) 55.35	(931) 45.42	(932) 35.24
(933) 30.06	(934) 24.82	(935) 20.85	(936) 55.19
(937) 45.26	(938) 35.10	(939) 29.93	(940) 24.71
(941) 22.07	(942) 55.03	(943) 45.11	(944) 34.97
(945) 29.82	(946) 24.61	(947) 23.30	(948) 54.89
(949) 44.98	(950) 34.86	(951) 29.72	(952) 24.53
(953) 54.77	(954) 44.86	(955) 34.75	(956) 29.63
(957) 25.75	(958) 54.65	(959) 44.75	(960) 34.66
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(969) 44.57	(970) 34.52	(971) 29.43	(972) 54.37
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NODAL FLOWS

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(807) -5.4041E-07  (817) -4.5290E-07  (827) -3.9515E-07  (836) -3.4970E-07
(845) -3.0781E-07  (854) -2.8044E-07  (863) -2.5793E-07  (871) -2.3716E-07
(879) -2.1466E-07  (887) -1.9818E-07  (895) -1.8385E-07  (902) -1.7003E-07
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(989) -1.4491E-08  (992) -9.1263E-09  (995) -4.4175E-09  (998) -1.0910E-08
(997) -5.4498E-08  (996) -3.7734E-08  (
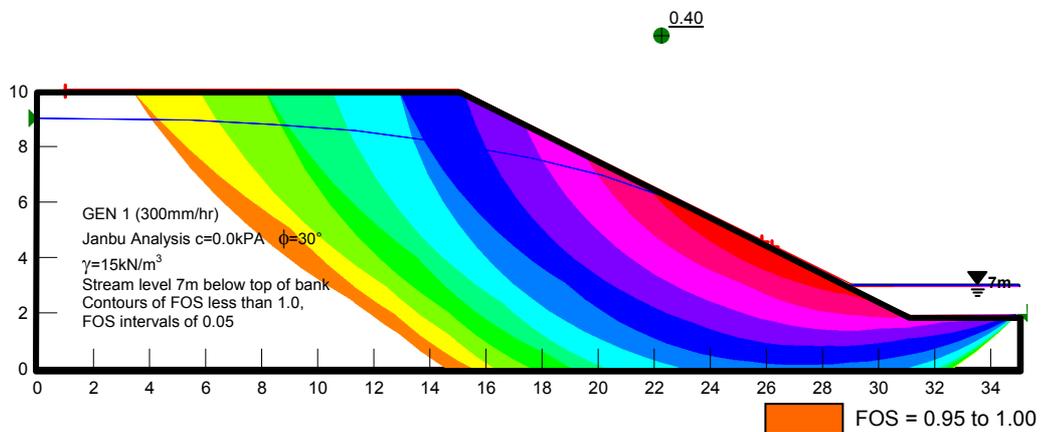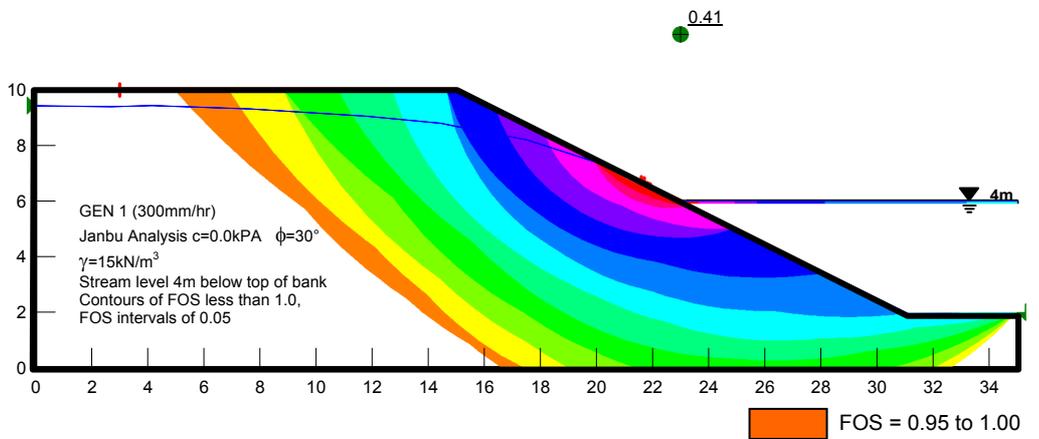```
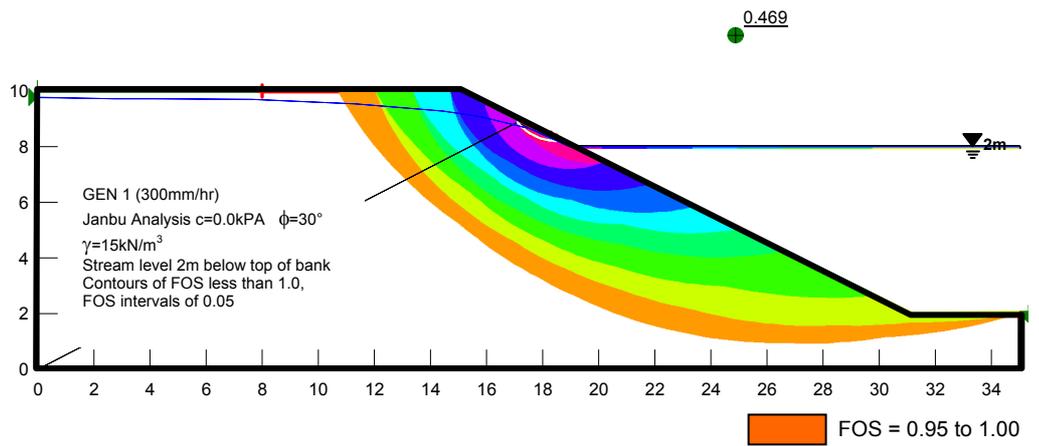
**TOTAL INFLOW**  =   0.0000
**TOTAL OUTFLOW** = -8.9183E-06

