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A Framework for Subsidence Practitioners to Optimise the Benefits and Practical Use of Root Barriers to Resolve Clay Shrinkage Subsidence and Prevent the Unnecessary Loss of Valuable Trees

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ABSTRACT

Context-Tree-related subsidence is a concern in Britain on cohesive clay soils, with significant costs incurred by insurers every year to rectify the resulting property damage. Tree removal is the preferred solution as it is relatively inexpensive, eliminates the cause, and prevents re-occurrence. However, there is increasing evidence highlighting the importance and value of trees, especially within urban environments such as reducing the effects of climate change, improving health and wellbeing, enhancing wildlife and crime reduction for example.

Aims-This thesis investigates the root barrier solution as an alternative to tree removal. Root barriers comprise a physical barrier installed, up to 5m deep, between the tree and the building thus preventing tree roots from reaching the foundations thus resolving clay shrinkage subsidence without removing the tree .

Regarding the root barrier solution, the literature review identified very little published information on deeply embedded root barriers to resolve tree-related subsidence and no published guidance for practitioners. The research fills the gap and aims to promote root barriers by considering costs, value for money, practical and knowledge concerns culminating in a design protocol for practitioner use.

Method Qualitative and quantitative data was used to research the practical use of root barriers alongside surveys within a post-positivist theoretical perspective. The mixed-method approach collected data from over 30 case studies combined with responses from informed practitioners using structured questionnaires.

Findings-Based on the analysis, root barriers are shown to be a viable and cost effective solution to tree-related subsidence. The research found that root barriers are cost-effective where multiple or large trees (over 500mm diameter) are involved in subsidence claims. The new design protocol produced from this study provides guidance for practitioners to design root barriers.

Further research in construction techniques and materials would be beneficial to overcome practical difficulties. Ultimately, because of this research, deciding whether to use root barriers will be more informed, preventing the unnecessary loss of valuable trees.

Keywords root barrier, subsidence, trees, building damage, clay shrinkage, design.

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ii Declaration

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Notation

d (b)	distance between building and root barrier
d (t)	distance between the tree and root barrier
D	overall distance between tree and building
h	depth of root barrier at the desired location
h (t)	depth of root barrier at a point closest to tree
h (b)	depth of root barrier at point closest to building
l	length of root barrier
h (f)	existing foundation depth

Notes

(min)	following a dimension refers to minimum distance e.g.
d (t min)	refers to the minimum distance between tree and barrier
(des)	following a measurement refers to design value, i.e. with any relevant factors of safety applied e.g.
h (des)	depth of root barrier with the factor of safety (FoS) applied

PART A

INTRODUCTION AND LITERATURE REVIEW

PART A-Introduction and Literature Review

1 Introduction

1.1 Professional Background

I am a Chartered Civil Engineer (CEng) and Member of the Institution of Civil Engineers (MICE), with over 30 years of experience in construction, engineering, design, and project management. I have worked for various contractors, loss adjusters, insurance companies, and consulting engineers during this period. For the past 12 years, I have been a director of Graeme Allen Consultancy Limited, a structural design practice located in North London. In this role, I design the structural elements for new builds, extensions, alterations, and foundations for domestic and commercial projects and prepare reports on subsidence damaged houses, acting as an expert witness.

In 2011, I embarked upon a master's at Anglia Ruskin University in Civil Engineering, gaining an MEng qualification in 2014. My research dissertation at the time was based upon my professional experience and entitled: -

“Root Barriers to Resolve Clay Shrinkage Subsidence Claims”.

In 2014 I decided to pursue the professional doctorate at Anglia Ruskin University, building upon the master’s dissertation with my continued involvement in clay shrinkage cases aligning with my professional practice. Also, I have a passion for the environment and how we can maintain, protect, and enhance future generations. The root barrier solution advances a rarely used but innovative method to resolve a practical problem whilst protecting and improving the urban environment.

1.2 General Introduction

This first chapter provides general background to clay shrinkage subsidence and explains how four concepts combine, causing damage to a building’s foundation. The standard solutions to the problem are identified, followed by concerns. Research aims and objectives presented towards the end of Chapter 1 provide the framework and justification for researching the root barrier solution.

It is appreciated that the explanation of the standard solutions, the value of trees, and the subsequent justification of the root barrier solution are detailed, but this forms an essential part of the process. The greater the value of a tree unnecessarily removed due to clay shrinkage subsidence, the greater the justification for alternative methods that retain the tree, such as a root barrier.

The defined aims and objectives derived at the end of this Chapter provide the main focus for the remainder of the thesis, acting as the underlying thread that binds the whole research process together.

1.3 Subsidence Defined

The term subsidence can have various meanings depending on the context. As subsidence damage to a building is usually resolved by insurance companies as part of an insurance claim, this thesis adopts the definition contained within most UK insurance policies. Subsidence covers damage to a building caused by: -

> *"the downward movement of the ground beneath the buildings that is not the result of settlement".* (Legal and General, 2020, p. 8)

Subsidence is not the same in insurance terms as settlement, which is usually defined as damage caused to a building by: -

> *"the downward movement of the land beneath the buildings as a result of compaction due to the weight of the buildings".* (Aviva Insurance, 2013, p.5)

Building subsidence due to clay shrinkage is not a new phenomenon. As early as the 1800s, architects were aware of the basics of the problem: "*but in open country situations, strong clay is apt to split and cause fracture to buildings unless the foundations be laid below the range of fissures which occur in it*". (Rogers, 1872)

The problem of subsidence damage to buildings became more prominent just after the Second World War when during a period of low rainfall cracks attributed to bomb damage were found to be caused by clay shrinkage. An article entitled 'The effects of fast-growing trees and shrubs on shallow foundations', written by W. H. Ward and published in 1947, warned of shallow foundations near trees. (Ward, 1947)

Household insurance policies included subsidence for the first time in 1972. However, it was not until the drought period of 1975/6, which prompted many claims that engineers, loss adjusters, arboriculturists, and insurers all became acutely aware of the problem's significance. Greater efforts were forthcoming to advise tree owners, tree managers, engineers, and the building industry generally on risks associated with shrinkable clays from nearby trees.

The typical household buildings insurance policy covers subsidence, heave or landslip whilst defining what is not covered, such as damage caused by settlement, or by shrinkage or expansion of parts of the buildings, as in the Aviva (Aviva Insurance, p. 12) policy wording contained in Table 1.1.

Table 1.1 Extract from policy (general exclusions) (Aviva Insurance, p. 12)

Main Exclusion Clause	Sub-Clause (if applicable)
Anything shown in the General Exclusions.	
The relevant excess shown on your schedule (unless we tell you in any part that an excess doesn't apply).	
If your buildings suffer subsidence, heave or landslip damage, regardless of the underlying cause of the damage, the subsidence, heave and landslip excess shown on your schedule will apply to your claim.	
Damage to fences gates and hedges caused by storm, or by falling trees and branches.	
Loss or damage caused by any of the following when your home has been left unoccupied for more than the period shown on your schedule	• malicious people or vandals • water escaping from or freezing in water tanks pipes plumbed in home appliances fixed equipment or fixed heating systems • theft or attempted theft
Theft, attempted theft malicious damage or vandalism by you paying guests or tenants	
Subsidence heave or landslip	• damage to any part buildings (e.g., a boundary wall or patio) unless we accept (or have already accepted) a claim for subsequent subsidence heave or landslip damage to the house flat garages or outbuildings. • if you knew when this policy started any part of the buildings had already been damaged by subsidence have a landslip unless you told us about it and we accepted it
Damage caused by settlement or by shrinkage or expansion of parts of the buildings.	
Damage caused by riverbank and coastal erosion.	
Frost damage (though we do cover damage to pipes caused by freezing)	
Wet or dry rot arising from any cause except where the rot was directly caused by	• something which is covered by this policy or • by repairs or preventative work carried out by the tradesperson we arranged to deal with your claim

1.4 Causes of Subsidence

Subsidence damage to a particular building initiates from various causes, such as shrinkage (and swelling) of clay soil, leaking drains, ground softening, frost heave, chemical attack, or mining operations.

The thesis concerns damage caused by shrinkage and swelling of clay soil encompassing most subsidence cases in the UK. (Institution of Structural Engineers, 2000, p. 71) (Freeman, et al., 1994, p. 12). This so-called 'Clay

Shrinkage Subsidence' results from volumetric changes of the clay soil beneath shallow foundations of an existing building initiated by moisture extraction from tree roots.

Figure 1.1 presents the four main components relevant to clay shrinkage subsidence: the weather conditions, the clay soil, the trees and the building. Before progressing to analyze specific interactions between these components, each is considered separately.

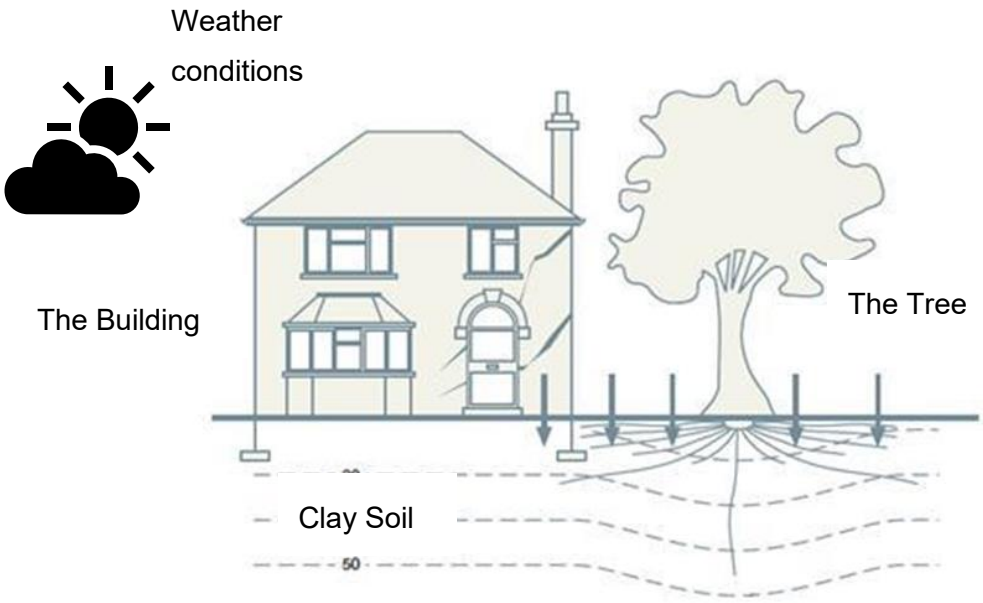


Figure 1.1 Concepts involved in clay shrinkage subsidence (Source Author)

1.4.1 Clay Soil

The term clay describes a soil with complex mineral content and particle size less than 0.002mm (2μm) and not visible to the naked eye. Clay minerals present are specific, naturally occurring chemical compounds predominately silicates. These minerals can be classified based on variations of chemical composition and atomic structure into nine groups: (1) kaolin-serpentine (kaolinite, halloysite, lizardite, chrysotile), (2) pyrophyllite-talc, (3) mica (illite, glauconite, celadonite), (4) vermiculite, (5) smectite (montmorillonite, nontronite, saponite), (6) chlorite (sudoite, clinochlore, chamosite), (7) sepiolite-palygorskite, (8) interstratified clay minerals (e. g., rectorite, corrensite, tosudite), and (9) allophane-imogolite. (Encyclopedia Brittanica, 2014).

The behaviour of clay soils differs from soils with larger particle size, such as sands or gravels, because clays' behaviour is not purely the result of frictional forces but intermolecular forces that depend on the clay mineralogy and the pore water chemistry. (Norbury, 2020, p. 48) Figure 1.2 reproduced from British Standard 1377, illustrates the very small particle size for clays (to the left of the chart) compared with other soils such as sand or gravel (British Standards Institute, 1990). The cohesive characteristics of clay soil is due to the attractive forces generated between the very small particles. (Fookes, et al., 2005)

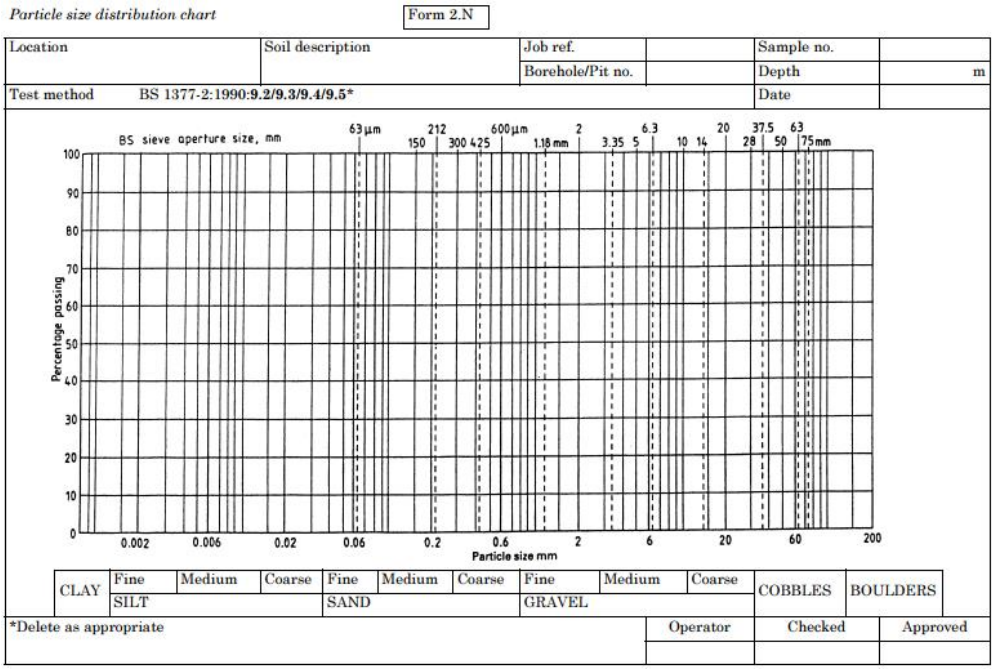


Figure 1.2 Particle size distribution graph, from BS 1377 Part 2 1990

The complex mineralogy and exceedingly small particle size combine to produce the essential characteristic of a clay soil of relevance to the thesis, namely its affinity for water and consequent volume change potential. (Building Research Establishment (BRE), 1996). Some clays swell easily and may double in thickness when wet (U S Geological Society, 2012) and the process by which some clay minerals swell when they take up water is reversible. Montmorillonite is particularly notable because it can store water within the particles between crystal layers and change volume more than other clay minerals. (Fookes, et al., 2005, p. 138)

The basic relationship between the volume of soil and water content for clays is shown in Figure 1.3. (Smith, 1982, p. 6)

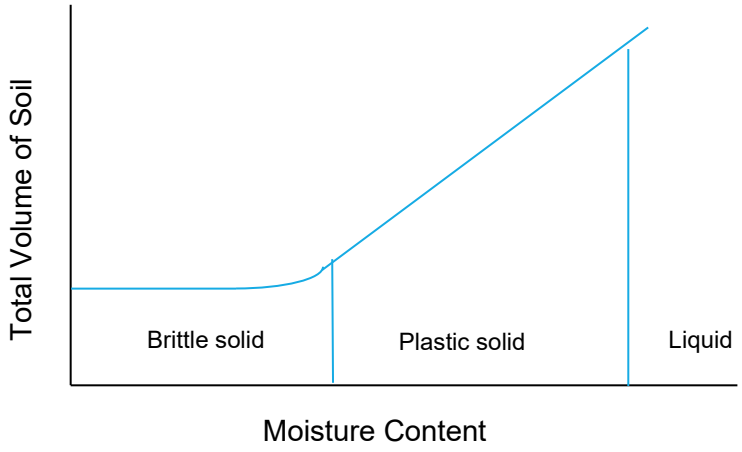


Figure 1.3 Relationship between volume and moisture content clay soil (Smith, 1982)

An idealised clay soil is shown in Figure 1.4. The water molecules (blue) are held between the clay mineral layers (brown) by complex intermolecular forces. It can be seen that with reducing water content, the mineral layers compact (due to intermolecular forces present) resulting in reduction in volume. (Fookes, et al., 2005 , p. 319). The process is reversible.

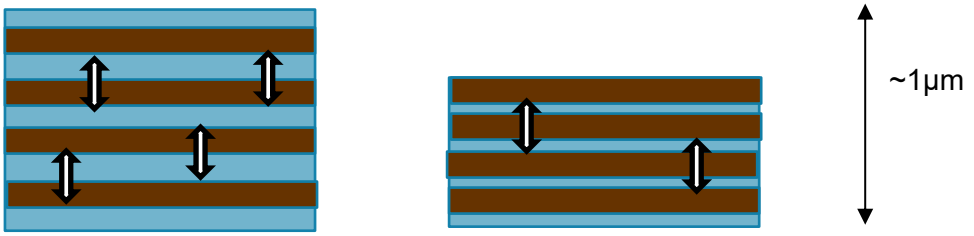


Figure 1.4 Idealised clay soil behaviour with change in moisture content

In contrast, as sands/gravels comprise of discrete particles, the voids may be filled with water or air. Figure 1.5 shows an idealised sand with voids filled with water (left) and air (right). Note that the soil volume remains constant despite changes in water content. (Smith, 1982, p. 12)

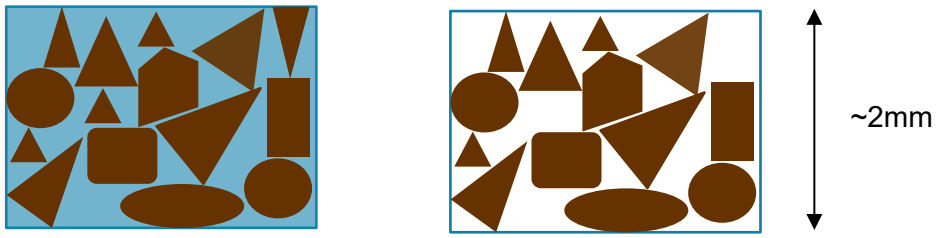


Figure 1.5 Idealised granular soil behaviour with changing moisture. Voids filled with water (left) and air (right) (Source Author)

Note also in Figure 1.4 and Figure 1.5 that the relative scales differ significantly. While the figures simplify the soil types' processes, they illustrate the general principles by which clay soil reacts to changing moisture content.

1.4.1.1 Investigations and Testing

The site investigations, designed to establish the clay soil properties during a case of clay shrinkage subsidence, will vary from case to case but usually involve trial pits excavated adjacent to the foundations and boreholes drilled within the trial pit to depths of up to 5m. Samples of the soil are taken from the boreholes and tested in the laboratory to identify specific properties of relevance to clay shrinkage.

Clay soils are generally classified for comparative purposes in BS 5930 Code of Practice for site investigation. (British Standards Institute, 1999)

1.4.1.2 Atterberg Limits

The Atterberg Limits determine the volume change potential of clays. The plastic limit (PL) and the liquid limit (LL) are determined based upon prescribed tests in BS 1377 (British Standards Institute, 1990). The tests determine the range in which clay soils remain plastic, i.e., not too dry to fall apart (PL) and not too wet to become fluid (LL). The plasticity index (PI) is calculated as LL-PL and quantifies the range of moisture content over which these changes occur. The greater the PI, the greater the volume change potential.

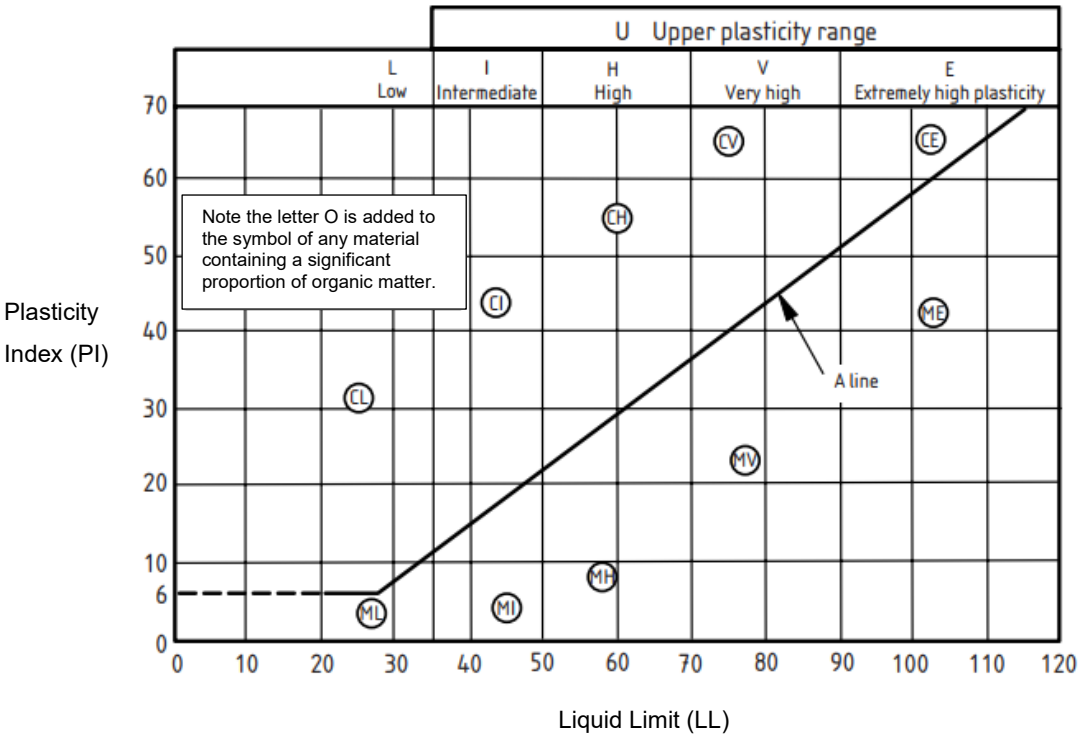


Figure 1.6 Plasticity chart for the classification of soils passing 425µm sieve (British Standards Institute, 1999)

Figure 1.6 indicates how clay soil is classified based upon the Plasticity Index (PI) and Liquid Limit (LL). (British Standards Institute, 1999) The A-line represents the distinction between clays (above the A-line) and silts (below). Typically, Oxford clays have a plasticity index (PI) of around 44% and London clays between 46 to 63%, corresponding to a high (CV) to very high (CH) volume change potential (Building Research Establishment, 1995)

1.4.1.3 Analysis of desiccation based upon test results

Clay soils are tested to determine the extent to which they have dried in relation to "normal" conditions. This so-called desiccation or drying of the soil forms an essential part of laboratory testing. The assessment of desiccation in clay soils from testing is covered in a BRE Digest (Building Research Establishment (BRE), 1996) and summarized under the following headings.

Soil moisture content. The moisture content can be a useful method of assessing the soil's desiccated condition at varying depths. Practitioners should exercise caution when interpreting soil moisture content results due to the inherent variability of soil moisture. The results should be used alongside other tests to make a more informed decision on whether the soil is desiccated.

The Driscoll Method has traditionally been used to estimate whether the soil is desiccated. Moisture content less than 0.5xLL indicates the onset of desiccation and significant desiccation when the moisture content is less than 0.4xLL.

Soil Suction Tests (Crilly & Chandler, 1993) Essentially, the test assesses the potential pressure gradient within a soil sample; the more negative the soil water potential, the more likely the soil is desiccated. This test is useful in an appropriate soil sample and should only be used in soil designated a heavily consolidated clay.

1.4.2 Weather Conditions

In the UK, clay shrinkage is a seasonal phenomenon. During the summer and into the autumn period, when weather conditions are drier, trees extract moisture from the clay soil, causing it to reduce in volume (shrink). In the wetter, winter months, trees are more or less dormant, and the soil moisture content increases, causing the clay to increase in volume (swell). (Driscoll & Skinner, 2007, p. 32).

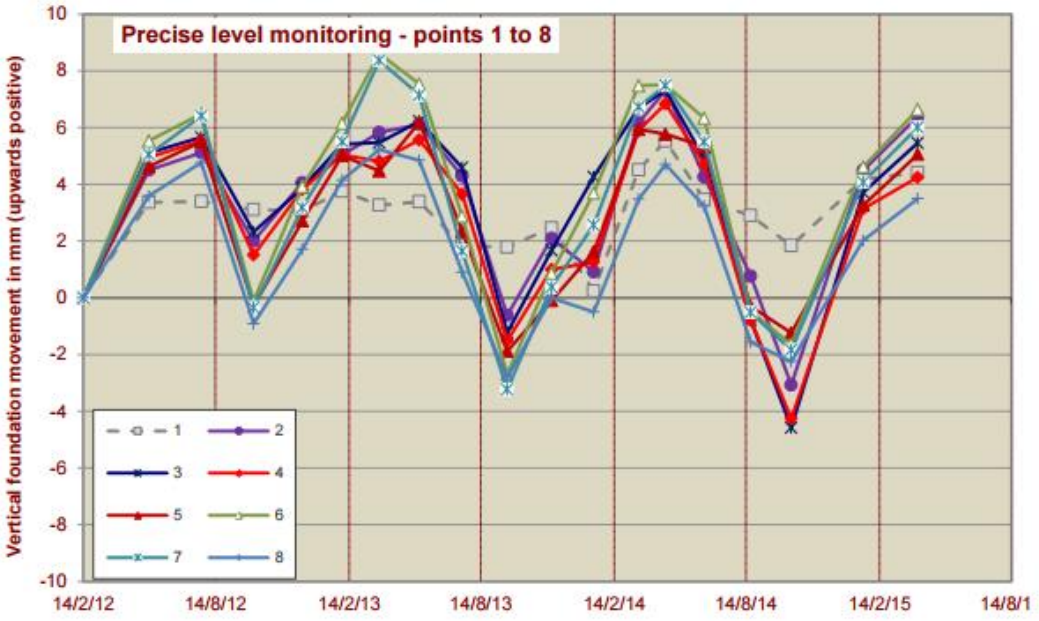


Figure 1.7 Level monitoring results showing actual foundation movement over time. (Source Author)

Figure 1.7 illustrates the direct effect on a building foundation of seasonal moisture content changes in clay soils with trees nearby. The graph shows the relative foundation movement at eight positions marked by a projecting screw fixed to the brickwork below the damp proof course. In this case, readings were taken between 14th February 2012 and 14th August 2015. Note typical clay shrinkage subsidence seasonal movement downwards in the summer and upwards in the autumn/winter period. The maximum movement was recorded at position 7, in the order of 12mm, closest to the tree. Position 1 shows the least foundation movement, further from the tree, with a maximum change in the order of 5mm.

Weather conditions are not predictable apart from the likely increase in wetter winters and drier summers that would exacerbate subsidence occurrences.

However, apart from highlighting the possible increase in subsidence due to certain weather conditions, the weather is not a variable that requires specific consideration through this research.

1.4.3 The Building (damage)

Subsidence type cracking has the following characteristics: -

- diagonal in direction
- wider at one end than the other
- start at and are widest at the free edge (such as an opening)

- tend to travel around openings
- they occur on both wall faces, e.g., internally and externally at the same location
- cracks are generally greater than 5mm wide. However, smaller cracks may be of concern, especially if they are likely to increase in size
- extend to ground level, usually through the damp proof course (DPC)
- will indicate a pattern consistent with downwards movement of one part of a building relative to another

It is common practice to categorize the damage's structural significance by the classification given in BRE Digest 251 shown in Table 1.2 produced by the Building Research Establishment.

Table 1.2 Extract from BRE Digest 251 crack widths (Building Research Establishment, 1995)

Category	Description	Size of crack
Category 0	Negligible	<0.1 mm
Category 1	Very Slight	0.1 - 2mm
Category 2	Slight	>2 but < 5mm
Category 3	Moderate	>5 but < 15mm
Category 4	Severe	>15 but < 25mm
Category 5	Very Severe	>25mm

Apart from the cracks' size, other important considerations are whether the damage is likely to increase, location, number of cracks and pattern. Furthermore, most buildings can accommodate slight seasonal or relative movement, especially older brick-built buildings with lime mortar. Therefore, it is only during a particularly dry summer or trees nearby that seasonal movement of the type shown in Figure 1.7 will cause cracking because damage results from excessive relative movements between one section of a foundation compared with another. For example, if the whole building moved downwards by, say, 10mm because of subsidence, there would be no damage, in theory. It is the excessive relative movements that cause damage, not necessarily the absolute value of the movement. The magnitude of the relative movement that a building can accommodate without causing cracking will vary depending on complex factors such as its construction and foundation depth.

1.4.4 The Building (foundation depth)

The foundation depth is relevant because research indicates that the effects of normal moisture evaporation (in the absence of trees) is restricted to the upper 0.9m

of clay soil (Institution of Structural Engineers, 2000). However, most UK buildings built before the 1960s have foundations 0.9m deep or less (Driscoll & Crilly, 2000) and are, therefore, susceptible to subsidence when no trees are present. Older buildings are particularly susceptible to this type of damage as their foundations may not meet current standards, such as the National House Building Council (NHBC) guidelines “Building near trees”. (Building Research Establishment (BRE), 1996)

Practitioners were aware of the tree risk as far back as 1972 when the British Standard Code of Practice “Foundations and Substructures for Non-industrial Buildings of not more than Four Storeys” within section 3.4.1, gave the following advice: -

> *'it is necessary to place the foundations at such a depth that volume changes (in clays) are not important or limit the movements by controlling vegetation. Buildings with foundations of not more than 1m deep should be kept at a distance from all trees of at least the mature height of the tree...This rule should also be observed for trees planted after the building is completed'.* (British Standards Institute, 1972)

Buildings constructed since the introduction of modern standards should meet minimum depth requirements and allow for nearby vegetation. Section 2.3 describes the current standards in more detail.

1.4.5 The Tree(s)

Trees are dynamic living organisms composed of roots, a trunk, branches and leaves. Trees operate by making their carbohydrates, fats, and proteins obtaining energy from the sun, and chlorophyll traps the energy to split water molecules into hydrogen and oxygen. The oxygen evaporates, and the hydrogen is combined within the leaf with carbon dioxide gas from the atmosphere, thus creating simple organic acids and proteins. (Tudge, 2005) To function, trees require water, and this water is effectively sucked from the surrounding soil by the fibrous roots. (O'Callaghan & Mercer, 2019)

It is the fundamental requirement of a tree to extract water from clay soil affecting its volume that is of particular interest in the analysis of clay shrinkage subsidence.

1.5 Remedies to Clay Shrinkage Subsidence

To mitigate or reduce the effects or causes of clay shrinkage subsidence, the main solutions, used since the 1960s to the present day, have been as follows: -

- 1960s underpinning common whereby soil moisture content changes did not influence deeper foundations

- 1980s tree pruning reduced moisture uptake of the implicated trees
- 2000s tree removal eliminated moisture extraction by implicated trees

The thesis considers the remedies, advantages and disadvantages in the following sections, before introducing the option of a root barrier.

1.5.1 Underpinning Solution

Underpinning increases foundation depth to a suitable level. Freeman outlines the various types of underpinning available and their advantages and disadvantages. (Freeman, et al., 1994) The types include mass concrete underpinning, pier and beam, and more recently mini piling. Mass concrete underpinning is achieved by excavating beneath the existing foundation and casting a new continuous concrete foundation at greater depth. This type of underpinning is carried out in stages so that the property is always supported. Pier and beam underpinning involve constructing isolated pad bases connected by beams that support the existing walls. Piled schemes involve constructing reinforced piles and concrete ground beams or concrete raft slabs to support the building.

Partial underpinning can be sufficient, although according to Lawson (Lawson, 2004, p. 102), some engineers and local authority building control officers have suggested that partial underpinning of a property may provide an uneven or unbalanced foundation. They argue that there may be a possibility that some differential settlement might occur in the future between the untreated and treated areas and cause damage. Lawson (Lawson, 2004) argues that there is nothing unsound with the principle of partial underpinning of a building provided that significant future settlement of untreated parts of the structure will not occur, or if some settlement is predicted, the damage will be slight, insignificant or controlled.

In the 1970s claims were generally handled by an engineer acting independently for the policyholder with a loss adjuster acting for the insurance company. Engineers, who may have been concerned by possible claims against them for repeat damage, would have, at that time, been more inclined to recommend underpinning as a longer-term solution. Consequently, underpinning was quite common in the 1970s and 1980s, until insurers became aware of increased claim costs. In the late 1980s and early 1990s, Insurers were keen to develop alternatives to expensive underpinning to reduce claim costs. (Lawson, 2004)

In the 1990s, the advent of the project managed subsidence claim was born. This arrangement saw the loss adjusters employing engineers to deal with both the engineering and loss adjusting elements of a claim. I worked for a well-known large loss adjuster at the time. I can confirm a closer collaboration with insurers so that

insurers were more likely to take on the increased risk of other solutions, such as tree management, instead of more expensive underpinning.

At present, the underpinning solution is usually only adopted for situations where the damage is very severe or where tree works may not be effective. In recent years, working as an independent consultant, I have noted a shift towards piling instead of traditional underpinning as a means of underpinning. This is partly due to health and safety concerns of deep traditional hand-dug underpinning. While fully stabilising the property's subsiding section, piling has the main drawback of leaving non-underpinned areas even more vulnerable to future movement. This increased vulnerability arises from the fact that piling creates a very rigid foundation. Only slight movement occurring to other parts of the structure may cause cracking to occur. Entire properties may be underpinned using piles, at greater expense, a so-called “piled raft foundation”, which overcomes the disadvantage of differential movement but at a high cost, typically in the region of £200,000 for a 3-bed detached property.

1.5.2 Tree Pruning Solution

In the 1990s, one of the favoured remedies to managing water loss from trees on shrinkable clay soils was pruning, pollarding or heavy crown reduction. An arborist provides specialist advice for tree works. (Institution of Structural Engineers, 2000, p. 78)

P.G Biddle, states (Biddle, 1992) within his Arboricultural Advisory Information advice note 108/92 that “If the movements are entirely seasonal, it may be possible to reduce the amplitude of this movement to an acceptable level by pruning the tree so as to remove leaf area … greatest benefits will be achieved if the building is near the outer limits of influence, pruning a large tree which is only a few metres from the building will probably have little benefit if there is a significant persistent deficit, pruning alone will not be effective”.

A planned pruning approach is suggested by LTOA (London Tree Officers Association , 2007) but this approach can lead to a reduction in visual and environmental value.

Pollarding, a more severe form of pruning, involves the removal of branches close to the trunk. The remedy of pollarding has resulted in some cases to a loss of amenity in urban areas. Figure 1.9 and Figure 1.10 illustrate the loss of amenity value when undertaking tree works, pollarding in this case.

Figure 1.8 Street scene before routine pollarding in London (Source Author)

Figure 1.9 Street tree after pollarding (Source Author)

Figure 1.10 Very severe pruning of a street tree (Source Author)

Figure 1.10 illustrates particularly how extreme pollarding can reduce a tree to no more than a stump. The report (London Tree Officers Association , 2007) agrees that cyclical pruning may lead to complaints about the level of work and increase demand on existing budgets. This option also highlights the need for a detailed survey (and re- survey) and a long-term resource commitment.

Some authors, however, state that minor pruning has been shown to have little overall effect on the water uptake of trees. (Lawson, 2004). Lawson says: -

> *"Pruning is unlikely to impact tree water loss in any linear way. Rather the tree's response to tissue loss will be dynamic and currently inherently unpredictable".*

and

> *"This contention is now supported by work developed by the Building Research Establishment and by the technical review set out in Chapter 2".*

Pruning should be accompanied by regular maintenance otherwise the moisture uptake of the tree is likely to increase over time. (Driscoll & Skinner, 2007, p. 45)

The Institution of Structural Engineers (ISE) (Institution of Structural Engineers, 2000, p. 78) suggest considering the following where tree pruning is envisaged: -

- amount of pruning to be carefully considered to prevent movement whilst avoiding excessive work to the tree
- repeated treatment (every 3 or 4 years) will be necessary
- tree amenity value to be maintained

Further advice on pruning is provided within the Royal Institute of Chartered Surveyors (RICS) draft online guidance notes. (RICS, 2013)

More recent research confirms the limitations of pruning to manage trees' water demand (O'Callaghan & Mercer, 2019). The authors cite research which in summary confirms; -

- crown reduction reduced soil drying in the year of pruning, but effects were small and did not extend into the following season
- crown thinning did not reduce soil drying for practical soil moisture conservation severe crown reduction of 70-90% volume would need to be applied
- reduction of up to 50% of the crown volume is not always effective in decreasing soil drying

The results of the HortLink project quoted by O'Callaghan and Mercer confirm that pruning trees to control water use is not an effective or reliable method of alleviating the risk of subsidence. This is because the extent of reduction required to be effective would be contrary to BS3998 (British Standards Institute, 2010), regularly repeated, and cyclical reductions could harm the tree's vitality and health.

Beneficial research has been undertaken to consider the effects of two contrasting canopy manipulations on London plane trees. (Hipps, et al., 2014). The research compared two canopy manipulations (thinning and pruning) to unpruned controls, determining the extent to which different pruning regimes reduce tree water use and soil drying. At the time of publication, it was stated to be the first time direct comparison between pruning regimes had been evaluated experimentally. Over four years, soil drying was measured using neutron probes (similar to Biddles method). The results indicate that a radical reduction of more than 85% of leaf area would be required to reduce tree water use. Canopy reduced trees showed rapid shoot regrowth and canopy leaf area recovery (CLA) within three years after treatment. A key observation was that leaf size and leaf area density (LAD) differences do not necessarily translate into differences in likely tree water use. Overall, large reductions in tree water use were short-lived, and frequent re-applications of canopy treatments are required to maximise soil moisture conservation.

To resolve clay shrinkage claims, as formerly mentioned, the larger reductions in water use are necessary. Regarding extensive tree works, as can be seen from Figure 1.9 and Figure 1.10, the author agrees severe pollarding can have a detrimental effect on the street scene and tree amenity. When trees are reduced to

no more than “an ugly stick” as in Figure 1.10, their benefits are reduced significantly.

To conclude, pruning may have a place in the strategies to resolve clay shrinkage subsidence; however, it has drawbacks, requires repeat visits, may damage the tree and is not always successful.

1.5.3 Tree Removal Solution

Due to concerns regarding the high cost of underpinning and disbenefits of pruning, tree removal has become one of the most popular solutions to clay shrinkage subsidence. The costs are low with tree removal, although the initial cost to remove the tree is higher than pruning, there is no need for repeated visits. Tree removal is virtually guaranteed as it eliminates the source of the problem (the tree).

According to Lawson, “there can be no doubt that removal of vegetation effectively stops the loss of water from clay and allows the soils to restore the equilibrium of moisture content”. (Lawson, 2004)

Driscoll and Skinner state: -

> *“removing the tree altogether will have the greatest and most immediate effect on the levels of desiccation in the soil.…If removal is feasible and all parties agree, the only risk is that of long-term heave”.* (Driscoll & Skinner, 2007, p. 44)

Not all agencies agree and suggest caution. The Institute of Structural Engineers (ISE) mention tree removal to be “the last resort solution”, (Institution of Structural Engineers, 2000, p. 78). The Royal Institute of Chartered Surveyors (RICS) suggest tree removal for medium damage claims. (RICS, 2013)

Driscol and Skinner mention that the damaging effect of heave should be considered if trees are being removed. Heave occurs when clay soil rehydrates following tree removal after many years of desiccation significantly increasing the clay soil's volume over and above the more recent subsidence. Heave is usually of concern where the tree is much older than the property, established by reference to the type of tree, distance to the building and desiccation from soil investigation results.

1.5.4 Remedies Section Summary

Table 1.3 summarises the advantages and disadvantages of the various solutions to clay shrinkage subsidence.

Table 1.3 Advantages and disadvantages of various solutions

Solution	Advantages	Disadvantages
Underpinning	Reliable solution	High cost Concerns over partial schemes Health and safety when deeper than 3m
Tree management	Low cost	Unreliable Can be unsightly
Tree removal	Low cost Reliable	Possible heave Loss of valuable trees

Tree removal is currently the preferred solution to clay shrinkage subsidence, and the author can confirm its popularity from experience.

The following section critically considers tree removal by exploring the implications regarding sustainability and the infrastructure's (the tree) value.

1.6 Concerns Regarding Tree Removal

Section 1.6 discusses tree removal issues, such as the potential scale of the problem, the number of urban trees, climate change predictions, and trees' known benefits.

1.6.1 Co-Incidence of Urban Areas and Clay Soils

There are potentially a large number of trees at risk from removal from clay shrinkage subsidence as urban areas coincide with large areas of clay soil, illustrated in Figure 1.11.

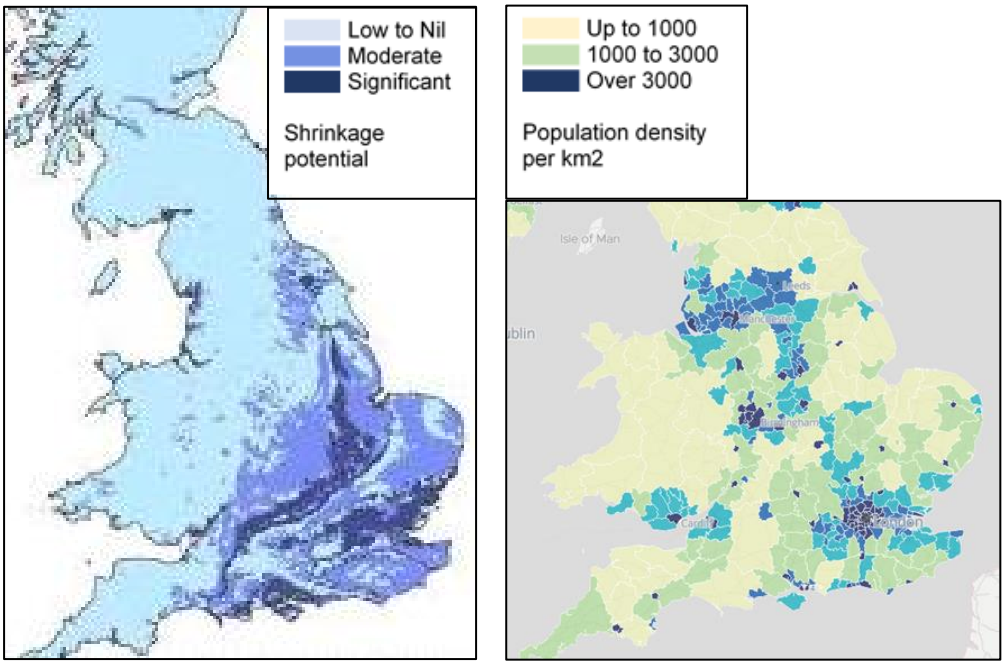


Figure 1.11 Clay soils in the UK (Society, 2019) and population density (Statistics, 2011)

The geological map to the left of Figure 1.11 from BGS (British Geological Society) shows the general areas of shrinkable clay soil in the UK. The map on the right

shows the population density. Note how the built-up areas of the South East coincide with clay subsoils.

Lawson estimates that around 60% of the nation's housing stock is built on subsidence prone clay soil. (*Mike Crilly, Geotechnical Officer, Building Research Establishment (BRE) - Personal Communication*) (Lawson, 2004) Lawson (Lawson, 2004) also states that approximately 20% of the nation's trees are street trees. Driscoll also confirms that many properties in UK are founded on shrinkable clay subsoils. (Driscoll & Skinner, 2007) O'Callaghan and Mercer also confirm that much of the South East's housing stock is prone to clay shrinkage differential movement. (O'Callaghan & Mercer, 2019)

Estimates made by O'Callaghan Associates Ltd using data available from various government and non-government agencies (Lawson, 2004) suggest that the number of genuinely urban trees is in the region of 100 million, possibly more.

A recent extensive survey conducted for the government found that 70% of urban trees in England fall within private property. (Britt & Johnston, 2008) Many of these trees that require protection will be close to buildings and risk causing damage.

O'Callaghan and Mercer confirm that Britain has over a billion trees in total and that the 2015 i-Tree survey of London's trees revealed that the capital has almost 8.5 million trees. (O'Callaghan & Mercer, 2019)

The above demonstrates that the co-incidence of clay soils, trees and built-up areas presents significant and ongoing risks concerning property damage from clay shrinkage subsidence.

1.6.2 Event Year Increases

The number of clay shrinkage subsidence claims (and the total cost to resolve) vary from year to year, depending predominantly on weather conditions. When the claims rise above 4x average in a particular year, this is known as "surge" or an " event year". In "Has Your House Got Cracks" (Freeman, et al., 1994) the author noted the rapid increase in claims between 1984 and 1992, providing valuable guidance for homeowners and those investigating claims.

A sevenfold increase in claims occurred during the unusually dry weather of 1989/90, taking the annual spend on subsidence to £550m in 1990 (Driscoll & Skinner, 2007), much of which was spend on underpinning. More recent figures (London Tree Officers Association , 2007) show the dramatic increase nationally in subsidence between 1994 and 2003.

Figures show:-

- 1994-27,660 claims at an overall cost of £125 million
- 1997-53,000 claims at an overall cost of £472 million
- 2003-55,000 claims at an overall cost of £390 million

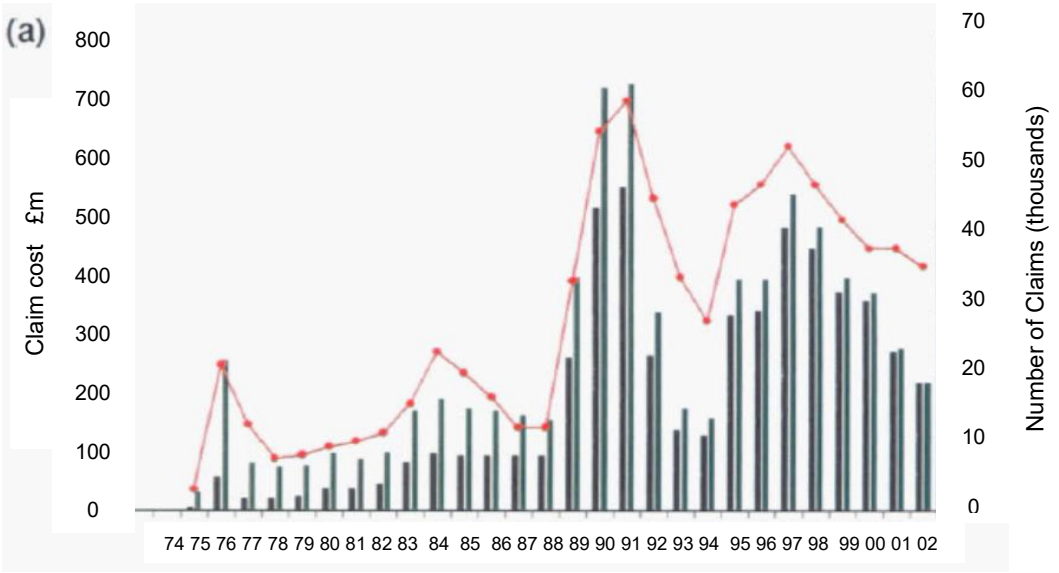


Figure 1.12 Extract from claim cost information 1975 to 2002 (Roberts, et al., 2006)

Figure 1.12 shows the claim cost information from 1975 to 2002. (Roberts, et al., 2006, p. 320) The higher number of claims reported in 1990, 1991 and 1997 is apparent. In a worse case situation, the number of claims during a particularly dry summer can be up to 10x the usual claim numbers in any particular year.

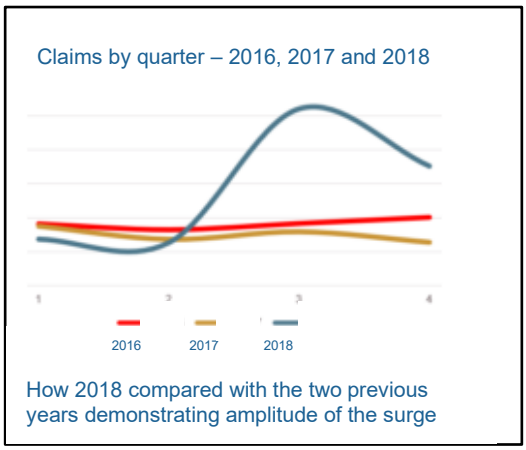
The “surge”, or so-called “event year incidences” are closely monitored by those involved in subsidence, such as Subsidence Management Services (SMS) one of the largest companies dealing with clay shrinkage subsidence. Their technical bulletin (Services, Feb 2019) considered the recent increase in subsidence claim numbers in the summer of 2018 and whether they might match those for 2003, a recognised surge year. 2003 delivered 55,000 claims. The Association of British Insurers (ABI), quoted by SMS, provided the data confirming 2018 delivered 23, 000 claims. The main surges in the last 15 years were:-

2003 55,000 claims (recognised surge)

2006 48,000

2018 23,000

Although the claim numbers for 2018 represented an increase of nearly 400% compared with the previous year (2017) claim numbers were still less than half of the previous recognised surges of 2003 and 2006.



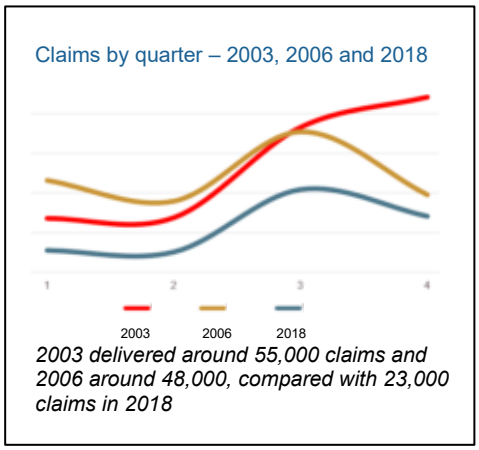


Figure 1.13 Extracts from SMS Technical Bulletin Feb 2019 (Services, Feb 2019)

1.6.3 Climate Change Predictions and its Effect on Subsidence

Predictions of the effects of global warming are for wetter winters and warmer, drier summers. These conditions are ideal for the onset of clay shrinkage subsidence. They would increase the claim numbers as drier summers magnify the damaging effect of seasonal moisture content changes, based upon the assertion that relative movements are more critical than actual values.

Quotations from leading insurers illustrate the evidence for climate change and its impact on subsidence.

> *"Climate change is likely to cause hotter, sunnier weather with more erratic rainfall, resulting in more droughts, which will increase the risk of subsidence. A prolonged heatwave may bake the ground, creating fissures that can tear apart the foundations of houses, bridges and factories.* (Actuaries, The Magazine of the Institute & Faculty of, 2019). *"As our climate continues to change, the risk of property damage from soil subsidence is not only increasing but also spreading to new regions in Europe".* says Matt Weber, head of property and speciality underwriting at Swiss Re.

Also,

> *"Climate change has already led to a dramatic – and often unforeseen – rise in soil subsidence risks in recent years",* says Swiss Re. (Actuaries, The Magazine of the Institute & Faculty of, 2019)

"Its model shows that large parts of the UK, France, Denmark, and northern regions of Germany, Spain and Italy have seen their potential subsidence risk jump by more than 50% compared to the period 1951-1970. Most of these regions have not adapted to the greater risk". Swiss Re notes. (Actuaries, The Magazine of the Institute & Faculty of, 2019)

"Worse is likely to come. Southern areas of England, France, Spain and Italy as well as countries across eastern Europe will see their risk of subsidence-related claims rise by a further 50% between 2021 and 2040 as climate change worsens". Swiss Re says (Lloyds, 2014)

And from the British Geological Society

"Looking to the future, warmer, drier summers and increases in annual temperature and rainfall variability are suggested for the UK. What is considered a heat wave today, is likely to be the norm in the 2050s and cool in the 2080s". (British Geological Society, 2014)

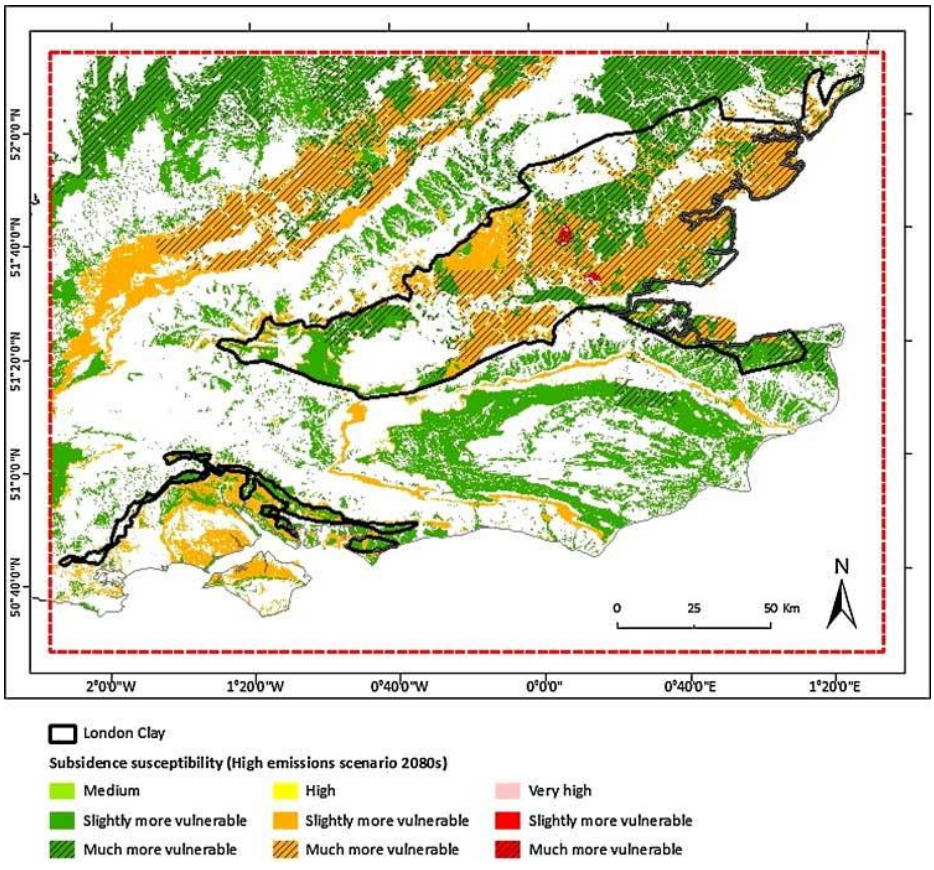


Figure 1.14 Subsidence susceptibility classification for the south-east of England (high emissions scenario 2080's)

Figure 1.14 uses the UKCIP02 scenarios (high emissions 2080s) The reference contains public sector information licensed under the Open Government Licence

v1.0. UKCIP 2011. Coastline courtesy of The Digital Chart of the World (DCW). (British Geological Society, 2014).

In the high emissions scenario, average temperatures are likely to rise by 2º to 4.5ºC. In the low emissions scenario, temperature increases of between 1º and 2.5º are predicted. The temperature changes will have consequential effects on rainfall, increasing in winter but decreasing in summer with summer droughts more frequent. Both scenarios (high and low) indicated in Figure 1.14 and Figure 1.15, respectively, indicate the adverse effects of climate change that are likely to increase subsidence in the coming century.

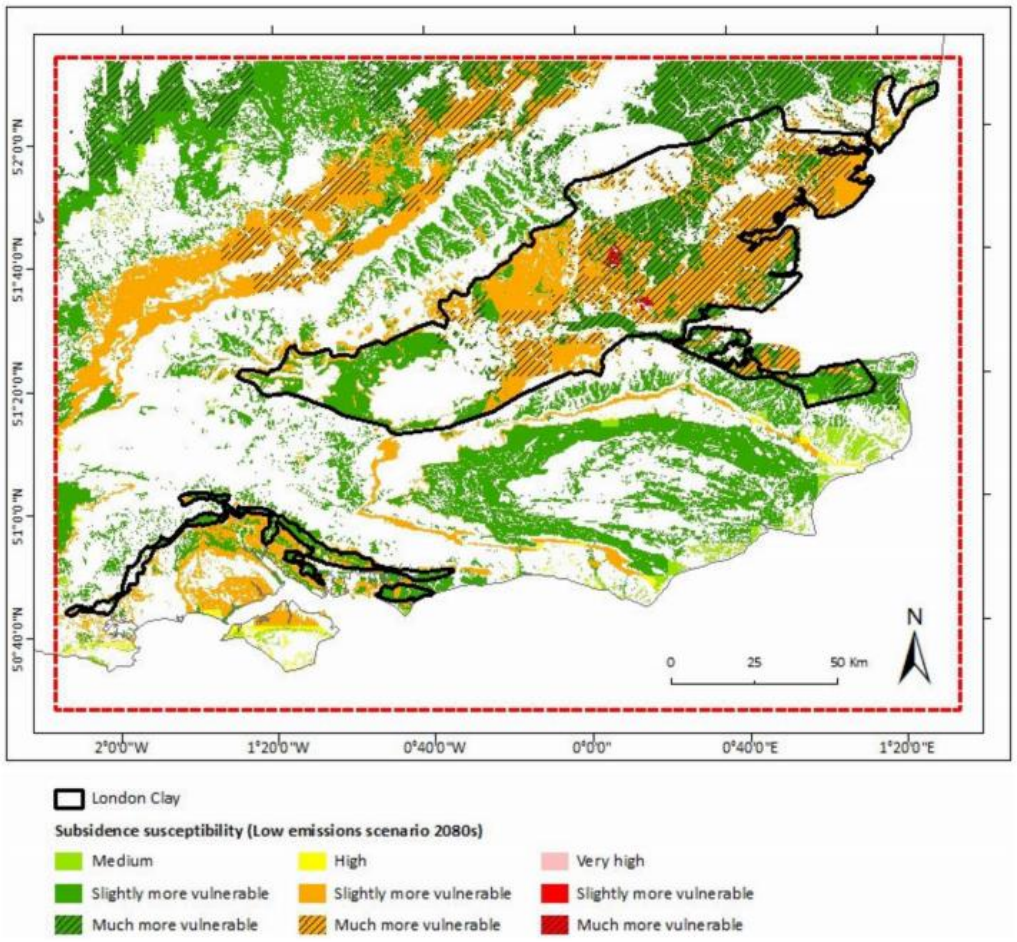


Figure 1.15 Shrink-swell susceptibility (2080s) for low emissions scenario

Further research and modelling of the relationship between climate and shrinkability have been undertaken to increase understanding of the potential consequences of these climatic precipitation and temperature changes on ground movement for clay soils (Harrison, et al., 2012). This particular research referred to past claims data and weather records to develop a modified model for predicting the future effects of climate change in the 2080s for low and high emissions scenarios. The research found that for the 2080s, nearly all of the area indicated in Figure 1.15 will have increased susceptibility to shrink-swell in a low emissions scenario. For the high

emissions scenario, many areas have increased from raised to significantly raised susceptibility. The model outputs confirm that precipitation and temperature work together to influence subsidence claims' number and value. The main geological area showing increased susceptibility is the London Clay formation.

1.6.4 The Value and Benefits of Trees, Especially Urban Trees

It is necessary to explore the value of trees, potentially removed during clay shrinkage claims. If trees do not have any value of significance, then tree removal to resolve a clay shrinkage problem should not be of significant concern.

The greater the value of a tree in a specific setting or location, the greater the damage its removal will cause. The more valuable trees, especially urban trees, the more critical the research. Similarly, if trees are not valuable, then they do not merit retention.

The physical and biological aspects of trees, how they live and grow, and their complexity, beauty and the resulting benefit to society are not immediately apparent.

The poet William Blake said: -

> *"The tree which moves some to tears of joy is in the eyes of others only a green thing that stands in the way".* (Blake, 1799) *William Blake*

Tudge has written extensively on the subject of trees (Tudge, 2005) and according to Tudge, a tree is much more than "*a big plant with a stick up the middle."*

Tudge affirms,

> *"Trees are of course at the heart of things. How could it be otherwise? The human lineage began in trees. We have left our first ancestors far behind but we are creatures of the forest still".* (Tudge, 2005, p. 404)

Various authors have emphasised the importance of studying the life of trees, how they live and why they matter and see how trees have shaped history.

It is estimated that trees have existed for approximately 350 million years. The Greek philosophers proposed all material things were made of four elements earth, air, fire and water. When it comes to trees, Tudge (2005, p. 254) affirms this is not far from the truth.

According to Tom Petherick in his introduction to his excellent book "How Trees Shape the World", (Petherick, 2006, p. 8)

> *"Trees are our link between the earth and the sky; symbolising strength, protection and longevity……their presence as natural and re-assuring as the*

land, the sea and the sky…..Our whole world is shaped by trees……..We feel grateful for their shade, their calming presence their inspiration and their companionship…….they are completely indispensable to the communities they serve".

"For our future we must look to trees". (Petherick, 2006, p. 9)

To understand trees, it is, in my view, essential to also consider the standard classification system, types, orders, species and to explore those species commonly encountered when dealing with subsidence claims in the UK.

1.6.4.1 Physiology and Classification

Tudge is careful to properly categorise trees by their proper Latin and Greek names as Tudge confirms this categorisation or "taxonomy" is both complicated and difficult. (Tudge, 2005, p. 8) Tudge bases his categorisation on the original system of classifying and naming living organisms, first devised by Carolus Linnaeus, the so-called father of taxonomy.

The inclusion of trees' taxonomy highlights that they are living organisms, part of the family of life on earth and have intrinsic value that we cannot disregard without thought or consideration. Tree classification begins with class, then order, followed by family, genus, and finally species such as: -

Quercus Robur L. (common or English oak). (species)

The L. after the species name refers to Linnaeus, who first made the classification. The various orders that relate to some of the most common trees involved in subsidence are: -

Order-Coniferales means cone-bearing and conifers are amongst the tallest trees in the world. In general, conifers are light lovers, and they proliferate to take advantage of the light. In the timber trade, conifers are lumped together as soft woods, although some soft woods are harder than hardwoods. Most common in subsidence of the eight families is Cupressaceae, e.g., Cypress or family Pinaceae, which includes pines and firs.

Order Malpighiales Willows (and poplars) send out underground stems to form vast clones, liking the edge of rivers helping to dry out wetlands acting like wicks.

Order Fagales (includes oaks, beeches, birches and chestnuts). Among some of the most iconic treasured and ecologically significant temperate broadleaf trees. The oaks (Quercus) are the biggest genus within the Fagales order, with 300 to 600 species in the UK, such as the English or common oak, and the sessile oak is

usually considered a forest tree. (Petherick, 2006). Oaks can have canopies up to 20m high with trunk diameters more than 1m.

Order Myrtales includes the eucalyptus, which is fast-growing and survives where other trees do not. Eucalyptus is not common in the UK, but they do specialise in extracting water from great depths.

Order Sapindales (includes maples and horse chestnuts). The field maple is native to the British Isles.

