THE ENVIRONMENTAL IMPACTS OF THE GROUNDWATER ON THE ST. LUCIA WETLAND

By

CLAUDIA BRITES

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Supervisor: Dr. D. Vermeulen

DECLARATION

I, Claudia Marques Brites, hereby declare that this dissertation submitted for the Magister Scientiae degree in the Faculty of Natural and Agricultural Sciences, Department of Geohydrology, University of the Free State, Bloemfontein in South Africa, is my own independent work which has not been submitted to any other institute of higher education. I further declare all sources cited have been acknowledged within the reference section.

C. Brites
April 2013

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List of Acronyms

ARC – Agricultural Research Centre

DAFF – Department of Agriculture, Forestry and Fishery

DWAF - Department of Water Affairs and Forestry

GCS – GCS Water & Environmental Consultants

GDP - Gross Domestic Product

Ha – Hectares

MAMSL - Metres above mean sea level

PPT - parts per thousand

SARS - South African Revenue Service

SAFCOL - South African Forest Company, Ltd

WGS 84 - World Geographic System 84

CHAPTER 1: INTRODUCTION

The timber industry forms an integral part of the South African economy, through the contribution of raw materials to satisfy the mining, construction and industrial markets, as well as by providing direct employment in mostly remote, rural areas. Approximately 1.3 million hectares of South African land is utilised for commercial timber plantations, of which 80% is located in the Mpumalanga, Eastern Cape and KwaZulu-Natal Provinces (DAFF, 2011). In addition, forests and woodlands play an important role in the protection and conservation of the soil, fauna and flora, moderating surface water flow and reducing sedimentation in streams (http://forestry.daff.gov.za).

Significant historic research has been conducted on the effect that plantations of timber species have on the groundwater resources. Plantations can influence the groundwater dynamics of a system by utilising soil water and thereby preventing aquifer recharge or by extracting water directly from the capillary fringe (Scott, 1993). As a result, the groundwater table is lowered. The effect on afforestation within the Nyalazi catchment is of relevance to quantify the impacts on the aquifer system.

1.1 Objectives

The main focus of this thesis is to collate and analyse the existing data consisting of groundwater levels and rainfall recorded within the Nyalazi plantation from 1995 to 2012, with the aim to:

- Determine the impact of the Nyalazi plantation on the groundwater levels;
- Determine the impact of the trees over the life cycle (from planting to felling); and
- Make a comparison between the effects of the *Pinus elliottii* species against the *Eucalyptus grandis Camaldulensis* species in order to quantify the effects of each species and to identify which is most detrimental to the groundwater environment.

1.2 Structure of the Thesis

The thesis consists of 11 chapters in total:

- Chapter 1 provides an introduction to the South African timber industry and also provides the objectives of the study.
- Chapter 2 contains the background information on timber plantations, the distribution across the country and their importance to the economy, with specific reference to the two main species present in the study area.
- In Chapter 3, the dynamics of the St Lucia system and components of the iSimangaliso Wetland Park are addressed.
- Chapter 4 is a discussion of the study area – the Nyalazi plantation.
- This is followed by Chapter 5, providing details on the methodology followed.
- Chapter 6 discusses the geological setting of the study area.
- In Chapter 7, the hydrogeological components are incorporated as well as the site specific groundwater level trend analysis.
- Chapter 8 provides a conceptualisation of the site, comparing the differences between the effects of the Pine and Eucalyptus species on the groundwater environment.
- A borehole rehabilitation plan is presented in Chapter 9, in order to improve the current status of the monitoring network.
- Chapter 10 presents the conclusions of the study and the resultant recommendations.
- Chapter 11 contains a list of references incorporated during this investigation.

CHAPTER 2: TIMBER PLANTATIONS

2.1 Introduction

As the primary objective of this study is to determine the impact of the timber plantations on the groundwater system, it is imperative to build an understanding of the different timber plantations and the importance within the South African environment. A commercial timber plantation, as described by the Department of Agriculture, Forestry and Fishing (DAFF, 2011) is a man-made forest which provides industrial timber products including sawlogs and mining timber. All forest types, including timber plantations play a pivotal role in the protection of soil and storage of carbon, thereby mitigating the effects of climate change (DAFF, 2011).

Commercial timber plantations cover an area of approximately 1.3 million hectares of South Africa, which amounts to 1.1% of forested land in the country. Majority of timber plantations in the country are located in three provinces, namely; Mpumalanga, the Eastern Cape and KwaZulu-Natal. Approximately 68% of plantations consist of exotic trees, with the balance consisting of natural vegetation (DAFF, 2011).

Mondi and Sappi are two of the front runners which are ranked within the top twenty largest pulp and paper companies in the world. Sappi was established in 1936 and Mondi in 1967. Both companies produce products on a global scale, with Sappi in the USA and Europe, and Mondi predominantly in Eastern Europe and Russia (The Wood Foundation, 2012). Between the two, Sappi and Mondi own approximately one percent of the total commercial forest land area of the country (Naledi, 2004).

This study focuses on *Pinus elliottii* and *Eucalyptus grandis Camaldulensis*, which are the two main tree species which are located in the Nyalazi plantation, within the St Lucia region.

2.2 Distribution of Plantation Areas

Over 80% of commercial plantations are located in Mpumalanga, the Eastern Cape and KwaZulu-Natal provinces (Figure 1), with the remainder in Limpopo and Western Cape, contributing a small percentage. According to the 2008 statistics as reported by DAFF (2011), the total extent and distribution of plantation area in South Africa was 510 263ha (hectare) in Mpumalanga, 486 020ha in KwaZulu-Natal and 153 380ha in the Eastern Cape Province. The plantation areas in Limpopo and Western Cape provinces were around the 50 000ha mark. Zero or a very small proportion was present in Free State, Gauteng and North West provinces.

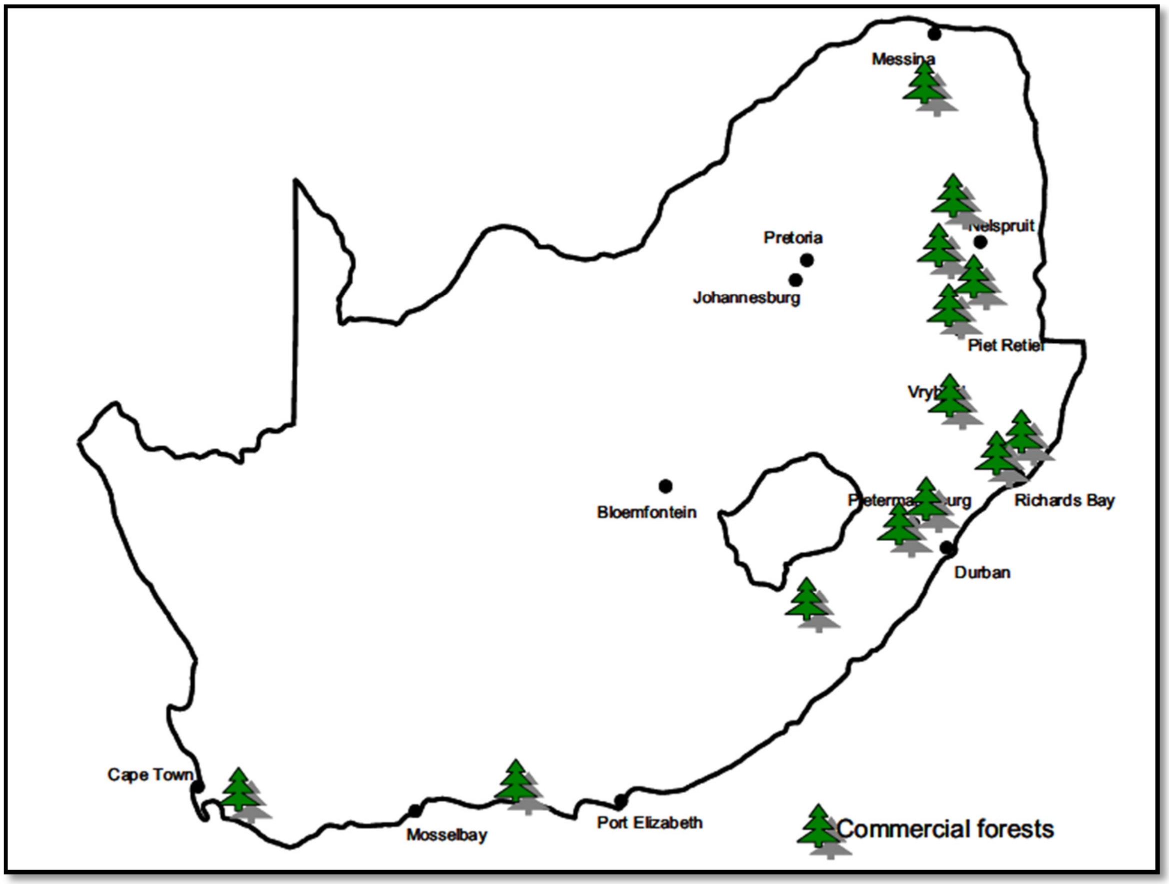


Figure 1: Location of Commercial Forests in South Africa (Naledi, 2004)

Pine plantations are grown in the higher regions of KwaZulu-Natal and Mpumalanga where the temperature is cooler, whereas Eucalyptus trees are grown in the lower lying area of the KwaZulu-Natal (coastal and midlands), Mpumalanga and around Tzaneen in the Limpopo province (Naledi, 2004).

2.3 Economic Importance

According to DAFF (2011), “South Africa’s forests are among the nation’s most important natural assets”. As reported in 2008, South African commercial plantations produced approximately 20 million m^3 roundwood, of which 8 million m^3 was softwood and 11 million m^3 was hardwood, which contributed R6 billion to the economy. In total, forestry contributes R22 billion to the GDP (Gross Domestic Product), annually, of which pulpwood is the largest contributor, followed by sawlogs (DAFF, 2011).

According to the South African Revenue Service (SARS), ‘the export of forest products has more than doubled in the last 10 years from R6.7 billion in 1999 to R14.8 billion in 2008’. This makes the forestry sector one of the top exporting industries in the country DAFF (2011). The total value of forest product exported (R101 billion) exceeded the total products imported (R62 billion) in 2008, therefore making South Africa a net exporter. Paper and pulp account for 73% of exported forest products, therefore being the main contributors (DAFF, 2011).

Forestry also plays an important role in poverty alleviation. In 2008, the industry employed 107 000 people in the forestry sector with additional employment provided through the paper and pulp, sawmilling, timber board and mining timber sectors (DAFF, 2011).

2.4 The Use of Timber

The primary function of a commercial timber plantation is to provide industrial timber products (DAFF, 2011). These timber products include sawlogs, pulp for the paper industry, poles for various uses and mining timber (Sappi Forests, 2004).

In the South African timber industry, two types of wood are used to produce pulp and paper, namely hardwood and softwood. The hardwood used is generally eucalyptus and pines are utilised as softwood. Softwood fibres are mainly used to produce newspaper, magazine and packaging grade paper based on the strength, whereas hardwood fibres are used to manufacture corrugated carton or in combination with softwood fibres to produce paper with a smooth finish which is suitable for good quality printing (Naledi, 2004).

Poles are generally used for building, fencing, transmission poles or telephone poles as well as for general purposes (Sappi Forests, 2004).

Mining timber is also a major user of timber. *Eucalyptus grandis* is the main species used to produce mining timber, while other Eucalyptus species are also used to a certain extent (Sappi Forests, 2004). *Eucalyptus grandis* is a preferred species for mining timber based on the form of the tree and the price (Bredenkamp & Schutz, 1984).

2.5 Timber Yields

An important factor which drives the decision regarding the species to be developed is the yield which will be produced. Based on the data supplied from SiyaQubeka, the yields produced for the Eucalyptus species was made available, specifically for the Nyalazi plantation. This includes data for two different rotation cycles. The first rotation was initiated between 1995 and 2001 and felled during 2003 and 2009. The second commenced during 2003 and 2009 and felling occurred in 2010 or is yet to be felled from 2014 to 2019 (anticipated felling dates).

Based on the data, the average timber yield was calculated and ranged from 95 to 933 tons per hectare for the first rotation and 130 to 165 tons per hectare (t/ha) for the second rotation. Generally, the average yield per hectare was calculated as 138 tons, excluding the 933 t/ha for compartment N4, as this was exceptionally high.

In Brazil, top yields of 65 dry tons (113m^3) per hectare per year were recorded specifically for Eucalyptus grandis over a 7 year rotation cycle.

Eucalyptus planted in China yields on average 175m^3 per hectare on a six year rotation cycle in comparison to pine plantations on a 12 year rotation yielding 100 to 150m^3 per hectare (www.sinoforest.com). This indicates that, generally eucalyptus plantations produce higher yields over shorter rotation periods.

According to Reynolds and Kosman (2012), the average natural pine plantation yields approximately nine tons per hectare per year compared to managed plantations which produce approximately 18 tons per hectare per year. Therefore based on the average 25 year rotation cycle or 30 years for the Nyalazi site, the total yield for each rotation averages between 450 to 540 tons per hectare.

Based on the statistics, it is proven based on the average tons per hectare on an annual basis, that eucalyptus produces much higher yields than pine species based on the fast growing nature of the eucalyptus species.

2.6 The Dynamics of a Timber Plantation

2.6.1 Pinus elliottii

Pinus elliottii commonly known Slash Pine, is a large, heavily branched conifer (Figure 2). This species grows at a rapid rate and reaches heights in excess of 30 metres (Gilman & Watson, 1994). This evergreen species is indigenous to the south eastern United States (Louppe *et al*, 2008).

The life cycle of a pine tree is initiated by the production of seedlings in a nursery (Lesch & Scott, 1997). The seeds are obtained from drying the cones in the sun, which are then planted with germination taking approximately 15 to 20 days, with a success rate of 85 to 90%. The seedlings are then transferred from the nursery and planted in the designated plantation area, 4 to 8 months after sprouting. At this age the seedlings have grown to an approximate height of 30 centimetres. The spacing intervals applied are generally 2.5 metres by 2.5 metres. Weed management is implemented after 2 years (Louppe *et al*, 2008). Thinning of trees occurs at 5 year intervals with the purpose of allowing the stronger trees to develop faster (Sabie, 2002). Thinning is an important factor which affects the growth of a plantation. It involves the removal of poorer, weaker trees in order to stimulate growth to increase the timber yields and volumes produced, as well as the quality of the timber. The material collected during this process is used in the production of paper (Lesch & Scott, 1997).

The rotation cycle applied is highly dependent on the end use of the Pines. The most favourable rotation cycle for is approximately 25 years whereas a longer rotation cycle ranging from 45 to 55 years is applied for timber (Louppe *et al*, 2008).

There is a range of different uses for the slow growing *Pinus elliotti*. The soft wood of this species is used for pulping based on the light weight of the wood, whereas the harder fractions which are heavier derived from the more mature generation is used for timber purposes. The timber is also often used as poles, based on the straight nature of the tree. The wood is also used in the construction industry, used for the building of ships and vehicles and smaller items such as toys, boxes, and furniture (Louppe *et al*, 2008).

Figure 2: Mature Pinus elliottii sketch (left) (http://texastreeid.tamu.edu) and photograph (right) (http://invasives.org.za/)

2.6.2 Eucalyptus grandis

Eucalyptus grandis W.hill ex Maiden (Figure 3), otherwise known as flooded gum or rose gum, is a tree indigenous to the east coast of Australia (Hunde *et al*. 2002). This rapid growing tree can reach heights of 43 to 55 metres with a diameter ranging from 122 to 183 centimetres (Burns & Honkala, 1990). This species of Eucalyptus is one of the most widely planted in commercial wood production, based on the large timber volumes produced (Hunde *et al*. 2002).

The Eucalyptus seeds are collected from the fruit grown on the tree, with the seed size being one millimetre. The seedlings are cultivated in plastic bags and planted at an age of two to six months, when a height of 20 to 30 centimetres is obtained. The different spacing arrangements can be two metres by two metres, five metres by five metres or three metres by one metre. Weed management is applied during the first few years of growth. The species is self pruning and coppices well (Louppe *et al*, 2008). Two to three coppice rotations are implemented before seedlings are replanted. The advantage of coppicing is that initial growth is faster from the coppice shoots, however, the risk involved is that the stump may die, with an average occurrence of 5% prevalent in South Africa (Burns & Honkala,1990).

The species is well known for rapid growth associated with short rotation cycles, with an average growth rate of two metres per year. At the end of an eight year rotation cycle, the average height of the tree summits 18 metres (Burns & Honkala, 1990).

According to research, average rotation cycles in Kenya, range from six years for wood used for domestic purposes, 10 to 12 years for wood used in the industrial industry and seven to eight years with the use being telephone poles (National Academy of Sciences, 1980).

Figure 3: Eucalyptus grandis sketch (left) (www.sappi.investoreports.com) and photograph captured at the Kwambonambi Plantation (right)

2.7 Rooting Depths of Timbers

A study conducted by Scott (1993), revealed that both Eucalyptus and Pine species have large rooting structures. Both species indicated the presence of deep vertical roots splitting off the large horizontal roots. The 22 year old Pines exhibited a larger root system compared to the seven year old Eucalyptus species. The depth of the Pine roots ranged from 2.7 to 4 metres, which was the depth of the water table indicating the roots were tapping into the water table. The Eucalyptus roots ranged from 1.3 to 2.6, which was shallower than the water table of 3.2 metres, which appeared to be fed by the capillary zone (Scott, 1993).

Pinus elliottii has a widespread lateral root system, where the maximum length of the roots may be twice the tree height. Deformation of the moderately sized taproots may occur due to shallow water tables, confining soil layers or incorrect planting techniques (Burns & Honkala,1990).

Root growth is significantly influenced by the structure and type of soil in which the plantation is situated. During the first year of growth, the taproot length of all seedlings are similar but the lateral root distribution was highest within the clay soils, less within the loamy soils and the least within the sandy soil. Eucalyptus seedlings roots are dominated by a taproot with a few lateral roots, depending on the conditions (Burns & Honkala, 1990).

2.8 Groundwater Use by Timbers

Timber plantations inclusive of Pine and Eucalyptus species disrupt the balance of groundwater regime based on the high evapotranspiration rates prevalent as well as the intrusive root system associated with the timbers. As a result, this has led to a reduction in the runoff as well as the lowering of the groundwater table based on the use of groundwater. Timber plantations utilise higher quantities of water in comparison to indigenous vegetation based on their deep rooting systems (Jones & Johnstone, 1997).

The unsaturated zone is divided into two horizons, namely the upper soil zone (A horizon) and underlying intermediate zone/unsaturated zone (B horizon) (Figure 4). The capillary zone, also known as C horizon, is located within the saturated zone, directly above the groundwater table (Jones & Johnstone, 1997).

Majority of the water uptake occurs within the upper A and B horizons. This essentially also results in a lowering of the water table based of the interception of water which would have recharged the groundwater system. The deep roots are classified as those which penetrate beyond the A and B horizons, which are mostly functional when there is an insufficient water supply within the upper two zones and the roots extract water from the capillary zone (Jones & Johnstone, 1997).

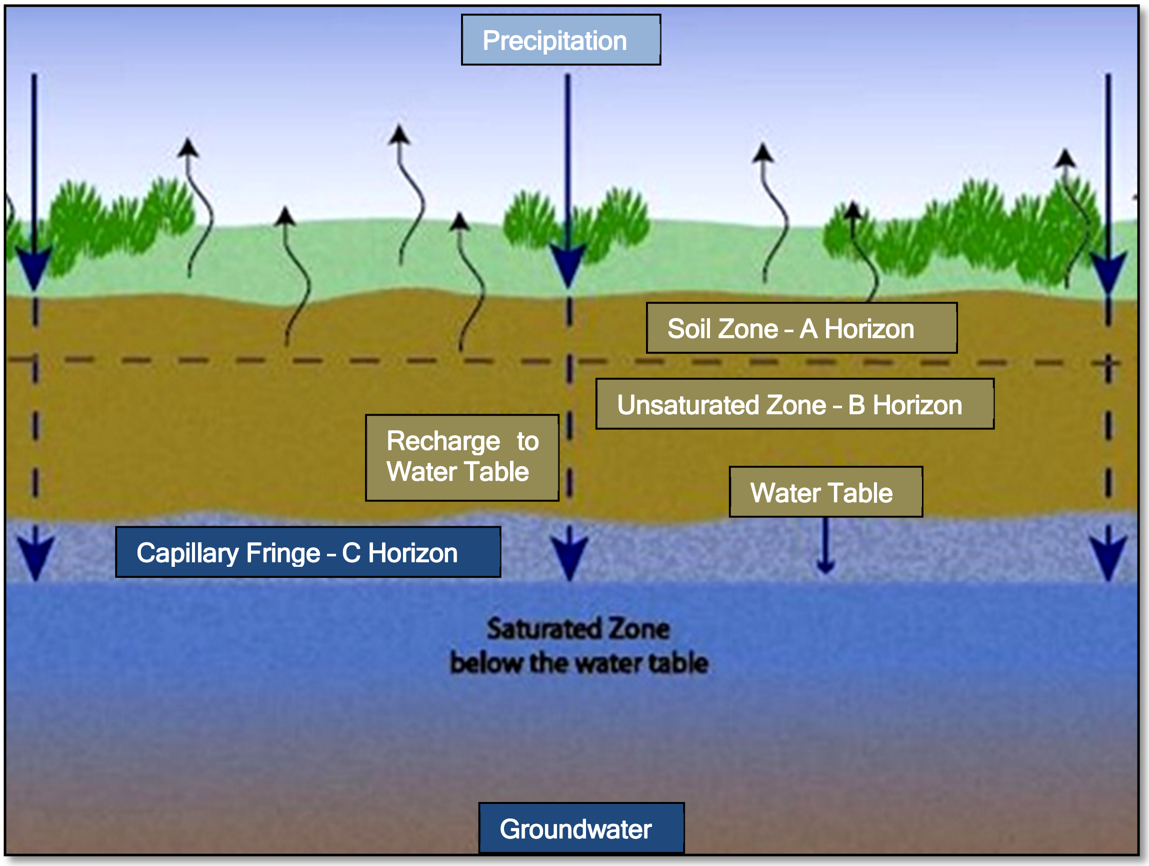


Figure 4: Soil zones (www.dwa.gov.za)

2.9 Similar Case Studies

According to a study conducted by Lesch & Scott (1997), a faster reduction in streamflow is apparent with Eucalyptus in comparison to Pines. The effects on streamflow were evident during the third and fifth years and after nine and fifteen years, respectively, there was no more contribution to streamflow. After the clearfelling of the Eucalyptus the streamflow only returned after 5 years (Lesch & Scott, 1997).

The presence of large scale Eucalyptus plantations have often resulted in the decline of groundwater levels, streamflow as well as recharge to groundwater, however the degree of impact is highly dependent on the size and location of the plantation as well as the special distribution. For example, a small site of less than 10 hectares with optimal dispersion may have insignificant impacts on the hydrology of the site. However, the high transpiration rates and rapid growth generally result in the species utilising vast amounts of water even though it is alleged that Eucalyptus is an efficient water user. The rates of transpiration for Eucalyptus exceed the rates associated with pines by a factor of 1.6 and that of grazing land by a factor of 3.5 (USDA, 2011).

Majority of the cases where negative hydrological impacts were evident based on the presence of Eucalyptus were areas which were previously afforested, governed by grasses and generally low rainfall areas (USDA, 2011).

A study conducted by Jobbagy and Jackson (2004), assessed the groundwater use and salinisation within grassland afforestation by studying 20 paired grassland and adjacent afforested areas ranging in size from 10 to 100 hectares located within the Argentine Pampas. The groundwater results collected over a two year period associated with a 40 hectare *Eucalyptus Camaldulensis* plantation indicated lower recharge to groundwater and a water table 38 cm lower than that of the adjacent grassland.

A study conducted by Horner *et al* in 2009 on a plantation trial of *Eucalyptus Camaldulensis* located in the Barmah-Millewa forest in South Eastern Australia, revealed a considerable decline in the water level resulting in lower water availability, fewer incidences of flooding. The water level dropped by 2.7 metres ±0.6 metres measured in six boreholes located at a radius of 1 km to 2 km from the study site. However, this also coincided with a period of drought which may have contributed to the decline of water levels (Horner *et al*, 2009).

The clear felling of native forests in Western Australia with the intent of developing the land for agricultural purposes has resulted in salinisation of the land as well as the rise of water levels which is considered a significant concern in Australia as well as semi-arid regions around the world. Agroforestry has been researched as a potential solution to combat this issue, which is a combination of both agricultural and forestry activities. Two experiments were researched. The first involved a pinius-pasture agroforest which covered an area of 58% of the previous felled area with a special distribution of 75 to 225 trees per hectare. The response was positive in lowering the water table by 1 metre over a period of 10 years from 1979 to 1989. An agroforest of Eucalyptus-pasture which covered 57% farmland, with 150 to 625 trees per hectare, lowered the yearly minimum saline groundwater level by 2 metres (Bari & Schofield, 1991).

The Kamarooka Project was established in Victoria, Australia, conducted by the Northern United Forestry Group (NUFG), with the intent to lower the groundwater table in order to reclaim land affected by salt utilising Eucalyptus trees. The change in water level and rate of tree growth were measured using dendrometers and sapflow meters. A decline of 20-30 cm in the water table was measured per month over a period of six months. Additionally, the water use per tree was calculated as five litres per day and based on an amount of 500 trees per hectare. This equates to 2500 l/day/ha (http://www.ictinternational.com).

According to Shyam Sunder (1996), a *Eucalyptus* species can transpire between 20 and 40 litres per tree on a daily basis.

CHAPTER 3: ST LUCIA SYSTEM

3.1 Introduction

The St. Lucia System is located along the south eastern seaboard of Southern Africa, in the province of KwaZulu-Natal, some 200 kilometres north of the port of Durban. The St. Lucia system is located within the iSimangaliso Wetland Park (meaning miracle), formerly known as the Greater St. Lucia Wetland Park (Figure 5), which was renamed in 2007 to prevent confusion with the Caribbean island Saint Lucia and to give the park an African personality (www.southafrica.info). The iSimangaliso Wetland Park is protected under the South African legal system and has been declared a protected area (Porter & Blackmore, 1998).

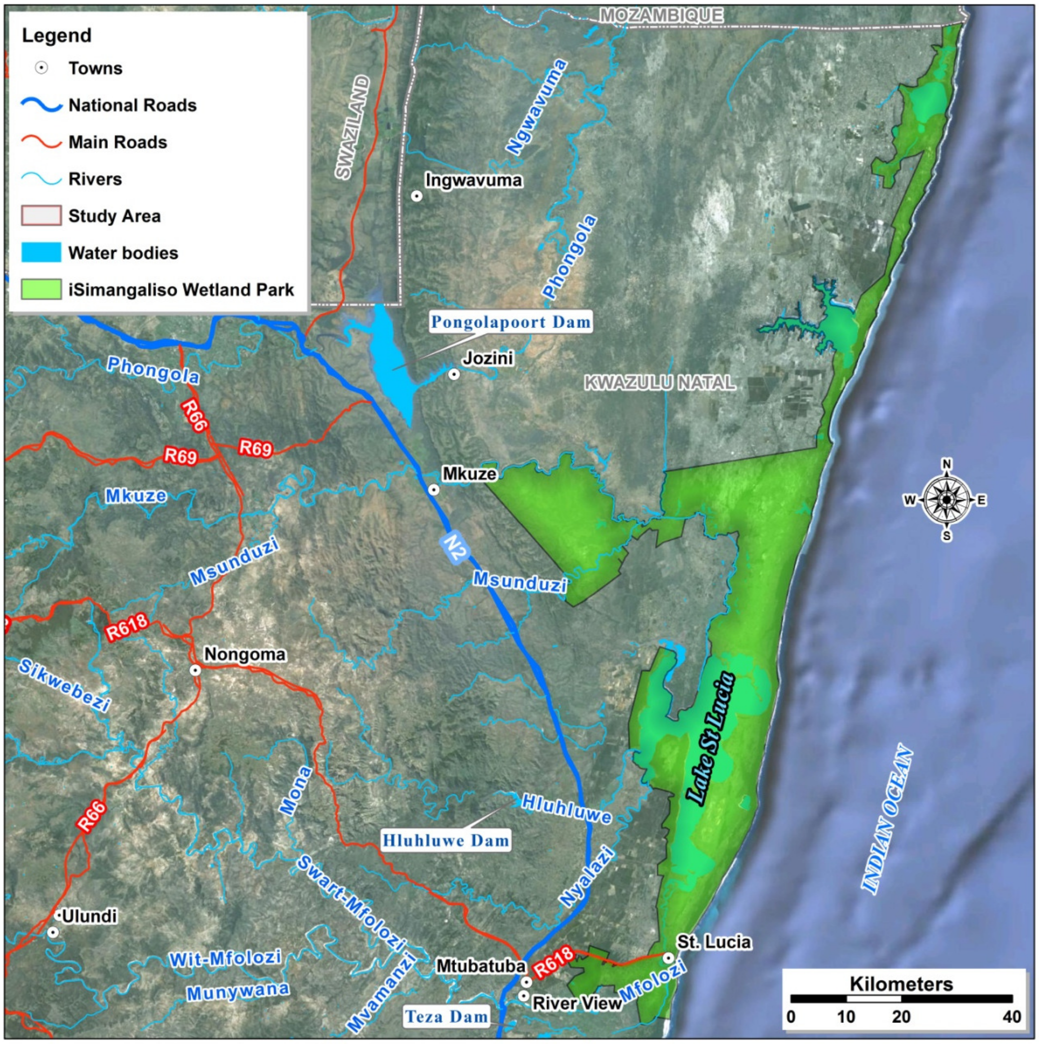


Figure 5: Extent of the iSimangaliso Wetland Park

The area consists of long, coastal plains separated from the coastline by dune barriers. The coastal plain is subdivided into several terrestrial and aquatic landscapes. The terrestrial component is comprised of grasslands, woodlands, forests, wetlands, swamps and mangroves. The coastal plain undulates gently where it coalesces with the Lebombo Mountain range to the west. Furthermore, the area is dotted with pans, lakes and rivers. The coastal lake systems are subdivided into two categories, namely; fresh water lakes and estuarine-linked lakes. Lake St. Lucia is the largest estuarine lake in Africa covering an area of 36 826 hectares and is discussed in more detail below. The fresh water input into the fresh water lakes, Bhangazi North and Bhangazi South is predominantly from groundwater seepage and surface water received from the catchments (Porter & Blackmore, 1998).

The iSimangaliso Wetland Park stretches 800 metres from the edge of the Lake and therefore no commercial forestry takes place in this area (Rawlins, 1991).

3.2 Lake St. Lucia

Lake St. Lucia is the largest estuarine system worldwide, extending 85km in length with an average depth of one metre (www.stluciasa.co.za). The lake is an important component of this dissertation as changes within the lake system may influence the groundwater levels in the surrounding areas (Rawlins, 1991). The lake, which is nestled within the Zululand coastal plain on the south east coast of Africa, is classified as a wetland which has received international recognition (Rawlins, 1991). The lake has been declared as both a Ramsar Wetland of International Importance as well as a World Heritage Site (The Water Wheel, 2009). St. Lucia Lake is divided into four different areas, namely; False Bay to the north west, North Lake, South Lake and the Narrows to the south (Vinke *et al*, 2011).

The lake hosts a wide variety of habitats in which both fauna and flora flourish. This includes, among other, herds of hippopotamus, flamingos, pelicans and other waterfowl, storks, herons and the Nile crocodile along the banks. The lake and associated wetlands form a sanctuary for several species of migratory birdlife. Based on the expansive size of the lake, it provides one of the most important areas in terms of sustaining aquatic organisms, both freshwater and estuarial species (Porter and Blackmore, 1998).

3.2.1 The History of Lake St. Lucia and Prolonged Degradation

Due to sediment accumulation and channeling since the 1930's, the St. Lucia/Mfolozi mouth closed (Porter & Blackmore, 1998). The freshwater input from the Mfolozi River is critical for the sustenance of the lake, especially during drier periods. The canalisation and draining of the Mfolozi swamps began in 1914 in order to allow for sugar cane development along the river floodplain. Conditions were exacerbated in 1936 when the main canal, Warner's Drain, was completed which resulted in the swamps losing their sediment filtering ability, by seizing the sediment and allowing water which was low in sediment through. As a result, by the 1940's, severe concern was raised regarding the sedimentation rates in the St. Lucia/Mfolozi mouth, which consequently choked up the mouth. Therefore both systems were isolated from the sea. A separate mouth was created for the Mfolozi River in 1952, by dredging, in order to prevent flooding of the farms upstream. An 'open mouth policy' was adopted by authorities with the use of a dredger to maintain the open mouth conditions of the lake (The Water Wheel, 2009).

More strain has been placed on the system due to the human influences on the remaining rivers by reducing runoff by approximately 20%, mainly based on the abstraction for irrigation, commercial forestry development and evaporation from farm dams (The Water Wheel, 2009).

3.2.2 Hydrological Aspects

Lake St. Lucia receives its freshwater inputs through five different river systems, namely; Mkuzi, Hluhluwe, Mzinene, Mpate and Nyalazi, with catchment areas ranging from 65 to 6000 km^2 (Porter and Blackmore, 1998). The contribution of fresh water from the five river systems amounts to a total of 295 million m^3 per annum (The Water Wheel, 2009).

Based on the extensive areal extent of the lake, the hydrological system is very susceptive to the effects of evaporation. The fundamental inputs of the water balance comprise of streamflow and rainfall, with the outputs dominated by evaporation and water expelled into the ocean. Evaporation exceeds precipitation resulting in a negative water balance (Porter and Blackmore, 1998).

Several pans and small wetlands are present within the lower lying areas which are generally ephemeral. According to Rawlins (1991), aerial photography indicates that commercial forestry has reduced the number and size of wetlands within the plantations areas. Since the development of forestry in the area, the pans have become waterless and are now occupied by trees, whereas the wetlands are only evident after heavy rainfall events (Rawlins, 1991).

3.2.3 Salinity of the Lake

The salinity of the lake is highly dependent on the freshwater inputs into the system. The salinity of the lake ranges from that of freshwater, near the mouth of the rivers to the salinity of sea water, 35ppt (parts per thousand). With the high freshwater input during high rainfall seasons, the water level of the lake also increases which results in outflow to the sea. Whereas, during drought periods, the lake level drops below sea level where the inflow of sea water may occur if the mouth is open, resulting in an increase in salinity. The lake can also become hypersaline, if the drought conditions persist for extended periods of time (Porter & Blackmore, 1998).

The salinity level of the lake is an integral component of the functionality of the system as many species have different toleration levels to the degree of change (Porter & Blackmore, 1998).

3.3 The Effect of Extended Periods of Drought

The severe drought which was prevalent from 1967 to 1972 resulted in increased evaporation and reduced freshwater inputs as the rivers to the north of the lake ran dry (iSimangaliso Wetland Park Authority, 2011). These periods of drought have impacted significantly on the lake system including the lake water level and volume (Kelbe *et al*, 1995). The current drought period which affects the area, started in 2002 and the decline in rainfall is evident as discussed in Section 4.4.

CHAPTER 4: STUDY AREA

4.1 Introduction

The study area is nestled in the St. Lucia region within the KwaZulu-Natal province. The Province is located along the eastern seaboard of South Africa. The area is well known for its vast stretch of coastlines, coastal grasslands, sugar cane plantations, woodlands and hilly topography.

4.2 iSimangaliso Wetland Park

The study area is located adjacent to the iSimangaliso Wetland Park, bordered to the east, north and north west by the Park. The iSimangaliso Wetland Park stretches 800 metres from the edge of the lake and therefore no commercial forestry takes place in this area (Rawlins, 1991).

4.3 The Study Area

The area of interest is located some 200 kilometres north of the port of Durban and approximately 20 kilometres north of the town of St. Lucia. The study area, the Nyalazi plantation, is located on the western shores of Lake St. Lucia. It is situated on a peninsula between the Nyalazi River, west of the site and Lake St. Lucia to the east (Figure 6). False Bay forms the north eastern boundary to the site.

Figure 6: Location of the study area

4.4 Climate

KwaZulu-Natal experiences sub-tropical coastal and temperate climatic conditions. The iSimangaliso Wetland Park has warm, moist summers, categorised as subtropical climatic conditions and mild, dry winters. The mean annual temperature surpasses 21°C. Majority of the rainfall, over 60%, occurs from November to March (during the summer months) with the balance occurring during the winter months (May to September).

Rainfall data was obtained for the Charters Creek weather station (W3E001) which is located to the east of the study area, in close proximity, along the periphery of Lake St.

Lucia at the following geographic co-ordinates: -28.200S and 32.417E. The data presented in Figure 7 is the average monthly data over the period from 1951 to 2011 (http://www.dwa.gov.za/hydrology).

According to this data set, the annual rainfall figures ranged from 532 mm to 1966 mm per year (measured from October to September) (http://www.dwa.gov.za/hydrology).

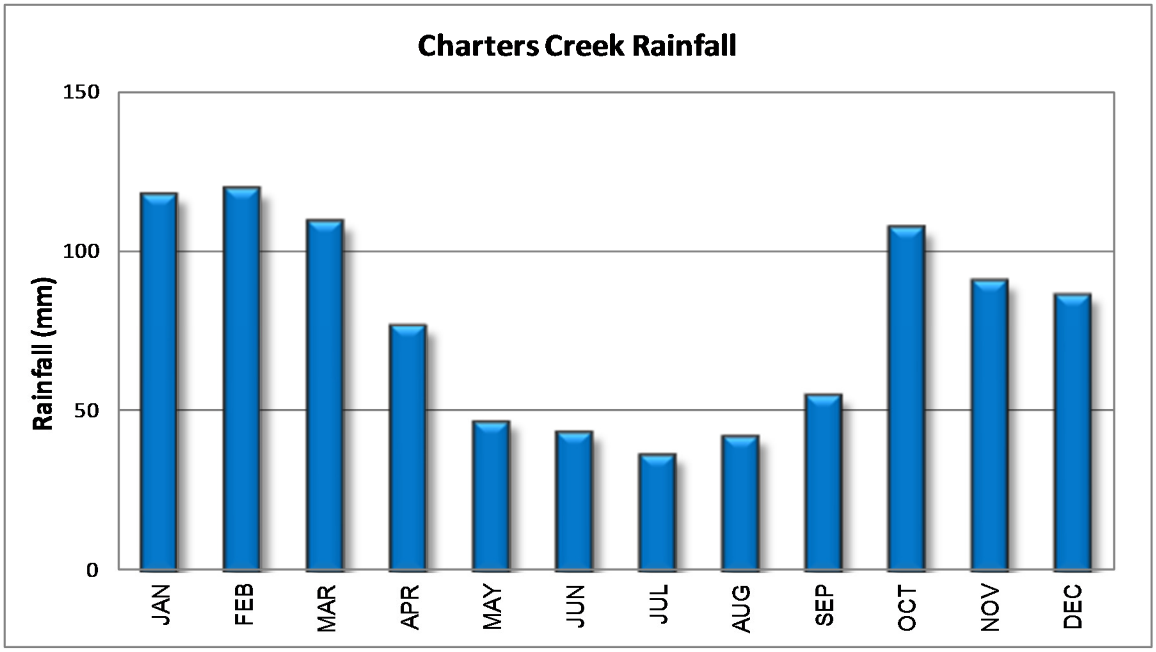


Figure 7: Rainfall measured at Charters Creek (http://www.dwa.gov.za/hydrology)

The data indicates similar rainfall patterns to the St. Lucia area, where higher rainfall is experienced in the summer season and minimal rainfall during the dry, winter season.

Rainfall data has been supplied by SiyaQubeka, which has been collected over the years. The site specific rainfall data for the adjacent Dukuduku plantation is plotted below in Figure 8. These are the average monthly rainfall figures based on the data collected from 1982 to 2011 at the rainfall station positioned at -28° 21'12,191"S and 32° 14'48,089"E. The trends are very similar to the rainfall of Charters Creek, except higher rainfall was recorded at this station.

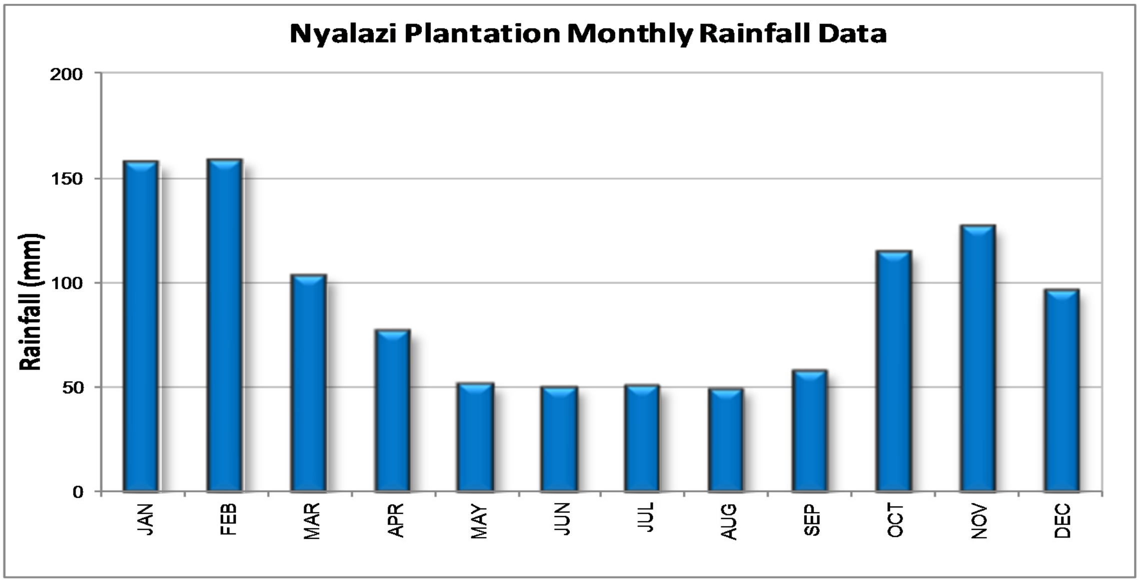


Figure 8: Rainfall measured at the adjacent Dukuduku plantation

The rainfall data, supplied as monthly figures have been represented in Figure 9 below as annual data. High rainfall was experienced in January 1984, due to Cyclone Domoina passing through the area (iSimangaliso Wetland Park Authority, 2011), which is confirmed by the data.

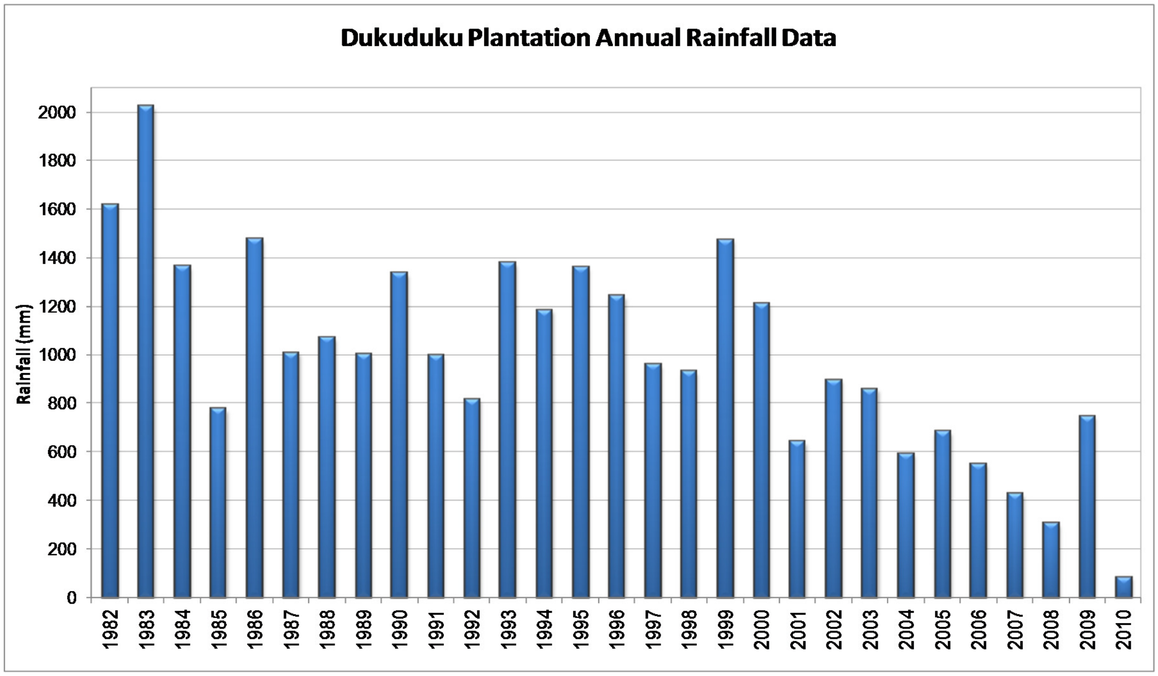


Figure 9: Rainfall data for the study area (1982 - 2010)

Overall the data indicates a decreasing trend over the period indicating the annual rainfall is currently lower than during the 1980's and 1990's. The highest annual rainfall recorded during this period was 2026mm in 1983/1984, with the average rainfall over the rainfall record period calculated as 866mm. Tropical cyclones have also traversed the area, which have resulted in large scale flooding (Porter & Blackmore, 1998). The rates of evaporation are high in the area, especially during the drier times of winter and early in spring. The evaporation in the area is approximately 1300mm per year (Porter & Blackmore, 1998).

4.5 Surface Topography

The regions surrounding the study area is characterised by sandy ridges, coastal dunes and depositional lowlands for river systems (Porter & Blackmore, 1998).