FLOOD RECESSION - HOMOGENEOUS BANK
GEN1 - Ksat=15 mm/hr, r= 300 mm/hr



FLOOD RECESSION - HOMOGENEOUS BANK
GEN12 - Ksat=15 mm/hr, r= 50 mm/hr



FLOOD RECESSION - LONGITUDINAL DRAINAGE
GENL10 - Ksat=15 mm/hr, r= 300 mm/hr

FLOOD RECESSION - LONGITUDINAL DRAINAGE
GENL11 - Ksat=15 mm/hr, r= 50 mm/hr



FLOOD RECESSION - TOE DRAINAGE LAYER
GENA8 - Ksat=15 mm/hr, Ksat(aq)= 300 mm/hr, r= 300 mm/hr
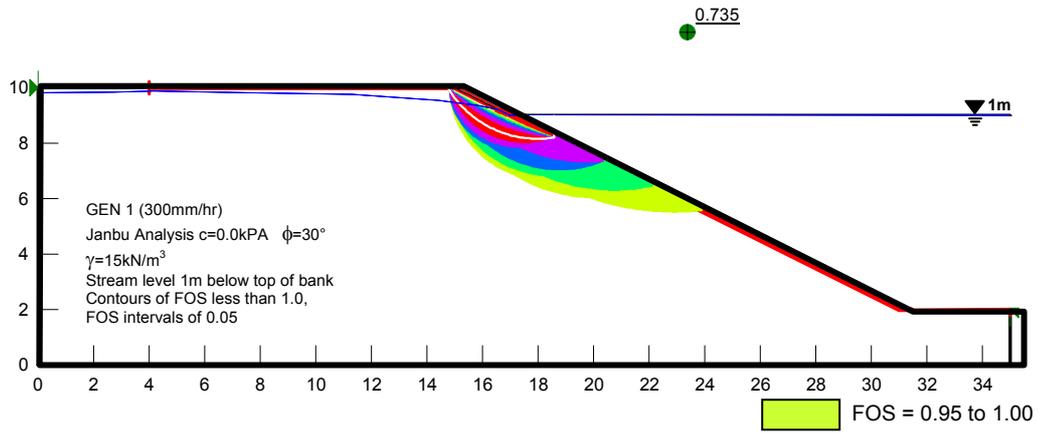