Order Lamiales The European ash is one of the great trees. Tudge states, “if it weren’t for human beings changing the landscape present-day post Ice age Britain would be covered with ash”. (Tudge, 2005)

Order Proteales (includes planes). The London plane (Platanus x Acerifolia) has the rare ability to shed its bark, and this attribute makes it ideally suited to more polluted urban areas. The tree can grow up to 30m high and, for this reason, can become a problem when near buildings on clay soil.

The information above summarised from two references (Petherick, 2006) *and* (Tudge, 2005)

The various species, genus, family and orders are designated according to their taxonomy. Figure 1.16 represents the class Eudicots showing some of the broad-leafed trees commonly involved in subsidence.

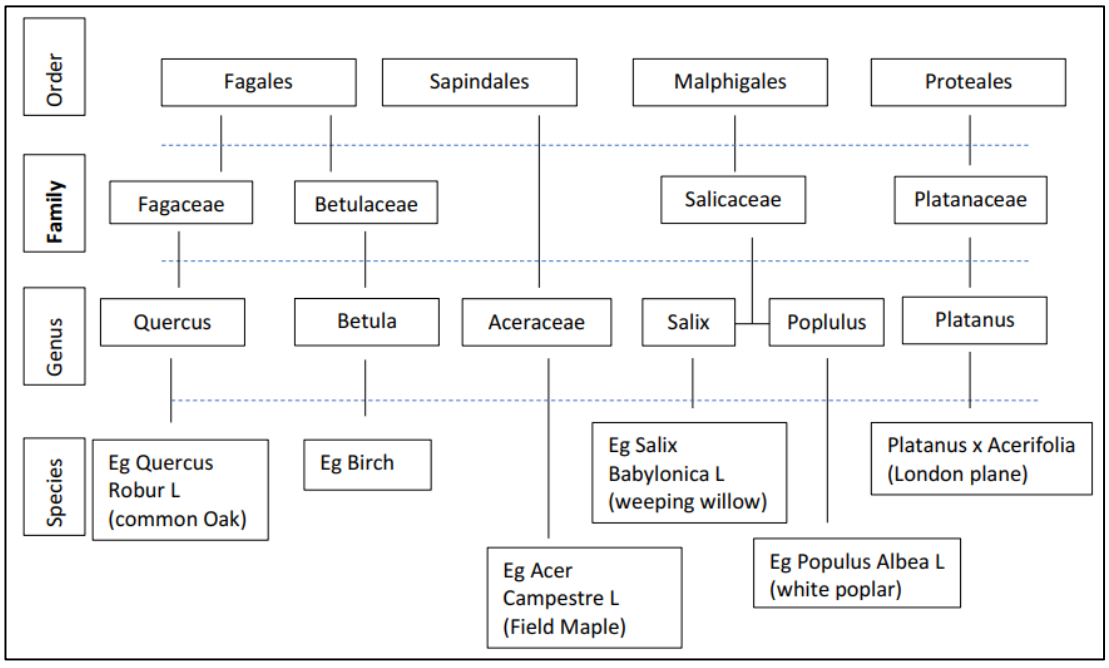


Figure 1.16 Indication of taxonomy for broad-leafed trees (class eudicot)

Tudge roots his book in modern taxonomy as it reflects “an evolution: and evolution reminds us of the glorious past of all living creatures, without it, ... biology makes no sense at all". (Tudge, 2005, p. 59)

This brief background to trees and their categorisation, naming and classification enables one to appreciate trees by understanding their position within the bigger picture of life on Earth. The listing does not explain why some trees root more deeply than others or why some use more water than others. The taxonomy seeks to emphasise that trees are living organisms, and their positive influence should be considered very carefully, not casually or indiscriminately, when making decisions regarding clay shrinkage subsidence.

1.6.4.2 The Benefits of Trees

The many benefits of trees, especially in urban settings, are well documented. The results of the London i-Eco Project extols the importance of London's trees. At the time of its publication in 2015 it was regarded as "the most extensive urban tree survey carried out in the world to date" by Sir Terry Farrell in the foreword. (Rogers, et al., 2015)

A PhD thesis entitled "Trees in Town, Factors affecting the Distribution of Trees in High-Density Residential Areas" (Hall, 2010) researched the distribution of urban trees in Manchester, part of which involved advocating the value and benefit of urban trees. Within the thesis, numerous references were cited worldwide, demonstrating the importance of trees in urban areas. Within the appropriate section of the thesis, 18 different benefits were identified and justified from the literature. These benefits include: absorbing CO_2 (and other gases), dealing with excess water and storm runoff, emitting oxygen, increasing air quality, removing small particles, help form ozone, cooling, health benefits, illness recovery, reduce stress, more relaxed and friendlier, encourage exercise and physical health, improving mental health, increasing house prices, increasing business rates, reducing crime and feeling safe. The main benefits of trees are considered under their respective headings including relevant sources.

Carbon Reduction

By means of background, before the development of coal in the mid-19th century, energy was mainly renewable. In particular, significant changes have occurred in the increased use of fossil fuels in the last 150 years, which are not renewable. Fossil fuels generate large quantities of CO_2, linked with rising temperatures, pollution and climate change. Other related issues include consumption, population growth, food production, natural resources, and industrial production.

As a society, we should accept that individuals cannot ignore the arguments surrounding global warming and environmental damage. We need to reduce the impact of human activity to ensure our continued survival and prosperity.

The Stern Review (Stern, 2006) confirms, “the cost of inaction outweighs the cost of mitigation”.

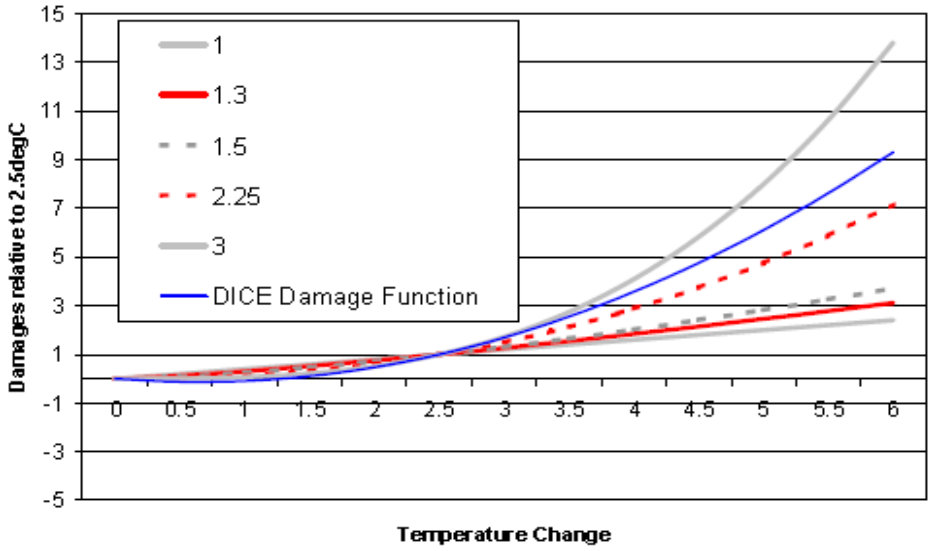


Figure 1.17 Graphical output showing how relative damage occurs with increasing temperature from Stern review (Stern, 2006)

Based upon the available information, Stern concludes “the scientific evidence is now overwhelming; climate change is a serious global threat, and it demands an urgent global response”. (Stern, 2006, p.vi) Trees are incredibly beneficial as they are net absorbers of CO_2 and reduce climate change's damaging effect.

Green Blue Urban state that planting trees remain one of the most effective ways of drawing excess CO_2 from the atmosphere. They affirm trees can absorb up to 48lbs of CO_2 per year, sourced from Department of Horticultural Science, North Carolina State University.

Oxygen Creation

Trees take in CO_2 from the atmosphere and through the process of photosynthesis within the leaves, in the presence of sunlight, produce oxygen which is then released back into the atmosphere. The chemical process is shown in Equation 1-1.

$$6CO_2 + 6H_2O\ (+\ \text{Light}) \rightarrow C_6H_{12}O_6 + 6O_2$$

Carbon Dioxide + Water (+ light) → Glucose + Oxygen

Equation 1-1 The Process of Photosynthesis (O'Callaghan & Mercer, 2019)

The Urban Forestry Network (Network, 2019) calculated that over a 50-year lifespan a forest tree generates almost $32,000 worth of oxygen.

Pollutant removal

Trees can improve air quality by removing and storing a surprising number of harmful pollutants such as: -

- Sulphur Dioxide
- Nitrogen Oxides & Particulates
- Carbon Monoxide
- Cadmium
- Nickel
- Lead

In Torbay, southern England, the contribution local trees make to air pollution removal, and carbon sequestration alone was estimated to be worth £6.4m a year. (TDAG, issue 3 November 2012)

Reduce Stormwater Runoff

It is well known that trees reduce stormwater runoff effectsy canopy interception (Xiao & McPherson, 2016). In the study by Szota et al various methods of directing stormwater run-off were quantified. (Szota, et al., 2019) The research concluded that there was potential to capture significant stormwater volumes using a designed Stormwater Control Measure (SCM). At the same time, the research did not identify any increase in growth rates due to an increase in stormwater.

Health Improvement

Exposure to greenspace can improve mental health, reduce blood pressure and stress levels, and increase physical activity. A joint research project piloted by the Institute for Clinical Evaluative Sciences, the University of Chicago, and the Rotman Research Institute concluded that: -

> *"People who live in neighbourhoods with a higher density of trees on their streets report significantly higher health perception and significantly less cardio-metabolic conditions (controlling for socio-economic and demographic factors). We find that having 10 more trees in a city block, on average, improves health perception in ways comparable to an increase in annual personal income of $10,000 and moving to a neighbourhood with $10,000 higher median income or being 7 years younger. We also find that having 11 more trees in a city block, on average, decreases cardio-metabolic conditions in ways comparable to an increase in annual personal income of $20,000 and moving to a neighbourhood with $20,000 higher median income or being 1.4 years younger".* (Kardan, et al., 2015, p. 1)

A study by Andrea Faber Taylor and Frances Kuo from the University of Illinois (Kuo & Taylor, 2004) suggests that trees and other greenspace can have a therapeutic effect for children suffering from Attention Deficit & Hyperactivity Disorder (ADHD), improving both their attention levels and social functioning. The same research also showed that students with regular access to trees and greenspace performed better in tests.

Trees decrease smog formation and have been shown to help reduce incidences of skin cancer, asthma, and stress-related hypertension illnesses (Tree Design Action Group). Green Blue Urban adds that other studies in the Netherlands indicate that communities reduce health complaints for every 10% increase in green space. Also, US studies suggest that hospital patients with a view of nature through hospital windows recover better after surgery.

The benefits to mental wellbeing within housing association situations has also been researched demonstrating how trees can have positive influence in a range of settings. (Winson , 2012)

Temperature Moderation and Shading

Roberts within the introduction to Tree Roots and the Built Environment state that "The substantial benefits provided by trees in built environments is not in question." (Roberts, et al., 2006, p. 5) The authors explain the many benefits which include temperature moderation and shading;

> *"Trees enhance the landscape.....and visual amenity. Trees help to moderate climate, temperature, sunshine and wind conditions by providing shade and shelter. Along roadsides..... trees offer clues to changing road configurations".* (Roberts, et al., 2006, p. 5)

Social Benefits and Urban Cohesion

The benefits are explained using a quote from HRH Price of Wales.

> *"Our urban forests, the trees and woodlands in and around our cities, have a vital role to play in promoting sustainable communities. As the most important single component of green infrastructure these trees can provide numerous environmental, economic and social benefits, contributing enormously to the health and welfare of everyone who lives and works in the urban environment ".* Quote by HRH Prince of Wales (Institute of Chartered Foresters, 13-14 April 2011)

1.6.4.3 Organisations Advocating Importance of Trees

Various Governmental and non-Governmental organisations are advocating the importance of trees and carrying out research such as The Forestry Commission , Trees and Design Action Group and Treeconomics.

The Trees & Design Action Group (TDAG) is a pioneering group of individuals, professionals, and organisations from both the public and the private sectors who have increased awareness of trees' role in the built environment throughout the United Kingdom. They state that “trees, especially urban trees, are therefore part of the solution to some of the key challenges of our age, from climate change to declining health and well-being”. (TDAG, issue 3 November 2012).

The group shares the collective vision that the location of trees, and all the benefits they bring, can be secured for future generations by influencing the planning, design, construction and management of our urban infrastructure. Trees can also help to create conditions for economic success.

The TDAG Guide (TDAG, issue 3 November 2012) confirms that over 80% of the UK’s population live in urban settings. Trees in and around built-up areas – which many call the “urban forest” – have become a vital component of the infrastructure that makes places work, look and feel better.

Cllr Philippa Roe, Leader, Westminster City Council said, “ We recognise that trees are an integral component of our townscape, and we are committed to maintaining and increasing our tree cover wherever practically possible……..manage our existing trees and plan for new trees to ensure that their benefits are enjoyed both now, and by future generations”. (TDAG, issue 3 November 2012)

The Guide (TDAG, issue 3 November 2012) sets out 12 principles for protecting trees in the urban environment. These are: -

- know your tree resource
- have a comprehensive tree strategy
- embed trees in policy and other plans
- make tree-friendly places
- pick the right trees
- seek multiple benefits
- procure a healthy tree
- provide soil, air, water
- create stakeholders
- take an asset management approach
- be risk-aware

- adjust management needs

The author has attended the regular meetings of TDAG to discuss trees and subsidence related issues.

Treeconomics (Treeconomics, 2019) is another organisation highlighting the importance of trees in the urban environment. “It is the goal and passion of Treeconomics to work to understand how trees improve our urban spaces, making them better places to live”. Treeconomics works internationally with community groups, research organisations, public bodies municipalities, and private businesses to complete projects that highlight the value of trees.

Green Blue Urban are a pioneering company whose mission is to enable sustainable cities through green and blue infrastructure. The information can be found on their website. (Green Blue Urban, 2019, p. 2) Green Blue Urban state, city life isn’t always easy, stating many benefits of trees and that but "trees can have surprising effects effects on the physical and psychological well-being of urban populations”.

1.6.4.4 London as a National Park City

In light of the environmental agenda and acknowledging the beneficial effects of trees, stricter controls on removing trees are being considered. The campaign to make London a National Park City recognising the importance and value of environmental factors of which trees form a large part. The campaign states.

> *“More than 80% of the UK’s population live in towns and cities. These urban areas now cover 7% of the UK and 10% of England. Think of urban landscapes and what comes to mind are industrial sites, houses, roads and rail lines. But in reality, it is a richly woven tapestry of greens and blues made up of gardens, rivers, parks, woodland, nature reserves, canals, meadows, woodland, allotments, streams and lakes. Together with our buildings, these green and blue parts of our cities can be made more valuable, wild and diverse than large parts of our countryside. They can be just as outstanding for their outdoor recreation opportunities and are certainly more accessible.” (National Park City London, 2014, p. 8)*

London is home to 8.6 million people and more than 8.3 million trees and 13,000 species of wildlife. One of its aims is to make 51% of London physically green.

1.6.5 Summary Concerns

This section has identified that the popular solution to clay shrinkage subsidence is tree removal and highlighted that: -

- many of the urban areas of the UK are founded on clay soils

- there are many millions of trees located in urban areas at risk of removal
- up to 10x clay shrinkage claims can occur during event years
- global warming is likely to increase the conditions suited to clay shrinkage subsidence

According to TDAG, there is a perception that trees causing subsidence are a major threat to urban trees. TDAG report says that the incidence of subsidence in urban areas caused by trees is far lower than assumed. One study in a London borough found that only 0.05 per cent of its building stock was affected by tree-related insurance claims annually (Trees and Design Action Group, February 2010, p. 19). Whilst the figures have not been substantiated; the author would argue that it is known that cases of subsidence can vary quite significantly from year to year depending mainly on weather conditions. (Driscoll & Skinner, 2007) In an event year, the number of claims can multiply significantly. Referring to the estimate above, 0.05% of the building stock is one in 2000. Multiply by 10 in an event year gives one in 200, equating to 5,000 properties in 1 million affected in an event year. Now, assuming two trees are affecting a single property, that would equate to 10,000 trees in one borough at risk of removal, which is a significant number.

The numerous benefits of trees presented by organisations and groups that aim to protect trees add to the extensive and growing body of knowledge advocating trees' value in urban areas. The review is sufficient to identify valid concerns regarding routine tree removal to resolve clay shrinkage claims, and that alternatives such as root barriers require consideration.

Before progressing, it is also important to mention that there are measures to protect trees from removal.

1.6.6 Existing Protection for Trees

1.6.6.1 Planning and corporate controls

Development Control Advice Notes (DCANs) represent non-statutory planning guidance which is intended to supplement, elucidate and exemplify policy documents, including Planning Policy Statements (PPSs) and development plans.

The purpose of this DCAN is to provide advice that will help to ensure that urban and environmental quality is maintained, amenity preserved, and privacy respected when proposals are being considered for new housing development within existing urban areas. "*The optimum solution will depend on the dimensions of the plot (particularly in relation to front of plot provision), the presence of mature trees, which should be retained".*

New development should respect the architectural, streetscape and landscape character of the area, and follow the established character in terms of:

- the setbacks of properties from the street
- the treatment of boundaries, both hard and soft
- the landscape structure and the presence of trees
- integrate existing landscape features

Where trees or landscape features form part of a backland plot, the design should seek to retain these and integrate them into the new development. (The Planning Service, Dept of the Environment, June 2002)

Corporate social responsibility (CSR) has become increasingly important, and many companies, such as Bovis Homes (Homes, 2016) are voluntarily adopting policies that respond to the challenges of sustainability and environmental protection. Clients, which include insurance companies that fund subsidence claims, and developers need to be aware of their impact on the environment. More companies are adopting environmental management systems, and there are many guides to assist in the process, such as the ACORN scheme.

Environmental Impact Assessments (EIA) are a means of systematically drawing together an assessment of a project's likely significant environmental effects. This process ensures that the importance of the predicted impacts, and the scope for reducing them, are appropriately understood by the public and the relevant authority before making its decision.

A tree preservation order is designed to prevent unwarranted felling of trees so that tree owners wishing to carry out work on a tree follow a procedure enforceable in law. Work to trees in conservation areas automatically requires permission and outside of conservation areas, certain high amenable trees require approval. Councils have the authority to place TPO on trees to protect them.

However, exemptions to TPO orders can be made for the “prevention or abatement of a nuisance”, which occurs in clay shrinkage cases. Consequently, TPOs are not always successful in preventing removing a tree that is causing a nuisance.

1.6.6.2 London Tree Officers Association

Due to the significant financial burden of tree-related subsidence claims against London Boroughs, the London Tree Officers Association (LTOA), representing all 33 London Boroughs, published, in 1992, guidance for reducing the incidence and costs of claims. The guidance was formulated following wide consultation and was updated in 1995, 2007 and 2008. The 'Risk' Limitation Strategy for Tree Root Claims' is regarded as encapsulating best practice regarding the prevention and

handling of alleged subsidence cases and is applicable wherever local authorities have to manage trees on shrinkable clay soils. (The London Tree Officers Association, 2008)

In summary, the LTOA recommends that local authorities should adopt the following risk limitation strategy: -

- instigate a regime of cyclical pruning of council tree stock in areas predisposed to building movement where this is appropriate
- provide dedicated resources for dealing with subsidence generated claims directed at council-owned trees
- instigate a regime of selective removal and replacement of street tree stock in areas predisposed to building movement where this is appropriate

The specific steps recommended to implement the strategy are as follows: -

- identify those areas predisposed to movement due to the presence of shrinkable clay soils
- identify high-risk trees in the areas of clay soils and if required, incorporate them into an appropriate tree pruning programme
- introduce regular management programmes that demonstrate an active approach on the part of the borough in those areas considered to be high risk

Whilst providing useful guidance, the LTOA recommendations are "an agreed and mutually beneficial process (that) will herald a new era of co-operation and partnership working between the two sectors (insurers and Local Authorities)" (LTOA, 2020), that are not legally enforceable.

1.6.6.3 The Financial Burden for Tree Root Encroachment

Tree owners carry a high potential financial burden where their trees are shown to be causing damage to a building.

The legal position is that an action for nuisance in law for tree root encroachment lies against the trees' controller. (L E Jones(Insurance Brokers) Ltd -v- Portsmouth City Council (2002) The organisation responsible for the control and maintenance of the trees must be reasonably able to foresee that damage would result from the action of roots from their trees. A Local Authority, Public Body or Housing Association is deemed to have such knowledge. (Solloway -v- Hampshire County Council (1981); Paterson -v- Humberside County Council (1995); and Kirk -v- London Borough of Brent (2005))

Tree root encroachment is a continuing nuisance, and limitation is not a defence. The date upon which the nuisance is abated and only underpinning or tree removal generally abate root encroachment. However, the person suffering damage must give the notice to allow the controller of the vegetation reasonable time to act (around 4 months (Jones -v- Portsmouth)) to abate the nuisance; otherwise, the cost of any subsequent underpinning is irrecoverable. If notice is given, underpinning of a structure to negate the effect of roots from vegetation within Local Authority control is recoverable (Delaware Mansions -v- Westminster City Council (2002))

In Loftus-Brigham -v- London Borough of Ealing (2003), the Court of Appeal held that the only question for the Court was whether the defendant's tree roots materially contributed to the damage and awarded full damages without any reductions to the claimant homeowner. The contribution could only be sought from a negligent party. A material contribution was anything other than de minimus. However, in Gerard-Reynolds -v- London Borough of Brent (2005), the court decided that the Local Authority was only responsible for that proportion of the damage resulting from the nuisance from their tree. It followed the Court of Appeal decision in Holtby -v- Brigham & Cowan (Hull) Limited (2000). Negligence is not a pre-requisite on the part of the other contributors to the damage.

Inadequacy of foundations is no defence against a claim in nuisance (Bunclark -v- Hertfordshire County Council (1977)), nor is the fact that trees were present prior to the construction (McCombe -v- Read (1955)). However, these older decisions may not be upheld for a modern property whose foundations did not comply with the standards in force at the time of construction and where vegetation was already present. "Modern standards of construction can be expected to take account of obvious hazards in the vicinity of the structure to be built" (Siddiqui -v- London Borough of Hillingdon (2003)).

The case of Berent -v- Family Mosaic Housing and London Borough of Islington (2012) reopened the debate on foreseeability of damage. The Judge considered that there needed to be a 'real risk' of damage and that the simple proximity of a tree to a building does not elevate the risk of damage from being a potential to a 'real risk' of damage. The social benefit of 'a treed' environment was highlighted in that it would not be reasonable to fell all trees that pose a risk (but not a 'real risk') to eliminate or minimise that risk.

However, the Court's decision in the recent case of Khan -v- Kane (2013) was that a layperson, which the Court described as a "reasonably prudent landowner", was liable for damage caused by a tree/trees without first being put on formal notice. In that case, the Court concluded that with knowledge of the general risk, the location,

size, and condition of the trees, a reasonably prudent landowner would notice the particular risk posed to the neighbouring property.

1.6.6.4 Summary section

There are safeguards to protect trees as described such as Environmental Impact Assessments, LTOA guidelines, CSR and Tree Preservation Orders. (TPOs)

However, despite protections in place, there remains a financial burden on tree owners in nuisance requiring them to pay compensation for damage to buildings caused by tree roots. This potential financial penalty makes tree owners more reluctant to retain trees implicated in subsidence damage, even though safeguards are in place.

Therefore, it is important that tree owners, such as local authorities and councils, have alternative methods, such as root barriers, to deal with clay shrinkage claims to minimise financial exposure if they wish to retain their trees.

1.7 Justification of Root Barriers

In the previous section, I identified a trend in tree removal to resolve clay shrinkage subsidence claims because it is relatively inexpensive, eliminates the cause and prevents re-occurrence of the problem.

There is increasing pressure on retaining trees from the environmental, social and financial aspects, and the full value of a tree is not always fully recognised. One of the critical factors that changed the way I viewed the paradigm or accepted norm was further study at master's level at Anglia Ruskin University in 2014. During my research, I gained a fuller appreciation of the critical issues concerning global warming, environmental protection and sustainability and the need for controlling action. Based upon these experiences, I started to reflect on the current process in dealing with subsidence claims, i.e., tree removal and asked myself the question.

> *"Is unchecked, routine removal of trees to resolve subsidence claims sustainable?"*

Sustainability is used in the sense that routine tree removal now meets the needs of the present, but is it compromising future generations' ability to meet their own needs? (Bruntland, 1987). It is not just a case of planting new trees when old ones are removed as it is precisely the older and larger trees that provide the most benefit and new trees would take many years to grow to the size of those removed. The controlling action, namely installing a root barrier instead of tree removal, requires consideration.

1.7.1 Philosophical Considerations

Since this thesis aims to attain the qualification of Professional Doctorate, it has been necessary, as a researcher, to explore further and understand the background and origins of the word philosophy and explore its meaning and interpretation through history. This journey of researching philosophy and well-known philosophers, which is not within my usual expertise as a civil engineer, has been challenging and beneficial.

Sullivan states that we philosophise not for purely practical ends but because it brings pleasure. Knowledge brings pleasure. He says that "So unless we free our minds by becoming critically conscious of what we hold uncritically and unconsciously we are liable to become victims of our own unconsciously held philosophy or the philosophy of others". (Sullivan, 1957, p. 5)

Philosophy can be a practical exercise making us examine the world around us and challenge accepted norms or paradigms.

Philosophy is found in living men, and one of the most well-known philosophers was Socrates (470-399BC) who lived in Athens. Socrates actively encouraged his students to argue about ideas. He believed knowledge was virtue. According to Robinson and Groves (Robinson & Groves, 2007), Socrates changed philosophy in that philosophical questions were about human morality and politics, not just about the universal nature of the physical world. Socrates did not write down very much, and this was left to his later disciples, such as Plato (427-347BC), however one of Socrates many sayings include: -

"The unconsidered life is not worth living".

This phrase is relevant today in the context of this thesis and research. It suggests that we need to think about what we do and lives can be enhanced through the process. In the context of this research, I would change the quote to "The unconsidered life (tree removal to resolve subsidence claims) is not worth living (produces damage to the environment)". This statement also has links with Kolb's learning cycle discussed in the following section that describes further this concept of continual reflection and change.

1.7.2 Kolb's Learning Cycle

Kolb devised the learning cycle as a continuous iterative process in four stages as a realistic reflection of how individuals learn from experience and testing. As this model is a cycle, it does not have a definitive starting point. The various stages of learning in this model are 'having an experience' followed by 'review' then 'concluding from the experience' and then 'planning the next step'.

Kolb's theory is relevant because it demonstrates that the learner must pass each stage and a weakness in one area will interrupt completion of the process to progress in the learning cycle.

Honey and Mumford built upon Kolb's work and applied it practically to work-based training schemes. In their theory, four learning styles were defined, namely Activists, Reflectors, Theorists and Pragmatists. Activists are gregarious personalities with an open mind who like to try new things for themselves. Reflectors are more cautious and prefer to collect data and ponder before reaching conclusions. Theorists like to analyse and synthesise and are keen on theorising, preferring rational objectivity above anything subjective or ambiguous. Finally, Pragmatists are generally impatient and practical people, keen on trying ideas to see if they work in practice.

The learning cycle and similarities between Kolb and Honey and Mumford's theories are illustrated in Figure 1.18.

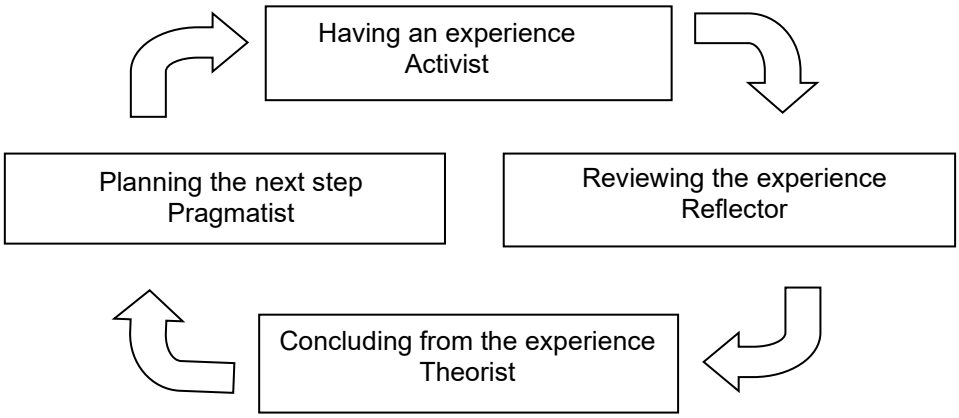


Figure 1.18 Kolb and Honey and Mumford theories compared and illustrated

This learning process or cycle of reflection and improvement is illustrated in Figure 1.19 Learning cycle Stages i to iv.

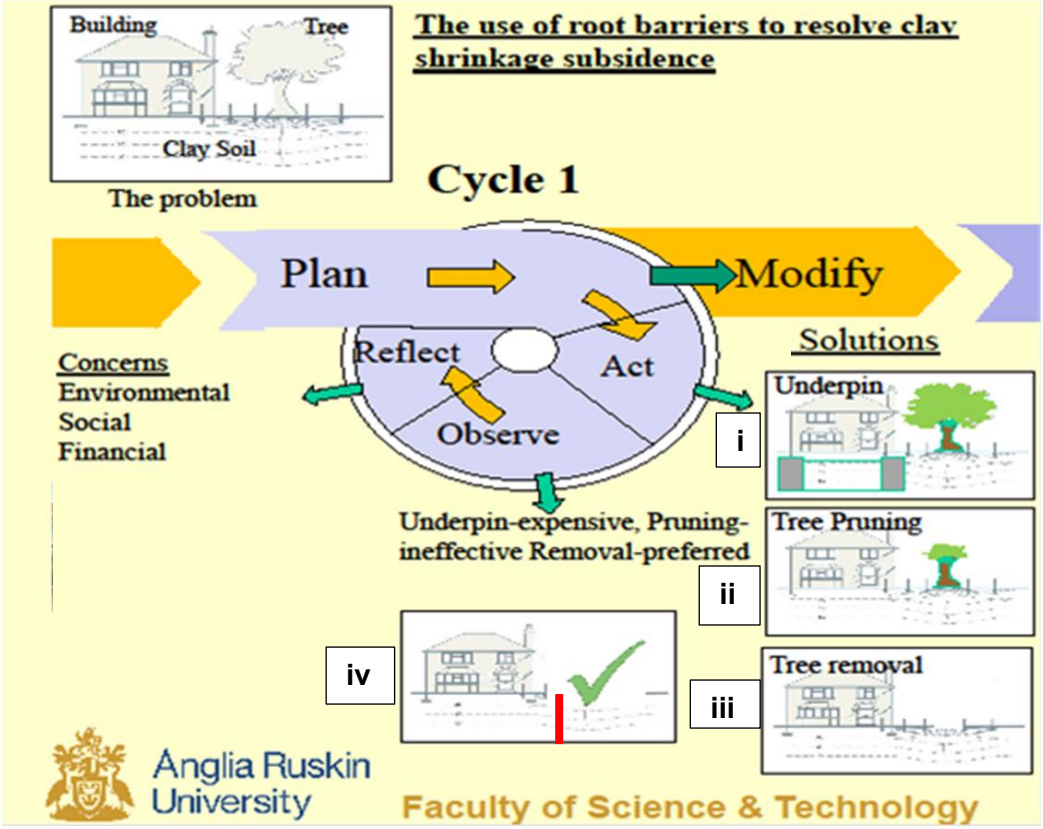


Figure 1.19 Learning cycle Stages i to iv (Source Author)

The first cycle (i) indicates the solution to clay shrinkage subsidence as underpinning in the 1970s followed by tree pruning (ii) in the 1990s and then the current practice of tree removal (iii). A further cycle is added, namely, that of the root barrier, (iv) justified earlier that controlling action is required to prevent the unnecessary loss of valuable trees in urban areas.

1.8 Diagrammatic Representation of a Root Barrier

A root barrier resolves the problem of clay shrinkage subsidence by stopping roots from reaching the foundations of a building whilst retaining the tree.

The root barrier solution is illustrated diagrammatically in Figure 1.20.

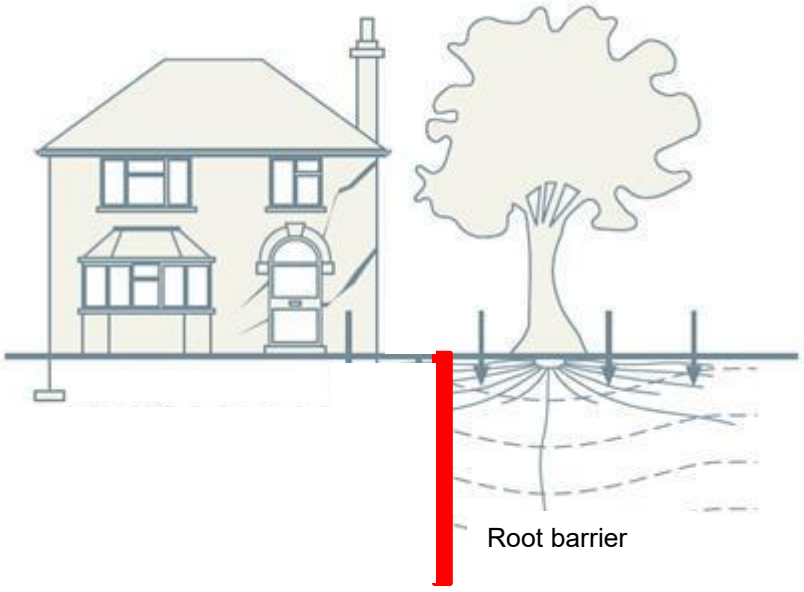


Figure 1.20 Root barrier solution (Source Author)

The root barrier is designed to provide a physical barrier between the building and the tree so that the roots are unable to reach the building and cause the damaging moisture content changes within the clay soil.

1.9 Root Barrier Viability

Root barriers are a viable alternative to tree removal in situations where there is adequate space to install the barrier between the building and the tree, as in the following examples. To illustrate where root barriers could be used as an alternative, consider the tree in Figure 1.21. The tree is impressive and has a high amenity value. The tree is close to properties, and if located on a clay soil could well be responsible for causing damage. This would be a case where those dealing with clay shrinkage cases would be seeking to look at the tree removal solution, whereas a tree root barrier could be adopted.

Figure 1.21 High value tree (Source Author)

Note the space around the tree, presumably owned by the Local Authority. The space would indicate that there may be a benefit in considering introducing a root barrier to avoid tree removal.

Figure 1.22 shows two hypothetical situations where there are multiple trees close to buildings that could be causing damage. Again, the trees have high amenity value, and there appears enough space to construct a barrier between the trees and the buildings if subsidence were occurring.

Figure 1.22 (a and b) High value trees and potential space for a root barrier (Southgate, North London) (Source Author)

1.10 Research Aims and Objectives

The root barrier justification leads to the introduction of the research aims and objectives. The aims and objectives act as a common thread through the entire thesis giving structure, direction and focus.

1.10.1 Research Aims

The two over-riding research aims are: -

- carry out an in-depth study of the benefits, disbenefits, practical use and perceptions of root barriers relevant to subsidence practitioners
- develop a framework, or design protocol, to optimise the use of root barriers and prevent the unnecessary loss of valuable trees

1.10.2 Research Objectives

To achieve the above aims, four specific objectives apply, as follows: -

1st identify the most important variables that would influence decisions to mitigate clay shrinkage subsidence with reference to the use of a root barrier

2nd identify the most important perceptions in the use of root barriers amongst subsidence practitioners

3rd analyse a) the variables and b) perceptions that influence the use, effectiveness and reliability of root barriers

4th develop design protocol for the design and construction of root barriers

1.10.3 Variables and Perceptions Defined

The term “variables” refers to the more tangible elements or attributes of a root barrier that can be more easily quantified, such as its height, depth or other physical property or characteristic. Variables take the form mainly of numbers, not words, mostly numeric, or a specific characteristic or defined property of a material.

The term “perceptions” refers to those less well-defined elements, less concerned with numbers but views, attitudes, concerns, or expectations. Words would best describe perceptions rather than numbers or fixed properties.

Whilst the two concepts of variables and perceptions have been separated initially, they should not be thought of as rigid compartments as there is overlap between the two. For example, if root barriers have been installed too shallow in the past (variable = depth of the root barrier) then there will be general concerns regarding reliability (perception).

The identification of the variables is placed before the consideration of perceptions as it is essential to appreciate and understand the more tangible properties (depth, length, materials etc.) before considering the less tangible perceptions (views or concerns) of practitioners in the use of root barriers.

1.10.4 Research Defined Additionally in Terms of Questions

The research aims will be also expressed in terms of research questions that the thesis seeks to address. Research questions are essential, as will be explained later, because research texts usually refer to research questions rather than aims and objectives, as in this research. The available literature can be utilised and more easily disseminated by aligning the research to the types of questions asked.

The types of questions that can be typically asked are (Booth, et al., 2016, p. 44):-

What? When? How? Why? Who? Where? and Whether? type questions.

In specific relation to this research the main questions being asked are: -

What are the main features or characteristics of root barriers? **What** materials are used?

How are root barriers installed? **How** do they work? **How** close can the barrier be installed to the building? **How** deep? or long? **How** should they be designed? **How** frequently are they installed?

Why was the root barrier a certain depth or positioned in a particular position? **Why** should we use or consider root barriers?

Of lesser importance are who? and where? type questions, for example, the thesis is not as concerned with questions such as: -

Who uses root barriers?

Where are they used?

The dominant questions therefore are, what? why? and how? questions, forming the basis of the research. This realization is not discussed further at this stage but becomes apparent later in the thesis.

1.11 The Scope of the Research

The research scope is limited to examining the option of a root barrier where existing trees are damaging existing buildings on shrinkable clay soil and where tree removal applies. The introduction of a root barrier would avoid removing the tree.

The research does not cover situations where a developer plants a new tree close to an existing building as the tree should be chosen specifically for the site and located appropriately. Similarly, the research does not include cases where a new building is being constructed near to existing trees, as the new building should have foundations designed to accommodate nearby trees.

Clay soil only is considered in this thesis, not gravels, rock or silt, as clay soil varies in volume depending on its moisture content and consequently is uniquely affected by nearby vegetation.

This research will focus on subsidence practitioners from insurance companies, loss adjusters, engineers, contractors, and arborists dealing with subsidence damage usually as part of an insurance claim.

1.12 Thesis Structure

The structure of the thesis follows an hourglass format in Figure 1.23.

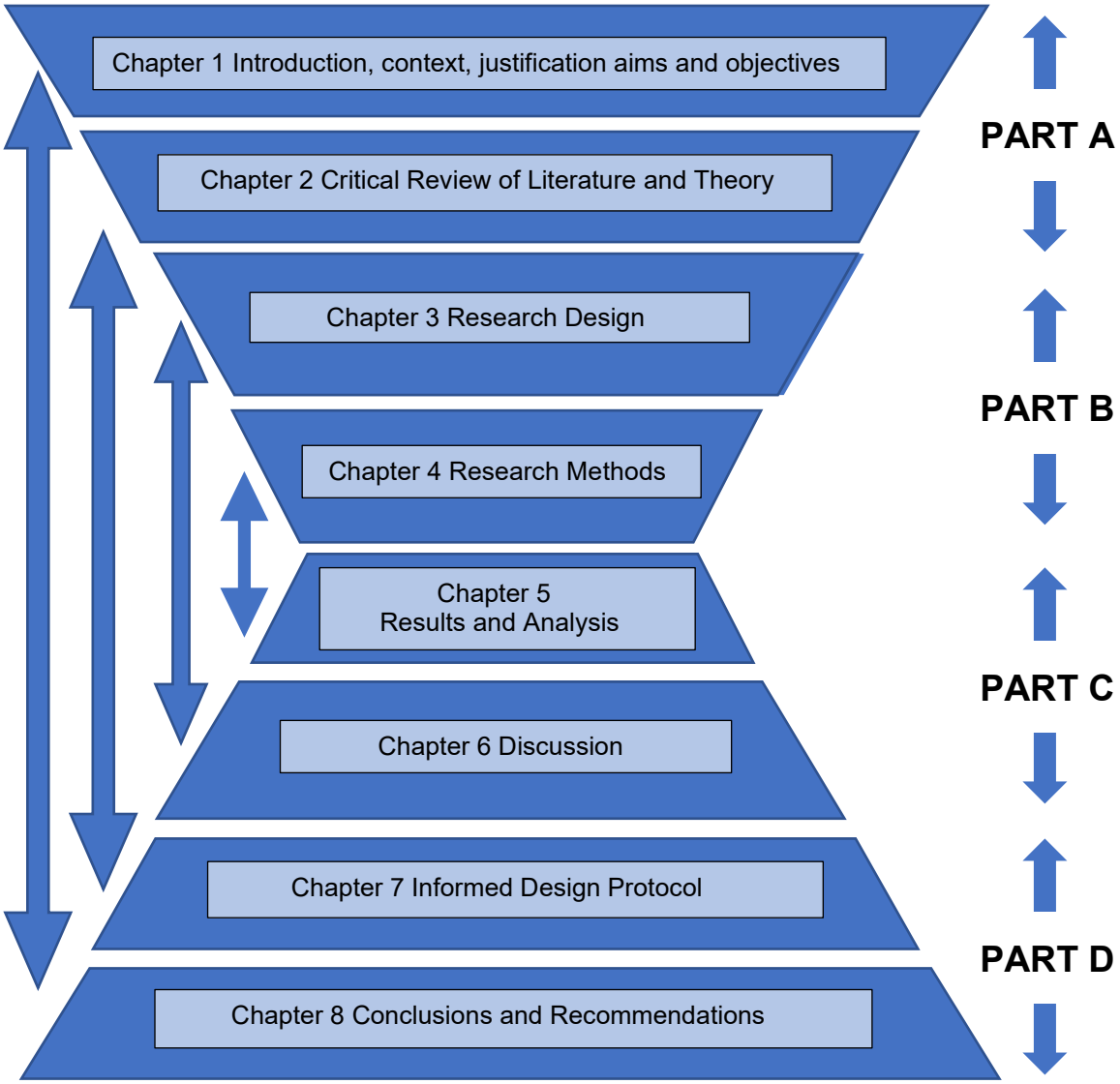


Figure 1.23 Indicative thesis structure (Source Author)

The format was chosen specifically as it demonstrates: -

- a logical order or progression
- the writing converges from Chapter 1 (introduction) to a focus in Chapter 4 (research methods) and then widens into 5 (results and analysis) expands further into Discussion leading to Chapter 7 (informed design protocol) and is completed in Chapter 8 (conclusions and recommendations)
- the linking together of chapters
- chapters inform each other

1.12.1 Logical Order

The chapters follow a logical order from Part A that covers the introduction and literature review. The introduction sets the scene within the context, justifies consideration to the use of root barriers and identifies the aims and objectives. The literature's critical review in Chapter 2 brings together the published work on the subject to analyse current knowledge and identify the gap. Specifically, the literature review is used in part to identify variables and perceptions.

Part B covers research design, separated into two parts. Research design (Chapter 3.0) considers philosophical positions and understanding of knowledge claims in so far as they relate to the research being undertaken. This leads to epistemological assumptions followed by theoretical perspectives and then the methodology required to achieve the aims and objectives. Research design (Chapter 4.0) considers the methods, specifically of data collection and the data collection instruments. This includes a more detailed explanation of the strategy adopted in collecting and analysing the data.

Part C includes the results that are presented and analysed in Chapter 5 and discussed in Chapter 6.

Part D brings the research to its culmination and includes the informed design protocol in Chapter 7.0, followed by conclusions in Chapter 8. The final chapter brings together the whole work identifying what has been achieved, validation, implementation, how the research fills the gap in knowledge and defining the contribution to knowledge.

1.12.2 Converging to a Focus

The writing converges to a focus in that the broad topic is first investigated in terms of subsidence claims management, engineering and the environment. As the subject is explored through literature review and theory, a general research methodology is established, leading to the methods by which the data will be collected. The results following from the data collection are presented then analysed leading outwards and expanding into discussions, the informed protocol and finally, conclusions.

1.12.3 Linking of Chapters

The linking of Chapters indicated within Figure 1.23 shows a logical progression from the introduction that defines the concepts leading to identification of the research aims and objectives in terms of variables and perceptions. Chapter 3.0 uses the concepts beginning with philosophical considerations and finishing with methodology. Chapter 4.0 uses the chosen methodology and its appropriate

methods (of data collection) to explain how the data will be collected. Once the data has been collected, Chapter 5.0 presents the results. Further, the link continues from Chapter 3.0 (methodology) to the analysis of the results Chapter 5.0, based upon the methodology adopted back to the introduction and original aims and objectives, that also draws inferences and links to theory and literature (Chapter 2.0).

Grix (2004), advocates the need to consider “each and every stage of the research process in the light of the preceding and subsequent stage and how one impacts on or connects with the other”.

1.12.4 Chapters Informing Each Other

Crotty (1998, pp. 11-12) explains in more detail how the links do not just go in one direction, i.e., forwards, but also backwards. Methods link back to methodology that link back to our ontological position. Crotty also explains how the links need to be consistent, for example the researcher needs to be consistently objective or consistently subjective. The conclusions should link back to the original aims and objectives and be consistent back through the methodology.

This linking also demonstrates an iterative process such that earlier chapters can also be modified and updated as later chapters are developed and vice versa. For example, the literature review may need to be updated because of findings within the results, such as a new theory identified or important paper considered. This then feeds back into the process and will affect the later sections in the thesis.

1.12.5 The Research Cycle

The research process is iterative, as explained in the text “The Craft of Research” (Booth, et al., 2016).

The text explains how researchers deal with practical problems, that may cost time or money. These are solved by doing something to eliminate or mitigate the condition causing the problem, in this case tree removal to resolve clay shrinkage. Practical problems lead to conceptual problems that arise when we do not understand something as we would like to. Conceptual problems are often called research problems. (Booth, et al., 2016, p. 51). The cycle is illustrated in Figure 1.24.

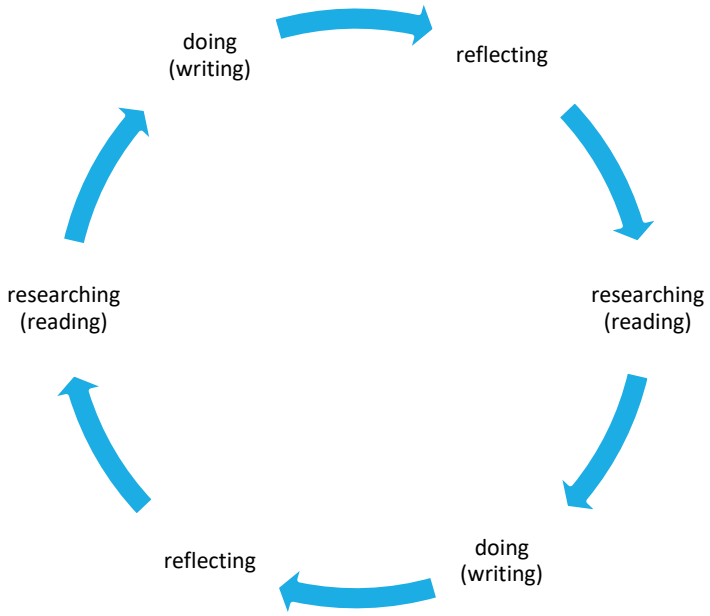


Figure 1.24 The research cycle linking practical and conceptual problems

This diagram further emphasises the cyclical nature of research and the continual reflexive process.

1.13 Linking Aims Objectives and Thesis Chapters

The aims and objectives represent the common thread that runs through the thesis indicated in Table 1.4. The table also illustrates how specific objectives are captured in relation to each of the chapters.

Table 1.4 The common thread

Objective	Chapter 2 Literature Review and Theory	Chapters 3 and 4 Methodology and Methods	Chapter 5 Results and Analysis	Chapter 6 Discussion	Chapter 7 Design Protocol	Chapter 8 Conc-lusions
1. Identify the most important variables regarding use of a root barrier.	Identify variables and develop initial theory					
2. Identify perceptions of root barriers amongst subsidence practitioners.	Identify perceptions from literature practice. theory					
3.Analyse the a) variables and b) perceptions that influence the use, effectiveness and reliability of root barriers.		Methodology designed to align with aims and objectives Methods explains how this will be achieved.	Present results and carry out analysis.			
4.Develop good practice principles for the design and construction of root barriers, and validation exercise				Discuss results and how they inform design protocol	Design Protocol	Summary and Conclusions

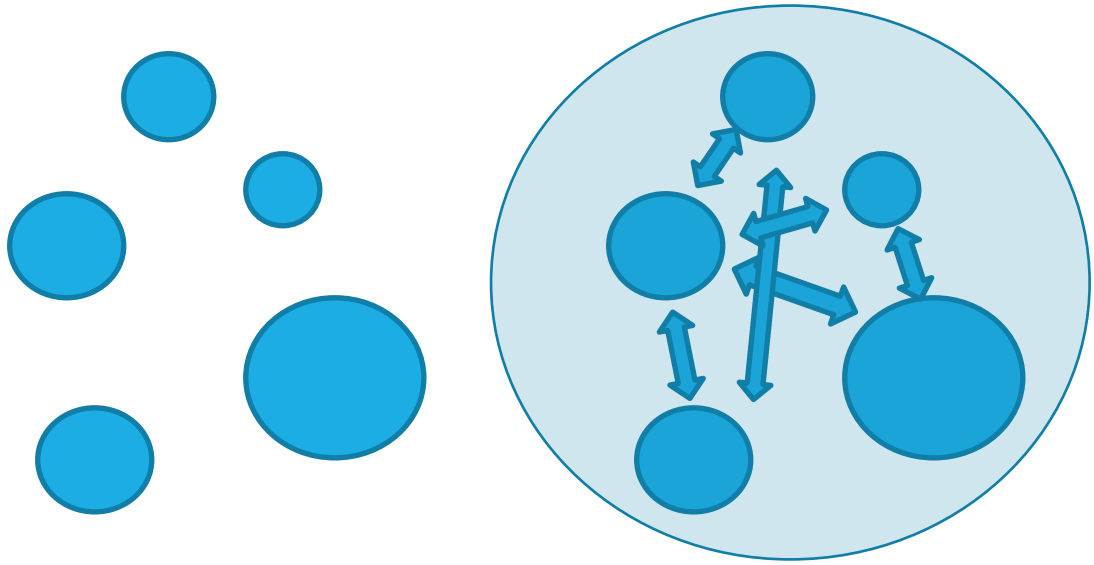
Note the diagonal arrow in Table 1.4, illustrating that earlier chapters deal with the first two objectives, and later chapters deal with later objectives. This theme is developed in Chapter 8.0 (Summary and Conclusions) to show each of the objectives' resolution.

1.14 Rationale

This research will endeavour to reduce tree removal's adverse effects in urban areas by challenging subsidence practitioners to consider root barriers.

For practitioners involved in a specialist field such as subsidence, I believe it is essential to share ideas to progress and develop alternative methods. This “Silo Approach”, as I have called it, protects companies from theft of intellectual property/designs and can provide a competitive advantage, but it can restrict progress.

These benefits of collaboration are illustrated in Figure 1.25. Here, the “silo approach” (left) and the alternative, more interactive and collaborative approach (right) are visualised.



“Silo Approach” Open and interactive approach

Figure 1.25 Silo vs open approach (Source Author)

In the silo approach (left), knowledge comprises the sum of the individual parts, whereas in the interactive approach the body of knowledge and expertise increase, represented by the large, shaded circle.

The open, interactive approach is encouraged through this research where published ideas are shared, enabling improved solutions.

1.15 Chapter 1 Summary

This Chapter introduced the mechanism of clay shrinkage subsidence, its cause and the various remedies such as underpinning, tree pruning and tree removal. Tree removal was identified as the preferred remedy as it is relatively inexpensive and removes the cause.

The significance of clay shrinkage subsidence and its potential to increase in the future was stated in the light of global warming predictions. The value of trees, especially in urban environments, was considered from numerous perspectives such as the environment, social and financial criteria. Trees for example have been shown to reduce the effects of global warming, reduce crime, improve health, improve air quality and increase property values.

The chapter then highlighted concerns with current practice (tree removal) with reference to Kolb's cycle of review and reflection and introduced the alternative remedy of a root barrier. A root barrier resolves the problem by preventing tree roots from reaching the building whilst retaining the tree and preserving its beneficial effects. It was postulated that the importance of finding alternatives to tree removal, such as a root barrier, to resolve clay shrinkage increase as the value of trees increase.

Following on from the justification of the root barrier option, the aims and objectives were stated to investigate the practical use of root barriers. (Section 1.10) The objectives introduced the concepts of "variables" (such a depth, width, materials and construction of root barriers) in the design and construction of root barriers and "perceptions" (views, concerns) from literature, theory and experience.

Finally, the thesis structure was described to illustrate the logical progression of the research to achieve the original aims and objectives.

2.0 Critical Review of Literature and Theory

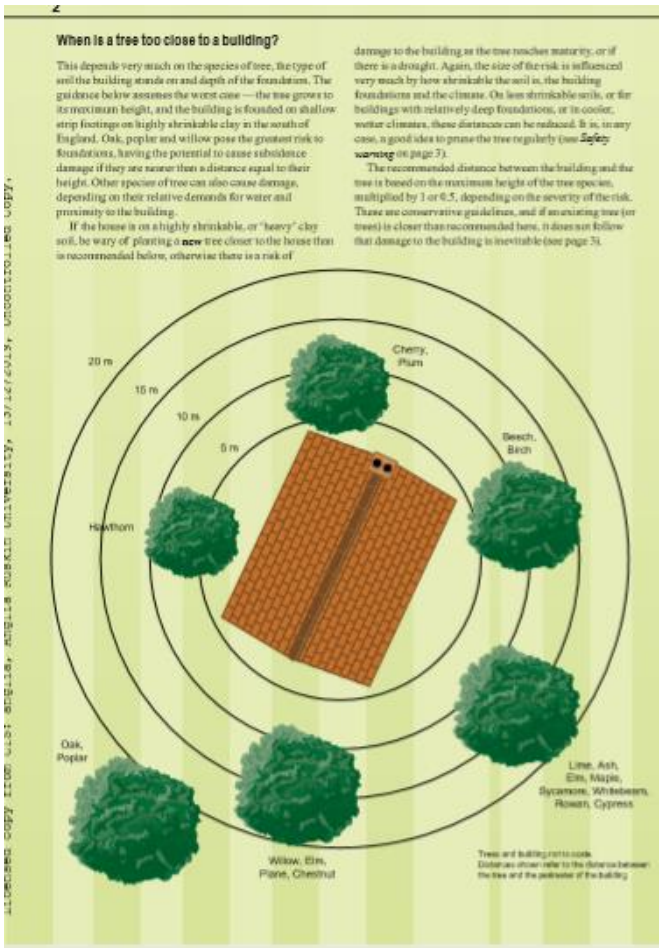
2.1 Introduction

Chapter 2.0 considers the literature and theory combined with the author's relevant experience concerning the overall research aims and objectives, namely identifying variables and perceptions in the use of root barriers. The critical review of literature and corresponding theory progresses to formal identification of variables and perceptions used in the research. Chapter 2.0 scrutinizes the various interactions between variables from literature and theory combined into a “first of its kind” initial design protocol for root barriers. Similarly, perceptions are combined within a cost- quality-time model for progression into research design.

2.2 Safe Tree Planting Distances

Historically it was found that not all tree species were equally likely to cause damage on a clay soil, resulting in the establishment of safe planting distances. For some years the Royal Botanic Gardens at Kew provided a service identifying roots implicated in subsidence and following a seminar at Kew in 1976 entitled “Tree Roots and Damage to Buildings', it was recognised that there was a need to make available more practical guidance on tree planting in relation to buildings on clay soils based on quantifiable data. As a result, Kew's data was published in 1981 in “ Tree Roots and Buildings”. (Cutler & Richardson, 1981) The 'Kew Tree Root Survey ” as it became known, provided information with which to evaluate the conditions under which trees might safely be planted near to buildings. The data presented for species/genus in tabular and graphical form identified the number of occurrences based upon distance between the tree and the damage. The data was split into bands within which 0-25%, 26-50%, 51-75%, 76-90% and 91-100% of cases occurred. The 100% value represented the maximum tree-to-damage distance. For an oak tree the 100% (maximum tree to damage) distance was 30m.

Later, the Building Research Establishment (BRE) published a guide to house foundations on clay soils, “Damage to Buildings Caused by Trees”, (Building Research Establishment, 1996). The BRE guide provided 'safe' distances between trees and buildings and reinforced earlier report BRE Digest 240. (Building Research Establishment (BRE), 1980)



When is a tree too close to a building?

This depends very much on the species of tree, the type of soil the building stands on and depth of the foundations. The guidance below assesses the worst case — the tree grows to its maximum height, and the building is founded on shallow strip footings on highly shrinkable clay in the south of England. Oak, poplar and willow pose the greatest risk to foundations, having the potential to cause subsidence damage if they are nearer than a distance equal to their height. Other species of tree can also cause damage, depending on their relative demands for water and proximity to the building.

If the house is on a highly shrinkable, or 'heavy' clay soil, be wary of planting a **new** tree closer to the house than is recommended below, otherwise there is a risk of damage to the building as the tree reaches maturity, or if there is a drought. Again, the size of the risk is influenced very much by how shrinkable the soil is, the building foundations and the climate. On less shrinkable soils, or for buildings with relatively deep foundations, or in cooler, wetter climates, these distances can be reduced. It is, in any case, a good idea to prune the tree regularly (see **Safety warning** on page 3).

The recommended distance between the building and the tree is based on the maximum height of the tree species, multiplied by 1 or 0.5, depending on the severity of the risk. These are conservative guidelines, and if an existing tree (or trees) is closer than recommended here, it does not follow that damage to the building is inevitable (see page 3).

20 m
15 m
10 m
5 m
Cherry, Plum
Beech, Birch
Hawthorn
Oak, Poplar
Willow, Elm, Plane, Chestnut
Lime, Ash, Elm, Maple, Sycamore, Whitebeam, Rowan, Cypress

Attached copy from: Building, Angela Murrin University, 17/07/2013, Unrestricted Copy.

Figure 2.1 Extract from BRE Good Repair Guide, 1996. (Building Research Establishment, 1996)

A paper published in the Arboricultural Journal containing data collected between 2002 and 2005 compares tree root distance and damage with the Kew surveys. The report validates Cutler and Richardson's data and shows that the two data sets are broadly similar. (Mercer & Reeves, 2011).

In the production of safe distance tables the authors did not collect information concerning the actual depth of roots which would be of particular interest in the design of root barriers.

2.3 NHBC Guidelines

The safe distance tables in Figure 2.1 assisted in new design although were not particularly useful for existing trees and existing buildings, for example, Biddle stated: -

> *"Such guidelines (safe distances) are impractical and are not universally accepted or implemented. The alternative approach is to increase foundation depth to permit most tree planting designs and natural regeneration, but in*

the past very little information has been available on the necessary depths". (Biddle, 1998, p. 107)

NHBC guidelines for new foundations on shrinkable clay soils near trees resolved the practical problem of determining foundation depths in the presence of trees on a clay soil.

The author has identified elementary NHBC foundation depth guidance dating back to 1974. Two categories of tree were used 1. poplar, elm and willow and 2. all others. Proposed foundation depth was based upon tree building distances as a proportion of tree height. (The National House Building Council, 1974). Updated guidelines were published in 1985 (NHBC Chapter 4.2 'Building near trees'), and these guidelines relied heavily on data from Tree Roots and Buildings (Cutler & Richardson, 1981) and monitoring the moisture content of clay soils near to trees over several years by Arboriculturalist Dr P.G. Biddle.

The NHBC guidelines (National House Building Council, 2019, p 4.2) include for: -

"foundation depths which have been established from field data, research, NHBC data and practical experience. The depths are not those at which root activity, desiccation and ground movement are non-existent, but they are intended to provide an acceptable level of risk. However, if significant quantities of roots are unexpectedly encountered in the base of the trench, the excavation may need to be deepened".

Appropriate foundation depths are presently calculated based on tree 'water demand' (high, moderate and low), the soils, the mature height of the tree and the distance between the tree and the building. For example, oak trees are broad leaf and high-water demand species, i.e., a species with a high potential to cause soil drying that leads to clay shrinkage subsidence damage.

The NHBC volume change potential classification shown in Table 2.1. (National House Building Council, 2019).

Table 2.1 Plasticity bands based upon Plasticity Index (PI) (National House Building Council, 2019)

Classification	**Modified Plasticity Index (PI)**
Low Plastic	< 20%
Medium Plastic	20-40%
High Plastic	> 40% e.g. London Clay
Very High Plastic:	>60%

The NHBC guidelines, although developed for new build houses, are extensively used by engineers and surveyors dealing with subsidence claims and indicate foundation depths that would be required for trees at a specified distance and assist in the design of underpinning. The tables are particularly suited to determine underpinning depths on the basis that the new foundations are taken down (underpinned) to the level that would be required if the building were newly constructed.

The NHBC tables use mature tree height (not actual height) which in the case of an English oak is 20m and Bay Laurel 10m, as can be seen in Table 2.2 Mature tree heights.

Table 2.2 Mature tree heights for use in NHBC tables (National House Building Council, 2019)

High water demand species	Mature height (m)	Moderate water demand species	Mature height (m)	Low water demand species	Mature height (m)
Broad-leafed trees:					
English elm	24	Acacia (False)	18	Birch	14
Wheatley elm	22	Alder	18	Elder	10
Wych elm	18	Apple	10	Fig	8
Eucalyptus	18	Ash	23	Hazel	8
Hawthorn	10	Bay laurel	10	Holly	12
English oak	20	Beech	20	Honey locust	14
Holm oak	16	Blackthorn	8	Hornbeam	17
Red oak	24	Japanese cherry	9	Laburnum	12
Turkey oak	24	Laurel cherry	8	Magnolia	9
Hybrid black poplar	28	Orchard cherry	12	Mulberry	9
Lombardy poplar	25	Wild cherry	17	Tulip tree	20
White poplar	15	Horse chestnut	20		
Crack willow	24	Sweet chestnut	24		
Weeping willow	16	Lime	22		
White willow	24	Japanese maple	8		
		Norway maple	18		
		Mountain ash	11		
		Pear	12		
		Plane	26		
		Plum	10		
		Sycamore	22		
		Tree of heaven	20		
		Walnut	18		
		Whitebeam	12		
Coniferous trees:					
Lawson's cypress	18	Cedar	20		
Leyland cypress	20	Douglas fir	20		
Monterey cypress	20	Larch	20		
		Monkey puzzle	18		
		Pine	20		
		Spruce	18		
		Wellingtonia	30		
		Yew	12		

Typical tabulated figures included within NHBC guidelines (National House Building Council, 2000) provided foundation depths for trees up to 30m high and 1m distant, as shown in Figure 2.2.