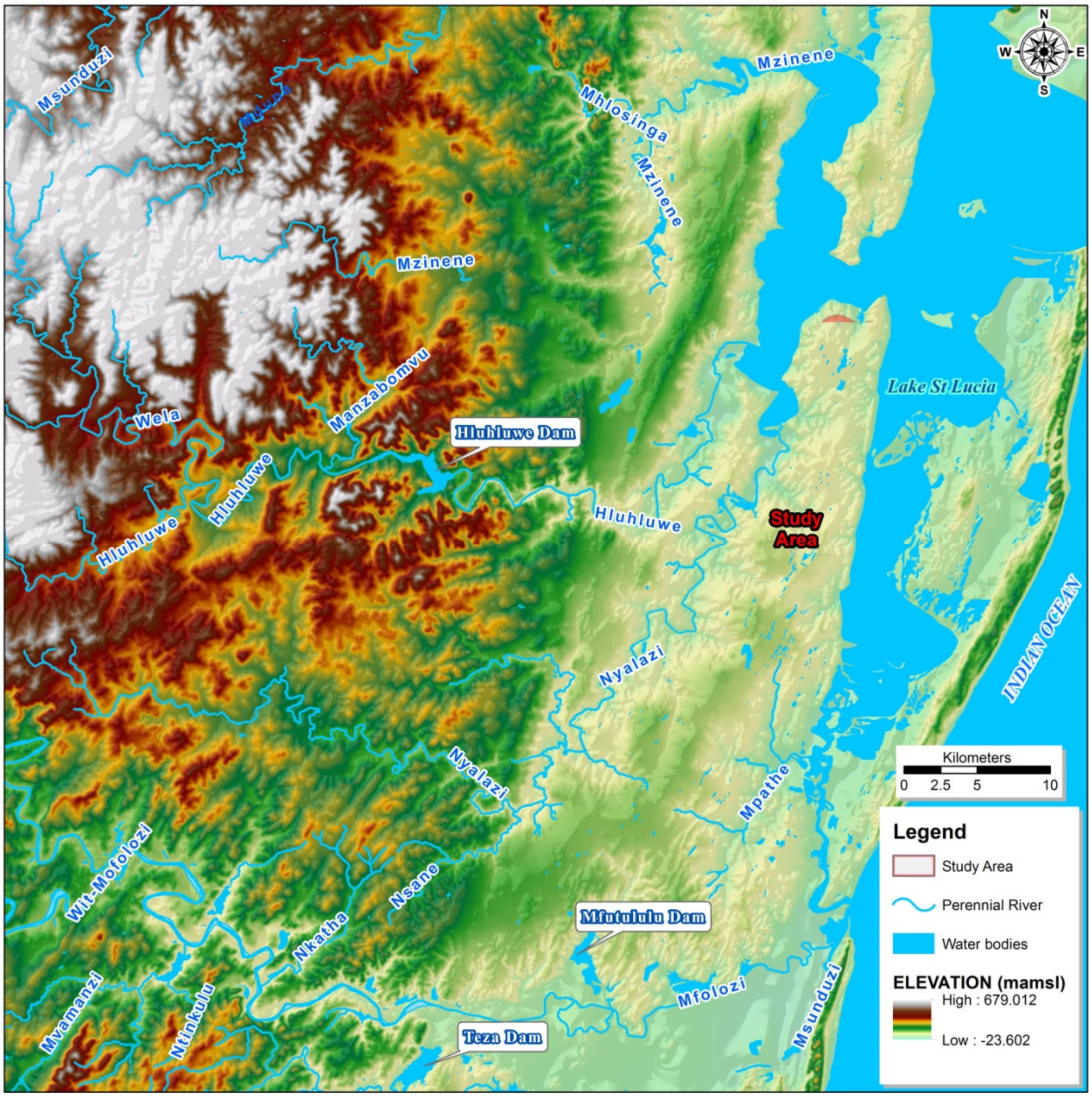


Figure 10: Topography of the study area

The study area lies alongside the base of the rocky, linear Lebombo mountain range, on a coastal plain which is associated with relatively flat, even topography (Figure 10) which slopes gently towards Lake St. Lucia to the east of the Nyalazi River to the west (Porter and Blackmore, 1998).

4.6 Vegetation and Land Use

A variety of diverse vegetation occurs throughout the iSimangaliso Wetland Park and surrounding areas, which includes grasslands, woodlands, shrubs and bushes, as well as vegetation associated with wetlands (Porter & Blackmore, 1998).

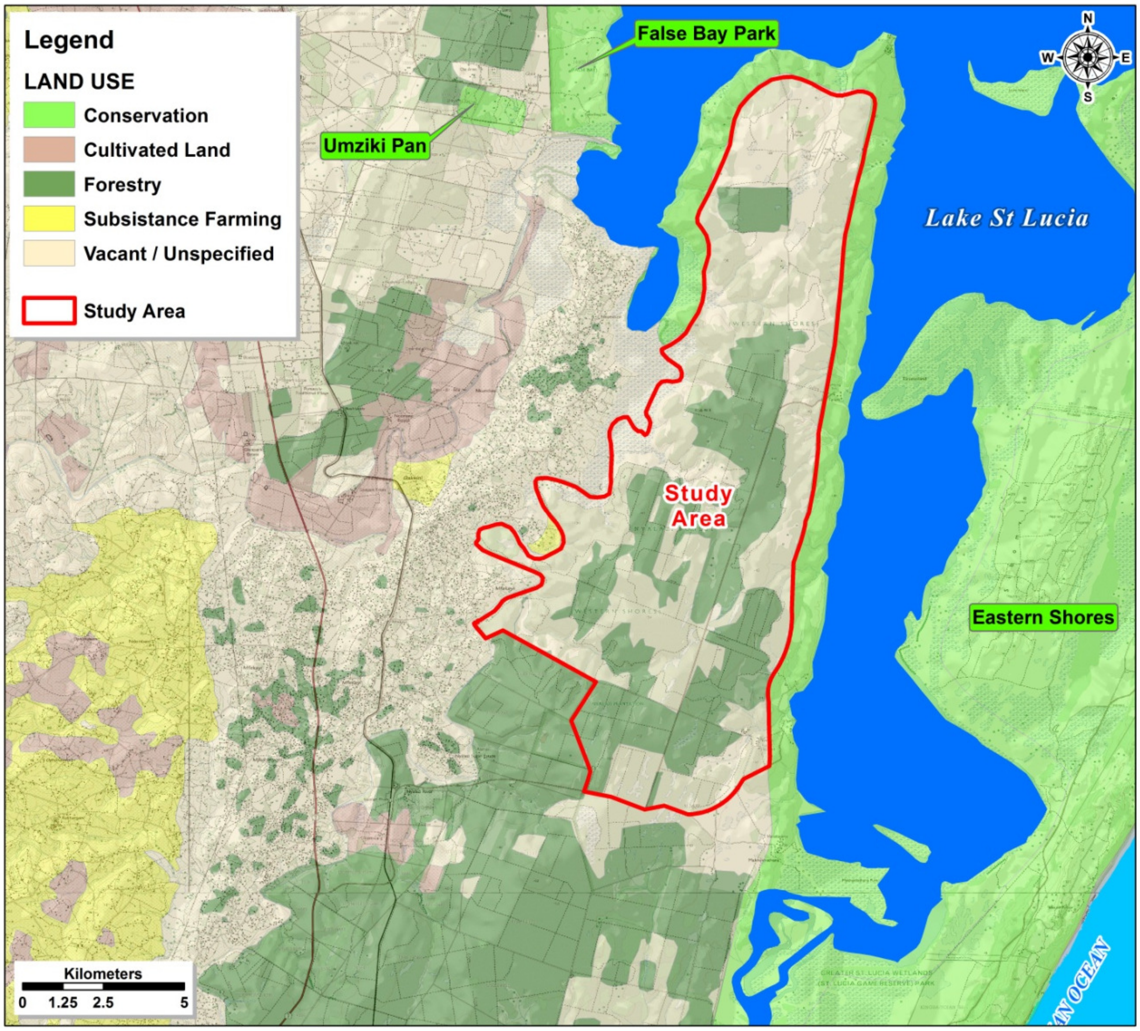


Figure 11: Vegetation cover of the study area

The western shores of Lake St. Lucia are swathed by a variety of vegetation cover. This includes indigenous grasslands, swamps, shrubs, thickets, trees and commercial timber plantations. The natural vegetation plays an essential role in the functioning of the St. Lucia Lake system. However, a great deal of this natural vegetation has been removed and substituted with timber plantations (Nomquphu, 1998).

The land use of the western shores is therefore characterised as commercial forestry (Figure 11). However, the iSimangaliso Wetland Park stretches 800 metres from the edge of the lake, which means no commercial forestry takes place in this area (Rawlins, 1991) and the land use is therefore classified as conservation. Therefore, the area also serves as a tourist destination with specific reference to Charters Creek and Fanies Island, which are camps located within the iSimangaliso Wetland Park (www.africatravelresource.com).

4.7 Soils

The overlying material in the area is mostly comprised of fine sand, silt, clay with organic material and alluvium of estuarine and aeolian origin (Lindley & Scott, 1987). The soils in the study area have a high sand content which is not easily differentiated from the cover sands. The organic component is generally low, with the exception of the surface layer in areas of thick vegetation. A study conducted on the eastern shores, whereby soil was augered, indicated surface layers comprised almost entirely of sand, or in other areas layers of 0.5 metres consisting of sand and organic material. Based on the sandy nature of the soil, surface water is not easily retained and infiltrates rapidly, with low surface runoff (Rawlins, 1991).

The western shores of the lake also consist of sandy soils. The specific site area is dominated by deep grey sands (Ha) distributed towards the centre of the peninsula (Figure 12) with the occurrence of duplex soils (Dc) along the perimeter of the site area (Land Type Survey Staff, 1972-2006). The simplex soils consist of sandier topsoil overlying the clay rich subsoil (Land Type Survey Staff, 1972-2006).

The soil depth class of the grey sands (Ha) according to Land Type Survey Staff (1972-2006) is greater than 1.2 metres. The clay content of these soils is low (less than 6%).

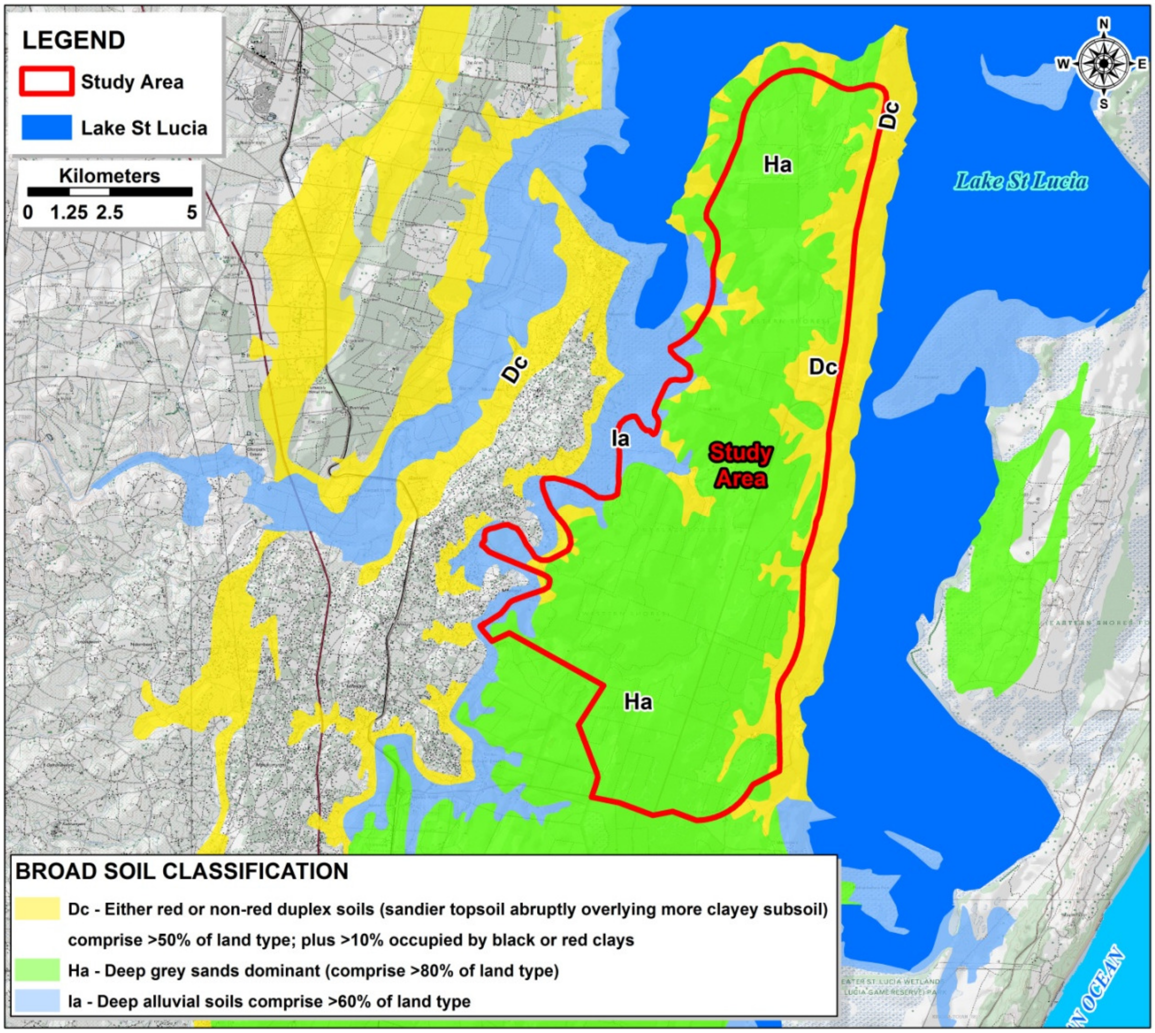


Figure 12: Soil cover of the study area

4.8 Hydrology

The study areas falls within the Mfolozi/Pongola Primary catchment, and the quaternary catchment W32H as indicated on Figure 13. As mentioned previously, the general relief of the area slopes towards Lake St. Lucia from the western Lebombo Mountains and as a result the lake is fed by several catchment systems. Lake St. Lucia receives its freshwater contribution from five different river systems. These are the Mkuzi, Hluhluwe, Mzinene, Mpate and Nyalazi Rivers, with catchment areas ranging from 65 to 6000 km^2 (Porter & Blackmore, 1998). The individual catchment areas are tabulated in Table 1.

Table 1: Catchment Areas

Catchment Name	Mkuzi	Hluhluwe	Mzinene	Mpate	Nyalazi
Area (km2)	6000	1000	800	62	700

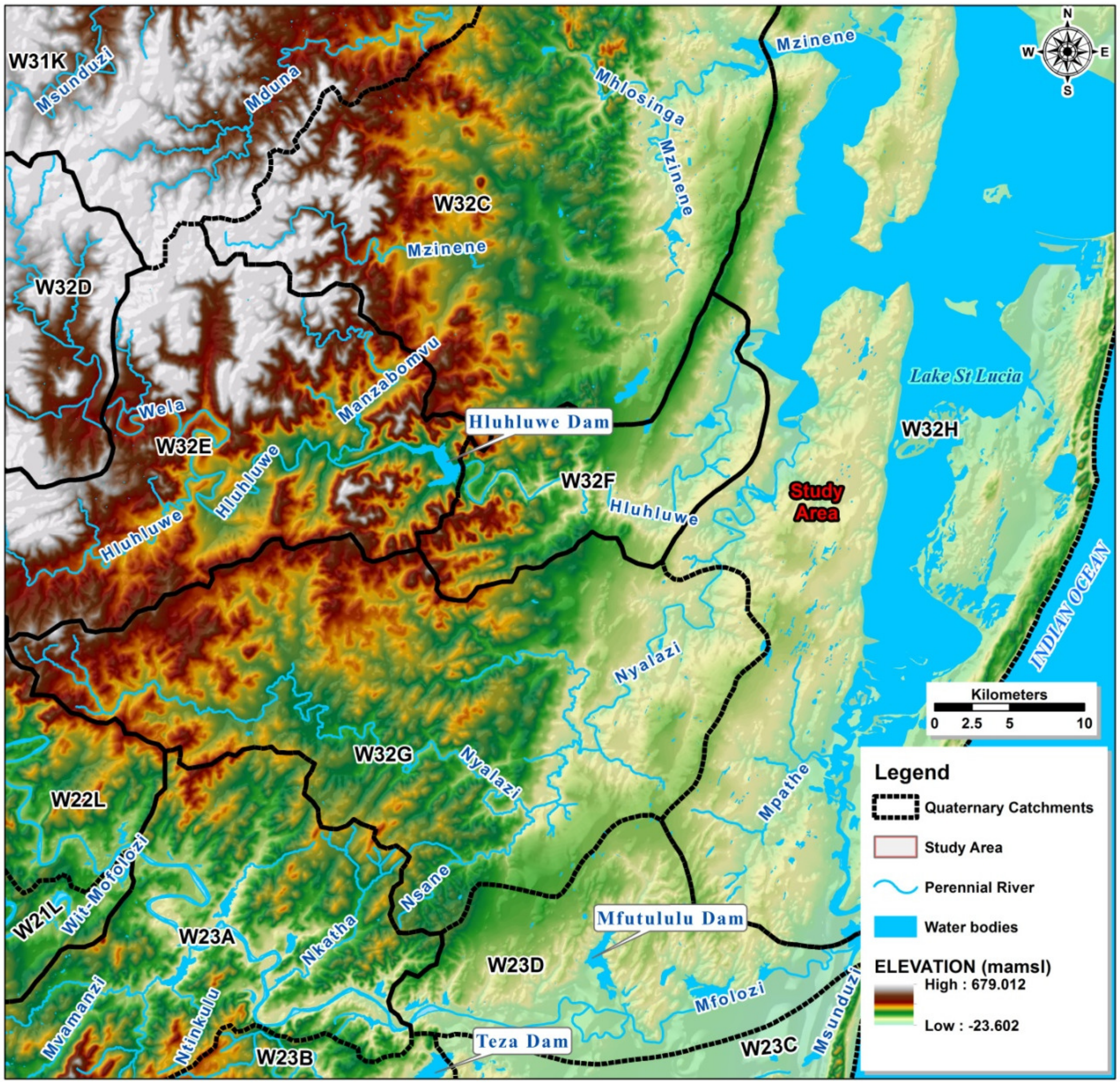


Figure 13: Quaternary catchments of the study area and surrounds

An additional input into the lake is groundwater seepage. During period of high precipitation and runoff, where these rates are higher than the groundwater seepage, the groundwater contribution to the lake is considered very low. However, this becomes an important factor during the drier period (Kelbe *et al*, 1995).

Several isolated pans and smaller wetlands are located in the low lying areas where the groundwater level surfaces. Wetlands are found where the coastal dune barrier meets the low lying plane and increases in number closer to Lake St. Lucia. Majority of the smaller wetlands appear to be sporadic and short lived whereas the larger ones are perennial (Rawlins, 1991).

CHAPTER 5: METHODOLOGY

5.1 Introduction

This chapter provides a description of the work which has been conducted on the project since 1995 to date. The reasoning behind the implementation of the groundwater monitoring system at the Nyalazi plantation, including the necessity will be addressed. A systematic approach is followed, whereby, the installation of the monitoring boreholes will be discussed followed by the groundwater and rainfall monitoring conducted at the study area.

5.2 Implementation of the Monitoring Network

The monitoring network was initiated by SAFCOL (South African Forest Company, Ltd) in 1995, now known as SiyaQubeka, in order to provide more information regarding the groundwater environment of the area and the resultant impact of the plantations on the ambient groundwater level of the site area. These concerns were raised by a number of interested and affected parties in the area (Jones & Johnstone, 1995).

The aim of the investigation was to, over time:

- Determine the impact of the Nyalazi forest on the groundwater levels;
- Determine the impact of the trees over the life cycle (from planting to felling);
- Establish a monitoring network, in order to monitor the system.

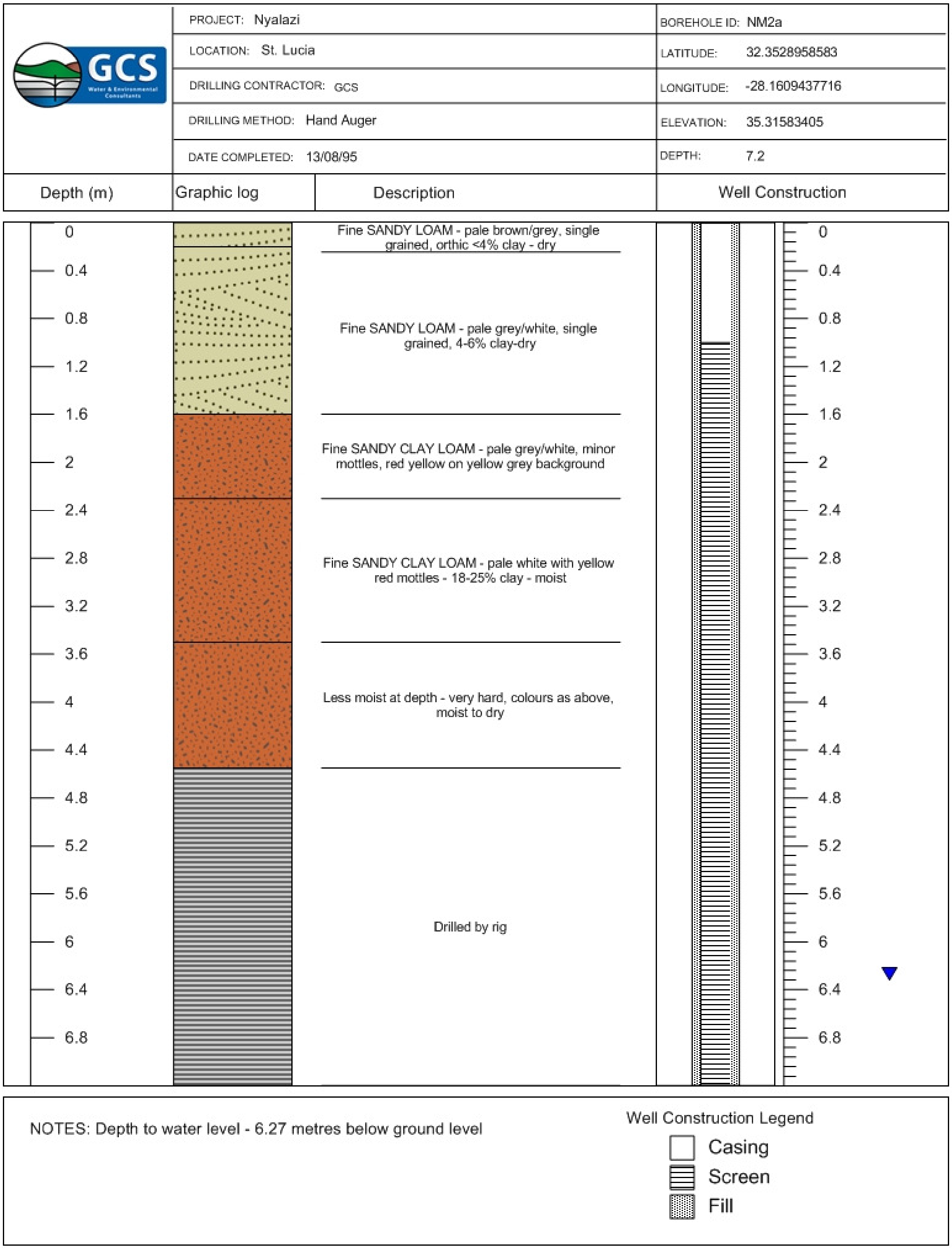
The locations of the monitoring boreholes were selected based on the land use, groundwater environment, age of the plantation, tree species and the soil types.

5.2.1 Drilling of monitoring boreholes

A field investigation was conducted at the Nyalazi plantation, which included the drilling of boreholes for monitoring purposes. The field work component of implementing the monitoring network was completed over the period 7 to 12 August 1995. The boreholes were logged in terms of soils and lithology by Mr. Ian Jones of GCS (Jones & Johnstone, 1995). In total, five boreholes were drilled within the Nyalazi plantation, courtesy of Richard Bay Minerals (RBM), utilising a reverse circulation drilling rig. The final depths of the boreholes ranged from 6.5 to 21.54 mbgl (metres below ground level) (Jones & Johnstone, 1995). An illustration of a borehole log is presented in Figure 14 for NM2a. Details of the lithologies are presented in the borehole logs in Appendix A and summarised in Table 2.

Table 2: Lithology Tables - Boreholes

Well	Depth		Strata
	From	To	
NN1a	0	8	Sandy Loam
	8	10	Clay
	10	11	Sandy Loam
	11	14	Sandy Silty Loam
NM1a	0	2	Sand
	2	5	Sandy Loam
	5	6	Clay
	6	7.07	Sandy Clay
NU2b	0	2	Sandy Loam
	2	3	Sandy Clay
	3	4	Sand
	4	10	Sandy Clay
NJ2A	0	4	Sandy Clay Loam
	4	11	Silty Sand
	11	15	Sand
NJ1a	0	1	Sand
	1	2	Sandy Loam
	2	7	Sandy Clay Loam
	7	9	Sandy Loam
	9	10	Sandy Clay Loam
	10	21.54	Sandy Silt Loam
WES01	0	2	Sand
	2	4	Clay
	4	5	Sand
	5	9	Silty Clay
	9	27	Silty Sand
	27	41	Silty Clay



PROJECT: Nyalazi
LOCATION: St. Lucia
DRILLING CONTRACTOR: GCS
DRILLING METHOD: Hand Auger
DATE COMPLETED: 13/08/95

BOREHOLE ID: NM2a
LATITUDE: 32.3528958583
LONGITUDE: -28.1609437716
ELEVATION: 35.31583405
DEPTH: 7.2

Depth (m)	Graphic log	Description	Well Construction
		Fine SANDY LOAM - pale brown/grey, single grained, orthic <4% clay - dry	
		Fine SANDY LOAM - pale grey/white, single grained, 4-6% clay-dry	
		Fine SANDY CLAY LOAM - pale grey/white, minor mottles, red yellow on yellow grey background	
		Fine SANDY CLAY LOAM - pale white with yellow red mottles - 18-25% clay - moist	
		Less moist at depth - very hard, colours as above, moist to dry	
		Drilled by rig	

NOTES: Depth to water level - 6.27 metres below ground level

Well Construction Legend
- ☐ Casing
- ▤ Screen
- ▨ Fill

Figure 14: Borehole log for NM2a

5.2.2 Auger hole drilling

During the field study, 16 piezometers were installed by means of a conventional soil auger with a diameter of 100 millimetres and a maximum depth of 5.4 metres. The collapsing of holes was evident when augering extended beyond the groundwater table, which was problematic. All piezometers were installed to a final depth greater than that of the groundwater table (Jones & Johnstone, 1995). Details of the lithologies are presented in the borehole logs in Appendix A and summarised in Table 2.

Table 3: Lithology Tables - Auger holes

Well	Depth (metres)		Strata
	From	To	
NU3a	0	1.5	Sandy Loam
	1.5	3.5	Clay
	3.5	3.6	Ferricrete
NU2a	0	2.6	Sandy Loam
	0.1	2.3	Sandy Loam
	2.6	4.99	Clay
NU1a	0	3.5	Sandy Loam
	3.5	5	Clay
NT1a	0	2.9	Sandy Loam
	2.9	3.4	Sandy Clay Loam
	3.4	4.76	Sandy Clay Loam To Sandy Clay
NT2a	0	0.8	Sandy Loam
	0.8	2.1	Clay

5.2.3 Groundwater monitoring

Upon the completion of the installation of the boreholes and piezometers, initial groundwater levels were measured in August 1995. The first series of groundwater level data was obtained mid-October 1995. Groundwater levels were recorded using a dip meter and data was obtained from all 21 monitoring points. Thereafter, groundwater levels were measured on a fortnightly basis. The monitoring is still on-going, however, majority of the monitoring points are dry as the groundwater level has fallen below the bottom of the hole (Jones & Johnstone, 1995).

5.2.4 Monitoring Point Localities

As discussed in Section 5.2.1 and Section 5.2.2, five boreholes and 16 piezometers were installed on site in August 1995. Table 4 below, provides the geographic co-ordinates for each monitoring point and the elevation in metres above mean sea level (mamsl).

The localities of these boreholes and piezometers have been plotted on Figure 15 which also illustrates the tree species being monitored.

Table 4: Boreholes and piezometer details

Borehole ID	WGS 84 Geographic		Elevation (mamsl)	Water Level (avg 1995)	Last water level measurement
	S	E			
NJ1a	-28.18597	32.40010	42.51	3.15	19.1 (2010)
NJ1b	-28.18606	32.40040	41.86	2.70	19.2 (2010)
NJ2a	-28.18558	32.41298	24.34	10.03	11.2 (2011)
NJ3a	-28.18446	32.40439	40.00	4.62	19 (2010)
NJ4a	-28.18137	32.40043	45.18	5.49	19.5 (2010)
NJ5a	-28.18551	32.41077	31.19	5.78	5 (2002)
NO2a	-28.17898	32.40105	38.12	4.97	7.8 (2008)
NO1a	-28.17944	32.40187	49.51	5.85	5.9 (2007)
NR2a	-28.10443	32.40737	40.04	2.92	4 (2009)
NQ1a	-28.12956	32.39705	29.19	1.79	1.64 (2008)
NN1a	-28.17190	32.38154	50.00	6.78	24.9 (2012)
NK1a	-28.19262	32.37297	45.24	2.41	2.65 (1998)
WES01	-28.16744	32.36905	50.44	-	24.25 (2010)
NM1a	-28.16588	32.36702	45.69	6.09	16.4 (2011)
NM2a	-28.16094	32.35290	35.32	7.45	14.5 (2008)
NU1a	-28.06202	32.41656	32.32	5.56	4.3 (2008)
NU2a	-28.06194	32.40781	34.44	5.68	4.5 (2008)
NU2b	-28.06194	32.40791	34.44	6.07	6 (2006)
NU3a	-28.06192	32.40333	35.68	3.82	3.8 (2006)
NT1a	-28.06203	32.41844	32.13	4.25	3.3 (2010)
NT2a	-28.06203	32.41940	32.06	2.28	4.1 (2010)
NR1a	-28.06798	32.40788	33.13	5.54	4 (2009)

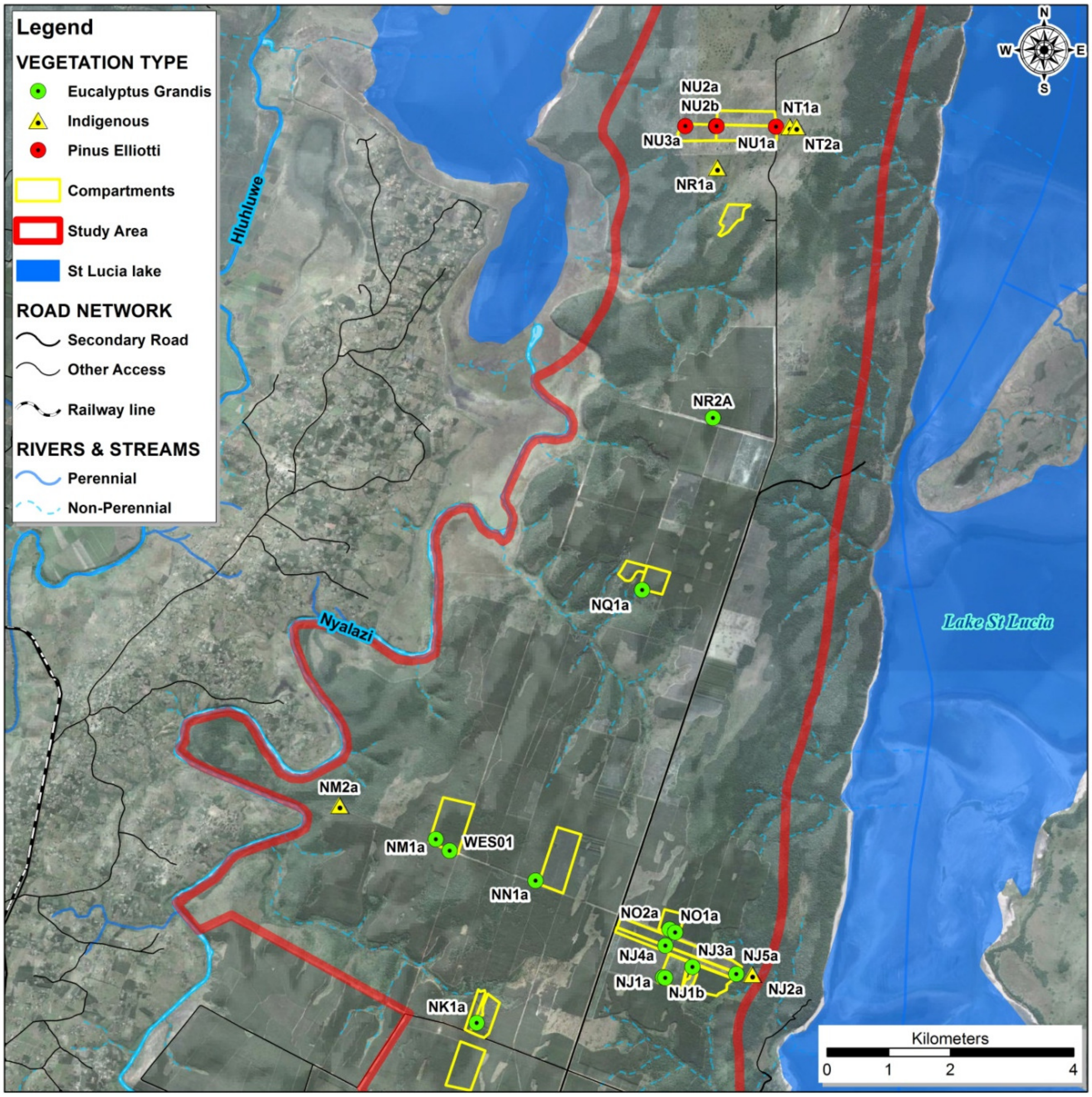


Figure 15: Monitoring borehole network map

5.2.5 Rainfall monitoring

The rainfall was also measured on a fortnightly basis. This was measured directly on site at the Dukuduku weather station, adjacent to Nyalazi, located at the following geographic co-ordinates: -28° 21’12,191”S, 32° 14’48,089”E.

The monitoring of the rainfall is an important aspect of the project, as it is important to measure the response of the groundwater level to the rainfall and recharge to groundwater.

5.2.6 Specific Tree Species Monitored

The monitoring points within the study area have been combined into four groups as tabulated below in Table 5. Also indicated, is the type of tree species which the different boreholes and piezometers were intended to monitor. The borehole positions have been illustrated on Figure 15.

Table 5: Monitoring Hole Positions and Tree Species

Group	**Compartment**	**Monitoring Hole Numbers**	**Type of Monitoring Point**	**Species**
1	J12	NJ1a, NJ1b	Borehole, Piezometer	*Eucalyptus grandis Camaldulensis*
	-	NJ2a	Borehole	Indigenous
	J14	NJ3a, NJ4a	Piezometer, Piezometer	*Eucalyptus grandis Camaldulensis*
	J13	NJ5a	Piezometer	*Pinus occulapia/ Eucalyptus grandis Camaldulensis*
2	D - Trials	NO2a	Piezometer	*Pinus elliottii/ Eucalyptus grandis Camaldulensis*
	D - Trials	NO1a	Piezometer	*Eucalyptus grandis Camaldulensis*
3 Cross-sections	North / South	NR2a	Piezometer	*Eucalyptus grandis Camaldulensis*
		NQ1a	Piezometer	*Eucalyptus grandis Camaldulensis*
		NN1a	Borehole	*Eucalyptus grandis Camaldulensis*
		NK1a	Piezometer	*Eucalyptus grandis Camaldulensis*
	East / West	NJ1a	Borehole	*Eucalyptus grandis Camaldulensis*
		NJ4a	Piezometer	*Eucalyptus grandis Camaldulensis*
		NN1a	Borehole	*Eucalyptus grandis Camaldulensis*
		WES01	Borehole	*Eucalyptus grandis Camaldulensis*
		NM1a	Borehole	*Eucalyptus grandis Camaldulensis*
		NM2a	Piezometer	Indigenous
4	U29, U28 and U3	NU1a, NU2a, NU2b, NU3a	Piezometer, Piezometer, Borehole, Piezometer	*Pinus elliottii*
		NT1a, NT2a, NR1a	Piezometer, Piezometer, Piezometer	Indigenous

Group 1 consists of six piezometers located within compartments J12-J14. The tree species monitored by these piezometers include *Eucalyptus grandis Camaldulensis*, indigenous bush and grass serving the purpose of firebreaks as well as a compartment of *Pinus occulapia*. The purpose of points NJ1a, NJ1b, NJ3a and NJ4a is to monitor the effect of the *Eucalyptus grandis Camaldulensis* over the life of plantation as this was planted concurrently to the implementation of the monitoring points. The *Pinus occulapia,* monitored by NJ5a was planted in 1976 and therefore the intention is to measure the current effects as well as post felling (Jones & Johnstone, 1995). The data obtained from point NJ2a monitoring the indigenous vegetation serves as baseline or background data which would represent the natural conditions of the study area. There is some overlap with some of the monitoring points where they occur on more than one Group. For example NJ1a forms part of Group 1 but also Group 3 as it lies along the east-west cross sectional line.

Group 2 consists of two piezometers, namely NO1a and NO2a, which are located within Compartment D. Two small plantations of *Eucalyptus grandis Camaldulensis* and *Pinus elliottii* were both planted in 1986 and the monitoring thereof is to compare the different effects of the two species (Jones & Johnstone, 1995).

The piezometers forming part of Group 3, were installed in order to create a cross section across the plantation areas. The north to south cross section is comprised of piezometers NR2a, NQ1a, NN1a and NK1a. Piezometers NJ1a, NJ4a, NN1a, NM1a and NM2a comprise the east to west cross section. As a result, these piezometers monitor the *Eucalyptus grandis Camaldulensis* tree species as well as the indigenous vegetation, grass and wetland related vegetation as they span across a large area of the site to form the cross section (Jones & Johnstone, 1995). The *Eucalyptus grandis Camaldulensis* were planted in 1995.

Group 4 consists of six piezometers which monitor the *Pinus elliottii* plantation which was planted in September 1967 (Jones & Johnstone, 1995). This plantation is located at quite a distance from the other plantations on site and is therefore isolated, thus there are no additional impacts from neighbouring plantations. This plantation is also surrounded by indigenous vegetation, thereby creating the ideal situation to monitor the impacts on the groundwater system. The piezometers monitor both the *Pinus elliottii* and indigenous vegetation in order to draw a comparison between the two (Jones & Johnstone, 1995).

5.2.7 Deeping of piezometer monitoring points

The water level in certain monitoring points declined beyond the bottom of the piezometer or borehole. Therefore, in March 1998, an effort was made to deepen these monitoring holes. Of the 21 monitoring points, seven were still functional and water level measurements were still obtained from the functional boreholes. An attempt to deepen the remaining 14 was made of which 4, were deepened successfully. The holes which were successfully deepened were NR2a, NT1a, NU1a and NU3a.

The monitoring points which were not successfully deepened were as a result of refusal on clay or the presence of small diameter galvanized pipes. Even though these were not successfully deepened in 1998, water levels were still recorded in some of these monitoring points. Additionally, monitoring points were also deepened at a later stage according to the water level graphs. The following boreholes were deepened, detailing the year they deepened in brackets, NM2a (2002), NN1a (2003), NO2a (2003), NT2a (2006). Several monitoring points were redrilled in 2007, which include the following, NJ1a, NJ2a, NJ3a, NJ4a, NM1a, NM2a and NN1a.

CHAPTER 6: GEOLOGY OF THE ST. LUCIA AREA

6.1 Introduction

Lake St. Lucia has been of environmental interest over recent decades which have lead to a significant amount of research being done in the region. However, majority of the research and interest in the topic is focused on the eastern shores of Lake St. Lucia.

In order to understand the groundwater environment of the area, it is important to conceptualise the integral components of the system. One of these components is the geological setting of the area. The soils and shallow lithologies are of particular interest to this study, as these are influential factors when investigating the hydrogeological setting which will determine the type of aquifers which may be present. The lithology of the site area is presented in the borehole logs in Appendix A.

6.2 Regional Geological Setting

6.2.1 Cretaceous Deposits

The Cretaceous deposits form a continuous succession which underlies the entire Zululand coastal area (Kelbe *et al*, 1995). The Cretaceous deposits range in thickness from 900 meters in the False Bay area to 1800 meters further north (Bredenkamp, 1992). This is a relatively thick layer which lies unconformably on the pre-Cretaceous granites and lavas (Rawlins, 1991). The contact zone between the Cretaceous and pre-Cretaceous is greater than 1000 meters below sea level and as a result will not influence groundwater system in the area (Rawlins, 1991).

The Cretaceous deposits are comprised mostly of sandstones, siltstones and shales, which form a thick wedge which thickens towards the west. These deposits dip gently seawards with an inclination of 3° in the west to 1° in the east (Nomquphu, 1998).

6.3 Tertiary Period

The sediments deposited during the Tertiary period form a discontinuous, near horizontal layer, which lies unconformably on the Cretaceous deposits (Nomquphu, 1998). The sediments were deposited during a period of seabed upliftment followed by submergence resulting in the occurrence of terrestrial and marine deposits (Kelbe *et al*, 1995). The marine deposits of this period (mostly comprised of limestones) are highly fossiliferous. These deposits are evident as outliers in Uloa, Mfolozi River valley and along the shores of Hell's Gate (Nomquphu, 1998).

6.4 Pleistocene Period

The Port Durnford Formation uncomformably overlies the deposits of the Tertiary period, which is predominately comprised of partly consolidated sandy deposits. The unit consists of a lower argillaceous and an upper arenaceous unit. The strata of the Formation consists of blue grey sandy mudstone (containing fossil remains) at the base, followed by yellow brown ferruginised sandstone, lignite or peat and consolidated sands as the uppermost layer (Nomquphu, 1998). The lower argillaceous unit was deposited under a transgressive period based on the occurrence of the mudstone and fossil remnants. The uppermost unit of the Formation was formed during regressive conditions with the evidence of cross bedding within the consolidated sandy deposit (Kelbe *et al*, 1995).

The thickness of the Formation ranges from 10 meters to 30 meters in the St. Lucia region, with the top of the Formation located at mean sea level (Rawlins, 1991). Outcrops of the Port Durnford are evident along the sea cliffs as well as sporadically along the periphery of Lake St. Lucia (Nomquphu, 1998).

6.5 Holocene Period

The Port Durnford Formation is overlain by a thin layer of recent sands, which consists of boulder beds, old red sands, cover sands, coastal dunes and calcarenites (Figure 16). These sediments were formed during periods of transgressions and regressions where both erosion and sedimentation occurred (Nomquphu, 1998). The coastal dunes, orientated in a north to south direction, consist of uniform sand which overlies pebble and boulder containing deposits. The origin of these sands is Aeolian and is also associated with marine regressions (Kelbe, Rawlins & Nomquphu, 1995).

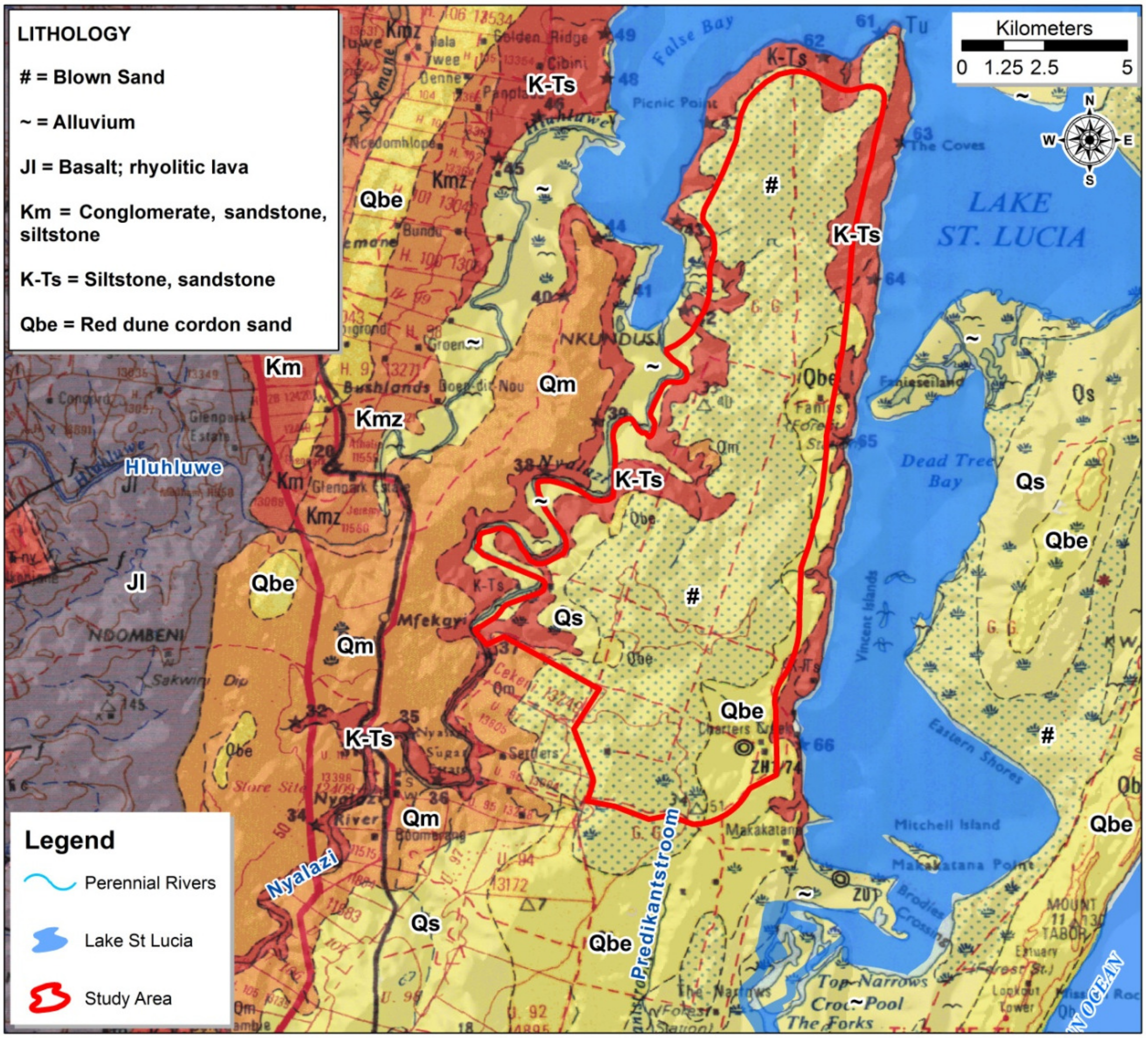


Figure 16: Geological Map of the Study Area

The dune ridges of the western shores are dominated by fine grained and well sorted sandy deposits with a thickness that ranges from 0.5 to 3 meters over the coastal plain (Kelbe *et al*, 1995).