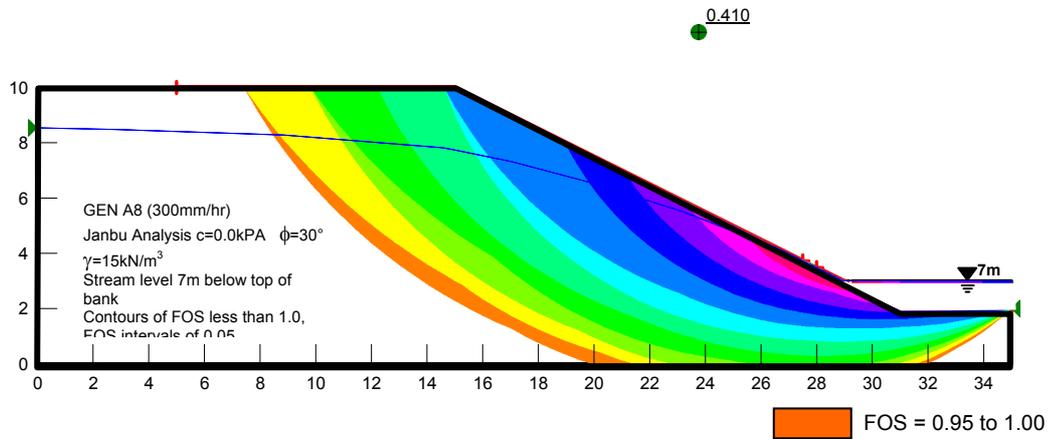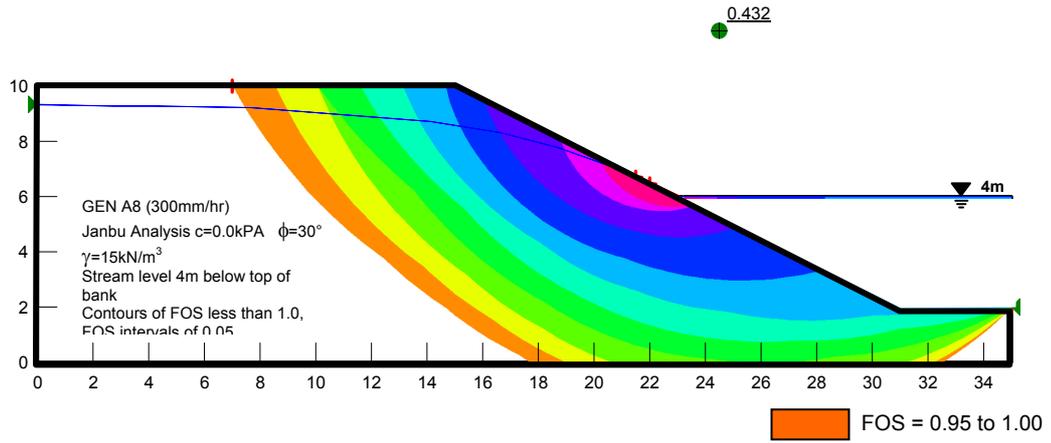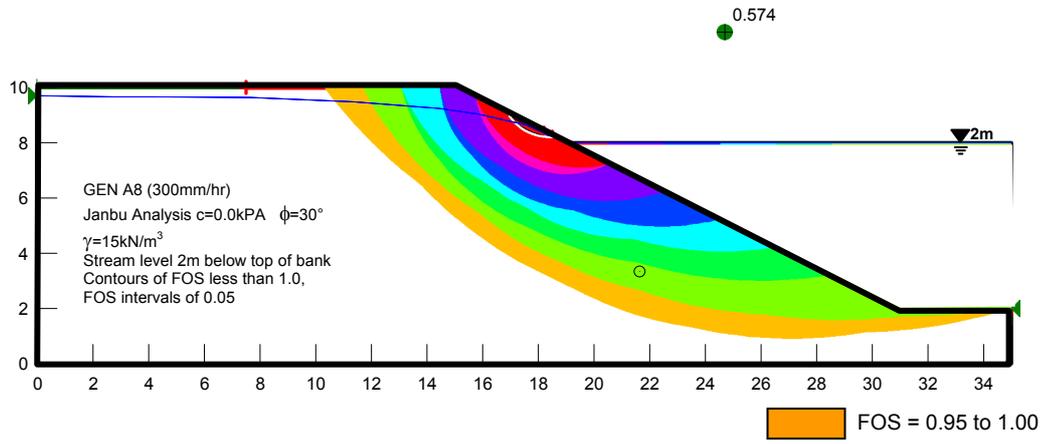FLOOD RECESSION - TOE DRAINAGE LAYER
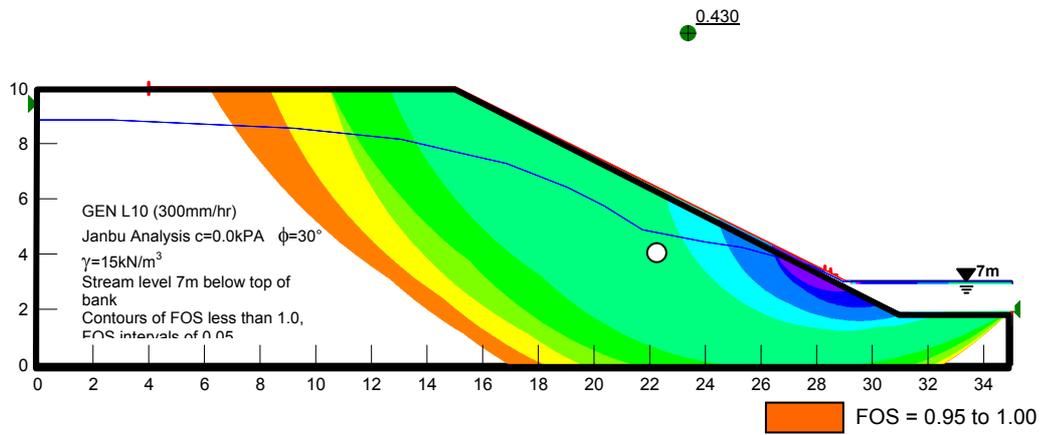GENA9 - Ksat=15 mm/hr, Ksat(aq)= 300 mm/hr, r= 50 mm/hr