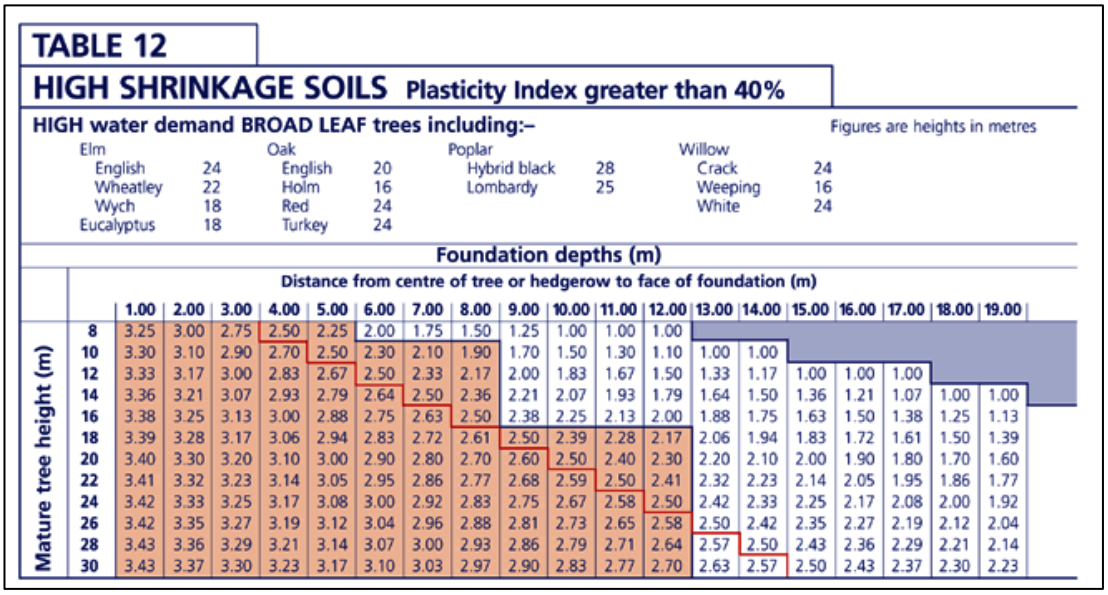


TABLE 12

HIGH SHRINKAGE SOILS Plasticity Index greater than 40%

HIGH water demand BROAD LEAF trees including:– Figures are heights in metres

Elm		Oak		Poplar		Willow	
English	24	English	20	Hybrid black	28	Crack	24
Wheatley	22	Holm	16	Lombardy	25	Weeping	16
Wych	18	Red	24			White	24
Eucalyptus	18	Turkey	24				

Foundation depths (m)

Distance from centre of tree or hedgerow to face of foundation (m)

Mature tree height (m)	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00	9.00	10.00	11.00	12.00	13.00	14.00	15.00	16.00	17.00	18.00	19.00
8	3.25	3.00	2.75	2.50	2.25	2.00	1.75	1.50	1.25	1.00	1.00	1.00							
10	3.30	3.10	2.90	2.70	2.50	2.30	2.10	1.90	1.70	1.50	1.30	1.10	1.00	1.00					
12	3.33	3.17	3.00	2.83	2.67	2.50	2.33	2.17	2.00	1.83	1.67	1.50	1.33	1.17	1.00	1.00	1.00		
14	3.36	3.21	3.07	2.93	2.79	2.64	2.50	2.36	2.21	2.07	1.93	1.79	1.64	1.50	1.36	1.21	1.07	1.00	1.00
16	3.38	3.25	3.13	3.00	2.88	2.75	2.63	2.50	2.38	2.25	2.13	2.00	1.88	1.75	1.63	1.50	1.38	1.25	1.13
18	3.39	3.28	3.17	3.06	2.94	2.83	2.72	2.61	2.50	2.39	2.28	2.17	2.06	1.94	1.83	1.72	1.61	1.50	1.39
20	3.40	3.30	3.20	3.10	3.00	2.90	2.80	2.70	2.60	2.50	2.40	2.30	2.20	2.10	2.00	1.90	1.80	1.70	1.60
22	3.41	3.32	3.23	3.14	3.05	2.95	2.86	2.77	2.68	2.59	2.50	2.41	2.32	2.23	2.14	2.05	1.95	1.86	1.77
24	3.42	3.33	3.25	3.17	3.08	3.00	2.92	2.83	2.75	2.67	2.58	2.50	2.42	2.33	2.25	2.17	2.08	2.00	1.92
26	3.42	3.35	3.27	3.19	3.12	3.04	2.96	2.88	2.81	2.73	2.65	2.58	2.50	2.42	2.35	2.27	2.19	2.12	2.04
28	3.43	3.36	3.29	3.21	3.14	3.07	3.00	2.93	2.86	2.79	2.71	2.64	2.57	2.50	2.43	2.36	2.29	2.21	2.14
30	3.43	3.37	3.30	3.23	3.17	3.10	3.03	2.97	2.90	2.83	2.77	2.70	2.63	2.57	2.50	2.43	2.37	2.30	2.23

Figure 2.2 Foundation depth assessment extract NHBC (National House Building Council, 2000)

Figure 2.2 from NHBC guidelines (National House Building Council, 2000) indicate new foundation depths extend up to 3.43m in the worse-case situation. In later versions (2005 onwards), NHBC does not provide foundation depths over 2.5m and advise these should be “engineer designed”. Further guidance is not provided as to how the engineer should proceed. The writer assumes that this 2.5m limit was introduced because NHBC directed engineers away from traditional strip footings for new build over 2.5m depth, encouraging use of piled foundations.

NHBC guidelines (National House Building Council, 2019, p. 4.2) state in this regard: -

> *“The interaction between trees, soil and buildings is dependent on many factors and is inherently complex. The relationship becomes less predictable as factors combine to produce extreme conditions. These are signified by the need for deeper foundations. Depths greater than 2.5m indicate that conditions exist where prescriptive guidance is less reliable”.* (National House Building Council, 2019)

The older versions of NHBC (where depths exceed 2.5m) remain valid at present as other standards or requirements for foundation depths have not superseded them. The NHBC depths remain the most practical tables to determine appropriate foundation depths in the presence of trees provided that when using the older tables (that include depths over 2.5m) sufficient caution is observed in their use, and appropriate factors of safety (FoS) or other precautions applied.

2.4 Limitations of NHBC guidelines

The classification within NHBC concerning tree water demand are not necessarily based upon evidence and arboricultural principles. Biddle suggests caution in using NHBC tables that “one should not be so naive to believe that trees' influence would actually follow such simple guidelines”. (Biddle, 1998, p. 307) Various examples of moisture deficits (25mm or more) are provided, from his own experience, deeper than NHBC depths.

Another important consideration with regard to NHBC tables is the classification of trees into high, moderate and low water demand categories. Historically trees were classified according to the incidences of damage so that Oaks with a high incidence of damage were classified as high water demand. Lawson and O; Callaghan (1995) assert that this water demand classification is not based upon arboricultural evidence and there is no scientific data to support the classification used. The article continues; -

> *“In the forest situation it can be seen that oak and beech transpire approximately the same amount of water per day which is at variance with the NHBC classification of oak as high water demand and beech as low in water demand”* (Lawson & O'Callaghan, 1995, p. 94)

Forest test results may not replicate urban environments where trees are under very different conditions of stress. Lawson and O’Callaghan suggest classifying trees according to their rooting habit rather than hypothetical water demand. According to Lawson, oak is deep rooted, which may explain why it is involved in incidences of clay shrinkage rather than being high water demand. The phrase “urban fitness” it is argued, may be a better term than water demand when referring to the water uptake of trees. (Lawson & O'Callaghan, 1995, p. 95)

Mercer and Reeves (2011) acknowledge that differences exist between species with respect to rooting patterns. The concept being conveyed by NHBC’s “water demand” is *“the lateral extent, depth and intensity of soil drying which is achieved by different tree species*”. The categorisation should be used as “guidelines rather than irrefutable facts”. (Mercer & Reeves, 2011, p. 242)

O’Callaghan and Mercer (2019) advise looking at NHBC tables differently. The Genera categorised as high water demand, tends to include trees that can form deep roots (oaks, elm, eucalyptus, poplar and willow). Trees with low water demand, according to NHBC typically produce shallow roots (birch, elder, hazel and hornbeam). (O'Callaghan & Mercer, 2019, p. 45)

With reference to the taxonomy and classification of tree species, (section 1.6.4.1 on page 53) there does not appear to be a direct correlation between certain taxonomic groupings when considering NHBC water demand or rooting depths. By means of an example, oaks are accepted as deep rooting trees that cause subsidence and high water demand according to NHBC (Genus=Quercus, Family= Fagaceae, Order=Fagales). Birches which are low water demand and shallow rooting appear in the same Order as oaks. (Genus=Betula, Family=Betulaceae, Order=Fagales). However, poplar and willow both share a common taxonomy in the Malphighiales Order and have high water demand and deep rooting characteristics. See Figure 1.16 (page 54).

Taxonomy, therefore, does not necessarily determine whether a tree will be deep or shallow rooting when considering clay shrinkage subsidence. The important consideration concerning the design of root barriers is the depth that roots may grow so that the root barrier prevents the passage roots in particular from growing under the barrier.

2.5 The Vegetation (tree root systems)

The Arboricultural Advisory and Information Service (AAIS) suggests (Marshall, et al., 1997) that roots occur mainly in the top 600mm of soil, but some species grow down to 5m. The thick structural roots which provide stability occur 3m from the trunk. These roots taper and repeatedly divide for many metres being no thicker than a finger. Smaller roots develop from any part of these roots and repeatedly sub-divide into a network of fine roots: the principal absorbers of water. The precise distribution of roots within the soil is impossible to predict as root growth is opportunistic.

Various authors have sought to understand tree roots' architecture and the depth of roots in (clay) soil. In 2020 a paper in the Arboricultural Association magazine entitled “Subsidence and tree rooting depth on shrinkable clay soils” sought to review the current literature. (Fraser, et al., 2020) The study's rationale was to analyze existing data to provide some level of foreseeability on the likelihood that a Genus of tree(s) will cause subsidence. The researchers recorded maximum rooting depth, tree height, distance between tree and building and PI from 815 cases between 1 October 2016 and 16 October 2017. Results were compared with the 2011 study by Mercer & Reeves, (2011), which confirmed the ten most common genera (the high risk genera) but slightly different results. They found that root depth correlated with tree height, but root depth could not be reliably predicted based upon the tree's height. There was also a correlation between root depth and the soil's plasticity, but soil plasticity cannot reliably predict root depth.

No significant relationship was found between distance and root depth in the study although a large proportion of the sample were within 10m of the building. In terms of depth, 36% were capable of rooting to depths below 2m. The deepest rooting trees were found among those that are the largest such as Quercus (oak), Populus (poplar), Platanus (plane) and Salix (willow).

Information concerning the actual physical distribution of roots would enable predicting direct and indirect threats to buildings and assist in designing suitable root barriers to protect buildings. Unfortunately, identifying the precise location of roots in the ground is not possible, mainly due to difficulties observing trees' root systems, even in the most routine way. Even in the best circumstances, for example, beneath forests or farm woodlands, the difficulties of investigating the root systems of trees are severe. Still, these difficulties become particularly severe and restrictive in built-up areas. Fraser et al. concluded that many tree genera can root to considerable depth and that further research is required to develop a model that predicts the depth of roots in clay soil. (Fraser, et al., 2020)

2.6 Biddles Work Concerning Moisture Deficit in Clay Soil Near Trees

Biddle (1998) was extensively involved in analysing tree root systems in his two-volume work that has greatly contributed to the goal of providing better information on the subject of clay shrinkage subsidence caused by trees. The work encompasses Biddles involvement in over 2000 cases and 23 years experience. Chapters 1 to 10 of Volume 1 cover the interaction of trees, soils, water and buildings. Chapters 11 to 16 describe investigation of subsidence and Chapters 17 to 20 cover remedies and prevention. Volume 1 includes 20 case studies that reflect the authors evolving approach to investigation, analysis and prevention.

Volume 2 provides a unique insight into the interaction between trees and clay soils and includes numerous tables and graphs of soil moisture reduction, overall deficits at various distances for 60 trees. The research involved installing

neutron probe moisture content measuring devices at specified distances from trees and recording moisture content seasonally and over several years. Figure 2.3 represents one such graph showing reduction in moisture content for a poplar tree on London clay located in Woodlock Park, Harrow. (Biddle, 1998)

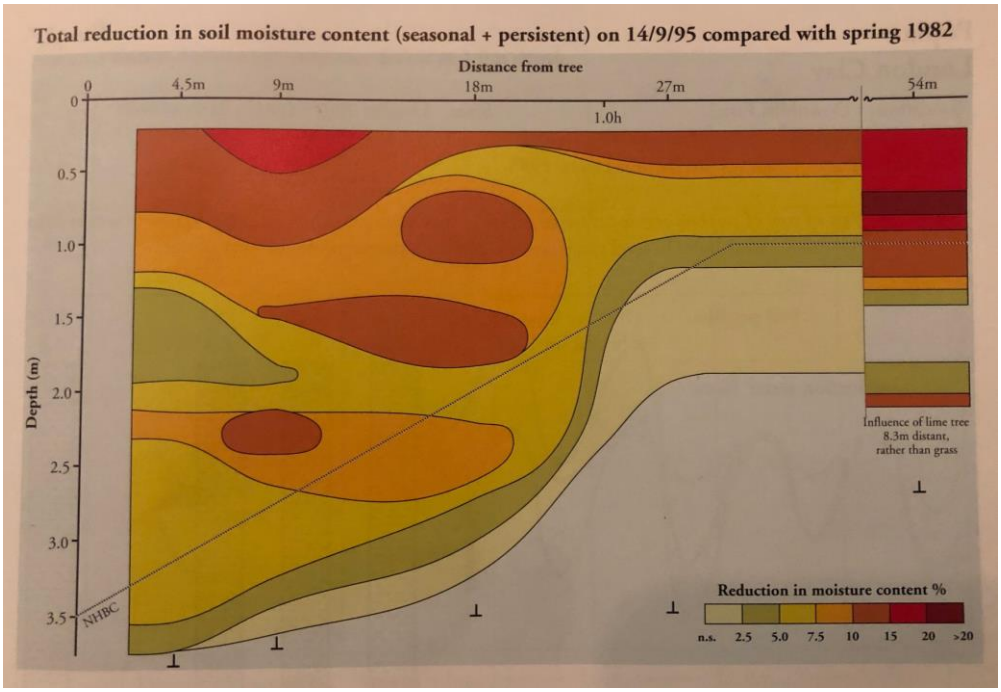


Figure 2.3 Reduction in Soil Moisture Content (seasonal and persistent) on 14/9/1995 Compared with Spring 1982 (Biddle, 1998)

Figure 2.3 shows the reduction in moisture content (measured using probes at 100 mm depth intervals) on 14th September 1995 (autumn reading) compared with the spring of 1982 (control reading). The moisture content values are calculated on a volumetric basis therefore a moisture content of say 43% in the spring represents 43mm depth of water in a100mm layer thickness. Moisture content of 30% (in the autumn, say) would represent a 13% reduction in moisture content (or 13mm over 100mm layer depth). As the probes were located at 100mm depth intervals the moisture contents on a volumetric basis provide direct readings of moisture reduction without adjusting for layer thickness. The graphs are plotted in bands from 0% to >20%. Biddle advised that 0.75% represents the limit of accuracy for moisture reduction at a specific depth which lies within the lower ban 0-2.5% on the graph legend.

Figure 2.3 illustrates how moisture reductions are not uniform or regular but gradually reduce as the tree's distance increases. Overlaid onto the graph Biddle includes a line representing foundation depths required according to NHBC guidelines, explained further in the following section.

The soil moisture deficit graphs, often shown alongside the reduction in soil moisture content graphs indicate the total moisture deficit (in mm) calculated as the sum of the moisture deficits for each 100mm layer below 1m depth. Graphs of moisture deficiency range from 0mm up to 250mm overall moisture deficit.

Soil moisture deficit graphs produced by Biddle are of particular interest as they measure the effect (moisture reduction caused by trees) rather than the cause, tree roots. Therefore, graphs of moisture deficit are arguably a more reliable indicator than rooting depth that moisture extraction is taking place within a clay soil.

2.7 Minimum Distance Between Barrier and Tree

While considering root growth, it is essential to recognise that when a fixed barrier is installed in the ground close to a tree, it should not cause damage to the tree (roots).

To prevent such damage to the tree roots the barrier must be positioned a minimum distance from the tree. BS5837 (British Standard Institution, 2012) offers such guidance and sets out the principles and procedures to be applied to achieve a harmonious and sustainable relationship between trees and structures.

Older versions of NHBC guidelines (pre 2005) contained a table of minimum distances between trees and fences for protection; however, later and current NHBC guidelines simply refer to BS5837.

In BS5837 trees are assessed by an Arboriculturist and categorised A, B, C or U according to characteristics such as condition, age, remaining life, rarity, and overall importance. Category A, B and C trees are retained and marked on site drawings (colour coded depending on category), whereas category U trees are retained. The trees that are dealt with as part of a subsidence claim requiring a root barrier will by default fall into category A or B.

The standard defines a root protection area as an area within which trees may not be disturbed. In clause 4.6.1, for single stem trees, the RPA should be calculated as an area equivalent to a circle with a radius 12 times the stem diameter. For trees with more than one stem, a modified calculation method should be used. In all cases , the stem diameter(s) should be measured in accordance with Annex C, and the RPA should be determined from Annex D. The calculated RPA for each tree should be capped to 707 m2 (15m radius).

Table 2.3 Root protection area to BS 5837 (British Standard Institution, 2012)

Table D.1 **Root protection areas**

Single stem diameter mm	Radius of nominal circle m	RPA m²	Single stem diameter mm	Radius of nominal circle m	RPA m²
75	0.90	3	675	8.10	206
100	1.20	5	700	8.40	222
125	1.50	7	725	8.70	238
150	1.80	10	750	9.00	255
175	2.10	14	775	9.30	272
200	2.40	18	800	9.60	290
225	2.70	23	825	9.90	308
250	3.00	28	850	10.20	327
275	3.30	34	875	10.50	346
300	3.60	41	900	10.80	366
325	3.90	48	925	11.10	387
350	4.20	55	950	11.40	408
375	4.50	64	975	11.70	430
400	4.80	72	1 000	12.00	452
425	5.10	81	1 025	12.30	475
450	5.40	92	1 050	12.60	499
475	5.70	102	1 075	12.90	519
500	6.00	113	1 100	13.20	547
525	6.30	124	1 125	13.50	573
550	6.60	137	1 150	13.80	598
575	6.90	150	1 175	14.10	625
600	7.20	163	1 200	14.40	652
625	7.50	177	1 225	14.70	679
650	7.80	191	1 250+	15.00	707

2.8 Root Barrier Literature Review

The literature review considers references relating directly to the use of root barriers. The first stage of this process was in examining the authors library of documents and books concerning clay shrinkage subsidence for root barrier references. This process's outcome revealed the general lack of published information on root barriers design or construction information.

For example, concerning root barriers to protect buildings they are: -

- not mentioned as a possible mitigation measure (London Tree Officers Association , 2007)
- BS 5837 “Trees in relation to design, demolition and construction” (British Standard Institution, 2012) does not mention root barriers and there are no guidelines provided for their use
- mentioned very briefly (Biddle, 1998), (Freeman, et al., 1994), (Institution of Structural Engineers, 2000)
- relate primarily to protection of hardscaping (Morgenroth, 2008)

Next, literature searches were undertaken using main databases of Science Direct, Google Scholar, EThOS (EThOS, 2019) and Construction Information Service (CIS).

The results from Science Direct and Google Scholar are shown in Table 2.4. using the following search process: -

- insert Search term (column 1)
- source (column 2) (e.g., Science Direct or Google Scholar)
- identify first 5 references title (mark relevant texts in highlighter)
- for remaining 20 references categorise broadly to identify if relevant to root barriers to protect buildings
- column 5 count number of occurrences relating to topic
- relevant texts root barriers to resolve clay shrinkage are highlighted

Table 2.4 Literature search process "Science Direct"

Column 1	Column 2	Column 3	Column 4	Column 5
Search Term	Ref.	First 5 texts	Remaining 20 texts categories	Count
Root barrier	Science direct	Root's barrier, viscosity solutions of obstacle problems and reflected FBSDEs	Root chemistry Root development	iiiii
		Cerium oxide nanoparticles alter the salt stress tolerance of Brassica napus L. by modifying the formation of root apoplastic barriers	Shallow barriers grasses or pavements	ii
		Effects of root morphology and anatomy on cadmium uptake and translocation in rice	Mathematical or non-related Crash tests Cancer treatment	iiiiiiiiiii
		Role of LOTR1 in Nutrient Transport through Organization of Spatial Distribution of Root Endodermal Barriers	Climate change	i
		Linking root traits and soil organic matter stabilization processes		
"Root barrier"	Science direct	Root's barrier, viscosity solutions of obstacle problems and reflected FBSDEs	Root chemistry Root development	iiiiiii
		Response of two perennial grasses to root barriers and fissures	Shallow barriers grasses or pavements Landfill barriers	iii
		Plant growth patterns in a tripartite strip relay intercrop are shaped by asymmetric aboveground competition	Green roofs	iiiii
		Cerium oxide nanoparticles alter the salt stress tolerance of Brassica napus L. by modifying the formation of root apoplastic barriers	Non related mathematical	iiii
		Relationships among Jatropha curcas seed yield and vegetative plant components under different management and cropping systems in Indonesia		

Note that no fields have been highlighted so this indicates the search did not find any relevant texts.

Table 2.5 Literature search "Google Scholar."

Column 1	Column 2	Column 3	Column 4	Column 5
Search Term	Ref.	First 5 texts	Remaining 20 texts categories	Count
Root barrier	Google Scholar	A review of root barrier research (Morgenroth, 2008) (reviewed as part of research	Root chemistry and development.	iiiiii
		Combined root barrier and watering collar arrangement (conical root deflector for pavements shallow founded)	Shallow barriers and management of tree roots for planting.	iiiii
		Weed control and root barrier (weed control barrier, usually horizontal)	Mathematical or non-related.	
		Root barrier (a US patent for a ribbed barrier, drawings/sketches only)	Non relevant eg health and dentistry.	iiii
		Root suberin forms an extracellular barrier that affects water relations and mineral nutrition in Arabidopsis (method for regulating water movement through the plant)	Physical root barrier designs and interlocking systems inc green roofs.	iiiii

Search Term	Ref.	First 5 texts	Remaining 20 texts categories	Count
"Root barrier"	Google Scholar	A review of root barrier research (Morgenroth, 2008) (	Root chemistry and development for specific plants	iiiiiii
		Weed control and root barrier	Shallow barriers grasses or pavements (less than 1m deep).	iiiiii
		Combined root barrier and watering collar arrangement.	Mathematical or non-related.	ii
		Effect of root contact on interspecific competition and N transfer between wheat and fababean using direct and indirect 15 N techniques.	Physical root barrier designs and interlocking systems inc green roofs	iiii
		Root barrier (Physical Design)		i

Note that one field has been highlighted relevant to the research and considered.

EThOS was additionally searched for the term root barriers and two items were found. (EThOS, 2019): -

- “Interactions between components of rubber agroforestry systems in Indonesia”.
- “The nitrogen economy of perennial ryegrass white clover associations”.

None of the above references identified during the searches are relevant to this research on root barriers to resolve clay shrinkage subsidence.

The results of further similar searches revealed the lack of literature on root barriers, the type required to resolve clay shrinkage subsidence claims. Additional searches are shown in the Appendix 12.9 demonstrating lack of literature relevant to the topic.

The above shows that there are no clear guidelines for those wishing to consider introducing tree root barriers in dealing with clay shrinkage subsidence claims for existing buildings. This lack of existing literature on root barriers illustrates the wide gap that the thesis seeks to fill.

2.9 Root Barriers to Protect Hardscaping (up to 1.5m deep)

There is abundant available literature on root barriers designed to protect shallow structures such as roads and pavements as the conflict between trees and urban infrastructure (roads and pavements) occurs in many parts of the world. By shallow, I refer to root barriers 1.0m deep or less.

The review noted within the report, Tree Roots in the Built Environment (Roberts, et al., 2006) and (Morgenroth, 2008) confirms that much of the work has been done on shallow barriers for protecting pavements and shallow structures from tree roots. This work concentrates on how roots are deflected downwards by barriers so that their influence on shallow structures is reduced rather than preventing root growth past the barrier.

In a study of red maple roots (Wilson, 1967), the author found that roots returned to their original direction after being deflected by a shallow barrier. Their final angle of growth was determined by the original angle of contact with the barrier, and on the distance they were in contact with it. Wilson identified the duration of contact between the roots and the barrier may be more important than the length of the barrier. In another study, poplar roots were only slightly deflected by short root barriers, but barriers of 10-12 cm length deflected almost half of the roots surveyed to continue in the same direction as the barrier.

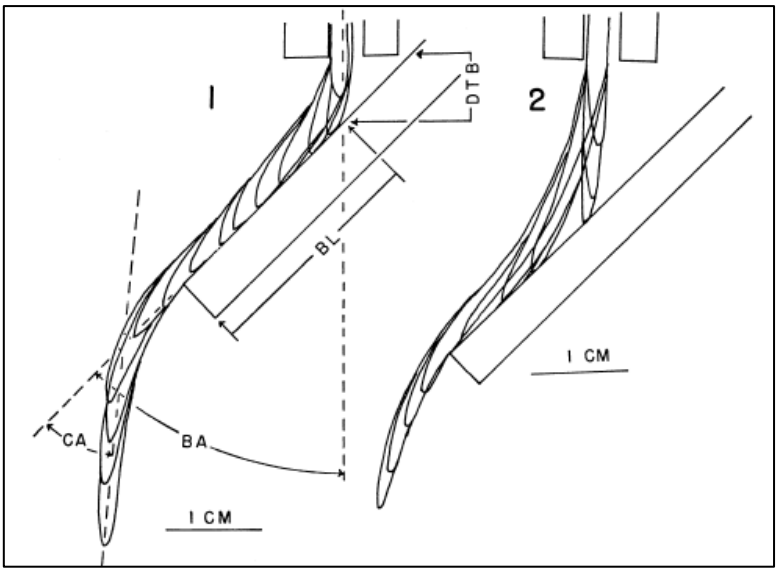


Figure 2.4 Growth of tree roots around a shallow barrier (Morgenroth, 2008)

A review of (shallow) root barrier research was conducted by Justin Morgenroth (2008). He confirmed that the installation of (shallow) root barriers represent a tree friendly approach to the problem. Brief mention of the problems associated in London clays is made, although the main concern of his review, as previously mentioned, is the protection of pavements and roadways, i.e., shallow structures. The barriers depths were commonly 300mm up to 600mm deep in some circumstances.

In the study of root growth near-vertical barriers undertaken by Smiley (Smiley, 2005), shallow barriers did change root growth patterns. However, these barriers were installed at 450mm depth and root growth under the barriers was expected. Such shallow barriers and not useful when considering barriers that prevent root trespass, at greater depth (up 5m), as would be required to resolve clay shrinkage.

Whilst the above noted research for shallow barriers does not apply for the type of barrier required to resolve a clay shrinkage claim, some of the principles and aspects of shallow barriers could be useful in this research, such as materials and gaining an understanding of the behaviour of roots in the ground.

2.9.1 Root Barriers to Protect Buildings

As previously stated, there is minimal published information on the design or construction or use of deep (over 2.5m) root barriers from the technical aspects. This is overcome by critically reviewing literature where root barriers are mentioned in various subsidence related texts, to assist in the identification of variables and perceptions.

A study on the available literature concerning deeper barriers was carried out by Department for Communities and Local Government (Roberts, et al., 2006). The document found that some authors have dismissed root barriers as an option for reducing damage, citing results that show most tree roots have an extraordinary ability to find their way over, under or around installed barriers, or that roots of both oak and sycamore, although deflected downwards by root barriers, returned to the surface within 1.2 m from the barrier, to avoid water logging and low soil aeration.

The general perception within literature is that deep root barriers to protect buildings/foundations in relation to dealing with clay shrinkage subsidence claims are unreliable (Freeman, et al., 1994) and should be avoided (Institution of Structural Engineers, 2000, pp. 76,78). Furthermore, Freeman (Freeman, et al., 1994) advises that root barriers are only a temporary solution.

In the comprehensive subsidence guide, root pruning and root barriers are mentioned to remedy subsidence damage. (Freeman, et al., 1994, p. 79) The guide questions whether the barrier will be truly permanent because roots may be able to grow around or under the trench. However, it does confirm that the barrier should prevent the time it takes for the roots to grow back. Lawson mentions the use of root barriers (Lawson, 2004) is possible although the practicality of such methods in the field would be dependent upon several factors such as: -

- physical treatment of the soil to alter bulk density
- the use of artificial root barriers could be considered in some situations

Lawson discusses the root barrier solution admitting that although root barriers with chemical or other controls can be utilised, “the site-specific requirements for ample working area and third-party requirements have combined to limit the use of root barriers within the management matrix”.

The Institution of Structural Engineer’s (ISE) guide to subsidence of low rise buildings mentions the use of root barriers briefly. (Institution of Structural Engineers, 2000, pp. 76,78) ISE states root barriers should be avoided if possible (p82) and suggests they can be used in ‘rare’ situations. The guide states (p78) that “*root barriers are less reliable (than tree works) and harder to implement than arboriculture remedies and may have undesirable side effects. Specialist advice should be sought when considering such methods (root barriers)”.* The text also warns against cutting roots without compensating by reducing crown area of the tree to minimise water stress. Other useful considerations mentioned are loss of stability when cutting roots and the possibility of disease affecting cut root ends. Root barriers should: -

- extend full distance of root spread
- extend above ground level
- carefully consider breaches such as drains
- avoid changed water flow by using microporous barriers (not fully tested)
- minimise damage to roots

The guide confirms root barriers are rarely used and that further research into root barriers should be carried out. (Institution of Structural Engineers, 2000, p. 116) stating "*root barriers deserve further research, but it is not clear whether it is receiving any attention. Further advice on the whole subject of root barriers would be useful".*

Root barriers are mentioned the comprehensive subsidence publication "Subsidence damage to Domestic Buildings" (Driscoll & Crilly, 2000). Table 3 (page 18) confirms that heave should also be considered, as well as expense and extent of the barrier whilst avoiding damage to trees by severing roots leading to instability. It further states that root barriers are untried, uncertain and require environmental acceptance.

Arboricultural practice Note 4 (APN4) (Marshall, et al., 1997) introduces and discusses the role of root barriers as a means of preventing root activity near building foundations. The guide describes root barrier design criteria and materials that might be adopted in their construction. confirming that a root barrier should be more effective than pruning, *"It is likely that a root barrier will be considerably more effective, and for longer, than repeatedly pruning the crown of a tree to reduce its water demand."* (p. 5), and that in order to be effective great care should be taken in the choice of materials and construction of the barrier.

A publication on subsidence (Driscoll & Skinner, 2007) covers the use of root barriers very briefly on page 46. The publication confirms that there is some limited documented information about the installation and performance of root barriers (e.g., from the Arboriculture Advisory and Information Service) and that at least one known commercial system is available. The publication lists circumstances where a barrier may be used, as follows: -

- low severity damage
- where damage occurred after exceptionally dry weather
- where a tree cannot be removed or reduced
- in situations where there is resistance to cost of underpinning

Biddle is another case in point covering the option of root barriers in Volume 1 of his 2-volume work (Biddle, 1998, p. 290). Biddle is concerned that if the barrier can be bypassed by roots growing through, around, under or over it, then the roots will

again proliferate in the soil beyond it. This, Biddle states, may lead to further damage, and, even worse, can lead to a sense of 'false security' (Biddle, 1998, p. 289-290). Biddle raises various concerns such as the "overwhelming practical objections". Biddle states the barrier must be deep enough, high enough and long enough to stop root growth above, below and to the sides. In addition, the tree should not be damaged and placed a minimum distance 1.5 x diameter, be at least 3m deep, provide adequate seal around underground services, and preferably permeable to allow water flow either side of the barrier. In Volume 1 various case studies are considered relating to subsidence and case study 1 refers to the use of a root barrier, 2m deep, that was effective and had resulted in heave of the building due to root severance.

2.10 Types of Barrier and Materials

There are various types of barrier material in use for root control and other disciplines such as shallow barriers or membranes within landfill sites.

Landfill sites will frequently require an impermeable barrier to prevent leachate from escaping the confines of the fill. These barriers are often of clay material with geotextile membranes. It may be useful to utilise similar methods or materials and adapt them for use in root barriers to protect buildings.

In terms of the material of the barrier, there are many suppliers who have provided product data sheets for their product.

In the root barrier research paper (Morgenroth, 2008), the available barriers are subdivided into three types: traps, inhibitors and deflectors. Traps allow small root tips to penetrate and allow water and gas exchange. Inhibitors use chemical intervention and deflectors are made of solid plastic, preventing the passage of roots. The three main types are divided into the two different groups for further assessment, impermeable and permeable.

Permeable barriers will allow transfer of moisture but still provide resistance to roots. Permeable barriers appear to be preferable as they prevent rapid moisture content changes either side of the barrier. Permeable barriers allow water pressures to equalise either side of the barrier minimising forces generated. The downside of such a barrier being that if water can permeate, equalising water content, then roots may be attracted to the outer, wetter areas. With a permeable barrier roots that do manage to make it through the mesh should be constrained and stunted, according to Wager and Barker, so that they

do not exhibit sufficient axial pressure to thicken and become damaging, unless present in large numbers. (Wager & Barker, 1983)

Diversion barriers that form a wall deflect roots from their original direction and certain improvements on this design include constructing the barrier with vertical ridges to direct roots downwards. (Barker & Pepper, 1995)

Impermeable barriers such as High-density polyethylene (HDPE) can withstand penetration by even the most vigorous of tree roots. Therefore, in applications that do not need a permeable barrier this will give the greatest degree of protection afforded by a flexible barrier material.

Chemical barriers are most often used to deflect surface-growing tree roots deeper into the soil where they will likely cause less damage to paved areas. (Roberts, et al., 2006), although there is a concern that the use of chemical and or biological methods carry with them adverse side effects such as soil pollution, ecology and conservation issues. However, some newer geotextile membranes are now impregnated with root inhibiting chemicals, which are environmentally neutral.

2.10.1 Proprietary Barrier Systems

Some proprietary systems include:-

Biorootbarrier (by PBA solutions) is a mechanically bonded geocomposite consisting of a copper-foil firmly embedded between 2 layers of geotextile. The material is flexible and permeable. Specifically used in arboriculture and Japanese Knotweed control where a permeable barrier is required. The biobarrier acts as a signal barrier diverting root growth both biologically and physically. The presence of copper does not constitute an eco-system burden or impact on groundwater.

PBA Solutions is a trading name of PBA Consulting Partnership LLP, registered in England, Bryn Gardens, Rake Road, Liss, Hants GU33 7HB.

Vertirootbarrier is a product developed by **DuPont** specifically for use as a root barrier. Its structure is semi rigid coated polypropylene barrier and non-permeable, i.e., watertight. Using a technically advanced fabric vertiroot barrier physically prevents and contains invasive growth. This product is specifically suitable as a vertical barrier in trenches or tree pits.

Flexi-root barrier is a flexible reinforced root barrier which is non-permeable and watertight. It functions as a physical barrier for use in arboriculture and for the control of invasive and aggressive plants including Japanese Knotweed control.

Terram Root guard (non-permeable) plus provides an impermeable high strength barrier and is a composite of non-woven geotextile and HDPE.

Terram Root Guard (Permeable). This barrier is non-woven, made of bonded Polypropylene and Polyethylene, and provides excellent resistance to tree roots. Terram Root-Guard has been shown to be effective in resisting root growth in all experiments according to the supplier. Terram Root-Guard has a high tensile strength, is resistant to puncturing and can withstand the differential forces that can develop in drying clay soils.

Further details of proprietary barriers may be found in the Appendix.

2.10.2 Durability of Root Barriers

A study was conducted (Moffat, et al., 1998) into the effectiveness of various forms of root barriers and found that polyethylene sheeting and herbicide-impregnated geotextile sheeting performed best. A full discussion of the various materials available is provided by Coder. (Coder, 1998)

2.10.3 Construction of Root Barriers

In terms of construction experience reveals that the main method is constructing a trench using a standard excavator bucket and the barrier installed in conjunction with concrete backfill.

2.11 Requirements of a Root Barrier to Protect Buildings

Based upon the literature review, available theory and experience, for a root barrier to be effective, it must be constructed between the tree and the building and satisfy the following main requirements: -

- prevent the passage of roots
- be of adequate depth to prevent roots from travelling below the barrier
- be of adequate length to prevent roots travelling around the barrier
- permeable or impermeable barriers that allow water to permeate still require to prevent root growth but allows the passage of moisture and nutrients
- not cause damage to the tree by being too close to the tree
- not cause damage to the building by being too close to the building
- satisfy site constraints e.g., boundaries, underground services, other buildings etc
- be rigid enough to be inserted in the ground without deformation.
- resistance to puncturing

- easily installed. Barriers should not become easily damaged when installed. Jointing of sections require careful consideration
- UV resistant
- biologically inert and preferably biodegradable within say 40-50 years

2.12 Vegetation (monetary cost estimates)

Many researchers such as Doick, Hall and Szota and organisations such as TDAG and LTOA list the numerous benefits of trees in the urban environment within a wide and growing body of research.

Defining the monetary value of trees as a concept provides enormous benefits. A monetary value can focus organisations, governments and individuals' attention to the benefits trees provide, and help quantify the losses incurred when trees are removed.

For this research, valuing trees has benefit in comparing the cost of a root barrier with the monetary loss incurred by removing a tree and directly linking issues concerning value for money.

2.12.1 Valuation Methods

Various authorities provide methods for calculating the monetary value of trees.

The Helliwell system, the CTLA (Council of Tree and Landscape Appraisers) methods (RICS, 2010) have developed tools for valuing trees.

The i-tree suite of tools (www.itreetools.org) developed by USDA (United States Department Agriculture) Forest Service provides urban and rural forestry analysis and benefit assessment tools. It takes account of specific factors in the tree value such as carbon dioxide sequestration, storm water runoff avoided, air pollution removed (Carbon Monoxide, Ozone, Nitrogen Dioxide, Sulfur Dioxide) and CO_2 stored.

Capital Asset Value for Amenity Trees (CAVAT) is widely adopted across the UK within local authority tree departments and by major landholding and transport organisations. (Doick, et al., 2018)

CAVAT is a trunk-based formula valuation method adjusted for tree health and function and it also includes in the valuation an amount for loss of amenity that other methods do not. I-tree can tend to under-estimate the true value by not including all the benefits that CAVAT includes. Values calculated using i-tree are usually lower than CAVAT presumably because not all the benefits included by CAVAT are

allowed for within i-tree. For the purposes of the research the CAVAT method is appropriate for the UK and it considers a wider range of benefits.

The CAVAT method is described online within the LTOA website where tools and information can be downloaded.

Link to latest updates provided on the LTOA website (London Tree Officers Association, 2019).

https://www.ltoa.org.uk/documents-1/capital-asset-value-for-amenity-treescavat

The publications promote wide use of the method because it is "important that valuers have at their disposal a range of valuation methods to choose from and an understanding of the purpose of a valuation in order to select the appropriate tool to use."

The authors of the CAVAT method acknowledge that: -

> *"The challenge for amenity tree valuation is that neither the intangible amenity of trees, nor the tangible benefits or services they provide are market goods (i.e., they are not exchanged or traded and there are no market prices that would allow the application of an income or sales based approach to valuation)."*

Some additional features of CAVAT include its allowance for human population density to account for all potential beneficiaries. It is also incorporated into the Joint Mitigation Protocol for use in the assessment of subsidence cases.

CAVAT has helped local authorities achieve appropriate compensation where publicly owned trees are damaged or removed without consent and to provide a basis for managing public trees as assets rather than liabilities. This value recognition includes all the benefits trees provide and could be used by insurance companies when considering mitigation options.

2.12.2 CAVAT Method

There are 2 methods for CAVAT, a full method and a quick method.

The full method has seven steps.

The first step establishes a base value, which the further six steps modify to achieve a final valuation. The steps of the full method are (Doick, et al., 2018) : -

- Step 1. Determining the "base" value (size multiplied by a unit value factor).

  Note that the species is not relevant, as an average of 10 species is used. Each tree considered separately and summed at step 7.

- Step 2. Adjustment to determine the “community tree index (CTI)” value (a value adjustment based on location, in terms of population density). Inner London and highly populated areas use a figure of 250% but 100% applies to most of the country.

- Step 3. Adjustment to determine the “location factor” (LF) value (a value adjustment made for the relative accessibility of the tree to the general public). Fully visible 100% reducing in 25% increments.

- Step 4. Adjustment to determine the “functional crown value [part 1]: structural framework” (an adjustment of the value according to crown size). An assessment of tree health and performance 100% if fully healthy reducing in 10% increments but requires expert assessment.

- Step 5. Adjustment to determine the “functional crown value [part 2]: Leaf cover completeness and condition” (an adjustment of the value according to the functional status (condition) of the canopy). 100% if fully healthy reducing in 10% increments but requires expert assessment.

- Step 6. Adjustment to determine the “amenity and appropriateness” value (a value adjustment for how well the tree species characteristics are suited to its location). Results in the range −60% to +60%. It is an expert assessment of how the tree’s positive or negative qualities affect its amenity contribution, given its specific location.

- Step 7. Adjustment to determine the “Full” value (a value adjustment for life expectancy (LE) and leading to the final value for the tree). LE greater than 80 years retain 100% of their Step 6 value; those with a LE of less than 5 years lose 90% of their Step 6 value.

The quick method follows the general approach of the full method, but is simplified for the population, by excluding less important factors and those that average out over a larger population. Expert arboricultural knowledge is required to assess tree value using the full method. The values calculated in the thesis are based upon the quick method. There is no significant loss of accuracy using the quick method; it requires less specialist tree knowledge and allows for the most important benefits that trees provide. The quick method involves the following steps.

Step 1 Determine Base Tree Value

Multiply area of the trunk by a Base Value, currently £15.88 per cm2 of trunk. Unit Base value £15.88 per cm2.

Table 2.6 Base value calculation CAVAT

Diameter D cm	Area A cm2	Base Value BV	Value A x BV £
10	78.540	15.88	£1,247
20	314.159	15.88	£4,989
30	706.858	15.88	£11,225
40	1256.636	15.88	£19,955
50	1963.494	15.88	£31,180
60	2827.431	15.88	£44,900
70	3848.448	15.88	£61,113
80	5026.544	15.88	£79,822
90	6361.720	15.88	£101,024
100	7853.975	15.88	£124,721
110	9503.310	15.88	£150,913
120	11309.724	15.88	£179,598
130	13273.218	15.88	£210,779
140	15393.791	15.88	£244,453
150	17671.444	15.88	£280,623
160	20106.176	15.88	£319,286

Step 2 Adjust for Population

The adjustment is based upon Table 2.7.

Table 2.7 Population density adjustment

Population density per hectare	% increase
<20	100
20 – 39	125
40 – 59	150
60 – 79	175
80 – 99	200
100 – 119	225
>119	250

The factor allows for increased value where more people live and therefore benefit. In very built-up areas such as central London the increase is 250%.

Greater London has an overall population density of 56 people per hectare, although local variations occur.

Step 3 Functionality Adjustment

The two considerations for the Functionality adjustment are:

1) Crown completeness. The value is reduced proportionately if • The crown has been reduced by pruning and the tree has not fully recovered; or • the crown has been reduced by natural causes, e.g., storm damage or disease, and the tree has not fully recovered; or • the crown has failed to develop normally, e.g., because of root restriction, shading or grafting, and is smaller than would be expected from the stem size • the crown is thin. This is irrespective of the nature of the causative factors and whether they harm the tree's appearance.

2) Functional condition. If the tree is in functionally poor condition, including disfigurement by disease obvious to the public, the value is reduced proportionately. Such conditions would include: • Leaf or shoot disease; • root disease, clearly affecting vitality, • canker, or severe trunk lesions, • fire damage.

Assessment does require specialist knowledge of arboriculture.

Step 4 Life Expectancy Adjustment

The adjustment allows for the tree being in place for a specified amount of time.

Table 2.8 Life expectancy adjustment

Life expectancy	Adjustment
80+	100%
40-80	95%
20-40	80%
10-20	55%
5-10	30%

It can be shown using the quick method that a large tree of any species with trunk diameter of 150cm in a heavily built-up area in excellent condition with long life - expectancy can have a significant value calculated as follows: -

Base value £280,623 (150cm diameter trunk) x 250% (population adjustment) x 100% (condition adjustment) x100% (age adjustment) = £701,550.

The values using the full method for a similar sized tree can be higher with additional adjustments for trees in very good condition and appropriate setting.

The argument presented and the derived values demonstrate that trees are valuable, although this is not always widely appreciated or acknowledged.

2.12.3 Summary Valuing Trees

Rather than viewing trees as a nuisance, a liability or a problem, should they be viewed as shown in Figure 2.5?

Figure 2.5 How valuable is a tree? (Shutterstock, 2021)

The fundamental question is how valuable a tree is and how an individual perceives a tree's value? If a tree was looked upon, as shown in Figure 2.5, it is unlikely to be removed except under exceptional circumstances.

2.13 Gap in Knowledge

One of the fundamental cornerstones of the doctoral research is identifying and subsequently filling a gap in knowledge.

The literature review has considered literature and theory relating to soils, trees, buildings, weather, and complex interactions. The literature review has also highlighted a lack of published information on deep embedded root barriers, up to 5m deep, the type of which that would be required to deal with clay shrinkage subsidence claims.

A gap is not a void as a void is an absence of any information whereas a gap conveys knowledge either side of the gap, like a crevasse in ice. The crevasse (or gap) exists because of the shoulders, as indicated in Figure 2.6.

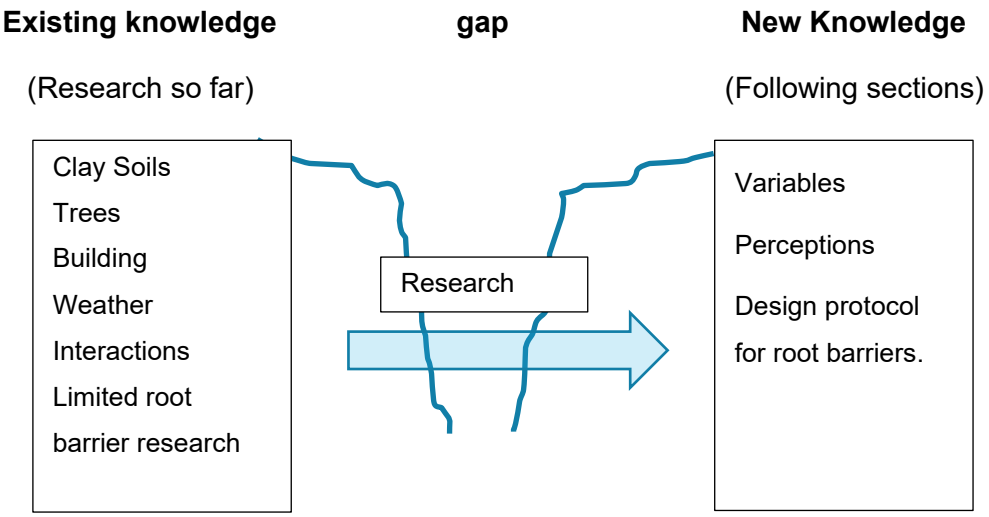


Figure 2.6 The current gap in knowledge (Source Author)

The research is the process by which one moves from the left, existing knowledge (up to this point of the thesis) toward the right (following section and subsequent chapters).

Having identified the gap that currently exists, the research progresses by listing variables and perceptions and then organising them into a theoretical framework to inform and direct the research design, results, analysis and discussions to achieve the original aims and objectives.

2.14 The Variables Listed

Through literature review and examination of theory the main variables regarding the use of root barriers are now listed in Table 2.9, with appropriate categorisation.

Table 2.9 Tabulated variables from literature and experience

Variable	Category
Clay soil properties (soil shrink ability)	soils
Property foundation depth	building and site
Property location	building and site
Costs of underpinning	building and site
Distance between the building and the barrier	building and site
Site features walls, paths, services, etc	building and site
Tree species	The tree(s)
Tree size (mature height)	The tree(s)
Tree vigour	The tree (s)
Tree age	The tree(s)
Tree trunk diameter	The tree(s)
Protecting trees from damage	The tree(s)
Distance between root barrier and the tree	The tree(s)
Depth of root barrier in the ground	the root barrier
Length of root barrier across the site	the root barrier
Root barrier materials used	the root barrier
Cost of installation of a root barrier	the root barrier
Root barrier construction method	the root barrier
Root barrier material durability (resist root penetration)	the root barrier

2.15 Theoretical Propositions (Initial Root Barrier Design Protocol)

The variables, organised within a theoretical framework or theory, form the basis of the initial design protocol (IDP). This IDP links specific variables, provides a basis for research methodology, and helps structure the results, analysis and discussion.

Theories are an integral part of research and having first identified the variables, the IDP generates logical links and identifies relationships. The psychologist Kurt Lewin (1890–1947), founder of the concept of “Action Research” (Lewin, 1946), was a proponent of the importance of combining “theory” and “practice” in the social sciences. Lewin's observation, otherwise known as “Lewin's Maxim”, “there is nothing as practical as a good theory” (see, e.g., Lewin, 1943) puts theory at the heart of research.

The IDP, or theory, is also necessary due to the lack of existing literature and theory identified in the literature review. Whilst this lack of literature is an advantage when demonstrating a knowledge gap, as no theory currently exists, there is also no guidance on how to combine variables in the design and construction of root

barriers. The theoretical proposition or IDP presented in the following section is new, developed from the individual component variables and existing, unrelated theories. The existing theories, identified in Figure 2.7 combine NHBC guidelines, British Standards, Codes, current practice and experience.

The IDP has been placed here in the thesis because it is integral to the literature's necessary engagement. In particular, the variables, The IDP brings together the limited literature on the topic of root barriers and combines it with related theory, literature and experience. The IDP also acts as a template to inform later sections such as methodology, assist design of the case study protocol, and provide a structure for results analysis and discussion, culminating in the informed design protocol in Chapter 7.0.

Figure 2.7 illustrates diagrammatically how disparate theories have been combined to form the basis of the initial design protocol.

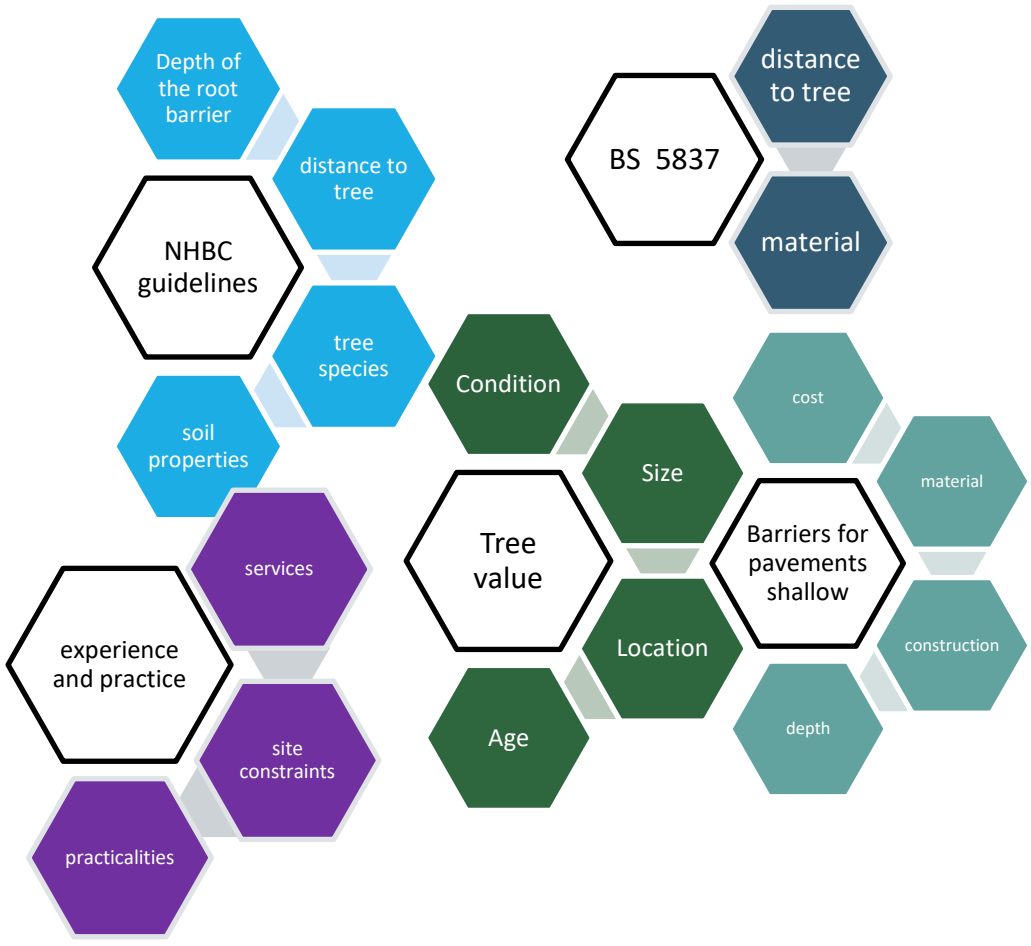


Figure 2.7 Existing theories combined for initial design protocol (Source Author)

2.16 The Initial Design Protocol

2.16.1 Variables Within Initial Design Protocol

The variables that will be considered in relation to the initial design protocol or theory are taken from the full list identified earlier in the chapter.

Table 2.10 List of variables for initial design

Variable	Category	Value
Clay soil properties (soil shrink ability)	soils	High shrinkability
Property foundation depth	building and site	1m
Distance between the barrier and the building	building and site	tbc
Site features walls, paths, services, etc	building and site	n/a
Tree species	The tree(s)	Oak
Tree size (mature height)	The tree(s)	20m
Tree vigour	The tree	Normal
Tree age	The tree	Mid age
Tree trunk diameter	The tree(s)	0.34m
Protecting trees from damage	The tree(s)	BS
Distance between root barrier and the tree	The tree	tbc
Depth of root barrier in the ground	the root barrier	tbc

Note that variables such as building damage severity, costs of underpin, location, durability, barrier materials are not included in Table 2.10. This simplifies the initial design protocol whilst accepting that their omission would not adversely affect the IDP's outcome.

The “value” column in Table 2.10 provides information used in the example to follow. “tbc” in the same column identifies the variables to be calculated using the design protocol, namely the depth of the root barrier its location.

2.16.2 Notation

The following notation is used in the protocol and maintained throughout the thesis.

d (t min) minimum distance between root barrier and tree

d (b min) minimum distance between building and root barrier

d (t) installed distance between root barrier and tree (actual)

D overall distance between tree and building

h depth of root barrier at desired location

h(f) existing foundation depth

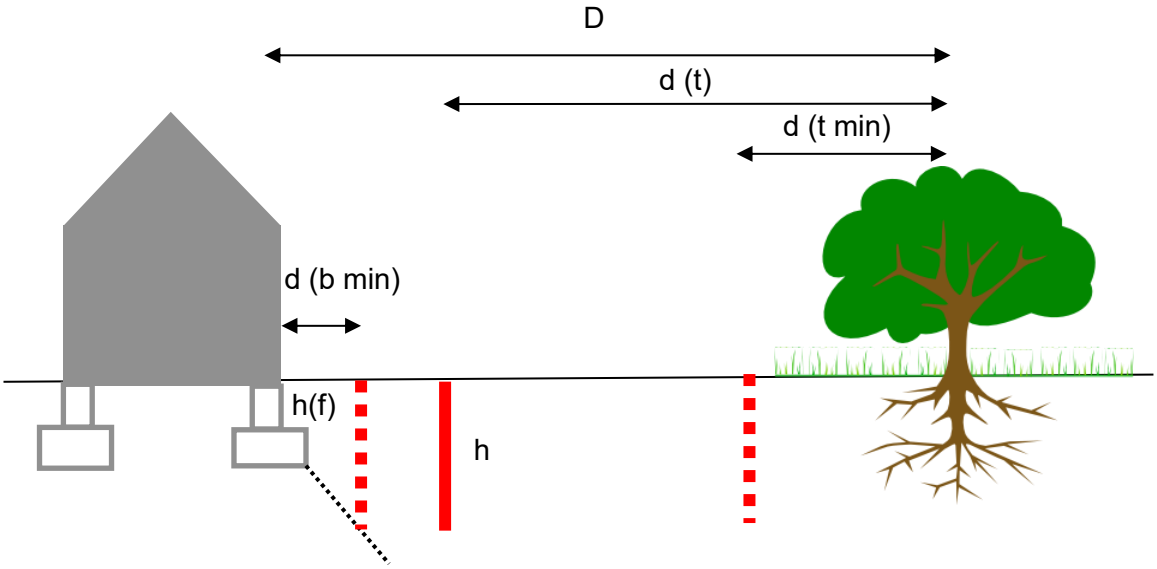


Figure 2.8 Notation defined (Source Author)

2.16.3 Considerations

Figure 2.8 demonstrates potential locations of a root barrier somewhere between *d (t min) (minimum distance barrier to tree) and the property d (b min).*

The minimum distance between the barrier and the tree d (t min) is determined by avoiding damage to the tree roots and is fixed for the tree type and characteristics.

The minimum distance between the barrier and the building d (b min) is governed by ensuring that the 45-degree load spread is maintained. This distance d (b min) depends on the depth of the existing foundations h(b) (known =1m) and barrier depth required (h) (unknown) as shown in Figure 2.8.

2.16.4 Input Information

The essential minimum input information required to calculate root barrier depth and location includes: -

- clay soil properties (high, medium or low shrink ability)
- existing foundation depth
- tree species and trunk diameter
- mature height of the tree
- overall distance between tree and the building

2.16.5 Calculation Stages

The calculation is carried out in the following stages: -

- calculate minimum distance between barrier and tree d (t min)
- calculate barrier depth at d (t min)
- determine position adjacent to the property at which point the barrier does not undermine foundations
- calculate barrier depth at intervals from the tree, starting at d (t min) up to d (b min)
- determine barrier location between d (t min) and d (b min)
- flow chart of process

The above stages are explained in more detail in the following sections.

2.16.6 Calculate Minimum Distance Between Barrier and Tree [d (t min)]

To prevent damage to the tree, the barrier must be positioned further than the minimum specified by **BS5837** (British Standard Institution, 2012)

Assuming 340mm diameter tree BS5837 requires a minimum distance of 12 x stem diameter = 4.1m.

Therefore, minimum distance tree to barrier d(t min) = 4.1m.

2.16.7 Calculate Barrier Depth Closest to Tree [h (t min)]

It has been determined that the root barrier must be constructed at adequate depth to prevent roots passing underneath. The appropriate theory to use to calculate the depth of the barrier is NHBC guidelines (National House Building Council, 2019). In section 2.3, the use of NHBC tables to calculate foundation depth for new buildings constructed near to trees for various tree species and distances on specific soils

was explained. The NHBC tables are also appropriate to similarly calculate the depth of a root barrier. If NHBC tables provide the depth below which tree roots influence is negated, it also applies to a root barrier. Underpinning depths are routinely calculated using NHBC tables and there is no other reference document that provides such practical guidance.

2.16.8 Calculate Minimum Distance Between Barrier and Building [d (b min)]

The minimum distance between the barrier and the building d (b min) is governed by ensuring that the 45-degree load spread is maintained. This distance d (b min) depends on the depth of the existing foundations h(b) (known =1m) and barrier depth required (h). The minimum distance however cannot be determined if depth (h) is unknown.

2.16.9 Calculate Barrier Depth Closest to Building [h (b min)]

To calculate the required barrier depth (h) closest to the building (at the position of d(b min) the distance from the tree is required (d), however, the distance required to avoid 45-degree infringement is unknown.

An indeterminate relationship is set up that can be resolved by calculating various barrier depths (h) at pre-set intervals from the tree and checking each location to identify if the 45-degree rule is infringed.

This process also enables the depth of the barrier to be determined at numerous locations to establish an ideal position between the two limits.

2.16.10 Calculate Barrier Depth at Various Distances from the Tree (h)

The depth of the barrier (h) is determined at pre-set 1m intervals (in the example below using NHBC tables), from the minimum distance d(t min) to D tabulated in Table 2.11.

.

Table 2.11 Example tabulated results

Inputs	**min dist tree to barrier**	**d (t min)**	**4**	**m**
	foundation depth	**h (b)**	**1.0**	**m**
	distance tree to building	**D**	**12**	**m**
distance tree to root barrier	distance building to root barrier	depth of barrier required (NHBC)		
d t	**D-dt**	**h**		
4	8	3.1		
5	7	3		
6	6	2.9		
7	5	2.8		
8	4	2.7		
9	3	2.6		
10	2	2.5		
11	1	2.4		
12	0	2.3		

Table 2.11 shows inputs as d(t min) =4m and an existing foundation depth of 1.0m.

The total distance tree to building is 12m.

Note the starting point for depth calculations is 4m as the barrier cannot be placed closer to the tree than this distance.

2.16.11 Calculations

Concerning Table 2.11, it should be noted that at 9m distant a 2.6m deep barrier would be required. There is a point at which the depth of the barrier and the 45-degree load spread co-incide.

This is given by Equation 2-1

h(b)+(D-d)>h

Equation 2-1 45-degree encroachment

In other words, the depth of the foundation h(b) plus the distance between the building and the root barrier (D-d) must be greater than the depth of the barrier (h). This ensures 45-degree load spread is maintained.