6.6 Conclusion

The geological units which influence the hydrogeological regime of the site area include the recent deposits of cover sands and the Port Durnford Formation. These geological successions are the most influential on the groundwater environment as these are the units closest to the surface. The Cretaceous siltstones underlying the Port Durnford Formation is considered impervious and based on the depth of the lithology, will not influence the shallow aquifer system associated with the study area (Kelbe *et al*, 1995).

CHAPTER 7: HYDROGEOLOGY OF THE ST. LUCIA AREA

7.1 Introduction of aquifer types in the St. Lucia area

An important factor to take into consideration when investigating the dynamics of the groundwater system and the trends of the groundwater level, are the aquifer characteristics of the study area. The study area is located on the Maputuland coastal plain, also referred to as the Zululand coastal plain, which is classified as a primary aquifer (sediments with high permeability which promotes rapid recharge) and is the largest of its kind in South Africa. High recharge is experienced within the upper formations of the coastal plain which are unconfined aquifers (Mkhwanazi, 2010).

Wetlands, estuaries and coastal lakes as well as other water bodies are associated with the primary aquifers present in the area, as these are directly connected through seepage and rivers. The shallow aquifers in the area were previously targeted for water supply for mining operations in the past which has since ceased (Mkhwanazi, 2010).

7.1.1 Alluvial Aquifer of the Western Shores

The study area overlies the widespread Zululand coastal plain aquifer which is comprised of Pleistocene and Holocene lithological units. This aquifer consists of unconsolidated clays and sands, which may be defined as an alluvial or primary aquifer (Rawlins & Kelbe, 1991) which is generally associated with high transmissivity and high rates of infiltration subsequent to rainfall events (Bredenkamp, 1992).

The rate of groundwater flow as well as the direction of flow is highly dependent on the characteristic hydraulic properties of the different layers. The sandy layers allow free movement of groundwater based on the high permeability and porosity, compared to the silts and clays with lower permeabilities which tend to reduce the movement of groundwater flow resulting in perched water tables (Rawlins, 1991).

Typical hydraulic parameters for these types of sands have been measured to have a porosity of 45%, specific yield of 35% and a permeability of 0.24 metres per day (Rawlins, 1991).

The Cretaceous siltstones underlying the Port Durnford Formation are considered impervious and based on the depth of the lithology, will not influence the shallow aquifer system associated with the study area (Kelbe *et al*, 1995).

7.2 Groundwater level data

Groundwater level data is available for the Nyalazi site area. The data was obtained through the continuous monitoring programme implemented at the site, whereby the water level was measured in 16 piezometers and five boreholes on a fortnightly basis. This was initiated in 1995; however, the water level at several of these monitoring points has since declined below the depth of the borehole/piezometer. Data gaps are evident for some boreholes where does was not collected for certain periods of time. Currently, only 2 boreholes have a suitable depth which enables groundwater level monitoring.

7.2.1 Elevation contours

A three dimensional illustration of the topography of the site area was constructed using the five metre contour data.

As is illustrated on Figure 17, the inland region of the site is at a higher elevation than the area closer to the lake, as expected. Therefore the topography slopes from the inland areas towards the lake. The topography of the site has been exaggerated in order to highlight the topographical differences in elevation across the site area.

It is also evident that the southern inland portion of the site is more elevated than the northern inland portion. The elevation and slope of the site area is an important factor to incorporate when investigating the groundwater flow on site.

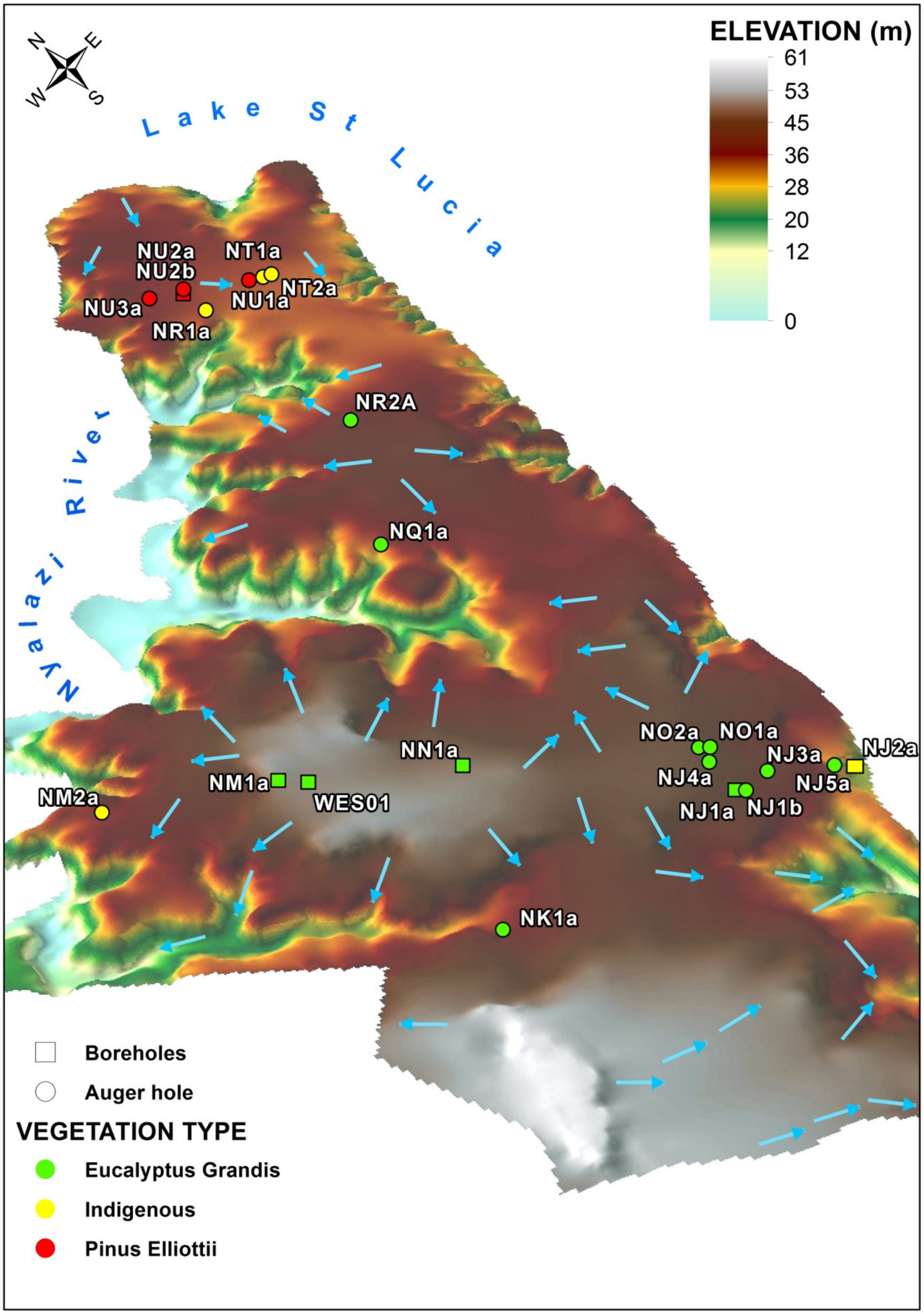


Figure 17: Three Dimensional Topographical Representation

7.2.2 Bayesian estimate

The water level data obtained in 1995 accompanied with the elevation data for the points were used to determine whether the groundwater levels correlate with the terrain elevation measurements of the site. This is defined as a Bayesian estimation. The groundwater levels measured in metres below ground level are converted and displayed as metres above mean sea level in order to draw a parallel with the elevation measurements. In this case, as illustrated on Figure 18, the water levels mimic the topography, with a correlation of approximately 93% as indicated on Figure 18.

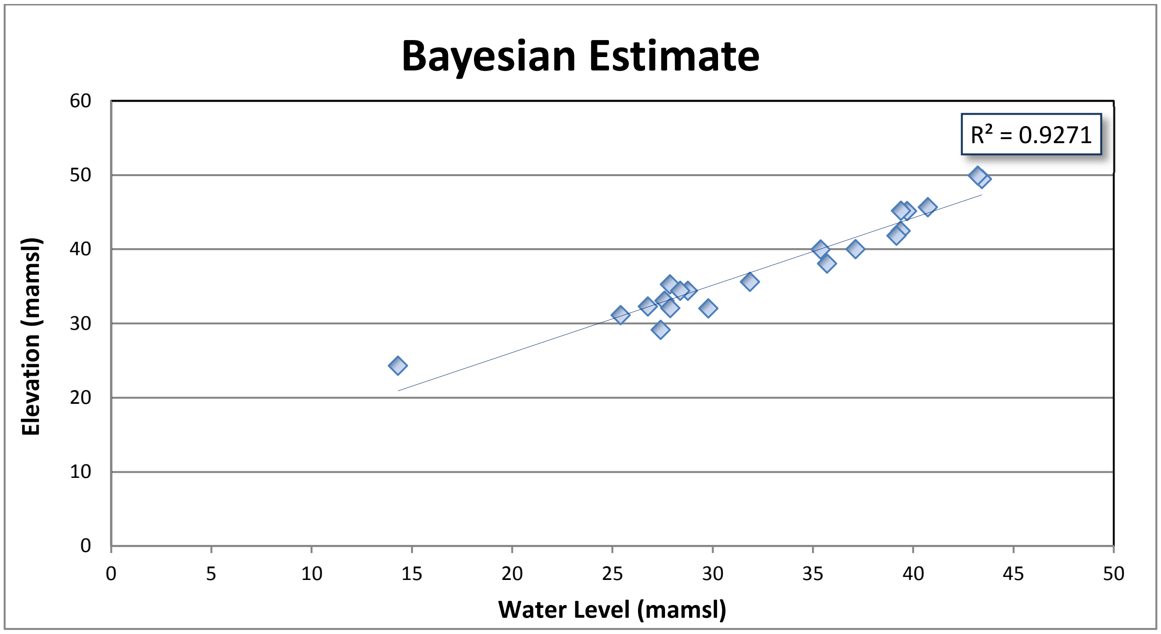


Figure 18: Bayesian Estimate

7.2.3 Groundwater level contours

A groundwater level contour map was constructed using the monitoring data collected in 1995. The water levels were measured fortnightly from mid October 1995 to mid-December 1995. The average of this data set was used to construct the water level contours.

Based on the data, the groundwater contours indicate that the groundwater flow direction is from higher elevation to lower elevation, evident from the flow vectors plotted on Figure 19. Therefore the groundwater within the confines of the site area flows from the high-lying inland area towards the lake bordering the eastern and northern sections and low lying areas adjacent to the Nyalazi River to the west. The exception is the area surrounding NQ1A, which is associated with a wetland area.

A comparison was made between the groundwater contours and flow vectors between 1995 and 2001. As depicted in Figure 19 and Figure 20, the groundwater flow direction has not been altered even though the groundwater levels have declined over this period of time. The data obtained was considered sufficient to create groundwater contours. This year was used as the cut off date as in the years to follow certain boreholes presented sporadic data which was not sufficient to create contours.

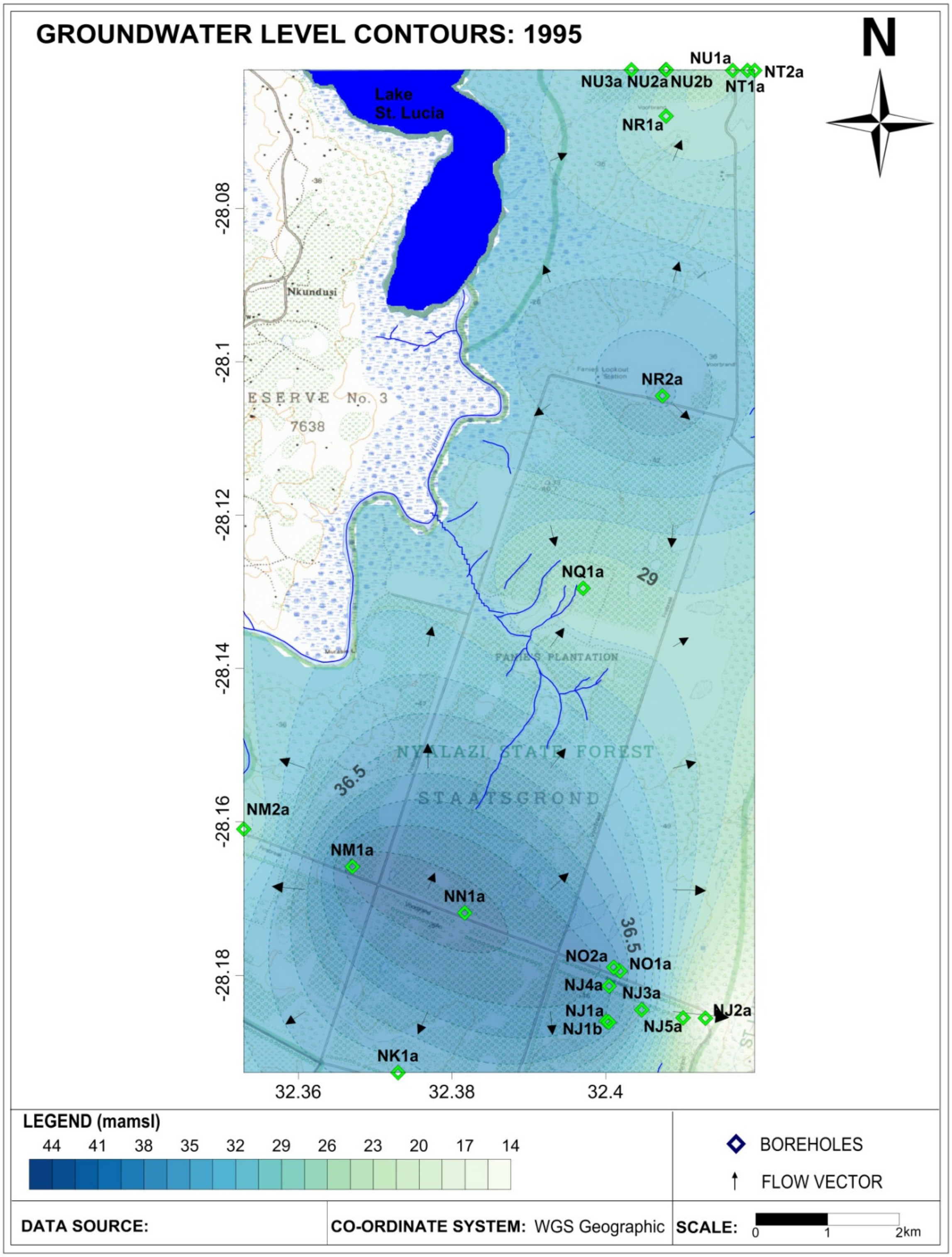


Figure 19: Water level contours for 1995

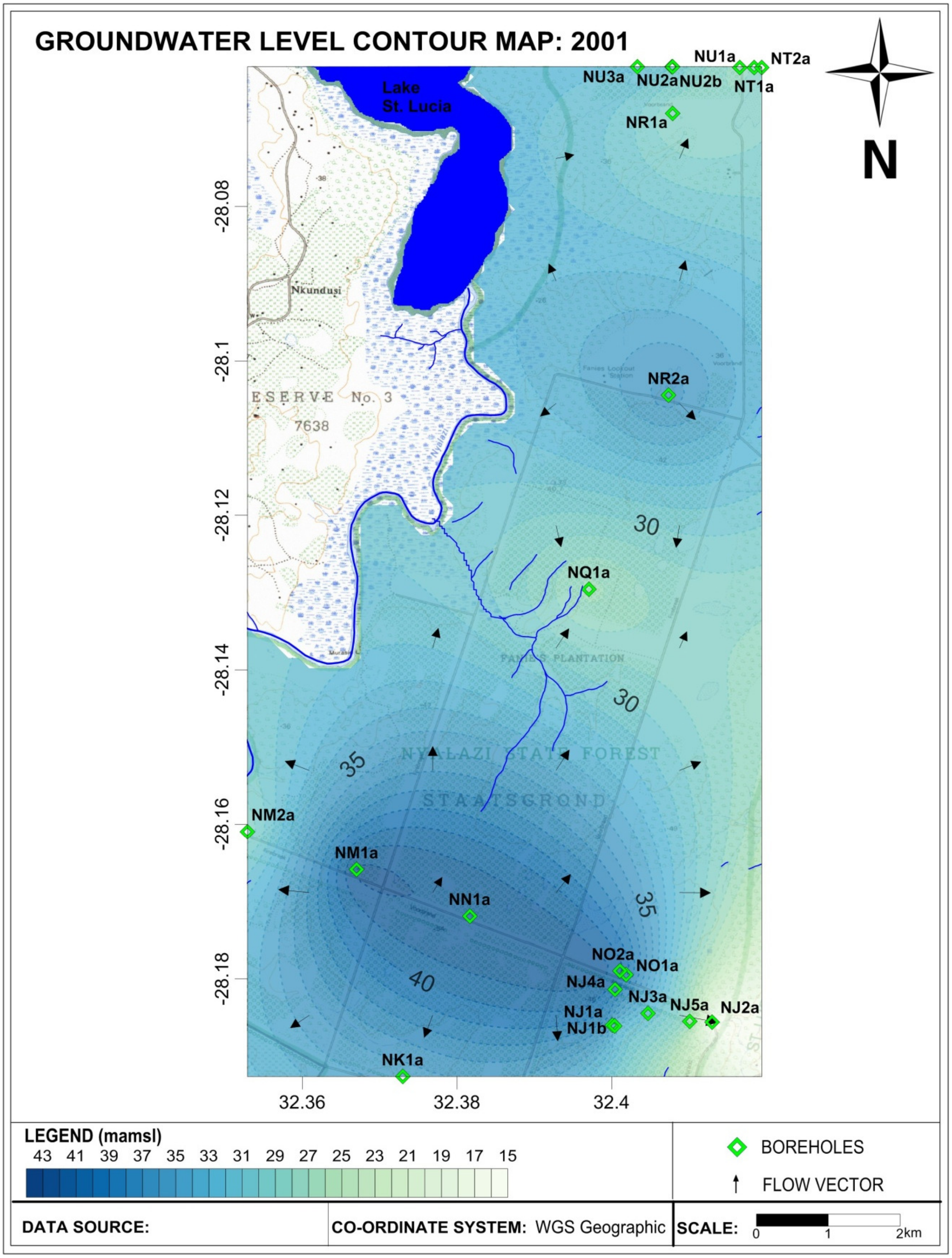


Figure 20: Water level contours for 2001

7.3 Groundwater Levels Trends

Even though the data set boasts 18 years' worth of water level records, no data was recorded for a large proportion of the monitoring points over long periods of time, resulting in a significant data hiatus. Therefore only the relevant data has been included and interpreted. The data gaps are largely attributed to the shallow depth of the piezometers, as the water level declined below this depth. The groundwater level trends are interpreted within the different groups in order to consider the effects of the neighbouring plantations which may play a significant role. It is also imperative to segregate the results for each different tree species in order to evaluate the trends and effects of the individual tree species.

7.3.1 Group 1

The localities of Group 1 are presented in Figure 21 as well as the relative compartments which are located in close proximity to the monitoring points.

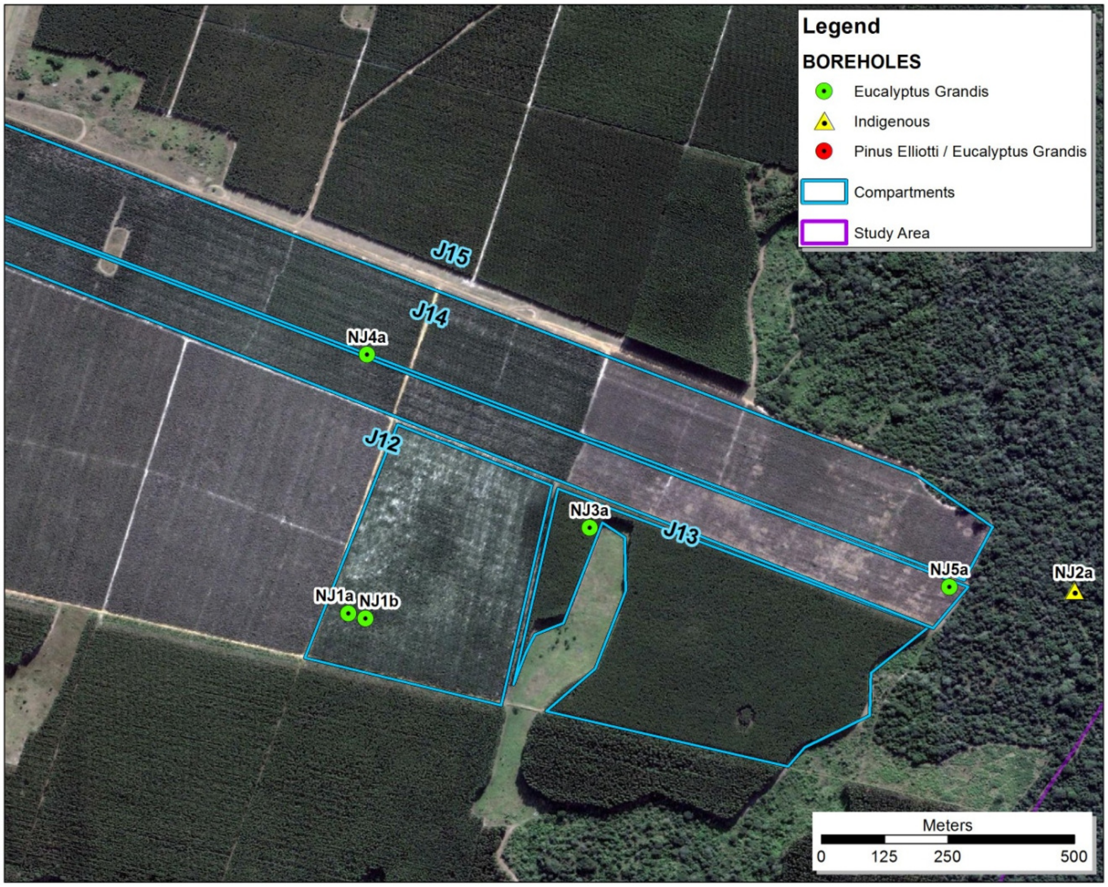


Figure 21: Localities of monitoring points of Group 1 and associated compartments

7.3.1.1 Eucalyptus grandis Camaldulensis - NJ1a and NJ1b

The *Pinus elliottii* compartment was established in 1978. Piezometer NJ1a and borehole NJ1b (photographed in Figure 23) are located 30 metres apart and were installed in August 1995 to monitor the *Eucalyptus grandis Camaldulensis* plantation which was planted in June 1995. Monitoring of the water level commenced mid October 1995. From October 1995 to March 1996, the water level rose 1.98 metres in monitoring point NJ1a and 2.19 metres in NJ1b over this period (Figure 22 and Figure 24).

This increase in water level (this refers to a rise in the water level) coincided with the first year of growth of the Eucalyptus species, after the felling of the preceding Pine tree species. However, this trend is noticeable in majority of the monitoring points and can therefore be most likely attributed to the response to the high rainfall received from October 1995 to March 1996 and the resultant groundwater recharge.

For NJ1a, a decline of on average 1.65 metres per annum was observed, calculated from the time the water level started to decline (after the initial rise), to the point where the monitoring point ran dry (March 1996 - June 1998). For a period of approximately 10 years, no data was obtained as the water level had declined below the depth of the piezometer and the piezometer was blocked at 5.6 metres. This was later deepened between 2005 and 2008 (no records of this was available) and data was once again recorded from March 2008 until February 2010. The piezometer is currently blocked at 7.1 metres although water level data was recorded up to a depth of 19 metres in 2010, indicating a minimum depth of 19 metres after the redrilling in 2008, however no information regarding the redrilling was available. It has been recommended in Section 9.1.1 that NJ1a is rehabilitated The total drop in water level over the period of 15 years which was monitored (1995 to 2010) was 15.66, based on an initial water level of 3.44 mbch and a final water level of 19.1. Therefore the average annual decline in water level was calculated by using the total drop of 15.66 meres divided by the 15 years of monitoring which results in an average decline of 1.04 metres per year.

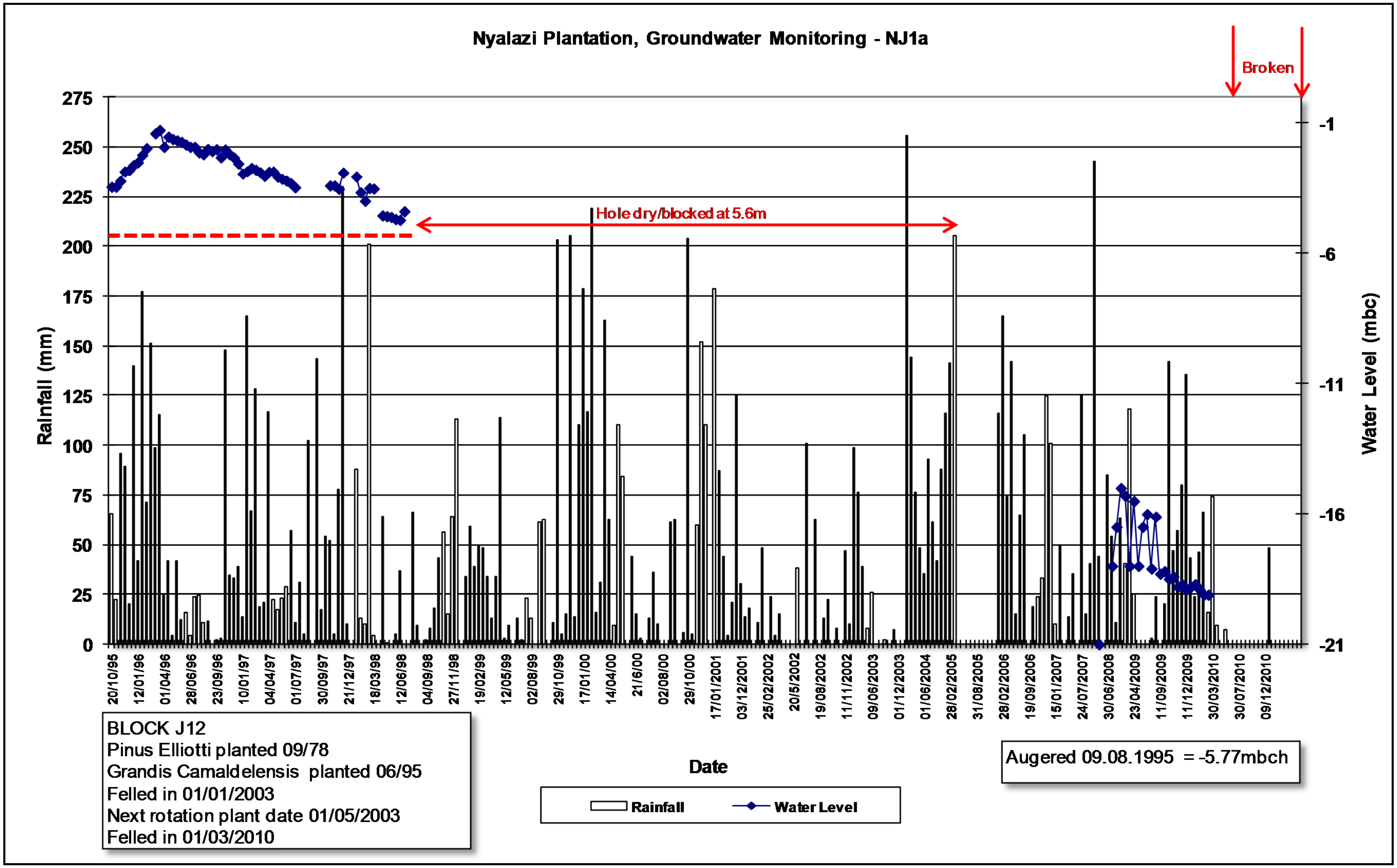


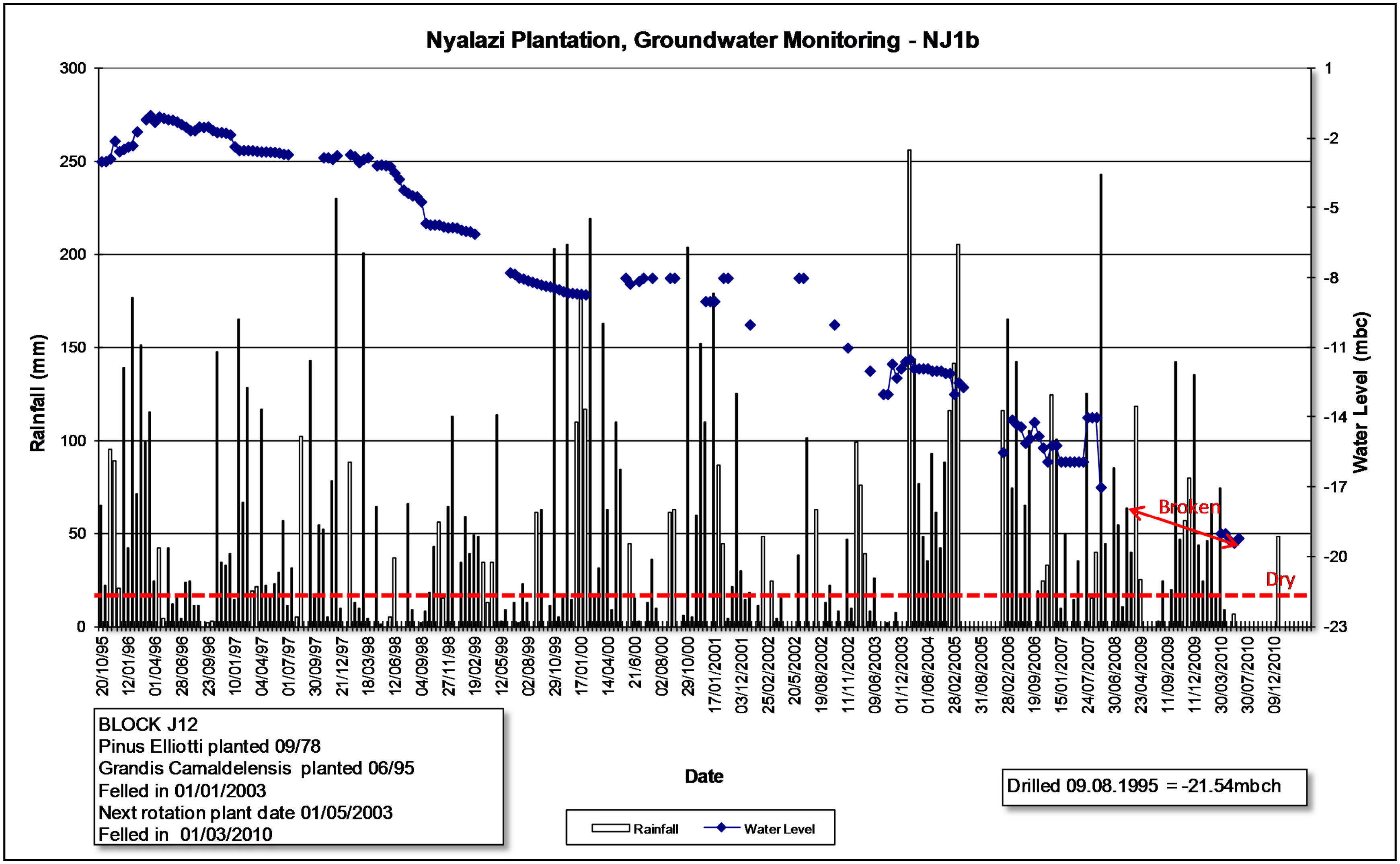
Figure 22: NJ1a Water Level Trends - 1995-2010

Figure 23: Monitoring point NJ1a (front) and NJ1b (back)

Borehole NJ1b indicated comparable results to NJ1a, when comparing the initial trends from 1995 to 1998 and indicates similar water levels between 2008 and 2010. The water level dropped at a rate of 1.1 metres per annum, based on data collected over 14.5 years and the depth of the borehole being 21.54 metres, which allowed for a larger data set (Figure 24).

The borehole was dry as of mid July 2010. During the August 2012 site visit, the monitoring point was evidently non functional as the casing was bent.

Although the downward trend of the water level is palpable in both monitoring points, the response to rainfall is also evident. After high rainfall events, the recharge to groundwater is noticed by the small spikes in the descending trendline.



BLOCK J12
Pinus Elliotti planted 09/78
Grandis Camaldelensis planted 06/95
Felled in 01/01/2003
Next rotation plant date 01/05/2003
Felled in 01/03/2010

Drilled 09.08.1995 = -21.54mbch

Figure 24: NJ1b Water Level Trends - 1995-2010

7.3.1.2 Pinus occulapia & Eucalyptus- NJ5a

The *Pinus occulapia* plantation was established in July 1978 and felled in July 1996. The initial water level was measured at 5.76 mbch in October 1995, which rose to 3.46 mbch five months later (refer to Figure 25). The rise in water level coincides with a high period of rainfall which occurred between October 1995 and April 1996. Eucalyptus was planted in June 1996, after the felling of *Pinus occulapia*. The water level fluctuated for a period of two years after which the monitoring point ran dry. Therefore no water levels were recorded between 2002 and 2010. The water level indicated a sharp increase from 5.76 to 3.46 metres. However, this trend (observed in late 1995/early 1996) is observed in monitoring boreholes in Group 1 (NJ1a, NJ1b and NJ3a), Group 2 (NO2a), Group 3 (NK1a) and Group 4 (NU1a, NU2a, NU2b, NU3a, NT1a, NT2a and NR1a) and coincides with the high rainfall received during the wet season of October 1999 to May 2000.

Likewise, shallow water levels were observed in December 2000 which corresponds with the wet season of 2000/2001 and therefore the shallower water levels are most likely as a result of the high rainfall received during this period.

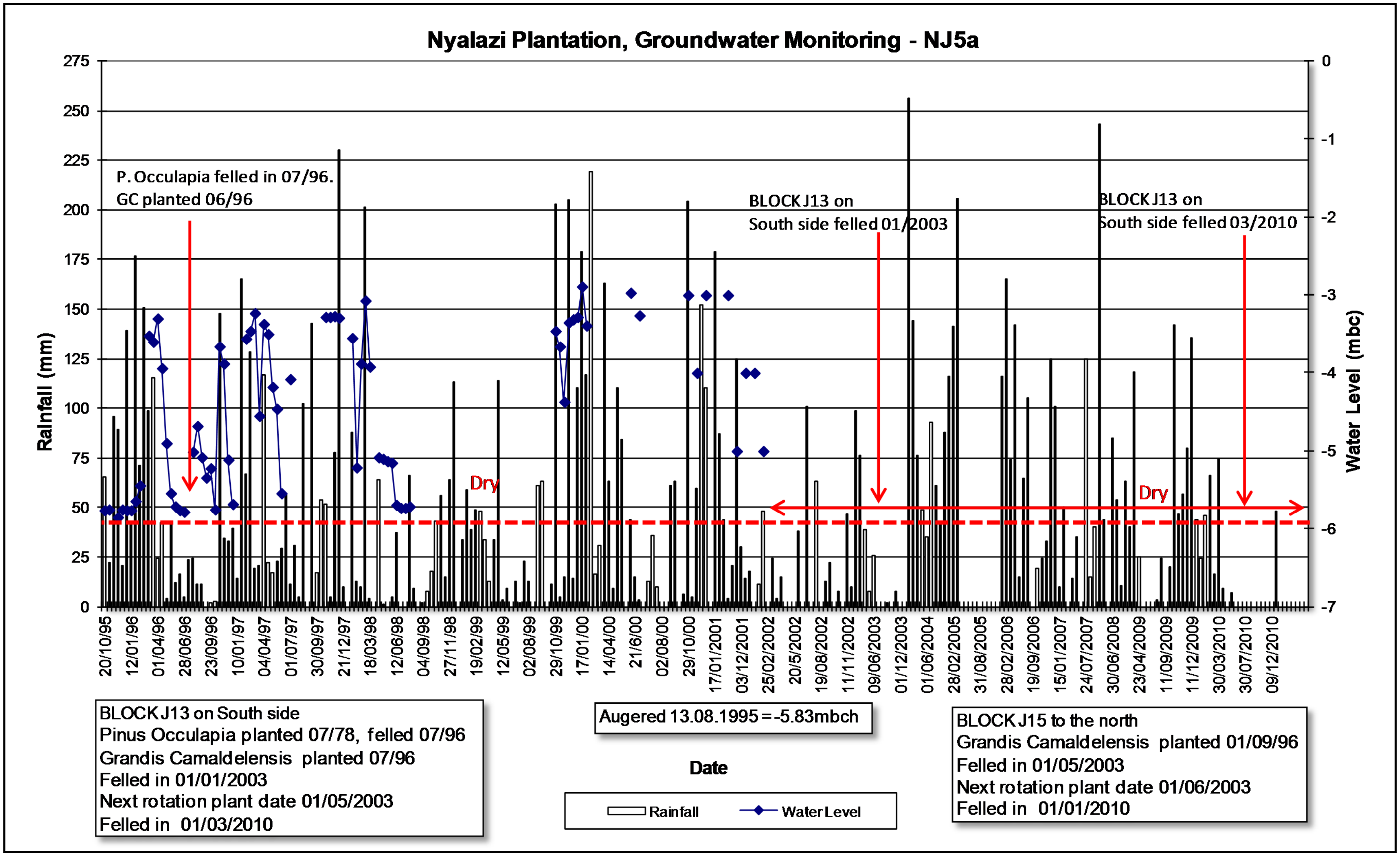


Figure 25: NJ5a Water Level Trends - 1995-2010

7.3.1.3 Indigenous – NJ2a

This monitoring point was installed within the indigenous vegetation (Figure 26) located adjacent to the *Pinus occulapia* plantation. The trendline is relatively stable compared to monitoring points located within the plantations (Figure 27).

There was a slight decline in the water level during the drier periods of 1998 and 1999 due to the low rainfall figures for that period, which then rebounded after the high rainfall during the wet season of 2000/2001. No water level measurements were recorded during 2009 and part of 2010, as the monitoring point was blocked during this time. The latest water level measured in February 2011, was 11.2 metres in comparison to the initial water level 10.04 metres, resulting in a drop of 1.16 metres over a period of 16 years. During the August 2012 site visit, the monitoring point was measured as dry with a depth of 10.65 mbgl.

Figure 26: Monitoring point NJ2a located within the indigenous area

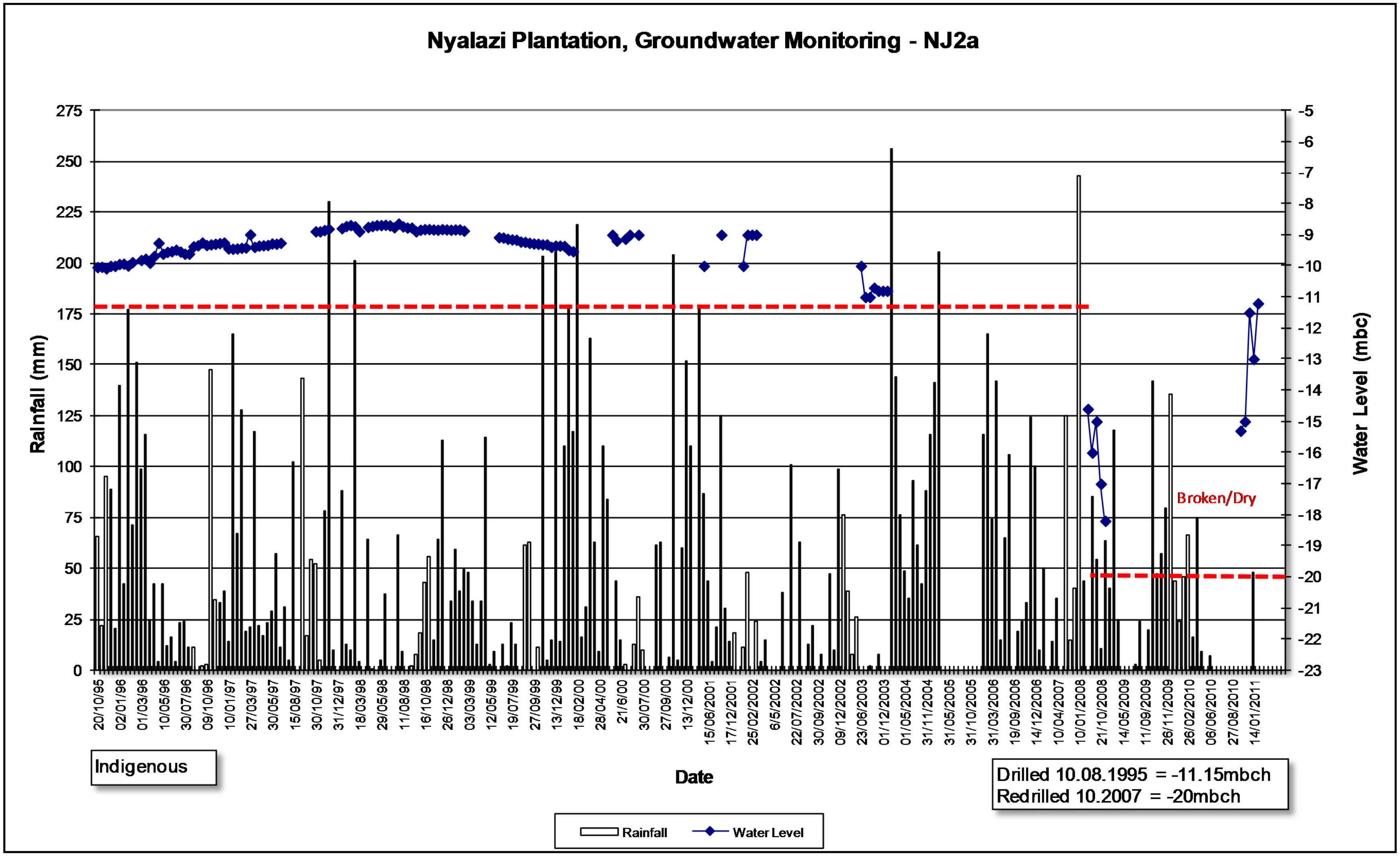
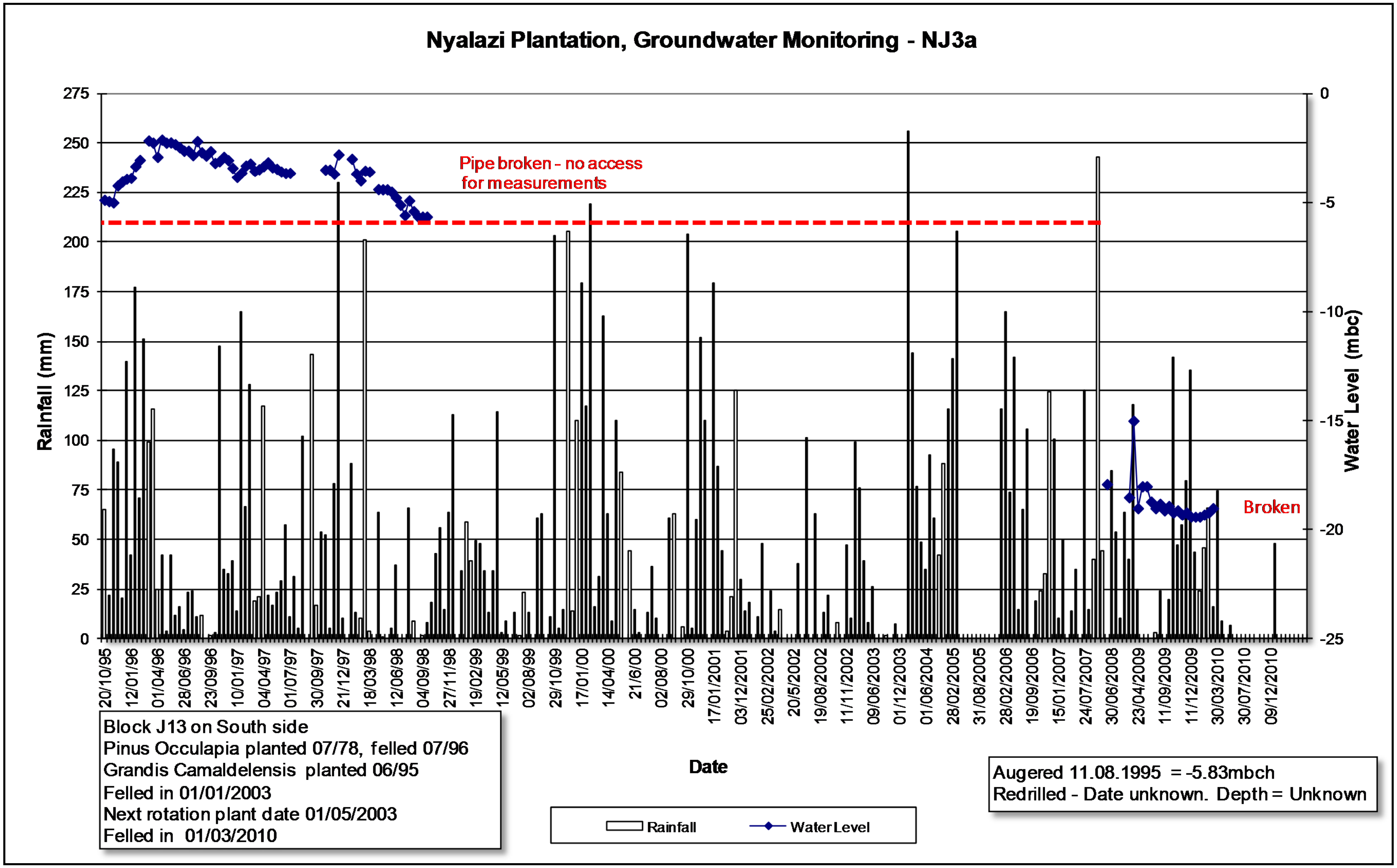


Figure 27: NJ2a Water Level Trends - 1995-2011

7.3.1.4 Eucalyptus/Firebreaks – NJ3a and NJ4a

NJ3a and NJ4a are located within the Eucalyptus plantation in close proximity to firebreak areas. Towards the end of 1995 and beginning of 1996, NJ3a indicated a positive response in the water level, which coincided with the felling of compartment J13, located immediately adjacent to the south (Figure 28). However, this increase in water level is as a result of the recharge to groundwater based on the high rainfall received during the wet season of 1995/1996. No measurements were recorded in NJ3a towards the end of 1998 and beginning of 2008 as this monitoring point was not functional during this time.