# APPENDIX E

# SLOPE STABILITY ANALYSIS DATA

Slope stability analysis of homogeneous streambank model GEN1 (300mm/hr)

Slope stability analysis of drainage layer streambank model GENA8 (300mm/hr)

0.568

GEN L10 (300mm/hr)

Janbu Analysis c=0.0kPA  φ=30°

γ=15kN/m³
Stream level 2m below top of bank
Contours of FOS less than 1.0,
FOS intervals of 0.05

2m

FOS = 0.95 to 1.00

0.546

GEN L10 (300mm/hr)

Janbu Analysis c=0.0kPA  φ=30°

γ=15kN/m³
Stream level 4m below top of
bank
Contours of FOS less than 1.0,
FOS intervals of 0.05

4m

FOS = 0.95 to 1.00

0.430

GEN L10 (300mm/hr)

Janbu Analysis c=0.0kPA  φ=30°

γ=15kN/m³
Stream level 7m below top of
bank
Contours of FOS less than 1.0,
FOS intervals of 0.05

7m

FOS = 0.95 to 1.00

Slope stability analysis of longitudinal drainage pipe streambank model GENL10 (300mm/hr)

**0.879**

GEN 3 (50mm/hr)

Janbu Analysis c=0.0kPA  φ=30°

γ=15kN/m³

Stream level 1m below top of bank

Contours of FOS less than 1.0,

FOS intervals of 0.05

FOS = 0.95 to 1.00

**0.790**

GEN 3 (50mm/hr)

Janbu Analysis c=0.0kPA  φ=30°

γ=15kN/m³

Stream level 2m below top of bank

Contours of FOS less than 1.0,

FOS intervals of 0.05

FOS = 0.95 to 1.00

**0.648**

GEN 3 (50mm/hr)

Janbu Analysis c=0.0kPA  φ=30°

γ=15kN/m³

Stream level 4m below top of bank

Contours of FOS less than 1.0,

FOS intervals of 0.05

FOS = 0.95 to 1.00

**0.422**

GEN 3 (50mm/hr)