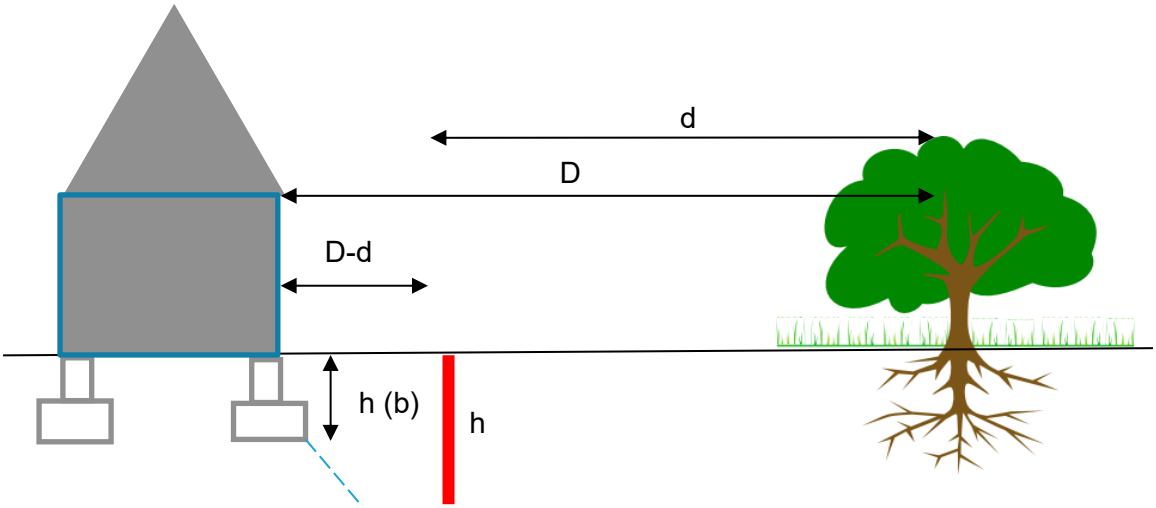


Figure 2.9 Identifying the zone where barrier may be installed (Source Author)

2.16.12 Spreadsheet Calculation

Table 2.12 produced within an excel spreadsheet includes a logical calculation in the final column checking the above criteria and generating a false or not false statement regarding encroachment onto the 45-degree line.

Table 2.12 Calculations within the spreadsheet

inputs	min dist tree to barrier	d (t min)	4	m
	foundation depth	h (b)	1	m
	distance tree to building	D	12	m
distance tree to root barrier	distance building to root barrier	depth of barrier required nhbc	check on suitability	
d	**D-d**	**h**	**h+(D-d)>D**	
4	8	3.1	ok	
5	7	3	ok	
6	6	2.9	ok	
7	5	2.8	ok	
8	4	2.7	ok	
9	3	2.6	ok	
10	2	2.5	ok	
11	1	2.4	FALSE	
12	0	2.3	FALSE	
input values	calculated value	input values	calculated value	

The barrier may be placed at between 4.1m and 10m distant from the tree at the depths shown in the example. The spreadsheet is useful because it is beneficial to have a range of locations for the barrier in case of obstacles or obstructions or features that may necessitate one location above another.

2.16.13 Flow Chart of Initial Design Protocol

The initial design protocol shown in Figure 2.10 determines the stages in the design of a root barrier.

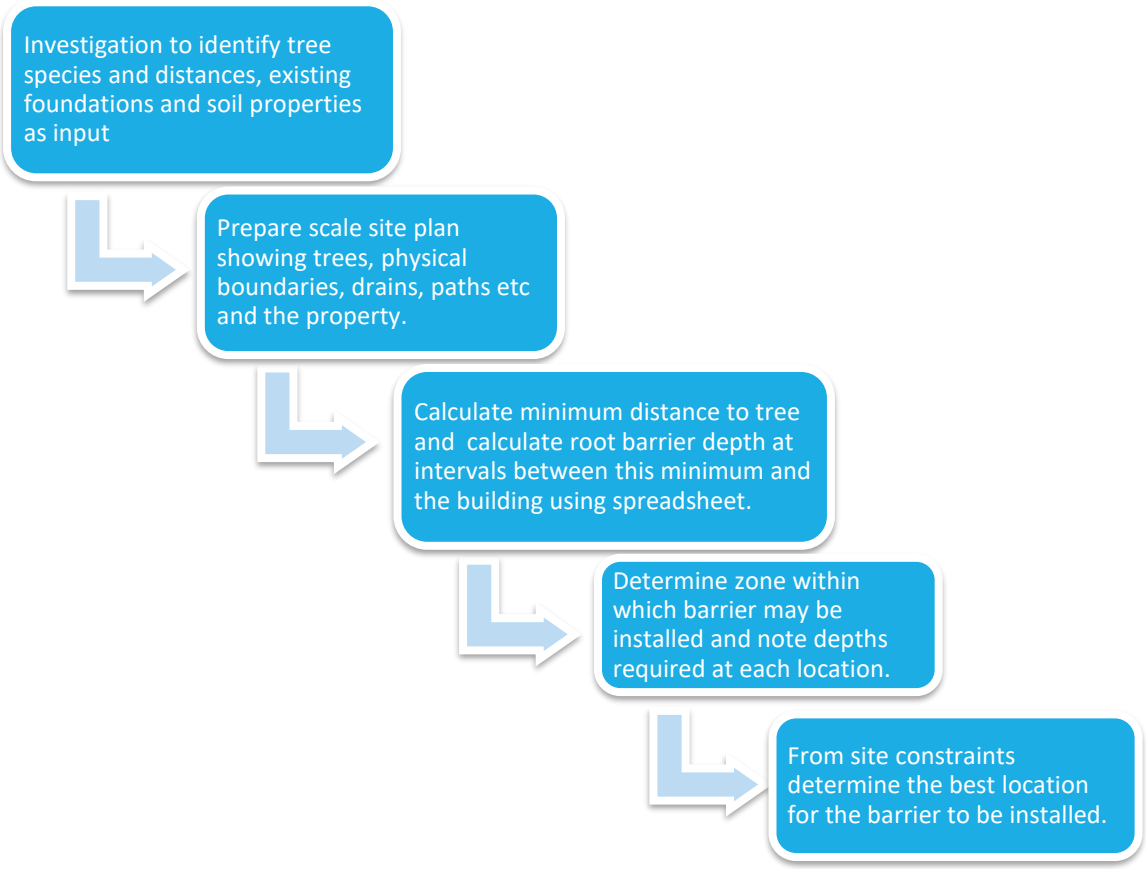


Figure 2.10 Initial design protocol process flow chart (Source Author)

2.16.14 Example

Figure 2.11 illustrates an example using the initial design protocol showing the tree, building and the barrier location chosen towards the garden's rear to avoid services.

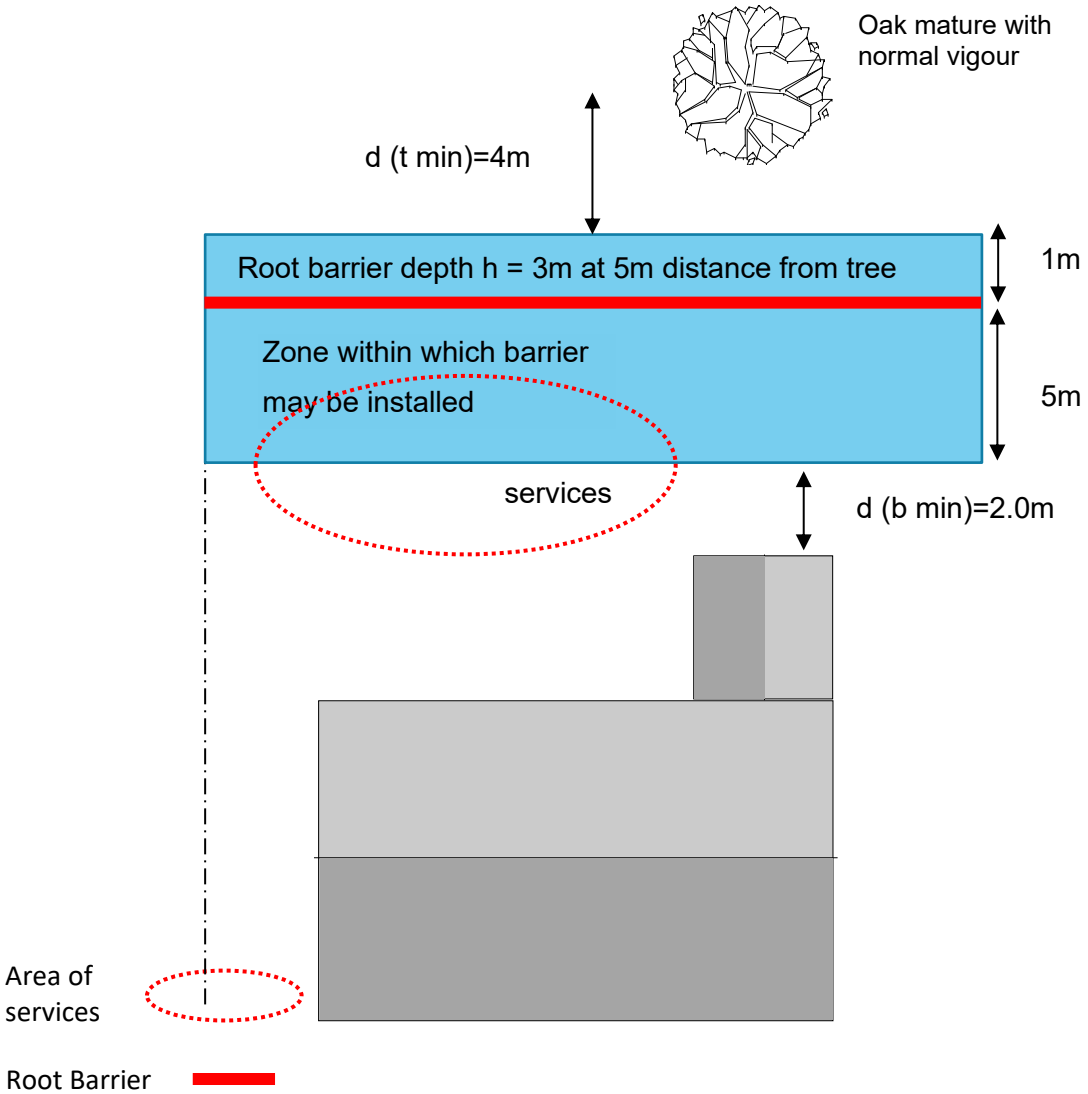


Figure 2.11 Example of root barrier located on plan of the site (Source Author)

Based upon the example in Figure 2.11, the following have been used.

Min distance between root barrier and building d (b min) = 2m
Min distance between root barrier and tree = d (t min) = 4m
Total distance between tree and building =12m

The zone within which barrier may be installed is marked on the plan with dimensions from the building and from the trees. The barrier is located, in this example, towards the rear of the rear garden, 5m from the tree. At this location depth of barrier required is calculated using the spreadsheet at h = 3.0m. This is deeper than would be required at say 9m distant (h = 2.6m) but services are avoided by placing the root barrier to the rear of the garden.

2.17 The Perceptions Listed

The perceptions are now considered through literature review and experience, with certain variables included to identify links in Table 2.13.

Table 2.13 Perceptions from literature and experience (Source Author)

Perception	Perception or Variable	Category
Root barriers are unreliable, or they are a temporary solution	perception	reliability
Avoid their use	perception	reliability
Site constraints limit their use	perception	practical
Should be used rarely	perception	
Undesirable side effects	perception	knowledge and practical
Could damage cut root ends	variable	Distance tree to barrier
They are difficult to install, a specialist operation i.e. companies do not have the expertise	perception	
Water flow concerns around barrier	variable	barrier material
Untried method	perception	reliability, knowledge
Uncertain	perception	reliability
Possible environmental damage	variable	barrier material
Root barriers are too expensive (from experience) and they are not good value for money	perception	cost
High Cost	perception and variables	cost of root barrier
Extent of the barrier	variable	length of barrier
Damage to trees by severing roots leading to instability	variable	distance tree to barrier
Unreliable	perception	reliability
Require environmental acceptance	variable	material and construction
Be of sufficient depth to prevent roots growing below	variable	depth of barrier
Cause disease within cut root ends	variable	distance tree to barrier and barrier material
Underground features e.g. drains	perception	practical
Hard to implement	perception	practical
Comments below from reference (Driscoll & Skinner, 2007)		
Useful where there is low severity damage	perception	cost
Useful where damage occurred after exceptionally dry weather	variable	weather
Useful where Tree cannot be removed or reduced	perception variable	cost reason for barrier
Used where there is resistance to cost of underpinning	perception variable	cost Reason for barrier

Table 2.13 lists the perception or concern from literature in the first column, identifies whether it relates primarily to a variable or a perception or both in the second column and the third column provides the general category. Where there is

a connection with variables this is also identified. In Table 2.13 perceptions are listed with appropriate categorisation with a view to fulfilling objective 2.

In the same way that the variables were identified from theory and literature and developed into the initial design protocol, the perceptions are categorised and grouped within a theoretical proposition so that links and patterns can be established to provide focus for the research, assist in structuring the results, analysis and discussion in Chapters 4 and 5.

Some of the perceptions are also associated with variables previously identified, such as reliability and the comment that roots can grow under (from literature) is related to the depth of the barrier which is considered under the list of variables. Table 2.13 also identifies those items that relate to variables, perceptions or both.

The perceptions may be combined under four main categories that summarise the perception. These are: -

- practical concerns
- knowledge concerns
- cost concerns
- reliability concerns

2.17.1 Theoretical Proposition Perceptions

The theoretical proposition seeks to develop relationships and a common link between the perceptions. The theory used is that of conventional project and operations management that utilises the concepts of cost, quality and time.

Operations management considers such issues of performance and concerns services and products upon which we all depend. Most companies understand the importance of operations management to improve efficiency, performance, quality, customer care, etc and ultimately profit. The 5 operations performance objectives used in performance management are, according to Slack et al (Slack, et al., 2010, p. 40) : -

- quality (fit for purpose)
- speed (working fast)
- dependability (available on time)
- flexibility (adaption to change)
- cost (value for money)

Figure 2.12 indicates how the components of cost, quality and time are inter-related.

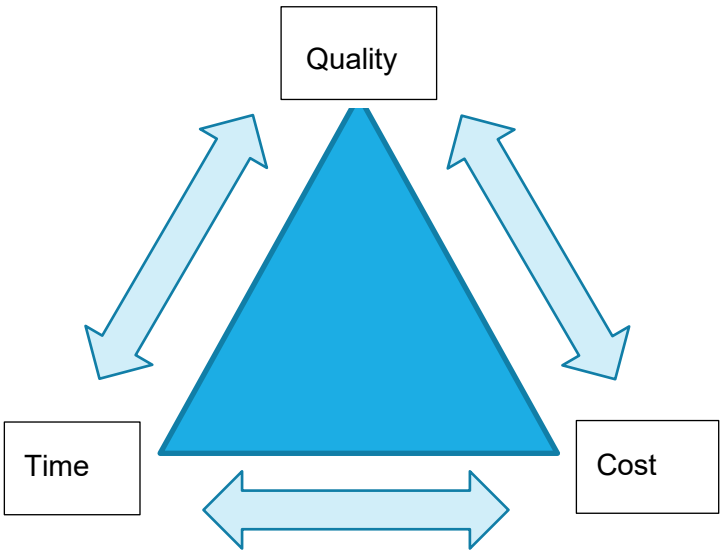


Figure 2.12 Quality Cost Time conceptualisation for perceptions (Source Author)

In terms of quality, the ISO 8402-1986 standard defines quality as, “the totality of features and characteristics of a product or service that bears on its ability to satisfy stated or implied needs.” Linked to quality is reliability and the difference is that quality shows how well an object performs its proper function, while reliability shows how well this object maintains its original level of quality over time, through various conditions.

Cost refers to the actual cost to implement but this also links with value for money. From experience value for money is at least as important as the cost of a product or service.

Time refers to the “doing” of an operation or process. The time to complete must be reasonable and not be excessive or consume too many resources. By means of an example, it could be that I could make a perfectly good chair; the costs could be low and the quality exemplary but if it takes me two years to make, then it will not be successful from a project management perspective.

The perceptions considered against cost quality and time.

Table 2.14 Perceptions vs cost, time and quality (Source Author)

Perceptions (The now)	Cost	Quality	Time	By overcoming these concerns with regard to cost, quality and time root barrier gains greater acceptance
Root barriers are unreliable, they do not work and are only a temporary solution. Avoid their use. Uncertain solution Used rarely	Costs of repeated returns	Poor quality leads to unreliability and if rarely used quality cannot improve	Time involved in redoing poor work Rarely used no expertise built up	
A specialist operation. There is insufficient data on their use. Untried solution.	Additional training and development costs	Inadequate knowledge or understanding leads to poor quality	Inadequate knowledge leads to more time in doing the work or design	
Root barriers are difficult to implement. Practicalities and site constraints limit their use.	Additional costs in diverting services or replacing walls etc	Difficulties in dealing with obstructions or services could lead to failure	Additional time in diverting services or replacing walls etc	
Most companies do not install root barriers, they do not have the expertise or skills.	Lack of expertise leads to increased costs	Lack of expertise leads to poor quality	Lack of expertise leads to increased time in completing the work	
Root barriers are too expensive. Tree removal is more cost effective. Value for money concerns.	High perceived cost of root barriers compared with tree removal	To achieve required quality costs would be too high	Tree removal is much quicker than root barrier installation	
Undesirable side effects, damage to trees, tree disease, environmental damage, water flow issues.	Cost to return and deal with problems caused by root barrier	Undesirable side effects are a sign of poor quality	Time to return and deal with ongoing issues and side effects	

Table 2.14 shows how perceptions relate to cost, quality and time concerns and that there needs to be a shift to the right, as shown by the arrows, to overcome these concerns and promote root barrier use, as shown in the right-hand column.

Table 2.15 lists the perceptions within cost, quality and time criteria.

Table 2.15 Perceptions in the use of root barriers (quality, cost, time)

	Perception
Cost	Practitioners may be aware of the solution and may have used in the past however the cost may deter practitioners from selecting a root barrier as an alternative to tree removal. Practitioners may not perceive a root barrier as cost effective or value for money. Practical implications as perceived by practitioners be it services, neighbours' gardens, features etc that would deter root barrier being considered on cost grounds. Training and development costs. Cost to repeat if solution does not work.
Quality	This can take the form of a general perception that root barriers are unreliable or that practitioners do not have the tools to initiate the solution. A lack of knowledge can drive it. Practitioners avoid root barriers due to quality concerns. Construction difficulties may give the impression that barriers cannot be reliably installed.
Time	Practitioners may be set in their ways only using solutions that they are aware of and not having the time to consider other options such as a root barrier. Not a routine solution therefore requires additional time, resources and expertise that practitioners may not have. Tree removal is quicker solution. Additional time if poor work needs to be repeated.

The four categories of perceptions should be linked to the concepts of cost quality and time.

Practical concerns link with time

Root barriers are difficult to implement, Issues dealing with services and site features, Construction is difficult and time consuming.

Cost concerns link with cost and value for money

Root barriers cost too much but more importantly are not value for money.

Reliability concerns link with quality

Reliability is linked to quality as if root barriers do not work, there is a high failure rate and there is a need to return.

Knowledge

The link to knowledge does not appear straightforward as there are four perceptions (practical, cost, reliability and knowledge) and three concepts; cost, quality and time.

Where do knowledge concerns fit? e.g., lack of expertise or experience in their use, lack of training, no design rules available etc. Booth et al comments as follows:-

> *"The consequences of a conceptual problem are a particular kind of ignorance. It is a lack of understanding that keeps us from understanding something else even more significant put another way because we haven't answered one question, we can't answer another that is more important".* (Booth, et al., 2016, p. 55)

The conceptual problem in this thesis would be the concerns of tree losses, and valuing trees sufficiently to argue for using root barriers leading to the discovery of knowledge concerning root barriers. It is the lack of knowledge and the need to research root barriers that gives rise to the research and knowledge appears to bind everything together.

Knowledge is therefore placed centrally and finds its place within the cost, quality time continuum (Figure 2.13)

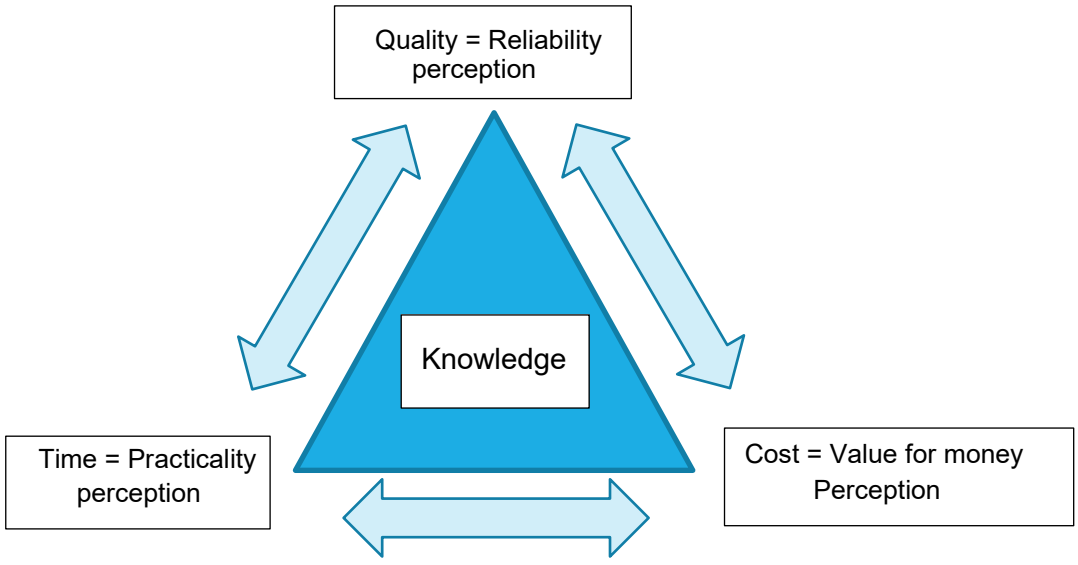


Figure 2.13 Cost quality time links to the four perceptions (Source Author)

To summarise, the three concepts of cost, quality and time have been linked directly to the four perceptions of cost (value for money), reliability and practicality respectively, all being held together by knowledge.

2.18 Overall Conceptual Framework (combining variables and perceptions)

The overall conceptual framework illustrated in Figure 2.14 "The Onion Ring" Barriers to progress, illustrates how the variables and the perceptions combine with practical, cost, knowledge and reliability concerns. According to Maxwell, the conceptual framework is a system of concepts, assumptions, expectations, beliefs, and theories supporting or informing your research. (Maxwell, 1996)

Figure 2.14 shows the tree removal solution centrally placed as the current default or "entrenched" position where practitioners currently operate. This entrenched position derives from the literature review and professional experience**.** The root barrier solution is shown outside the outer ring as the research's desired aim and objective. To move from the entrenched central position to the outer desired position (root barrier), there are obstacles or concerns to overcome as previously identified, namely practicality, cost, knowledge and reliability concerns, all of which have links to the cost, quality, time continuum.

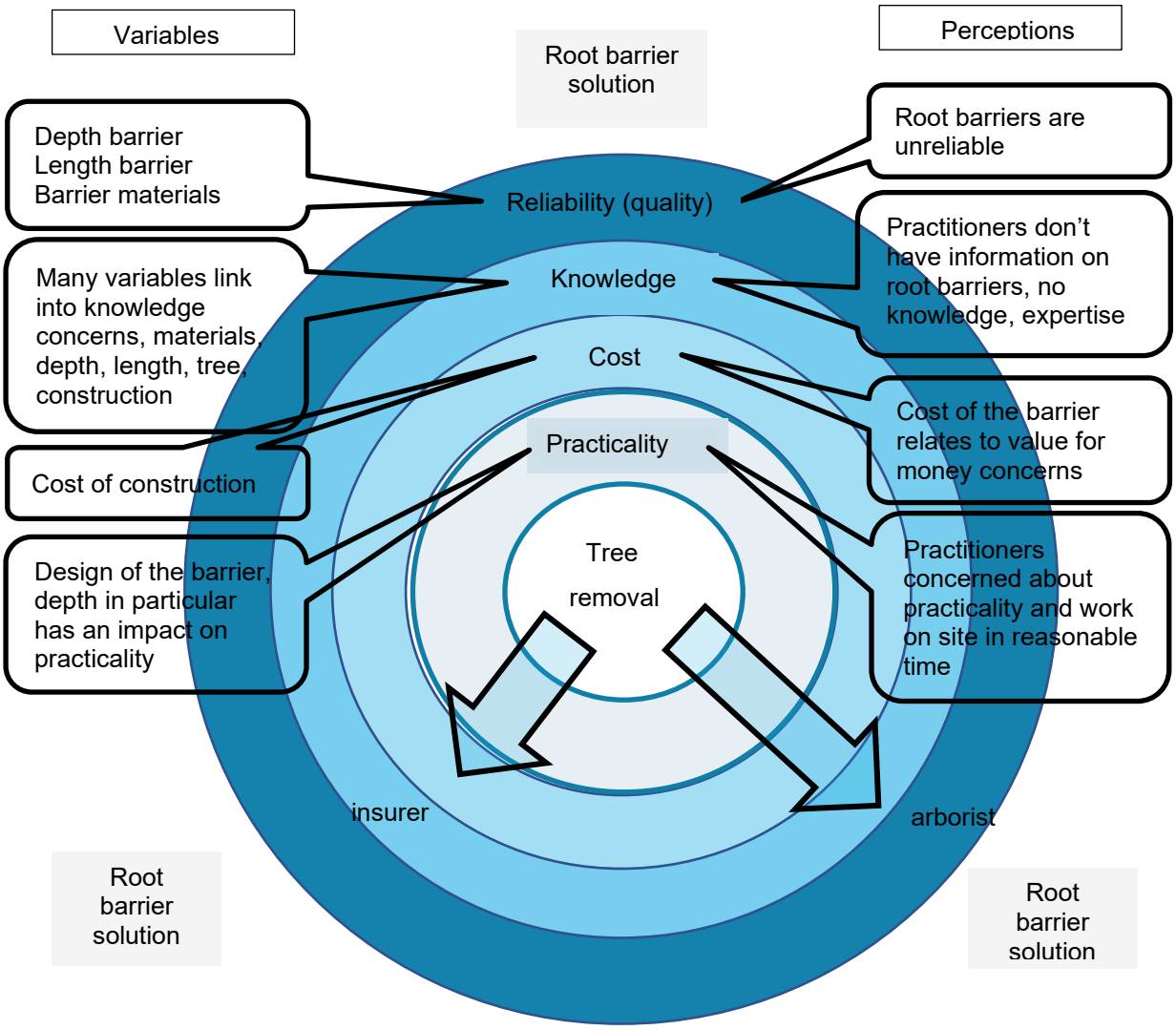


Figure 2.14 "The Onion Ring" Barriers to progress (Source Author)

The concentric circles represent hurdles or obstacles preventing root barriers being used or considered to deal with clay shrinkage. The arrows show the direction of flow, practitioners who begin at the centre (tree removal) and work towards the outside (root barrier) but have not reached the root barrier position at the present time.

Practitioners are currently situated somewhere within the “Onion Ring” with no means of “escaping” to the root barrier solution while there are genuine practical, cost, knowledge and reliability concerns.

A particular insurer, for example, could be situated in the cost ring but an arborist held up in the knowledge ring as insurers may be initially more entrenched in the tree removal position due to cost concerns, and the need to limit claim cost, than arborists.

One of the main aims of the research is to identify these barriers and seek to understand and overcome them so that there is a movement from an entrenched position in the middle (tree removal) to the alternative of a root barrier, on the outside.

2.19 Contribution to Knowledge

The contribution to knowledge comprises of identifying the benefits of root barriers over other methods and developing a strategy for the implementation of root barriers.

Concerns have been identified within current practice, in the subsidence context, if the true value of trees in the urban environment is considered. This forms the basis of making the case for change in developing alternative solutions, such as a root barrier.

The research contributes to professional practice by highlighting the importance of developing alternative solutions to tree removal when dealing with clay shrinkage subsidence with specific regard to root barriers. By considering the perceptions of root barriers amongst practitioners the various obstacles to their implementation may be quantified.

The research should identify the merits of root barriers in specific circumstances and identify where they are likely to be successful.

Decisions on whether to use root barriers will be more informed because the choice will be based on better information giving greater confidence leading to increased use as shown in Figure 2.15.

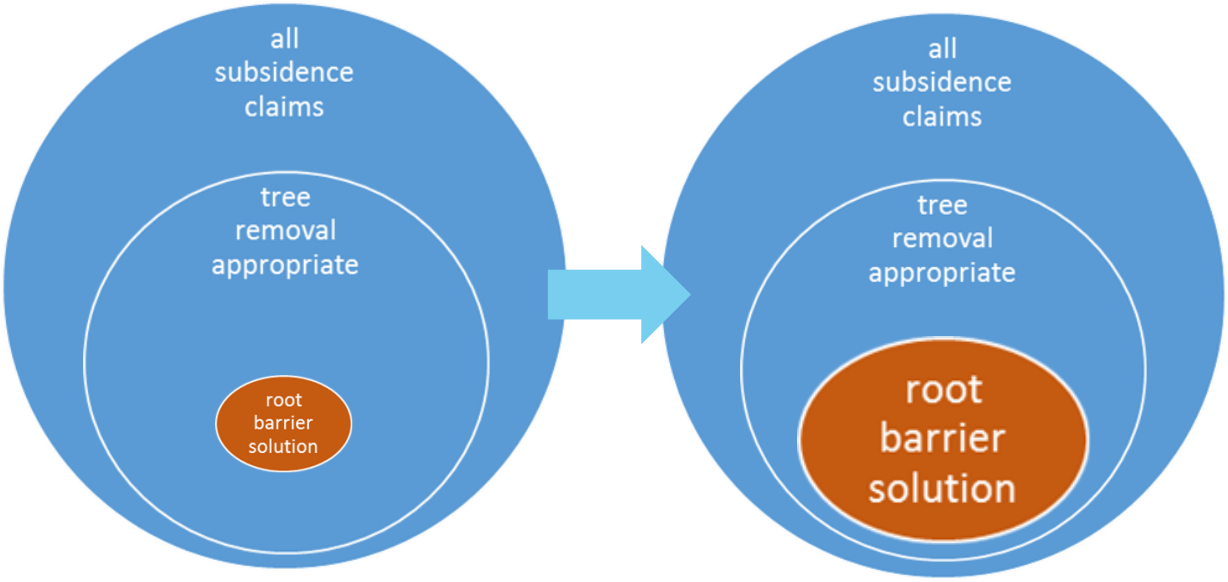


Figure 2.15 Contribution to knowledge, before & after research (Source Author)

2.20 Closing the Gap

Returning to the crevasse analogy mentioned earlier in the chapter and illustrated diagrammatically in Figure 2.16.

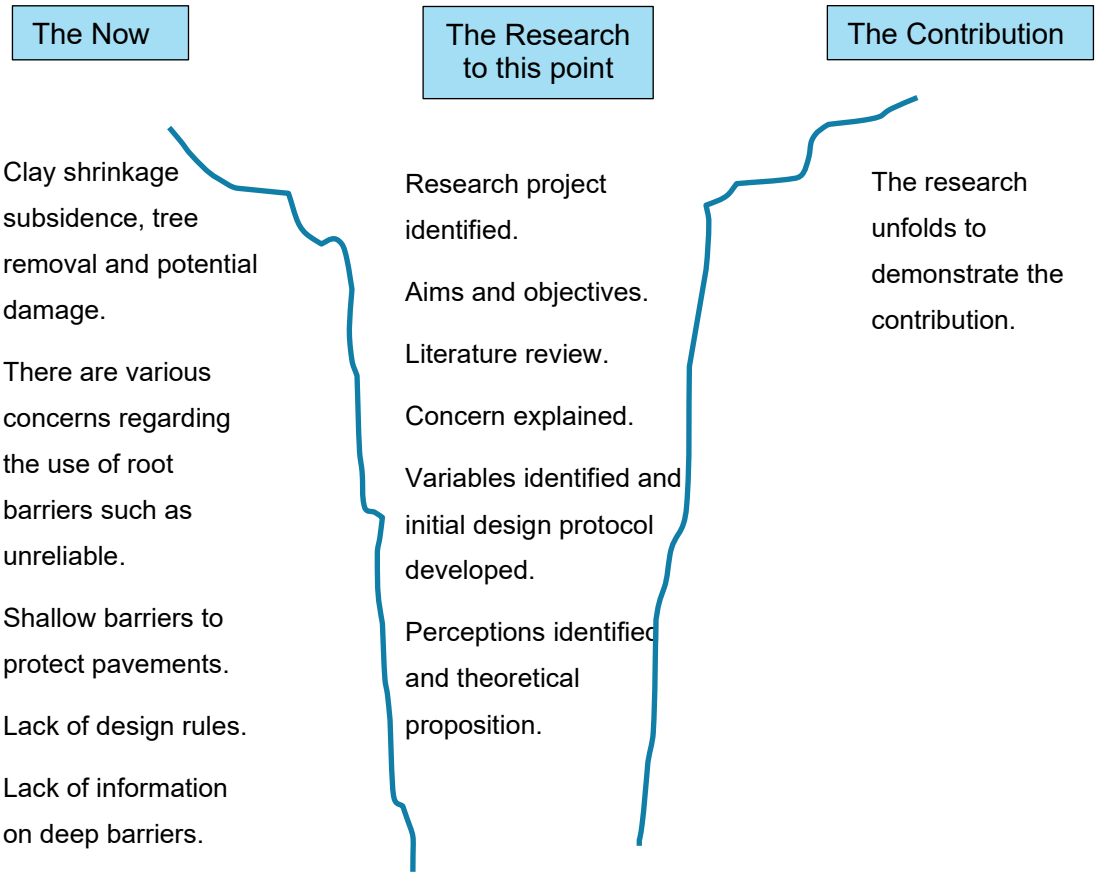


Figure 2.16 Crevasse analogy (closing the gap) (Source Author)

The research unfolds from the present position to fill the gap and demonstrate a contribution.

2.21 Summarizing Chapter 2

Chapter 2 reviewed the relevant texts concerning clay shrinkage subsidence from various fields of expertise such as subsidence claims management, arboriculture, soils and materials. The texts were linked to the variables relevant to research into the practical use of root barriers. The chapter identified the lack of published literature or research or guidelines regarding the use of root barriers to resolve clay shrinkage subsidence. It was noted that whilst this lack of literature identifies a clear gap in knowledge, it does not provide a platform upon which to build theory in the use root barriers. Regarding variables, the initial theory had to be constructed and concerning perceptions, it was necessary to review current literature. The Chapter also formed links and relationships between variables by considering existing theories, such as NHBC guidelines, and explained how they related to the research. The process of creating order from disorder concerning variables and perceptions is illustrated in Figure 2.17.

Start of research	Chapter 2
No pattern and irregular	Separate out
Unrelated to root barriers	Relate to root barriers
No structure	Theorise/order
No relative importance	Provide relevance

Following Chapters
Variables and perceptions with structure
Relative importance established
Ordered
Pattern established

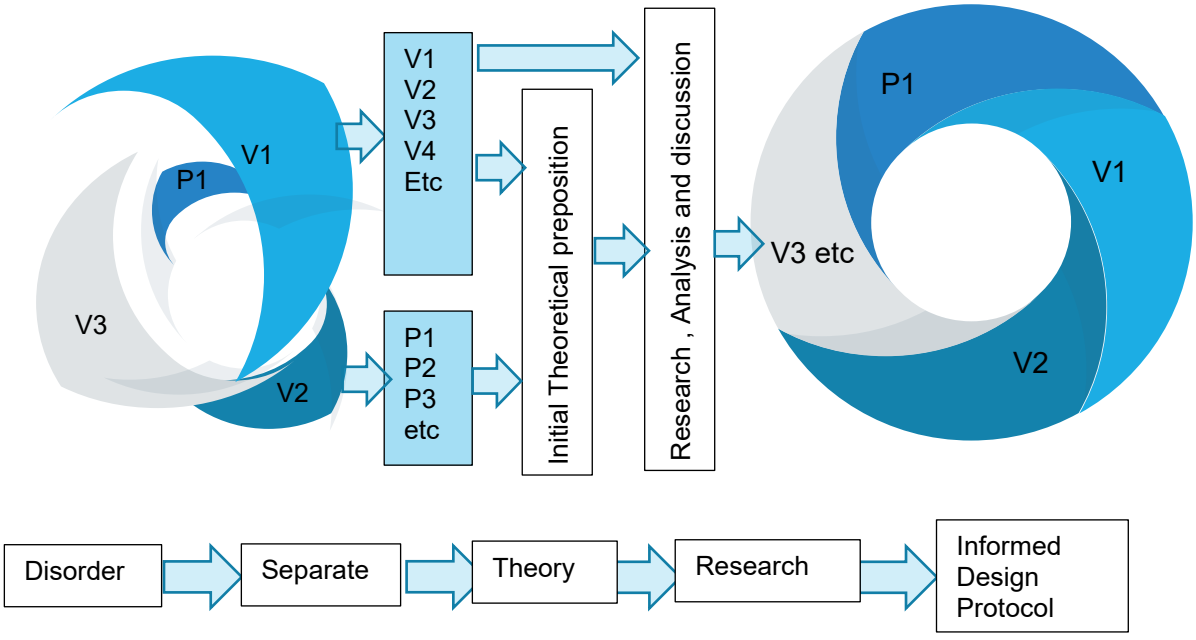


Figure 2.17 Research outline (creating order from disorder). Prefix V refers to "variables" and prefix P refers to "perceptions" (Source Author)

PART B

RESEARCH DESIGN

PART B Research Design

3.0 Research Design

3.1 Introduction

The earlier chapters have justified the use of root barriers and established the research aims and objectives. Through literature review the most important variables and perceptions in the use of root barriers were identified fulfilling objectives 1 and 2. The variables and perceptions were defined and categorised leading to development of theoretical propositions for variables and perceptions necessary to progress to subsequent stages of the research. Variables were combined into the initial design protocol and perceptions categorised and combined into a project management type theoretical proposition or framework of Cost, Quality and Time.

The next two chapters build upon the previous two chapters to achieve the research aims and the third objective, namely to: -

> "analyse a) the variables and b) the perceptions that influence the use, effectiveness and reliability of root barriers".

This chapter entitled "Research Design" covers the theory concerning the chosen methodology and the appropriate methods. Concerning methodology, the research's ontological position, is followed by the epistemological stance, which leads into theoretical perspective that informs the methodology. Methods follow methodology and describe how the data will be collected.

At this point there must be clarification between the terms "methodology" and "methods" as they appear remarkably similar and are often used interchangeably in the literature. Crotty agrees, as within the introduction of his text on the Foundations of Social Research (Crotty, 1998, p. 1) he states:-

> *"research students often express confusion at the array of methodologies and methods laid out before them and they are not usually laid in a highly organised fashion. Whilst philosophical underpinnings are mentioned what is not clear is how the methods and methodology relate to the more theoretical elements and to add to the confusion the terminology is far from consistent."*

Crotty's (Crotty, 1998, p. 3) definition of "methodology" is "the strategy, plan of action, process or design lying behind the choice and use of particular methods and linking the choice and use of methods to the desired outcomes."

A dictionary definition states "methodology" is "a set or system of methods, principles and rules for regulation ..... the underlying principles and rules of

organisation of a philosophical system or enquiry procedure." (Random House Unabridged Dictionary, 1993). According to Grix, research methodology is "concerned with the discussion of how a particular piece of research should be undertaken". (Grix, 2004, p. 32) In this thesis the term methodology refers to the more general, underlying principles, or overarching system or understanding of how the research will be conducted. Within the term methodology the thesis includes ontology, epistemology and theoretical perspective. Methodology precedes method, covered in the following Chapter 4.

Methods follow on logically and consistently from methodology. According to Crotty methods are "the techniques or procedures used to gather and analyse the data related to some research question or hypothesis". A dictionary definition states, "a procedure, technique or way of doing something *esp.* in accordance with a definite plan". (Random House Unabridged Dictionary, 1993)

Another useful way of viewing the term "method" and as used in this thesis, would be "data collection instruments", as used by Gray. (Gray, 2004)

The terms methodology and method may be clarified by means of an example.

If a client were planning to build a hotel, the "methodology" would be researching the area, obtaining finance and permission, choosing the location, determining the size, number of rooms and storeys, high end quality and made of reinforced concrete.

The "method" would be the detailed architectural plans, structural drawings, room layouts, the staff working in the hotel, including finer details such as wall finishes, and decoration all of which would be covered under "method".

3.2 Methodological Overview

Crottys, "The Foundations of Social Research" (Crotty, 1998) has been used alongside "The Foundations of Research" by Grix (Grix, 2004) to inform aspects of this chapter. The ideas and approaches of both scholars, with additional elements from other selected authors, have been combined as appropriate.

Crotty's table (Crotty, 1998, p. 5) provides the overview and logical progression, beginning with ontology and epistemology and ends with methods.

Table 3.1 Research design (Crotty, 1998)

Chapter 3 Methodology			
Epistemology (sits alongside Ontology)	**Theoretical Perspective**	**Methodology**	**Methods**

Crotty accepts that ontology as a concept precedes epistemology; however, he considers that issues of ontology can be dealt with adequately by considering epistemology.

The Grix sequence follows a similar pattern to Crotty; however, Grix separates ontology and epistemology concepts, but both lead to methods. Grix also adds the term sources. The Grix sequence is shown in Table 3.2.

Table 3.2 Grix structure of research design

Chapter 3 Methodology			Chapter 4 Methods	
Ontology	**Epistemology**	**Methodology**	**Methods**	**Sources**

Grix includes the term "sources", covered in the methods chapter.

Whilst both authors attempt to rationalise terms, they do sometimes use different words for the same concept. For example, what Crotty calls theoretical perspective Grix does not include in the table and calls it "a paradigm or broad approach", both of which inform the methodology. Grix refers to foundational ontology (Grix, 2004, p. 61), whereas Crotty uses the term realist (Crotty, 1998, p. 10) for the same concept.

Each section in this chapter includes a table that highlights the logical progression through research methodology. The progression through research design, illustrated in Table 3.2, is from left to right. However, within this research, it should be acknowledged that a more right to left approach occurred. The methods were

advanced before matters of ontology, epistemology, and theoretical perspective were fully resolved. Crotty is however sympathetic of such an approach as he states, “we hardly start our research with the epistemology, I am an objectivist therefore I will study ….We typically start with a real-life issue (root barriers in this thesis), develop aims and objectives , methodology and methods”. What is necessary however, according to Crotty is to go back to these fundamentals of epistemology and affirm the link, logic and consistency.

3.3 Methodological Categories

Using Crotty’s model, the fuller list of possible categories under each of the main headings, are listed within Table 3.3.

Table 3.3 Main headings and categories in research design (Crotty, 1998)

Ontology **Epistemology**	**Theoretical Perspective**	**Methodology**	**Methods**
Objectivism	Positivism	Experimental research	Sampling
Constructivism	Post positivism	Survey research	Measurement and scaling
Subjectivism	Interpretivism	Phenomenolog-ical research	Case study
	Phenomenology	Grounded theory	Observation
	Critical enquiry	Heuristic enquiry	Questionnaire
	Feminism	Action research	Focus group
	Postmodernism	Discourse analysis	Life history
		Feminist standpoint research	Narrative
		Case study methodology	Visual ethnographic methods
			Statistical analysis
			Data reduction
			Interpretive
			Document analysis

The categories under each heading require consideration regarding their relevance to the research on root barriers. According to Crotty, there are various ontological positions and epistemological stances, several methodologies and a wide range of methods. These various positions and stances logically relate to one another. The most important consideration is to remain consistent through the process and to be able to demonstrate or justify why research has been undertaken in a particular way.

Crotty emphasises the importance of studying how others have gone about the research task and,

"attending to recognised research designs and their various theoretical underpinnings exercises a formative influence upon us……it is by no means a matter of plucking a methodology off the shelf. We acquaint ourselves with the various methodologies. We evaluate their presuppositions. We weigh their strengths and weaknesses. Having done all that and more besides we still have to forge a methodology that will meet our particular purposes in this research". (Crotty, 1998, p. 14)

3.4 Ontology

It was earlier stated that ontology is the starting point of research and precedes theoretical perspectives and methodology considerations.

The key concepts to consider in this section are: -

- realist or foundational ontology
- the relativist or anti-foundational ontology

According to Grix, (Grix, 2004, p. 57) "ontology and epistemology are to research what footings are to a house: they form the foundations of the whole edifice". This quote and being relevant to this research on root barriers and protecting house foundations make the point that ontology comes first and requires later elements to remain consistent.

Ontology is the study of "being". It is concerned with "what is"; it raises questions concerning the nature of existence and with the structure of reality (Crotty, 1998). Ontology asks big questions such as, what is truth? what is meaning? and what is the nature of reality?

As certain epistemological stances are often compatible with certain ontological positions, Crotty (Crotty, 1998, p. 11) explains that as they often arise together, he considers dealing with ontological issues as they emerge without including it specifically in his schema. He reserves talk of ontology for those occasions when we need to talk about "being".

3.4.1 Background Philosophical Considerations

Philosophers have considered these "big" questions raised by ontology for many thousands of years. Sullivan's book, entitled An Introduction to Philosophy (Sullivan, 1957), has been most useful and informative in understanding the link between ancient philosophers and the current research process. One common theme amongst the early philosophers, such as Heraclitus (535-475 BC), was "change". He maintained the world is always changing, in a constant state of conflict and change (Gray, 2004). Heraclitus illustrated this by his famous saying,

“you could never step into the same river twice”. Parmenides (c 515-c445 BC) agreed with Heraclitus that empirical (obtained by the senses) knowledge was unreliable and subjective.

As Sullivan mentions at this early age the classic problems of philosophy were set up, “the problem of the one and the many, of sameness and difference, of change and permanence and appearance and reality”. Heraclitus represents the sensist position that reality is what falls immediately under our senses. Parmenides working with the Pythagoras tradition represents reason to the point of excluding the testament of our senses (rationalism). The reconciliation of these extremes was destined to be one of the permanent problems of philosophy.

Gray sees this distinction as one of the Heraclitean ontology of becoming and the Parmedian ontology of being. Gray continues: -

> *“it is the latter that has held sway in western philosophy. Hence reality is seen as being composed of clearly formed entities with identifiable properties. Once entities are held to be stable, they can become represented by symbols words and concepts.”*

3.4.2 Realist or Foundational Ontology

The realist ontological stance asserts that beliefs must be justified by some means and fall into two categories, basic beliefs and beliefs that derive from basic beliefs.

Aristotle (384-322 BC) learnt within Plato's academy and wrote some 400 books and one of his achievements was to invent deductive logic.

Aristotle held foundational beliefs when recognising the importance of induction and by observing swimming frogs we can make an informed guess that all frogs can swim: -

- all frogs can swim (premise)
- this is a frog (premise)
- therefore, it can swim (conclusion)

By generalising from specific frogs to a species we can start to do science, we can use inductive generalisations to deduce a conclusion about an individual frog, which gives science the power of prediction.

This concept of classification is also embodied in the way trees are categorised into genres, species within the introduction (page 53, section 1.6.4.1). Tudge states (Tudge, 2005, p. 46)

"*Aristotle unlike Plato was a naturalist who liked to look at nature; and he was the first philosopher that we know about who tried to devise a natural classification that truly reflected the essences of different forms. In doing so he set out the most basic rules of taxonomy".*

In modern foundationalism, beliefs are held to be properly basic if they were either self-evident axiom or incorrigible. One such axiom is René Descartes's axiom "I think therefore I am". René Descartes (1596-1650) was a French mathematician who investigated the workings of the mind in relation to the external world and emphasised the difference between perceiving and thinking. His "discourse on method "(1637) sought to discover a new kind of accurate scientific knowledge by following a few simple procedure rules. He thought that clear mathematical thinking about the world was correct but that sensory experiences of it were all subjective and flawed. To illustrate the point, we can be certain of the size and weight of an orange but not in its colour, smell or taste. His methods were determinedly objective and logical. John Locke progressed these ideas and was the so-called founder of empiricism which insists that fundamental human knowledge must come from the senses. Locke agreed with Descartes that our minds only experience a representation or mental images. Our experience of an orange is mixed as its qualities of size and weight are in the orange and objective and scientific and measurable. Its secondary qualities of colour, smell and taste just affect our sense organs and so are subjective and relative.

This research considers real entities known and experienced, such as a house, soils, weather and a tree. These entities are mainly justified by calculation or reason or by argument. Based upon the above, it would seem most appropriate to identify this research-based upon realist or foundational ontology. Also, this realist ontology relates to who a person is, for example, an engineer than to a philosophical viewpoint per se. Engineers are generally realists in their ontological views in their work.

3.5 Epistemology

Epistemology deals with "the nature of knowledge, its possibility, its scope and general basis" (Hamlyn & W, 1995). "Epistemology is concerned with providing a philosophical grounding for deciding what kinds of knowledge are possible and how we can ensure they are both adequate and legitimate".

Epistemological positions may be classified into three broad headings of objectivist, subjectivist, and constructivist. These are considered in the following sections as they relate to the research aims and objectives.

3.5.1 Objectivism and Subjectivism

Objectivism advances that things exist as meaningful entities independently of consciousness and experiences that have truth and meaning residing in them as objects. (Crotty, 1998) Crotty explains that a tree in the forest is a tree "regardless of whether anyone is aware of its existence or not; that this tree carries intrinsic tree-ness irrespective of whether human beings recognise it as a tree. When human beings do recognise it as a tree, they are discovering the meaning that has been lying there all the while waiting for them to discover".

Philosophers linked to an objectivist stance include Pythagoras (571-496 BC) and Francis Bacon (1561-1626). Pythagoras lived in southern Italy and asked the same big question as philosophers before him but he thought the answer was to be found in mathematics. This reliance on mathematics to solve problems indicates an objective viewpoint. Students will be aware of one of his most famous theories, Pythagoras Theorem, namely, the square on the hypotenuse equals that of the square on the opposite two sides.

Francis Bacon was an English politician and was the first to state that "knowledge is power". Bacon took a philosophical interest in the new scientific methods of empirical observation, experimentation and induction employed by scientists like Galileo (1564-1642). Galileo's repetition of the work of Nicolaus Copernicus (1543) in Italian (rather than Latin) so called "Dialogue on the Great World Systems" re-iterated that the earth travelled around the sun which was not popular with the Church of the time as it was believed to be a threat to their teachings.

In contrast to objectivism, subjectivism asserts that the object makes no contribution to the generation of meaning, it comes from somewhere else such as from our unconscious, dreams, primordial archetypes or religious beliefs for example, as distinct from the object. According to Crotty, meaning does not come out of an interplay between subject and object but is imposed on the object by the subject. The object makes no contribution to the generation of meaning.

This concept of subjective vs objective viewpoints was reinforced by one of the Atomists Anaxagoras (500-428 BC) who acknowledged that all things were made of tiny things (atoms). The matter had objective qualities like weight, shape and size but other qualities like smell that only came into being when the atoms of the objects interact with the atoms of the human nose.

Robinson suggests (Robinson & Groves, 2007, p. 35) that the ancient philosophers had either of two tendencies: -

OBJECTIVE BIAS SUBJECTIVE BIAS

These stances of objectivism and subjectivism could be viewed as two extremes. Objectivism is the idea that the objects have meaning and being in themselves and subjectivism because it is the human inter-action with objects that creates meaning. In other words, objectivism holds the view that the object holds all power and influence and in subjectivism, the subject holds the power and influence.

Therefore, we understand a world that we are experiencing, our own creation interpreted by us (subjective) and the real world (objective) that is unrestricted by time and space and the limitations of the human mind. The interrelationship between these two extremes appears the context of much philosophy argument.

3.5.2 Constructivism

Constructivism rejects the objective view of human knowledge. Constructivist epistemology accepts that there is an interrelationship between subject and object. There is no objective truth waiting for us to discover it. Truth or meaning comes into existence in and out of our engagement with the realities in our world. There is no meaning without a mind. Meaning is constructed. (Crotty, 1998, p. 9)

3.5.3 Summary of the Research Epistemology

Crotty has summarised the distinctions between objective, subjective and constructive positions in the following way: -

> *Epistemology bears mightily on the way we go about our research. Is there objective truth that we need to identify and can identify with precision and certitude? Or are there just humanly fashioned ways of seeing things whose*

processes we need to explore and which we can only come to understand through a similar process of meaning making? And is this making of meaning a subjective act essentially independent of the object or do both subject and object contribute to the construction of meaning? Embedded In these questions is a range of epistemological stances each of which implies a profound difference in how we do our researching and how we present our research outcomes. (Crotty, 1998, p. 9)

Consequently, this research into root barriers and associated disciplines of engineering, soils, materials and construction is objective, i.e., object centred, well defined, measurable and "scientific". The success or otherwise of a root barrier can be objectively tested by identifying whether the damage is resolved or by monitoring to show that the ground movement has ceased. A bridge or a building (or a root barrier) can be shown to work by objective and scientific calculations rather than requiring any meaningful subjective viewpoints. One may hold the belief that a bridge or building (or root barrier) will work but it is objective calculations, engineering theories, predominantly based upon numbers, that will supersede subjective views.

However, the same argument may not strictly apply when considering the value of trees, as in this research, because trees and individuals' views are not so easy to define as a bridge or a building. The thesis considers commonly held views concerning the current method of resolving a specific problem (clay shrinkage subsidence) and of deciding upon repair options, requiring placing a value on a tree. One may be able to show the benefits of trees by scientific methods but whether the tree stays or is removed (during a subsidence claim for example) may be based upon subjective views of the tree in question. For example, a homeowner or practitioner may be set in their usual ways of doing things and removing a tree rather than basing decisions on purely scientific or other evidence about the correct solution or the value of a tree. The perception of a tree can be different depending on an individual's outlook and experience and therefore tends towards a more subjective viewpoint.

Crotty advises however, that only one stance is used, not a combination of epistemologies. (Crotty, 1998, p. 15). Crotty states the importance of being consistent (Crotty, 1998, p. 16) : -

"if we seek to be consistently objectivist, we will distinguish scientifically established objective meanings from subjective meanings that people hold in everyday fashion and that at best reflect or mirror or approximate objective meanings. We will accept of course that these subjective meanings are

important in people's lives and we may adopt qualitative methods of ascertaining what those meanings are. This is epistemologically consistent. It has a downside, all the same. It makes people's everyday understandings inferior epistemologically to more scientific understandings. In this way of viewing things, one cannot predicate of people's everyday understandings the truth claims one makes for what is scientifically established. If we seek to be consistently constructionist, we would have put all understandings, scientific and non-scientific alike on the very same footing".

There may be subjective aspects when considering trees; however, they can be considered objectively without reverting to a subjective epistemology. The constructivist's stance would be too far removed to be relevant or appropriate as this view tends to treat objective and subjective realities as equally important and implies significant interplay between object and subject that would not be appropriate.

To summarise, this research maintains a foundational ontology and an objectivist epistemology, highlighted in Table 3.4.

Table 3.4 Research progress (ontology and epistemology)

Chapter 3 Research Design			
Ontology	**Epistemology**	**Theoretical Perspective**	**Methodology**
Foundational	Objectivism	Positivism	Experimental research
	Constructivism	Post positivism	Survey research
Anti-foundational		Interpretivism	Phenomenological
	Subjectivism	Phenomenology	Grounded theory
		Critical enquiry	Heuristic enquiry
		Feminism	Action research
		Postmodernism	Discourse analysis
			Feminist
			Case study

3.6 Theoretical Perspective

The theoretical perspective follows from epistemology and informs the methodology and "provides a context for the process, grounding its logic and criteria". (Crotty, 1998, p. 7). The theoretical perspective is a statement regarding assumptions brought to the research task and reflected in the methodology. By expounding the theoretical perspective that is our view of the natural world, the assumptions are grounded.

The key concepts to consider in this section are: -

- positivist
- post-positivist
- interpretivism

Grix however, uses the term research paradigm instead of theoretical perspective which can sometimes add to the overall confusion when discussing research methodologies.

Crotty (Crotty, 1998) points out that there are logical connections between the above concepts and those in the preceding sections. For example, referring to Table 3.3, you would need to rule out a direct connection between constructionism, or subjectivism, to positivism since positivism is objectivist by definition. "Without a thoroughly objectivists epistemology, positivism would not be positivism as we understand it today". Further, Crotty states we could not draw a line from subjectivism (or objectivism) to phenomenology as "phenomenology and constructionism are so intertwined that you could not be phenomenological while espousing an objectivist epistemology".

The direct connection between the objectivist epistemology and the positivist and post-positivist theoretical perspectives is quite logical and consistent.

The following section briefly considers the interpretivist stance in the first instance and then concentrates on the chosen epistemology (objective) and its related theoretical perspectives.

3.6.1 Interpretivism

Crotty states interpretivism looks for culturally derived and historically situated interpretations of the social life world. In terms of epistemology, interpretivism is closely linked to constructionism (Gray, 2004, p. 20). As Gray states: -

> *"Interpretivism asserts that natural reality and social reality are different and therefore require different kinds of method. While the natural sciences are looking for consistencies in the data in order to deduce "laws" (nomothetic) the social sciences deal with the actions of the individual (ideographic)".*

Although valuable, this stance does not align with the chosen ontological and epistemological stances and for this reason does not require further consideration.

3.6.2 Positivism and the Scientific Method

The so-called "standard view" of science derives directly from a philosophical approach known as "positivism" (Robson, 2002, p. 19). Positivism itself can be

defined in different ways but tends toward the objective belief that “one reality exists and it is the researcher’s job to find it”. (Robson, 2002, p. 27)

According to Robson, positivist approaches tend towards collecting data, quantitative data and cause and effect. For example, the bursting of car radiators at low temperature is causally linked to the fact that water freezes at 0 degrees C, direct cause and effect.

The following paragraphs are a paraphrase of Crotty’s explanation of the positivist and post-positivist theoretical perspectives (Crotty, 1998, pp. 18-41) in the chapter entitled, “Positivism, the March of Science”.

Crotty explains how objectivism has been directly associated with positivism which developed very much during the spirit of enlightenment in 17th century England (Francis Bacon) and 18th century France. The word positivist has replaced terms such as “positive science” and “positive philosophy” and assumes there is an un-ambiguous and accurate knowledge of the world. The term positive is used in “positive science” in the sense that something is posited and science *Scientia* meaning knowledge is firmly grounded. What is posited or given is by direct experience, observation, experiment and comparison. As a theoretical perspective, Positivism is concerned with facts and empirically (through the senses) verifiable knowledge. Some proponents of positivism were Edmund Hesserl and as far back as Galileo who envisaged a mathematicised world.

The confidence in science encompassed by the positivist perspective stems from a conviction that scientific knowledge is both accurate and certain contrasting with opinions, beliefs and feelings that we gain in “non-scientific” ways. Scientific knowledge purports to be objective and science ascribes no meanings, instead it discovers meaning, for it is, as Crotty says, “able to grasp objective meaning, that is meaning already inherent in the objects it considers. To say that objects have such meaning is to embrace the epistemology of objectivism and positivism is wholly objectivist through and through”.

The positivist theoretical perspective is highly systematic, regular, well organised, consistent and deals with absolute principles. It is enormously powerful and has driven many technological breakthroughs and major discoveries, Crotty argues.

However, positivism as described above has been the subject of criticism.

The scientific world is not the everyday world we experience, and it tends to distance us from the world we experience. Crotty continues that positivism “holds a tight grid on the world it observes, and there is a chasm between what science purports to do and what it does”.

Heisenberg (1901-76) one of the founders of quantum theory and subatomic particles, talks of the uncertainty principle. Sub-atomic particles are altered by the very act of being observed, thus dispelling the notion that the observer and the observed all wholly independent.

Popper talks of positivist science as making a guess and not being unable to disprove it, despite strenuous efforts to do so. For example, because water boils at 100 degrees centigrade under certain conditions and has done countless times, it is not proof that it will always boil at 100 degrees. Popper states that “every scientific statement must remain tentative forever”. (Popper, 1959, p. 280)

Furthermore, many scientific theories such as quantum theory have emerged whose development requires accepting more than just direct observation of empirical (from our senses) data.

3.6.3 Post-Positivism

In response to the above criticisms of positivism Crotty introduces the term post-positivist which attempts “to reign in” its excessive claims. Post-positivism is more modest, a less arrogant and less dogmatic form of positivism whilst retaining its essential features. Post positivists: -

> *“admit that, no matter how faithfully the scientist adheres to scientific method research outcomes are neither totally objective nor unquestionably certain. They may claim a higher level of objectivity and certitude for scientific findings than for other opinions and beliefs but the absoluteness has gone and claims to validity are tentative and qualified”.* (Crotty, 1998, p. 40)

It is this stance of post-positivism that retains the scientific process. Still, it does not hold on to absoluteness or certainty but talks of probabilities rather than certainties and approximation of truth rather than truth itself. This type of science best describes the research into the practical use of root barriers. It retains the objective epistemology but allows for interpretation and uncertainty, especially regarding considerations of the less certainty in determining trees' value. Table 3.5 summarises the logical process.

Table 3.5 Research progress (theoretical perspective)

Chapter 3 Research Design Part 1 Methodology			
Ontology	**Epistemology**	**Theoretical Perspective**	**Methodology**
Foundational or Realism	Objectivism	Positivism	Experimental research
	Constructivism	Post positivism	Survey research
Anti foundational		Interpretivism	Phenomenological
	Subjectivism	Phenomenology	Grounded theory
		Critical enquiry	Heuristic enquiry
		Feminism	Action research
		Postmodernism	Discourse analysis
			Feminist
			Case study

Table 3.5 highlights the foundational ontology, objective epistemology and post-positivist theoretical perspective as logical and appropriate for the research providing a firm basis for progression to methodology.

3.7 Methodology

3.7.1 Introduction

As defined within the introduction to this chapter, the methodology is the plan of action or design lying behind the choice and use of particular methods. According to Grix, research methodology is "concerned with discussing how a particular piece of research should be undertaken and so can best be understood as the critical study of research methods and their use". (Grix, 2004, p. 32)

As Gray points out (Gray, 2004), the choice of research methodology is determined by several factors. These include whether the researcher believes there is some sort of external truth out there that needs discovering or whether the research task is to explore and unpick people's multiple perspectives in natural field settings.

The methodology, and its alignment with the research aims and objectives, is discussed before considering the topic of inductive and deductive research. Various methodologies are then considered starting with the most objective (and scientific) methodology of experiment. Other methodologies are considered to establish whether they align with ontology's underlying principles, epistemology, and theoretical perspective determined earlier in the chapter. Methodologies appropriate to this research and that align with the underlying principles provide the focus of attention in the section whilst less appropriate methodologies are mentioned briefly with the reasons why they have not been progressed.

Note that within the framework presented so far in this chapter there is no mention of qualitative or quantitative methods. These are key concepts that do require to be considered, however as Crotty argues, and I agree, qualitative and quantitative considerations should be dealt with at the level of methods.