The measurements recorded in March 2008, after the deepening of the hole, indicated a significant drop in the water level since the last recorded measurement in 1998. No information was available regarding when the monitoring point was deepened or the final depth. Overall, the trendlines of NJ3a were very similar to NJ1a over the monitoring period and in March 2010, the last water level recorded for these two points were approximately 19 metres for both points. At the start of the monitoring, the water level of NJ3a was slightly deeper than NJ1, which has dropped at an average of 0.7 metres per annum compared to 1.1 metres per annum in NJ1a, indicating a slightly more distinct effect within the plantation as opposed to closer to the firebreak areas. The monitoring point was not identified during the August 2012 site investigation.



Block J13 on South side
Pinus Occulapia planted 07/78, felled 07/96
Grandis Camaldelensis planted 06/95
Felled in 01/01/2003
Next rotation plant date 01/05/2003
Felled in 01/03/2010

Augered 11.08.1995 = -5.83mbch
Redrilled - Date unknown. Depth = Unknown

Figure 28: NJ3a Water Level Trends - 1995-2010

NJ4a was visited during the site visit conducted in August 2012 and illustrated in Figure 29 below. The current depth was measured as 5.59 mbch (metres below collar height), with the monitoring point being dry. The monitoring of NJ4a over the period from late 1995 to late 2002 indicated a slight increase in the water level from 5.5 to 4.5 metres (Figure 30).

However, after a 5 year hiatus, the water level had declined to 18.2 metres indicating a significant decrease (this refers to a drop or decline in the water level) over this period. The drop in water level over this interval was similar to the trend observed in NJ3a.

Although NJ3a and NJ4a are located within the Eucalyptus plantation in close proximity to firebreaks, the effect of the plantations on the water levels are still evident.

Figure 29: Monitoring point NJ4a located within the indigenous area

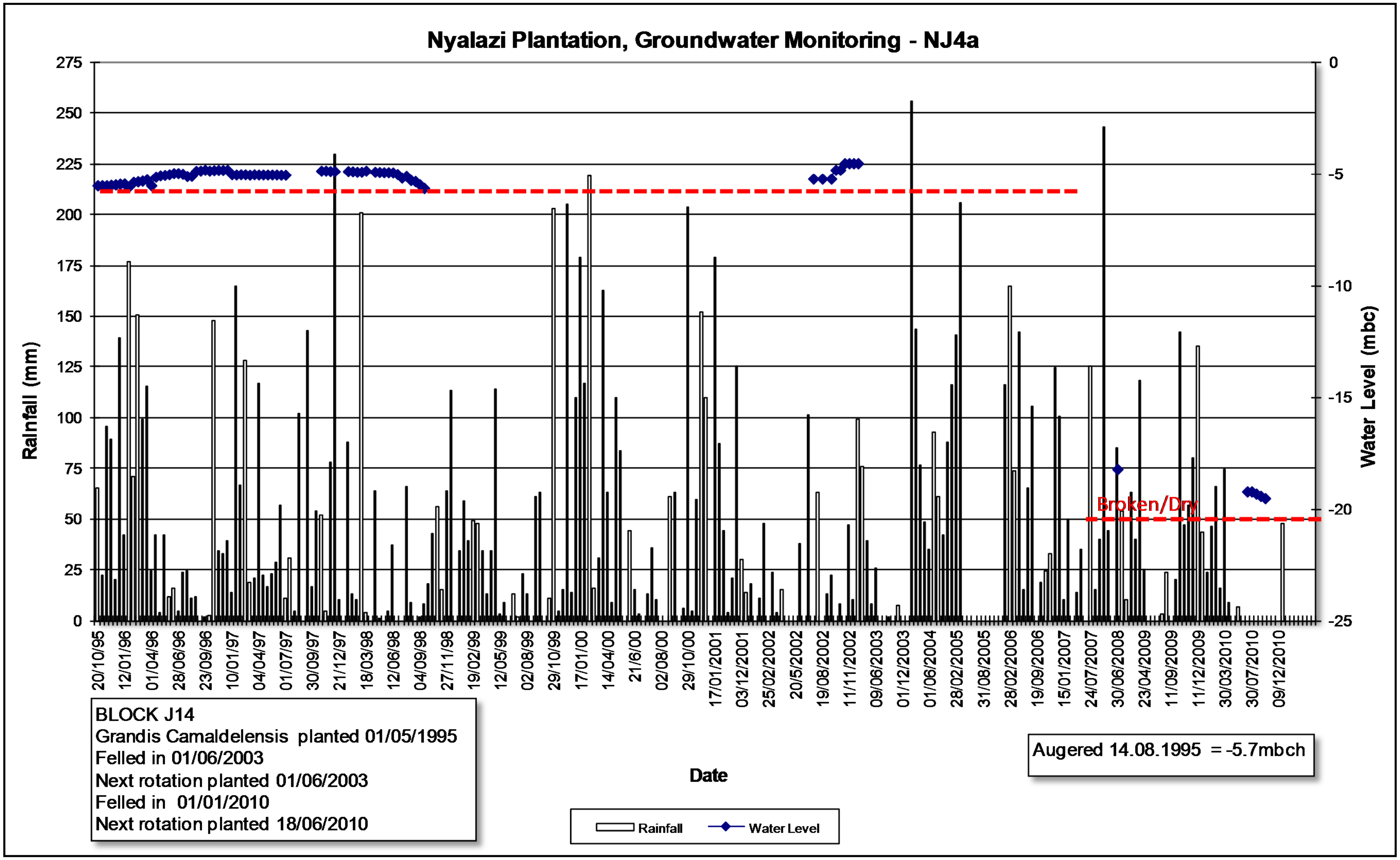


Figure 30: NJ4a Water Level Trends - 1995-2010

7.3.2 Group 2

A small area of *Pinus elliottii* and *Eucalyptus grandis Camaldulensis* species were planted in compartment D, adjacent to each other, in October 1986. The two piezometers, NO1a and NO2a (Figure 32 and Figure 34) were installed to determine the impact of the different species on the groundwater level. The localities of the monitoring points and associated compartments monitored are presented in Figure 31.

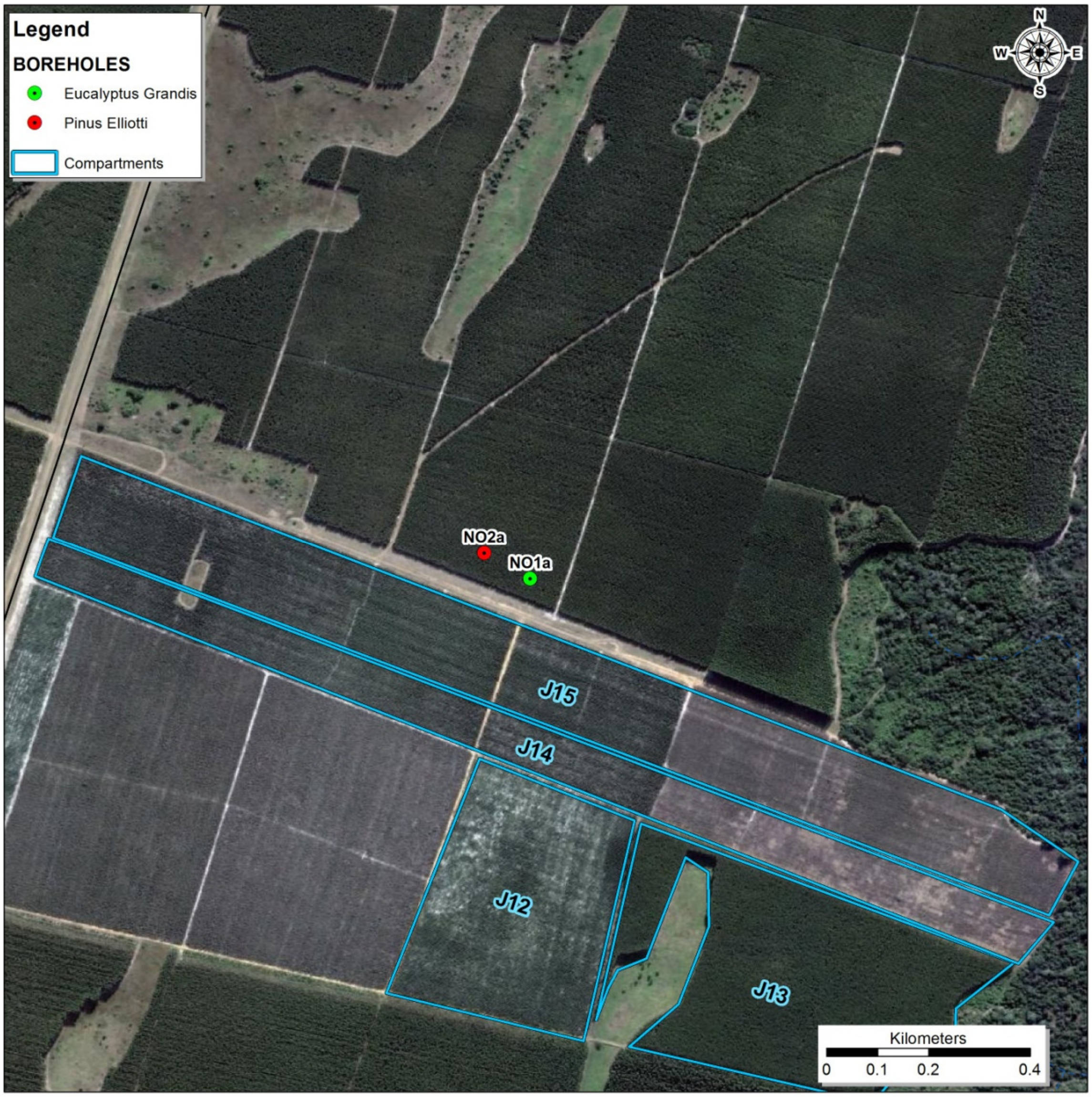


Figure 31: Localities of monitoring points of Group 2 and associated compartments

7.3.2.1 Eucalyptus grandis Camaldulensis – NO1a

The *Eucalyptus grandis Camaldulensis* was planted in October 1986 however n information was available regarding the felling dates. The water level measured within this Eucalyptus plantation was lower in comparison to the adjacent Pine plantation, with a difference ranging from 1 to 2.6 metres (refer to Figure 33).

The trend illustrated a steady rise from late 1995 to early 1996, with sudden negative responses due to the periods of lower rainfall within this period. This is a similar trend to the one discussed in Section 7.3.1.2. During mid 1998, the evident decline in water levels was most likely as a result of the drier climatic conditions. No more data was available post 1999, as the borehole was dry. The depth of the monitoring point measured in August 2012 was 6mbch.

Figure 32: Monitoring point NO1a

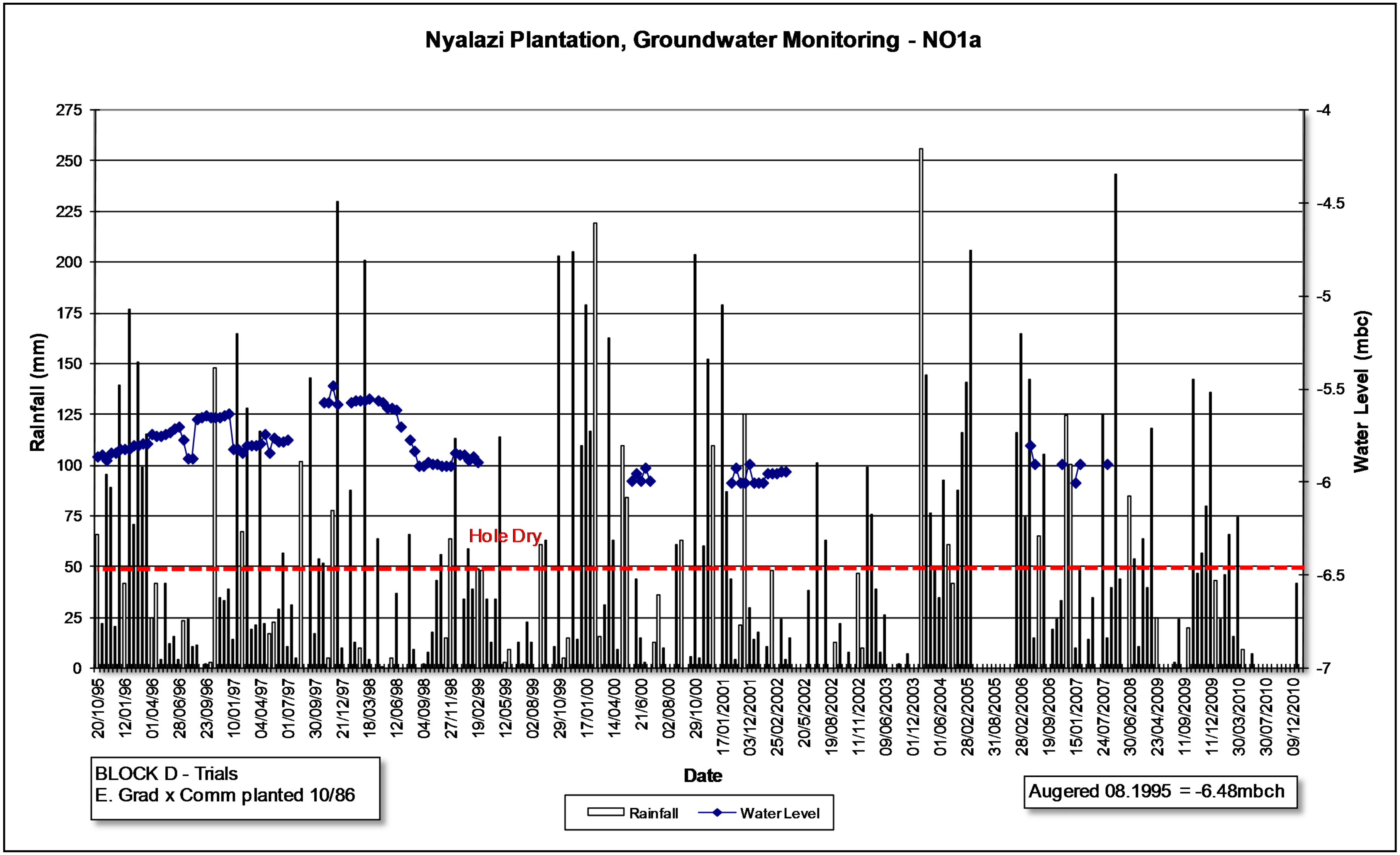


Figure 33: NO1a Water Level Trends - 1995-2010

7.3.2.2 Pinus elliottii – NO2a

The groundwater levels were slightly shallower associated with this Pine plantation, ranging from approximately one to two metres higher than the adjacent Eucalyptus compartment (Figure 35). The water level peaked in early 1996, after which a gradual decrease was observed. This is slightly different to the Eucalyptus trees monitored by NO1a (refer to Figure 33), which indicated a more gradual rise until 1998. The piezometer was dry from 1998 to 2003. No data was available regarding the felling and planting dates of these compartments. The data indicated the monitoring hole was redrilled/deepened in 2003, however no details regarding the depth is available. Sporadic measurements were recorded from August 2003 until June 2009, which indicated fluctuations in the water level. The monitoring point investigated in August 2012 was measured as dry with a depth of 8.94mbch.

Figure 34: Monitoring point NO2a

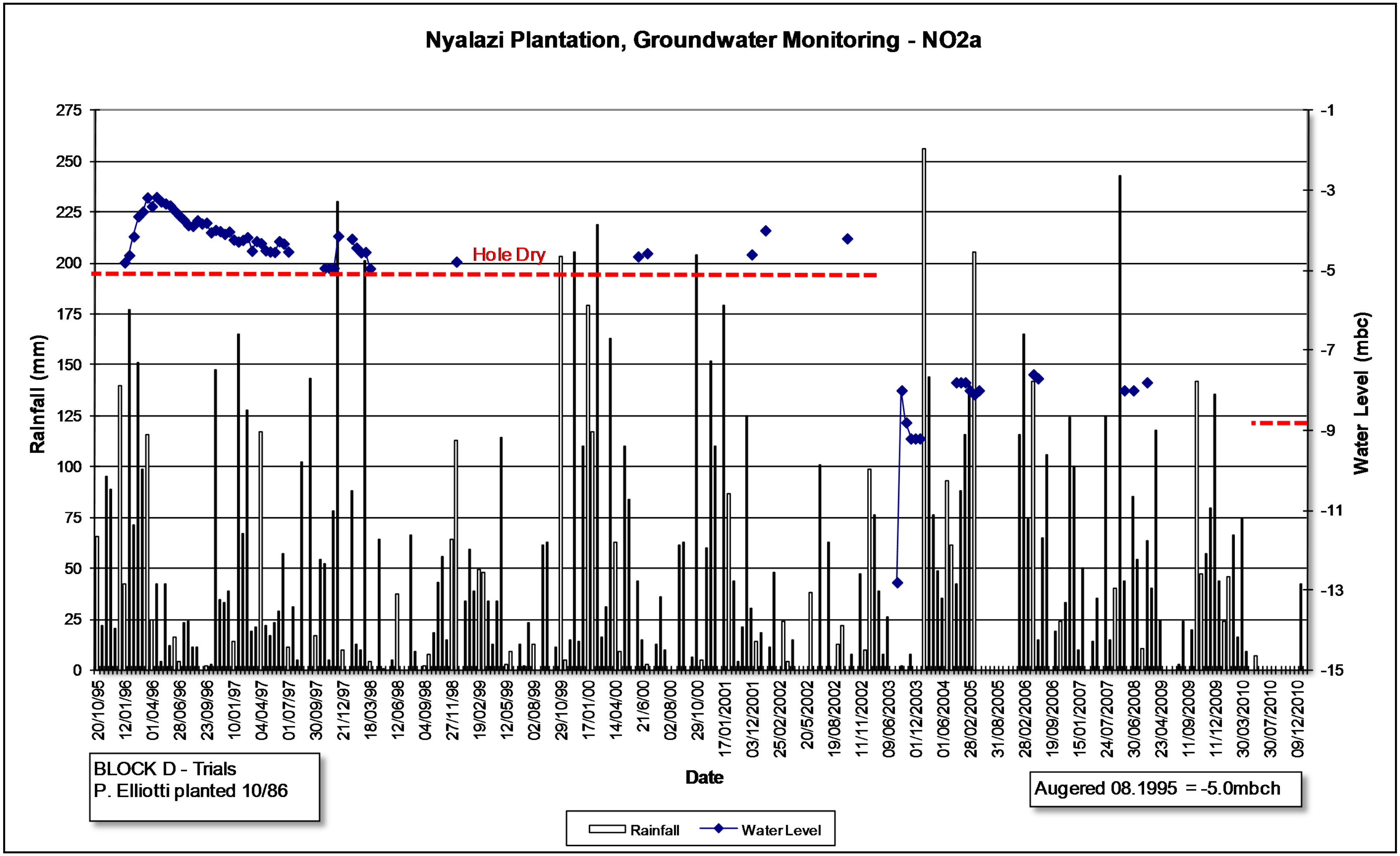


Figure 35: NO2a Water Level Trends - 1995-2010

7.3.3 Group 3

Piezometers NR2a, NQ1a, NN1a and NK1a were installed to create a north-south cross section across the study area. Likewise, an east-west cross section was created utilizing piezometers NJ2a, NJ4a, NN1a, NM1a and NM2a. The localities of these monitoring points and compartments monitored are presented in Figure 36.

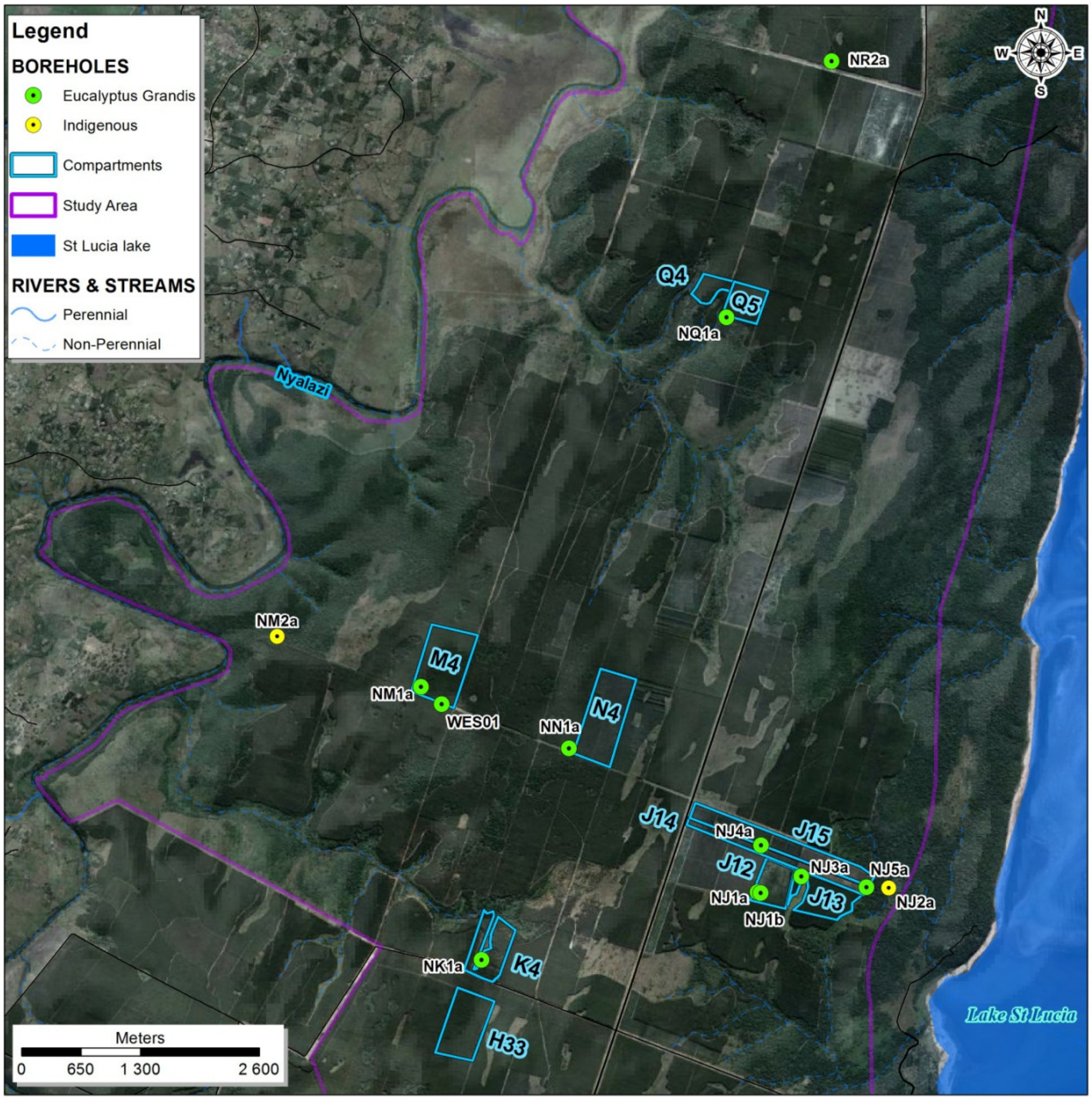


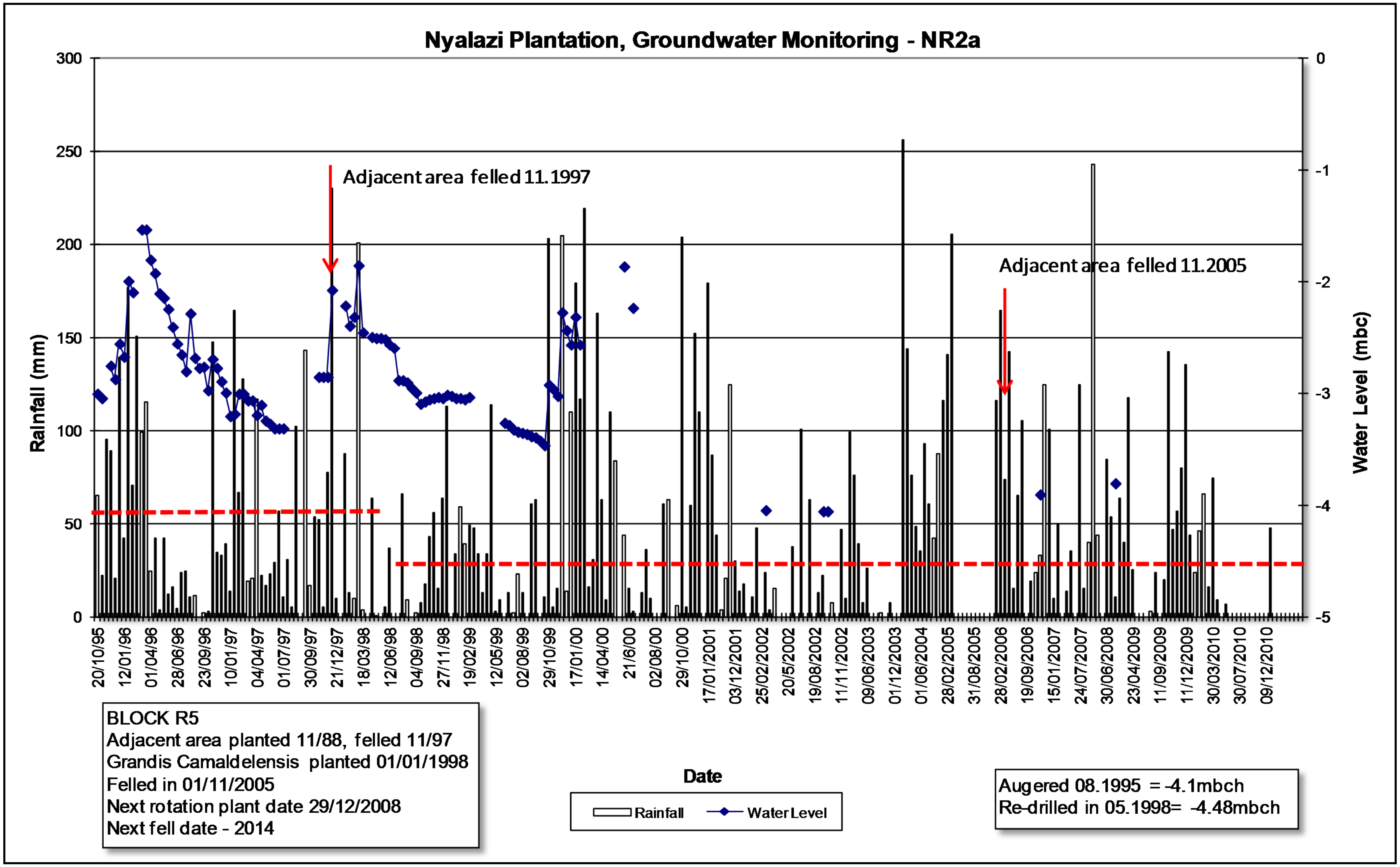
Figure 36: Localities of monitoring points of Group 3 and associated compartments

7.3.3.1 North-south cross section

Piezometer NR2a (Figure 37), located at the northern tip of the cross sectional line, monitors the adjacent Eucalyptus plantation, planted in 1998 and felled in 2005. The rotation prior to this, which was planted in November 1988 and felled in November 1997, was the Pine species.

Figure 37: Monitoring point NR2a

The data indicates a rise in the water levels (Figure 38) over a period of four months (during late 1995 to early 1996), to the highest water level recorded for this monitoring point followed by a steady decline over the year to follow. The rise in water level may be attributed to the high rainfall recorded in early 1996. The decline coincides with a very low rainfall period of seven months (March 1996 to October 1996). Subsequently, the water level rise in 1997 corresponds to the felling of the adjacent plantation in November 1997 as well as high rainfall figures recorded over this period. The rise in water level is most likely as a result of the high rainfall due to increased recharge to groundwater, as this trend is observed in other monitoring points too.



Adjacent area felled 11.1997

Adjacent area felled 11.2005

BLOCK R5
Adjacent area planted 11/88, felled 11/97
Grandis Camaldelensis planted 01/01/1998
Felled in 01/11/2005
Next rotation plant date 29/12/2008
Next fell date - 2014

Augered 08.1995 = -4.1mbch
Re-drilled in 05.1998= -4.48mbch

Figure 38: NR2a Water Level Trends - 1995-2010

Piezometer NQ1a, located in the Eucalyptus area (Figure 39), indicated similar trends to other boreholes as discussed in Section 7.3.1.2, with the increase occurring in late 1995 to early 1996 followed by a decrease until mid 1997. The monitoring point was measured as dry beyond late 1998 (refer to Figure 40).

The piezometer is currently destroyed as the casing has been removed and the hole is filled up, with only the marker post remaining.

Figure 39: Monitoring point NQ1a

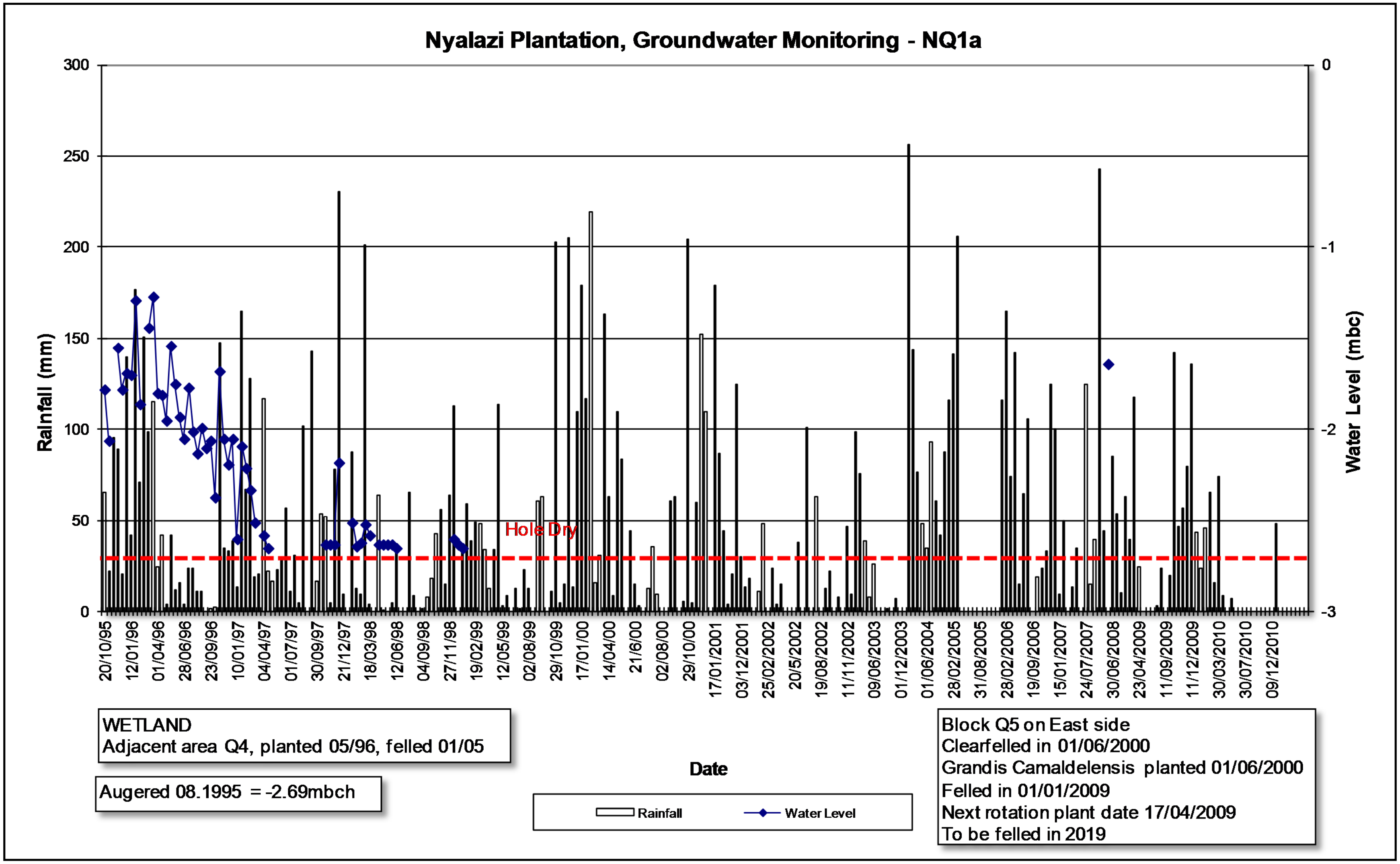


Figure 40: NQ1a Water Level Trends - 1995-2010

NN1a (Figure 41), monitoring the Eucalyptus plantation planted in March 1995 provides substantial data from 1995 until 2012 (Figure 43).

The initial trend observed when monitoring commenced, indicated a rise in water level in late 1995 which then declined and stabilised in 1997. The monitoring point was blocked for an extended period and was therefore deepened in July 2003 and after this deepened monitoring point ran dry, a new borehole was drilled adjacent to the old point in October 2007 (Figure 42). The measurements indicated a steady decline from 2008 until 2012, when the last measurement was recorded. On average, the water level declined by 1.1 metres per annum over the 17 year monitoring period. The rate of decline in water level measured proves to be one of the more rapid trends observed for the area. The current water level measured in August 2012 was measured as 24.92mbgl. The upper casing portion has been removed and the borehole is in a poor condition.

Figure 41: Old NN1a monitoring point – destroyed by fire

Figure 42: Newly drilled NN1a monitoring point

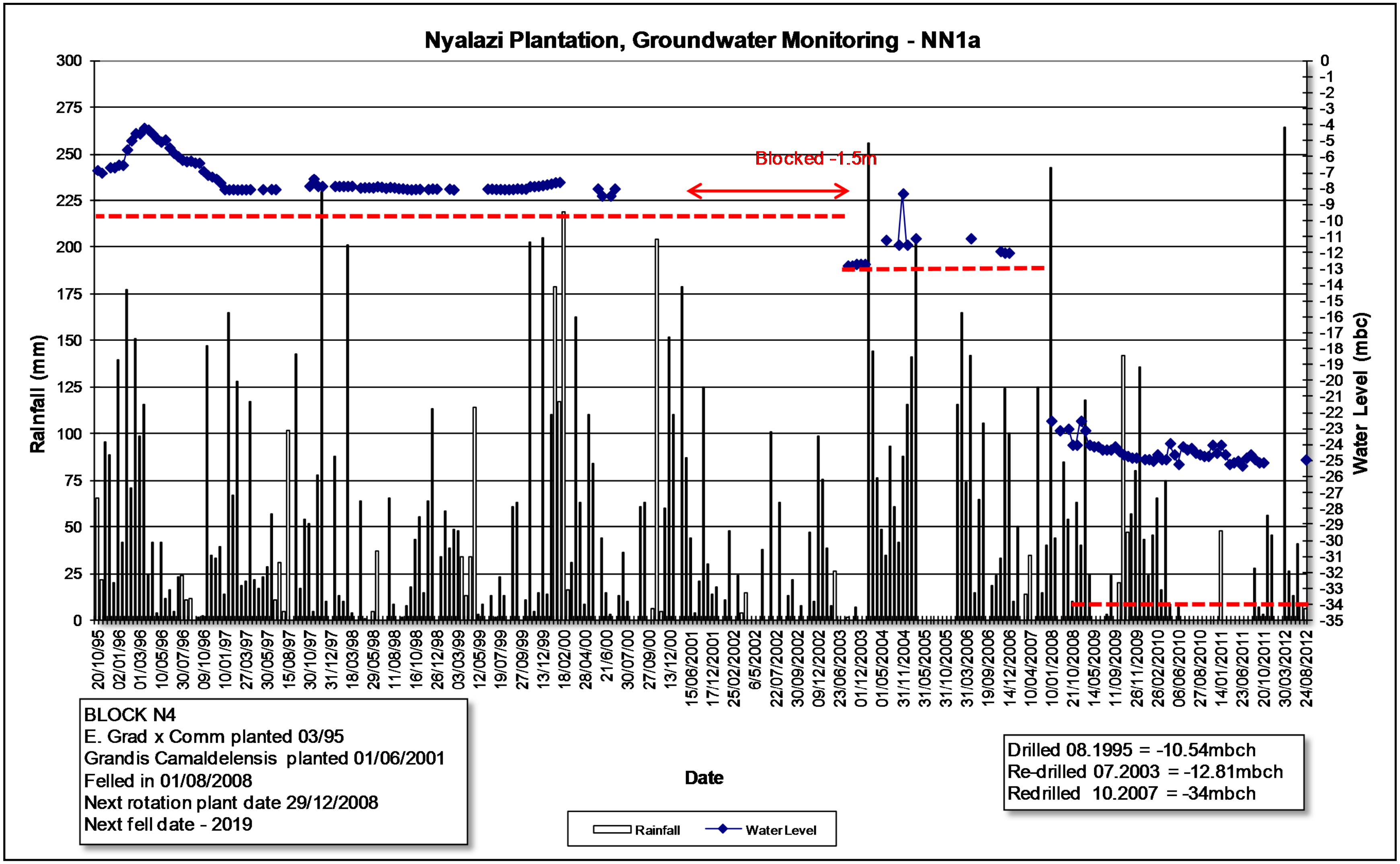


Figure 43: NN1a Water Level Trends - 1995-2011

During the site visit conducted in August 2012, it was evident that the casing has been removed from the monitoring point NK1a and the monitoring hole has been filled with sand (Figure 44). NK1a indicated comparable trends to other monitoring points in 1995/1996 where the rise and fall of water levels could be attributed to rainfall patterns and ultimate groundwater recharge (Figure 45). No further data was captured beyond 1998 as the monitoring point was dry.

Figure 44: NK1a Monitoring point

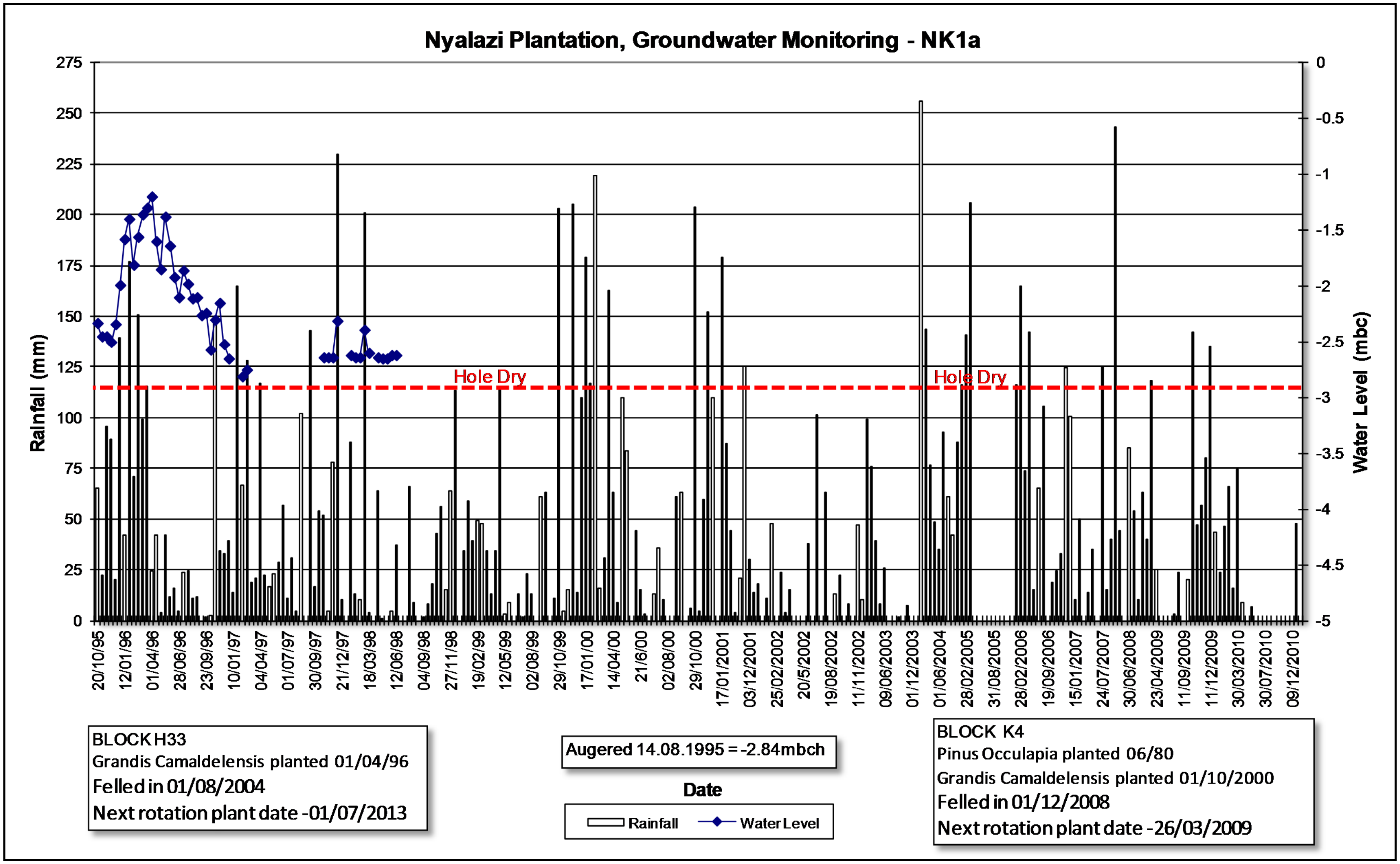


Figure 45: NK1a Water Level Trends - 1995-2010

7.3.3.2 East-west cross section

Piezometers NJ1a and NJ4a also form part of Group 1 and NN1a forms part of the north-south cross section of Group 3 and have therefore already been addressed.

Monitoring point NM1a was not located during the site visit conducted in August 2012. Only the initial water level measured in 1995 and the last water level measured in 2010 were utilised for piezometer NM1a. The inconsistent measurements captured from 1996 to 2010 are not reliable and therefore disregarded (refer to Figure 46). The water level, measured as 6.8 metres in 1995 and 17 metres in 2010, resulted in an average decline of 0.7 metres per year. The monitoring point was recorded as dry beyond 2011.

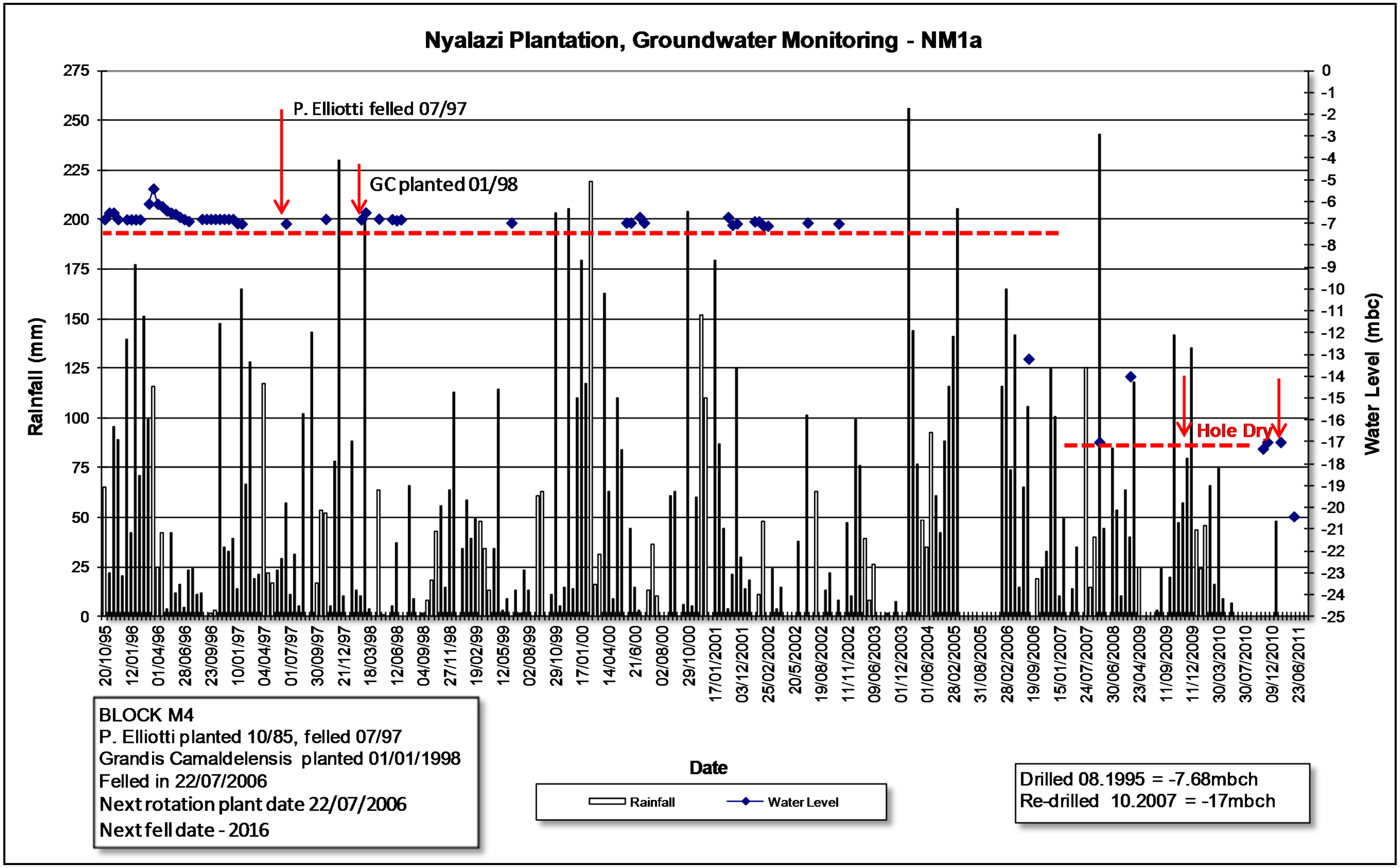


Figure 46: NM1a Water Level Trends - 1995-2011

An additional borehole, WES01 was drilled in November 2011 (Figure 47), in close proximity to NM1a. This borehole is located approximately 260 metres south east of NM1a. The water level recorded in WES01 in November 2011 was 24.25 metres below ground level. This level is deeper than the last water level recorded in NM1a of 20 metres, which indicates the water level continues to decline. The borehole was not accessible during the August 2012 site visit and therefore no updated water level was recorded.