Janbu Analysis c=0.0kPA  φ=30°

γ=15kN/m³

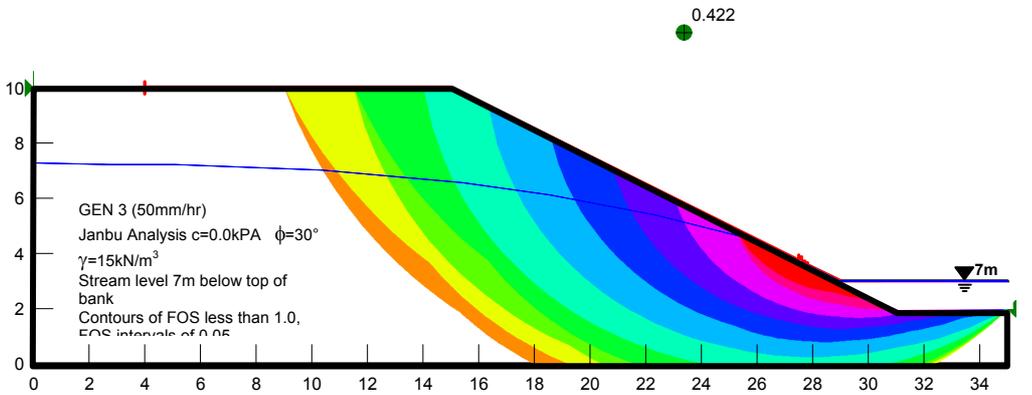Stream level 7m below top of bank

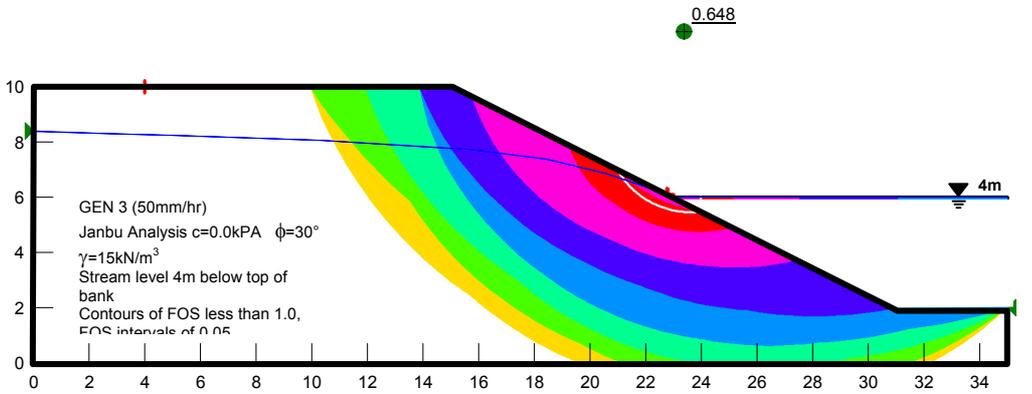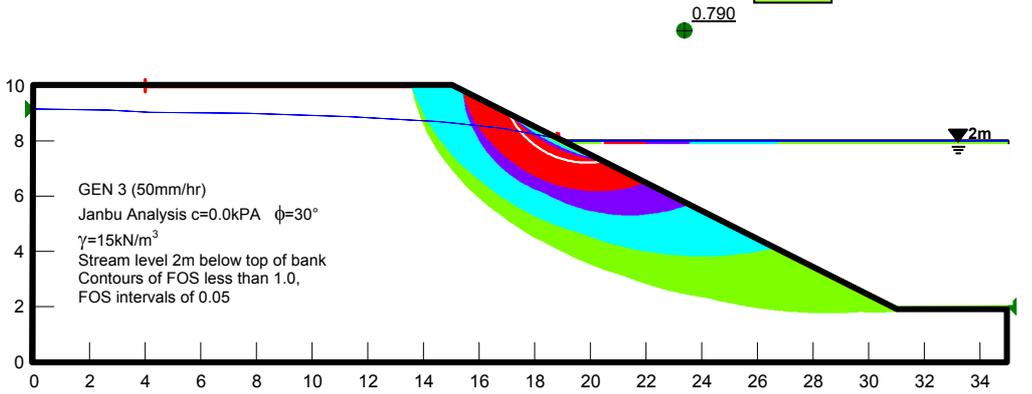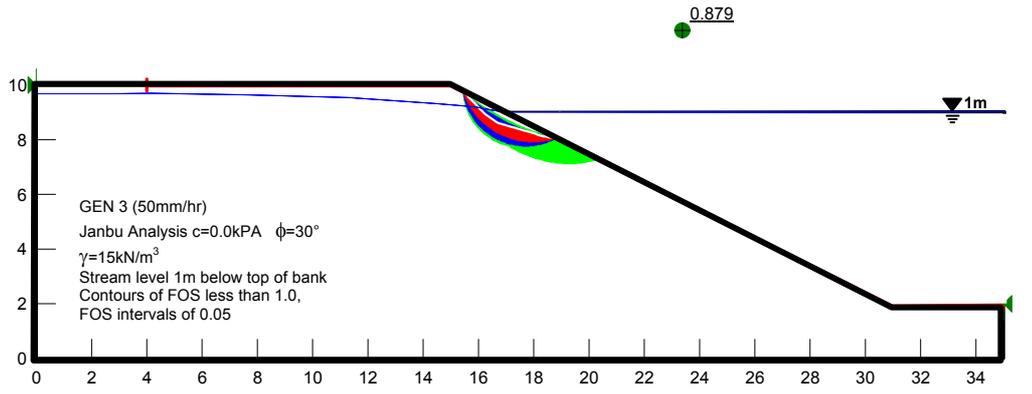Contours of FOS less than 1.0,