3.7.2 Aims and Objectives Focus

The research methodology should be guided by the research questions, aims and objectives. According to Robson, "The research strategy and the methods and techniques employed must be appropriate for the questions that you want to answer". (Robson, 2002). Crotty agrees that the methodology should be informed by the research questions and Grix who states that the research questions inform methodology.

Table 3.6 Research design (Crotty, 1998)

Chapter 3 Research Design Methodology and Methods					
Ontology	**Epistemology**	**Theoretical Perspective**	**Research aims and objectives or questions**	**Methodology**	**Methods**
Foundational or Realism	Objectivism	Positivism		Experimental research	Sampling
	Constructivism	Post positivism		Survey research	Measurement and scaling
Anti foundational	Subjectivism	Interpretivism		Case study	Case study
		Phenomenology		Grounded theory	Observation
		Critical enquiry		Heuristic enquiry	Questionnaire
		Feminism		Action research	Focus group
					Visual ethnographic methods
				Phenomenological	Statistical analysis
					Data reduction
					Comparative analysis
					Interpretive
					Document analysis

Table 3.6 shows the current stance with aims objectives (or research questions) positioned between the theoretical perspective and methodology. Chapter 1 introduced the aims and objectives, which are: -

Objective 1. Identify the most important variables that influence decisions to mitigate clay shrinkage subsidence using a root barrier.

Objective 2. Identify perceptions of root barriers amongst subsidence practitioners.

Objective 3. Analyse the a) variables and b) perceptions that influence the use, effectiveness and reliability of root barriers.

Objective 4. Develop good practice principles in the design and construction of root barriers and validation exercise in which it is the intention that practicing professionals will endorse the value of the professional doctorate.

Methodological decisions are also based upon the research questions such as: -

What are root barriers and how can they resolve clay shrinkage claims? **What** are the features or characteristics of root barriers? **What** materials are used?

How are they installed? **How** do they work? **How** should they be designed?

Why should we use or consider root barriers?

3.7.3 Experimental and Quasi experimental Research

Starting with the most objective methodology, that of experiment and quasi experiment. Quasi-experimental research draws on the experimental methodology but in a less controlled manner.

Gray covers the field of experimental research, which tends to follow a predominantly objective epistemology and a positivist theoretical perspective. (Gray, 2004)

Experiment also tends towards truth seeking and the collection of quantitative data and a deductive approach. Experimental research methodologies tend to be those that are confined to a laboratory and completed under controlled conditions. The process involves identifying dependent and independent variables and maintaining some elements constant whilst varying others and measuring the response.

In this case, because the installation of root barriers is carried out in the field, they are very difficult to control on real sites. It would not be feasible to deliberately vary the depth for example and measure the outcome in such real-life situations. The inter-relationship is too complex and inadequately defined for this to be feasible, and the costs prohibitive.

Therefore, the experiment is more suited to the “scientific” study of a concrete beam or slab that could be analysed mainly from theory and then tested in controlled laboratory conditions.

The process of design and installation of a root barrier is not so specific and controllable. Issues concerning perceptions, views, reliability, value for money are also involved and for these reasons experiment or a laboratory-based methodology for the research into the practical use of root barriers is inappropriate.

3.7.4 Analytical Surveys

Descriptive and analytical surveys are described by Gray (Gray, 2004). Surveys play an important part of research; however, they would not be appropriate in this research as it would be difficult to gather valuable technical and specialist information as required for the variables by asking respondents or participants. The respondents would need to have expert knowledge in the use of root barriers, which was easily and rapidly accessible to respond to a survey.

As specialists undertake such work, it is most unlikely that they would have the knowledge or expertise to respond to such questions as the depth of the barrier, length, cost, and construction method.

Perceptions could be collected using analytical surveys such as views on reliability or practicality; however other methodologies need to be considered as they may be better suited in this respect.

3.7.5 Interpretivist Methodological Approaches

Crotty lists a variety of methodologies based upon the interpretivist theoretical perspective. While these approaches are not aligned with the research, it is useful and beneficial to briefly consider them, even if they are to be discounted.

Grounded theory is typically useful when there is a lack of theory and concepts to describe and explain what is happening. Grounded theory looks to provide an explanation or theory behind events, primarily by use of interviews and existing documents. Grounded theory tends to rely upon open and axial coding techniques to identify themes and build the theory. Grounded theory can help inform design decisions by better understanding how a community of users currently use a product or perform tasks.

Ethnographic seeks to capture, interpret and explain how a group organisation or community experience and make sense of their lives in the world. When researching ethnographically, the researcher is immersed in the target participants' environment to understand the goals, cultures, challenges, motivations, and themes that emerge. Rather than relying on interviews or surveys, the researcher experiences the environment first-hand, and sometimes as a "participant observer."

Phenomenological study uses a combination of methods, such as conducting interviews, reading documents, watching videos, or visiting places and events, to understand the meaning participants place on whatever is being examined. The methodology relies on the participants' own perspectives to provide insight into their motivations.

The **Narrative** approach weaves together a sequence of events, usually from just one or two individuals to form a cohesive story. The researcher conducts in-depth interviews, reads documents, and identifies themes to illustrate a particular “story” and the influences that created it.

The culture of subsidence is not relevant to the research and I am more concerned with the details, variables and perceptions than the narrative. It would be difficult to obtain specifics from participants based upon any form of survey or observation of individuals, confirming such methodologies would not be appropriate. Furthermore, the historic changes in subsidence and how they affect root barriers does not form part of the research.

3.7.6 Case Study Methodology

Case studies are included within the range of methodological approaches described by both Crotty and Gray. Yin is also a well-known advocate of the case study methodological approach and his text “Case Study Research, Design and Methods” (Yin, 2009) has been an invaluable resource.

To clarify, a case study is a methodology, not just a method (of data collection). A case study defines a broad approach to research being the plan of action or design lying behind the choice and use of particular methods. Yin (Yin, 2009) refers to case study being a “method” in his text; however, according to the definitions I have used, including Crotty and Gray, he is actually referring to a case study as a “methodology”. For example, Yin refers to a case study as an “all-encompassing method(ology)” covering the logic of design, (Chapter 3) data collection techniques (Chapter 4), approaches to data analysis (Chapter 5) and reporting (Chapter 6).

Yin also deals with common objections or “disdain” to the use of case studies. One such objection is that there is a lack of rigour, being sloppy and not following systematic procedures. Perhaps, Yin argues, this is due to there being fewer specific procedures in case study research. Another objection is that they provide little evidence for scientific generalisation. Yin’s response is that case studies are analogous to experiments in many ways and that experiments like case studies are generalisable to theoretical propositions and not to populations or universes. Previously I have discussed how the purely positivist, scientific method has come under attack in recent years and to this it should be added that there is no reason why case studies cannot be carried out in a scientific manner, provided the usual safeguards are in place as would be the case for experiments.

Another objection mentioned by Yin is case studies take too long and they result in massive unreadable documents. Yin describes how this can be overcome: -

"Finally, the objection is that case studies are unable to measure the variation of an outcome by altering one or other variables, as would be the case in experiments. Case studies can provide evidence to supplement experiments if this type of measurement of variation were required".

Yin states that case studies can answer the how and why questions that experiments cannot. The disadvantage of an experiment is that it divorces a phenomenon from its context (Yin, 2009, p. 18) whereas case studies retain the real-life context of an event or process.

The arguments presented above confirm that case study methodology is appropriate for the research of the variables (length, depth, materials, trees, soils etc) in the practical use of root barriers within the real-life context whilst remaining consistent with objective epistemology and post-positive theoretical perspective.

However, the Case Study approach would not be ideal for capturing certain research elements such as perceptions, and another methodology will be considered for this aspect.

3.7.7 Survey Methodology

Whilst case study can obtain rich data on variables from knowledgeable participants and work completed in the field it would not be ideal to provide information on perceptions of the wider community involved in clay shrinkage subsidence.

Questionnaires have the advantage that they allow relatively large amounts of data to be collected under controlled conditions, they are relatively inexpensive, and the inflow of data is quick and from numerous respondents.

Type of questionnaires are: -

- structured (quant) with precise questions and coded responses e.g., larger surveys
- semi-structured as above but with some flexibility, allow some probing of the responses
- unstructured consist of a series of topics that are quite loose, requires more varied answers, the respondent can provide views, e.g., focus groups, face to face interviews

Types of questions include: -

- behavioural (what people do, fact based rather than opinion based)

- attitudinal, attitudes or beliefs, opinions, e.g., how satisfied are you? (often based upon Likert scale of say 1-5. The middle answer (3) allows respondents to “sit on the fence”).

In view of the foregoing, the survey methodology, incorporating questionnaire method (of data collection), would be appropriate to progress analysis of variables in this research.

3.7.8 Qualitative and Quantitative Research

3.7.8.1 Background

Before describing the case study and survey questionnaire methods in more detail, the concepts of qualitative and quantitative research are introduced and discussed in relation to the aims and objectives.

In the broad sense qualitative data is data in the form of words and quantitative data is data in the form of numbers. Whilst certain perspectives may use a more qualitative or quantitative form of data, for example objective epistemology tends towards collecting data in the form of numbers and subjective epistemology tends to collect data in the form of words, Crotty argues, and the author concurs, that consideration of qualitative versus quantitative approaches occurs at the level of methods, not methodology. (Crotty, 1998, p. 14) Crotty states it is more a matter of positivism versus non-positivism or objective vs subjective than a matter of quantitative versus qualitative. He argues that it is possible for a quantitative piece of work to be offered in a non-positivistic form. On the other hand, there is plenty of scope for qualitative research to be understood in an overall positivist or post-positivist setting.

Broad areas of research have historically aligned with either the quantitative or qualitative traditions. For example, quantitative methods have traditionally aligned with the scientific or positivistic and post positivistic traditions. Qualitative methods have aligned with many interpretivist methodologies, such a heuristic enquiry or ethnography for example.

Robson in his text “Real World Research” (Robson, 2002) advocates the use of the terms “fixed” and “flexible” research as alternatives to the more traditional terms “quantitative” and “qualitative” respectively. His book separates methodologies early on into the broad headings of fixed (quantitative) or flexible (qualitative) research. The terms are used interchangeably in the following section.

3.7.8.2 The Quantitative (Fixed) Approach

According to Amgad Badewi (Badewi, 2017), the quantitative approach is suited to research that fills a knowledge gap and tends towards a pragmatist world view. I.e., a single reality exists.

Robson affirms that a fixed design strategy calls for a tight pre-specification before data collection and if the researcher cannot pre-specify the design, he should be cautious using the fixed approach. (Robson, 2002, p. 87) Furthermore, Robson states the link between theory and research in fixed designs is more straightforward so that fixed designs are theory driven and data is almost always in the form of numbers. (Robson, 2002, p. 96)

Robson's "fixed" research characteristics are shown in Table 3.7.

Table 3.7 Characteristics of quantitative or fixed research

Fixed-Quantitative-(objective)
theory driven
tight pre-specification
numbers
research fixed at outset
rarely include qualitative data
should be piloted
data analysis deals with aggregates, statistics, tendencies, identify patterns and processes
detached researcher, the object speaks for itself
statistical analysis

3.7.8.3 Qualitative Approach

The qualitative approach is best suited to solving a specific problem and tends towards an interpretive world view. Words, phrases and descriptions are characteristic of qualitative research.

Robson affirms that flexible designs typically anticipate that the design will emerge and develop during data collection. The flexible design evolves during data collection being typically non-numerical usually in the form of words. Flexible designs can include the collection of numerical data whereas fixed designs rarely include qualitative data. (Robson, 2002) Table 3.8 lists Robson's flexible design characteristics.

Table 3.8 Characteristics of qualitative or flexible research

Flexible- Qualitative- (subjective)
theory develops
mainly words
research evolves
can include collection of quantitative data
pilot not essential
data analysis deals with words and phrases, themes, less rigid entities
involved researcher, researcher as an instrument of data collection and a focus for participants views (p166)
case studies, ethnographic studies, grounded theory

3.7.8.4 Mixed Methods Approach

The mixed-method approach encompasses both qualitative and quantitative data analysis. In combination, the advantages of each method complement the other, making a stronger research design with increased validity and reliability. The inadequacies of individual methods are minimized and threats to internal validity are realised and addressed. (Cresswell, 2003)

Case studies, according to Yin, are included within the array of qualitative research methods (Yin, 2009, p. 18); however, Yin points out that case study "is not just another form of qualitative research". Case studies can include and even be limited to quantitative evidence. To summarise, case studies can have qualitative data, quantitative data or a mix of both.

Robson also allows for a mixed approach where research could have a flexible phase followed by a fixed phase or there could be a flexible element within an otherwise fixed design. This combined approach is analogous to the so-called mixed method approach when referring previously to quantitative and qualitative approaches. A design however, according to Robson, cannot be flexible and fixed at the same time. (Robson, 2002, p. 87)

3.7.9 Choosing Consistent Approach

Regarding the characteristics of fixed (quantitative), flexible (qualitative) and mixed, it is apparent that the nature of this research into variables and perceptions is mixed in both case studies and within survey questionnaire. According to Creswell (Cresswell, 2003), the decision regarding the two alternatives, quantitative or qualitative, requires the researcher to consider two relevant criteria a) the researchers own experience and b) the audience.

As a practising engineer, I have a technical background and the audience is most likely technical and scientific. Therefore, it could be argued that a mainly quantitative approach would be better suited to the research, especially from the audience perspective. However, I have taken the view that the overriding consideration in the research method should be the nature of the data being collected, and as the research has characteristics of both qualitative (flexible) and quantitative (fixed), the research should be suitably aligned towards a mixed methods approach. This decision is supported as the characteristics of both methods outlined in Table 3.8 and Table 3.7 form part of the research into root barriers.

Table 3.9 shows the type of data (qualitative or quantitative) expected in relation to the objectives. Within the qualitative and quantitative approaches there are numerous variations and emphasis. Under typology (fourth column) the description refers to the significant data type (uppercase) and data of less significance in lower case.

Table 3.9 Objectives Data Collection and Justification

Objective	**Qualitative words Flexible Design**	**Quantitative numbers Fixed Design**	**Mixed Methods Typology**
Objective 3a Analyse Variables	Qualitative data in the form of words construction methods, main concerns, comments and views	Variables relate to mainly quantitative data in the form of numbers e.g., barrier depth, tree size, distances, costs.	QUANT qual
Objective 3b Analyse perceptions.	Captures mainly feelings and perceptions views and understanding of the value of trees. Perceptions of reliability.	Value of trees, how many barriers installed, do they work in your experience?	QUAL quant.

3.7.10 Inductive or Deductive Reasoning

Research styles vary depending on the data to be collected. Research may be deductive, abductive or inductive. The general style of the research for the variables will be predominantly inductive as illustrated in Chapter 2 that little research has been undertaken in this field. Starting with fragmented source information gathered from field practitioners the data will be analysed to establish the overriding principles and factors that determine the outcome, (Gray, 2004); in this case the successful resolution of a subsidence claim using a root barrier.

The differences between inductive and deductive approaches of enquiry are shown in Figure 3.1, illustrating that the inductive approach may be subject to change and modification during the process as more data and information becomes available.

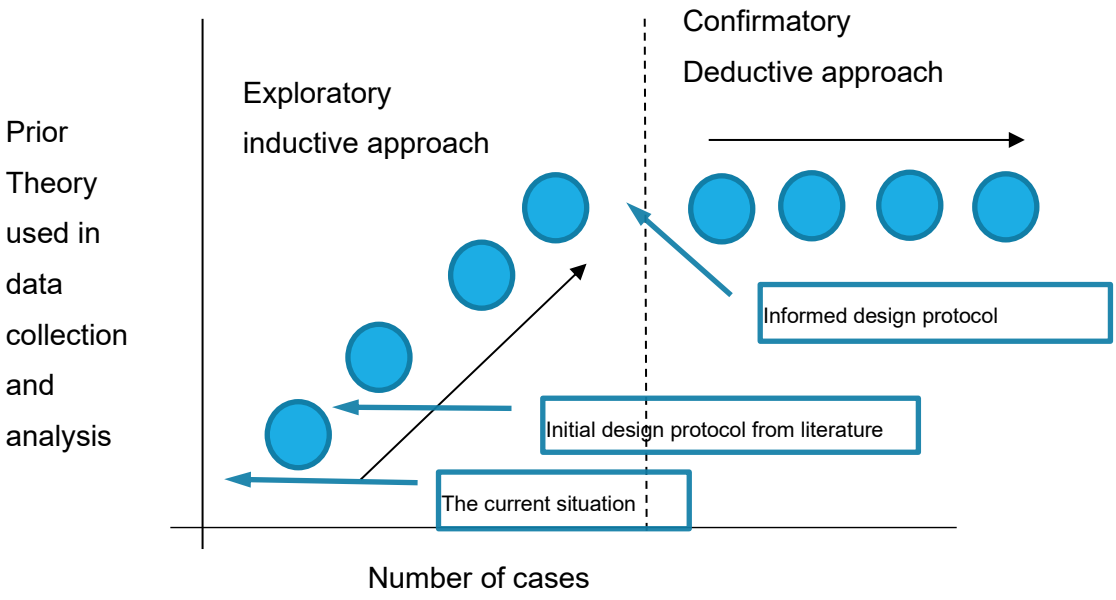


Figure 3.1 Inductive vs deductive reasoning (Source Author)

Both perceptions and variables require this research to build up a more complete picture. The variables will be dealt with in an inductive manner as the research's starting point is minimal information and lack of coherence. Following the literature review, the initial design protocol was established, providing coherence, but these design rules require testing and verification. The initial protocol will require modification and improvement through the entire research process.

Field testing and use of the rules will then become more deductive as the theory is tested. As Gray mentions (Gray, 2004, p. 6) the inductive approach does not set out to corroborate or falsify a theory, instead through a process of gathering data it attempts to establish patterns, consistencies and meanings.

The fact that root barriers are not widely used, presented in the introduction, was followed by a preposition as to why this could be the case based upon four perceptions. This process of validating the perceptions will be handled in a more deductive manner. In other words, does the data tend to prove or disprove this viewpoint?

3.8 Summarizing Chapter 3 - Research Methodology

This chapter has considered the appropriate methodological approaches to this research and the various ontological and epistemological positions as they relate to the appropriate theoretical perspective that inform the methodology. This process determined that the research into the practical use of root barriers would suit a foundational or realist ontology, objective epistemology and post-positivist theoretical perspective.

The various methodologies were then considered to identify which would be most appropriate for collecting the required data in researching the practical use of root barriers, answering the research questions, and aligning with the aims and objectives. It was also necessary to ensure that the chosen methodology aligned back to the chosen epistemology and theoretical perspective.

Ultimately, case study was adopted as the most appropriate methodology to analyse the variables (such as depth, length, cost etc.) in the practical use of root barriers using a mixed-method approach.

Survey methodology was selected to investigate perceptions by means of questionnaires.

The methodologies of case studies and survey share similar ontological and epistemological roots. Therefore, they will complement each other, so that results from questionnaires can be merged with one or some of the variables researched by case study methodology. The logical process is shown in Table 3.10.

Table 3.10 Research progress based upon (Crotty, 1998)

Chapter 3 Research Design Part 1 Methodology					**Chapter 4 Methods**
Ontology	**Epistemology**	**Theoretical Perspective**		**Methodology**	**Methods**
Foundational or Realism	Objectivism	Positivism		Experimental research	Sampling
	Constructivism	Post positivism		Survey research (perception)	Measurement and scaling
Anti foundational	Subjectivism	Interpretivism		Phenomenological	Case study
		Phenomenology		Grounded theory	Observation
		Critical enquiry		Heuristic enquiry	Questionnaire
		Feminism		Action research	Focus group
				Case study (variables)	Visual ethnographic methods

Research aims and objectives

Alternatively, using Gray's pictorial representation, Table 3.11 summarises the research position. (Gray, 2004, p. 30).

Table 3.11 Research progress using Gray pictorial description

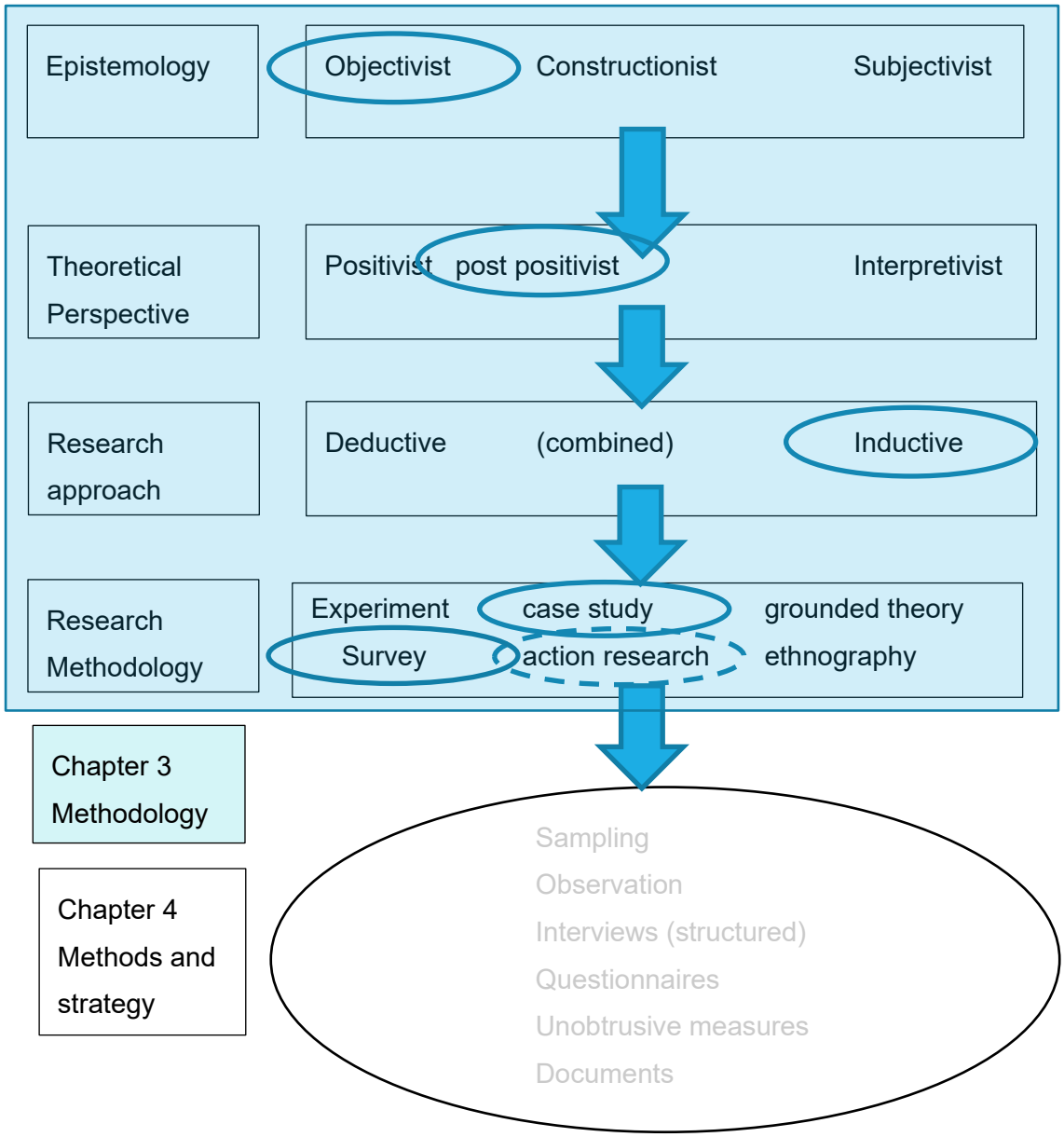


Table 3.11 shows the main considerations of epistemology, theoretical perspective, research approach flowing to methodology in a slightly different format to Crotty's. The ellipse indicates data collection methods, in grey type, not yet fully identified, to be determined and explained in the following chapter.

4.0 Research Methods

4.1 Introduction

This chapter deals with research methods defined as “the techniques or procedures used to gather and analyse the data related to some research question or hypothesis”. (Gray, 2004). It builds upon the previous chapter providing the specifics of the case study and survey methodologies as they relate to research into the practical use of root barriers.

Another useful way of viewing the term “method” as used in this thesis, would be to add the term “of data collection”. The data collection methods for case study and survey (questionnaire) are described in more detail in this chapter with emphasis on precisely how, where and from whom the data was collected.

4.2 Case Study Method (of data collection)

4.2.1 Introduction

The case study method outlines the precise strategy utilised to collect data concerning the variables in the design and construction of root barriers. Good case studies are difficult to do and “unlike other research methods, a comprehensive catalogue of research designs for case studies has yet to be developed”. (Yin, 2009, p. 25) Yin does however, in his text, produce a comprehensive design process and many of these processes, including those of others, where appropriate, have been adopted in the methods and strategy covered later.

Yin asserts that “case study research includes procedures common to all types of research method(ologies) such as protecting against threats to validity, maintaining a chain of evidence, and investigating and testing rival explanations.” (Yin, 2009)

Having determined case study as a methodology, Robson (Robson, 2002, p. 178) defines a case study as: -

> *“A strategy for doing research which involves an empirical investigation of a particular contemporary phenomena within its real-life context using multiple sources of evidence”.*

By replacing “contemporary phenomena” in the above statement with “root barriers” the definition holds firm confirming that this research aligns with the case study approach.

Gibbs further explains the “real life context” (Gibbs, October 14 2012) being the environment where the phenomena is occurring and the importance of “being there, going where the phenomena is occurring”. In this research the use of case studies

enables the research to take place in the real-life context, in the field, from practitioners installing root barriers.

The case study methodology has value in explaining an organisation, entity, company, and also an event, as in this case. Case studies can draw on rich data. A case study involves a deep understanding through multiple types of data sources. "The distinctive need for case studies arises out of the desire to understand complex (social) phenomena allowing investigators to retain the holistic and meaningful characteristics of real-life events". (Yin, 2009, p. 4)

Gray confirms that case studies tend to be much more specific in focus and can explore many themes but from a much more focussed range of participants. (Gray, 2004, p. 123) Furthermore, the case study methodology is ideal when how? and why? questions are being asked about a specific topic over which the researcher has no control, and which concentrate on contemporary events.

Yin advocates considering the type of research questions being asked to confirm whether a research method is appropriate. (Yin, 2009). He goes on to say that the "how" and "why" questions are best suited to the use of case studies, as in this research.

How are root barriers installed? How do they protect trees? How do they work? How should they be designed? etc.

Why should I use or consider root barriers? Why are they value for money? etc.

What are root barriers and how can they resolve clay shrinkage claims? What are the features or characteristics of root barriers? What materials are used?

Yin (Yin, 1993) has carried out much research into this approach advocating case studies, stating they can be based upon multiple examples of the same issue and that knowledge can be built up from a knowledge of many individual cases.

Apart from being suitable for answering how and why questions, case studies are appropriate in situations where there is a contemporary set of events over which the investigator has no control. (Yin, 2009, p. 13) The contemporary event is the use of root barriers over which the investigator does not have direct control.

This research has identified two aspects, namely, variables and perceptions. The variables that consider length, depth, soils, trees, construction methods, materials and costs are ideally suited to research by the methodology of case studies. Case study is particularly appropriate in obtaining the technical data from participants via documents because, as previously mentioned, in analytical surveys, respondents would have access to the specific information required. Case studies can also

interpret multiple sources of evidence (documents, interviews, drawings), which would be required to investigate the variables.

Yin advocates at an early stage defining the units of analysis in case studies. The units of analysis comprise the overall case and the embedded units within the case. Yin advises that this requires the researcher at the very outset to confirm what the case is. Is the research seeking to understand an individual, a patient, a student, a programme, organisational change, a university, an organisation, a situation or a process?

As defined by this research, the unit of analysis is designing and installing a root barrier to resolve a clay shrinkage subsidence claim. Note that the unit of analysis is not a participant or an organisation or an individual. The embedded units of analysis are the variables and perceptions.

4.2.2 Individual or Multiple Cases

Gibbs identified various types of case study from literature (Gibbs, October 14 2012). Information taken from a lecture at Huddersfield University. These are: -

- individual
- set of individual cases
- community studies
- studies of organisations and institutions
- studies of events roles and relationships

Each type of case study has been considered in

Table 4.1 to determine the type of case study relevant to this research. The table indicates whether the method would be appropriate.

Table 4.1 Types of Case Study

Types of Case Study	Chosen	Reason
Single case A critical case? Extreme or Unique? Representative of the whole?	No	Would not provide sufficient breadth. Which case would be chosen and there is no data to confirm this would be typical or the extreme case? I would need to look at several cases first to find what is typical and want/need to look at variations.
Set of individual cases	Yes	Numerous cases would provide depth and rich data for comparison, identify trends, patterns, maximums and minimums, averages.
Community Studies	No	Research is not related to a specific community.
Social group studies	No	Research not related to social aspects.
Studies of organisations and institutions	No	The research is not interested in how different practices or organisations deal with root barriers; the unit of analysis is not the participant but the process.
Studies of events, roles and relationships	Yes	The research relates to the event of root barrier installation, roles and relationships.

The single case study would not provide enough breadth to the research on variables. A major disadvantage of a single case study, and the reason for its rejection, is the requirement to find the model, unusual or typical case. This would not be feasible with root barrier research as it would not be possible to determine the model or ideal case until numerous cases had been first investigated.

The set of individual cases is appropriate and provides various advantages. Yin (Yin, 2009) refers to this type of case study as multiple case study approach. The evidence from multiple cases is often considered more compelling than that of single case designs, (Yin, 2009, p. 53), analogous to repeated experiments. A set of individual cases is ideally suited to collect data concerning variables.

Having determined the multiple case approach is appropriate, the next consideration relates to determination of the number of cases that would be required. Yin points out however that a sampling logic should not be used in case studies and the "typical criteria regarding sample size are also irrelevant". The researcher should think of this decision as a reflection of the number of case replications both literal and theoretical that you need or would like to have in your study " (Yin, 2009). Designating the number of replications depends on the certainty required regarding the multiple case results. The greater certainty lies with a larger number of cases. Yin argues that when the theory is straightforward, only 2 or 3 cases may be required, however, if the theory is subtle or a high degree of certainty is required, Yin suggests 5 or 6 replications.

The research being undertaken concerning design and installation of a root barrier involves 22 questions from the pro-forma to investigate 19 variables. The total number of 33 cases is considered more than adequate, given that Yin advocates 5 or 6 cases if the theory is subtle or high accuracy is required. Also, the more replications, the greater chance of dealing with rival explanations, as additional

cases may draw up alternative solutions or considerations that were not discovered in earlier cases.

4.2.3 Basic Type of Case Study

Figure 4.1 compares single or multiple case holistic vs single or multiple case embedded approaches.

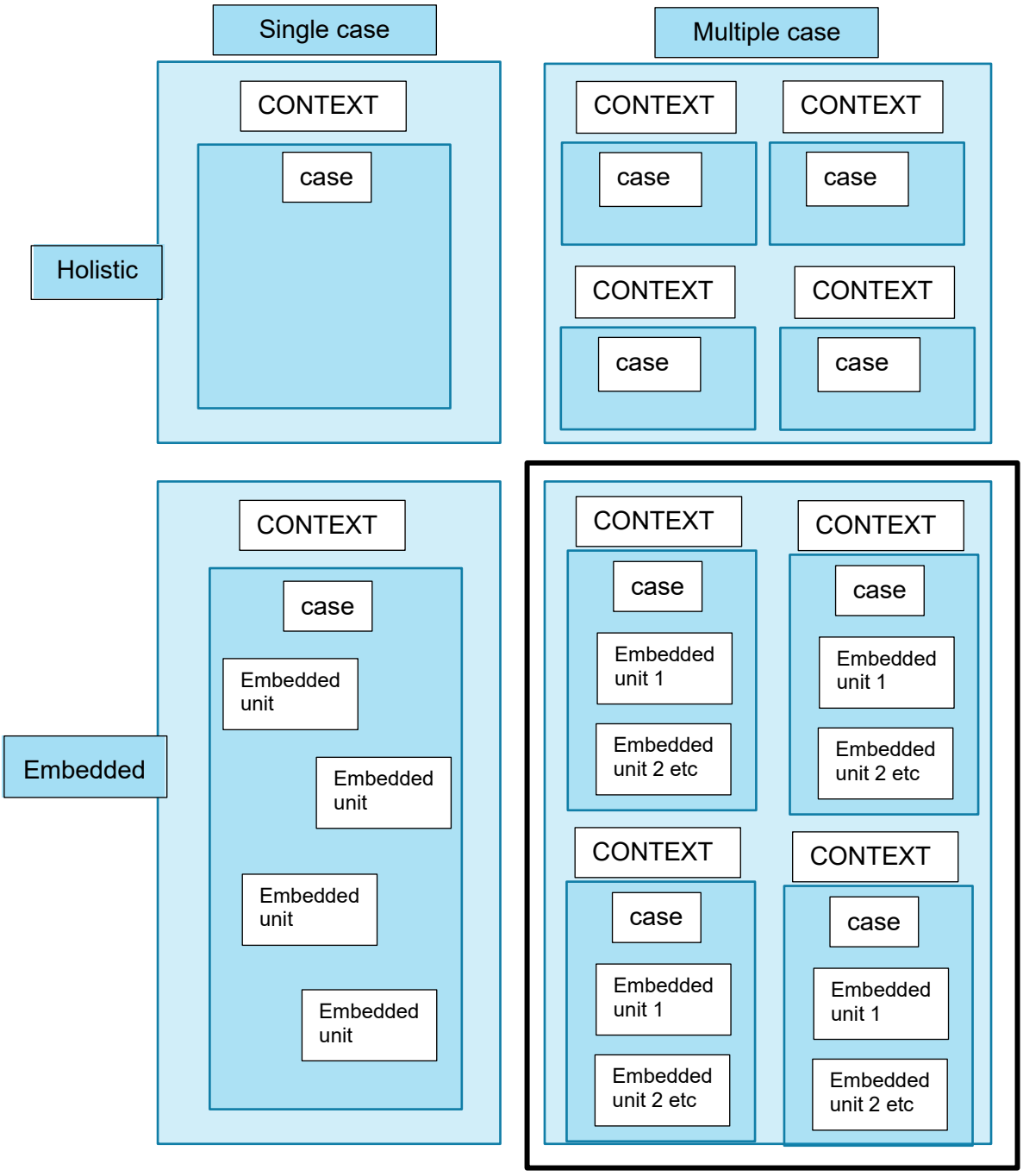


Figure 4.1 Holistic vs multiple case study from Yin (Yin, 2009, p. 46)

In this research, the variables are embedded within the cases. Holistic refers to the case being considered as a single entity or process. The bottom right diagram in Figure 4.1 best describes the research that is being undertaken. The embedded

units of analysis are the variables previously identified and selected related perceptions that are capable of capture during case study.

4.2.4 Descriptive, Exploratory or Explanatory type

A case study can be, according to Yin, (Yin, 2009) : -

- descriptive (describing what has taken place)
- exploratory (discovering potential new information not previously known)
- explanatory (beginning to understand why certain things are happening)

The case study method will encompass all the above elements. The results of case studies enable descriptions of the case to explain what has happened in that situation. The exploratory element identifies what has been done combining with the explanation of what was done and why.

4.2.5 Overall Structure

The overall case study design illustrated in Figure 4.2 was based upon Yin's case study approach. (Yin, 1993)

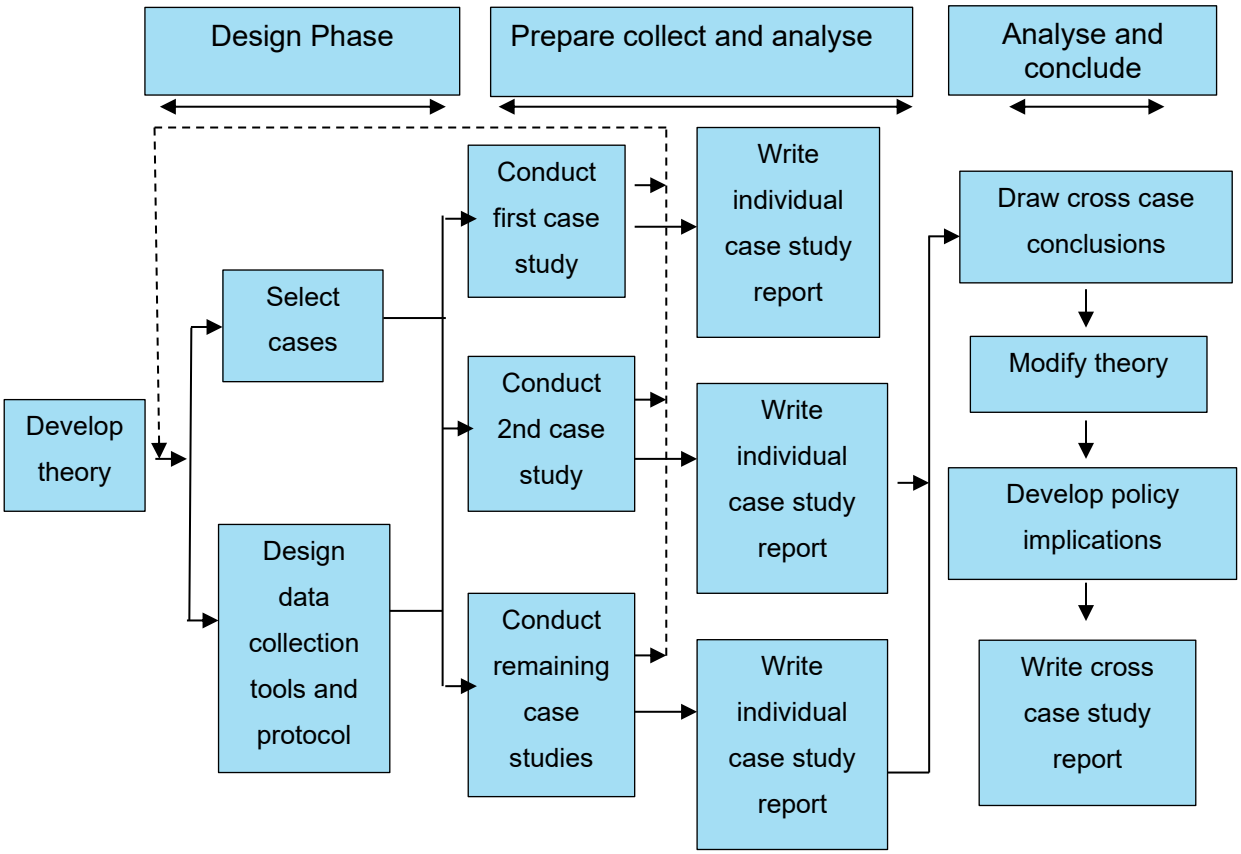


Figure 4.2 Multiple case study method Yin 1993 and (Yin, 2009, p. 57)

In Figure 4.2 the "Develop Theory" stage was completed in Chapter 1, comprising the initial theoretical proposition (initial design protocol) for the variables. The

following stages of prepare, collect, analyse and conclude are covered in the following sections.

4.2.6 Further Categorization

Table 4.2 further identifies where the case study methodology fits within special and temporal categorisation.

Table 4.2 Case study categorisation

Cases	**Spatial variation**	**Temporal (time) variation**	
		Yes	**No**
One	None		Single case study diachronic
One	Within Case	Single case study synchronic	Single case study synchronic and diachronic
Several	Cross case and within case	Comparative method	Comparative historical
Many	Cross case	Cross sectional	Time series cross sectional
Many	Cross case and within case	Heirarchical	Heirarchical time series

The analysis will encompass multiple cases, cross case and within case, highlighted in Table 4.2.

4.2.7 Selecting and Finding Participants or Practitioners

Before cases can be selected, the owners, or gatekeepers, need to be identified and then approached requesting participation. Participants were initially selected from companies with access to specific files for case study and the more detailed technical information regarding practical implementation of root barriers.

It is necessary to state that the use of the word practitioner or participant has been used consistently to refer to organisations involved in the case study method. The use of the word practitioner or participant re-enforces the concept of greater involvement and knowledge compared with respondents used when referring to the questionnaire method of data collection.

However, finding practitioners proved difficult in this research due to the relatively small population of knowledgeable participants involved in clay shrinkage subsidence and the specialist nature of root barrier installation.

A list of 11 possible participants for the case studies was compiled developed from contacts at the subsidence forum, internet search, historic contacts and referrals from others. The participants were all contacted during the research requesting cases for case study.

Participants were contacted with a written request by e mail or letter, followed up by a phone call emphasising the importance of the research and potential benefit to participants.

- suggesting a date for the one-day visit
- confirming purpose to visit your offices and discuss the use of root barriers (specific area) with you
- confirming this was part of the data collection phase of my Professional Doctorate, entitled “The Use of Root Barriers to Resolve Clay Shrinkage Subsidence Claims”
- advising that I would also very much appreciate the opportunity of looking at real cases that you have been involved in

Participants were also encouraged to participate by the author placing an article in the inaugural Subsidence Forum newsletter in December 2018. From the article one respondent replied to the request, although they were already included on the list of knowledgeable participants.

The text of the article seeking participants follows.

"Members of the Subsidence Forum would be aware that subsidence claims located on shrinkable clay soils are usually caused by trees. Clay shrinkage subsidence is most often resolved by either heavy pruning or removal of the implicated trees. Research suggests that pruning trees can be ineffective and only a short-term solution (Biddle, 1992). *Removal of vegetation is preferred as it resolves the problem and is relatively inexpensive. However, there is increasing evidence highlighting the importance and value of trees, especially in urban environments, from environmental, social and financial criteria. Tree removal as a routine solution may not be sustainable in the future, especially if there are stricter controls on the removal of trees or if clay shrinkage subsidence increases due to the effects of global warming, for example.*

Due to concerns about the loss of valuable trees in the urban environment I am currently undertaking a professional Doctorate (ProfDoc) at Anglia Ruskin University looking at an alternative solution to tree removal that involves construction of a root barrier, thus preventing tree roots from reaching the foundations. Previous research into root barriers suggest they could be unreliable (Freeman, et al., 1994) and The Institution of Structural Engineers have suggested further research be carried out. By means of literature review, appropriate methodology, questionnaires, interviews and case studies the characteristics, advantages and disadvantages of the root barrier option are considered in the thesis leading to the development of a framework, or roadmap for the use of root barriers to resolve subsidence claims.

If you would like to comment, contribute to the research or have any relevant cases where root barriers have been installed then please contact me on the email below or via the subsidence forum."

For more information, please contact Graeme Allen.

Whilst all potential participants were positive concerning the research, ultimately only two were willing to share cases; some did not reply, others did not have any cases and others were not keen to participate.

A list of all the knowledgeable prospective participants within Table 4.3 (with names and addresses removed for ethical reasons) identifies whether they agreed to participate in the research.

Table 4.3 Full list of participants case study

Participant	Type of company	contact details	Agreed to participate?
Participant 1	Contractor	Names and addresses were retained for contact but removed for ethical reasons	Agreed and provided cases
Participant 2	Arborist		Agreed and provided cases
Participant 3	Engineer		Authors own cases
Participant 4	Arborist		Spoke to at 2017 subs forum. Did not have enough cases for study
Participant 5	Arborist		Consultant who has views on root barriers and has seen many installations but does not have physical files for review/case study (Dec 2017) but provided contacts
Participant 6	Engineer		Does not have direct involvement in root barriers but useful contacts provided
Participant 7	Loss adjuster		Request sent by email 13th March 2018. Referred to others who have cases
Participant 8	consultant		Valuable knowledge regarding materials used in root barriers (Phoned 9/11)
Participant 9	Contractor		No cases provided
Participant 10	Arborist		Merged with participant 11
Participant 11	Loss adjuster		Involved in many projects. Request sent by email 13th March 2018. Declined offer of cases for case study as protecting commercial advantage
Participant 12	Arborist		No response to enquiry.

For those participants that agreed to share data the ethical issues were in place to safeguard data, designs and intellectual property.

One participant involved in subsidence claims declined involvement as they had invested heavily in the use of barriers over many years developing patent systems to their commercial advantage.

Ultimately two knowledgeable participants agreed to provide data for the case studies. These were participant 1 and participant 2, participant 3 is the author using data from 2 cases.

In total 33 case studies were used in data collection.

4.2.8 Sources of Evidence

The case study method inherently draws upon rich data sources. The six most used sources of evidence (methods of data collection) that align with case study methodology according to Yin (Yin, 2009) are as follows: -

- interview (structured and semi structured)
- documentation
- archival records
- direct observation
- participant observation (open and covert)
- physical artefacts

The data was gathered for case studies using structured interview, archival records and documents.

4.2.9 Collect Data

The method of data collection for knowledgeable participant 1 was a one-day site (office) visit on 18th January 2018 to review files and collect the data and populate the pro-forma. In order to maintain consistency, the visit was arranged for one whole day with the first hour discussion, followed by case review and review at the end of the day to include the structured interview. No screening of cases was involved, i.e. the cases that were reviewed were the only files provided by the participant. Cases 1 to 4 (4 cases).

For participant 2 data collection was by means of the populated pro-forma and a site visit on 12th September 2019 during which time the structured interview was completed alongside case review discussion. Similarly, no screening was carried out, i.e. all the cases included in the case study were the only files provided during the data collection process. Cases 5 to 31 (27 cases).

Participant 3 included the author's own cases taken from file records. Cases 32 and 33 (2 cases).

4.2.10 Construct Validity (case study)

Construct validity refers to identifying the correct operational measures for the concepts being studied. This is achieved by: -

- using multiple sources of evidence to achieve converging lines of enquiry
- establishing a chain of evidence

- the draft reviewed by participants

The above were achieved in the research by ensuring the data was sourced from various participants and respondents in various technical fields. The results and analysis, once completed, were issued to participant 2 seeking comments and any comments received were incorporated in the results and discussion. In terms of data collection case studies use multiple sources of evidence therefore provide rich data addressing these concerns regarding construct validity (Gray, 2004, p. 129)

4.2.11 Controlling Bias (case study)

The cases were obtained from three practitioners and two viewpoints 2 x engineers (6 cases) and arborists (27 cases) reducing the effects of participant bias. In other words, no one field of expertise dominated.

Bias was also controlled by adopting a pro forma to ensure standardisation, as only the specific previously identified variables were collected within a consistent form. For the individual case studies, and in order to ensure consistency, criteria were developed (theory development) before individual cases were investigated.

Yin suggests controlling bias by the investigator not relying on pre-conceived positions and being open to contrary findings. (Yin, 2009, p. 72) To some extent, this was achieved by sending the results to participant 2 as mentioned above, minimising bias and being open to alternative views.

4.2.12 Data Triangulation

Data triangulation was ensured by collecting data from different sources (or data collection instruments). The instruments were documents, drawings, method statements and file notes. It could be argued that these are still from a single source of documents. It would be reasonable however, to assume that documents hold reliable and valid information within the organisation.

Notwithstanding the above, triangulation was enhanced by using a different method of data collection, or data collection instrument of structured interview during the case study data collection visits. The structured interview provided a different form of data assisting in this triangulation process.

Figure 4.3 illustrates how triangulation of data sources was achieved.

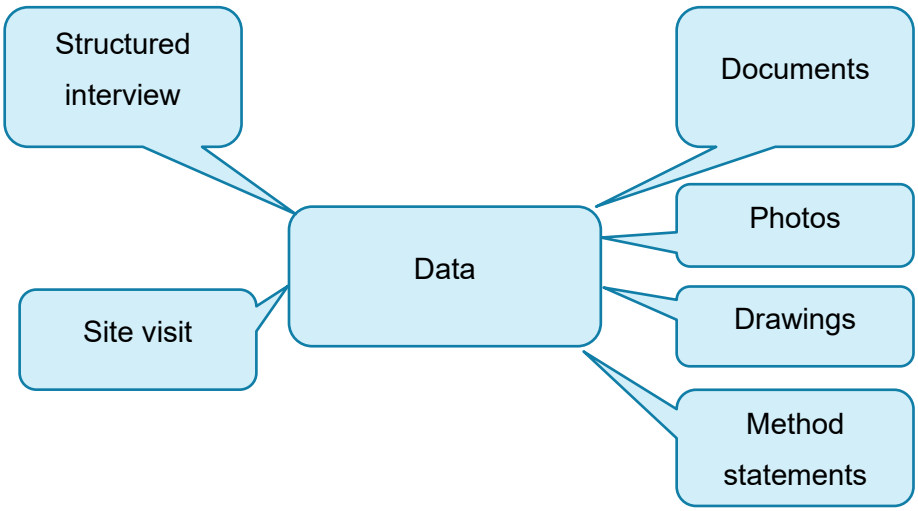


Figure 4.3 Triangulation of data sources

4.2.13 Reliability

Yin refers to reliability in case studies referring to the premise that if an investigator followed the described procedure, they would arrive at similar findings and conclusions. (Yin, 2009, p. 45). According to Yin, the goal of reliability is to "minimise the errors and biases of a study".

Therefore, the procedures have been recorded in this chapter to enable replication and the pro-forma could be easily replicated.

4.2.14 Linking Case Study Questions with Variables

The proforma was designed to link directly with the previously determined variables seeking the more detailed information in a standard format.

The specific questions gather the quantitative data (site and general location, root barrier characteristics, depth, materials and construction, investigations, monitoring, cost and vegetation remaining). Additional questions gather qualitative data (Why was the root barrier option chosen? Were there any particular difficulties encountered? perceptions and experiences and whether deemed successful?).

The pro-forma also allowed for any additional comments or notes to pick up the participant's information not on the form or important for a particular case but not collected by the pre-set questions.

Table 4.4 lists the 22 case study questions (left column) together with the embedded units of analysis (variable or perception on the top row) and the shading identifies where the questions connect with variables and or perceptions.

Table 4.4 Grid linking case study questions to variables

	Obtain general information	Clay soil properties	Property foundation depth	Distance building and barrier	Site features wall etc	Tree species	Tree size (mature height)	Tree vigour	Tree age	Trunk diameter	Protecting trees from damage	Distance root barrier and tree	Depth root barrier in the ground	Length root barrier	Root barrier materials	Cost of installation	Construction method	durability of materials	Site constraints	Could damage cut root ends	Root barriers are difficult to install	Unreliable and untried/tested
Site Location	■																					
Postcode	■																					
Date installed	■																					
Design of the root barrier		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■			
Barrier material.		■										■	■	■	■	■		■				
Construction method.				■									■		■	■	■	■		■	■	
Plan of the site with location barrier.	■			■	■							■		■					■			
Soils information	■	■																				
Level or crack width monitoring results.	■																					■
Extent of repairs to the property	■																					
Cost of the root barrier	■												■	■	■	■	■		■		■	
Tree that was saved by root barrier.	■					■	■	■	■	■	■											
Vegetation remaining.						■	■	■	■	■	■									■		
Depth of root barrier		■	■	■	■	■	■	■	■	■	■	■	■		■	■	■	■		■	■	■
Length of root barrier					■	■	■	■	■	■	■	■	■	■	■	■	■	■		■	■	■
Why chosen	■																					■
Difficulties encountered											■	■	■	■	■	■	■	■	■		■	
Monitoring after																■						■
Was solution successful	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Photos additional	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Comments	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■

4.2.15 Share Data Case Study Data Analysis

Data from the case studies were analysed and descriptive statistics reported in tables and via other relevant visuals.

One feature that distinguishes case study from other research methods is that the case study data and the report are often one and the same, whilst being presentable and enabling others to replicate or evaluate the data obtained.

4.2.16 Limitations (case study)

One of the most challenging aspects of case study research is identifying and obtaining meaningful and relevant data. As there has been no published detailed research on this topic, the research cannot rely on previous journals or published literature.

Three participants encompassing 33 cases is considered sufficient to provide rich data relating to variables for analysis.

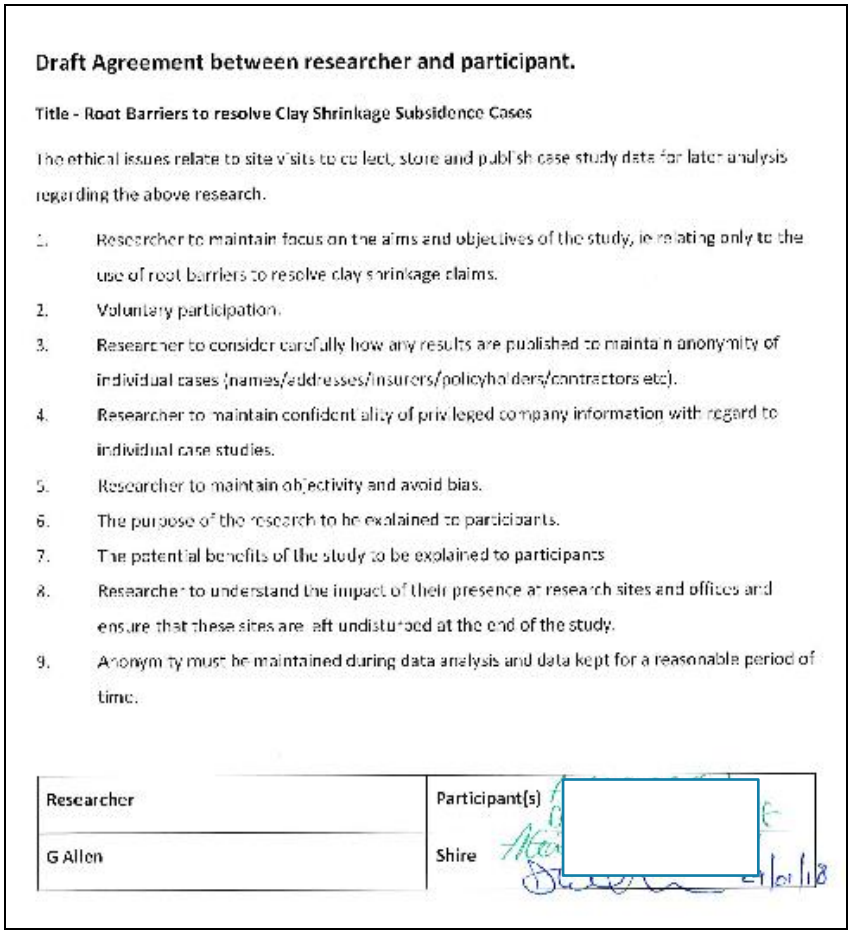
4.2.17 Ethics (case study)

Ethical consistency was achieved by maintaining confidentiality and protecting privileged company information to avoid possible financial loss, as individual companies may be very protective about their designs or methods in the use of root barriers.

Other ethical considerations relating to the case studies are listed: -

- Voluntary participation was emphasized.
- Participants must understand purpose and procedures of the study.
- Participants must understand that they have the right to a copy of the results.
- Participants must understand the potential benefits of the study and that their privacy will be respected.
- Researchers must understand the impact of their presence at research sites and ensure that these sites are left undisturbed at the end of the study.
- Care must be taken to identify and nullify any actual or perceived issues where power between the researcher and participant could be abused.
- Anonymity must be maintained during data analysis and data kept for a reasonable period.
- Ensure that writing is free of bias towards any group. (E.g., age, ethnicity, sexual orientation, race, gender, etc.)
- The details of the study must be carefully explained within the actual report to allow readers the opportunity to judge the ethical quality of the study for themselves.
- The signed agreement between researcher and participant builds trust and ensures that ethical considerations for both parties are in place.
- With regard to documents, the responses should be confidential so that no individual could be identified.
- Draft agreement prepared.

The agreement is shown in Figure 4.4.



Draft Agreement between researcher and participant.

Title - Root Barriers to resolve Clay Shrinkage Subsidence Cases

The ethical issues relate to site visits to collect, store and publish case study data for later analysis regarding the above research.

1. Researcher to maintain focus on the aims and objectives of the study, ie relating only to the use of root barriers to resolve clay shrinkage claims.
2. Voluntary participation.
3. Researcher to consider carefully how any results are published to maintain anonymity of individual cases (names/addresses/insurers/policyholders/contractors etc).
4. Researcher to maintain confidentiality of privileged company information with regard to individual case studies.
5. Researcher to maintain objectivity and avoid bias.
6. The purpose of the research to be explained to participants.
7. The potential benefits of the study to be explained to participants
8. Researcher to understand the impact of their presence at research sites and offices and ensure that these sites are left undisturbed at the end of the study.
9. Anonymity must be maintained during data analysis and data kept for a reasonable period of time.

Researcher	Participant(s)
G Allen	Shire

Figure 4.4 Researcher participant agreement form (Source Author)

4.3 Questionnaire method of data collection

4.3.1 Introduction

The survey methodology was justified in the previous chapter as appropriate to progress analysis of the perceptions using a questionnaire method. To reiterate, the perceptions being researched relating to cost, quality and time are.

- practical concerns
- cost concerns
- knowledge concerns and
- reliability concerns

Questionnaires form an integral part of survey methodology and a questionnaire would be capable of providing useful and meaningful data from subsidence practitioners and arborists in relation to perceptions.

Questionnaires have limitations in that more technical data may not be readily available. In this research, not all respondents may have sufficient knowledge to

provide the technical information required concerning the practical use of root barriers. This concern will be partly overcome by careful design of the questionnaire so that information gathered is appropriate to the audience, whilst data concerning variables and the more technical aspects will be collected using case study.

The word “respondent” has been used consistently to refer to individuals involved in the survey methodology. The use of the word respondent reinforces the notion of the individual’s lesser involvement in the practical use of root barriers than the use of the word participants in the case study method.

The method's characteristics are explained in this section insofar as they relate to the analysis of the perceptions in the use of root barriers.

The method (of data collection) for the questionnaire is described under the main headings of: -

- find the respondents
- questionnaire design
- ask for permission
- collect data
- share data
- controls

4.3.2 Find Respondents

The questionnaire was designed to seek general views and perceptions regarding cost, quality, time and knowledge concerns from practitioners on root barriers. Respondents were chosen specifically as those involved in dealing with subsidence claims but would not necessarily have any specific knowledge of the use of root barriers.

Practitioners such as loss adjusters, engineers, arborists, insurance companies could have been approached individually in order to seek perceptions on the practical use of root barriers. However, this approach would have been very time-consuming as hundreds of such companies were involved in clay shrinkage claims. Further, it would have been difficult to control who had completed the response within the company approached. Consequently, a low response rate would have been expected.

The best opportunity of obtaining responses from multiple respondents was at conferences or meetings where practitioners, i.e., those involved in subsidence or working with trees, would be present.

Two groups were considered appropriate for collection of questionnaire data: -

- The annual conference of the Subsidence Forum held at BRE Watford
- TDAG (Trees and Design Action Group)

Additional questionnaire results were obtained during case study data collection visits. The subsidence forum and TDAG respondents are described below.

4.3.2.1 Subsidence Forum

The Subsidence Forum meets annually, with approximately 100 attendees at the annual conferences being representative of the general views within the subsidence industry.

The author formally requested, and was accepted, to present at the October 2016 Subsidence Forum on the subject of research into the practical use of root barriers. The meeting was held at Building Research Establishment (BRE) Watford facility.

With reference to list of attendees at the Subsidence Forum, all major groups were represented: -

- the largest insurance companies dealing with building damage claims in areas prone to clay shrinkage subsidence
- loss adjusters and engineers dealing with clay shrinkage as cases of clay shrinkage are usually delegated by insurers to loss adjusters and occasionally engineers
- arborists or those involved in tree management as implementation of root barriers is often delegated to arborists with detailed knowledge of trees and root growth
- specialist groups or companies such as materials suppliers or contractors involved in root barrier implementation
- special interest groups such as TDAG (Trees and Design Action Group) or local authorities involved directly or indirectly in root barrier implementation

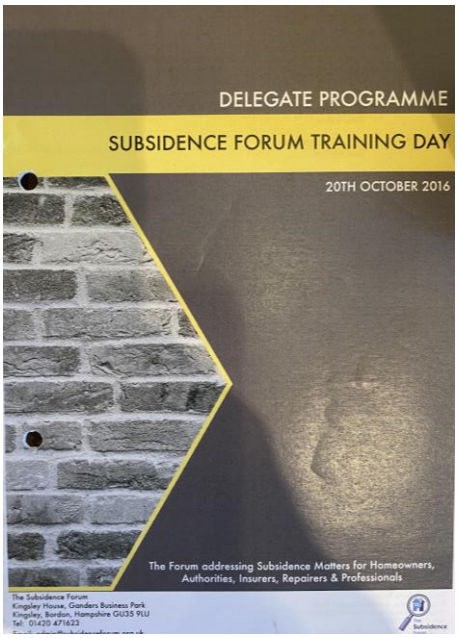


Figure 4.5 Subsidence Forum training day brochure

The delegate list included members of the following fields of expertise, followed in brackets by the total number and percentage of the total: -

- arborists (11, 9%)
- insurers (22, 18%)
- consultants (engineer/surveyor/project manager) (24, 20%)
- contractors (21, 19%)
- solicitors (7, 6%)
- investigations/geotechnics (10, 8%)
- loss adjuster (14, 12%)
- council/local authority (6, 5%)
- other (4, 3%)

The data illustrates the wide range of disciplines represented and the spread, with the highest attendance from consultants (20%) followed by insurers (18%) and contractors (19%).

4.3.2.2 TDAG (Trees and Design Action Group)

TDAG is a group of individuals, professionals and organisations from both the public and the private sectors who have come together to increase awareness of the role of trees in the built environment. The author has attended several meetings held by TDAG in respect of involvement with research into root barriers.

A formal request to present at a regular meeting was accepted in March 2019. There were 15 participants at the meeting representative mainly of arborists and council officers dealing with tree related issues.

4.3.2.3 Other Respondents

One of the participants (2 individuals) also completed the questionnaire who provided data in the case study during the structured interview.

4.3.3 Questionnaire Design

Specifically, the main research survey will include questions that require numeric answers to include rankings, counts, and variable information, i.e., perceived value of trees, frequency in use of root barriers, main concerns.

The questionnaire was designed to capture broader qualitative data concerning perceptions in the use of root barriers from practitioners to achieve the aims and objectives.

The questions were carefully worded and generalised as it was anticipated that not all the participants would be able to provide technical or specific data on the use of root barriers. The approach adopted in analysing the data will be via grouping, identifying trends, recording scores for qualitative data and calculating averages from quantitative data.

The most appropriate method of data analysis will be determined by the type of data collected in the questionnaire. Categorical data as defined by Gray, (Gray, 2004, p. 286) consists of nominal data (sets or categories) or ordinal data (ordered). Quantifiable data is divided into two types, interval data or ratio data. The main difference between interval data and ratio data being that interval data does not have zero point of origin. The nominal and ordinal data collected from the questionnaire would be best suited to non-parametric type tests, such as chi-squared, since the population from which the data have been collected cannot be assumed to be normally distributed. (Gray, 2004, p. 287) The specific data analysis process appropriate to the questionnaire results is described in section 5.3.