Figure 47: Monitoring borehole WES01

Piezometer NM2a, was installed in May 1995 (Figure 48), situated within the indigenous vegetation on the western boundary of the plantation and has been dry for majority of the monitoring period. A response to the high rainfall during 2000 was evident with an increase in the water level. The monitoring point was re-drilled in July 2002 (Figure 49) which was measured as dry from 2009 onwards (Figure 50). The current depth measured in August 2012 was 15.13mbgl.

Figure 48: Old monitoring point NM2a

Figure 49: Newly drilled borehole NM2a

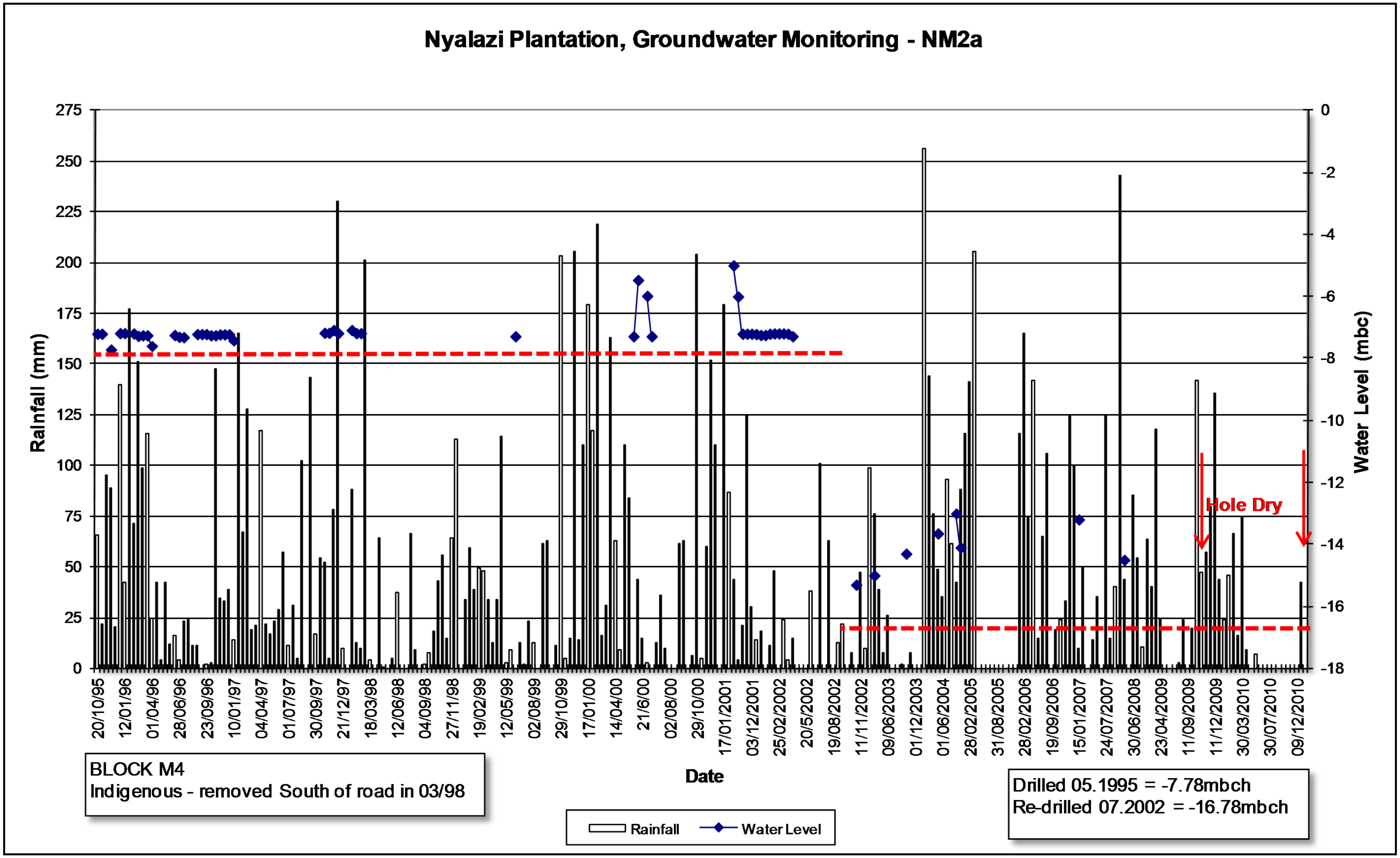


Figure 50: NM2a Water Level Trends - 1995-2010

7.3.4 Group 4

All seven monitoring points were located within or adjacent to compartment U28, U29 or U3. The plantation consisted of *Pinus elliottii* which was planted in September 1967. This plantation was completely isolated with no neighbouring plantations which provided the ideal system to determine the effect on the groundwater levels with no additional influences from other tree species. The localities of the monitoring points and compartments monitored are presented in Figure 51.

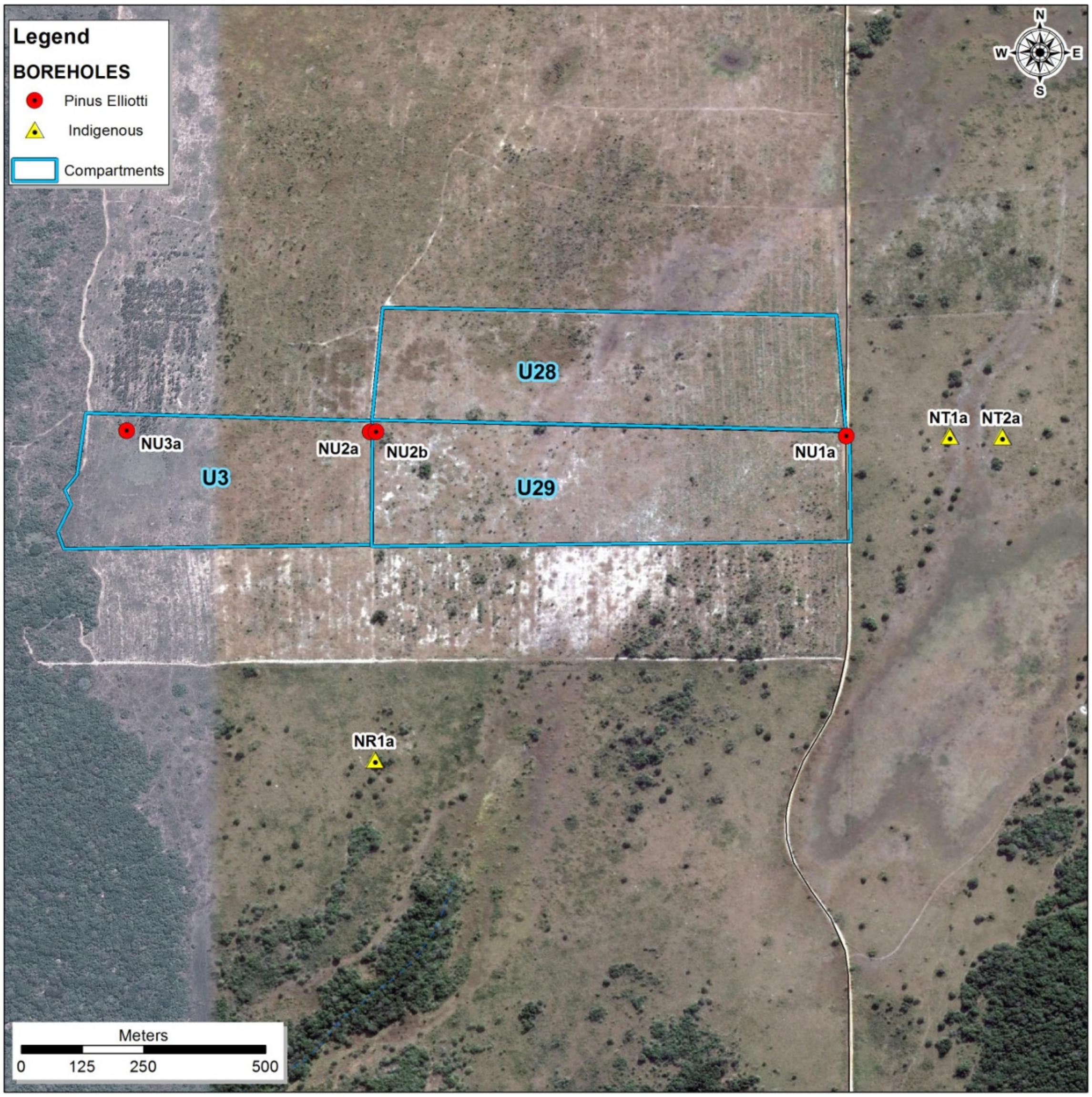


Figure 51: Localities of monitoring points of Group 4 and associated compartments

7.3.4.1 Pinus elliottii - NU1a, NU2a, NU2b, NU3a

The initial monitoring data available for NU1a indicates a direct response to groundwater recharge based on the rainfall figures of the wet and dry seasons (refer to Figure 52).

Certain sections within compartment U29 to the south of NU1a were clear felled in October 1997. The positive response in the groundwater levels coincide with the felling but are also related to the response of high rainfall during this period, as observed in several other monitoring points. This was followed by a steady decline in the water level which may be attributed to the dry winter of 1998. Subsequent to the felling of compartment U28 to the north in September 1999, the water level rose but also coincided with the high rainfall received during the wet season of 1999/2000. This trend was also evident in all monitoring points located within the northern Pine plantations including the furthest monitoring point NR1a monitoring the indigenous area to the south. This monitoring point was not located during the August 2012 site visit as it has been destroyed.

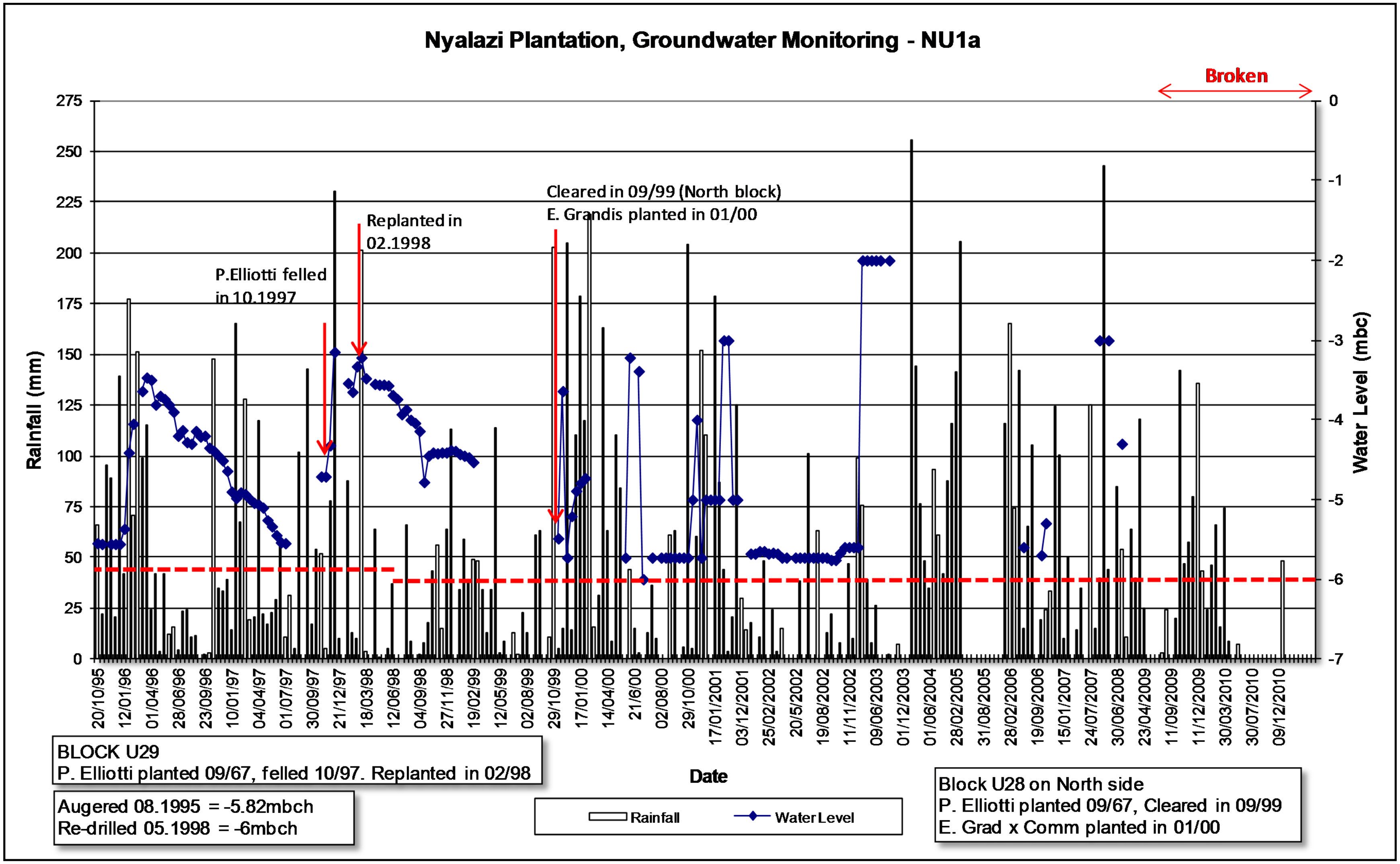


Figure 52: NU1a Water Level Trends - 1995-2010

NU2a and NU2b are located near the junction of compartments U28, U29 and U3. During the August 2012 site visit, these monitoring points were not located and therefore it is concluded that the two points have been destroyed, most likely by elephants in the area. The area now consists of indigenous vegetation as illustrated in Figure 53. The two monitoring points were located approximately 10 metres apart and therefore indicate virtually identical trends as indicated in Figure 54 and Figure 55, for NU2a and NU2b, respectively. The trends are also very similar to NU1a, with the exception of a more gradual decline during the period of 1998 in NU2a and NU2b compared to the sharp decrease in NU1a.

Figure 53: Area where NU2a and NU2b were located

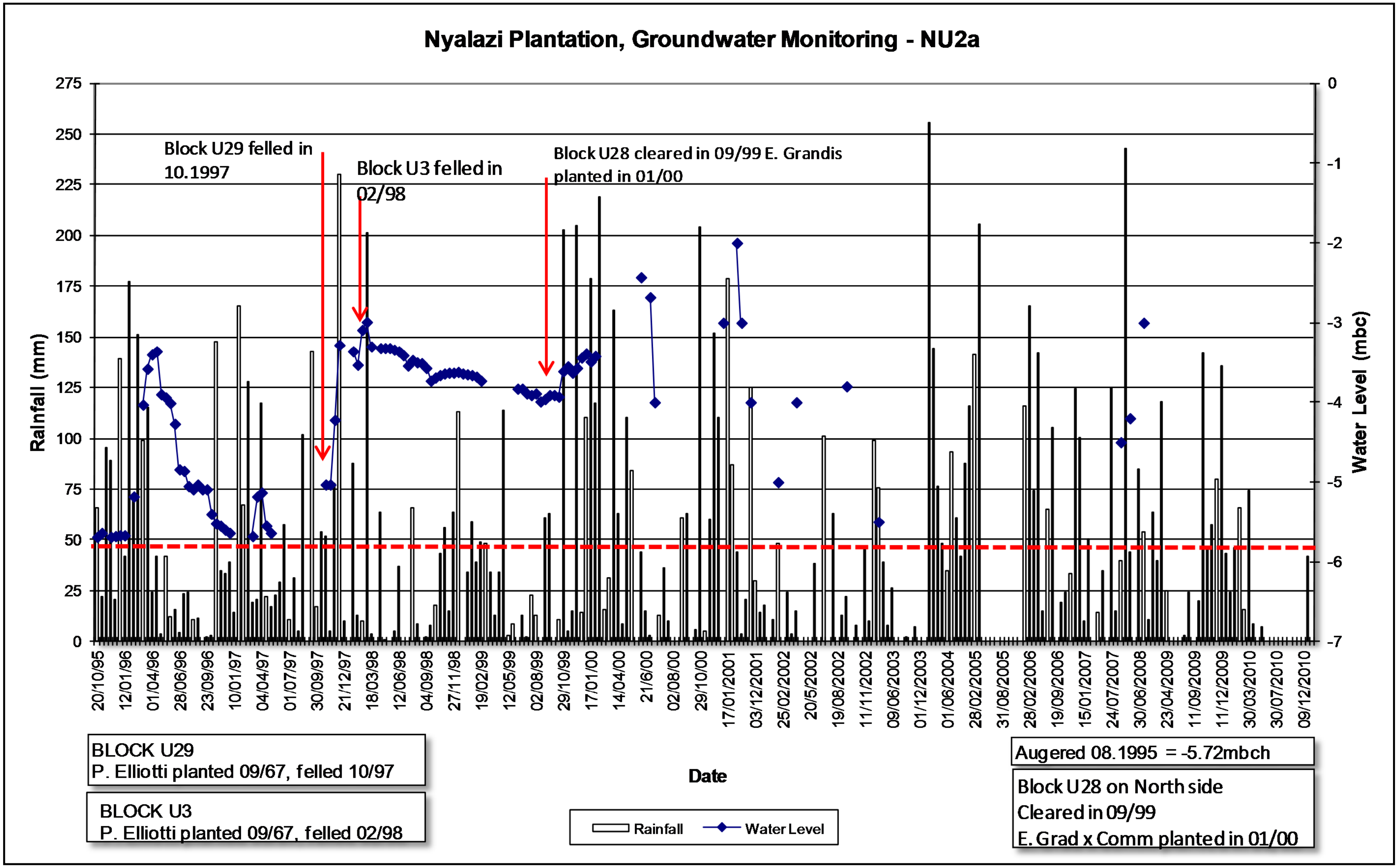


Figure 54: NU2a Water Level Trends - 1995-2010

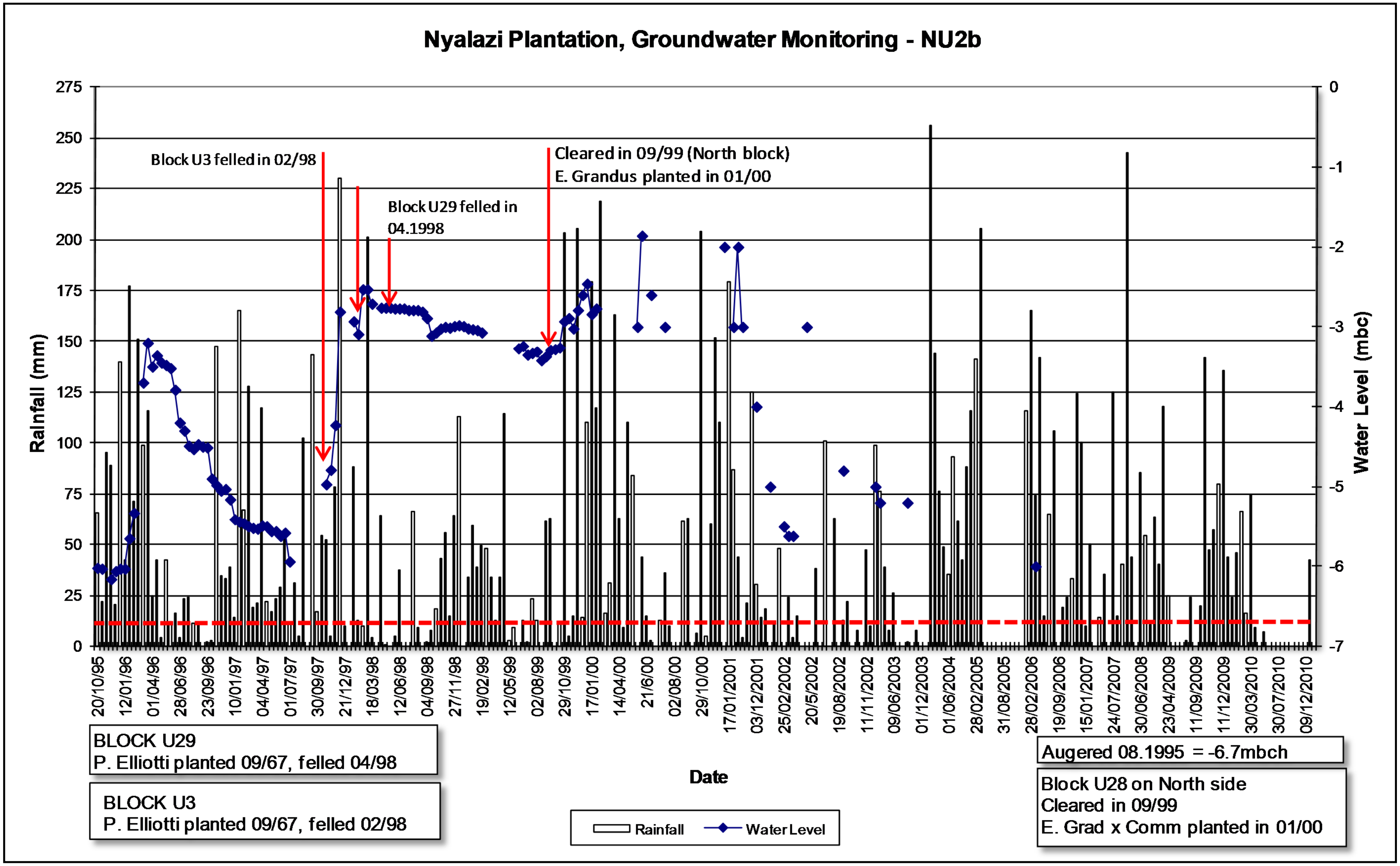


Figure 55: NU2b Water Level Trends - 1995-2010

NU3a was located within compartment U3 along the western portion of the Pine plantations (Figure 56), however, was not located during the August 2012 site visit and has therefore been destroyed. The trend observed from the monitoring data indicates similar observations to the other monitoring points within this plantation (Figure 57).

However, it is evident that during the dry winter months when the rainfall decreased, the water level plummeted much more rapidly than any of the other monitoring points within the northern Pine plantation. At this stage, the reason for sharp increases and decreases in the water level trends when compared to the smoother trends of nearly monitoring holes is unknown and more data regarding the underlying lithology would be required.

It is also noticeable that the water level did not recover or rebound after the felling of compartment U3 and adjacent compartment U29. This rebound in water level was most likely suppressed by the low rainfall season of March 1998 to September 1998.

Figure 56: Area where NU3a was located

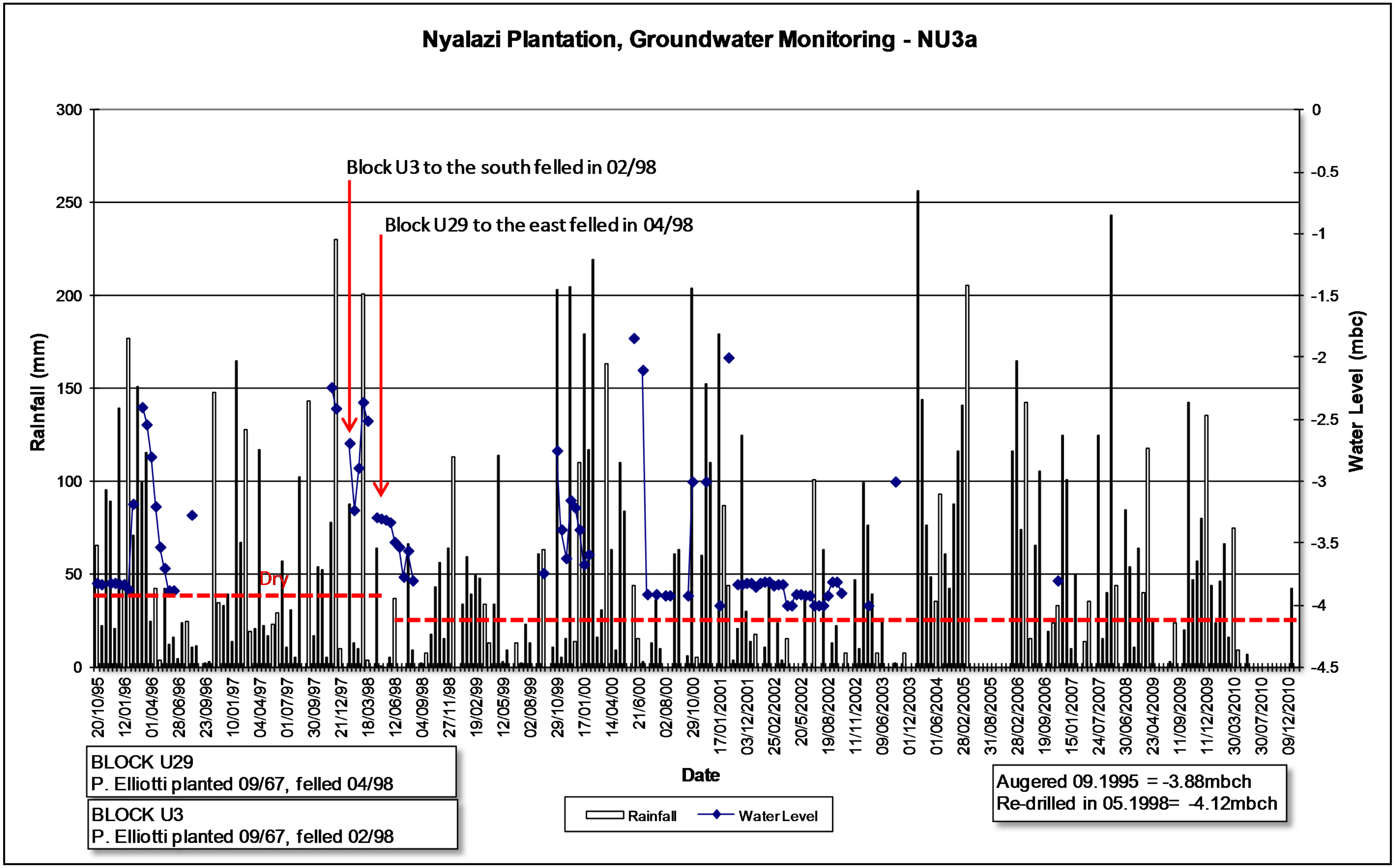


Figure 57: NU3a Water Level Trends - 1995-2010

7.3.4.2 Indigenous – NR1a, NT1a & NT2a

Monitoring point NR1a is located approximately 200 metres from the southern boundary of the plantation situated within the indigenous vegetation (Figure 51). The location of the monitoring point was identified during the August 2012 site visit, marked by a wooden pole as presented in Figure 58, however, the casing was found adjacent to the monitoring point and the hole was not identified and is therefore most likely backfilled with sand.

An increase was evident following the high rainfall in late 1995 and early 1996 (refer to Figure 59), followed by a decline in 1996 due to the low rainfall and subsequent low recharge to groundwater. The rise of the water level in late the 1997's is not likely due to the felling of the nearby plantations in January 1998, as the rise was evident prior to the felling and reached the shallowest level recorded in January 1998. This was followed by a decline once again after the felling which is most likely attributed to the dry winter season of 1998. Subsequent to this, the monitoring point was measured as dry for the greater part of the monitoring period which followed. After high rainfall periods, the water level rose to a level measured between 4 and 5 metres. The most up to date recordings indicated the monitoring point as dry before it was destroyed.

Figure 58: Monitoring point NR1a

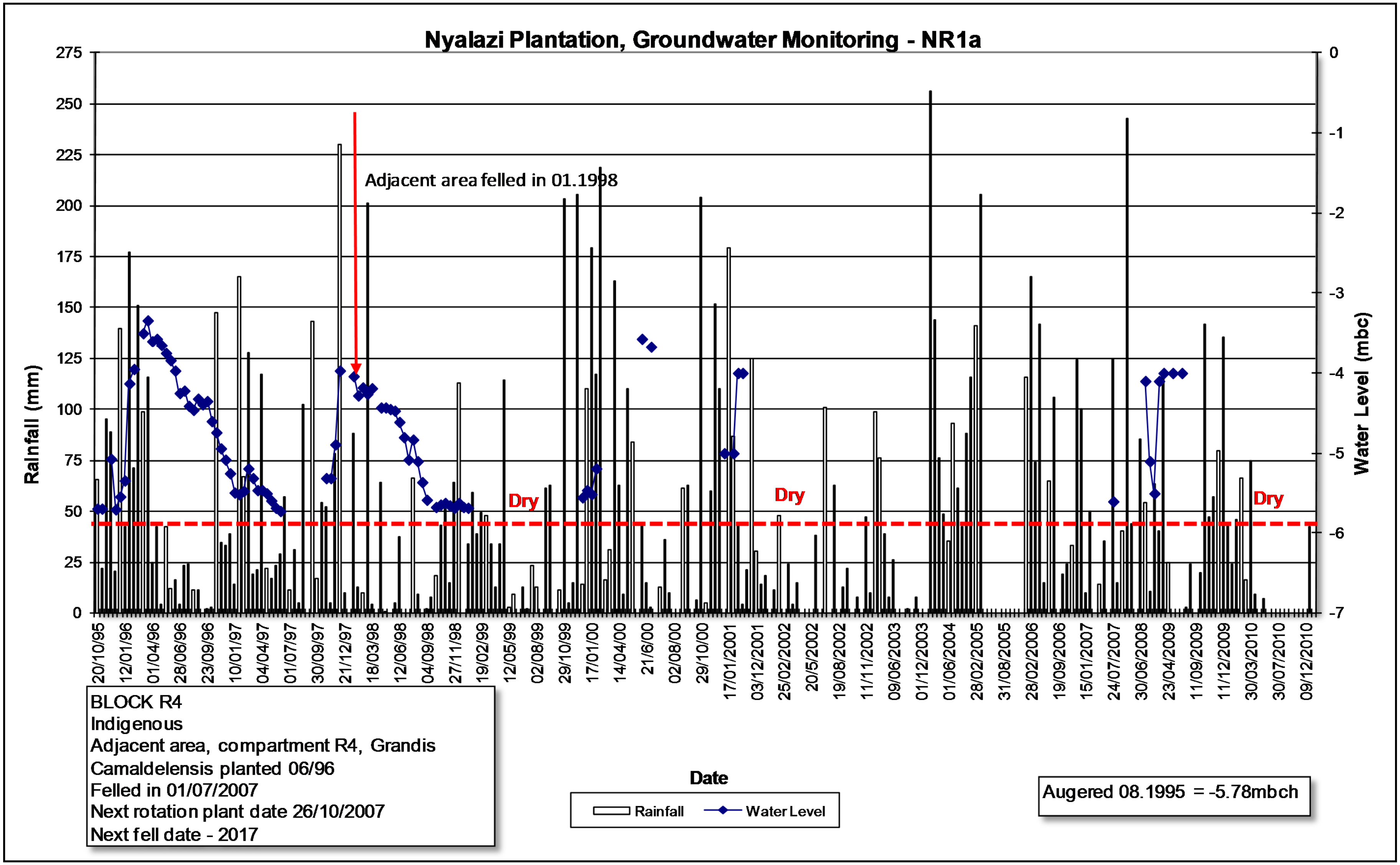


Figure 59: NR1a Water Level Trends - 1995-2010

NT1a is located approximately 200 metres east of NU1a and the eastern boundary of the Pine plantation, with the purpose of monitoring the indigenous vegetation. Figure 60 displays the current status of the monitoring point, where the casing has been damaged. The water level trends of NT1a (Figure 62) are almost identical to those of NU1a, which is located within the plantation. The exception is that the water level of NT1a is slightly shallower than those measured in NU1a. On average, NT1a indicates a water level which is between 0.5 metres and 1 meter shallower than NU1a. This is most likely due to the fact the NT1a is located within the indigenous vegetated area and NU1a is within the plantation. The depth obtained during the August 2012 site visit, was measured at 4.36mbch, with a collar height of approximately 0.29 metres.

Figure 60: Monitoring point NT1a

NT2a is located approximately 100 metres east of NT1a (Figure 61) and also monitors the indigenous vegetation. NT2a also indicates comparable trends to the nearby NT1a and NU1a monitoring points (Figure 63). The trend in this monitoring point indicates a more gradual fluctuation whereas the other two indicated sharp responses in the water level. The initial water level of 2.42 mbch recorded in NT2a, was also shallower than those measured in NT1a and NU1a of 4.24mbch and 5.55mbch respectively, which are closer to the plantation. No data was collected between 2001 and mid 2004, for unknown reasons.

Figure 61: Monitoring point NT2a

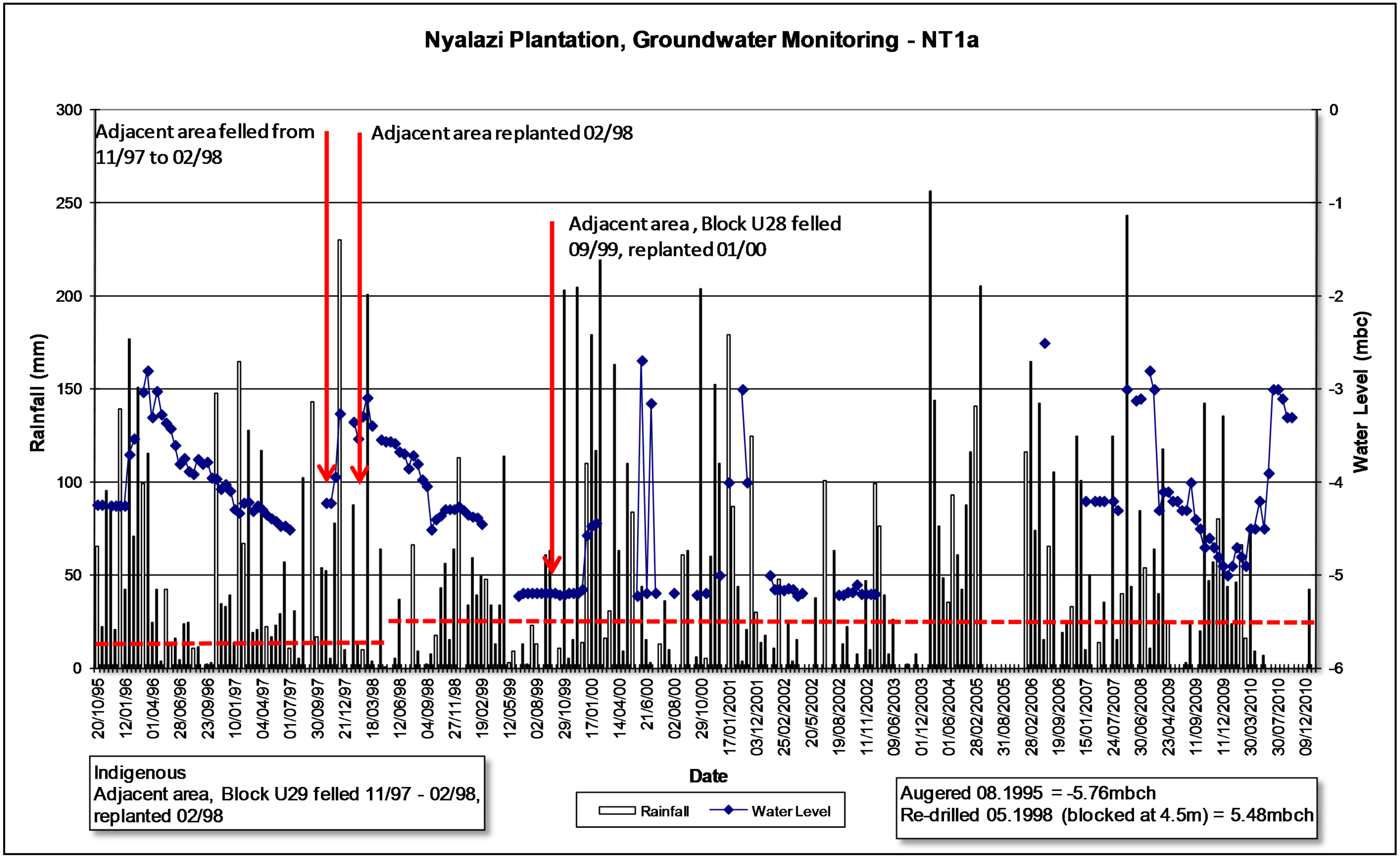


Figure 62: NT1a Water Level Trends - 1995-2010

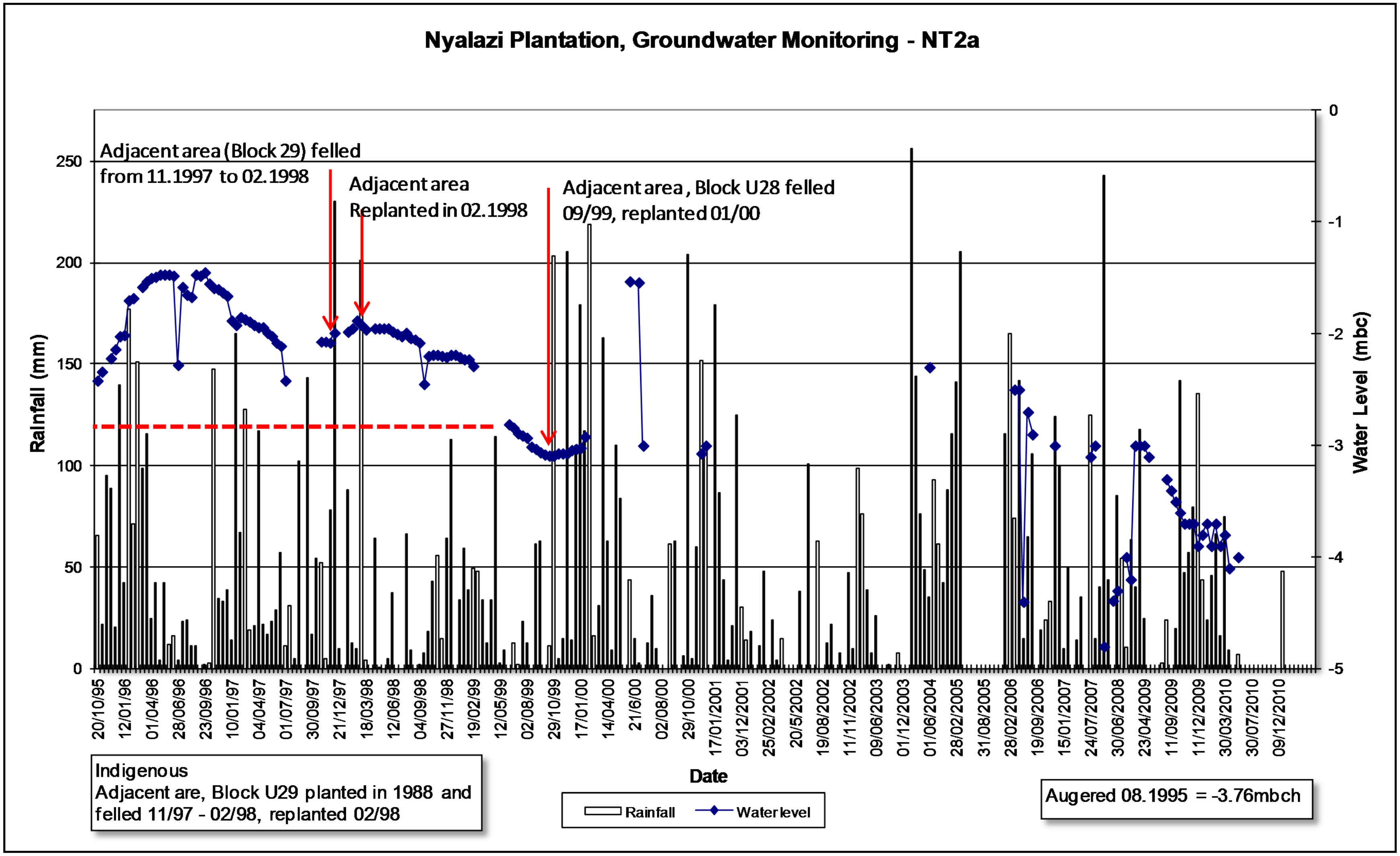


Figure 63: NT2a Water Level Trends - 1995-2010

7.4 General Trend Observations

Based on the evident use of groundwater by timber plantations, the general trendline expected, is a declining one (lowering of water levels). However, a more realistic trendline is illustrated in Figure 64. The trendline represents one rotation cycle of the eucalyptus species, which is on average, a period of seven years. The slight rise in the groundwater levels indicate the response to recharge of the aquifer as a result of rainfall. This occurs during the wet season on an annual basis. However, the recharge from rainfall proves to be inadequate to overcome the groundwater usage from the trees which results in a constant decline of the groundwater table.

Previous studies conducted by Kienzle & Schulze (1992), simulated recharge as zero during model simulations on Eucalyptus plantations, based on the fact that timber intercepts higher amounts of rainfall in comparison to natural vegetation. However, based on the results of this study, recharge is evident at the site during the wet season, based on the small peaks evident within the data, indicating that the infiltration of water exceeds the field capacity of the intermediate zone.

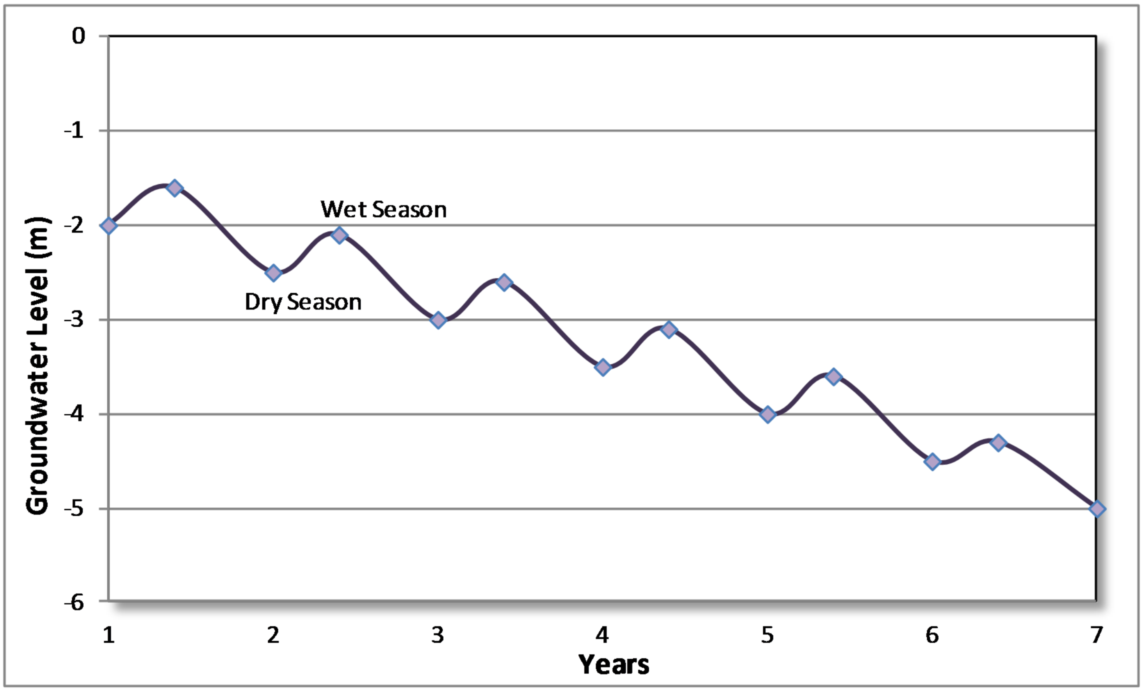


Figure 64: Expected groundwater level trendline

7.5 Conclusion

The study area is underlain by the widespread Zululand coastal plain aquifer which is comprised of unconsolidated clays and sands, which may be defined as an alluvial or primary aquifer (Rawlins & Kelbe, 1991). This type of aquifer is associated with high transmissivity and infiltration rates subsequent to rainfall events (Bredenkamp, 1992). The water level data collected from the study area over 17 years indicated a good correlation with the topography. The data also indicates that the groundwater flow direction is from the topographical high inland areas towards Lake St. Lucia and the Nyalazi River.

The 18 years' worth of data was analysed for each monitoring point, however, a drawback to this study is the data gaps present, where the water level was not measured for a period of time.