FOS intervals of 0.05

FOS = 0.95 to 1.00

Slope stability analysis of homogeneous streambank model GEN3 (50mm/hr)

**0.813**

GEN A9 (50mm/hr)
Janbu Analysis c=0.0kPA  φ=30°
γ=15kN/m³
Stream level 2m below top of bank
Contours of FOS less than 1.0,
FOS intervals of 0.05

FOS = 0.95 to 1.00

GEN A9 (50mm/hr)
Janbu Analysis c=0.0kPA  φ=30°
γ=15kN/m³
Stream level 4m below top of bank
Contours of FOS less than 1.0,
FOS intervals of 0.05

FOS = 0.95 to 1.00

**0.590**

GEN A9 (50mm/hr)
Janbu Analysis c=0.0kPA  φ=30°
γ=15kN/m³
Stream level 7m below top of bank
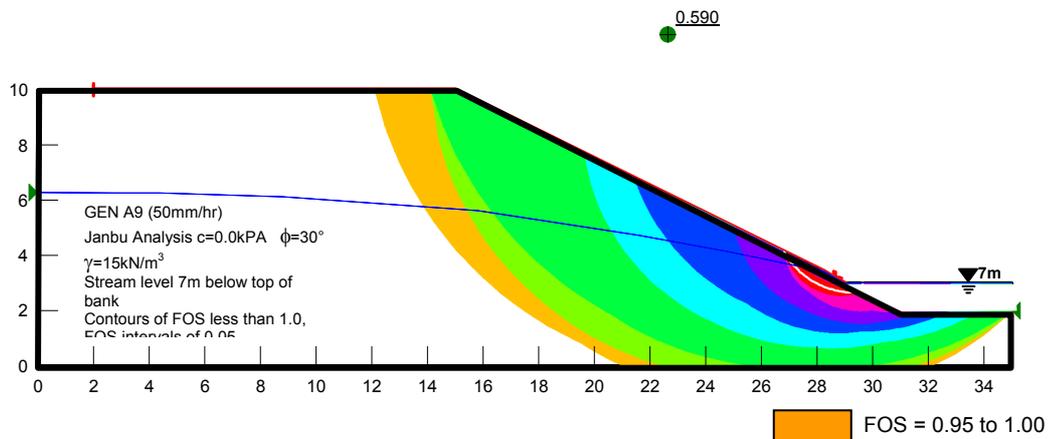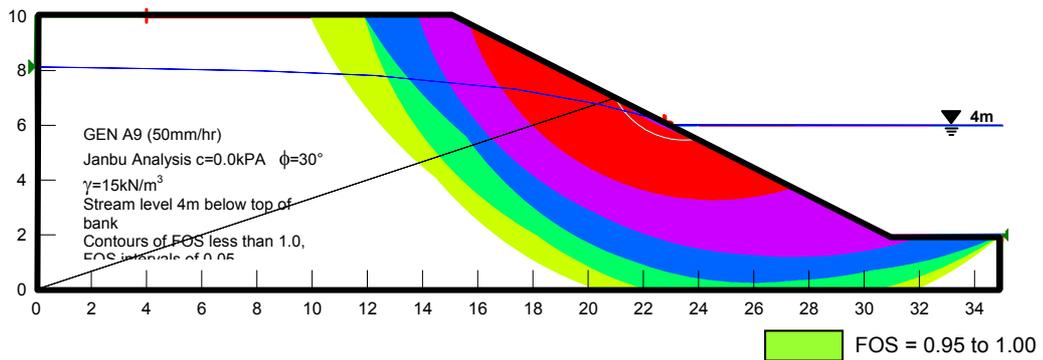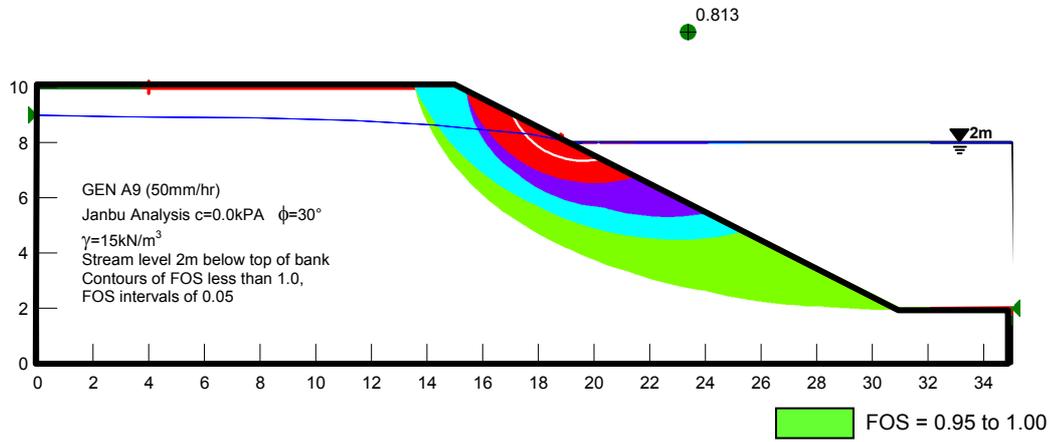Contours of FOS less than 1.0,
FOS intervals of 0.05