The following nine questions explain the purpose of the question and how each question links to the original aims and objectives. The explanation indicates the type of data being collected, how the perceptions were captured and how the question relates to variables either directly or indirectly.

Question 1

What is the general perception on the use of root barriers to resolve clay shrinkage subsidence claims?

A positive, (would usually consider using)

B neutral, (would sometimes consider using)

C negative, (would rarely consider using)

D no view on root barriers

The purpose of the question was to identify general perceptions following the planned talk. For example, were delegates views generally positive, neutral or negative towards root barriers?

The ordinal data response does not specifically identify where the concern may be, such as practical, cost, knowledge, reliability, quality or time. The question is as a suitable introduction to the remaining questions and sets the scene, asking participants to consider their overall and initial views in the light of the presentation.

The question links to variables indirectly, researched by the case studies but does not specifically identify a variable of concern. For example, the respondent may have a negative view of root barriers because they have been aware of situations where they have been installed in the past at inadequate depth (variable depth of the root barrier) leading to failure. Alternatively, the respondent may have come across a situation where a root barrier was installed because it was much less expensive than underpinning (variable cost of underpin) leading to a more positive response.

Question 2

How often are root barriers considered (not used) when dealing with clay shrinkage in your experience. This includes cases where they are only considered but not necessarily used?

A More than 75% of cases

B Between 75% and 25% of cases

C less than 25% of cases

D don’t know

The question intends to identify how many of the delegates consider the root barrier solution when dealing with clay shrinkage cases. The ordinal data collected within categories A to D explores whether respondents are aware of root barriers being a viable alternative solution to tree removal.

The question seeks views on knowledge concerns as if there was a lack of expertise available then root barriers would not be considered in the first instance. The question seeks participants underlying perceptions of root barriers being unreliable or too expensive for example, as this would have a direct influence on the answer provided. The question links to variables indirectly but does not specifically identify a variable of interest.

Question 3

What would you consider to be the main difficulty with the root barrier solution?

A Practical difficulty e.g., services or installation

B Cost when compared with tree removal

C Lack of understanding/design rules

D Unreliable

The question seeks the respondent's views by collecting nominal data on the main difficulty in the use of root barriers linked to four perceptions identified in Chapter 1. Apart from identifying specific concerns the responses assist in focusing attention on those aspects of root barriers that are considered the most problematic in the participant's experience.

The question links to variables indirectly, researched by the case studies. For example, if the concern were cost identified by the response then the variables most relevant could be: -

- cost of underpin
- cost root barrier
- construction method
- length of barrier

Question 4

If you have installed root barriers, in your experience have they been successful?

A all of the time (100%)

B most of the time (>75%)

C some of the time (<75%)

D no (direct) experience of their use

The question drives further into the perceptions in the use of root barriers to identify if delegates were aware of the root barrier solution being successful in their experience. The ordinal data collected links directly with perception that root barriers are unreliable, the outer ring in the concern conceptualisation (Figure 2.14).

To keep responses succinct, four responses were provided. The range for root barriers working most of the time was set at 75% which is quite low. This would represent 1 failure in 4. The question would also identify how many respondents have no experience in their use.

It would have been useful to have tracked answers at the subsidence forum so that it would be apparent which other responses were provided for those that answered this question with A for example.

Where the final answer asks whether the participant has experience of their use it is on the basis that they have not been directly involved in a root barrier installation. For example, I may not have been on a cruise (at the time of writing) but I would have a good idea what was involved and what the experience would entail.

Questions 5, 6 and 7 included a photo of an example tree obtaining ratio data on the value of the specific tree over a 30-year period.

Q5 What in your view is the value of this tree over a 30 year period?

A Over £1,000,000

B Between £1m and £250,000

C Between £250,000 and £50,000

D Less than £50,000

Note

£1,000,000 over 30 years =£33,000 per year

£250,000 over 30 years = £8,300 per year

The first tree is a large and dominant oak tree. It was expected that delegates would score this tree highly and of particular interest would be the actual value provided by respondents compared with the actual value that may be determined by calculation.

Question 6

What is the value of this tree over a 30 year period?

A Over £1,000,000

B Between £1m and £250,000

C Between £250,000 and £50,000

D Less than £50,000

Note

£1,000,000 over 30 years =£33,000 per year

£250,000 over 30 years = £8,300 per year

The second tree was chosen being significantly smaller than the previous tree. Again, delegates' responses regarding the actual value is considered significant. The addition of different trees allows interpretation of the relative value as well as absolute values for comparison.

Question 7

What is the value of this tree over a 30 year period?

A Over £1,000,000

B Between £1m and £250,000

C Between £250,000 and £50,000

D Less than £50,000

Note £1,000,000 over 30 years =£33,000 per year

£250,000 over 30 years = £8,300 per year

The tree was of intermediate size between the previous two and medium comparative value and importance. Delegates' responses regarding the actual value and relative value would be important.

Question 8

Who should specify and take the lead role in the use of root barriers?

A Loss Adjusters/Engineers

B Arborists

C Contractors

D Don't know

The question requires delegates to determine the type of company, individual or specific expertise required or necessary to take the lead role in designing and installing root barriers.

The question is linked with perception, "knowledge" rather than dealing with practical, cost or reliability concerns. What type of company has the necessary expertise to deal with design and installation of root barriers?

The question is linked with question 3, "main concern", in that if the main concern with installation of root barriers is practical for example, then perhaps contractors or those with knowledge of dealing with site works, services and ground works should take the lead role in the design and use of root barriers.

Question 9

Would you consider a root barrier even if there were no objections to tree removal?

A Yes

B No

C No (direct) experience using root barriers

The question seeks to identify whether tree removal is always the first solution considered, irrespective of the tree's value or importance. Are other solutions such as a root barrier considered if there are no objections or concerns raised with regard to the removal of a tree, however important or valuable the tree may be?

The question is linked with the first two questions obtaining ordinal data on general perceptions and "how often are root barriers considered?".

Figure 4.6 shows diagrammatically how the nine questions inter-relate regarding both perceptions and variables.

4.3.4 Mapping Questionnaire (the big picture) (Source Author)

The following diagram shows how the questions link with the variables and perceptions.

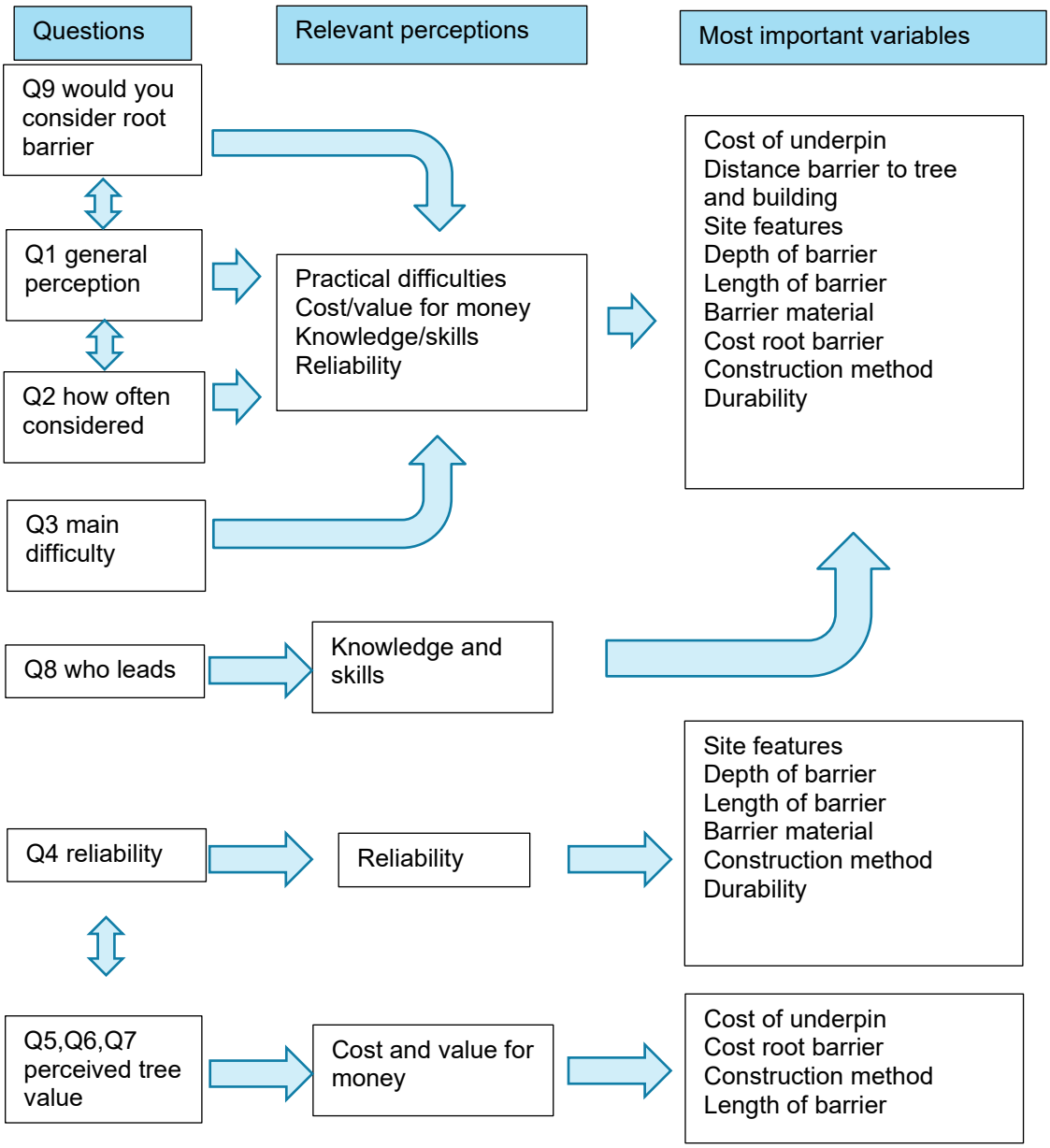


Figure 4.6 Mapping questions to perceptions and variables

The participants were allowed approximately 1 minute to answer the questions using the response pad provided at BRE Watford. For TDAG the responses were written in paper form and collected at the end of the session.

4.3.5 Ask Permission

Permission was presumed from the Subsidence Forum and TDAG by their formal acceptance of the author's request to present at their meetings. In addition, before the presentations commenced, delegates were informed at the outset that data would be collected at the end of the presentation being part of a research project into the practical use of root barriers. Finally, participation was voluntary in that if

participants did not wish to take part then they would not provide answers to the set questions.

4.3.6 Collect Data

At the Subsidence Forum an electronic voting system was used. After each question the respondents pressed a key on their individual keypad with the appropriate answer. The answers for each question were displayed on the main screen in terms of total votes for each possible answer before moving to the next question.

This method proved helpful in that each question could be closed and respondents were aware of other's answers before moving to the next question. It enabled a pause for recollection before moving on. The electronic system did not allow individual tracking of responses.

At TDAG responses were collected in paper format and the responses were collected at the end of the session. It can be seen in the appendix that the answers were not provided on the typed form as the proforma response sheet was not available.

The raw results from each event are shown in Appendix 12.11 and 12.12.

The conference presentation and questionnaire also provided an opportunity for potential participants to be identified for inclusion within the case study methodology.

At the end of the presentation practitioners were asked to send comments on the presentation to seek their general views for inclusion in the research.

Positive responses included: -

- participants providing information on additional literature
- a possible case study

4.3.7 Share Data

The results of the questionnaire, and analysis are provided in Chapter 5.

4.3.8 Controlling Bias

The method adopted for the questionnaire incorporated a presentation and an integral set of nine questions. This procedure-controlled bias as all participants received the same presentation and had a similar starting point. The presentation enabled respondents with less experience or knowledge of root barriers to participate in a more meaningful way. All questions were presented in the same environment, same time, and same date under the same conditions.

Furthermore, answers were recorded and published directly before the next question was asked, aiding overall consistency.

4.3.9 Replication Strategy

An important concern regarding research is replication and ensuring that the research, if undertaken by another, should be capable of reproduction. In other words, the replication strategy demonstrates that others can repeat and verify, if necessary, what has been done.

Replication was achieved by using one presentation combined with the questionnaire, delivered immediately following the presentation. Although the precise participants would be difficult to replicate, provided they were from similar backgrounds and groupings, the results should be similar if other researchers conducted it.

After a pre-set presentation, introducing the nine questions eliminated effects for setting, timing, circumstances, and environment, influencing the respondents in a questionnaire.

4.3.10 Limitations

There are limitations concerning the survey design and implementation that should be acknowledged. For example, with regard to TDAG respondents, information concerning their professional background and experience was not obtained during the questionnaire. For the Subsidence Forum, information concerning background and experience was collected by reference to listed attendees. The questions concerning tree value were not based upon specific tree or tree species but generalized to three broad types in terms of size. The number of participants for TDAG was low compared with Subsidence Forum and respondent numbers could have been increased by adopting online questionnaires involving the wider TDAG community. Nevertheless, by grouping certain questions the number of TDAG respondents for specific themes was significantly increased.

4.3.11 Validation

The presentation included background information, the original research proposal, aims and objectives. This ensured that those present with less detailed technical knowledge would understand the basic concepts and the intention of the research. It establishes all participants on a level playing field so that any pre-conceived ideas or bias or uncertainty regarding the purpose of a root barrier would be minimised.

The presentation is reproduced in Appendix 12.8 to illustrate how it sets the scene and formed an integral part of the data collection process in elimination of bias, increasing validity and reliability.

4.4 Triangulation

The rigour of the research and its validity are enhanced by triangulation. Robson (Robson, 2002, p. 174) advocates four forms of triangulation: -

- multiple sources of evidence
- methodological triangulation
- observer triangulation
- theory triangulation

The multiple sources included the participants from the Subsidence Forum and the TDAG group. Within the Subsidence Forum different sources were subdivided within the 9 individual disciplines.

Methodological triangulation is achieved using questionnaires, as described in this section, in addition to case study. Whereas case study was used primarily to research variables, and questionnaire to research perceptions, the two concepts cannot easily be separated so that there are elements of perceptions researched within case study and variables within the questionnaire. This combining of methods (case study and questionnaire) to investigate variables and perceptions achieves methodological triangulation.

Observer triangulation is achieved by using more than one observer or participant and this is demonstrated in the total number of combined responses for the questionnaires from the Subsidence Forum (76), TDAG (16) and case study (2) total 94.

Theory triangulation seeks to link the perceptions and variables within discussion to the initial design protocol for variables and the cost, quality time model for perceptions.

4.5 Summarizing Chapter 4 - Research Methods

Chapter 4 described in detail the methods (of data collection) for the two methodologies selected in Chapter 3 of case study (for the variables) and survey (for the perceptions).

Initially the concepts of qualitative and quantitative data were explained in relation to the research, summarised broadly as data in the form of words (qualitative) and numbers (quantitative). The research was aligned with a mixed methods approach

comprising qualitative and quantitative data with variables concerned mainly, but not exclusively, with quantitative data and perceptions concerned with mainly words.

Firstly, the case study method was defined in relation to units of analysis, type of case study, structure and characteristics necessary to investigate variables in the use of root barriers. The questions within the case study proforma were linked directly to variables and mention was made concerning the general way the data would be analysed in Chapter 5. The threats to case study method, such as bias and validity, were discussed with mention of how these threats would be controlled or eliminated by the research approach. The questionnaire method (of data collection) was described as necessary to investigate perceptions in the use of root barriers. The nine questions were linked directly to each of the perceptions (and variables), maintaining the common thread of aligning data collection with objectives.

Table 4.5 illustrates the logical progression from methodology to methods aligned with research objectives and how they link to the following chapter (results and analysis).

Table 4.5 Progression through research

Objectives	**Methodology** **Chapter 3**	**Method** **(of data collection)** **Chapter 4**
Objective 1 and 3a. Identify and analyse the most variables that influence the use and effectiveness of root barriers.	Case study	Case study Three participants documents, drawings, photos, calculations, including structured interview

Objectives	Methodology	**Method (of data collection)**
Objective 2 and 3b. To identify and analyse perceptions of root barriers amongst practitioners.	Survey	Questionnaire Subsidence Forum and TDAG

Chapter 5 Results and Analysis

PART C

RESULTS,

ANALYSIS AND DISCUSSION

PART C Results, Analysis and Discussion

5.0 Results and Analysis

5.1 General Introduction

The case study and questionnaire results, presented within this chapter, include individual and combined analysis aligned with theoretical propositions previously developed fulfilling objective 3.

The results are first presented for the case study obtained from documents (drawings, file records, photos, method statements and file notes) as the data collection instrument to populate the case study pro-forma. Additional data was collected during case study visits by means of a structured interview. The results analysis for case studies is structured using headings from the initial design protocol established in Chapter 1 for the variables.

The survey methodology considered perceptions using questionnaires as the method of data collection, fulfilling objective 3b. Whilst case studies were primarily used for analysing variables and questionnaire for the perceptions it should be emphasized that there was interplay between variables and perceptions so that they did not always fit into distinct categories.

5.2 Case Study Results and Analysis

5.2.1 Data Analysis General

Yin, one of the main proponents of case study research, accepts that case study methodology does not benefit from numerous historic and generally accepted methods for dealing with the results as other methodologies (Yin, 2009). Furthermore, Yin states: -

> "…*the analysis of case study evidence is one of the least developed and most difficult aspects of doing case studies. Unlike statistical analysis there are few fixed formulas or cookbook recipes to guide the investigator. Instead, much depends on an investigators' own style of rigorous empirical thinking along with a sufficient presentation of evidence and careful consideration of alternative interpretations".* (Yin, 2009)

Yin advocates various approaches to analyzing the data from case studies. He suggests putting information into different arrays, making a matrix of categories, placing the evidence within those categories, creating data displays, flow charts, and other graphics, tabulating the frequency of different events and examining the complexity of tabulations. Other practical suggestions include studying the output to

determine any meaningful patterns, and such is a frequency of occurrences and connecting them to the original research design.

Case studies are used to establish themes, links and relationships between the important variables in root barriers. These techniques include pattern matching, identifying rival explanations, explanation building and cross-case synthesis. This chapter will adopt these methods using the quantitative and qualitative data whilst reserving discussion for Chapter 6.

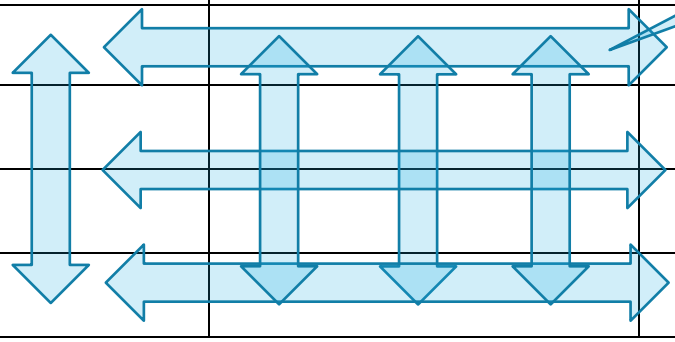
The various strategies in this chapter include: -

- obtaining “a feel” for the data, i.e., the story the data tells
- compare against previous theory (in this case initial design protocol)
- identify significant trends and similarities across cases and across participants
- grouping of data sets for further analysis
- identify significant differences across cases or participants
- linking of results to the research objectives
- consideration of perceptions embedded within case study data

The individual responses to the 22 case study questions from the 33 cases and 3 participants were combined onto an excel spreadsheet forming the case study database reproduced within appendix 12.4. Filters were applied to the case study database so that individual characteristics could be identified, separating the categorical data such as type of root barrier from the quantifiable data such as root barrier depth. Excel spreadsheet was adequate for the purpose without the need for proprietary data analysis software. The typical method of data presentation and analysis is shown in Table 5.1.

Table 5.1 Cross case and cross question analysis

Questions	Participant 1	Participant 2	Participant 3
	Provided 4 cases 1 to 4	Provided 27 cases Cases 5 to 31	2 cases 32 and 33
Questions 1 To Question 22			



From the raw data, slight modifications to the main case study database were required, without altering the data, as follows: -

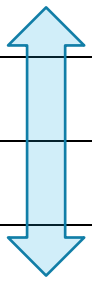
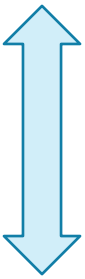
- where cells were duplicated these were merged to assist in results analysis collecting like data and reducing repetition
- specific information relating to addresses was removed from the master spreadsheet to ensure confidentiality and each case was given a unique number
- the base results were modified so that the question that asked about crack and level monitoring was separated into two questions so that specific answers could be identified
- tree species identified as high or moderate water demand
- soils classified as high or medium shrinkage

The case study database was printed at A1 size to gain an overall view of all the cases, assisting in cross referencing, pattern matching and comparing results. The results in A4 readable format are presented in Appendix 12.4.

5.2.2 The "Story" of the Data

Every case tells its own story, and the story, or narrative, forms an integral part of case study analysis. Cases 1 to 4 (participant 1) and cases 32 and 33 (participant 3) provided rich and detailed data for the cases reviewed. The data for participant 2 cases was not provided to the same level of detail being mainly factual without narrative. Analysis follows the process arrows in Table 5.2, vertically within cases as opposed to horizontally across cases.

Table 5.2 Individual case analysis-the story of the data

Questions	Knowledgeable participant 1	Knowledgeable participant 2	Researchers own cases
	Cases 1 to 4	Cases 5 to 31	Cases 32 and 33
Question 1 to Question 22			

5.2.2.1 Participant 1 (Cases 1 to 4)

The documents drawings, notes, method statements and photo documentation for the cases is provided in Appendix 12.5. Personal or identification information has been removed from the documents.

Cases 1 to 4 were obtained from participant 1, an engineering firm based in Worcestershire. For these 4 cases rich data was sourced from the site visit and direct file review thereby populating the proforma.

The projects identified represent cases completed in the last few years which amount to one or two cases per year on average.

There were fewer cases reviewed (4 total) for this participant compared with participant 2 (27 cases), however the richer data obtained more than compensates for the fewer cases.

Turning now to the individual cases.

Case 1 was completed in 2014 in Ely and instructed by a loss adjuster. The root barrier was installed at a depth of 4m and was 17m long. The root barrier solution was adopted as they were unable to remove the trees in the neighbour's garden. The reason for this was not identified in the files. Within the case study documents contained in Appendix 12.5 there is a written method statement describing the method for cutting roots and a procedure for installing the steel sheeting that comprises the root barrier. The process involves drilling 300mm diameter holes at the depth required (for the barrier) with 50mm (min) overlap. This is achieved using T5000 rotary auger rig capable of dealing with 1200kg mass. Sheet piles are driven into the softened/loosened ground using 64kg Rhino hammer off a tower scaffold. The sheet piles were M11 type.

The comprehensive written method statement also mentions dealing with the site features such as fences and scanning for services, how to deal with surplus material, access issues, and re-instatement. There is also a note for the arboriculturist confirming that all roots in the trench will be severed during the augering process and that no portland cement was to be used on the tree side of the trench. The note confirms that the sheets have a watertight interlock so that no cement grout used on the house side would leach onto the other side.

The file includes 9 photos of the work on site. The photos show the plant used to install the sheet piling, scaffold tower and protections. Of note, and this will be addressed later, is the proximity of the barrier to the house foundations.

Finally, an A3 drawing shows the root barrier location in relation to the property. The drawing shows the location of services, trees, height and distance to the property. The drawing also shows the neighbouring properties. The drawing is to a scale of 1:100 and shows all important dimensions.

Case 2 was completed in 2011 at Romford in Essex. The 4m deep, 28m long barrier was installed using the participants previously described method as in case 1 above. In this case three alternative solutions were priced, piling, traditional underpin and root barrier and the root barrier solution was the most cost effective. The file includes 6 photographs of construction and 5 A3 drawings. Drawing 130/05 shows the site's plan at 1:100 scale, showing services, buildings, named trees and the precise location of the root barrier in relation to the trees and to the property. It can be seen in this drawing how the U-shaped barrier extends at least 8m beyond the corners of the property. Drawing 130/01 shows the building and trees to the same 1:100 scale but with graded contour rings around each of the trees. These contour rings correspond to the depths required of potential underpin for each tree. The depths on the contour rings have been calculated using NHBC foundation depths. The depths reduce from a maximum of 2.3m (closest to the trees) to 1m. The maximum depth of 2.3m is required due to 4 out of 5 trees (maple (genus=acer)) and the other hornbeam.

It should be noted, however, and this will be discussed later, that although 2.3m was the maximum depth calculated (closest to the tree) the barrier was installed at 4m depth throughout. Drawing 130/02 shows the damage to the property, in plan, together with crack widths. Drawing 130/03 shows one of the priced alternative schemes of traditional underpinning. The maximum depth of 3.5m was determined closest to the trees in the area of most damage reducing to 1.5m deep further from the damage towards the main party wall. Drawing 130/04 shows the other alternative of piled solution comprising 23 mini piles in the area of damage.

Case 3 root barrier was installed in a built-up area of central London in 2017. Steel sheet piles were used as in cases 1 and 2 by this participant. The barrier was 5m deep and 60m long. Site notes indicate that this was a very restricted site with restricted access. The property comprised a block of flats with associated difficulties of having to deal with multiple occupants. Therefore, this situation was quite different from that of an individual property or household where only a few occupants would be affected. A more detailed procedure was prepared for the method of installing the sheet piling. The method statement included details for dealing with drains and services crossing the site and finishing the root barrier at the top.

Preliminaries and site set up was not undertaken by the participant installing the barrier. This was presumably due to the depth and length of the barrier being installed.

The process of installation was like that of other cases except 4m or 5m depth of barrier was used. The process also involved excavating initially a 2m trench. Four photos clearly show the completed barrier within the wider 2m deep trench and the block of flats in proximity.

Two A3 drawings are included within the documentation record showing how the participant dealt with services in the ground, firstly drains and secondly gas/electric runs.

The drawings and notes show that there was a row of plane trees that were saved as a result of installing the root barrier, a total of 5 large trees, together with a row of smaller trees and shrubs.

Case 4

Case study 4 was in Eastleigh, Hants and constructed in 2014. The file did not contain specific design information; however, the construction was steel sheet pile as in the previous cases and pre-bored. The photos show the plant used to push the piles into the ground as a small handheld pneumatic type hammer. The cost of the root barrier was £14,000 with one maple tree saved as result of constructing the root barrier. The barrier was 4m deep and 16 metres long and notes indicate that the tree could not be removed.

In total 9 photographs are included within the file as shown in the appendix. The photographs show the method of installation of the barrier using a JCB type digger within a reasonably open garden area laid to lawn with patio. Additional photos show the completed barrier with reinstatement including a brick dwarf wall rebuilt.

One drawing is reproduced showing the location of the barrier in relation to the property. Note the root barrier appears to have been constructed close to the tree in this example.

5.2.2.2 Participant 2 (Cases 5 to 31)

The pro forma was initially populated by the participant and further information on specific cases was achieved during the site visit and structured interview. The participant expertise was mainly within arboriculture.

Participant 2 produced 27 cases (5 to 31) which is significantly more cases than participant 1 and 3, however there was less detailed data obtained. Consequently, there is less detail here in reviewing the individual case narrative as few had accompanying documents, drawings or method statements.

Participant 2 preferred to identify difficulties as one single block encompassing all their cases whereas Participant 1 difficulties were completed individually.

Looking at the full array of cases populated by participant 2 it is apparent that they are located across England but mainly in the South. The participant completed root barrier installation to their own design although specific designs and drawings were not obtained during the data collection process.

In terms of barrier material two types were used a polypropylene geomembrane and a type of woven copper sheet geotextile.

The preferred method of construction was by excavating a trench and placing the barrier within the trench, which was then backfilled with gravel, although there is a case where the trench was excavated using an innovative vacuum suction technique.

The participant provided clay soil properties for all cases.

In all cases the participant made specific reference to whether level or crack monitoring had been received from the loss adjuster. This is important from the point of view of checking whether the root barrier had been successful or not as in some cases the level monitoring was continued after installation of the barrier.

The participant did not provide any information on the extent of repairs to the property, although valuable data concerning the costs for the barrier were provided for all 27 cases.

In all cases specific mention was made to the trees that were saved because of the root barrier including both their height and distance from the property, although due to the lack of drawings it was not possible to determine where the barrier had been constructed in relation to the building and the tree.

Both the depth of the barrier and the length of the barrier were provided and upon initial review of the results it appears that the majority were constructed at 4 metres depth, the minimum being 2.5 metres and the maximum being 4.5 metres depth.

In terms of why the barrier was chosen, instead of providing individual case results the participant advised that in general the root barrier was chosen because trees had TPO (tree protection orders) or that the root barrier was less expensive than underpinning.

Similarly, in terms of the main difficulties encountered, the participant provided the list of the most common issues as dealing with services, fencing and walls, hard surfacing and hard landscaping, restricted access, 3rd party agreements, storage for trench arisings and gravel and overhead cables.

In response to the case study question “was the solution successful”? in all cases the response was yes.

There were no additional comments apart from case 13 where the participant mentioned that a very large rock was encountered in the ground.

5.2.2.3 Participant 3 Cases 32 and 33

The documents drawings, notes, method statements and photo documentation for the cases is provided in Appendix 12.6. Personal or identification information has been removed from the documents.

Case study 32 was in located in Southend. The author was involved in the case due to the homeowner's complaint regarding the extent of repairs. Ultimately the root barrier solution was adopted because the local authority was very reluctant to remove the tree. There was adequate space between the tree and the building for a root barrier to be installed. The root barrier solution was also less expensive than underpinning, which would have been difficult in this situation. One concern with partial underpinning in this case was determining where the underpinning should be stopped, as there was a risk of damage occurring at the junction between the underpinned and non-underpinned sections. The root barrier overcame this concern. The implicated tree was a London plane 10m distant from the building.

The design of the root barrier in terms of depth and length was completed by the author’s own practice, although the construction and materials were determined by the loss adjuster and contractor who controlled the overall costs of the project.

The root barrier was installed at a depth of 2.5 meters which corresponded to NHBC guidelines and the distances from the tree to the barrier and barrier to the house are indicated on the drawing shown within the appendix. In terms of material, a woven fabric with copper core was used within an excavated trench and mass concrete

backfill. The plant used to excavate the trench was a Kuboto U27-4 JCB type digger. The site works lasted three days comprising excavation and construction of the root barrier. During construction of the barrier the clay soil was examined for roots and interestingly, no roots were found below 1 metre depth.

Level monitoring did continue for a short period following construction of the root barrier. As far as the level monitoring is concerned, it demonstrates that the amount of movement reduced following installation of the root barrier, but the duration was not significant enough to confirm its success as at least 12 months monitoring is usually required over all 4 seasons.

This case was also used as the case study pilot. The pilot case is what Yin sometimes calls the pre-test or a formal dress rehearsal. From this pilot study or pre-test, the author determined some of the main questions in the case study protocol that would be collected during the case study. However, amendments occurred as the study progressed reinforcing the view that the pilot leans more towards the exploratory role of case study design. With the benefit of experience , the pilot can have a more explanatory or confirmatory focus in the later stages. (Robson, 2002)

Case study 33 was one of the author's cases completed in 2018. Numerous trees damaged the community hall within a public park. The building had some inherent defects however clay shrinkage was demonstrated. There was particularly rich data for this claim including tree information, tree species and distances, services location, soils information, root depth, level monitoring, repair proposals and costings. The author's involvement was to review the damage, consider liability aspects and the feasibility of a root barrier within a report. Our report assessed the desiccation levels for each of the 8 main indicators to give an overall impression of the soil's desiccated state.

The desiccation assessment is based upon guidance from ISE contained in "subsidence of low-rise buildings" (Institution of Structural Engineers, 2000) which states,

"*A note of caution the detection of desiccation can be more difficult than assumed. As each of the techniques has its own disadvantages, one should use many different criteria and only conclude that desiccation is present if the various tests corroborate each other, of these tests the measurement of soil suction is usually the most reliable method*".

Figure 5.1 shows the location of level monitoring points around the building and Figure 5.2 the level monitoring readings for case 33. Refer to Figure 1.7 for explanation of how the data is generated.

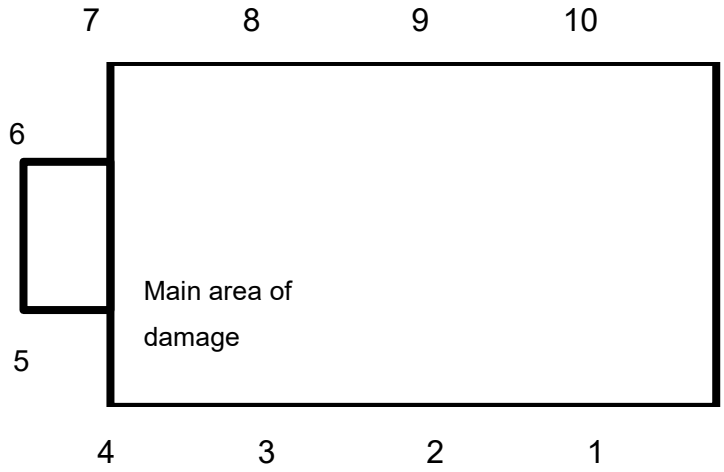


Figure 5.1 Level monitoring points 1 to 10 (Source Author)

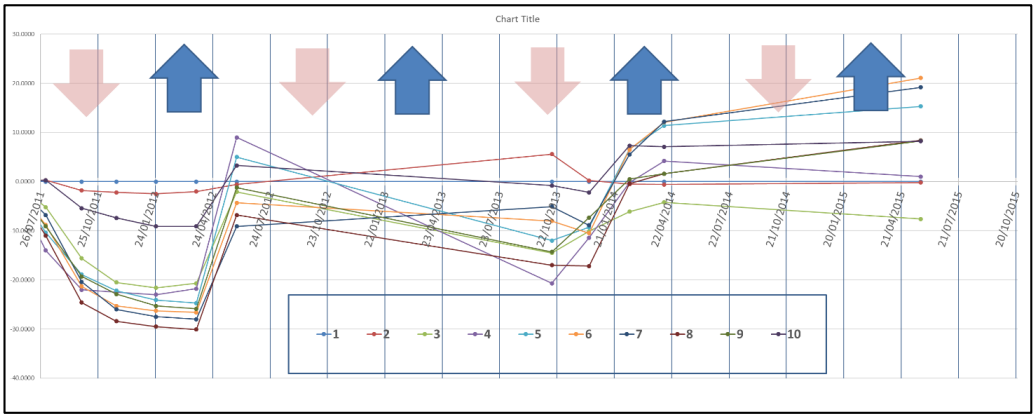


Figure 5.2 Level monitoring results (Source Author)

Note in Figure 5.2 that the author has placed arrows in the expected direction of movement in a genuine clay shrinkage case to assist in diagnosis.

The three options for repair to the building were as follows: -

- option 1 reinstate to its original condition
- option 2 demolish and rebuild in the current location
- option 3 demolish and rebuild in tree-free area

The cost of each above repairs was in the region of £350,000.

The root barrier cost was assessed at £40,000 plus vat, indicating a significant saving in root barrier installation compared with the repairs proposed.

In total, ten trees were at risk to resolve clay shrinkage subsidence claim, namely pear, willow, sycamore, 3 x English oaks, lombardy poplar and a weeping willow.

One of the lombardy poplars was removed as it was close to the building and the proposed location of the root barrier, and in view of the numerous trees remaining, it was considered acceptable that one of the trees be removed.

The proposal to introduce a root barrier significantly reduced the tree owner's liability regarding tree root trespass as if roots are prevented from reaching a building by introducing a root barrier, the case in nuisance for root encroachment is eliminated.

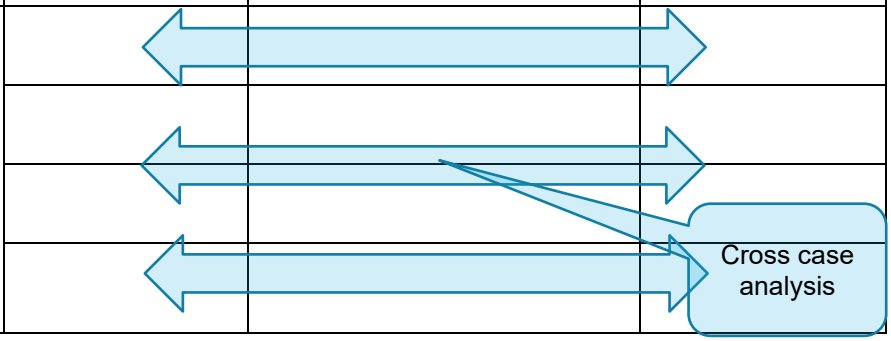
In this case a full design for a root barrier was completed, however the barrier was not installed as a separate agreement was reached between the tree owner and building owner for resolving the damage.

5.2.3 Case Study Results in Relation to Initial Design Protocol

In Chapter 2 the Initial Design Protocol (IDP) for variables was established from literature and disparate theory. The IDP provided the basic design process for a single tree. The following sections presenting the results for all cases uses the main headings of the IDP as a template.

The cross-case matching is illustrated in Table 5.3.

Table 5.3 Cross case and cross question analysis

Questions	Knowledgeable participant 1	Knowledgeable participant 2	Researchers own cases
	Provided 4 cases 1 to 4	Provided 27 cases Cases 5 to 31	2 cases 32 and 33
Questions 1 to Question 22			

The following sections also seek to identify any anomalies or rival explanations that, if significant, would be subject to further discussion later in the thesis.

5.2.4 Input Variables

The input variables considered in the initial design protocol are listed in Table 5.4.

Table 5.4 Variables considered in initial design protocol

Variable		Comment
Clay soil properties (soil shrinkability)	Soils	All these variables were identified in the case studies as being relevant in the design of root barriers and should be retained.
Property foundation depth	Building and site	
Distance between the building and the tree	Building and site	
Location	Building and site	
Tree species	The tree(s)	
Tree size	The tree(s)	
Tree trunk diameter	The tree(s)	
Protecting trees from damage	The tree(s)	
Root barrier location relative to tree	The tree(s)	
Depth of root barrier in the ground	The root barrier	
Length of root barrier across the site	The root barrier	

The variables in Table 5.4 proved relevant in all the case studies and will be retained. Additional variables such as barrier materials, construction method and costs are considered later under separate headings together with perceptions, reliability, or value considerations.

5.2.4.1 Notation

d (t min) Distance between root barrier and tree (minimum)

d (b) Distance between building and root barrier

d Installed distance between root barrier and tree (actual)

D Overall distance between tree and building

h Depth of root barrier at desired location

h (b) Existing foundation depth

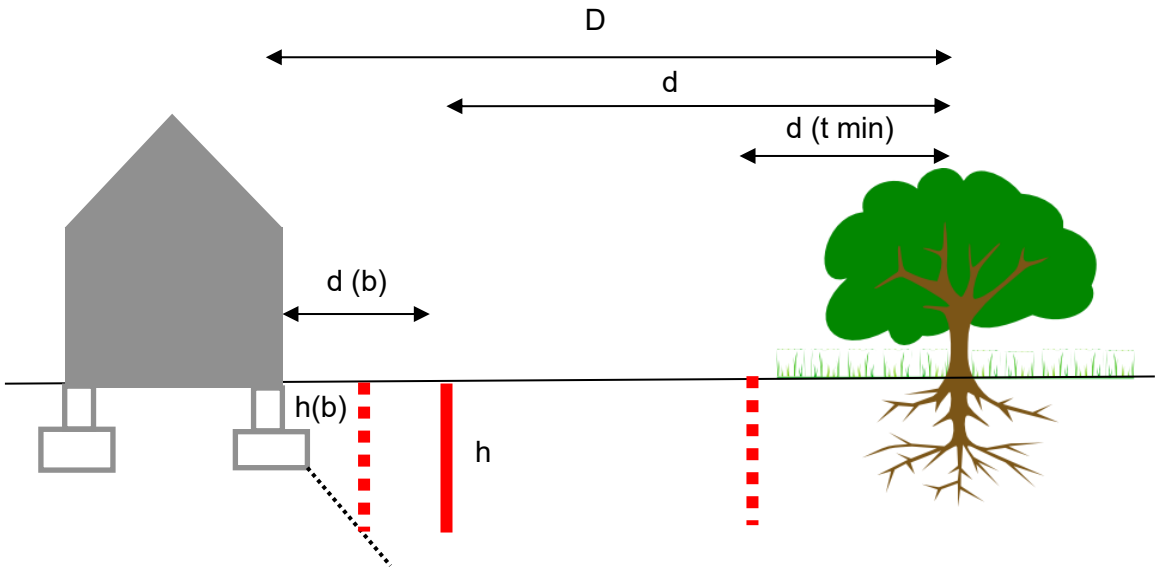


Figure 5.3 Notation defined (Source Author)

5.2.4.2 Input Information

The initial design protocol required site investigation information, information regarding the trees and existing foundation depths.

The initial design protocol catered for the situation where there is only one tree. In practice however, and the case studies confirm, the design protocol would have to deal with situations where there were multiple trees.

The case studies have shown the benefit of producing a scaled plan of the site to include all relevant trees' location, height, species, and size. The plans included the building's location in relation to the trees. They highlighted the area of damage and site features, adjoining buildings, and most importantly, electric, gas, water, drainage, foul, and surface water.

5.2.5 Distance Between Tree(s) and Root Barrier d t(min)

The minimum distance between the tree (or trees), d (t min) and the root barrier is required to avoid damage to either the tree or its roots.

The case studies did not specifically identify how this variable had been determined however in the cases where scaled plans were provided and tree species identified the minimum distance provided was checked to identify whether it concurred with the minimum distance calculated using BS 5837 (British Standard Institution, 2012). Information regarding age and vigour were obtained from photos where such were provided.

The results from participant 2 did not include information regarding the barrier's precise position in relation to the tree; therefore, only participants 1 and 3 were assessed under this heading.

Table 5.5 Tree to barrier distances

Cases (where plans had been provided showing location of root barrier in relation to tree)	**Tree to barrier distance provided**	**Tree to barrier distance by calculation**	**Comment**
Case 1	9.8m	Fir, 20m high according to drawing. By reference to photos estimated trunk diameter 400mm. Distance required by BS 5837 =5m distance.	Requirement satisfied
Case 2	2.5m	Tree diameter and vigour not known. Tree to barrier distance 2.5m from drawing.	Minimum distance likely not achieved however tree data not known.

Case 3	7m	Tree to barrier distance 7m from drawing. Required distance mature trees normal vigour 350-750 = 6m	Satisfied
Case 4	2m	Tree to barrier 2m maple/acer tree.	No satisfied.
Case 32	6m	Barrier to tree distance 6m satisfied	Distance satisfied
Case 33	6m	Barrier to tree distances varies min 6m.	Distance satisfied. Where trees were due for removal barrier distances not achieved and not required.

The exercise's outcome confirmed that not all barrier distances achieved those suggested British Standard requirements BS 5837. (British Standard Institution, 2012)

5.2.6 Distance Between the Building and the Root Barrier d (b)

The location of the barrier in relation to the building within the initial protocol determined that there should be a 45-degree exclusion zone so that the barrier did not undermine the foundations.

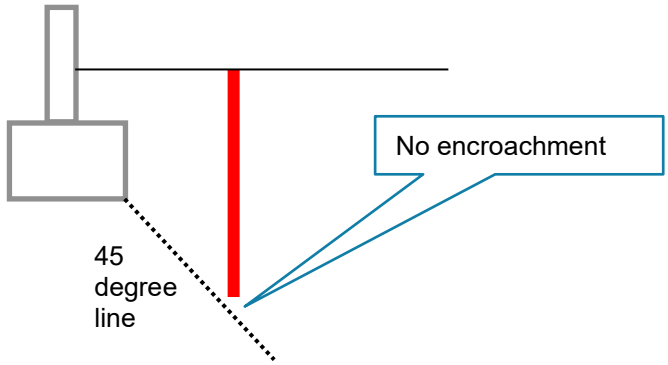


Figure 5.4 The 45-degree encroachment line between root barrier and base of foundation (Source Author)

Regarding the results, the rich data from participant 1 together with authors cases participant 3 were used to check the case results.

Participant 1 case 1 confirms that this exclusion zone was not adopted, and that the barrier was installed 1m from the property at a depth of 4m, located much closer to the building than this rule would allow.

1m+1m < 4m = (encroachment)

Participant 1 case 2 indicates a distance between the property and barrier of 2m and a barrier depth of 4m. Assuming 1m deep footings, as is often the case, this would confirm that the barrier would also encroach on the 45-degree exclusion area.

2m +1m < 4m = (encroachment)

In case 3 the distance between building and barrier was 3m and with a 5m deep barrier and 1.6m deep existing foundations (based upon site investigation results) encroachment would not occur.

3m+1.6m < 5m (encroachment)

Participant 1 case 4 confirmed that there was no encroachment to the 45-degree line.

Participant 2 advised that their barriers were installed at some distance from the building and outside of the 45-degree exclusion area with gravel backfill, not concrete during the structured interview. A discussion took place regarding this finding and it was agreed that if the root barrier had been within the exclusion zone, gravel (loose) backfill would not be appropriate.

This finding requires further investigation as it represents a rival explanation and departure from the initial design protocol and is discussed in the next chapter.

5.2.7 Depth of the Root Barrier

The initial design protocol or theoretical proposition determined that the root barrier should be constructed at sufficient depth to prevent roots passing underneath.

Regarding the depth of the installed barrier (h) in the case studies the following aspects are relevant: -

- depth of the barriers, averages, maximum, minimum
- depth of the installed barrier in relation to NHBC guidelines
- varying the depth of the barrier rather than constant depth
- method for calculating depths of barrier for multiple trees

5.2.7.1 Depth of Barrier, Averages, Maximum and Minimum

The initial rules developed a calculation for the depth at certain distances based upon NHBC guidelines. (National House Building Council, 2019)

Table 5.6 shows the average depth of the root barrier from case studies.

Table 5.6 Barrier depths from case studies

	totals all	divider	average all	totals participant 1	average participant 1	totals participant 2	average participant 2	totals participant 3	average participant 3
Depth of the root barrier (m)	**128**	**33**	**3.9m**	**17.0**	**4.3m**	**104.6**	**3.9m**	**6.5**	**3.3m**

The results show that across all 33 cases an average depth of 3.9m for participants 1 and 2. For participant 3 average was 3.3m but this was based only on 2 cases.

The maximum depth was 5m and the minimum 2.5m.

5.2.7.2 Depth of Barrier Compared with NHBC

The overall average root barrier depth from all participants was 3.9m. The NHBC design chart (Table 5.7) does not provide for depths below 3.5m. For example, a 26m high, high water demand tree, 1m distant requires 3.43m foundation depth (worse case).

Table 5.7 NHBC foundation depths (National House Building Council)

TABLE 12

HIGH SHRINKAGE SOILS Plasticity Index greater than 40%

HIGH water demand BROAD LEAF trees including:–

Elm		Oak		Poplar		Willow
English	24	English	20	Hybrid black	28	Crack
Wheatley	22	Holm	16	Lombardy	25	Weeping
Wych	18	Red	24			White
Eucalyptus	18	Turkey	24			

Foundation depths (m)

Mature tree height (m)	Distance from centre of tree or hedgerow to face of foundation													
	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00	9.00	10.00	11.00	12.00	13.00	14.00
8	3.25	3.00	2.75	2.50	2.25	2.00	1.75	1.50	1.25	1.00	1.00	1.00		
10	3.30	3.10	2.90	2.70	2.50	2.30	2.10	1.90	1.70	1.50	1.30	1.10	1.00	1.00
12	3.33	3.17	3.00	2.83	2.67	2.50	2.33	2.17	2.00	1.83	1.67	1.50	1.33	1.17
14	3.36	3.21	3.07	2.93	2.79	2.64	2.50	2.36	2.21	2.07	1.93	1.79	1.64	1.50
16	3.38	3.25	3.13	3.00	2.88	2.75	2.63	2.50	2.38	2.25	2.13	2.00	1.88	1.75
18	3.39	3.28	3.17	3.06	2.94	2.83	2.72	2.61	2.50	2.39	2.28	2.17	2.06	1.94
20	3.40	3.30	3.20	3.10	3.00	2.90	2.80	2.70	2.60	2.50	2.40	2.30	2.20	2.10
22	3.41	3.32	3.23	3.14	3.05	2.95	2.86	2.77	2.68	2.59	2.50	2.41	2.32	2.23
24	3.42	3.33	3.25	3.17	3.08	3.00	2.92	2.83	2.75	2.67	2.58	2.50	2.42	2.33
26	3.42	3.35	3.27	3.19	3.12	3.04	2.96	2.88	2.81	2.73	2.65	2.58	2.50	2.42
28	3.43	3.36	3.29	3.21	3.14	3.07	3.00	2.93	2.86	2.79	2.71	2.64	2.57	2.50
30	3.43	3.37	3.30	3.23	3.17	3.10	3.03	2.97	2.90	2.83	2.77	2.70	2.63	2.57

Regarding case 1, the root barrier was designed for a Coniferous tree 20m high and 9m distant. NHBC guidelines would indicate a maximum depth of 1.62m (HWD and high shrinkage soil), whereas the barrier was installed at a depth of 4m, significantly more than the minimum NHBC requirement.

Case study 2, which provided the calculation indicated a depth required of 2.1m whereas the barrier was installed at a depth of 4m.

This observation concerning depth from the case study results is considered further in Chapter 6, section 6.2 “Depth of the Root Barrier”. In particular, the discussion identifies the extent to which increased depth should be provided given that an increase in barrier depth provides greater reliability but represents an increase in costs and construction difficulty.

5.2.7.3 Case Study Data Grouping

The 33 case studies involved numerous tree species with different water demand on varying clay soil types (high, medium and low shrinkable). Tree water demand/soil combinations were therefore grouped to assist in data analysis and compared with the nine NHBC graphs for broad leaf trees (all combinations of high, moderate or low water demand trees and high, medium or low plasticity soils.

A total of eight cases were discounted as shown in Table 5.8 as all the required information concerning the trees and soil type was not provided. Concerning the remaining 25 cases, the highest soil/tree combination incidence was high shrinkage soil and high water demand tree. 11 cases were identified within this grouping, denoted “Group 1” as shown in Table 5.8. The second highest incidence were moderate water demand trees on high shrinkage soil comprising 6 cases in Group2. Group 3 comprised of the third highest incidence, namely moderate shrinkable soil and high water demand trees. The final group comprised of 3 cases with less onerous combinations of soil and tree. Table 5.8 shows all four groupings with the specific cases identified.

Table 5.8 Soil and Tree groupings for case study

Group	**Soils (shrinkage potential)**	**Tree (water demand)**	**No of cases**	**Specific Cases**
Group 1	High	High (all oak trees)	11	1,5, 6, 8, 11,14, 19, 20, 24, 29 and 31
Group 2	High	Moderate	6	2, 3, 4, 25, 28 and 32
Group 3	Medium	High	5	7, 9 13, 15 and 22
Group 4	Medium	Medium or Low	3	17,18 and 27
Discounted			8	10,12, 16,21, 23,26,30 and 33

Note that when dealing with each group, the tallest tree in the group was used. Data analysis progresses within individual groups and compares results for depth of the root barrier with varying distances and construction date. Data for the individual

groupings follows in Table 5.9 to Table 5.11. The tables show date installed, actual depth, NHBC depth and increase over NHBC for each case within the specific group. The precise barrier location was not always specified, however, for the purposes of the analysis, where not provided it was assumed to be located midway between the tree and the building.

Table 5.9 Group 1 case studies

	Group 1				
Case	**1**	**5**	**6**	**8**	**11**
Date Installed	1.6.14	1.5.13	26.10.12	7.11.12	30.6.14
Duration (years)	7.4	8.4	9.0	8.9	7.3
Soil PI NHBC	H	H	H	H	H
Tree Water Demand	H	H	H	H	H
Actual Depth	4	4	4	4.6	4
Distance	7.0	10.0	13.8	6.0	3.8
NHBC depth	2.80	2.50	2.13	2.90	3.13
Increase over NHBC	1.20	1.50	1.88	1.70	0.88
% increase	43%	60%	88%	59%	28%

	Group 1 (cont)					
Case	**14**	**19**	**20**	**24**	**29**	**31**
Date Installed	5.9.14	14.3.16	22.2.16	29.3.17	13.11.18	24.7.19
Duration (years)	7.1	5.6	5.6	4.5	2.9	2.2
Soil PI NHBC	H	H	H	H	H	H
Tree Water Demand	H	H	H	H	H	H
Actual Depth	4.5	4	4	4	4	3.5
Distance	5.0	7.0	5.5	4.0	4.0	8.0
NHBC depth	3.00	2.80	2.95	3.10	3.10	2.70
Increase over NHBC	1.50	1.20	1.05	0.90	0.90	0.80
% increase	50%	43%	36%	29%	29%	30%

Table 5.10 Group 2 case studies

	Group 2					
Case	**2**	**3**	**4**	**25**	**28**	**32**
Date Installed	1.6.11	1.6.17	1.6.14	22.1.18	11.10.18	
Duration (years)	10.4	4.4	7.4	3.7	3.0	
Soil PI NHBC	H	H	H	H	H	H
Tree Water Demand	M	M	M	M	M	M
Actual Depth	4	5	4	4.5	2.5	2.5
Distance	3.0	9.0	3.0	4.0	7.5	6
NHBC depth	2.18	1.75	2.18	2.11	1.86	1.97
Increase over NHBC	1.82	3.25	1.82	2.39	0.64	0.53
% increase	83%	186%	83%	113%	34%	27%

Table 5.11 Group 3 case studies

	Group 3				
Case	**7**	**9**	**13**	**15**	**22**
Date Installed	22.7.13	9.12.13	25.7.14	23.9.14	9.5.16
Duration (years)	8.2	7.8	7.2	7.1	5.4
Soil PI NHBC	M	M	M	M	M
Tree Water Demand	H	H	H	H	H
Actual Depth	4.5	4	4.5	2.5	4
Distance	6	5	5	8	6
NHBC depth	2.54	2.57	2.58	2.33	2.50
Increase over NHBC	1.96	1.43	1.92	0.17	1.50
% increase	77%	56%	74%	7%	60%

The assigned independent variable is the distance (tree to barrier) graphically shown on the x-axis. The dependent variable, the depth of the root barrier, which is predicted, is shown on the vertical y-axis, where illustrated graphically. Horizontal and vertical scales are standardised to assist graphical representation. To assist identification group 1 cases are depicted with a Δ, group 2 with ☐and group 3 with O. For group 1 cases the depth of the root barrier was plotted against NHBC requirement. The graphical results are shown in Figure 5.5.

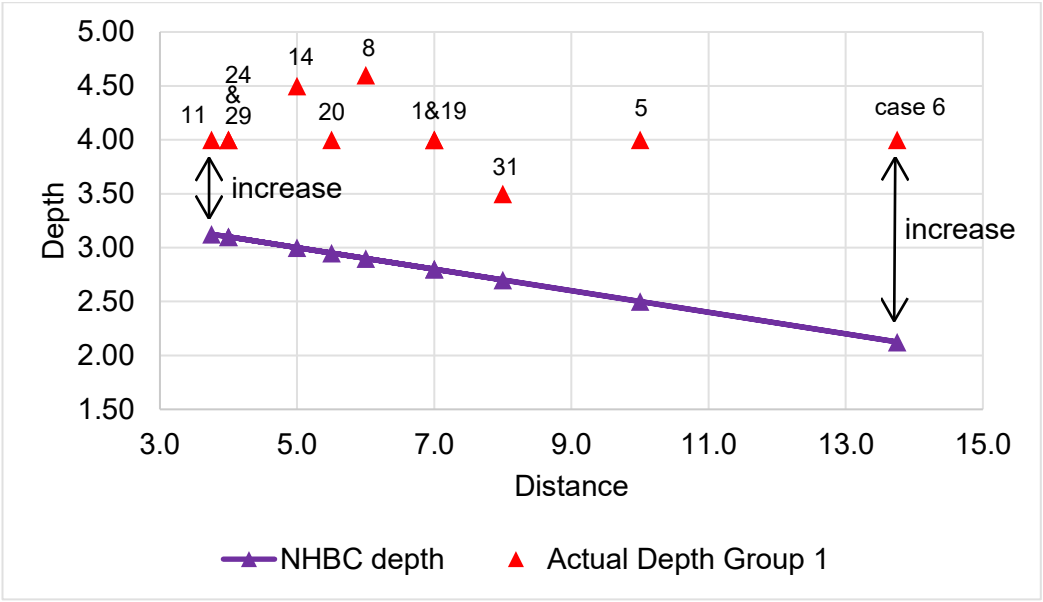


Figure 5.5 Actual vs design depths Group 1 (HWD, HSS)

Figure 5.5 also shows the case numbers in Group 1 (11 total indicated above the icon) illustrating the increase over NHBC.

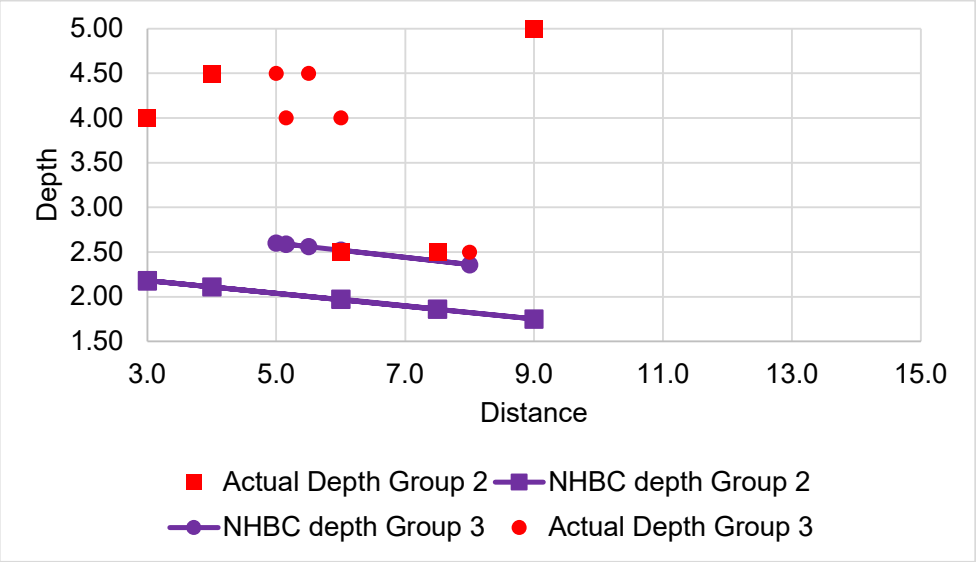


Figure 5.6 Group 2 and Group 3 NHBC and actual depths

Figure 5.6 illustrates, on the same diagram, both group 2 and group 3 actual depths vs NHBC.

Further examination of the percentage increase in depth, compared with NHBC, was carried out for all three groups, calculating summary statistics shown in Table 5.12. For example, in case 1, NHBC depth of 2.8m and actual depth of 4m equates to a percentage increase of (1.2/2.8) x 100 = 43%.

Table 5.12 Summary statistics (increase to NHBC) groups 1, 2 and 3.

Statistic in relation to NHBC depths	Group 1	Group 2	Group 3
Ranking (NHBC tables)	1st (most onerous)	3rd (least onerous)	2nd
Mean Increase	45%	88%	54%
Standard Error	6%	24%	13%
Median increase	43%	83%	59%
Mode	43%	83%	#N/A
Standard Deviation	19%	58%	28%
Sample Variance	3%	34%	8%
Range	60%	159%	70%
Minimum increase	28%	27%	6%
Maximum increase	88%	186%	76%
Count	11	6	5
Confidence Level (95.0%)	0.12	0.61	0.35

Note that with reference to Figure 5.5 and Figure 5.6 the most onerous cases in terms of NHBC depth required is group 1, high water demand tree and high shrinkable soil. The second most onerous is group 3, high water demand tree on

medium shrinkable soil followed by group 2 moderate water demand tree on highly shrinkable soil (least onerous).

Referring to Table 5.12, the mean and median increase over NHBC for group 1 is the lowest, followed by group 3 and then group 2. The results suggest that the least onerous NHBC tables (group 2) have been increased the most in determining the depth of the root barrier.

Excel's statistics functions performed additional statitstical analysis. The standard deviation and variance are measures of dispersion from the mean value (Bee & Bee, 1993) and are shown in Table 5.12 for each group. The variance and standard deviation for group 2 cases is the largest, followed by group 3 and then group 1. The summary statistics suggest that where the more onerous NHBC tables were used in group 1, increases in root barrier depth were least and demonstrated less variability than the less onerous NHBC tables.

The findings are summarised in Table 5.13.

Table 5.13 NHBC increases with group

	Group 1	**Group 2**	**Group 3**
NHBC ranking	1st (most onerous)	3rd (least onerous)	2nd
Increase to NHBC	3rd (lowest)	1st (highest)	2nd
Variability	3rd (lowest)	1st (highest)	2nd

5.2.7.4 Depth changes over time

Analysis of the case study data identified a correlation between the increase depth over NHBC and the installation date, as shown in Figure 5.7. The linear trendlines for each group, shown individually, show a tendency for the depth increases over NHBC to reduce over time.