The water levels generally indicate a direct response with the rainfall. During periods of high rainfall the water level responded in a positive manner with a rise followed by a decline during the drier periods.

Limited historical information was available for the Pine plantation, however based on the data available; it was evident that the mature Pine plantations had minor effects on the groundwater environment of the Nyalazi Plantation. Majority of the monitoring points indicated very shallow water levels initially recorded with the mature Pine species between 1995 and 1998, after which they were removed. After three years of monitoring, the data indicated the water levels within the plantation were between 3 and 4.5 mbgl. The water level within the indigenous areas was between 2 and 4.5 mbgl.

A significant impact was evident based on the presence of the Eucalyptus grandis Camaldulensis species, with an average decline in the water table of approximately 1 metre per annum for some compartments. There is an evident overall downward trend for majority of the monitoring points associated with the Eucalyptus plantations. Several of these boreholes are not deep enough and require rehabilitation in order to continue monitoring.

CHAPTER 8: CONCEPTUALISATION OF THE NYALAZI PLANTATION SITE

8.1 Introduction

From the analysis of the water level trendlines over the specified monitoring period, it is evident that both the *Pinus elliottii* and *Eucalyptus grandis Camaldulensis* tree species have impacted the groundwater environment within the Nyalazi plantation. However, the degree of impact still needs to be quantified as part of this study.

8.2 Analysis of cross sectional data

8.2.1 Pinus elliottii

The data collected from the northern Pine plantation was utilised in order to determine the impact of the Pine plantation on the groundwater levels against the natural vegetation surrounding the plantation. The monitoring points within this plantation created a traverse stretching from the west, where NU3a is positioned, past NU2a and NU2b located at the midpoint of the plantation and NU1a located along the eastern boundary of the plantation. NT1a is located east of NU1a within the indigenous area and NT2a is the monitoring point located furthest from the plantation. Figure 65 plots the elevation of this cross sectional area, measured in metres above mean sea level (mamsl) as well as the water level elevation also measured in mamsl. The graph indicates that the topography slopes in an easterly direction.

The water level data presented in Figure 65 is based on the initial water level recorded in October 1995 and the water levels recorded in December 1998, when the monitoring programme was implemented. The Pines in these compartments were planted in September 1967 and with a lifespan of approximately 30 years, were felled between October 1997 and April 1998. Thereafter, Eucalyptus replaced the Pines which were then felled between 2001 and 2003. The exact date of felling is unknown and it is estimated that the trees were felled during this period and compartments U, T and portions of R were handed back to the St. Lucia Wetland Park, as know at that stage. Therefore the entire area of compartment U where the Pines and the Eucalyptus were stationed was cleared out. The area now consists of grass and natural vegetation with the remnants of the old tree trunks.

The water level data therefore represents the water level in the area, associated with the 28 years old Pine species at that stage. The data firstly indicates very shallow groundwater levels present in union with the mature Pines, with the water level ranging from 1.08 to 5.82 mbgl. Secondly, the influence of the mature Pines on the groundwater is evident from the data collected in 1995. The deepest water level recorded along the cross section of monitoring points was present at points NU2a and NU2b located in the centre of the planted area. As the distance from the plantation boundary increased, measured as 180 metres at NT1a and 280 metres at NT2a, the water level begins to taper and was located shallower to the surface in comparison to the areas within the plantation. The data collected in December 1998 indicates similar water levels for NU3a and monitoring points NT1a and NT2a located in the indigenous areas. However, the water levels are shallower for the monitoring points located within the plantation. Therefore from 1995 to 1998 the water levels rose in association with the Pine species. This rise may be attributed to the rebound of the groundwater level after the felling of the Pine compartments in late 1997 and early 1998 which were replaced with Eucalyptus. However, this also coincided with a period of very high rainfall which would have contributed to this rise in water level.

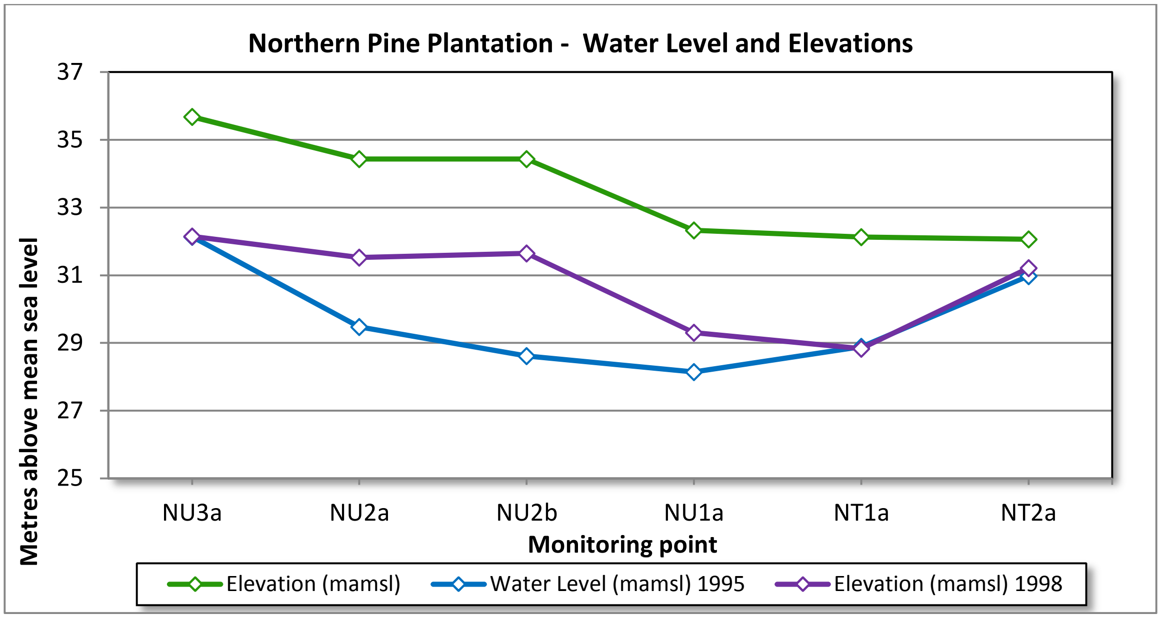


Figure 65: Comparison of water levels and elevation within the northern Pine plantation using data of October 1995

8.2.2 Combination of Pine and Eucalyptus

The data collected from the current Eucalyptus plantations, was obtained from a series of monitoring points which created a cross section across the Eucalyptus plantation with indigenous vegetation on either end of the cross section. The data was selected from monitoring points located along this cross section which had sufficient data recorded from 1995 and 2008. These points were, NM2a located within the western indigenous area, NM1a, NN1a, NJ3a and NJ1b all located within the plantation area and NJ2a situated on the eastern end within the indigenous vegetation.

The compartments associated with this cross section, were occupied by Pines prior to Eucalyptus. The Pines were felled in 1995 or 1998, depending on the different compartments and were replanted with *Eucalyptus grandis Camaldulensis*. Therefore the data for 1995 in Figure 66 is representative of the effect of the Pine plantations as no Eucalyptus was present at that stage. The data plotted for 2008 represents the effect of the Eucalyptus plantations. Figure 66 plots the elevation as well as the water level elevation measured in mamsl for the data collected in 1995 and 2008. The data sets obtained during 1995 and 2008 were both plotted in order to make a comparison between the effects of the Pine species versus the Eucalyptus species.

The purple line in Figure 66 represents the water level associated with the Pines in 1995. At this stage, the age of the Pines ranged from 10 to 18 years (not all records were available for the dates the Pines were planted). The data indicates relatively shallow water levels present ranging from 2 to 9.8 mbgl. The deepest water level was recorded in NJ2a, located in the indigenous area. NJ2a is located on a slope towards the Lake, therefore free draining towards the Lake may occur which may be the reason for the deeper water levels.

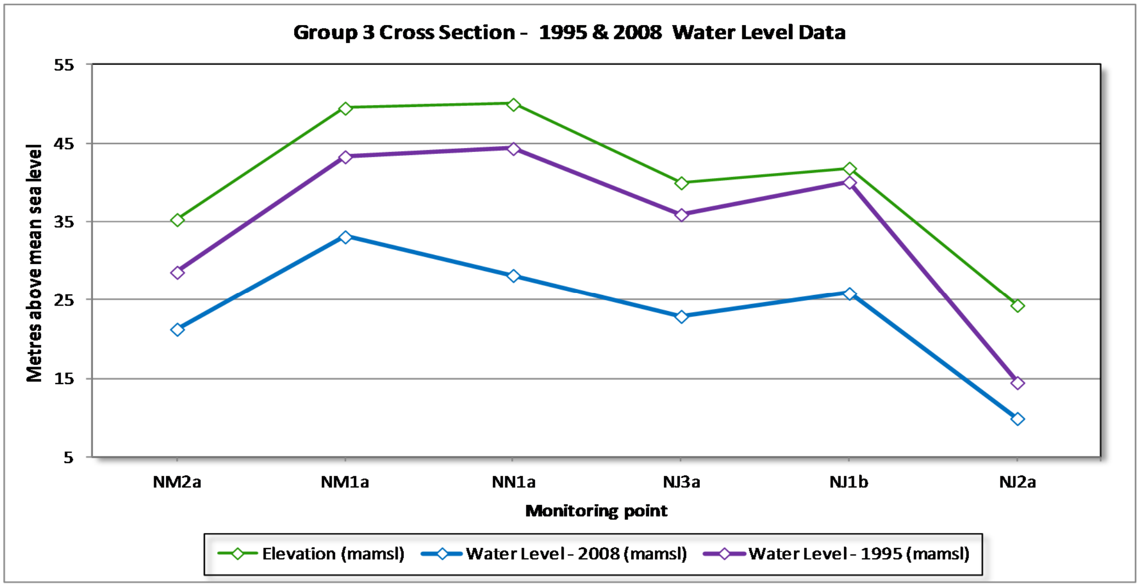


Figure 66: Comparison of water levels and elevation along the Cross Section of Group 3

The blue line represents the water level associated with the Eucalyptus plantations in 2008. The data indicates a significant decline in the water level in comparison to 1995. The water levels within the indigenous vegetation on either side of the planted areas were in the region of 14 mbgl, whereas within the plantation it ranged from approximately 16 to 22 mbgl. Even though less of an impact is evident within the indigenous vegetation, a decline was still recorded. However, the extent of the impact of the impact cannot be determined as there are no monitoring points beyond these areas to determine the radius of impact.

Over the period of 13 years from 1995 to 2008, the water level dropped approximately 4.5 to 7.3 metres within the indigenous vegetation located adjacent to the Eucalyptus plantation. However, the water level within the plantation declined between approximately 10 and 16 metres over this period.

8.3 Average decline in water levels

The average decline in water levels was calculated using the monitoring data at hand. This was calculated for each monitoring point based on the initial water level recorded in October 1995 and the final water level recorded or the point at which the monitoring point was measured as dry. Thereby the average annual decline in the water level was determined using the total difference in the water level over the period for which monitoring data was available. This was conducted for the Eucalyptus and Pine species as well as the indigenous vegetation.

Figure 67 below indicates significant annual declines in the water level associated with the Eucalyptus species, in the range of 1 metre per year. Sufficient data was recorded in monitoring points NJ1a, NJ1b, NJ3a, NJ4a, NJ5a and NN1a in order to calculate accurate averages over the monitoring period. Not all monitoring points provided sufficient data in order to be representative of the actual decline over the period monitored. Points NK1a and NQ1a only presented two to three years of data and therefore do not provide an accurate approximation of the average decline.

The data recorded within the Pine plantations, only record the water levels associated with the Pine species from 1995 until 1998, when the compartments were felled and replaced with Eucalyptus species. During the course of 2001 and 2002, the Eucalyptus compartments present in the northern compartments, were felled as the land was returned to St. Lucia Wetland Park, as known at that stage and was restored with indigenous vegetation. Therefore, the data associated with the Pine species from 1995 to 1998 does not allow for accurate calculations of the annual decline in water levels. However, the data recorded during this period, does reflect the state of the groundwater system correlated with the mature Pines at 30 years of age. At this stage of maturity, shallow water levels are present which would lead to a conclusion that there is minimal decline in the water levels associated with the Pines in this area.

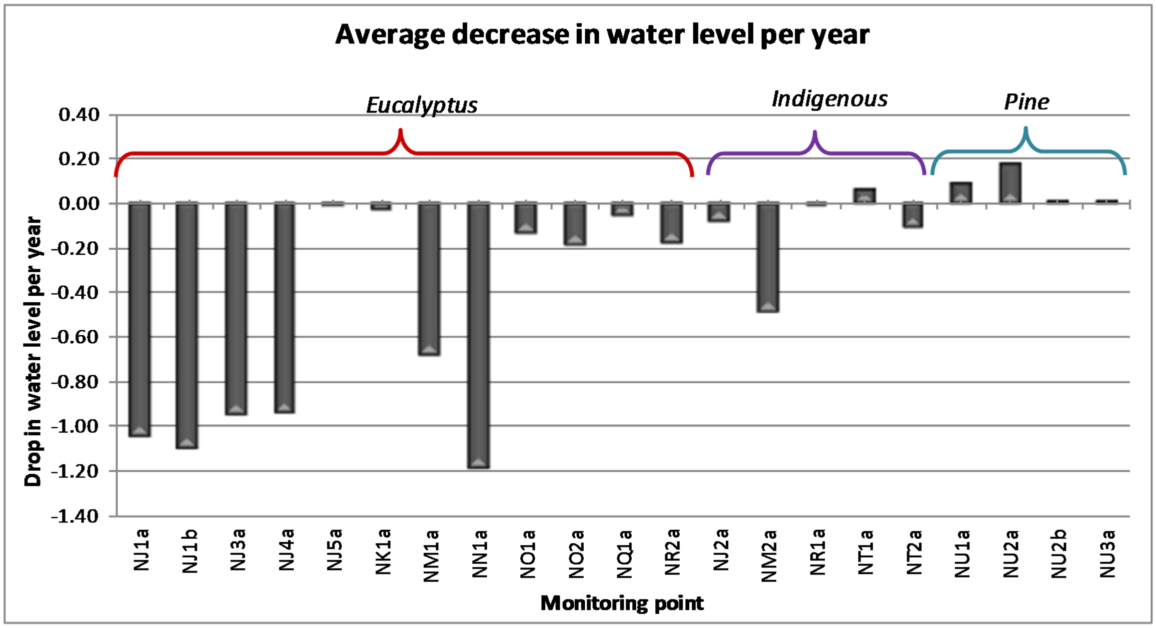


Figure 67: Average decrease in water level per year for the different species

The response within the indigenous vegetation is both positive and negative. Monitoring point NM2a indicated a significant decline over the monitoring period, with an average decline of 0.5 metres per annum. The monitoring point is situated in the indigenous vegetation, however still located in close proximity to a Eucalyptus compartment located approximately 40 metres from the plantation. The effect of this compartment is evident in data presented.

Monitoring point NT1a, located adjacent to the Pine plantation which occupied the area until 1995, which was replaced by Eucalyptus and finally restored back to indigenous land indicated that the water levels had recovered even after the presence of Pines from 1967 to 1998 and Eucalyptus from 1998 to 2001/2002. This most likely as a result of the system reaching equilibrium once the plantation was removed and the area was restored to its natural state.

8.4 Total Water Usage of the Plantation

In order to determine the total water consumption of the Nyalazi plantation, the following approach was applied. The total volume abstracted from storage was calculated as well as the amount of precipitation associated with the total commercially planted area of the Nyalazi plantation, as it is assumed all rainfall is used by the trees through canopy interception, evapotranspiration and water located within the soil moisture zone. Together, this amount represents the total water consumption of the plantation.

The change in total volume was calculated from 1995 to 2001. This was done in Surfer 11, whereby the water level elevation were contoured as a 3D surface for 1995 and 2001 and the volume between the two surfaces was produced, with a value of 31 564 863m^3. In order to calculate the actual volume of water within this total volume between the two surfaces, the specific yield was incorporated. According to Heath (1982), the specific yield for sand is 22%, which therefore yields a volume of approximately 7 million m^3 water, which has been removed from storage over this six year period, which approximates to 1.15 million m^3 per year.

Additionally, another factor which has to be taken into consideration is the contribution of groundwater to the lake and adjacent Nyalazi River. This was calculated using Darcy's Law, as follows:

Q = KIA

Q = Discharge = volumetric flow rate, volume of water flowing through an aquifer per unit time (m^3/day)
K = Hydraulic conductivity = ability of material to allow water to move through it, expressed in terms of m/day (distance/time). It is a function of the size and shape of particles as well as the size, shape, and connectivity of pore spaces
I = Hydraulic gradient = difference in height between the two points over the distance
A = Area through which the groundwater is flowing, cross-sectional area of flow (aquifer width × thickness, in m^2)

A value of 0.24m/day was used for the hydraulic conductivity (Rawlins, 1991). The average hydraulic gradient was calculated as 0.005 and the area was calculated using the perimeter of the site along which discharge would occur to the lake or river (53 444m^2). Figure 68 presents the boundary of the river and lake along which discharge would occur. This was multiplied by the aquifer thickness (assumed to be two metres), resulting in a volume of 102 000m^3. The exact aquifer thickness is unknown and therefore an assumption was made. However, this does not appear to make a significant difference in the calculation when this parameter is altered. The total discharge calculated amounts to 122m^3/day or 44 676m^3/year.

Q = KIA
= 0.24m/day x 0.005 x 102 000m^3
= 122m^3/day

Therefore the total volume of water within storage which is lost based on the presence of the plantation, is 1 150 000m^3 minus the 44 676m^3 discharged to the lake/river. This amounts to 1 112702m^3 on a yearly basis.

Figure 68: River and Lake Discharge boundary used for calculation

If it is assumed that all rainfall is also utilised by the plants, through canopy interception, evapotranspiration, utilising water within the soil moisture zone and assuming runoff is negligible for the site, then the amount of rainfall is also considered as water which is consumed by the plantation. This was calculated by determining the amount of rainfall which falls only on the commercially planted area. The average annual rainfall for the site area is 866mm/annum (0.866m/annum) and the area of commercial plantation within the site area is 69 405 000m^2. This results in an amount of 60 million m^3 per year. Therefore the total volume of water lost by the plantation on an annual basis is roughly 60.1 million m^3 per year, which equates to 8820 m^3/year/ha which can also be expressed as 24 m^3/day/ha.

SiyaQubeka provided the information that the distribution of trees is 1666 trees per hectare during the Eucalyptus rotations and 1333 for pine rotations. The total water usage for the plantation was calculated during periods of both Pine and Eucalyptus occupation, and therefore an average of 1500 trees per hectare was used. Based on this information, it is therefore calculated that the average loss of water in one tree within this specific plantation is 16 litres per day. This is similar when compared to the 5l/day/tree calculated for the Kamarooka Project (www.ictinternational.com) and the research of Shyam Sunder (1996) stating that Eucalyptus species can transpire between 20 and 40 litres per tree per day. The loss of water calculated for this project although similar to other case studies does differ. This may be attributed to the site specific conditions for each case study which differs, one of the major contributing factors to the differences may be the different climatic conditions.

8.5 Conceptual Model of the Northern Pine Plantation

All data collated and discussed thus far was compiled and incorporated into a conceptual model of the isolated northern Pine compartments. As discussed earlier, this is the ideal scenario based on the isolation of the Pine plantation with no influence from any other tree species other than the surrounding natural vegetation.

The conceptual model incorporates the pedological and geological information obtained during the installation of the monitoring points where the lithology was logged. The uppermost layer consists of sandy loam underlain by clay and sandy clay (refer to Appendix A).

The northern Pine plantation is subdivided into different compartments, with compartments U28 and U29, and compartment U3 bound by indigenous vegetation to the east and west, respectively. The Pines represent a mature generation which were planted around 1967 and therefore approximately 28 years old as of 1995. The groundwater levels recorded in the monitoring points during 1995 have been incorporated into the conceptual model.

The conceptual model, presented in Figure 69, therefore illustrates a scenario of a mature Pine plantation surrounded by indigenous vegetation underlain by an alluvial aquifer. The outcome of the presence of the Pine Plantation is clear. Slightly deeper water levels are associated with the plantation areas and shallower levels within the adjacent indigenous vegetation. However, the overall observation which is evident from this scenario is the shallow water levels, ranging from 1 to 5 metres below ground level, in conjunction with the mature 28 year old Pine species.

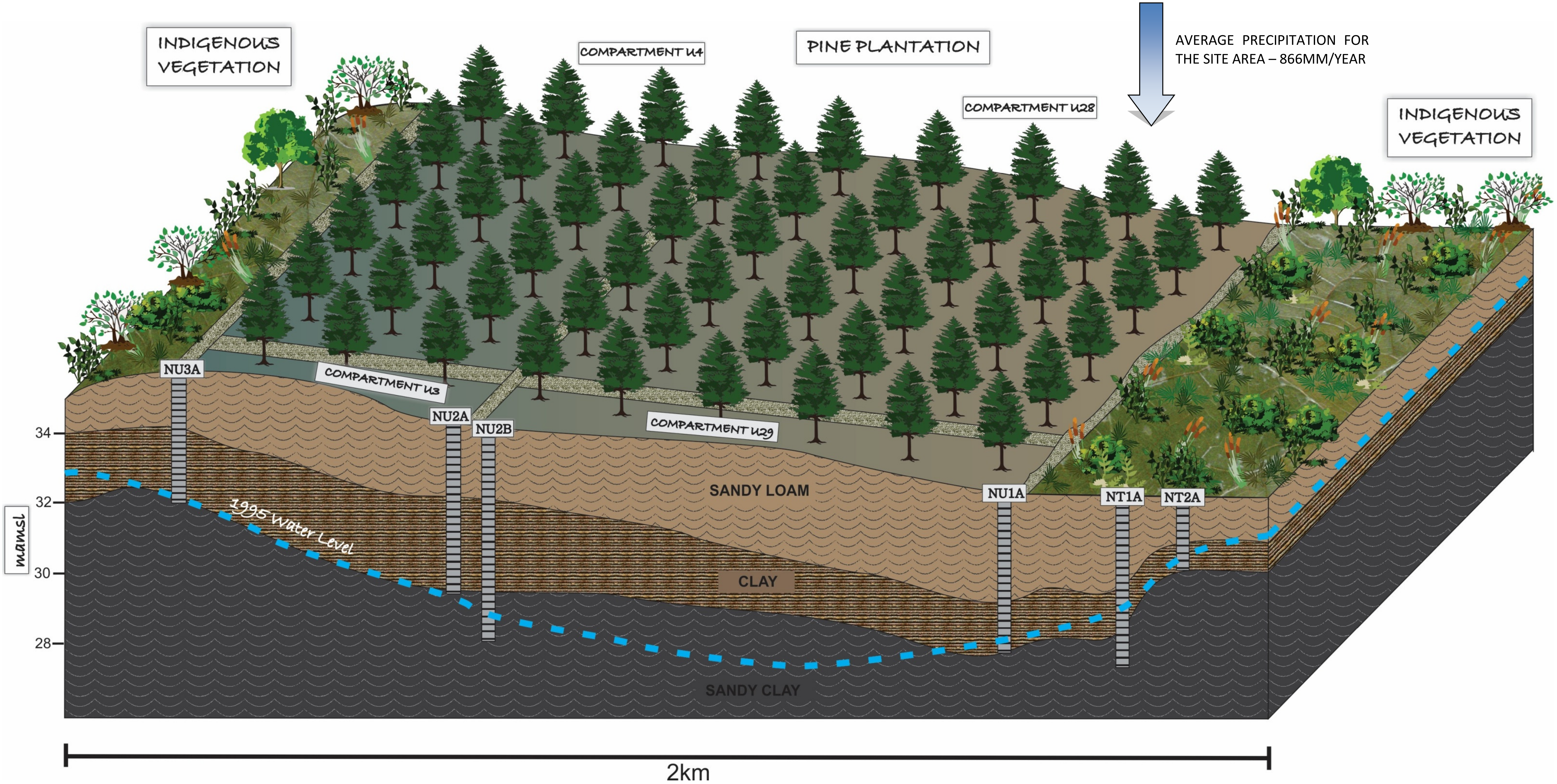


Figure 69: Conceptual Model of the Northern Pine Plantation (1998)

8.6 Conceptual Model of the Eucalyptus Plantation

All data collated and discussed thus far was compiled and incorporated into a conceptual model of the Eucalyptus compartments. The conceptual model was constructed along the cross sectional profile of Group 3 monitoring points (refer to Table 5). Unlike the northern Pine scenario, the Eucalyptus compartments have had several influences:

- Firstly, the previous Pine plantation which preceded the Eucalyptus;
- The presence of firebreaks separating different compartments; and
- Different rotation cycles.

The conceptual model constructed in Figure 70, therefore, similarly to the Pine plantation, illustrates a scenario of a Eucalyptus plantation surrounded by indigenous vegetation underlain by an alluvial aquifer, however; it does not represent a mature plantation, but rather one with varying maturity.

The conceptual model indicates relatively shallow water levels present during 1995, where the Pine species was still present. A significant impact is evident, during the period of when the Eucalyptus species was introduced from 1998 until the cut-off for the data reliability. The model illustrates the noteworthy impact as a result of the Eucalyptus species.

Over the period of 13 years as indicated in Figure 70, the water level dropped between 10 and 16 metres within the plantation, compared to the drop of 4.5 to 7.3 metres in the adjacent indigenous vegetation.

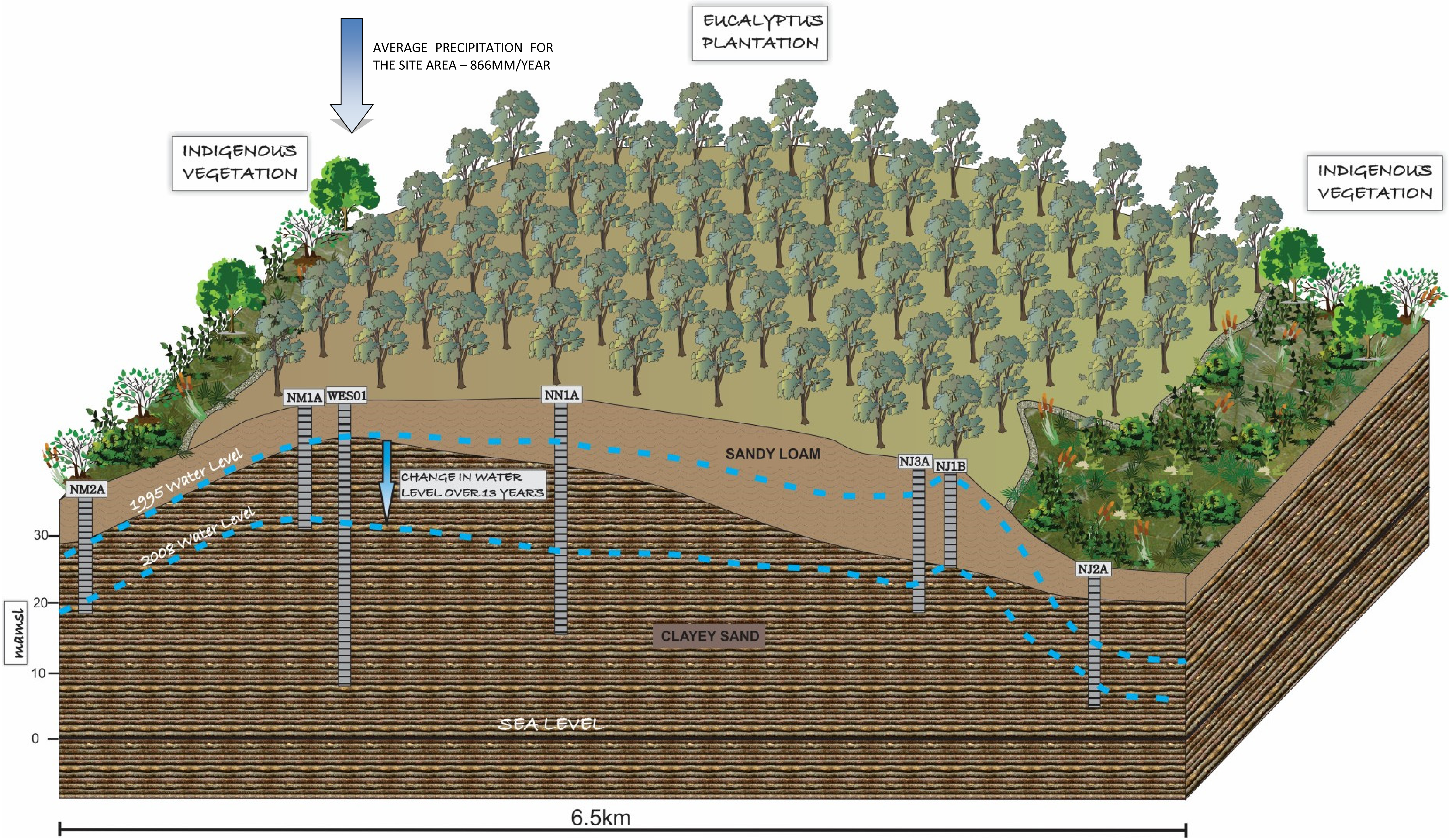


Figure 70: Conceptual Model of the Eucalyptus Plantations

8.7 Conclusion

From the data analysis, it has been evident that *Pinus elliottii* and *Eucalyptus grandis Camaldulensis* tree species do have an impact of the groundwater system associated with the site. Therefore, the conceptual model was constructed for both the Pine and Eucalyptus plantations in order to quantify the effects of the plantations on the groundwater level.

Determining the effects of the Pines proved to be difficult based on the data at hand as no historic data was available. The initial water level monitoring data was collected when the Pines were at an age of around 28 years. This indicated relatively shallow water levels which ranged from 5.82 mbgl near the central portion of the compartment to 1.08 mbgl within the adjacent natural vegetation. Ultimately, there is an impact associated with the presence of the Pines as the water level is deeper within the plantation as opposed to the surrounding natural grasses and shrubs where the groundwater level begins to taper towards the surface. However, the water levels were still shallow at this stage and as a result the impact may be classified as minimal.

Conversely, the water level data associated with the *Eucalyptus grandis Camaldulensis* plantation indicated different results. The Eucalyptus species indicated a significant impact with the lowering of the groundwater table between 10 and 16 metres over a period of 13 years within the plantation area. A less significant impact was evident within the adjacent indigenous areas with a decline of 4.5 to 7.3 metres over the same period, indicating the impact extends beyond the plantation area. This proves that timber plantations, specifically Eucalyptus utilise higher quantities of water in comparison to indigenous vegetation.

Another method was applied to quantify the overall effect of the Nyalazi plantation on the hydrogeological system which was to calculate the total water consumption of the commercially planted site area. This comprised of the total volume of water removed from storage, which was calculated as 1.15 million m^3 per year. Additionally, the precipitation which fell within the commercially planted area was also considered water which was utilised by the trees, which totalled 60 million m^3 per year. In total, the volume of water lost by the plantation is 60.1 million m^3 per year. Additionally, this water loss can be expressed as a loss per tree. This is calculated based on the commercially planted area and the amount of trees planted per hectare. Based on this a water loss of 16 litres per tree per day was calculated based on the data for this specific plantation. This is comparable to water losses calculated for Eucalyptus plantations in Australia.

CHAPTER 9: GROUNDWATER MANAGEMENT WITHIN NYALAZI PLANTATION

9.1 Introduction

From the monitoring results obtained, it is evident that the Eucalyptus species has impacted upon the groundwater environment in the study area. As such, continual water level monitoring is imperative in order to further comprehend the impacts of the species relative to the natural groundwater conditions. Currently, the groundwater monitoring regime installed within the Nyalazi plantation is sufficient in terms of the species monitored (Eucalyptus or indigenous vegetation) as well as the spatial distribution of the monitoring boreholes. However, the actual status of the boreholes are in poor condition as many have been destroyed by fires or wildlife, have collapsed or are dry as the depth of instalment was not sufficient at the time.

9.1.1 Rehabilitation of Monitoring Boreholes

As a result of the current monitoring network status, recommendations are made in order to upgrade the necessary boreholes to allow for continuous monitoring across the study area. The boreholes recommended for rehabilitation are discussed in Table 6 and illustrated in Figure 71. This is the minimum amount of rehabilitation required to collect data from the different areas within the study area.

Table 6: Monitoring Boreholes recommended for rehabilitation

Borehole	Monitoring Description	Action Required
NT2a	Located within the northern portion of the study area, within the indigenous area west of the old Pine and Eucalyptus plantation which was cleared from 2001-2003	Blocked at 1.07 metres, therefore the blockage needs to be removed. If the monitoring point is dry after it is unblocked, it is recommended to redrill a new borehole.
NM2a	Located within the indigenous vegetation. Borehole was re-drilled in the past and is currently blocked and dry.	Remove blockage. If a water level measurement is then possible, upgrade the headworks to ensure validity as a monitoring borehole.
NJ1a	Borehole is located within the Eucalyptus plantation. Drilled to 21 metres but is blocked at 7 metres.	Remove blockage and upgrade headworks.
NJ2a	Located east of the plantation within the indigenous vegetation. Borehole is blocked at 11 metres.	Remove blockage and upgrade headworks.

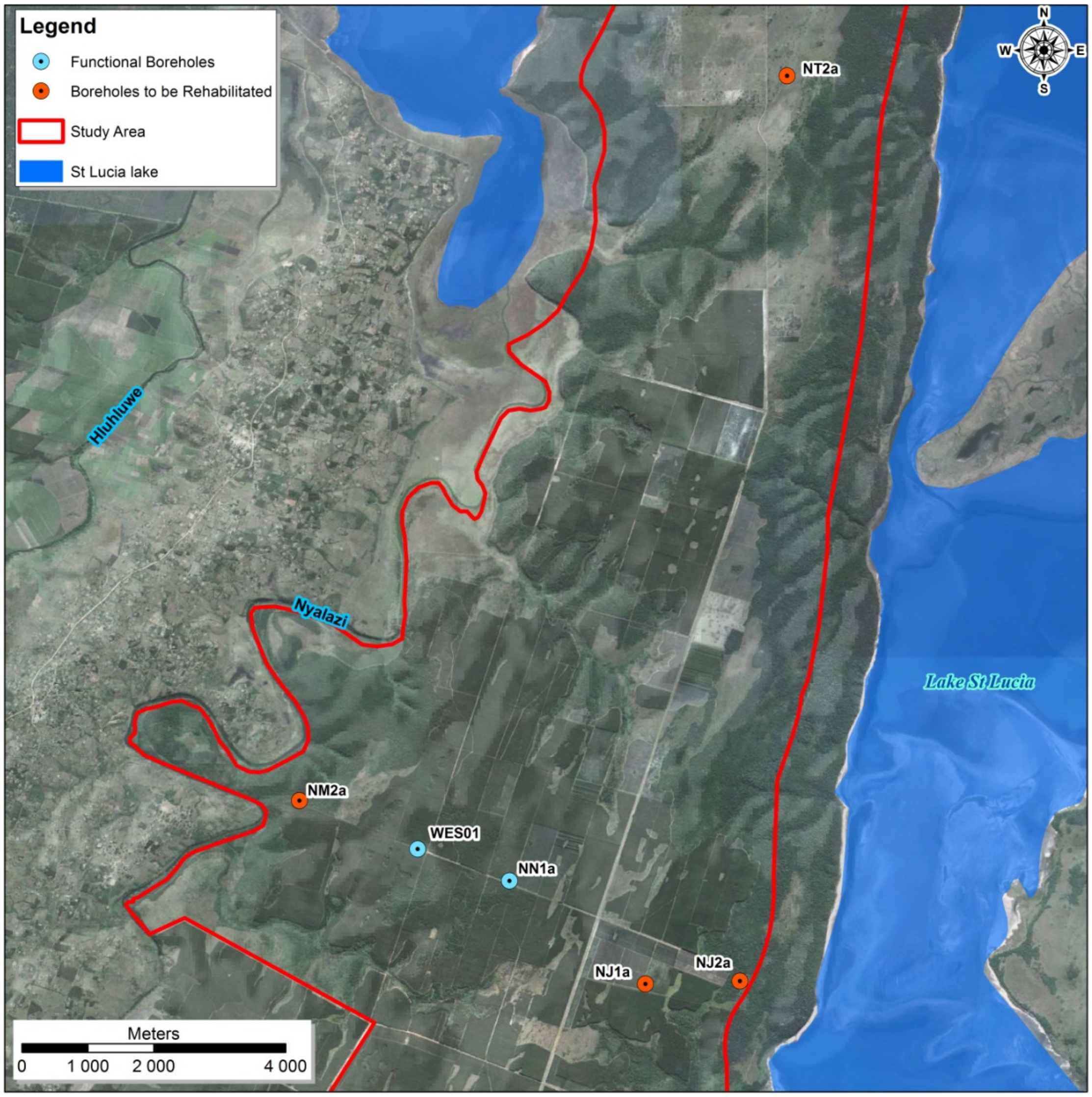


Figure 71: Borehole Rehabilitation Map

Additionally, one borehole in the study area is still functional and deep enough to obtain water level data. This borehole is NN1a and should be continually monitored. However, the borehole requires some maintenance as it is completely open and the headworks need to be upgraded. Borehole WES01 was drilled in the study area in November 2011, to a depth of 45 metres and should therefore also be incorporated in any future monitoring conducted within the study area.

Furthermore, it is imperative that the rainfall data is also continually captured as is currently taking place for the study area, in order to couple this with the water level monitoring.

Together with the water level data to be captured in the study area, once the boreholes are in a functional state again, continuous data interpretation can be used to re-evaluate the impact on the groundwater system and to identify the stage at which the groundwater level stabilises.

9.2 Conclusion

Based on the current status of the monitoring network present on the site, whereby several monitoring points have been damaged by fires and wildlife, or are dry, it is recommended that the most critical monitoring points are rehabilitated. These monitoring points are NT2a, NM2a and NJ2a which monitor the adjacent indigenous vegetation as well as NJ1a which monitors the Eucalyptus plantation. Additionally, two monitoring boreholes are still functional within the plantation, namely NN1a and WES01.

The continual groundwater level monitoring will allow for a more substantial database and also to determine if the groundwater stabilises and reaches an equilibrium stage or continues to drop over time. The aforementioned rehabilitation and redrilling of boreholes is the bare minimum required in order to ensure the data collected is worthwhile and representative of the site.

CHAPTER 10: CONCLUSIONS

10.1 Introduction

Based on the investigative studies conducted on the groundwater regime associated with the Nyalazi plantation, several conclusions are evident. These were based on the 17 years worth of groundwater level monitoring data which was supplied by SiyaQubeka and interpreted for the purpose of this study.

A critical component of this thesis was to construct a conceptual model for the two main components of this study, namely the *Pinus elliottii* and *Eucalyptus grandis Camaldulensis* plantations within the study area. The conceptual model collated the relevant information in order to assess the site as a whole.

10.2 Climatic Conditions

The study area has warm, moist summers, categorised as subtropical climatic conditions and mild dry winters. The mean annual temperature exceeds 21°C. Majority of the rainfall occurs from during the summer months (November to March) with the balance occurring during the winter months. The average rainfall calculated for the site, based on the data collected is 866mm per annum. The evaporation rates are high in the area, which is approximately 1300mm per year (Porter and Blackmore, 1998). It is generally this high transpiration rate which disturbs the water balance of the system due to the high water loss through this process.

10.3 Geology & Hydrogeology

The study area is underlain by the widespread Zululand coastal plain aquifer, an alluvial or primary aquifer, which consists of unconsolidated clays and sands with high transmissivity and infiltration rates. The geological formations underlying the site area include the recent deposits of cover sands and the Port Durnford Formation, which are the most influential on the groundwater environment as these are the units closest to the surface (Kelbe, Rawlins, Nomquphu, 1995). Groundwater flow appears to mimic the topography and flows towards the St. Lucia Lake and Nyalazi River to the west.

10.4 The Overall Effects of Pine and Eucalyptus Plantations on the Groundwater Level

Limited historical information was available for the Pine plantation, however based on the data at hand; it was evident that the mature Pine plantations had minor effects on the groundwater environment of the study area. Shallow water levels were associated with the Pine plantations during this time; however the water levels of 5.82 mbgl within the plantation were deeper that the 1.08 mbgl water level measured within the adjacent indigenous vegetation.

Conversely, the Eucalyptus species indicated a significant impact with the lowering of the groundwater table between 10 and 16 metres over a period of 13 years within the plantation area, which equates to an average decline of 1 metre per year. A less significant impact was evident within the adjacent indigenous areas with a decline of 4.5 to 7.3 metres over the same period, indicating the impact extends beyond the plantation area. This proves that timber plantations, specifically Eucalyptus utilise higher quantities of water in comparison to indigenous vegetation.

Similar results were evident from other studies conducted in Western and South Eastern Australia as well as Argentina which indicated a decline in the groundwater levels in comparison to the surrounding grassland areas due to the presence of the Eucalyptus plantations. Additionally reduction in streamflow and recharge to groundwater was also observed.

Ultimately, the total water usage of the commercially planted area was calculated by determining the total loss of water in storage as well as the amount of precipitation (which counts as water lost through canopy interception, evapotranspiration and the soil moisture zone) over the plantation area. Therefore the total volume of water lost by the plantation on an annual basis is roughly 60.1 million m^3 per year, 112 702m^3 per year lost through storage and 60 million m^3 per year lost through rainfall. This can also be expressed as a loss of 24 m^3/day/ha. Resultantly, this equates to a loss of 16 litres per tree per day, when expressed in a more applicable unit of measurement, based on the spatial distribution of 1666 Eucalyptus trees or 1333 pine trees present per hectare. The water usage of 16l/day/tree calculated for the Nyalazi plantation is comparable to other studies. An average of 5l/day/tree was presented for the Kamarooka Project, whereby Eucalyptus trees were used as a method of reclaiming land affected by salt with the purpose of lowering the water level. Similarly, research conducted by Shyam Sunder (1996) states that different Eucalyptus species can transpire between 20 and 40 litres per tree per day. The water usage of the trees is clearly evident in the constant decline of the water levels on the site.

Based on the conclusions of the study continual monitoring of the groundwater levels is essential. SiyaQubeka has expressed interest in upgrading the borehole monitoring network indicating a proactive strategy in order to monitor the extent of the impact on the environment. In order to achieve this, several boreholes require rehabilitation and in the event that this is not possible, redrilling will be necessary in order to reach the required depth for groundwater monitoring to continue. It has been recommended that three boreholes within the indigenous area are rehabilitated/redrilled and one within the Eucalyptus plantation. Together with the two existing functional boreholes within the Eucalyptus plantation this should be sufficient in order to obtain the data required to continue the monitoring programme.