FOS = 0.95 to 1.00

Slope stability analysis of drainage layer streambank model GENA9 (50mm/hr)

**0.717**

GEN L11 (50mm/hr)

Janbu Analysis c=0.0kPA  φ=30°

γ=15kN/m³
Stream level 2m below top of bank
Contours of FOS less than 1.0,
FOS intervals of 0.05

FOS = 0.95 to 1.00

**0.622**

GEN L11 (50mm/hr)

Janbu Analysis c=0.0kPA  φ=30°

γ=15kN/m³
Stream level 4m below top of
bank
Contours of FOS less than 1.0,
FOS intervals of 0.05

FOS = 0.95 to 1.00

**0.791**

GEN L11 (50mm/hr)

Janbu Analysis c=0.0kPA  φ=30°

γ=15kN/m³
Stream level 7m below top of
bank
Contours of FOS less than 1.0,
FOS intervals of 0.05

FOS = 0.95 to 1.00

**Slope stability analysis of longitudinal drainage pipe streambank model GENL11 (50mm/h**

File Edit Set View KeyIn Draw Sketch Modify Tools Window Help

**KeyIn Material Properties**

| Matl | Strength Model | Description | Color |
|------|----------------|-------------|-------|
| 1 | Mohr-Coulomb | Sandy SILT | |
| 2 | No strength (e.g. Water) | Water | |

1 | Mohr-Coulomb | Sandy SILT | | Set...

**Basic Parameters**

Unit Weight: 15
Phi: 30
Cohesion: 0.49

Advanced Parameters

Unit Wt. above WT: 0
Phi B: 0
Anisotropic Fn.: 0

Copy    Insert    Delete    OK    Cancel

For Help, press F1

X: 7.08112 m    Y: 19.062677 m

Start   2 Microsoft Of...   Adobe Acrobat ...   2 Windows Ex...   GenL11 7m ch...   EN   100%   8:00 a.m.

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File Edit Set View KeyIn Draw Sketch Modify Tools Window Help

**KeyIn Material Properties**

| Matl | Strength Model | Description | Color |
|------|----------------|-------------|-------|
| 1 | Mohr-Coulomb | Sandy SILT | |
| 2 | No strength (e.g. Water) | Water | |

2 | No strength (e.g. Water) | Water | | Set...

**Basic Parameters**

Unit Weight: 9.807

Advanced Parameters

Copy    Insert    Delete    OK    Cancel

For Help, press F1

X: 7.08112 m    Y: 19.062677 m

Start   2 Microsoft Of...   Adobe Acrobat ...   2 Windows Ex...   GenL11 7m ch...   EN   100%   8:00 a.m.

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