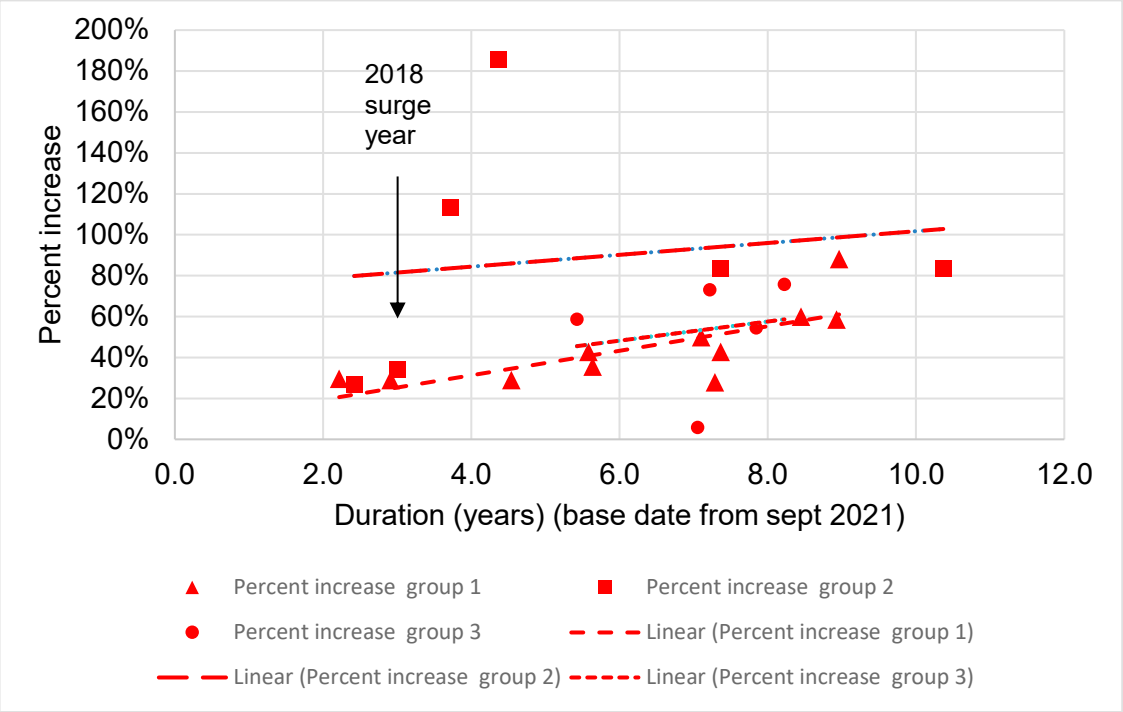


Figure 5.7 Duration and depth correlation

Figure 5.7 would suggest that as more experience was gained in installing root barriers the percentage increase over NHBC decreased.

5.2.7.5 Varying the Depth

None of the case study results indicate, except the author's own case 33, that the depth varied as the barrier location extended away from the trees as would be the case if designed strictly according to NHBC tables.

The discussion of depth variation for individual root barriers is reserved for the following chapter.

5.2.7.6 Depths with Multiple Trees

Case numbers 2, 32, 33 with multiple trees show graphical output on a scaled drawing with various trees accurately positioned in relation to the building. Concentric circles were drawn indicating required barrier depth indicating how multiple trees can be accommodated using this method.

A spreadsheet calculation was used within the initial design protocol to determine the depth of a root barrier at various distances based upon the NHBC requirement. However, the case studies have revealed a drawback of this method in that it only allows for one tree at a time to be calculated and most cases, as evidenced, have numerous trees.

The scaled plan also enabled identifying various possible locations for the root barrier as the best location is not necessarily the one that produces the least depth.

In case of obstacles or obstructions or features the best location may be one that avoids such features, obstacles or services rather than designing or locating the barrier based upon depth considerations alone.

5.2.8 Length of the Barrier lb

The foregoing has considered the depth of the barrier and its location not its length. A partial barrier, illustrated within Figure 5.8 was installed in all the case studies.

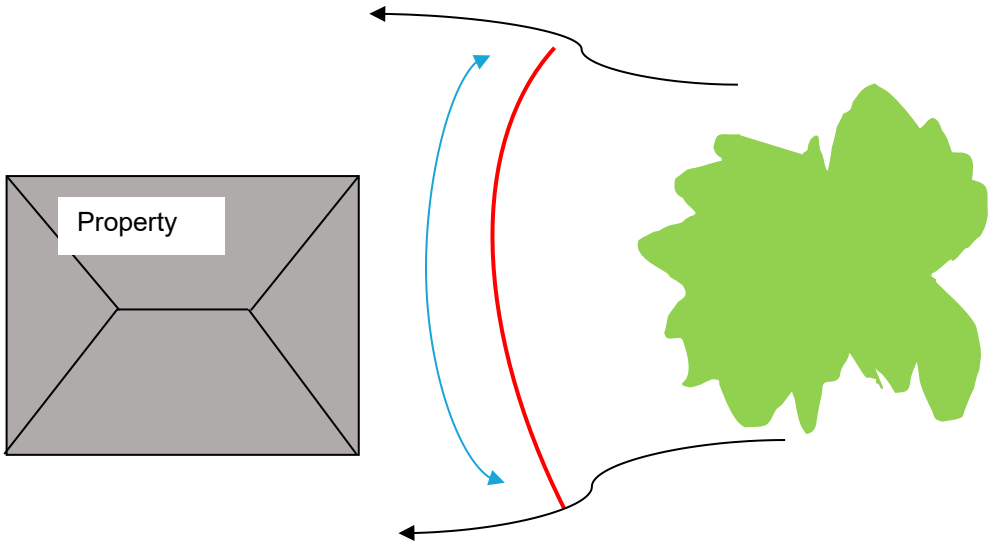


Figure 5.8 Partial root barrier between tree and building (Source Author)

Results from the case studies were used to calculate the average barrier lengths for all participants and individual participants. The results are shown in Table 5.14.

Table 5.14 Root barrier length from case studies

	Totals all	divider	average all	totals participant 1	average participant 1	totals participant 2	average participant 2	totals participant 3	average participant 3
Length	**707**	**33**	**21.4**	**121.0**	**30.3**	**483.0**	**17.9**	**102.5**	**51.3**

The lengths of the root barriers for all cases averaged 21.4m based upon a total number of 33 cases.

In terms of individual participants, the averages were participant 1 (30.3m), participant 2 (17.9m) and participant 3 (51.3m).

The average length of 17.9m for participant 2 is the most reliable figure as participant 1 and 3 average lengths were based upon statistically fewer cases.

In addition to the data in Table 5.14, regarding overall and average lengths, the results from individual case studies where drawings were available were examined to identify the lengths of the root barriers in relation to the tree and the building and overlap, i.e., how far past the building did the barrier extend?

Cases 1 to 4 and 32 and 33 provided the additional data as drawings or calculations were available. The overlap or additional distances are as follows: -

Case 1 = 1m

Case 2 = 9m

Case 3 = 1m

Case 33 = 3m

The results indicate that the barrier extends beyond the building and the area of damage by varying amounts, with no clear pattern. Once identified, the extent to which this overlap may be required is discussed in the following chapter.

5.2.9 Costs of Root Barrier Installation

The costs considered under this heading are actual costs of the root barrier installation. The case studies have provided useful and valuable data concerning the costs of installing root barriers to investigate whether they are cost-effective when compared to underpinning or tree removal.

Table 5.15 summarizes root barrier installation costs from case studies based on the root barrier's depth and length.

Table 5.15 Root barrier costs per m2

	Totals all	Divider	Average all	Totals participant 1	Average participant 1	Totals participant 2	Average participant 2	Totals participant 3	Average participant 3
cost incl. vat	£740k	31	£24k	£181k	£45k	£559k	£21k		
depth (m)	128	33	3.9	17.0	4.3	104.6	3.9	6.5	3.3
length (m)	707	33	21.4	121.0	30.3	483.0	17.9	102	51.3
area of root barrier	2812	33	85	544	136	1879	69	389	194
cost per m2				£1184	£296	£8354	£309.4		

Table 5.15 presents overall costs and individual participant costs. Participant 3 figures are not included as cost data was not obtained for these cases.

The results show that root barriers average cost per m2 for participant 1 was £296 per m2 and for participant 2 £309 per m2. These results show very good consistency with an overall average £300 per square metre.

The average depth overall was 3.9m.

The average length was 21.4m overall.

Based upon Table 5.15 using an average cost of £300 per m2 the cost for an average root barrier of 3.9m depth and 21.4m length amounts to 3.9 x 21.4 x 300 = £25,038 including vat.

The results can be compared with the value of trees saved by introduction of the root barrier, informing perceptions regarding cost and value for money.

The result of £300 per square metre may be used for initial pricing or when comparing root barriers to underpinning or other solutions for costing purposes.

Further analysis of costs is completed within section 6.7.1 where costs for each type of barrier are considered together with an exploration of whether the cost is related to the depth of the root barrier.

5.2.10 Barrier Material and Construction.

Case studies provided information concerning materials and construction in the use of root barriers. As the materials and method tended to be connected, they are considered together.

Participant 1 (4 cases) generally used steel sheet piling as the barrier material. The participant has developed a system of pre-boring so that the sheet piles can be installed more easily. The piles themselves are of an interlocking type.

Participant 2 (in 26 of 27 total cases) constructed barriers by initially excavating a trench using JCB digger with trench support using sheeting. The root barrier was installed within the trench, incorporating backfill to provide stability to the barrier as the trench was wider than the barrier material. The barrier material used was WLS Flexline 1.5mm Propylene/ethylene copolymer geomembrane.

Participant 2 in one case, utilised a system of vacuum suction to excavate a narrow trench. The clay soil was first softened using water jets. According to the participant, this system was particularly successful, reducing soil excavated and backfill volume, reducing costs overall.

Further materials details are contained in Appendix 12.2.

5.2.11 The Vegetation

Table 5.16, Table 5.17 and Table 5.18 list all the trees retained by the installation of a root barrier for all participants.

Table 5.16 Trees participant 1

Case			
1	**2**	**3**	**4**
oak	maple	plane	maple
	maple	plane	
	maple	plane	
	maple	plane	
		plane	

Table 5.17 Trees participant 2

Case								
5	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
oak	oak	oak	oak	oak	unkn	oak	oak	oak
			oak				oak	ash
							oak	sycamore
Case								
14	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**
oak	oak	oak	maple	lime	oak	oak	oak	oak
oak	oak			beech	oak			
oak				cypress				
oak				pine				

Case								
23	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**
oak	oak	maple	oak	beech	Lond. plane	oak	oak	oak
s chestnut	lime	maple	sycamore				willow	oak
maple	lime		ash				ash	
			hawthorn					

Table 5.18 Trees participant 3

Case	
32	**33**
London plane	pear
	willow
	sycamore
	English oak
	English oak
	English oak
	lombardy poplar
	weeping willow

The most frequent trees retained are first, 33 oaks, 9 maples, 7 London planes, 3 sycamores, 3 ash, 1 lime, 3 willows, 2 beech, 1 cypress, 1 pine, 1 sweet chestnut, 1 hawthorn, 1 lombardy poplar and 1 pear.

5.2.12 Tree Protection in Law

The case studies, where information was available, indicate that root barriers were installed where the trees could not be removed but did not state why they could not be removed. In three cases participant 1 indicated that trees were not able to be removed but did not clarify precisely the reason why this was the case. Cases 5 to 31 state reasons that trees were not removed as “unable to remove due to TPO” or “more cost effective than underpin”, without identifying specifics. In case 32 the local authority resisted removal. In case 33 the root barrier was chosen to avoid removing multiple trees and was more cost-effective than the other proposed solutions.

5.2.13 Case Study Links with Perceptions

In addition to the questionnaire, certain responses from the case studies were also identified as being related to perceptions and used especially where additional comments had been made in the responses.

The main perceptions under consideration are reliability, practical, cost and knowledge concerns.

5.2.13.1 Reliability Concerns Identified in Case Studies

In terms of reliability and whether a root barrier is successful, all respondents advised that their implementation had been successful. It is not apparent whether return visits have been made in all cases to confirm the success or otherwise of the solution with post-implementation monitoring or site inspections, for example.

Case study results cover a 10 year period (case 2 was installed 2011) and in this period there has been one surge (23,000 claims) in 2018. The root barriers installed before 2018 have therefore been tested by 2018 surge, although the 23,000 claims in 2018 were less than half the previous events of 2003 and 2006 as mentioned in section 1.6.2 on page 47. The interview for participant 2, who provided most of the case study results and confirmed cases were successful was undertaken in September 2019. The visit took place after the 2018 surge although it could be argued that any concerns with root barriers due to the surge had not yet been realised. It could also be the case that some other participants, who were not involved or declined to be involved, were reluctant to share in the root barrier research because of unsuccessful cases.

It is noted that once a root barrier has been installed and the property repaired, there may not be any process whereby loss adjusters or insurers return to check whether the root barrier has been successful. However, in this regard, knowledgeable participant 2 completed level monitoring after installing the barrier as a check on its performance. This enables the participant to check whether the barrier has been successful in achieving the objective of preventing roots from reaching the building. Of course, the building would have been repaired and it would be feasible to check for further damage, but new damage does not always appear immediately.

Level monitoring over a 1-year period would be the desired aim as it records the actual movement of the building post-installation and is, therefore, a direct form of measurement as opposed to checking for new cracking, which is more indirect. This final stage of checking the effectiveness will be considered in the informed design protocol as an effective means of checking that the root barrier has been successful.

Whether roots can grow under or around a root barrier is not demonstrated in the cases observed. It has been demonstrated that root barriers are installed at a depth greater than NHBC would require. It is proposed to determine the depth of a root barrier by adding a safety factor (FoS) to ensure that roots are prevented from growing under the barrier.

The case studies demonstrate how with a designed process, careful choice of barrier material, appropriate construction techniques at suitable depths (averaging 4m in the case studies), and single or numerous trees in proximity, the solution was successful.

5.2.13.2 The Cost of the Root Barrier Identified in Case Studies

As a result of the data gathered during case studies, rich data was obtained regarding the costs of installing root barriers. It is necessary to compare the cost of a root barrier with underpinning and tree works to inform cost effectiveness. Losses incurred as a result of removing trees is included in the calculation of the cost effectiveness of the root barrier solution.

5.2.13.3 Practical Concerns Identified in Case Studies

The practical concerns regarding the installation of root barriers have been confirmed valid as a result of analysing the results of the case studies. The participants have identified the practical concerns, either case-specific or collectively.

The photographs in Appendix 12.5 and 12.6 attached to specific cases illustrate how installing a root barrier within an existing site can be problematic, especially when

materials need to be transported to and from the area of construction. Figure 5.9 is a typical example showing the plant and machinery used in this case and potential difficulties manoeuvring within the site.

Figure 5.9 Case 2 photo of plant/machinery in close proximity to the building

Practical concerns will also dictate health and safety priorities and issues that may arise where workers are dealing with heavy plant in restricted areas whilst avoiding services and features. These safety issues include requirements to support open trenches and avoid persons or objects falling into open trenches.

5.2.13.4 Knowledge Concerns Identified in Case Studies

In Chapter 2 it was stated that knowledge concerns encompass all aspects of practicality, cost, and reliability on the cost quality time theoretical proposition. Knowledge concerns were not demonstrated in the case studies as the participants were successful and experienced in the design and construction of root barriers. The case studies demonstrate that the design and construction of root barriers is a specialist operation and this aspect is discussed further in the following chapter.

5.2.14 Validation Case Study Results

A summary of the main results was sent to the participant 2 so that they could comment on the information provided. The summary issued included the main outcomes being a condensed version of the full text. Comments received were incorporated into the final thesis.

5.2.15 Summary Case Study Results and Analysis

The case study results and analysis section has highlighted common themes, patterns and quantitative data including rival explanations, patterns or issues for further consideration in the following chapter.

The initial design protocol proved robust in terms of the variables, although case studies highlighted that it did not deal easily with multiple trees. The variables such as minimum distance to the tree, tree species, soil properties, depth of the root barrier, length, materials and construction were consistently important and relevant in case study review. Case studies reveal root barriers were not always installed within a 45-degree exclusion requiring further consideration.

The results have confirmed that the installed root barrier's depths were significantly deeper than would be required strictly by NHBC guidelines, which requires further assessment. Also, the installed root barriers' depth was not varied as would be the case if NHBC were used strictly.

Root barriers extended beyond the area of damage, but the extent varied from case to case.

Valuable information was collected in terms of the species, types and size of trees retained using a root barrier. Oak was the most common tree saved by the root barrier. The trees' values were not calculated within this section as this is reserved for Chapter 6, Discussion.

5.3 Survey Results and Analysis (Questionnaire)

5.3.1 General Introduction

The research investigated the perceptions in the use of root barriers using a questionnaire.

The perceptions or concerns identified in Chapter 1 were: -

- practical concerns
- cost concerns
- knowledge concerns
- reliability concerns

The following results comprise responses to the nine questions from two respondent groups; the subsidence forum (77 respondents) and TDAG (14 respondents). Bar charts display ordinal data derived from questions 1,2,4, and 9 and pie charts display nominal categorical data for questions 3 and 8.

Ratio quantifiable data concerning perceived tree values is displayed on bar charts and graphical output for each question is followed by observations concerning the results. Appendixes 12.11 and 12.12 contain the raw data for each question.

5.3.2 Test for Independence

In order to assist in the discussion concerning the results the two respondent groups (Subsidence Forum and TDAG) were tested for independence using the non-parametric chi-squared test. The chi-squared test enables us to determine whether the two groups are in some way similar or associated (Robson, 2002, p . 418) and is undertaken before the results are individually discussed in sections 5.3.5. to 5.3.11.

The chi-squared test starts by tabulating the number of responses for each question from each group and then calculating expected values. A condition of using chi-squared is that expected values should be greater than 5. Due to the small TDAG sample size this condition was not met for individual questions. However, in Section 3.7.8.3 the characteristics of qualitative research in relation to the questionnaire were established, particularly that data collected in the form of words or phrases can be used to identify themes in the phrases and words collected. Questions 1,2,4 and 9 collect the required ordinal data in four distinct themes as shown in Table 5.19. If these themes are grouped, it is possible to increase participant numbers and overcome expected values being less than 5 enabling the chi-squared test to be used.

Initially, proceed with the null hypothesis Ho, that the two groups are independent i.e. that the group they belong to does not influence their response to a certain question. (Robson, 2002, pp. 400-401) The chi-squared test tells us how likely it would be to get the result (difference between actual and expected scores) by chance alone. The expected frequencies are calculated assuming independence before calculating the chi-squared value. Suppose the calculated value is less than the value provided (within tables for specified degrees of freedom and at a certain level of significance). In that case, we conclude that the null hypothesis stands. The two groups are independent, i.e., belonging to a certain group (Subsidence Forum or TDAG) has no influence on the response provided. If the calculated value is greater than the tabulated value, our inference would be to reject the null hypothesis suggesting that the response provided is associated with the group they belong to. Finally, it should be noted that chi-squared test is not a measure of the degree of relationship or the form of relationship between two groups, but is simply a technique of judging the significance of such association to assist in data analysis.

Table 5.19 Questionnaire themes

Theme	Q1	Q2 (consider root barriers)	Q4 (are root barriers successful)	Q9 (would you consider)
Positive	A positive	A more than 75%	A all of the time B most of the time	A yes
Neutral	B neutral	B 25% to 75%	C some of the time	n/a
Negative	C negative	C less than 25%	n/a	B no
No view	D No view	D don't know	D no experience	C No experience

The results for the grouped questions Q1, 2, 4 and 9 indicated in Table 5.19 have four themes of positive, neutral, negative or no view as shown in Table 5.20.

5.3.3 Grouped Questionnaire Results

The chi-squared test has been carried out using summed actual results from grouped questions 1,2, 4 and 9 shown in Table 5.20.

Table 5.20 Grouped Results

Questions 1,2,4 and 9	Actual		
Response	**Forum**	**TDAG**	**Total**
positive	78	**23**	101
neutral	50	**5.5**	55.5
negative	99	**8**	107
no view	73	**22.5**	95.5
Total	300	59	359

The test proceeds by calculating the expected values assuming null hypothesis H_o that the results from each group are independent as described in section 5.3.2 and shown in Table 5.21.

Table 5.21 Expected Values

Questions 1,2,4 and 9	Expected		
Response	**Forum**	**TDAG**	**Total**
positive	84.4	16.6	101
neutral	46.4	9.1	55.5
negative	89.4	17.6	107
no view	79.8	15.7	95.5
Total	300	59	359

In Table 5.21 the expected values are calculated assuming independence by multiplying each row total in Table 5.20 by the appropriate column total and dividing by the overall total. For example, subsidence forum expected negative response is calculated as follows:-

(107 x 300) / 359 = 89.4

Next, the differences between actual and expected are squared, in accordance with chi-squared procedure and divided by the expected value for each group and question. The individual results are shown in Table 5.22, summed and compared with the chi-squared value corresponding to the significance level of 0.05 and 3 degrees of freedom.

Tables may be used to establish the chi-squared value and in this case excel spreadsheet formula was used to determine a significance level equal to 7.81.

Table 5.22 Chi Squared table (chi-squared values)

Questions 1,2,4 and 9	Forum	TDAG
Response	0.49	2.47
positive	0.28	1.44
neutral	1.03	5.22
negative	0.58	2.95
no view	2.38	12.08
Group Totals	2.38	12.08
Overall Total	=2.38+12.08= 14.46	

As the overall total in Table 5.22 (14.46) is greater than 7.81 (chi-squared value) the null hypothesis is not fulfilled and there is insufficient evidence to show that two groups are independent. This result means that the response to the questions is influenced by belonging to one or other of the groups (Subsidence Forum or TDAG) indicating the groups have differing views on the subject of root barriers and trees.

5.3.4 Individual Questionnaire Results

The following graphical representations of the data in Figures 5.10 to 5.18 include pie charts for nominal categoric data and bar charts for ordinal data as convention dictates. With regard to individual question responses, where TDAG respondents provided two answers for the same question, half a response point was allocated to each answer. Descriptions and analysis include the number of respondents with applicable percentages in brackets. The vertical scale for bar charts for each question remains the same for Subsidence Forum and TDAG to assist comparison.

5.3.5 Question 1 Results

Question 1	Response headings
What is your general perception on the use of root barriers?	A. Positive, (would usually consider using)
	B. Neutral, (would sometimes consider using)
	C. Negative, (would rarely consider using)
	D. No view on root barriers

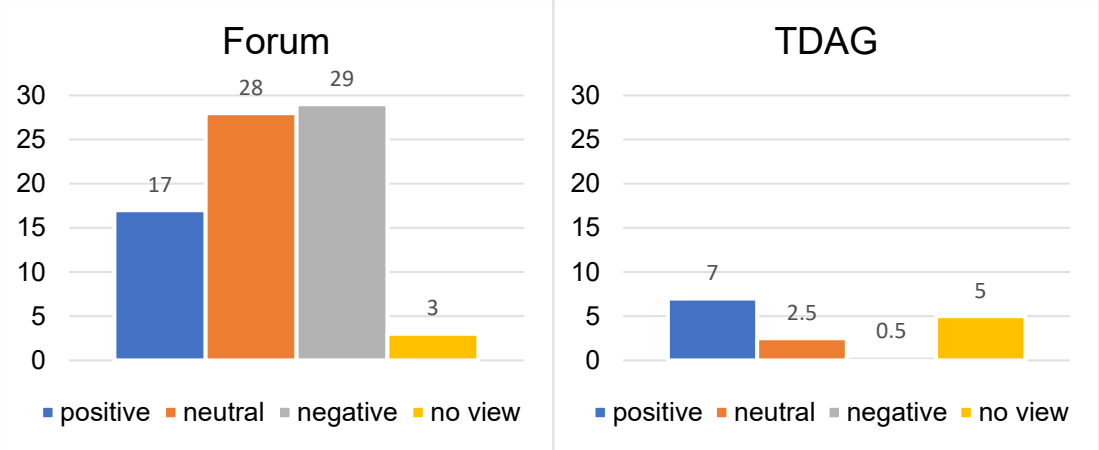


Figure 5.10 Question 1 results

The results for question 1 are also linked with questions 2, 4 and 9. The individual results indicate that the positive view amongst Subsidence Forum was 17 respondents (22%), and TDAG returned 7 positive responses and corresponding higher overall percentage at 47%.

Neutral or negative accounted for the majority of the Subsidence Forum 57 responses (74%) whereas there were 3 responses within TDAG representing 20% of the total.

The responses indicate that the majority of the Subsidence Forum (60 out of 77 or 78%) do not have a positive perception of the use of root barriers whereas TDAG tended to a more positive stance with 47% positive.

Comparing results, large differences are revealed in the 3rd and 4th option showing that the Subsidence Forum were significantly more negative than TDAG concerning the root barrier option.

5.3.6 Question 2 Results

Question	Response headings
How often are root barriers considered?	A. More than 75% of cases
	B. Between 75% and 25% of cases
	C. Less than 25% of cases
	D. Don't know

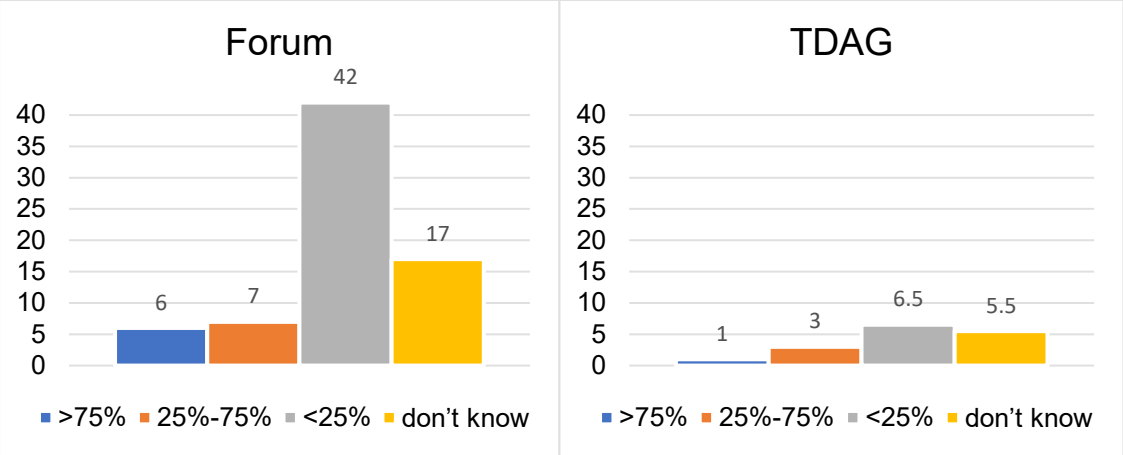


Figure 5.11 Question 2 Results

Question 2, linked with Question 1, is a general question that seeks to identify general perceptions without being specific regarding the perception being considered.

For Subsidence Forum, root barriers are usually not considered, with only 6 (8%) considering root barriers more than 75% of the time. The TDAG results show only one respondent (6%) consider root barriers more than 75% of the time.

The results indicate that root barriers are generally not considered when dealing with clay shrinkage claims, which may be due to negative perceptions such as practical, cost, knowledge, or reliability concerns. If root barriers are not being considered, this restricts the opportunities for their use and the potential to exploit the option are being overlooked.

Question 2 results were reasonably well matched overall.

5.3.7 Question 3 Results

Question	Response headings
What is the main difficulty with the root barrier solution	A. Practical difficulties, e.g., services or installation
	B. Cost when compared with tree removal
	C. Lack of understanding/design rules
	D. Unreliable

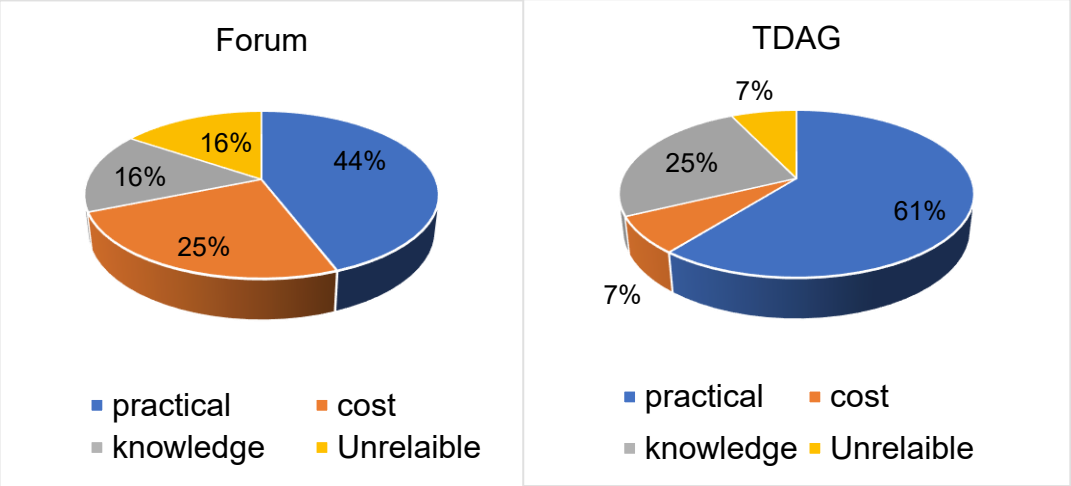


Figure 5.12 Question 3 Results

The responses indicate where practitioners perceive the main difficulty with root barriers. The results indicate that practical difficulties dominate and are of the most concern, with 34 respondents (44%) of the Subsidence Forum and 8 (61%) of TDAG. This category includes issues such as dealing with site features, services, fences, boundaries etc.

Apart from practical difficulties, the cost of a root barrier was the second most important concern amongst the Subsidence Forum, with 19 responses (25%). However, the cost issue needs to be considered alongside alternatives such as underpinning and tree removal with full consideration of the tree's value. If trees were generally more highly valued, then the cost of a root barrier would not inevitably feature as a significant concern.

Lack of understanding or knowledge was second-ranked amongst TDAG with 3.5 responses (25%).

5.3.8 Question 4 Results

Question	Response headings
In your experience have they been successful?	A. All of the time (100%)
	B. Most of the time (>75%)
	C. Some of the time (<75%)
	D. No experience

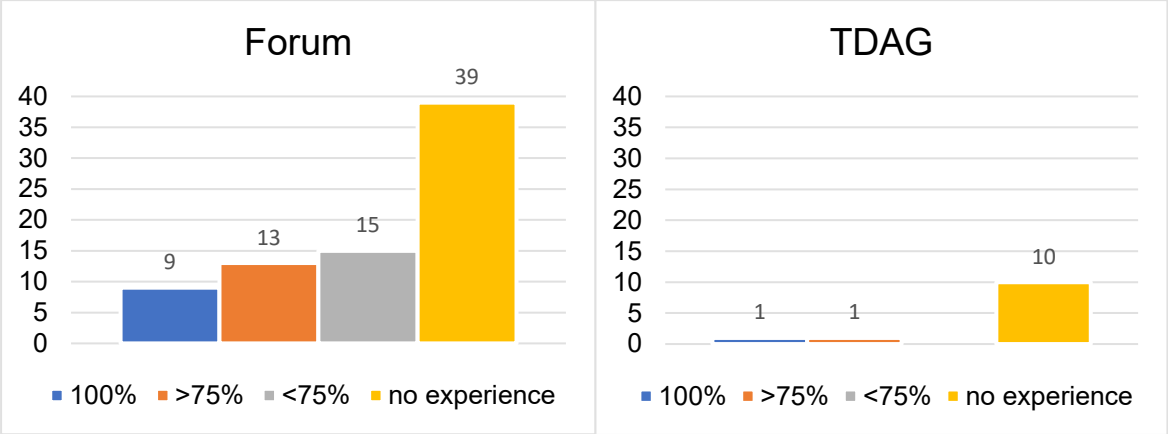


Figure 5.13 Question 4 results

The question seeks views on reliability perception and is linked with questions 1 and 2.

39 (51%) of the Subsidence Forum respondents had no direct experience of reliability, presumably because they had not been involved in post-installation procedures to check whether the barrier had been successful.

Of those that had direct experience (37 respondents within the Subsidence Forum), 15 out of 37 (41%) were aware of root barriers being successful some of the time < 75%. The majority (59%) (22/37) of those who had experience were aware of root barriers being successful all of the time or more than 75% of the time.

TDAG demonstrated little experience in the reliability of root barriers.

Concerning Question 4, the Subsidence Forum had mixed experience in the success of root barriers, whereas TDAG indicated their lack of experience in the actual use or involvement with root barriers.

5.3.9 Questions 5, 6 and 7

Question 5 Value of tree shown over 30 years	**Response**
	A Over £1,000,000
	B Between £1m and £250,000
	C Between £250,000 and £50,000
	D Less than £50,000

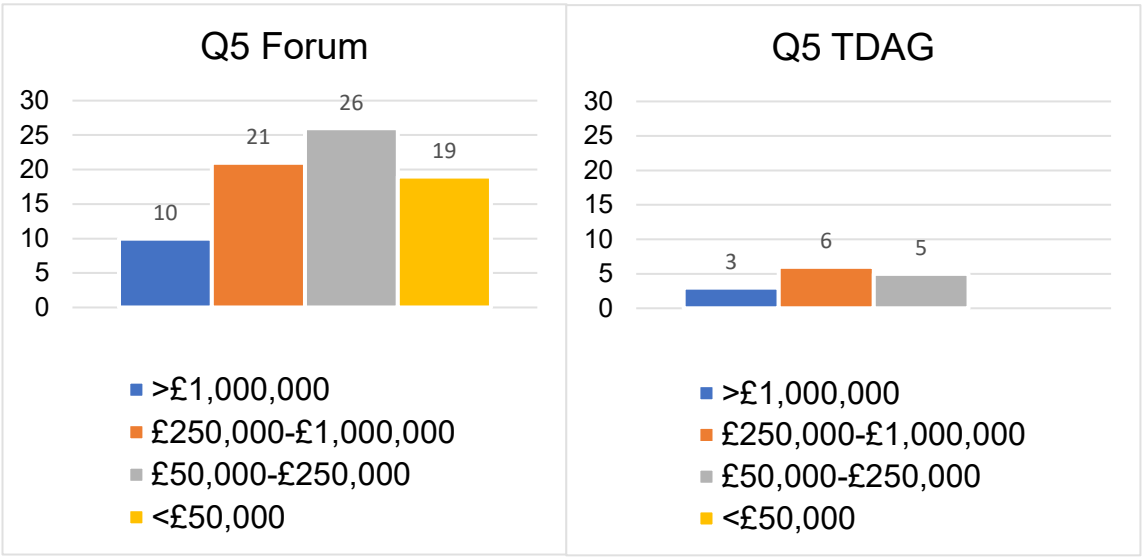


Figure 5.14 Question 5 results-high value tree

Question 6 Value of tree shown over 30 years	**Response**
	A Over £1,000,000
	B Between £1m and £250,000
	C Between £250,000 and £50,000
	D Less than £50,000

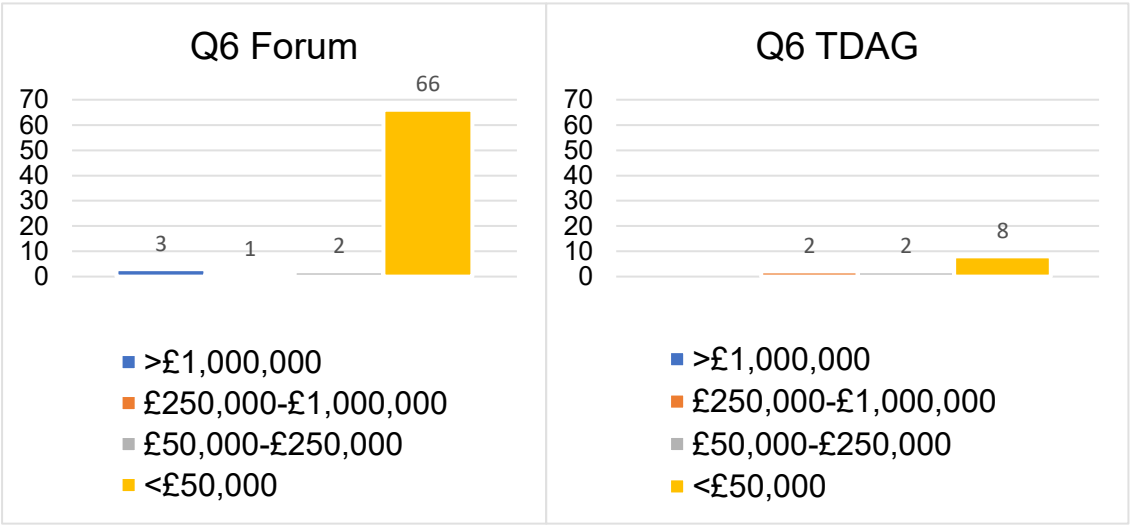


Figure 5.15 Question 6 - low-value tree

Question 7 Value of tree shown over 30 years	Response
	A Over £1,000,000
	B Between £1m and £250,000
	C Between £250,000 and £50,000
	D Less than £50,000

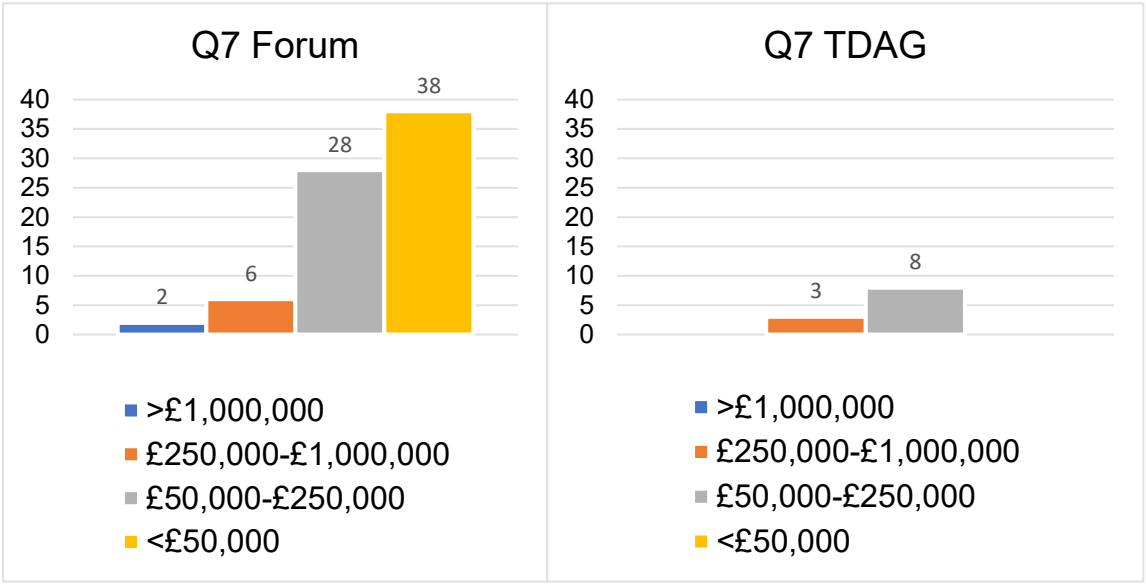


Figure 5.16 Question 7 results

The three linked questions 5, 6 and 7 collecting ratio data were specifically designed to seek the value of three different sizes of tree over 30 years and this was emphasized during the presentation as a tree's value is maintained over many years not just the short term. A value of £1,000,000 over 30 years amounts to £33,300 per year. Respondents were asked to consider tree values in four ranges.

The results show, for Question 5 (large oak) the majority of TDAG respondents provided a value between £250,000 and £1,000,000 whereas the majority of Subsidence Forum valued the tree at the lower range of £50,000 to £250,000. The Subsidence Forum and TDAG respondents demonstrated less variation in valuation range as will be discussed in the following sections.

Wider variations were found for Question 6 with the vast majority of the Subsidence Forum (66 out of 72) and TDAG (8 out of 12) valuing the tree at the lowest level of less than £250,000. With regard to Question 7 (medium tree) the majority of the Subsidence Forum valued the tree at the low level although more respondents valued the tree in the range £50,000 to £250,000

The results indicate some wide variations in how respondents value trees confirming the independence of the two groups established in section 5.3.2 combined with the uncertainty in the perceptions of value of trees, in monetary terms. In discussion these results concerning perceived value will be compared with CAVAT values.

In order to analyse the results further it is necessary to calculate the overall average tree values from the multiple respondents and convert to a fixed value. The average value within each range is shown in Table 5.23.

Table 5.23 Average tree value assessment from questionnaire results

Range	Value taken as average
>£1,000,000	£1000000
£250,000-£1,000,000	£625000
£50,000-£250,000	£150000
<£50,000	£25000

The overall average tree value is then calculated in Table 5.24 for the Subsidence Forum (questions 5,6 and 7) by using the following process:-

Step 1 Multiply the average value in the range (column 3) by the number of respondents in that range (column 4) to obtain figure in column 5.

Step 2 Add the results of column 5 for each range (column 6).

Step 3 Divide column 6 total by total number of respondents to obtain the overall average tree value (column 7).

Table 5.24 Calculating average subsidence forum perceived tree values

Column 1	Column 2	Column 3	Column 4	Column 5	Column6	Column 7
	range	value £000,s	total	value x number £000's	sum of columns £000's	Overall Average tree value
Tree 1 Oak	>£1,000,000	1000	10	10000	27500	£361,842
	£250,000-£1,000,000	625	21	13125		
	£50,000-£250,000	150	26	3900		
	<£50,000	25	19	475		
Tree 2 small	>£1,000,000	1000	3	3000	5575	£77,431
	£250,000-£1,000,000	625	1	625		
	£50,000-£250,000	150	2	300		
	<£50,000	25	66	1650		
Tree 3 medium	>£1,000,000	1000	2	2000	10900	£147,297
	£250,000-£1,000,000	625	6	3750		
	£50,000-£250,000	150	28	4200		
	<£50,000	25	38	950		

The results from Table 5.24 (rounded to nearest £1,000) indicate the large oak tree was valued at £362,000, the smallest tree in Question 6 was valued at £77,000 and the medium tree was valued at £147,000.

In broad terms the oak was perceived as nearly 5 times more valuable than the small tree and the medium tree was over double the value of the small tree.

For TDAG a similar procedure was followed to calculate the overall average tree value shown in Table 5.25 alongside the Subsidence Forum overall averages. `

Table 5.25 Calculating average TDAG perceived tree values

	Value £000s	Total response	value x number £000s	sum of columns £000s	TDAG average	Forum average Table 5.24
Col1	**Col 3**	**Col 4**	**Col 5**	**Col 6**	**Col 7**	
Tree 1 Oak	1000	3	3000	7500	£535,714	£361,842
	625	6	2500			
	150	5	750			
	25	0	0			
Tree 2 small	1000	0	0	1750	£145,833	£77,431
	625	2	1250			
	150	2	300			
	25	8	175			
Tree 3 medium	1000	0	0	3075	£279,545	£147,297
	625	3	1250			
	150	8	1200			
	25	0	0			

The TDAG results in Table 5.25 indicate all trees were valued more highly than Subsidence Forum. Tree 1 was valued at over £500,000 by TDAG which is worth noting as a very significant value. This increased value may be explained by participants in TDAG being more involved in tree protection and management. Discussion of the above results is reserved for the next chapter and in particular how the results compare with calculated tree values using the CAVAT method.

5.3.10 Question 8

Question 8	Response
Who should specify and take the lead role in the use of root barriers?	A. Loss Adjusters/Engineers
	B. Arborists
	C. Contractors
	D. Don't know

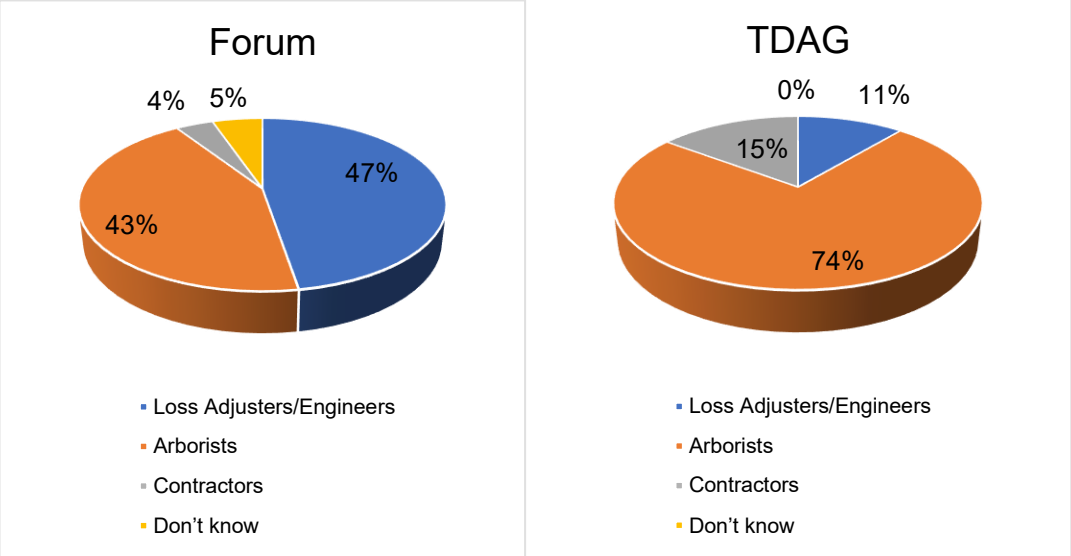


Figure 5.17 Question 8 results

Subsidence Forum opinions were split concerning the lead role between loss adjusters/engineers and arborists, although if loss adjusters and engineers are divided 50/50 then it would be arborists that should take the lead role, according to the Subsidence Forum, i.e., 18 (23%) engineers, 18 (23%) loss adjuster and 33 (43%) arborist.

Concerning TDAG the view was clearly 13 (74%) respondents consider that arborists should take the lead role in designing and constructing root barriers.

Very few respondents considered contractors should take the lead role or did not have a view or a preference.

Question 8 further illustrates TDAG preference for arborists to take the lead design role.

5.3.11 Question 9

Question 9	Response
Would you consider a root barrier even if there were no objections to tree removal?	A. Yes
	B. No
	C. No experience using root barriers

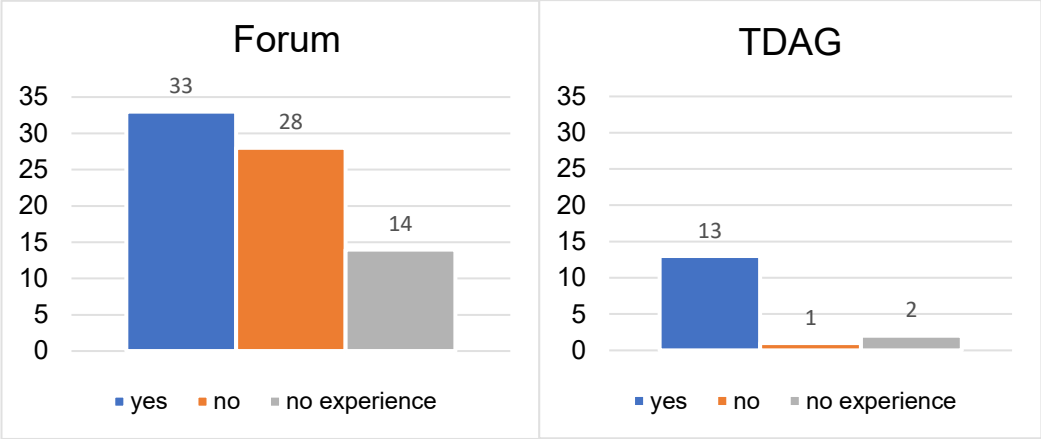


Figure 5.18 Question 9 results

There appears a willingness to adopt the root barrier solution amongst practitioners overall. Thirty three respondents (44%) of the Subsidence Forum said they would consider the option, which was significantly higher amongst TDAG at 13 (81%).

28 out of 61 (46%) of Subsidence Forum members (of those that had direct experience), stated that they would not consider a root barrier than TDAG, where (from those that had a view) the figure was 1 (7%).

The figures are encouraging from the TDAG responses regarding those that are willing to consider root barriers. There remains a majority of practitioners within the Subsidence Forum that appear not yet ready to consider root barriers as a solution to clay shrinkage subsidence, even if there were no objections to tree removal.

Question 9 illustrates the TDAG preference for considering the root barrier if there were no objections to tree removal alongside the Subsidence Forum's more cautious view.

5.3.12 Participant 1 Semi-Structured Interview Results

The semi structured interview took place on 18th January 2018 at the offices of participant 1. The first part of the visit involved collecting data for the case studies (4 total) and the interview was carried out after the data had been collected.

The various questions raised are shown in Table 5.26. Responses provided were measured on a scale of 0 to 10 with 0 strongly disagreeing and 10 strongly agreeing

Table 5.26 Participant 1 semi-structured interview

Question	Response scale 0=strongly disagree 10=strongly agree
Root barriers are rarely used and could be used in more situations	6
Root barriers are rarely used because practitioners are unaware of the solution being available?	5
Root barriers are rarely used because of fear they will not work	2
Root barriers are rarely used because even though they are considered a viable the cost is too high	5
Root barriers are rarely used because of lack of knowledge expertise as there is little published information on their design and construction	3
Root barriers are rarely used because after consideration of the obstacles they are too difficult to overcome e.g., services features and site constraints	8
Root barriers are rarely used because policyholder owner wants the tree removed	5

The first three questions are linked and the results in Table 5.26 confirm that the practitioner tended to the view that root barriers are rarely used and that they could be used in more situations. The respondent was unable to clarify whether this was due to practitioners being unaware of the solution (Question 2, response = 5), however they did not consider this was due to a fear they would not work (Question 3, response = 2).

In response to the 4th question concerning root barriers being rarely used due to high costs the response was to neither agree nor disagree.

The main reason that root barriers were rarely used was, according to the participant, due to site constraints with the returned score of 8 (agree).

The overall ranking for the agreed infrequent use of root barriers was: -

- site constraints (8-agree tending towards strongly agree)
- unaware, cost and policyholder concerns (5-neither agree nor disagree)
- lack of published information (3-disagree)
- fear they will not work (2-disagree tending towards strongly disagree)

The following additional questions were presented, and answers provided as shown.

Question. What are the main advantages of root barriers?

Response. Root barriers cut the roots so that the solution is the same as tree removal.

Question. What is the main disadvantage of root barriers?

Response. Site constraints. The participant agreed that further research is needed.

A general discussion ensued regarding root barriers as a solution to clay shrinkage subsidence claims. The participants agreed that trees have value and this value should be considered early on in a clay shrinkage claim.

The participant has completed about 6 root barriers in the last few years and four of these as mentioned, were available for the case study. The participant has another 5 or 6 cases of root barrier installation in progress although they are not currently available.

The question was asked concerning the reasons why root barriers were installed in the 4 cases reviewed. The participant advised they would generally become involved later in the overall process; therefore, some of the aspects regarding the root barrier, damage to the property, crack monitoring etc., were not included within their files.

The survey questionnaire delivered to the subsidence forum and TDAG was also presented to the participant. The questions and responses are provided in Figure 5.19. Note that two responses are provided representing the views of the two personnel involved in the interview from the participant company.

	Question	Response	Result
1	General perception on the use of root barriers	A. Positive, (would usually consider using) B. Neutral, (would sometimes consider using) C. Negative, (would rarely consider using) D. No view on root barriers	**A A**
2	How often are root barriers considered?	A. More than 75% of cases B. Between 75% and 25% of cases C. Less than 25% of cases D. Don't know	**B B**
3	The main difficulty with the root barrier solution?	A. Practical difficulties e.g., services or installation B. Cost when compared with tree removal C. Lack of understanding/design rules D. Unreliable	**A A**
4	In your experience have they been successful?	A. All of the time (100%) B. Most of the time (>75%) C. Some of the time (<75%) D. No experience of their use	**A A**
5	Value of an identified tree over a 30 year period	A Over £1,000,000 B Between £1m and £250,000 C Between £250,000 and £50,000 D Less than £50,000	**A A**
6	Value of an identified tree over a 30 year period	A Over £1,000,000 B Between £1m and £250,000 C Between £250,000 and £50,000 D Less than £50,000	**C C**
7	Value of an identified tree over a 30 year period	A Over £1,000,000 B Between £1m and £250,000 C Between £250,000 and £50,000 D Less than £50,000	**B B**
8	Who should specify and take the lead role in the use of root barriers?	A. Loss Adjusters/Engineers B. Arborists C. Contractors D. Don't know	**A A**
9	Would you consider a root barrier even if there were no objections to tree removal?	A. Yes B. No C. No experience using root barriers	**A A**

Figure 5.19 Questionnaire results participant 1

The results indicate a positive view on root barriers, which is not surprising given that the participant was providing projects for case study.

Root barriers were considered in 25% to 75% of cases.

The main difficulty was re-iterated as practical difficulties, site constraints and services.

The practitioner confirmed a 100% success rate for root barrier installation.

Concerning the perceived value of trees, the practitioner provided the highest possible score for the oak tree at over £1,000,000 over a 30-year period. The medium sized tree returned an average value of £625,000 and for the small tree £150,000.

Loss adjusters/engineers were considered the appropriate lead designer and root barriers would always be considered even if there were no objections to tree removal.

5.3.13 Participant 2 Semi-Structured Interview

The semi-structured interview took place in the participants Newcastle offices during data collection on 12th September 2019.

Participant 2 preferred to identify difficulties as one single block encompassing all their cases, whereas for knowledgeable participant 1, this was completed individually.

In terms of construction, the participant confirmed that they use a 300mm or 450mm wide trench, governed by digger size, which is most often a 6-8 tonne JCB type machine. The root barrier material is lowered into the trench, and the trench backfilled.

The participant showed the author a sample of the root barrier material in use comprising copper impregnated polypropylene. They advised that Cutex barrier was preferred to the older Flexline type. Data sheets for these materials are included in the appendix.

In terms of backfill, gravel was preferred, not concrete, due to mainly environmental and cost concerns.

In the participant's opinion, root barriers usually fail because they are not deep enough. The participant knew of examples where 2m depth or less barriers were installed, and these had failed. This, according to the participant, leads to a negative opinion on the reliability of root barriers.

In terms of frequency of installation, the participant advised that their organisation installs approximately one root barrier every 2 months on average—these date between Oct 2012 to July 2019.

The cases presented in the results represent approximately 75% of work done on root barriers. The participant would comment that their organisation has installed approximately 40 root barriers in the last 6 years.

Each job within the case study (27 total) forms part of a complete file, with photos.

The participant advised that photos and other file information could be obtained but there would be potential confidentiality concerns.

The participant was not aware of any root barriers that did not work.

Difficulties encountered were not listed individually for each of the 27 cases as the participant preferred to group these together.

The main difficulties in the use of root barriers, as advised by the participant during the meeting were as follows: -

- access for plant and machinery
- space to work
- neighbouring consent if third parties involved
- services
- reinstating as existing after disruptions
- fences and walls

There was an extended discussion on the location of the root barrier in relation to the property. The participant tended to use gravel backfill with the root barrier constructed some distance from the house, i.e., no examples were identified where the root barrier was very close to foundations. It was agreed that if root barriers were located closer than 45-degree load spread with gravel backfill, this could lead to problems. It was further agreed that concrete backfill should be used in such situations as there would be less risk of undermining foundations. In the case where barriers were closer than 45-degree utilising concrete backfill the participant suggested that the work would need to be done in stages to prevent undermining house foundations.

5.3.14 Summarizing Questionnaire Results

This chapter presented the results of questionnaires delivered to the subsidence forum, TDAG and participants 1 and 2 involved in case study.

The subsidence forum results were more representative and from a larger sample than TDAG, although the latter produced valuable results.

Overall, there is a negative perception in the use of root barriers with practical difficulties being the most common concern. The practical concerns related mainly to services in the ground. Overall, respondents experience in the use of root barriers was limited. Of the respondents who had experience of root barriers, most were aware of them being successful more than 75% of the time.

Respondents were asked about their perceptions of certain trees' value, a large oak, a medium sized tree, and a small tree. The average perceived value of the oak tree amongst subsidence forum respondents was £360,000 and for TDAG £550,000. The small tree was not valued highly by the subsidence forum (£77,000) whereas TDAG placed a perceived value of £157,000 on this tree. The medium-sized tree was valued at £147,000 for the subsidence forum and £245,000 by TDAG. Overall, TDAG placed a 40% higher value on all the trees than the subsidence forum.

Respondents considered that loss adjusters, engineers and arborists should take the lead role in designing and constructing root barriers with a preference for arborists.

The results demonstrate a willingness amongst practitioners to consider the root barrier option, even where there were no objections to tree removal.

The following chapter discusses these results in relation to the original aims and objectives.

5.4 Chapter Summary

The chapter presented the results of the case studies and questionnaires and included analysis of the data concerning perceptions and variables in the practical use of root barriers. Figure 5.20 shows how the results and analysis (highlighted) links with other chapters, leading to the discussion.

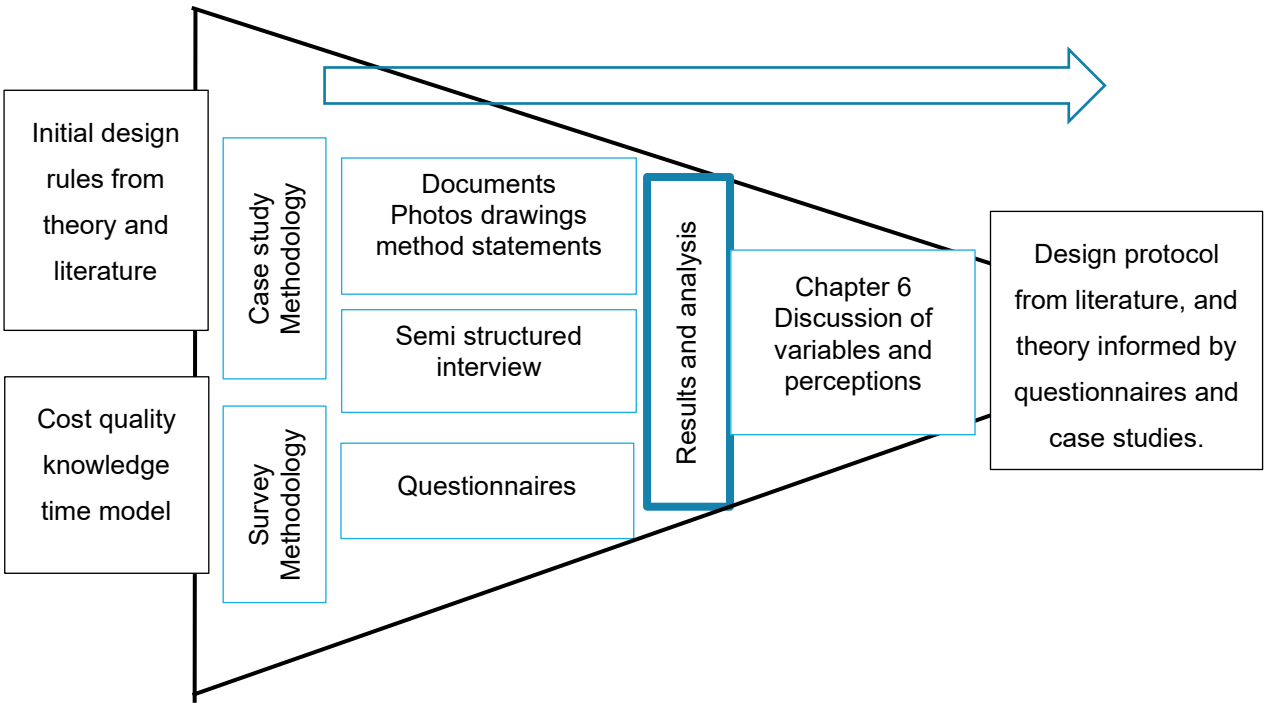


Figure 5.20 Diagrammatic view of the research (Source Author)

6.0 Discussion

6.1 General Introduction

Within this chapter the results of the case studies, semi structured interviews, and questionnaires are rationalized and discussed with specific reference to the original aims and objectives.

The case study results are discussed fulfilling objectives 1 and 3a (variables) under the following main headings: -

- depth of the root barrier (design depth, varying depths)
- length of root barrier
- the trees (size, species, value)
- location of the root barrier in relation to the tree and the building
- materials and construction

The perceptions are discussed using results and analysis from the questionnaires and case studies where appropriate to satisfy objective 2 and 3b (perceptions). The main headings for perceptions within this chapter are: -

- practical considerations
- cost and value for money
- knowledge concerns
- reliability of root barriers

The variables and perceptions within this chapter should not be viewed strictly within discrete, separate compartments as previously, but viewed more collectively as the relationships have developed. For example, materials and construction are discussed jointly as they are very closely related with the choice of materials having a direct influence on construction method and vice versa.

The case studies did not reveal any new variables or perceptions; however, it was apparent that those identified initially in chapter 2 were not all of equal importance.

Referring to the full list of variables and perceptions identified in Chapter 2, mention should be made at this stage of those variables or perceptions that are not progressed or have been incorporated into the main variables in discussion, such as: -

- severity of damage
- soils and site investigations
- legal issues (tree protection)
- property type
- weather conditions

The damage severity was not a significant issue in the case studies or the questionnaires and is not progressed in discussion. Where there is significant damage and where tree removal would not be an appropriate solution, it follows that neither would a root barrier be appropriate. Ultimately, if tree removal can resolve a case of clay shrinkage then in theory so would a root barrier as they are effectively the same.

The property type did not affect the outcome of case studies as the root barrier option should be capable of resolving any type of property with any type of damage where tree removal is appropriate.

Legal protection for trees was mentioned in case studies although there was insufficient detail to draw meaningful conclusions in this regard.

The case studies have shown, and experience confirms, that in some cases clay shrinkage is proposed, trees identified for removal, but other dominant causes are operating such as defective construction, loading effects, drainage problems or causes unrelated to clay shrinkage.

Due to the potential value of trees and the importance of identifying clay shrinkage as the dominant cause by specific trees, it is proposed that a robust procedure for checking desiccation is adopted as indicated in case study 33. This process of confirming causation is explained more fully in the informed design protocol.

Dealing now with the main variables and firstly the depth of the root barrier.

6.2 Depth of the Root Barrier

One of the most important variables identified from the research was the installed depth of the root barrier. This variable requires extended discussion due to its importance in positioning the root barrier, reliability, cost, practicalities, and construction method.

Chapter 2 identified that NHBC guidelines provide necessary information concerning the depth of foundations required with trees nearby and theoretically the required depth for a root barrier to avoid roots growing below. However, the case studies results demonstrate that root barriers were installed at greater depth than NHBC would require.

Participant 2 specifically mentioned in the structured interview that root barriers failed, in their experience, mainly because they were not deep enough. The participant knew of examples where 2m or less barriers were installed, and these had not surprisingly failed. This, according to the participant, leads to negative opinion on the reliability of root barriers.

The depth was established in the 33 case study results and analysis section as averaging 3.9m, with a recorded maximum depth of 5m and minimum depth of 2.5m. Results analysis within section 5.2.7 identified percentage increases in depth for three groupings and a trend for reduced percentages for the most recent root barriers.

These results from case studies demonstrate that a FoS has been allowed for in the depth calculations, perhaps because the installed depth is the standard depth that practitioners use or perhaps to allow for concerns over reliability or that roots were found in the site investigations below the depth NHBC would require. Perhaps the practitioner view is that once the machinery and materials are on site, it is more cost-effective to provide additional depth and reassurance that roots will not extend below the barrier.

Biddle's graph shows the moisture deficiency caused by trees at specific distances (Biddle, 1998). There is a reduction in expected moisture content combined with tree -induced soil moisture deficiency below the NHBC line. This research demonstrates that moisture extraction, by tree roots is still occurring below the depths NHBC recommend.