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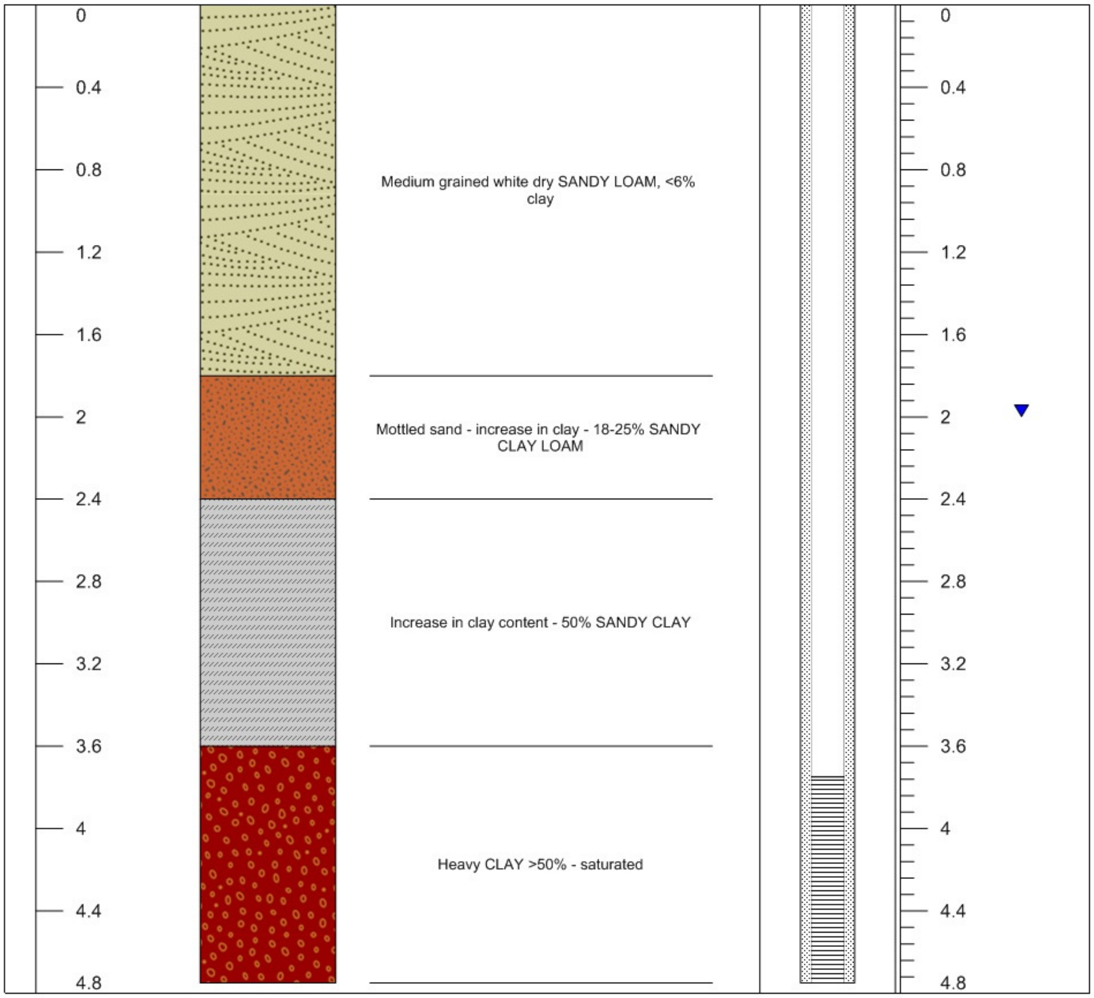
APPENDIX A
BOREHOLE LOGS

PROJECT:	Nyalazi	BOREHOLE ID:	NJ1a
LOCATION:	St. Lucia	LATITUDE:	-28.185972228
DRILLING CONTRACTOR:	GCS	LONGITUDE:	32.4000995029
DRILLING METHOD:	Hand Auger	ELEVATION:	56.7
DATE COMPLETED:	09/08/95	DEPTH:	4.75

Depth (m)	Graphic log	Description	Well Construction



Medium grained white dry SANDY LOAM, <6% clay

Mottled sand - increase in clay - 18-25% SANDY CLAY LOAM

Increase in clay content - 50% SANDY CLAY

Heavy CLAY >50% - saturated

NOTES: Depth to water level - 1.97 metres below ground level

Well Construction Legend

☐ Casing

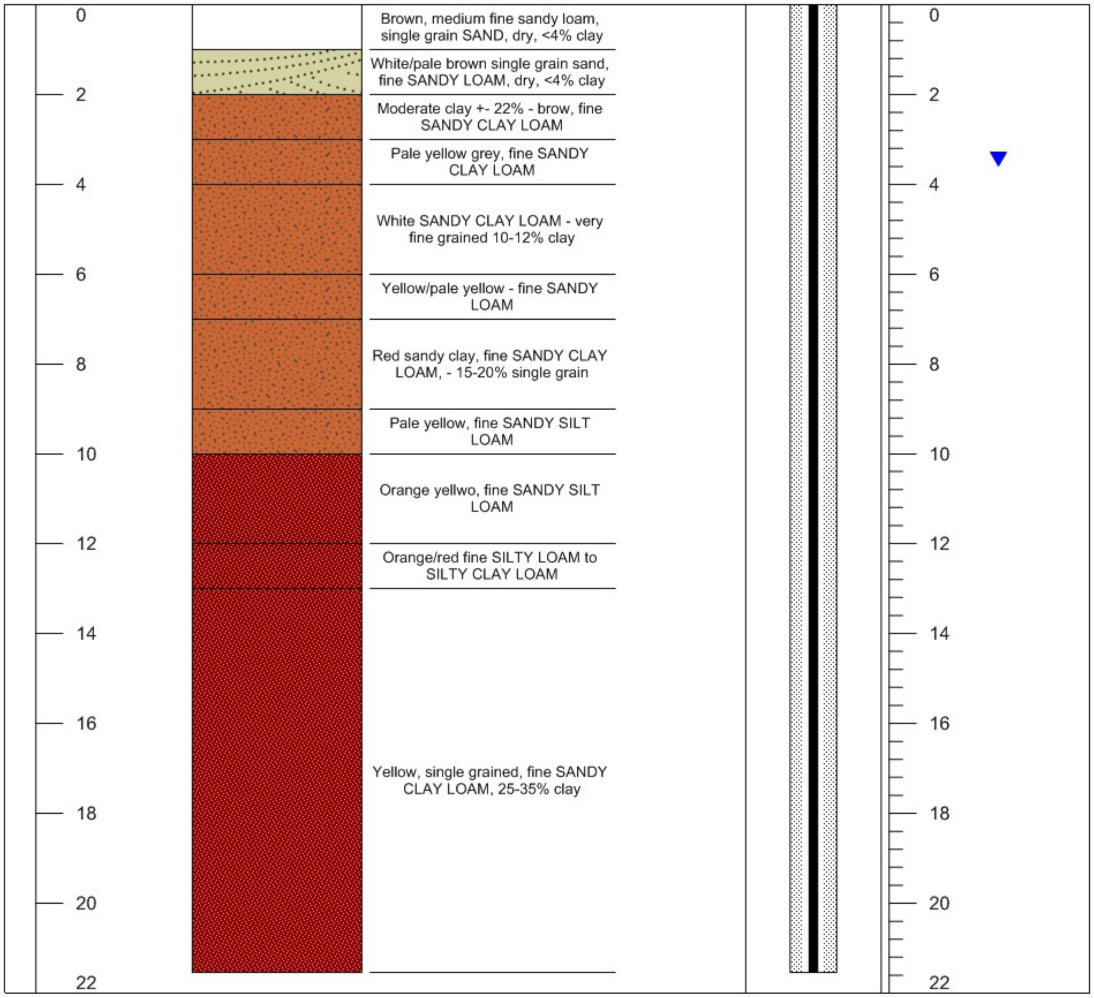
▤ Screen

▨ Fill

PROJECT: Nyalazi
LOCATION: St. Lucia
DRILLING CONTRACTOR: RBM
DRILLING METHOD: Reverse Circulation
DATE COMPLETED: 10/08/95

BOREHOLE ID: NJ1b
LATITUDE: -28.185972228
LONGITUDE: 32.4000995029
ELEVATION: 41.86079407
DEPTH: 21.54

Depth (m)	Graphic log	Description	Well Construction



Brown, medium fine sandy loam, single grain SAND, dry, <4% clay

White/pale brown single grain sand, fine SANDY LOAM, dry, <4% clay

Moderate clay +- 22% - brow, fine SANDY CLAY LOAM

Pale yellow grey, fine SANDY CLAY LOAM

White SANDY CLAY LOAM - very fine grained 10-12% clay

Yellow/pale yellow - fine SANDY LOAM

Red sandy clay, fine SANDY CLAY LOAM, - 15-20% single grain

Pale yellow, fine SANDY SILT LOAM

Orange yellwo, fine SANDY SILT LOAM

Orange/red fine SILTY LOAM to SILTY CLAY LOAM

Yellow, single grained, fine SANDY CLAY LOAM, 25-35% clay

NOTES: Depth to water - 4.33 metres below collar

Legend Title
■ Steel
▒ Fill

PROJECT: Nyalazi

LOCATION: St. Lucia

DRILLING CONTRACTOR: RBM

DRILLING METHOD: Hand Auger

DATE COMPLETED: 10/08/95

BOREHOLE ID: NJ2a

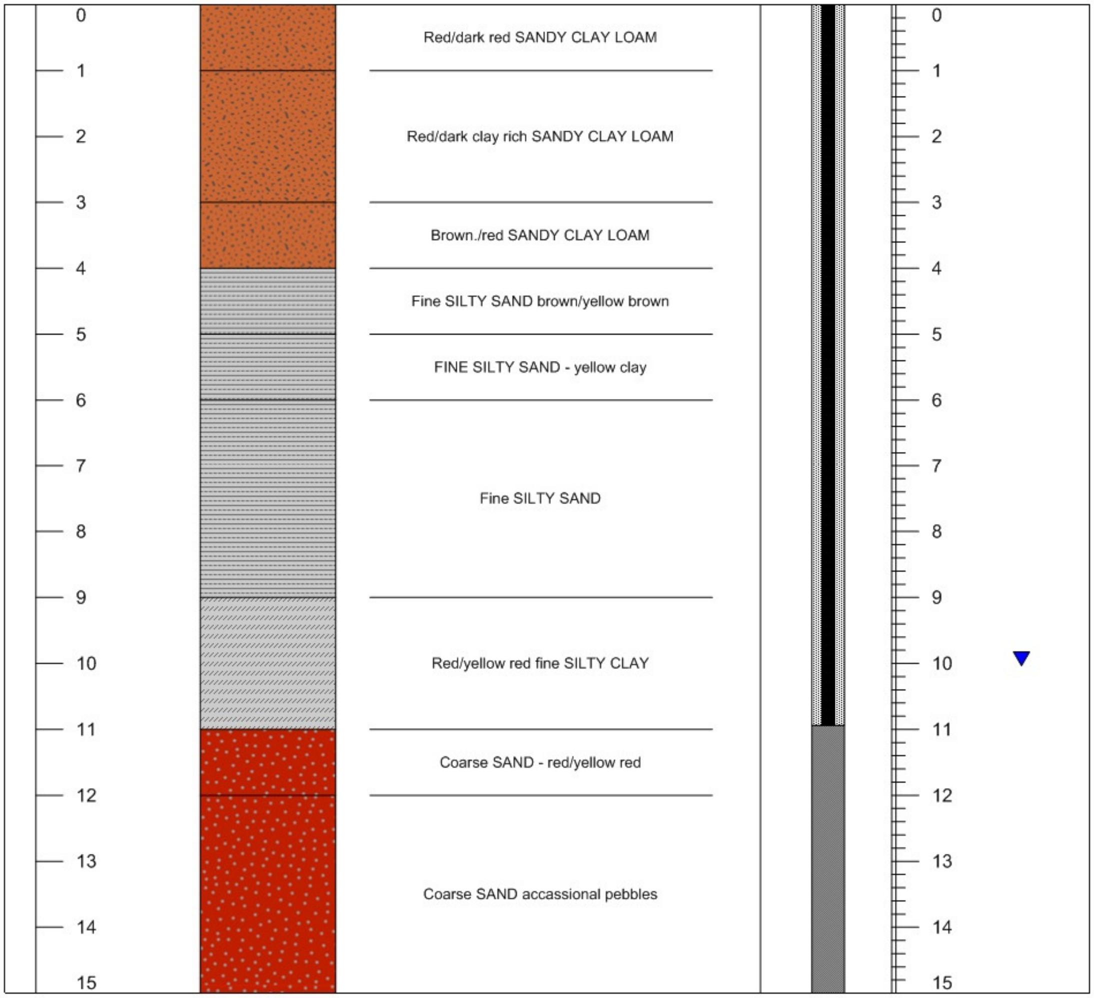
LATITUDE: -28.1855770159

LONGITUDE: 32.4129840703

ELEVATION: 24.34

DEPTH: 15

Depth (m)	Graphic log	Description	Well Construction

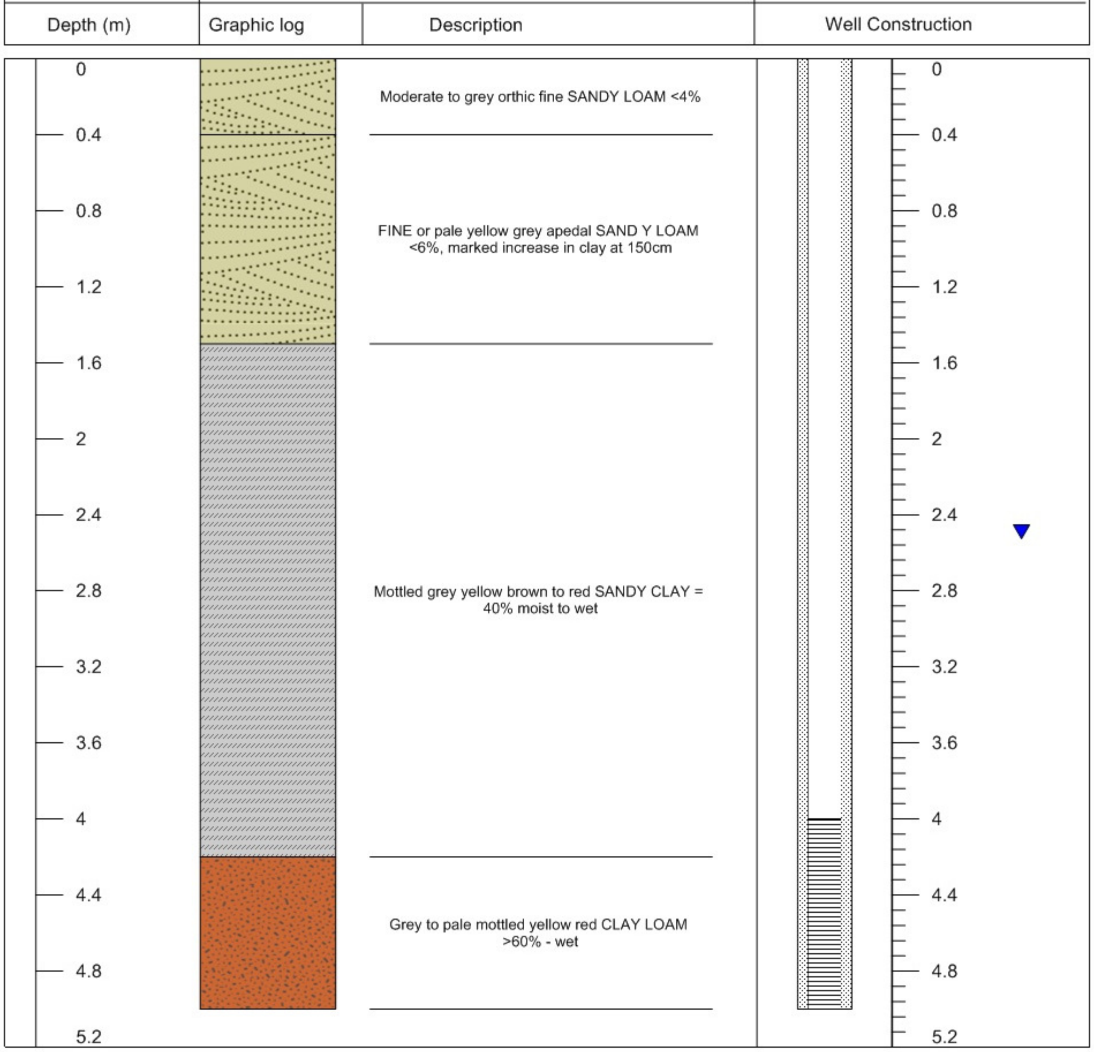


NOTES: Depth to water level - 9.94 metres below ground level

Well Construction Legend

- ■ Steel
- ▩ Collapsed
- ▒ Fill

PROJECT: Nyalazi	BOREHOLE ID: NJ3a
LOCATION: St. Lucia	LATITUDE: -28.1844570598
DRILLING CONTRACTOR: GCS	LONGITUDE: 32.4043850189
DRILLING METHOD: Hand Auger	ELEVATION: 40.00141907
DATE COMPLETED: 11/08/95	DEPTH: 5



Moderate to grey orthic fine SANDY LOAM <4%

FINE or pale yellow grey apedal SAND Y LOAM <6%, marked increase in clay at 150cm

Mottled grey yellow brown to red SANDY CLAY = 40% moist to wet

Grey to pale mottled yellow red CLAY LOAM >60% - wet

NOTES: Depth to water level - 2.49 metres below ground level

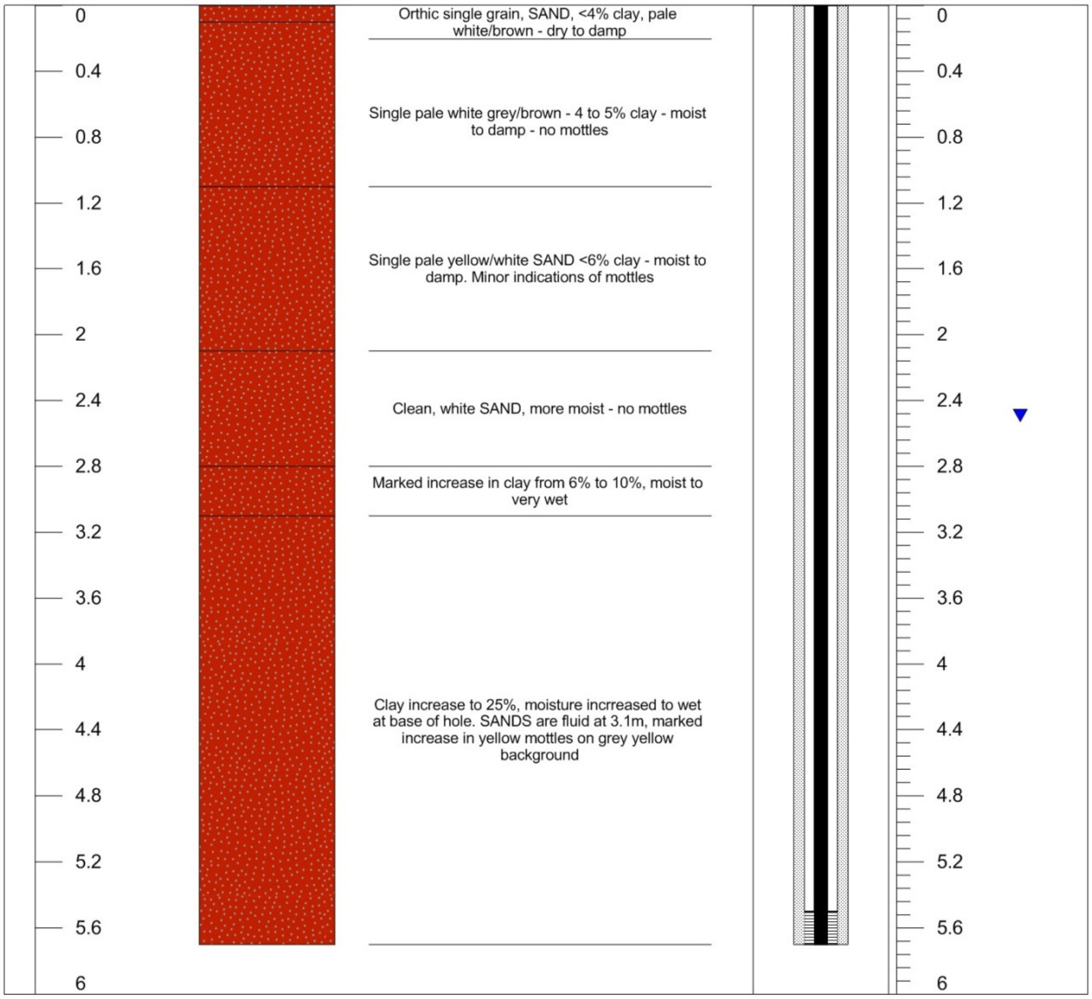
Well Construction Legend

- ☐ Casing
- ▤ Screen
- ▒ Fill

PROJECT: Nyalazi
LOCATION: St. Lucia
DRILLING CONTRACTOR: GCS
DRILLING METHOD: Hand Auger
DATE COMPLETED: 14/08/95

BOREHOLE ID: NJ4a
LATITUDE: -28.1844570598
LONGITUDE: 32.4043850189
ELEVATION: 40.00141907
DEPTH: 5.7

Depth (m)	Graphic log	Description	Well Construction



Orthic single grain, SAND, <4% clay, pale white/brown - dry to damp

Single pale white grey/brown - 4 to 5% clay - moist to damp - no mottles

Single pale yellow/white SAND <6% clay - moist to damp. Minor indications of mottles

Clean, white SAND, more moist - no mottles

Marked increase in clay from 6% to 10%, moist to very wet

Clay increase to 25%, moisture incrreased to wet at base of hole. SANDS are fluid at 3.1m, marked increase in yellow mottles on grey yellow background

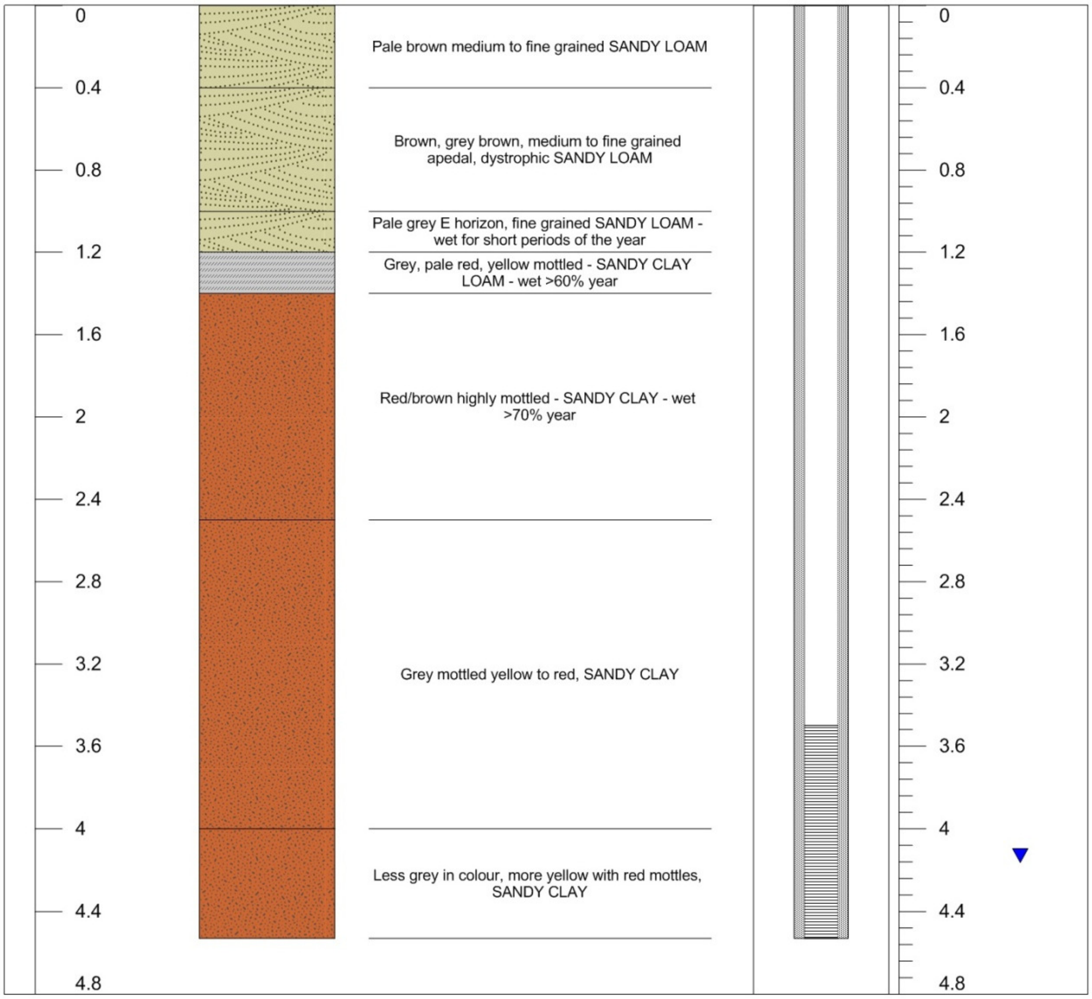
NOTES: Depth to water level - 4.4 metres below ground level

Well Construction Legend

- ▨ Fill
- ■ Steel
- ☐ Casing
- ▤ Screen

PROJECT: Nyalazi	BOREHOLE ID: NJ5a	
LOCATION: ST. Lucia	LATITUDE:	-28.1855080542
DRILLING CONTRACTOR: GCS	LONGITUDE:	32.4107749998
DRILLING METHOD: Hand Auger	ELEVATION:	31.18867874
DATE COMPLETED: 10/08/95	DEPTH:	4.53

Depth (m)	Graphic log	Description	Well Construction



Pale brown medium to fine grained SANDY LOAM

Brown, grey brown, medium to fine grained apedal, dystrophic SANDY LOAM

Pale grey E horizon, fine grained SANDY LOAM - wet for short periods of the year

Grey, pale red, yellow mottled - SANDY CLAY LOAM - wet >60% year

Red/brown highly mottled - SANDY CLAY - wet >70% year

Grey mottled yellow to red, SANDY CLAY

Less grey in colour, more yellow with red mottles, SANDY CLAY

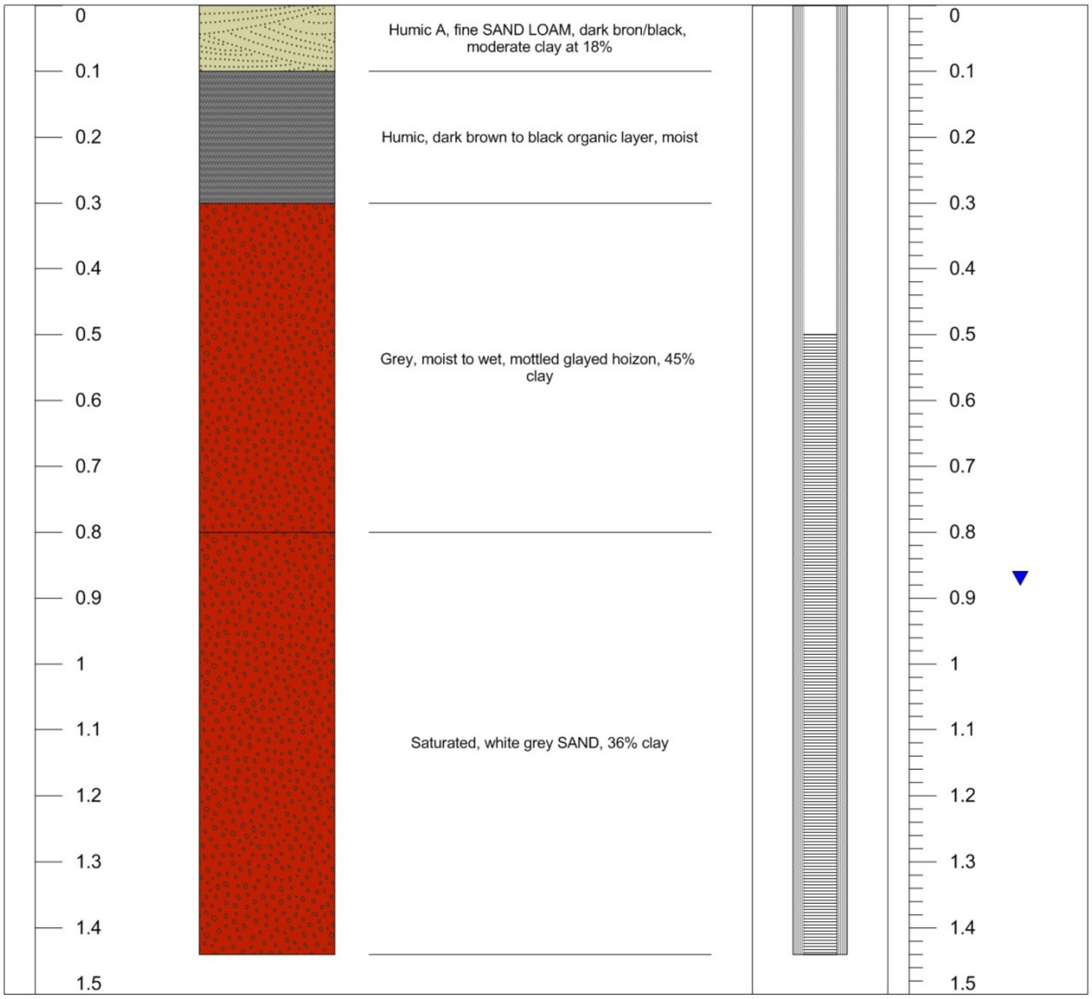
NOTES: Depth to water level - 4.13 metres below ground level

Well Construction Legend

- ☐ Casing
- ▤ Screen
- ▩ Fill

PROJECT: Nyalazi	BOREHOLE ID: NK1a
LOCATION: St. Lucia	LATITUDE: -28.1926180696
DRILLING CONTRACTOR: GCS	LONGITUDE: 32.3729720098
DRILLING METHOD: Hand Auger	ELEVATION: 38.12093735
DATE COMPLETED: 14/08/95	DEPTH: 1.44

Depth (m)	Graphic log	Description	Well Construction



Humic A, fine SAND LOAM, dark bron/black, moderate clay at 18%

Humic, dark brown to black organic layer, moist

Grey, moist to wet, mottled glayed hoizon, 45% clay

Saturated, white grey SAND, 36% clay

NOTES: Depth to water level - 0.87 metres below ground level

Well Construction Legend

☐ Casing

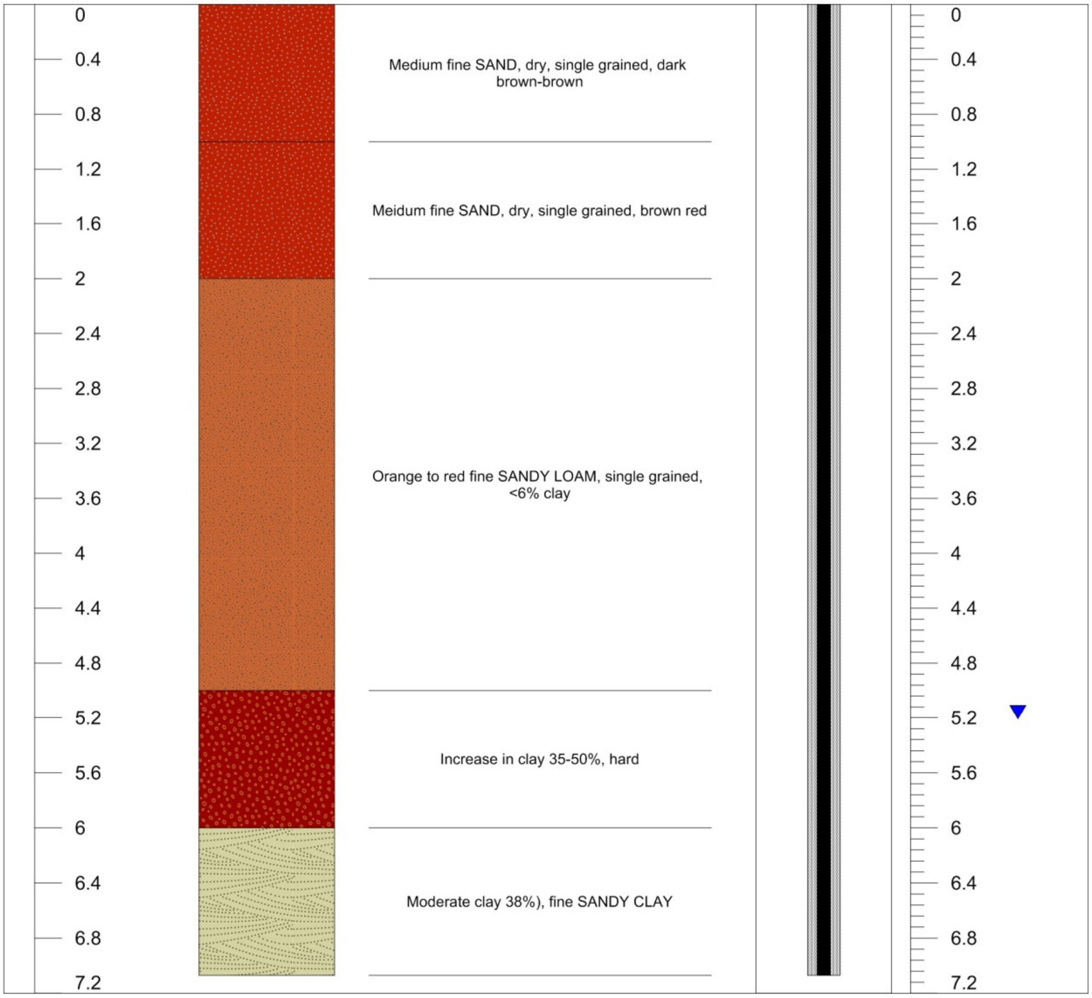
▤ Screen

▨ Fill

PROJECT: Nyalazi
LOCATION: St. Lucia
DRILLING CONTRACTOR: RBM
DRILLING METHOD: Reverse Circulation
DATE COMPLETED: 8/13/95

BOREHOLE ID: NM1a
LATITUDE: -28.1658822586
LONGITUDE: 32.3670188311
ELEVATION: 49.51
DEPTH: 7.07

Depth (m)	Graphic log	Description	Well Construction



Medium fine SAND, dry, single grained, dark brown-brown

Meidum fine SAND, dry, single grained, brown red

Orange to red fine SANDY LOAM, single grained, <6% clay

Increase in clay 35-50%, hard

Moderate clay 38%), fine SANDY CLAY

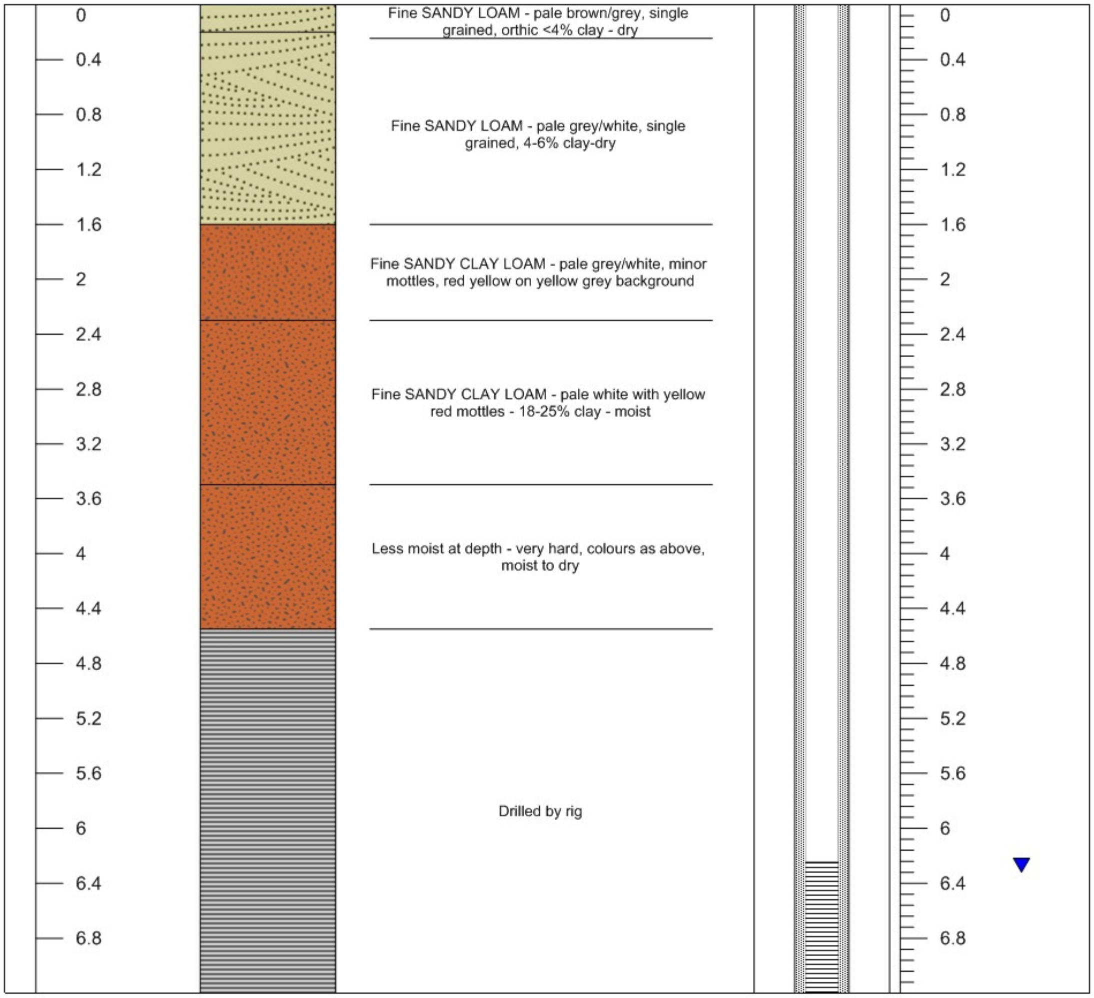
NOTES: Depth to watre level - 5.16 metres below ground level

Well Construction Legend
- ■ Steel
- ▨ Fill

PROJECT: Nyalazi
LOCATION: St. Lucia
DRILLING CONTRACTOR: GCS
DRILLING METHOD: Hand Auger
DATE COMPLETED: 13/08/95

BOREHOLE ID: NM2a
LATITUDE: -28.1609437716
LONGITUDE: 32.3528958583
ELEVATION: 35.31583405
DEPTH: 7.2

Depth (m)	Graphic log	Description	Well Construction



Fine SANDY LOAM - pale brown/grey, single grained, orthic <4% clay - dry

Fine SANDY LOAM - pale grey/white, single grained, 4-6% clay-dry

Fine SANDY CLAY LOAM - pale grey/white, minor mottles, red yellow on yellow grey background

Fine SANDY CLAY LOAM - pale white with yellow red mottles - 18-25% clay - moist

Less moist at depth - very hard, colours as above, moist to dry

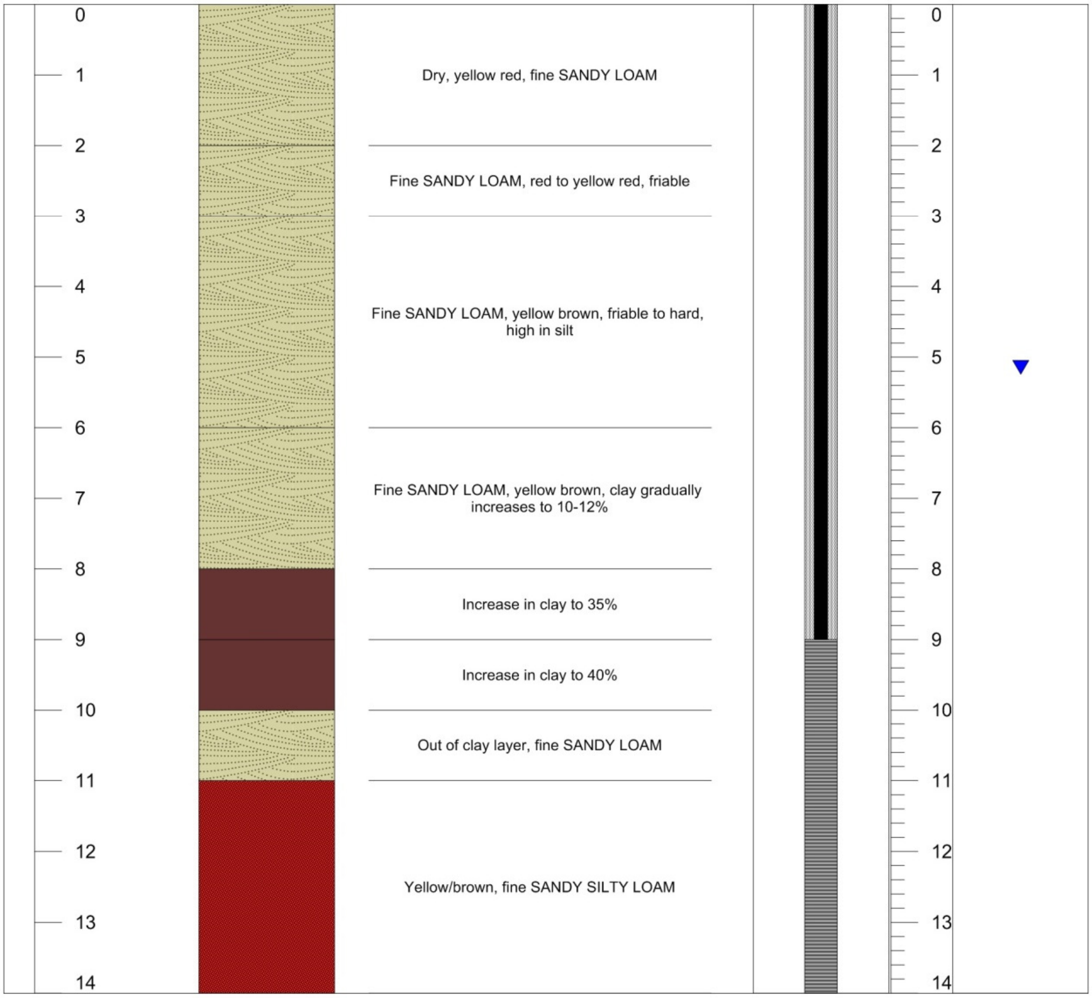
Drilled by rig

NOTES: Depth to water level - 6.27 metres below ground level

Well Construction Legend
☐ Casing
▤ Screen
▩ Fill

PROJECT: Nyalazi	BOREHOLE ID: NN1a
LOCATION: St. Lucia	LATITUDE: -28.1719039009
DRILLING CONTRACTOR: RBM	LONGITUDE: 32.3815441866
DRILLING METHOD: Reverse Circulation	ELEVATION: 52
DATE COMPLETED: 13/08/95	DEPTH: 14

Depth (m)	Graphic log	Description	Well Construction



Dry, yellow red, fine SANDY LOAM

Fine SANDY LOAM, red to yellow red, friable

Fine SANDY LOAM, yellow brown, friable to hard, high in silt

Fine SANDY LOAM, yellow brown, clay gradually increases to 10-12%

Increase in clay to 35%

Increase in clay to 40%

Out of clay layer, fine SANDY LOAM

Yellow/brown, fine SANDY SILTY LOAM

NOTES: Depth to water level - 5.15 metres below ground level

Well Construction Legend

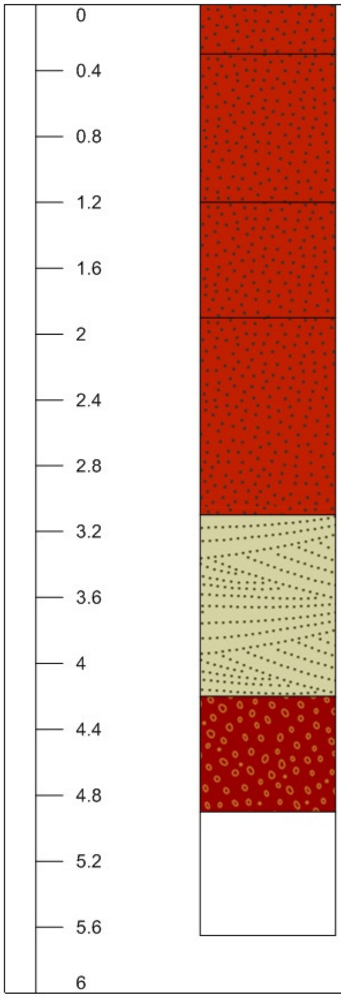
■ Steel

▤ Collapsed

▨ Fill

PROJECT: Nyalazi	BOREHOLE ID: NO1a
LOCATION: St. Lucia	LATITUDE: -28.1794382726
DRILLING CONTRACTOR: GCS	LONGITUDE: 32.4018670198
DRILLING METHOD: Hand Auger	ELEVATION: 45.23832321
DATE COMPLETED: 13/08/95	DEPTH: 4.9

Depth (m)	Graphic log	Description	Well Construction



Pale grey, brown, single grained orthic A, <2% clay, fine SAND, dry

Pale grey brown, single grained B, 2-4% clay, dry

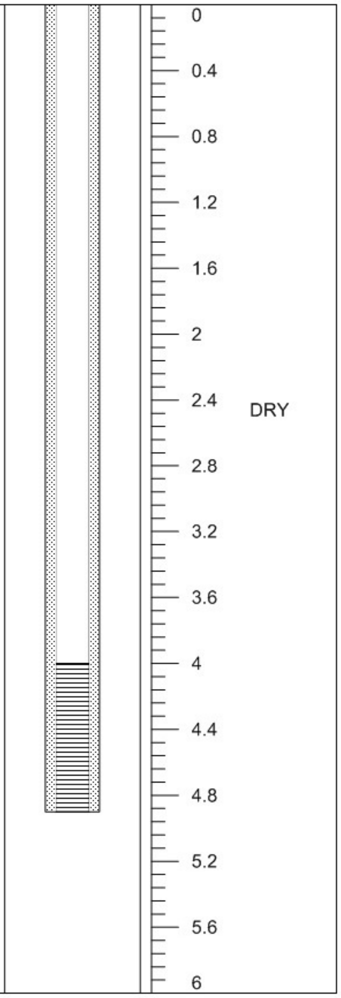
Pale white/yellow, white 4-6% clay - moist to slight;y moist

First signs of mottles, only slight increase in clay 8%, roots at 3.24m

Loss of mottles back to fine SANDY LOAM - single grain less clay - 4-6% max, roots at 4.5m

Dramatic increase in clay 10-15% increasing to 35% at base of hole - soil very moist

Steel piezometer driven into above



NOTES: Auger hole dry

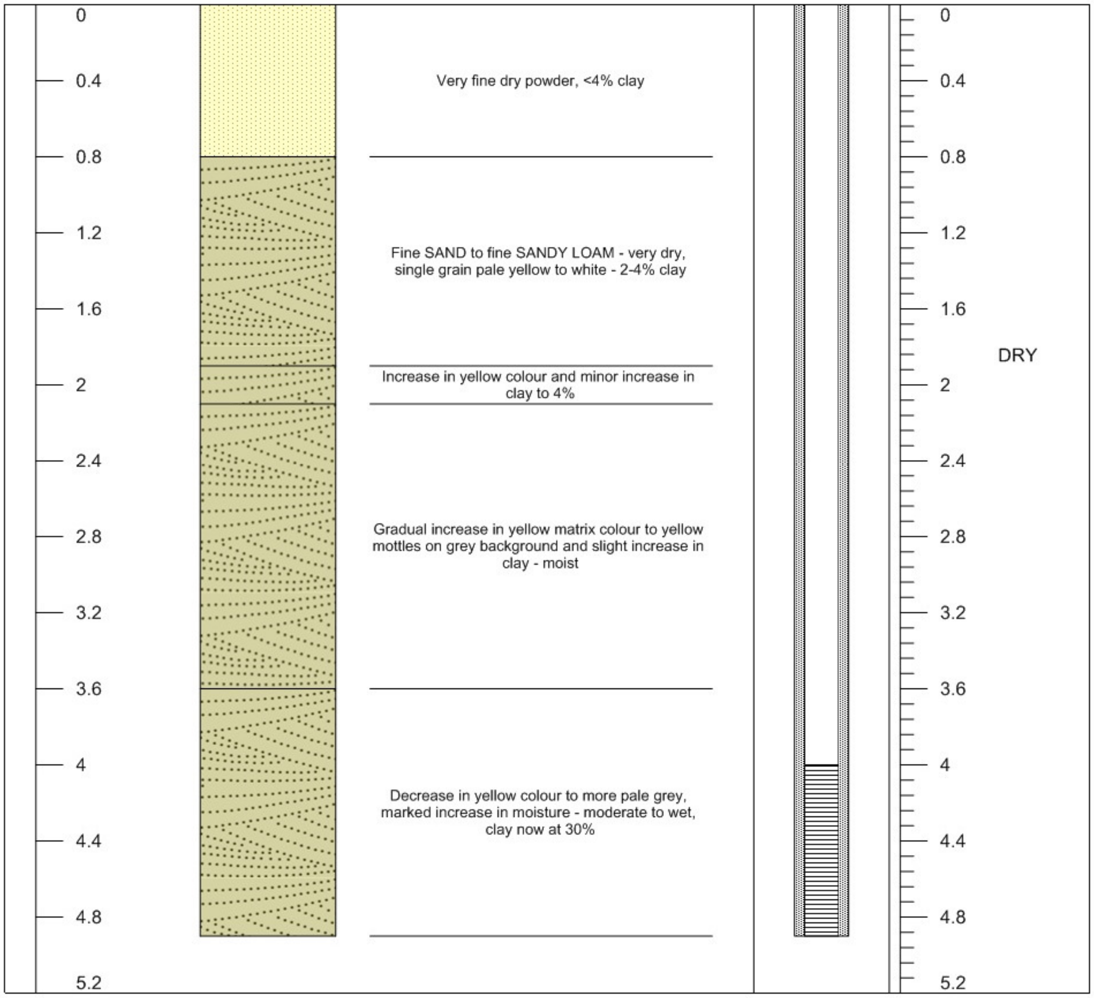
Well Construction Legend

- ☐ Casing
- ▨ Fill
- ☰ Screen

PROJECT: Nyalazi
LOCATION: St. Lucia
DRILLING CONTRACTOR: GCS
DRILLING METHOD: Hand Auger
DATE COMPLETED: 14/08/95

BOREHOLE ID: NO2a
LATITUDE: -28.1789835573
LONGITUDE: 32.4010549155
ELEVATION: 45.69213104
DEPTH: 4.9

Depth (m)	Graphic log	Description	Well Construction



Very fine dry powder, <4% clay

Fine SAND to fine SANDY LOAM - very dry, single grain pale yellow to white - 2-4% clay

Increase in yellow colour and minor increase in clay to 4%

Gradual increase in yellow matrix colour to yellow mottles on grey background and slight increase in clay - moist

Decrease in yellow colour to more pale grey, marked increase in moisture - moderate to wet, clay now at 30%

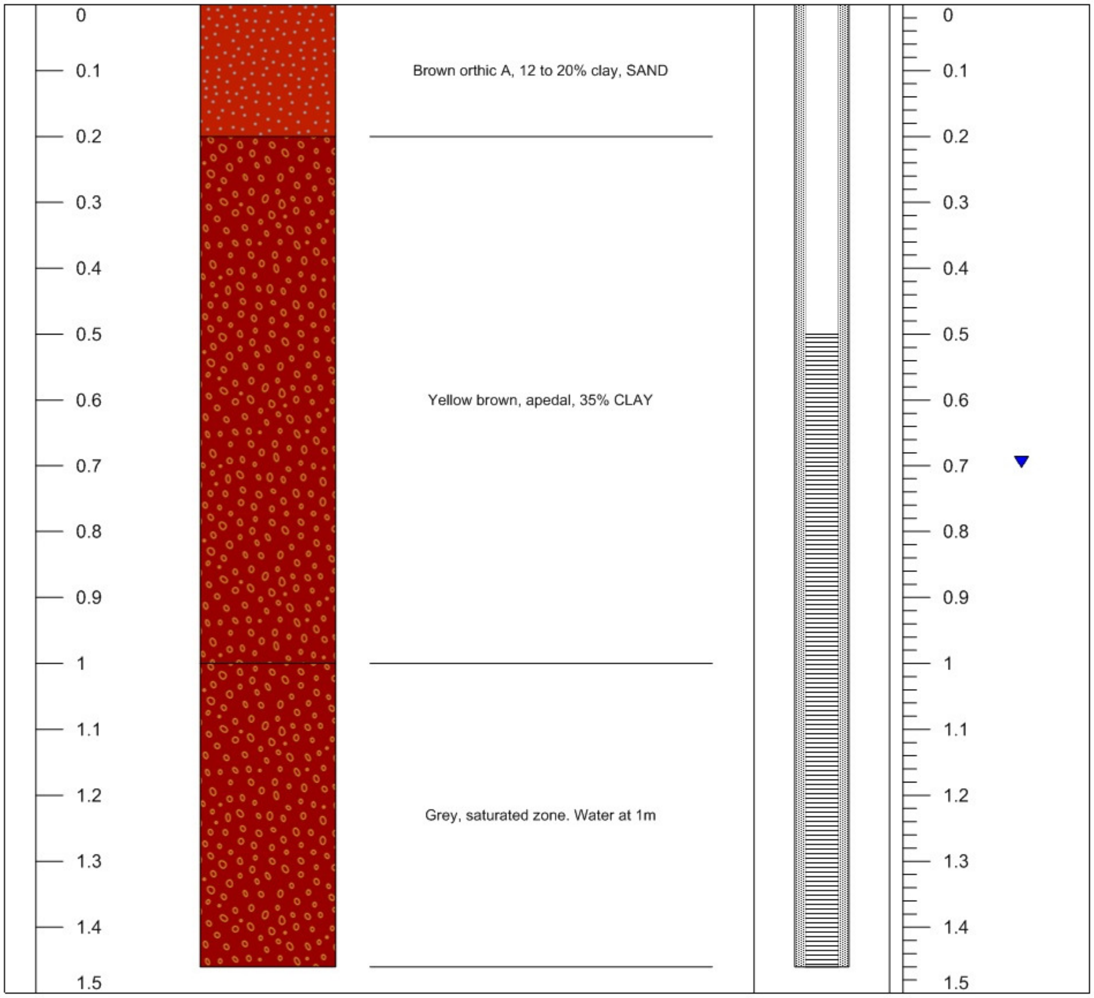
NOTES: Auger hole dry

Well Construction Legend

☐ Casing
▤ Screen
▨ Fill

PROJECT:	Nyalazi	BOREHOLE ID:	NQ1a
LOCATION:	ST. Lucia	LATITUDE:	-28.1295641258
DRILLING CONTRACTOR:	GCS	LONGITUDE:	32.3970549992
DRILLING METHOD:	Hand Auger	ELEVATION:	29.19324684
DATE COMPLETED:	14/08/95	DEPTH:	1.46

Depth (m)	Graphic log	Description	Well Construction



Brown orthic A, 12 to 20% clay, SAND

Yellow brown, apedal, 35% CLAY

Grey, saturated zone. Water at 1m

NOTES: Depth to water level - 0.69

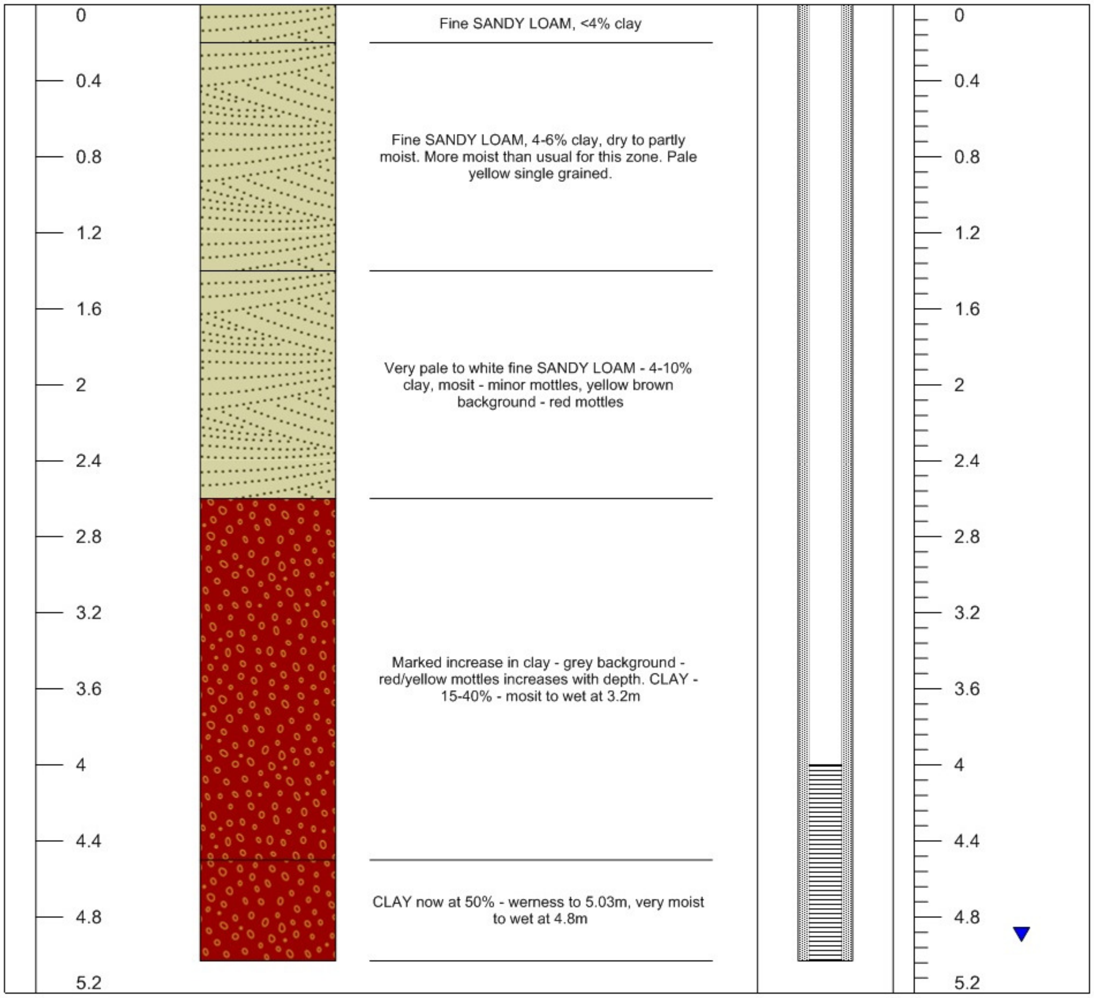
Well Construction Legend

- ☐ Casing
- ▤ Screen
- ▨ Fill

PROJECT: Nyalazi
LOCATION: St. Lucia
DRILLING CONTRACTOR: GCS
DRILLING METHOD: Hand Auger
DATE COMPLETED: 13/08/95

BOREHOLE ID: NR1a
LATITUDE: -28.0679824098
LONGITUDE: 32.4078769077
ELEVATION: 33.13352203
DEPTH: 5.03

Depth (m)	Graphic log	Description	Well Construction



Fine SANDY LOAM, <4% clay

Fine SANDY LOAM, 4-6% clay, dry to partly moist. More moist than usual for this zone. Pale yellow single grained.

Very pale to white fine SANDY LOAM - 4-10% clay, mosit - minor mottles, yellow brown background - red mottles

Marked increase in clay - grey background - red/yellow mottles increases with depth. CLAY - 15-40% - mosit to wet at 3.2m

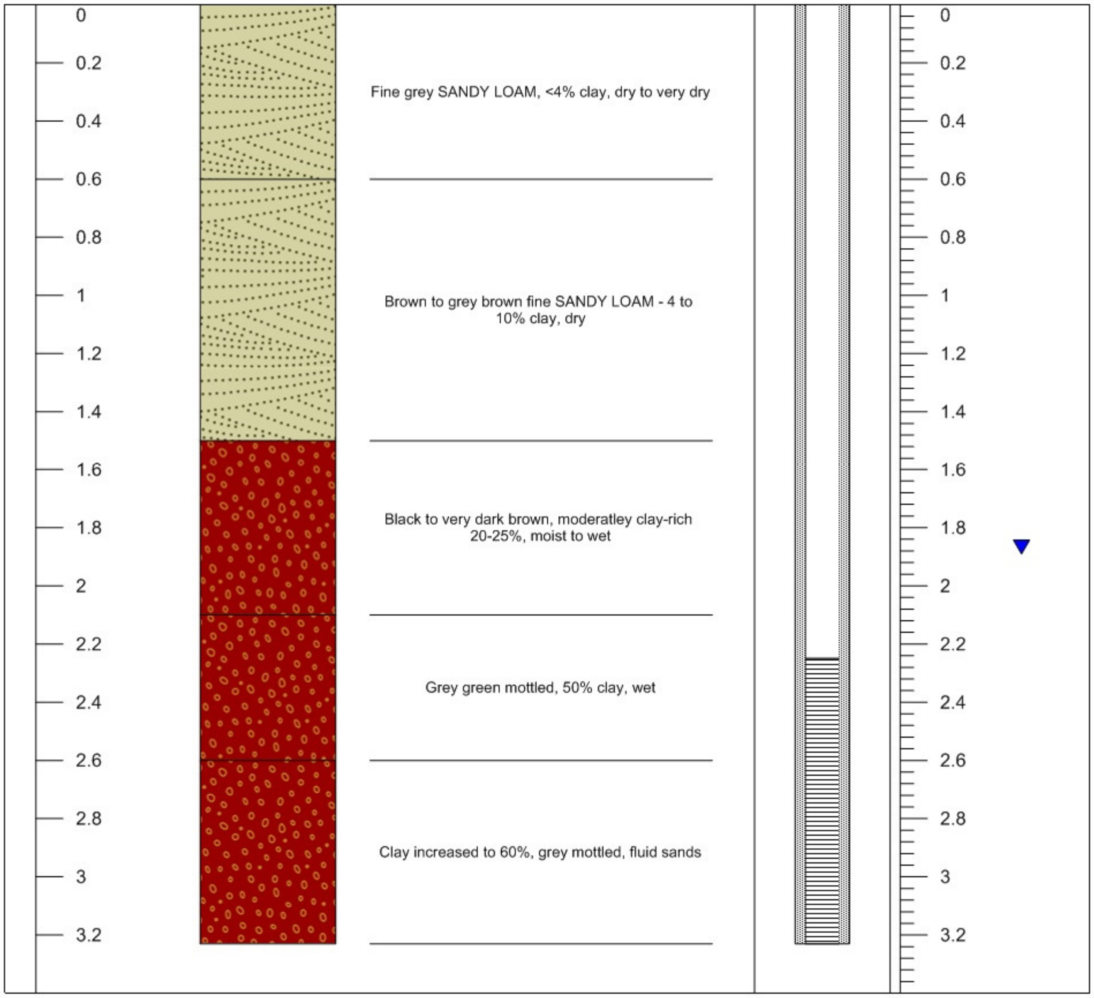
CLAY now at 50% - werness to 5.03m, very moist to wet at 4.8m

NOTES: Depth to water level - 4.89 metres below ground level

Well Construction Legend
☐ Casing
▤ Screen
▨ Fill

PROJECT: Nyalazi	BOREHOLE ID:	NR2a
LOCATION: STt. Lucia	LATITUDE:	-28.1044342465
DRILLING CONTRACTOR: GCS	LONGITUDE:	32.4073715876
DRILLING METHOD: Hand Auger	ELEVATION:	40.04283142
DATE COMPLETED: 14/08/95	DEPTH:	3.23

Depth (m)	Graphic log	Description	Well Construction



Fine grey SANDY LOAM, <4% clay, dry to very dry

Brown to grey brown fine SANDY LOAM - 4 to 10% clay, dry

Black to very dark brown, moderatley clay-rich 20-25%, moist to wet

Grey green mottled, 50% clay, wet

Clay increased to 60%, grey mottled, fluid sands

NOTES: Depth to water level - 1.86 metres below ground level

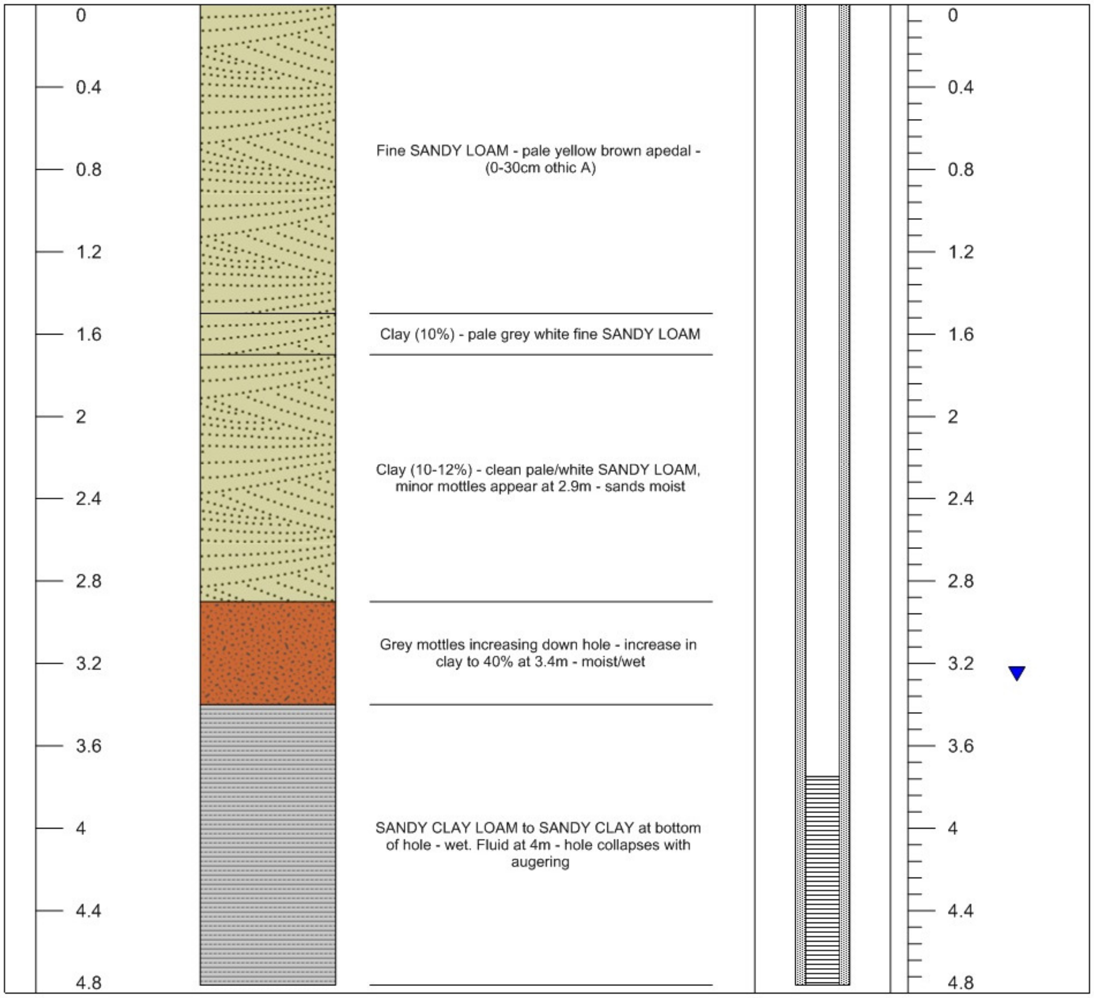
Well Construction Legend

☐ Casing
▤ Screen
▨ Fill

PROJECT: Nyalazi
LOCATION: St. Lucia
DRILLING CONTRACTOR: GCS
DRILLING METHOD: Hand Auger
DATE COMPLETED: 12/08/95

BOREHOLE ID: NT1a
LATITUDE: -28.0620270851
LONGITUDE: 32.4184375863
ELEVATION: 32.13132477
DEPTH: 4.76

Depth (m)	Graphic log	Description	Well Construction



Fine SANDY LOAM - pale yellow brown apedal - (0-30cm othic A)

Clay (10%) - pale grey white fine SANDY LOAM

Clay (10-12%) - clean pale/white SANDY LOAM, minor mottles appear at 2.9m - sands moist

Grey mottles increasing down hole - increase in clay to 40% at 3.4m - moist/wet

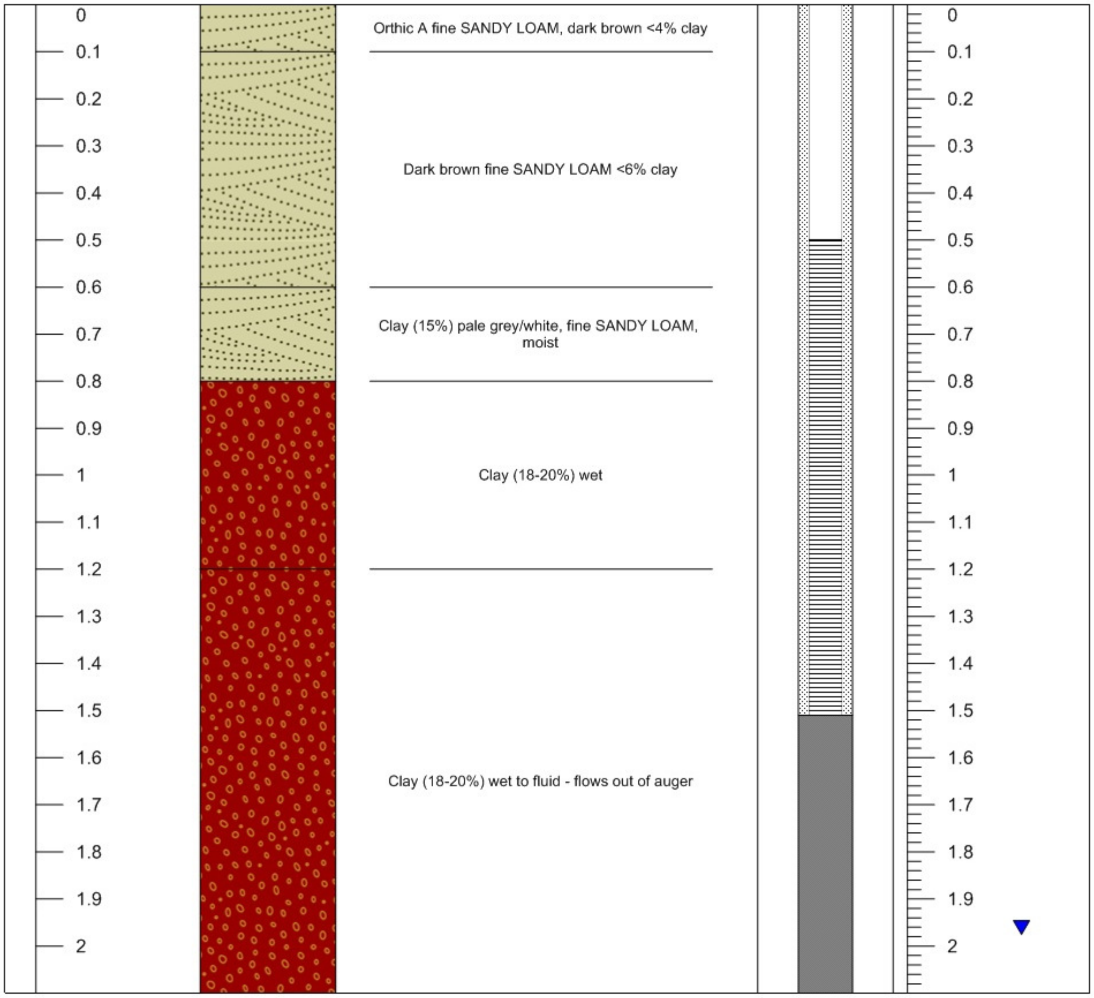
SANDY CLAY LOAM to SANDY CLAY at bottom of hole - wet. Fluid at 4m - hole collapses with augering

NOTES: Dpth to water level - 3.25 metres below ground level

Well Construction Legend
☐ Casing
▤ Screen
▨ Fill

PROJECT: Nyalazi	BOREHOLE ID:	NT2a
LOCATION: ST. Lucia	LATITUDE:	-28.0620311621
DRILLING CONTRACTOR: GCS	LONGITUDE:	32.4194039066
DRILLING METHOD: Hand Auger	ELEVATION:	32.05923462
DATE COMPLETED: 12/08/95	DEPTH:	2.1

Depth (m)	Graphic log	Description	Well Construction



Orthic A fine SANDY LOAM, dark brown <4% clay

Dark brown fine SANDY LOAM <6% clay

Clay (15%) pale grey/white, fine SANDY LOAM, moist

Clay (18-20%) wet

Clay (18-20%) wet to fluid - flows out of auger

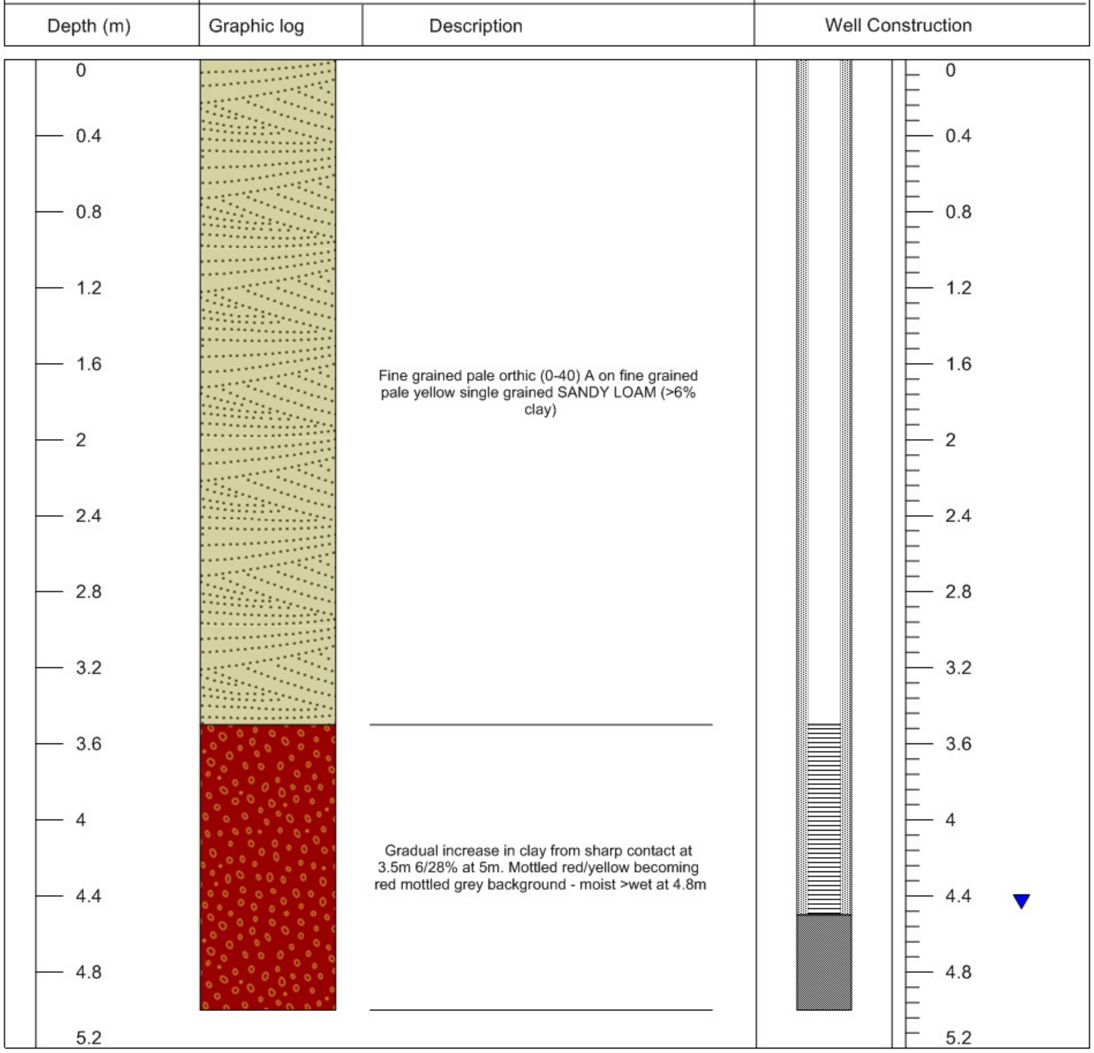
NOTES: Depth of water level - 1.96 metres below ground level

Well Construction Legend

- ☐ Casing
- ▨ Collapsed
- ☰ Screen
- ░ Fill

PROJECT: Nyalazi
LOCATION: St. Lucia
DRILLING CONTRACTOR: GCS
DRILLING METHOD: Hand Auger
DATE COMPLETED: 11/08/95

BOREHOLE ID: NU1a
LATITUDE: -28.0620190963
LONGITUDE: 32.4165556748
ELEVATION: 32.32471848
DEPTH: 5



Fine grained pale orthic (0-40) A on fine grained pale yellow single grained SANDY LOAM (>6% clay)

Gradual increase in clay from sharp contact at 3.5m 6/28% at 5m. Mottled red/yellow becoming red mottled grey background - moist >wet at 4.8m

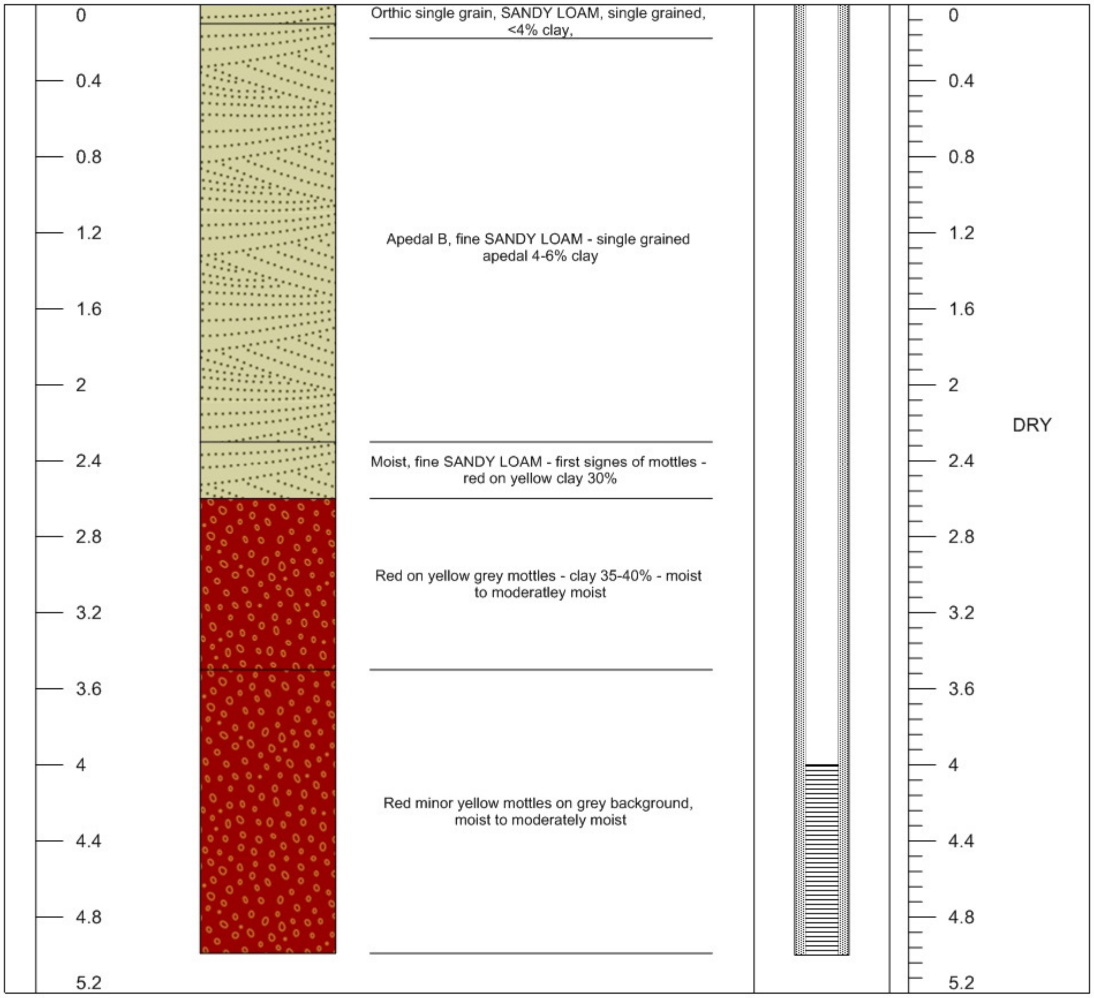
NOTES: Depth to water level - 4.43 metres below ground level

Well Construction Legend

☐ Casing
▨ Fill
▤ Screen
▩ Collapsed

PROJECT:	Nyalazi	BOREHOLE ID:	NU2a
LOCATION:	St. Lucia	LATITUDE:	-28.0619365697
DRILLING CONTRACTOR:	GCS	LONGITUDE:	32.4078083196
DRILLING METHOD:	12/08/95	ELEVATION:	34.43669891
DATE COMPLETED:	Hand Auger	DEPTH:	4.99

Depth (m)	Graphic log	Description	Well Construction



Orthic single grain, SANDY LOAM, single grained, <4% clay,

Apedal B, fine SANDY LOAM - single grained apedal 4-6% clay

Moist, fine SANDY LOAM - first signes of mottles - red on yellow clay 30%

Red on yellow grey mottles - clay 35-40% - moist to moderatley moist

Red minor yellow mottles on grey background, moist to moderately moist

NOTES: Auger hole dry

Well Construction Legend

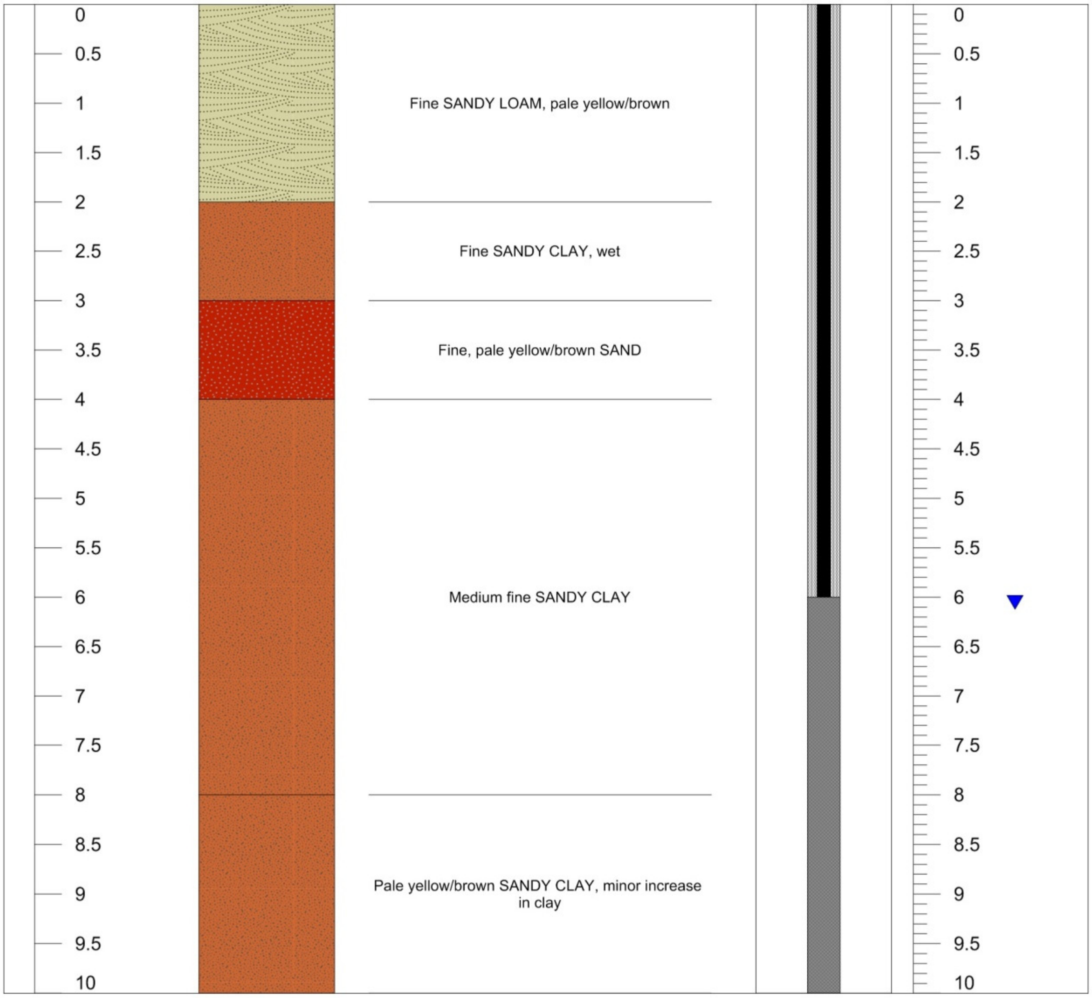
☐ Casing

▤ Screen

▨ Fill

PROJECT:	Nyalazi	BOREHOLE ID:	NU2b
LOCATION:	St. Lucia	LATITUDE:	-28.0619368891
DRILLING CONTRACTOR:	RBM	LONGITUDE:	32.4079100511
DRILLING METHOD:	Reverse Circulation	ELEVATION:	34.44
DATE COMPLETED:	12/08/95	DEPTH:	10

Depth (m)	Graphic log	Description	Well Construction



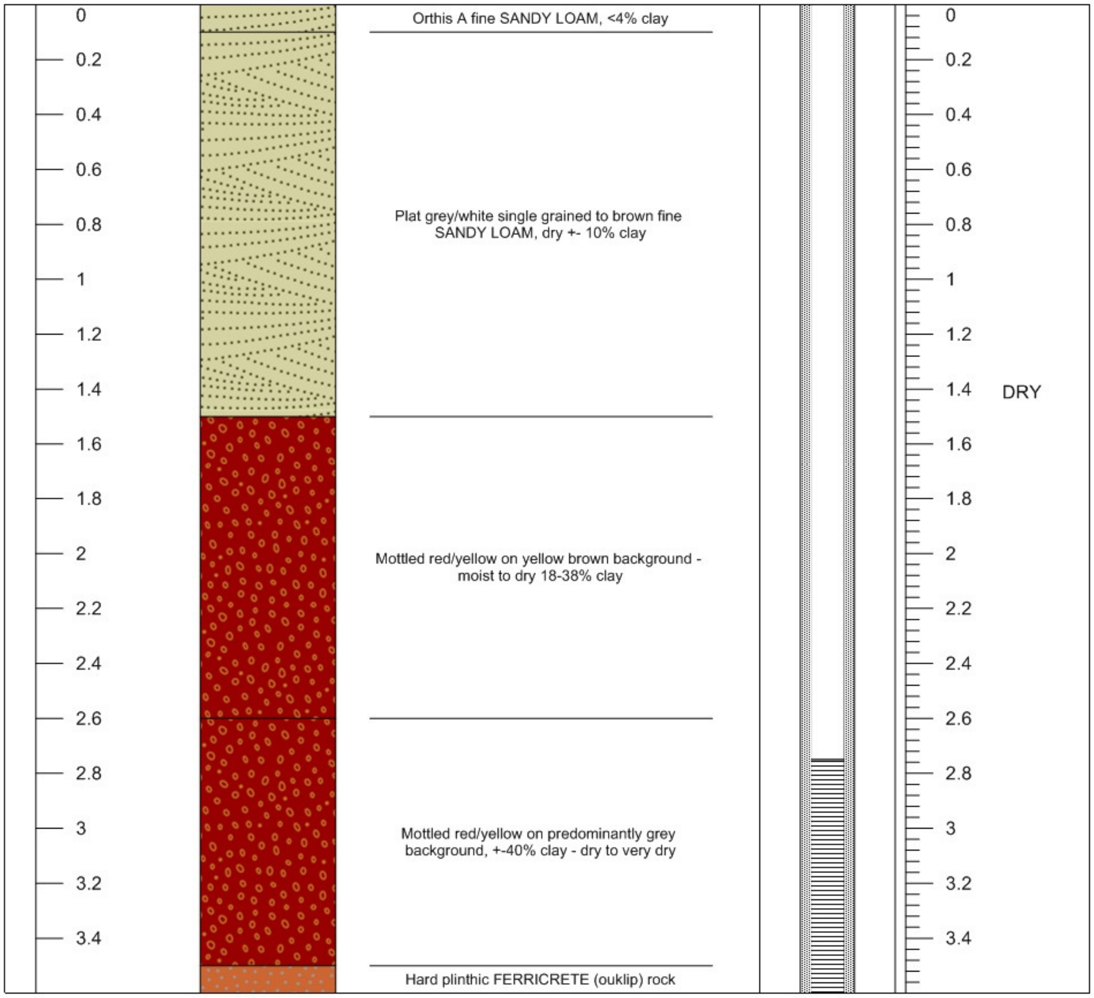
NOTES: Depth to water level - 6.05 metres below ground level

Well Construction Legend

- ■ Steel
- ▩ Collapsed
- ▥ Fill

PROJECT: Nyalazi	BOREHOLE ID: NU3a
LOCATION: St. Lucia	LATITUDE: -28.0619171497
DRILLING CONTRACTOR: GCS	LONGITUDE: 32.4033327134
DRILLING METHOD: Hand Auger	ELEVATION: 35.67756653
DATE COMPLETED: 13/08/95	DEPTH: 3.6

Depth (m)	Graphic log	Description	Well Construction



Orthis A fine SANDY LOAM, <4% clay

Plat grey/white single grained to brown fine SANDY LOAM, dry +- 10% clay

Mottled red/yellow on yellow brown background - moist to dry 18-38% clay

Mottled red/yellow on predominantly grey background, +-40% clay - dry to very dry

Hard plinthic FERRICRETE (ouklip) rock

NOTES: Auger hole dry

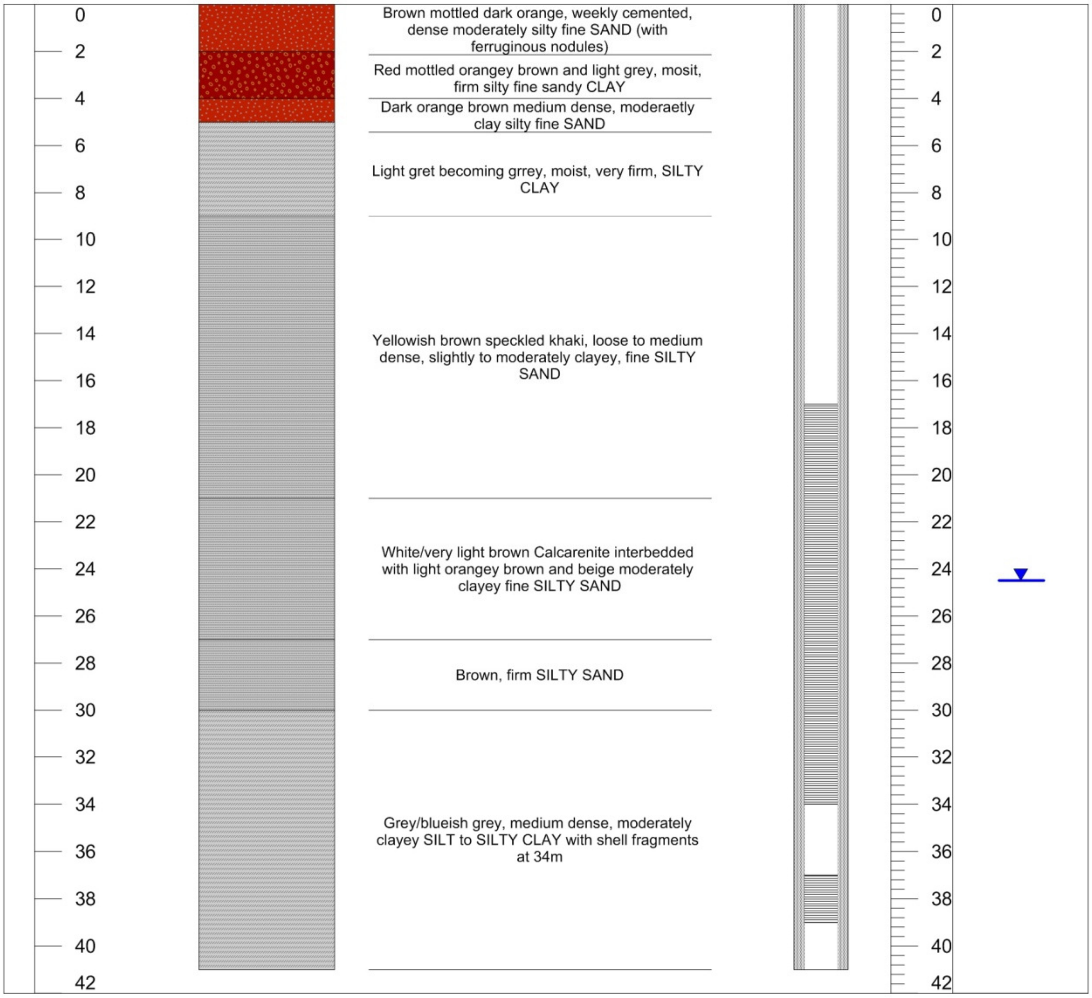
Well Construction Legend

☐ Casing
▤ Screen
▨ Fill

PROJECT: Nyalazi
LOCATION: St. Lucia
DRILLING CONTRACTOR: Kwa_Natal Drilling
DRILLING METHOD: Mud Rotary
DATE COMPLETED: 12/30/2011

BOREHOLE ID: WES01
LATITUDE: -28.16744
LONGITUDE: 32.36908
ELEVATION: 52
DEPTH: 41

Depth (m)	Graphic log	Description	Well Construction



Brown mottled dark orange, weekly cemented, dense moderately silty fine SAND (with ferruginous nodules)

Red mottled orangey brown and light grey, mosit, firm silty fine sandy CLAY

Dark orange brown medium dense, moderaetly clay silty fine SAND

Light gret becoming grrey, moist, very firm, SILTY CLAY

Yellowish brown speckled khaki, loose to medium dense, slightly to moderately clayey, fine SILTY SAND

White/very light brown Calcarenite interbedded with light orangey brown and beige moderately clayey fine SILTY SAND

Brown, firm SILTY SAND

Grey/blueish grey, medium dense, moderately clayey SILT to SILTY CLAY with shell fragments at 34m

NOTES: Depth to water level - 24.25 metres below ground level

Well Construction Legend
- ☐ Casing
- ▤ Screen
- ▨ Fill