It is proposed to introduce a factor of safety (FoS) to the NHBC depth calculations to standardize the increased depth to avoid situations where the depth was arbitrarily increased without regard to any specific parameters. NHBC guidelines suggest caution when depths above 2.5m are calculated, indicating that FoS would be

appropriate. Furthermore, FoS are commonplace when dealing with many engineering components such as structural beams and columns, and a similar approach is suggested for determining the design depth of the root barrier. It is also considered appropriate to base the FoS upon the NHBC guidelines as these provide the widely adopted practical guidelines.

6.2.1 Determine Factor of Safety (FoS) or Design Depth for Root Barriers

It is proposed to identify a conservative and a less conservative FoS and check the results against the case study results and Biddle graphs of moisture deficiency. Three root barrier depths should be calculated, firstly the NHBC depth (based upon NHBC tables) and two design depths, a conservative and less conservative depth with different factors applied.

There are 9 NHBC graphs for broad leaf trees for high, moderate or low water demand trees and high, medium or low plasticity soils. Concerning case studies, three groupings were identified in Chapter 5 and the highest soil/tree combination incidence was high shrinkage soil and high water demand tree

To investigate further the FoS, the results from the 11 case studies relating to group 1 combination have been plotted together with NHBC depths and proposed design lines 1 and 2 in Figure 6.1. The grouping is particularly relevant as all trees were oak so that constant mature height of 20m was used.

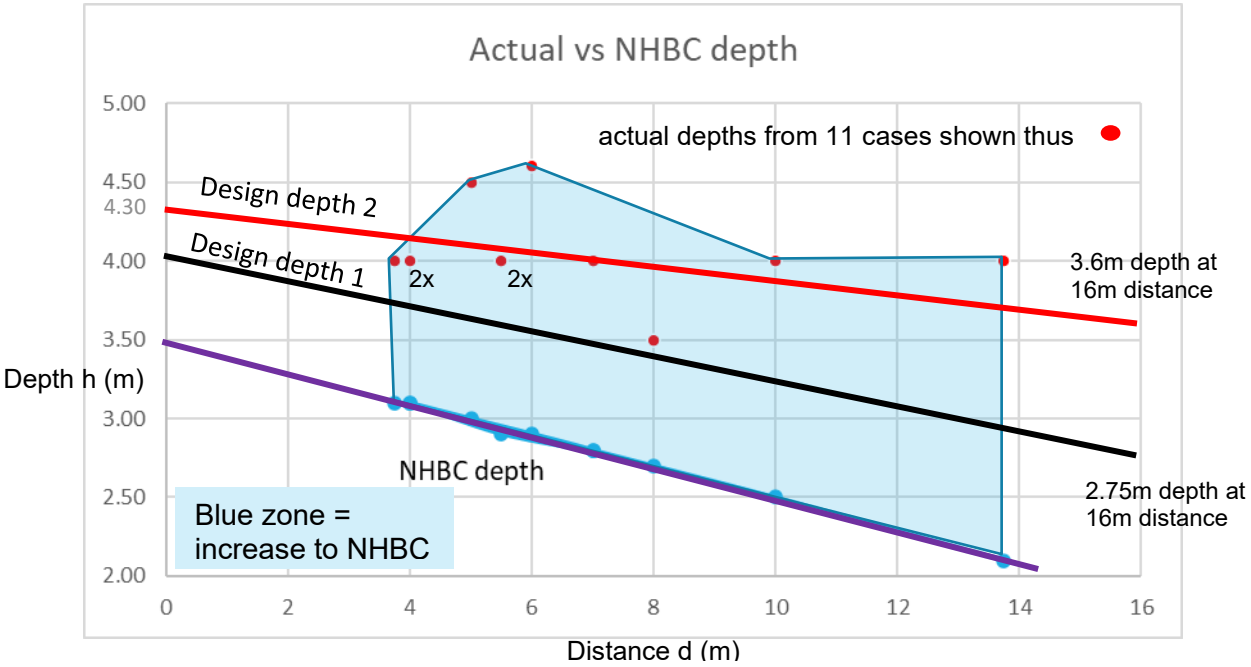


Figure 6.1 Actual vs design depths (HWD, HSS) with design depths 1 and 2

Two additional lines are design depths representing two increased depths over NHBC depths at various distances. The design depths 1 and 2 have been plotted to satisfy:-

- Design depth 2 provides for root barrier depth in excess of 7 of the 11 cases with 4 cases have deeper barriers installed. (note 2x refers to two cases with the same results). Depth is designed to reduce as distance increases.
- Design depth 1 provides for depth deeper than all the root barriers installed for the nine cases whilst maintaining reduced depth as distance increases.

The design lines are arbitrarily drawn at this stage as they will be tested for adequacy in the following section based upon data from case studies and checked against Biddle graphs.

The shaded blue area shows the envelope of the maximum extent of installed barriers compared to the NHBC line.

The three steps in establishing formulas for the factors of safety for the two design lines, line 1 and line 2 are as follows: -

Step 1 calculate equation of NHBC line

Step 2 determine equation of design lines 1 and 2 as indicated by lines in Figure 6.1.

Step 3 check adequacy of design lines 1 and 2

Step 1-Calculate NHBC line equation

Firstly, it is necessary to identify equation of the NHBC line in y=mx+c format.

y=depth (h) and x=distance (d)

The equation of NHBC line is: -

$$y = -0.10x + 3.5 \text{ (NHBC)} \quad (\text{or } h = -0.10d + 3.5)$$

Equation 6-1 Equation of line NHBC

Step 2-Determine design line 2 (very conservative)

The design depth 2 (very conservative) is slightly less than some of the actual depths and reduces with increasing distance intercept at 4.3m.

The equation of line 2 is.

$$y = -0.044x + 4.3 \quad (\text{or } h = -0.044d + 4.3)$$

Equation 6-2 Equation of line 2 very conservative

To convert from NHBC to design line 2 it is necessary to add 0.059 x d (6% increase based upon distance) and add h = 0.8m.

(-0.103 + **0.059** = -0.044)

Example at 10m distance NHBC gives 2.5m depth.

Design depth = 2.5 + (6% x 10) + 0.8m = 3.9m

Table 6.1 calculates a root barrier's depth at various distances from the tree using the very conservative FoS with a 20m high HWD broadleaf (English oak) on high shrinkable soils. The increase in depth over NHBC is equivalent to 6% (x distance) plus 0.8m.

Table 6.1 Design depth line 2 (very conservative)

		20m high HWD broad leaf (English oak) high shrinkable soils						
			F of S	% increase	6%			
			F of S	Addn depth	0.8	m		
	Distance	**4**	**6**	**8**	**10**	**12**	**14**	**16**
	NHBC value	3.1	2.9	2.7	2.5	2.3	2.1	1.9
F of S	**Depth increase 6%xd**	0.24	0.36	0.48	0.60	0.72	0.84	0.96
F of S	**Fixed addn. depth**	0.8	0.8	0.8	0.8	0.8	0.8	0.8
	Design depth 2 (line 2)	4.1	4.1	4.0	3.9	3.8	3.7	3.7

Table 6.1 confirms that at 10m distance the NHBC depth would be 2.5m and the design depth (very conservative) would be 3.9m. This is graphically illustrated in Figure 6.2.

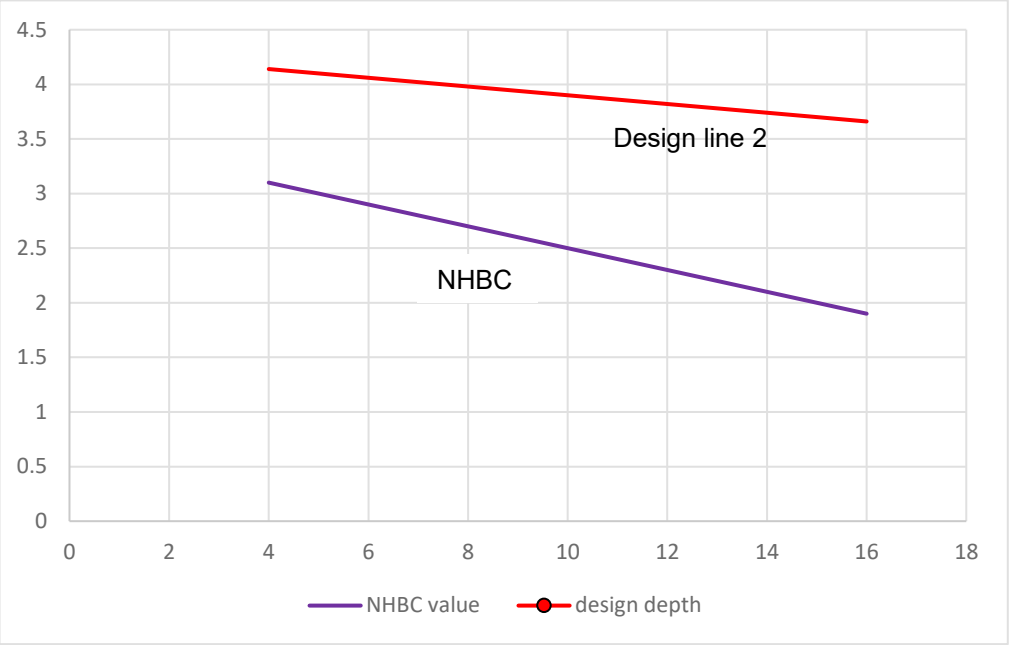


Figure 6.2 Graph comparing NHBC depth of root barrier with depth derived from very conservative FoS (line 2)

Step 2-Determine design line 1 (conservative)

For the less conservative design line 1, a similar approach has been adopted and the equation of line 1 is as follows: -

$$h = -0.078d + 4.0$$

Equation 6-3 Equation of line 1 conservative compared with NHBC

To translate NHBC to design line 1 add (0.03 x d) and add 0.5m.

(3% increase x distance plus 0.5m)

The table and graph of line 1 is shown within Table 6.2 and Figure 6.3.

Table 6.2 Design line 1

		20m high HWD broad leaf (English oak) high shrinkable soils						
			F of S	% increase	3%			
			F of S	Addn depth	0.5	m		
	Distance	**4**	**6**	**8**	**10**	**12**	**14**	**16**
	NHBC value	3.1	2.9	2.7	2.5	2.3	2.1	1.9
F of S	**depth increase %**	0.12	0.18	0.24	0.30	0.36	0.42	0.48
F of S	**fixed addn. depth**	0.5	0.5	0.5	0.5	0.5	0.5	0.5
	design depth 1 (line 1)	3.7	3.6	3.4	3.3	3.2	3.0	2.9

For example, at 10m distance NHBC depth would be 2.5m and design depth using FoS (conservative) 3.3m.

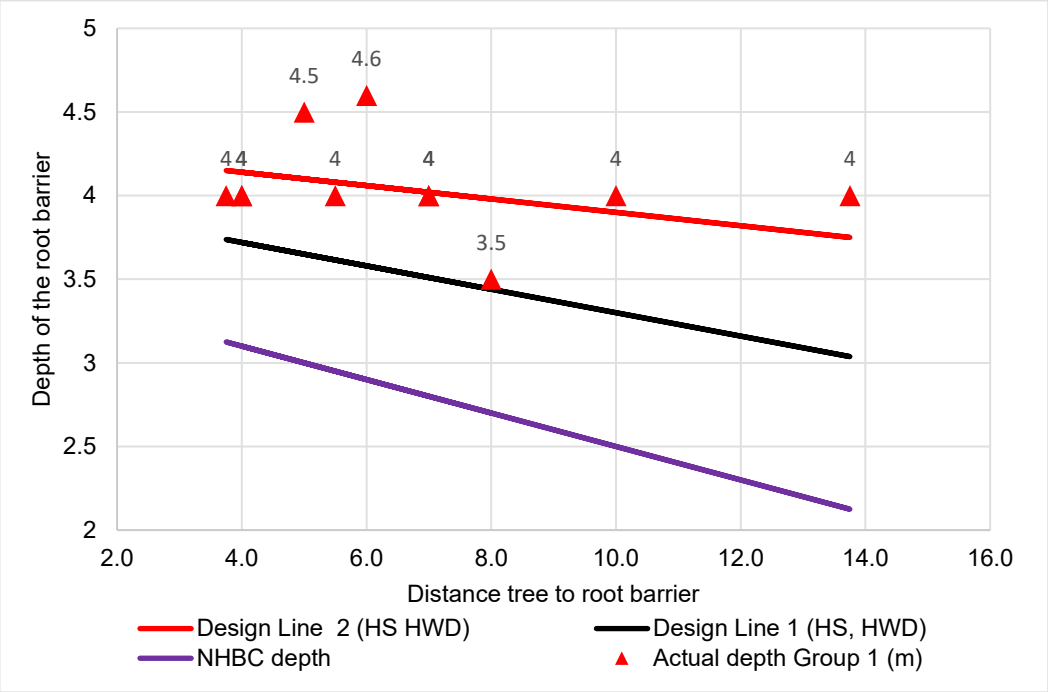


Figure 6.3 Design line 1 (also showing NHBC and design line 2)

To summarise the two FoS established equate to: -

Very conservative	Line 2	NHBC depth + (6% x distance) + 0.8m
Less conservative	Line 1	NHBC + (3% x distance) + 0.5m

Step 3-Check adequacy of design lines 1 and 2

It is necessary to consider the extent to which roots may grow below these design lines. For example, is 6% x d + 0.8m too onerous resulting in un-economic designs? To explore this question in more detail it is necessary to refer again to the Biddle graphs.

It was stated in Chapter 2 that Biddle in his most comprehensive work in 1998 produced, in Volume 2, (Biddle, 1998) 144 graphs patterns of soil drying for 60 trees on varying clay soils. One such graph is shown in Figure 2.3 which indicates the reduction in soil moisture content on a specific date (usually during the autumn period) at various distances from the tree compared with the control or spring average. The reduction at each location (100mm depth intervals) is banded 0-2.5%, 2.5%-5%, 5%-7.5%, 7.5%-10% and so on up to <20%. Other graphs show the total soil moisture deficit on a specific date compared with the spring average, again with varying distance from the tree. The soil moisture deficit graphs are banded 2.5-5%, 5% to 10%, 10% to 15%, 15% to 25% and so on up to 250%.

The graphs also include the NHBC design line.

It is noted that there remains moisture deficiency and moisture deficit below some of the NHBC design lines which indicates that roots are extracting moisture and are therefore active at this depth.

Biddle states that limiting value of 0.7% moisture reduction is the limit of accuracy and not significant. Similarly soil moisture deficits of 2.5% and 5% are dotted as these represent the “lower end of statistical significance”. (Biddle, 1998)

To understand the reliability or confidence regarding design lines 1 and 2, which both produce root barrier designs deeper than NHBC guidelines, the design lines 1 and 2 were superimposed on the Biddle graphs and the NHBC line.

The lower band of soil moisture content (0% to 2.5%) contains the non-significant 0. 7% figure. The next band (2.5% to 5%) indicates significant moisture reduction so that 5% moisture reduction or moisture deficiency has been taken as the limiting value of soil moisture reduction that indicates root are present and thus be affecting soil moisture content.

The Biddle graphs with London Clay soil were used to maintain consistency with the case study cases in group 1 used to establish the design lines. The 18 trees with London Clay soil within Biddle graphs are listed below.

Trees 1, 2, 3, 4, 12, 17, 18, 21, 22, 25, 26, 27, 35, 36, 39, 40, 43 and 44.

The graphs for each tree showing moisture reduction or overall deficit compared with spring average are shown in the appendix. The original NHBC and superimposed design lines are line 2 (very conservative) and line 1 (less conservative). Each of the graphs was checked to determine whether 5% or more moisture deficiency was present indicating the extent to which roots may be present below each design line.

For example, the graph for tree 4 (graph 4b) is shown in Figure 6.4 with NHBC line and design lines 1 and 2 representing 3% plus 0.5m and 6% plus 0.8m respectively

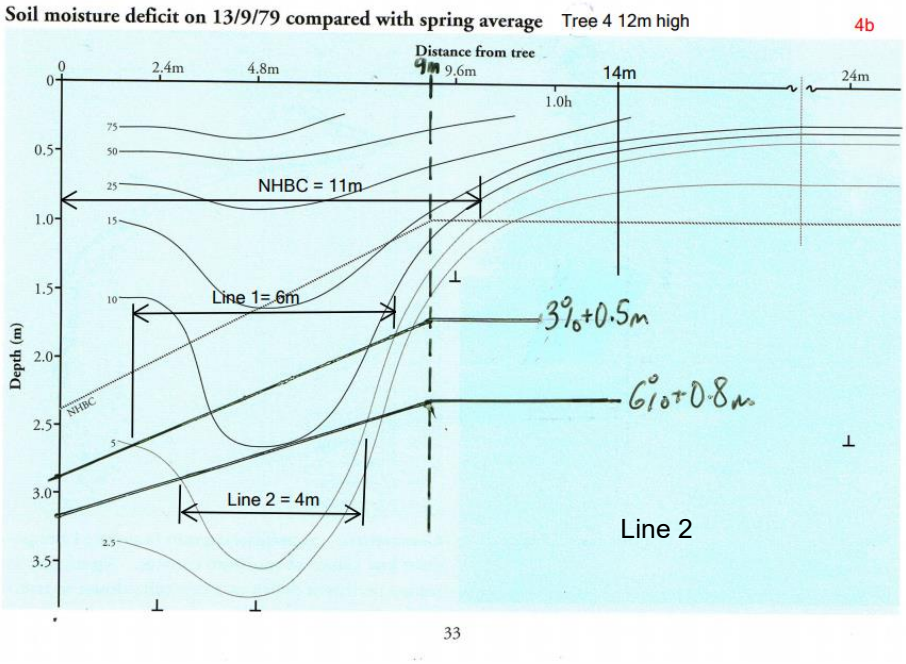


Figure 6.4 Biddle graphs with overlay (typical example)

As previously mentioned, the limiting value of 5% moisture deficiency has been used throughout. Note in Figure 6.4 that there is a 5% deficiency below the NHBC line for a horizontal distance of 11m. Similarly, there is 5% deficiency for 6m for line 1 (conservative) and 4m for line 2 (very conservative). By examining the extent to which roots may be growing below the design lines (5% limiting value), based upon horizontal distances, a relative assessment of the confidence of each FoS can be determined.

The outcome of the above exercise repeated for all graphs for all trees is shown below firstly for the NHBC line, then line 1 (the less conservative FoS, 3% x d plus 0.5m) and then line 2 (6% + 0.8m). The horizontal distance where roots may grow below is given for each tree. Each distance affected was based upon minimum 14m overall (or the height of the tree) because a baseline is required for comparison. The depths at this distance usually revert to the minimum 1m for NHBC and it is not anticipated that root barriers will be installed at distances from the tree greater than the distance that produces minimum foundation depth of 1m.

Table 6.3 FoS confidence assessment

Tree and graph no.		Total distance considered	NHBC above 5%	Line 1 above 5%	Line 2 above 5%
1	a	14	13	0	0
1	b	14	14	9	0
2	a	14	4	0	0
2	b	14	2	0	0
3	a	14	0	0	0
3	b	14	4	0	0
4	a	14	0	0	0
4	b	14	11	6	4
12	a	17	4	4	4
12	b	17	17	17	5
17	a	14	0	0	0
17	b	14	0	0	0
18	a	14	0	0	0
18	b	14	0	0	0
21	a	14	0	0	0
21	b	14	0	0	0
22	a	19	0	0	0
22	b	19	2	0	0
25	a	14	17	0	0
25	b	24	18	0	0
26	a	24	24	6	0
26	b	24	24	0	0
27	a	24	10	0	0
27	b	21	16	0	0
35	a	21	0	0	0
35	b	14	0	0	0
36	a	14	7,5	4	3
36	b	14	11	3.5	2.5
39	a	14	0	0	0
39	b	14	14	17	13
40	a	14	0	0	0
40	b	14	9	3	0
43	a	14	0	0	0
43	b	14	0	0	0
44	a	14	7	0	0
44	b	14	6	0	0
Totals		**574**	**227**	**69.5**	**31.5**

The full set of 36 graphs with overlays are shown in Appendix 12.10.

To summarise the findings derived from Table 6.3, for the NHBC line, roots may grow below the NHBC design line (5% or more moisture reduction) a total horizontal distance of 227m out of a total 574m equating to 40% of the total distance.

Similarly, for design line 1 (conservative) 5% or more moisture deficiency occurs for a distance of 69.5m out of 574m equating to 12%.

For design line 2 (very conservative) 55 or more deficiency occurs over 31.5m out of 574m equating to 5%.

Therefore, design line 1 provides just over 3 x confidence level of NHBC (40/12)

Design line 2 provides 8 x confidence level of NHBC (40/5) and 2.5 x confidence of line 1 (12/5).

Note that because some roots may grow below these design lines it does not follow that roots will grow below the barrier or that there will be damage. It provides a level of assurance and comparative assessment of the increased confidence in using a FoS and supports the case study results where depths were increased over and above NHBC.

To further check the above assessment using alternative approach, Biddle produced a graph with actual results from experience. (Biddle, 1998, p. 307)

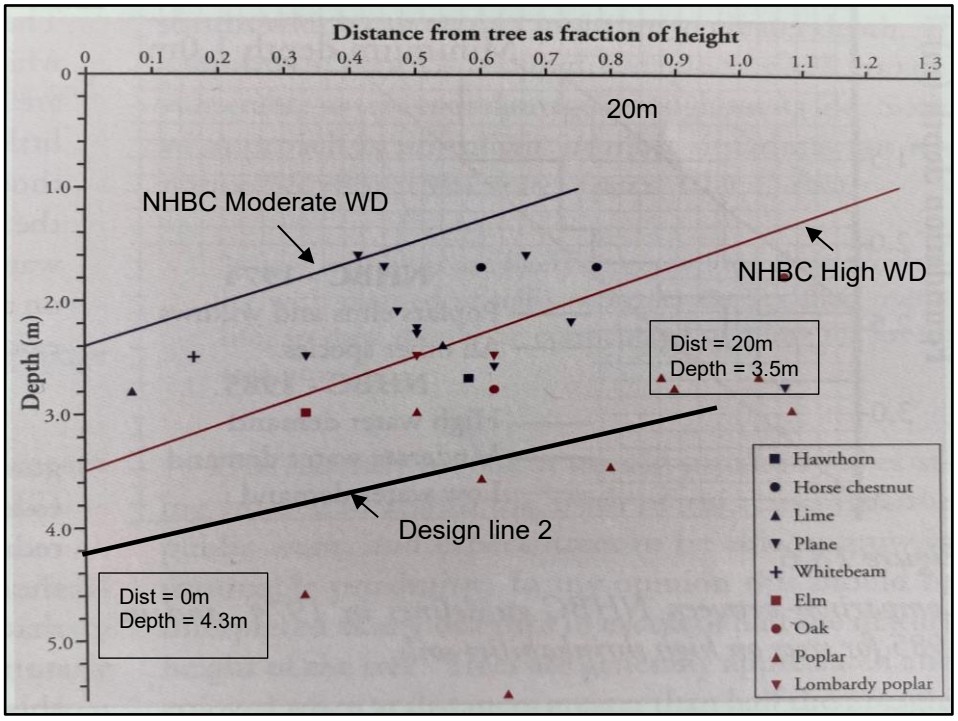


Figure 6.5 Biddle graph shows depths of significant moisture deficit (>25mm) during investigations of damage in 1976 and 1977 for various London clay trees. (Biddle, 1998, p. 307 vol 1)

The very conservative FoS (line 2) NHBC plus 6% x d + 0.8m has been overlain on Figure 6.5 and this shows that for a root barrier constructed at the depth shown by the solid black line, the moisture deficits are less than 25mm and roots are less likely to be growing below the barrier compared with NHBC.

Note that the FoS adjustment effectively flattens out the NHBC line so that the root barrier depth is less variable, as shown in Figure 6.6. Figure 6.5 shows a deeper

barrier closer to the tree and a shallower barrier further from the tree, but further from the tree the depth is proportionally more than the increase applied nearer the tree.

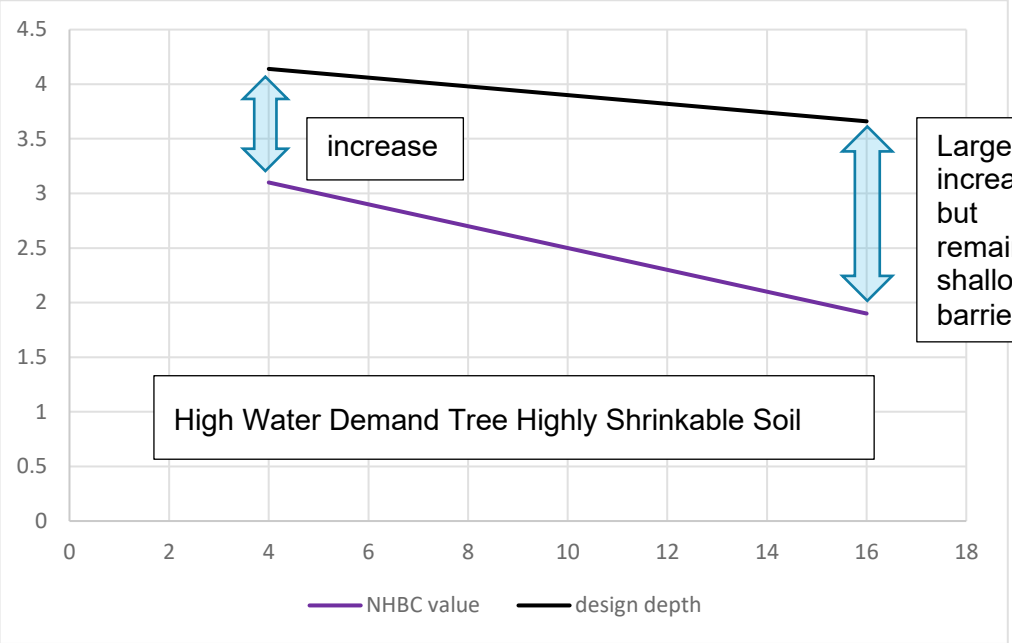


Figure 6.6 FoS adjustment (Source Author)

Two factors of safety have been considered based upon the case studies and these have been cross checked against Biddle graphs using a criteria of 5% or more moisture deficiency to indicate where roots may grow below the barrier.

- a very conservative FoS of 6% x distance plus 0.8m in addition to NHBC guidelines with an 8x confidence that roots will not grow below based upon NHBC
- a less conservative FoS of 3% x distance plus 0.5m in addition to NHBC guidelines with a 3x confidence that roots will not grow below based upon NHBC

6.2.2 Safety Factors for Group 2 and Group 3 Soil/Tree Combinations.

Group 2 and group 3, soil and tree combinations as indicated in Table 5.8 were also checked against the results for group 1 in section 6.2.1. Graphs were plotted showing actual root barrier depths, design lines 1 and 2 based upon the respective NHBC line. Figure 6.7 demonstrates that three root barriers were installed at depths in excess of NHBC and respective design lines 1 and design lines 2 (using appropriate NHBC tables). Design line 2 (calculated in section 6.2.1.) was also plotted on the graphs representing the high shrinkage soil and high water demand tree.

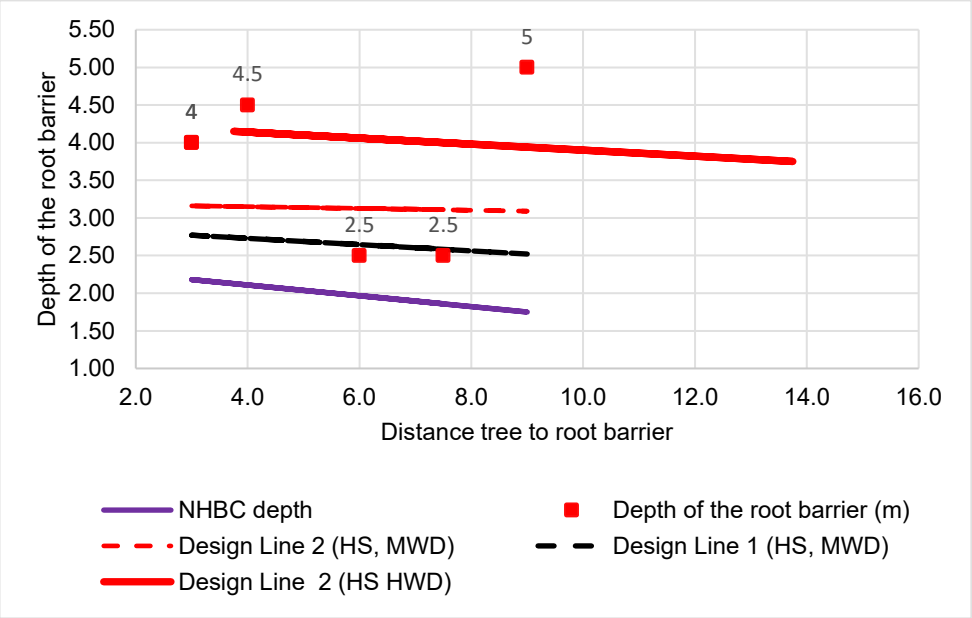


Figure 6.7 High Shrinkage Soils and Moderate Water Demand Tees (Group 2)

A similar exercise plotting depths for group 3 trees and comparing with NHBC, appropriate design lines 1 and 2 and design line from 6.2.1 is shown in Figure 6.8.

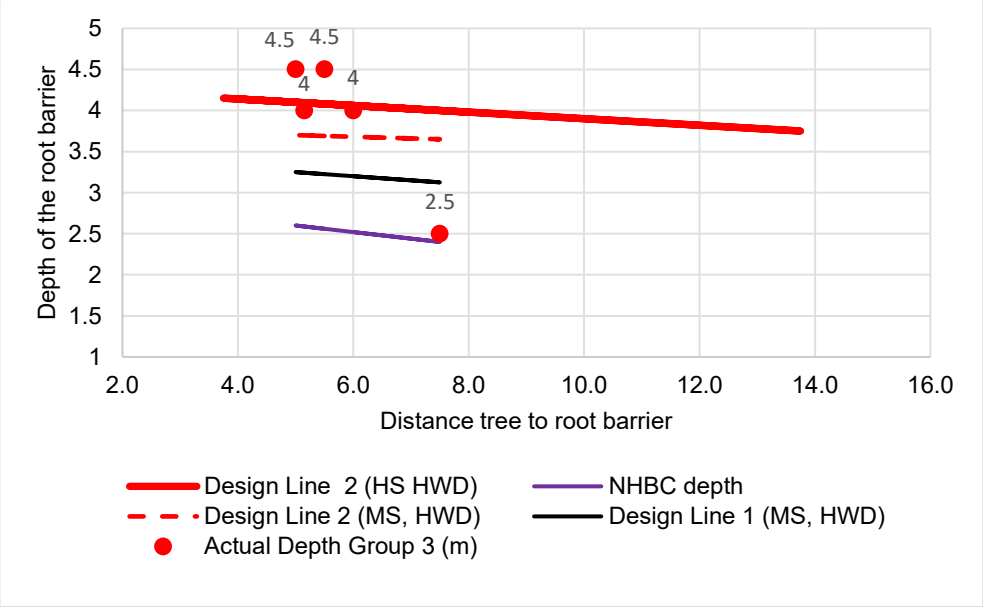


Figure 6.8 Medium Shrinkage Soils and High Water Demand Tees (Group 3)

Figure 6.8 demonstrates that four of five root barrier depths are in excess of the respective design lines 1 and 2 with two slightly above design line 1 for HW demand trees and HS soil combination calculated in 6.2.1.

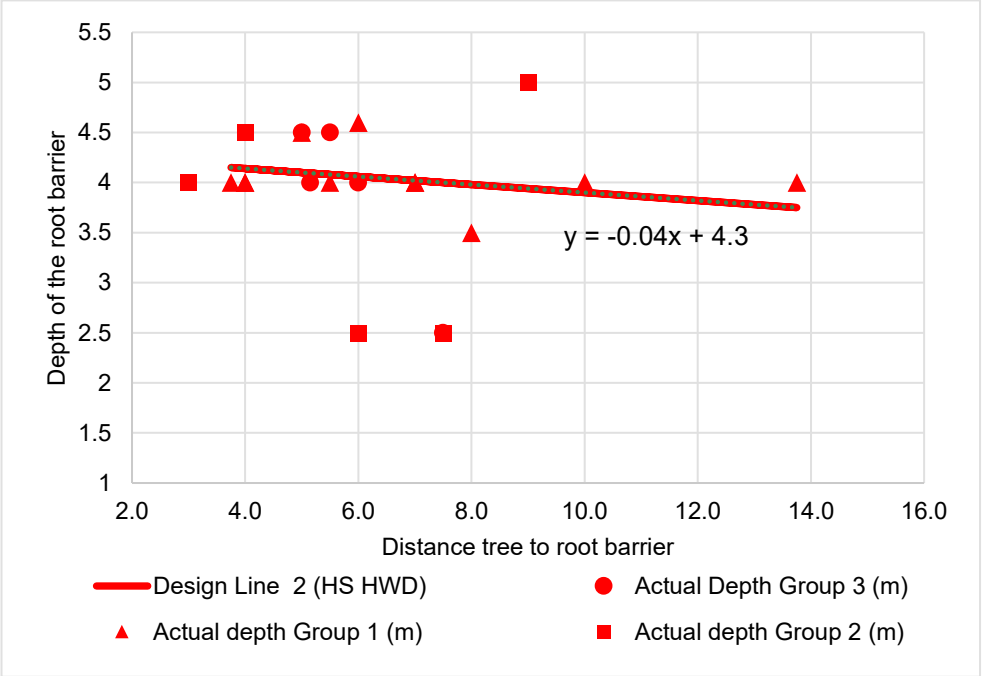


Figure 6.9 Actual Root Barrier Depths Groups 1, 2 and 3 Combined

All cases for groups 1, 2 and 3 are shown in Figure 6.9 alongside the design line 2 for HWD tree and HS soils.

The outcome of the above exercise determines that the NHBC value used in calculating design lines 1 and 2 should be based upon the NHBC line for high shrinkable soil and high water demand tree in all cases.

6.2.3 Summary Depth of the Root Barrier

The depth of the root barrier is one of the most important considerations and the method proposed to increase depths over NHBC guidelines suggests a FoS comprising of a multiplier and extra depth.

It is proposed to use design line 2 (NHBC (HS, HWD) + 6% x distance + 0.8m) to determine the depth of the root barrier using the mature height of the specific tree.

These factors of safety could be adjusted depending on the acceptable risk but should be stated and published within the design documents.

6.2.4 Depth Calculations for Multiple Trees

The initial design protocol allowed for one tree however in most cases there is more than one tree and an alternative method is required due to the complex inter-action between depths at various locations of the site.

The advanced method suggested for multiple trees involves placing concentric circles on a scaled plan (Figure 6.10) with the depth required marked for each tree.

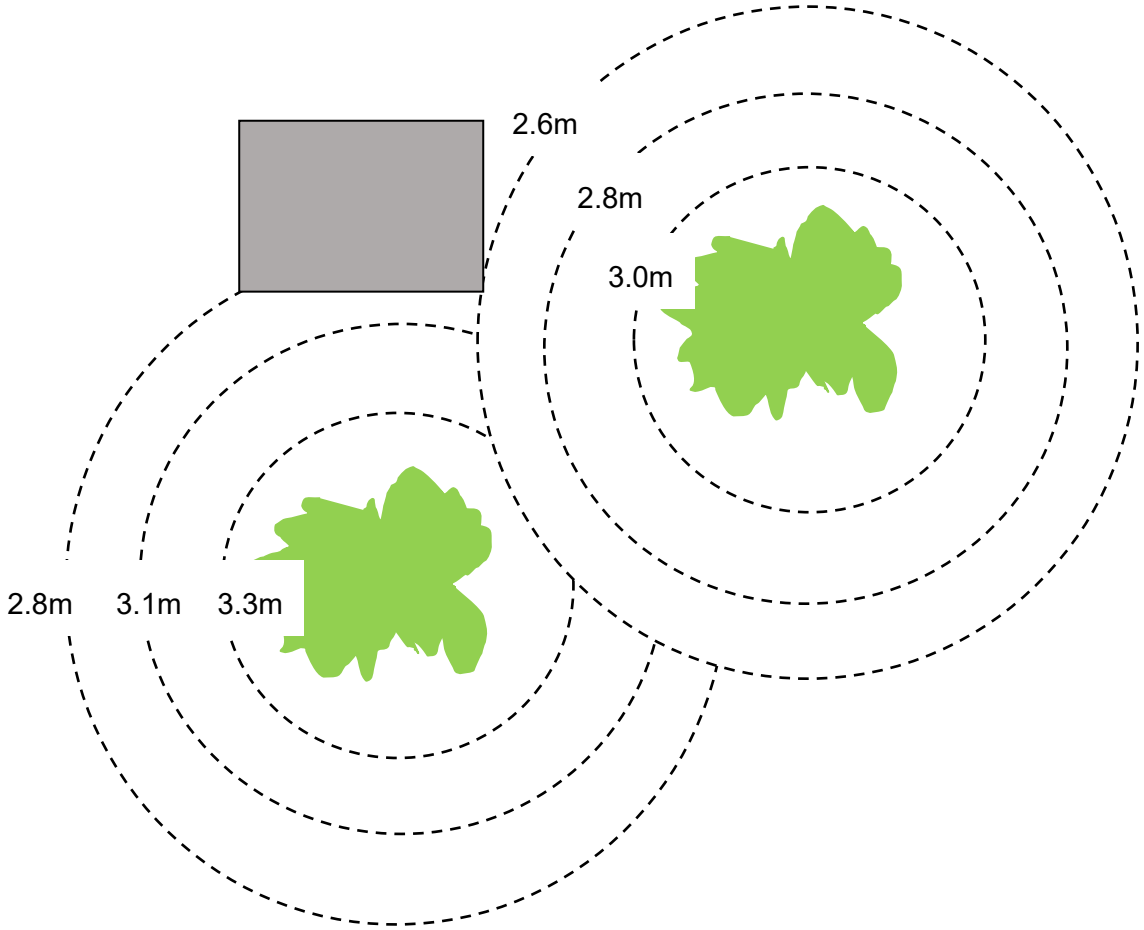


Figure 6.10 Multiple tree depth diagram (Source Author)

The case studies demonstrated that it was advantageous to have a range of possible locations identified for a root barrier as the best location is not necessarily the one that produces the least depth. In case of obstacles or obstructions or features, the best location may be one that avoids such features, obstacles or services rather than designing or locating the barrier based upon depth considerations alone.

The depth indicated should be the design depth and not the NHBC depth.

6.2.5 Varying Barrier Depth

The depth of the barriers remained constant and did not vary despite the tree to barrier distances increasing as the barrier extended across the site. The one exception to this observation was case 33, the author's own case, where the depth was varied depending on the position of the barrier in relation to the trees as required by NHBC guidelines.

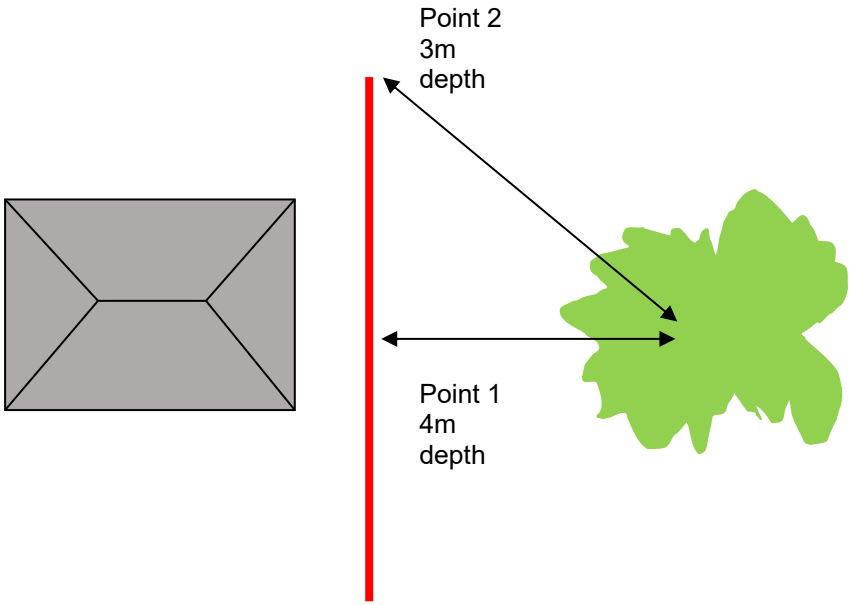


Figure 6.11 Varying depth (Source Author)

In Figure 6.11 Varying depth", at point 1 the barrier design depth is 4m whereas at point 2 only 3m depth is required because it is further from the tree.

Varying the root barrier depth could results in significant savings based upon the average costs of root barriers of £300 per m2 calculated in Section 5.2.9. The varying depth however may be more difficult and complicated for contractors if they prefer to install barriers at a single depth for uniformity and simplicity.

6.3 Length of the Barrier

Ideally a root barrier should encircle the tree **Figure** 6.12, preventing all roots from reaching the building.

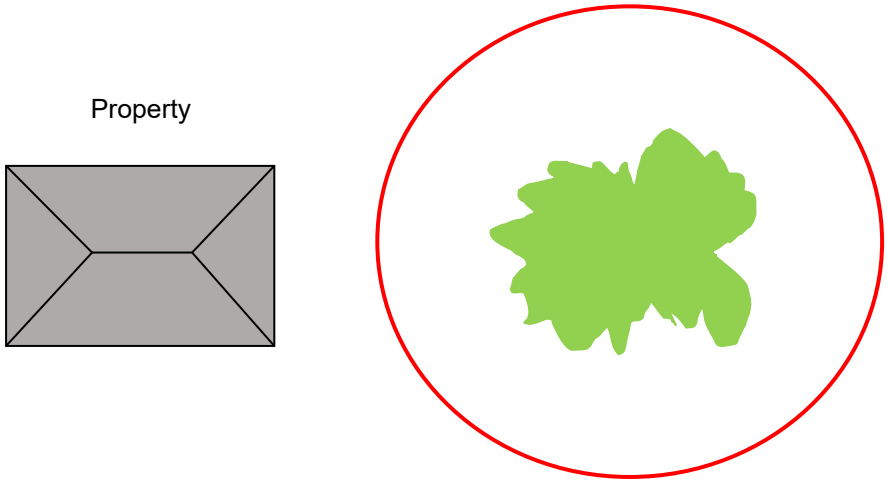


Figure 6.12 Root barrier and building (ideal situation) (Source Author)

However, due to site constraints and cost considerations the case studies have demonstrated that root barriers do not encircle trees but extend beyond the property by varying amounts. An encircling barrier as shown in Figure 6.12 would however severely restrict the tree's ability to source water from the ground and may cause damage to the tree.

The partial barrier shown in Figure 6.13 illustrates the risk that roots will grow around the barrier and reach the building.

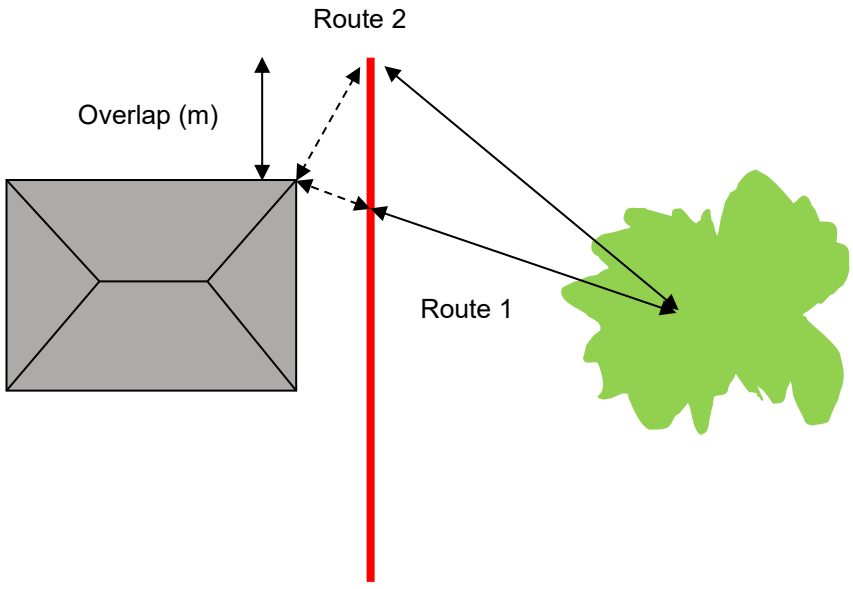


Figure 6.13 Partial barrier (Source Author)

Partial barriers have the advantage that they restrict water uptake in only one direction and the roots are free to source water in the opposite directions, avoiding the possibility of damage to the tree especially in the summer period.

The question remains however to what extend and by what distance should the root barrier extend beyond the property or feature that is seeks to protect? This is referred to as the "overlap" in Figure 6.13.

The research has not been able to provide a definitive answer to the above question through case study. However, APN 4 (Marshall, et al., 1997) addressed the issue and suggested the barrier should extend to at least the height of the tree although the reference states that roots can grow up to 3 x the height of the tree.

Extending the barrier a distance equal to the height of the tree either side of the building would require very long barriers especially if large trees were involved in the damage. The average length of barriers in case studies was 21.4m.

The problem could be approached by considering the additional distance that roots would need to travel in route 2 (around the barrier) compared to route 1 which is direct. This approach takes the view that the increased distance results in roots becoming shallower to the point that they no longer present a risk to the property. It is therefore proposed that the additional distance (route 2) is checked to identify if it complies with the minimum tree to building distances listed in chapter 2 section 2.2.

The maximum overlap could also be idealized as the length required to increase the distance sufficiently to enable the foundation depth to comply with NHBC rules.

Certainly, a minimum of 2m overlap beyond the property should be achieved as evidenced by case studies and the barrier should extend further than this 2m minimum to property boundaries, fences where this is economical and achievable.

As with the depth procedure it is proposed that the designer specifies the distance that the barrier will extend beyond the tree influence "the overlap" and communicate this information within the design documents and to the client.

6.4 Tree Information

Information concerning the trees is required in order to determine the depth and location of the root barrier. The required information includes actual tree height, mature height, trunk diameter at 1.5m height above ground, species and condition.

The case studies show that oak was the most popular tree saved with 33 incidences, the next highest were maples and London planes (9 and 7 respectively). It is interesting to note the high incidence of Oaks saved, possibly because these tend to be the most attractive trees. Valuing of trees is covered later in section

6.7.4, although it is of interest to note that the species does not have an effect on value using the CAVAT method. The value is related primarily to trunk diameter. The condition of the tree however is important as this affects the CAVAT value and requires specialist arboricultural knowledge.

6.5 Location of the Root Barrier

The two elements that determine the location of a root barrier are a) the minimum distance to the tree and b) the minimum distance to the building. Once the two distances have been determined the root barrier may be positioned between the two calculated extremes.

6.5.1 Distance Between Root Barrier and Property

The variable is concerned with the location of the barrier in relation to the building in particular whether it is closer or further than the 45-degree line drawn from the base of the foundations as shown in Figure 6.14.

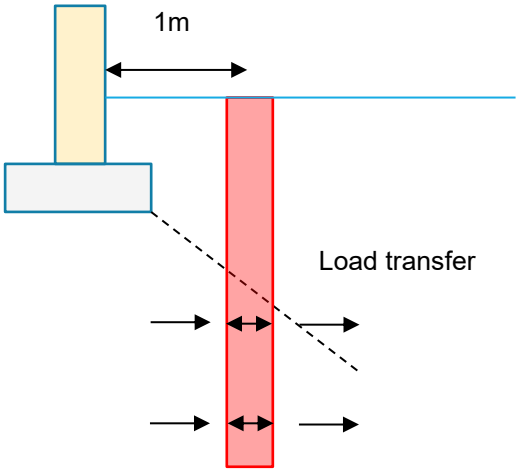


Figure 6.14 Load transfer across barrier (45-degree intercept) (Source Author)

The criteria used in the initial design protocol established the depth of the existing foundations h (b) and then calculated the required barrier depth (h) using an iterative procedure to ensure that the 45-degree load spread was maintained.

It was identified however in the case studies by participant 1 that root barriers were installed closer than the 45-degree rule with concrete backfill so that the infilled trench would resist lateral forces from the foundation and thus not undermine the foundations.

It is suggested that where there is encroachment inside the 45-degree line, the barrier should have concrete or rigid backfill to ensure that the lateral loads from foundations are transferred across the root barrier to the soil on the opposite side.

In such cases the barrier should be installed in short lengths, say 2m and in a strict sequence so that foundations are not undermined at any point in time ensuring that the property is always adequately supported while the concrete sets.

Where there is no encroachment on the 45-degree line gravel or compressible backfill may be used.

6.5.2 Distance Between the Root Barrier and the Tree

The distance was calculated using BS5837 (British Standard Institution, 2012) as indicated within the initial design protocol. Case studies did reveal some deviation from the rule and is not proposed to amend these minimum distances to avoid the possibility of causing damage to the tree by installing a root barrier.

6.6 Practical Concerns

6.6.1 General Considerations

The first of the perceptions to consider is those of practical concerns.

The questionnaires indicated that this was the biggest concern in the construction of root barriers and from experience I would tend to agree practical issues can restrict their use.

These practical concerns emanate from: -

- materials and methods of construction
- dealing with services
- obstructions
- site features

Co-operation is necessary as root barriers may pass across property boundaries and the adjoining owners may not give permission, especially if they are un-affected by damage.

The case studies have demonstrated that the materials used in the construction of root barriers and the construction method are inter-linked and related to practical concerns.

6.6.2 Materials

Materials used within case studies are summarised Table 6.4. Further details of the materials may be found within the individual case study database within Appendix 12. 4 and more detailed results for participants 1 and 3 within Appendix 12.5 and 12.6.

Table 6.4 Root barrier materials

Barrier material	Source
steel sheet piles	participant 1
WLS Flexline 1.5mm Propylene/ethylene copolymer geomembrane	participant 2
copper sheet mechanically encapsulated between a woven polypropylene geotextile and a high strength nonwoven polypropylene geotextile	participant 2 and 3
biobarrier with 1mm low density polythene	literature

The most popular material in case studies was WLS Flexline 1.5mm Propylene/ethylene copolymer geomembrane.

Some barriers incorporated a copper core known to repel tree roots, such as CuTex shown in Figure 6.15. More examples of root barrier materials are contained within Appendix 12.2.

Figure 6.15 CuTex copper impregnated root barrier material (Green-Tech, 2021)

6.6.2.1 Permeability of the Barrier

In the case studies root barriers were both permeable and impermeable. It is important to consider whether an impermeable barrier would create different soil conditions either side of the barrier. References cited in Sections 2.8 to 2.10 refer to characteristics of permeable and impermeable barriers. An impermeable barrier would prevent normal water flow through the barrier and create varying moisture contents either side of the barrier. The different moisture contents either side of the barrier in clay soil would lead to volumetric changes that in theory could deform the barrier or damage services that pass through the barrier. Permeable barriers would allow normal water flow through the barrier, whilst preventing root growth, thus equalizing moisture content and minimizing any volumetric changes that could lead to such damage.

To discourage root growth, the barrier should be fitted tightly against the undisturbed soil face on the ‘tree side’ of the trench. If the barrier material used is impermeable to water as well as to roots, the wetter soil near the building may expand as the drier soil nearer the tree contracts. Even so, an air gap between the barrier and the soil may then develop. As rain collects in this gap, together with adequate aeration, conditions conducive to root growth could develop. Roots will tend to grow down the face of the barrier until they could possibly pass beneath. (Biddle, 1998, p. 290)

6.6.3 Construction Method

The method of construction has practical implications in the use of root barriers such as achieving the required depth of the barrier, avoiding site features and services. Photographs of root barrier installation during site works are included within Appendix 12.5 and 12.6.

The case studies indicate two main methods of construction, namely: -

- pre-boring and installation of rigid piles
- excavate trench, 300 to 400mm wide, insert barrier and backfill with either concrete or gravel

An innovative method from participant 2 involved water injection under pressure to create a thin trench and sheets installed within the thin trench.

The above cases demonstrate how the materials and method are inter-linked.

6.6.4 Site Features and Boundaries

The site features comprise many aspects, therefore these have been divided into categories such as services, (gas, electric, drainage, water), physical site features (fences, boundaries, gates) and surface treatments (patios, paths, drives, grass, gravel).

6.6.4.1 Dealing with Services and Underground Structures

The case studies have identified that dealing with services is a significant issue in the construction of root barriers that may limit their use requiring careful design and construction choices.

Where more detailed information was available for individual cases it was possible to identify how the services and other site constraints affected design and construction method. In terms of jointing, special care was required in Case 3 as the long barrier was constructed close to existing underground service pipes.

Practical concerns arising from services have been resolved in case studies by either avoiding services or designing for them. Case study 3 included drawings

showing how underground pipework could be protected and the barrier constructed around services using prescribed jointing techniques.

The intention with a root barrier is to provide a significant obstacle to the passage of roots and the presence of services should not cause a significant problem. If small areas are difficult to seal completely then this should not have an adverse effect on an otherwise intact barrier system. The author has identified some work that has been carried out investigating the effect of buried pipes (rigid structures) on geotextiles specifically related to liners around waste sites (Zhu, et al., 2009), whereby a simplified model was developed to estimate the effect of the buried structures on liner performance.

6.6.4.2 Site Features

Site features can restrict the use of barriers. For example, the barrier may require to be run under a patio or driveway. Case study 32 required excavating the front driveway illustrated within appendix 12.6 which contains full details of the case. Ultimately the cost of replacing or reinstating features forms part of the solution and this has been considered within the costings derived for root barriers, as would be the case for underpinning.

Figure 6.16 Case study 32 construction of root barrier below front driveway

6.6.4.3 Site boundaries

Site boundaries may restrict the length of a root barrier. However, the author would argue that the intention with a root barrier is to minimise the passage of roots so that movements to the building are within acceptable levels that the building can tolerate. Consequently, a barrier that does not extend fully or beyond boundaries should not

cause a significant problem provided the effect of the discontinuity on the performance of the barrier can be quantified.

No single type of root barrier will stop all roots under all conditions, as features of the barrier, the site, installation and maintenance are all critical (Coder, 1998).

Increased co-operation with neighbours to extend barriers under their gardens or close to fences would assist and early contact with neighbours is suggested.

6.6.5 Future Developments

Excavating trenches using a JCB type digger is very disruptive and requires space for the plant and machinery to operate. Consequently, the author is particularly interested in considering advances in materials and construction to alleviate practical concerns as this appears central to progressing the root barrier option, in conjunction with the barrier's physical characteristics.

An alternative method of excavation was adopted in case 25 by participant 2 where a vacuum suction method was adopted for excavation. This example shows that innovative methods of installing root barriers can be successful.

Finding alternative less intrusive methods of construction in conjunction with appropriate materials would represent a paradigm shift in the use of root barriers, similar to the shift that occurred in the underpinning industry following the introduction of mini piling rigs that could enter houses through doorways meeting minimum head height restrictions. Once this type of mini piling rig had been introduced the possibility of mini piling inside residential properties became a reality.

The author has identified through literature review specific plant that could be developed to achieve a narrow 5m deep slot in clay soil. This plant is often used to cut service trenches but traditionally these trenches are only up to 2m deep. Plant would be required that could achieve greater depths but still be versatile and manoeuvrable on restricted sites in a residential setting. The plant illustrated in Figure 6.17, commonly known as "Ditch Witch", acts as a large chain saw often used for shallow (up to 2m) thin trenches. Could this type of plant be modified to cut thin trenches 4m deep or greater?

Figure 6.17 Ditch Witch RT45

Information on the plant obtained from Ditch Witch website. (Witch, 2019)

Rigid barriers pressed or driven into the ground in conjunction with plant capable of cutting a slot to assist sheet pile driving deserve further consideration. The barrier would be manufactured to the appropriate length and interlock with adjacent sheets. PG Biddle raises concerns regarding such interlocking barriers (or sheet piling) (Biddle, 1998) as roots may grow through any gaps; however modern jointing technology should be capable of resolving such concerns.

The selection of materials that remain rigid and plant-based which decompose over time would be beneficial so that the legacy issues of plastic root barriers are minimized. Such barriers constructed from plant-based resins could be permeable to the flow of water whilst stopping root growth. After 30 years of use the roots would have grown to avoid the barrier and a new root barrier installed if required. Such resin materials could be made stiff enough to be pressed or hammered into the ground through narrow pre-cut slots and interlock to provide additional strength and continuity.

Figure 6.18 Interlocking stiff resin piles

Guidance is provided within TRL report 533 (Transport Research Laboratory (TRL), 2002) regarding the use of plastic sheet piling in highways operations. The reference cites advantages of plastic or recyclable sheet piling over conventional steel piling. These advantages include ease of handling and transportation of the lightweight piles, improved corrosion resistance to both fresh and saltwater, better resistance to chemicals, the opportunity to use recycled materials in manufacture and a competitive price. This guidance would apply to root barriers especially with regard to strength and stiffness required to drive sheet piling into the ground.

Further details of vinyl sheet piles distributed by Greenwall is provided within the Appendix. The benefits stated include: -

- exceptional durability
- ecological – 100 % recyclable
- resistance to corrosion
- resistance of mechanical damage
- weather resistance
- UV resistance
- light weight
- easy installation and good performance
- no maintenance
- competitive price

It was established that root barriers need to be continuous to prevent the passage of roots.

However, do barriers need to be continuous to achieve this aim and how would discontinuities affect their performance? Discrete piles or short lengths of barrier would be easier to install and could be interrupted to avoid services. Two examples are shown in Figure 6.19.

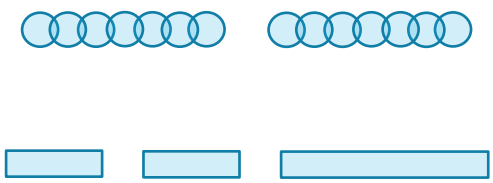


Figure 6.19 Examples of non-continuous barriers (Source Author)

The barriers shown in Figure 6.19 would be easier to install than continuous barriers and would assist in avoiding services. However, how effective would they be in stopping enough roots to reduce moisture extraction sufficiently to resolve the building damage?

The solution in Figure 6.19 would be analogous to pruning of trees rather than removal in that the effect of roots would be reduced but not removed or eliminated altogether. Note that as stated in Chapter 2 it is the excessive relative movements that cause damage not necessarily the absolute value of the movement.

The impact of introducing new and innovative methods of construction and materials on the perceptions such as practicality would be significant. Further research would be beneficial as the development of innovative methods of construction may determine whether root barriers can be installed more frequently, in restricted sites and at reduced cost.

6.7 Value for Money and Cost of Root Barriers

Initially, the perception was identified that stated that root barriers were too expensive or did not provide value for money. In order to consider issues surrounding cost and value for money it is necessary to discuss four elements.

- cost of installing a root barrier
- cost of underpinning
- cost of tree removal/pruning
- value of a tree (monetary)

If the cost of installing a root barrier can be shown to be lower than the cost of underpinning or lower than the loss in amenity value (due to tree removal) then value for money can be demonstrated.

6.7.1 Cost of Installing a Root Barrier

The case study results identified the costs of installing root barriers (page 216 Table 5.15) and calculated an average cost of £300 per square m to install a root barrier for costing and pricing purposes.

Additional analysis under this heading considers costs for each barrier type and considers whether there is a correlation between cost of the barrier and depth installed. The cases being considered are summarised in Table 6.5.

Table 6.5 Cost categorisation

Barrier type	No of cases	Case numbers	participant
Prebore and steel sheets	4	1,2,3,4	1
WLS Flexline machine excavated	21	5-24 and 26	2
Vacuum suction	1	25	2
Copper sheet machine excavated	5	27-31	2

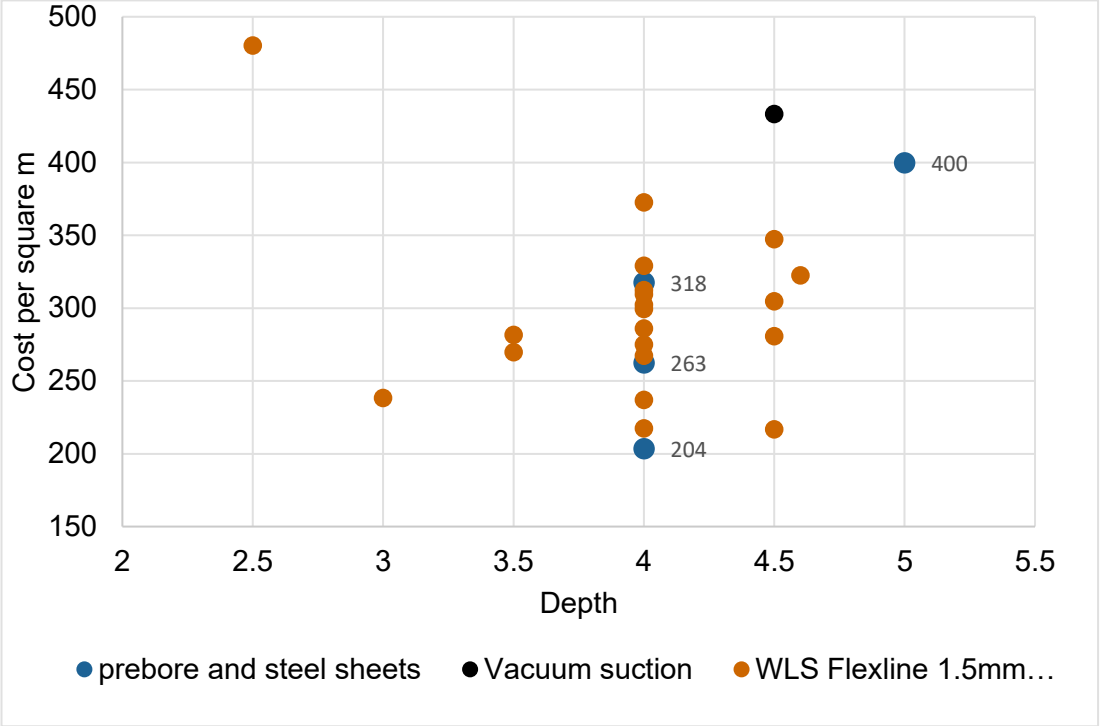


Figure 6.20 Cost vs depth for each barrier type

Figure 6.20 shows that the vacuum suction method was the most expensive (per m^2) when compared with other barrier types of equivalent depth, and more economical than 5m deep barrier using steel sheets. It is apparent that the cost for prebored steel sheets increases from an average of £262 for 4m deep barriers to £400 for a 5m deep barrier. This result however is based upon 4 results overall.

6.7.2 Cost of Underpinning

It is difficult to quantify the cost of underpinning as there are many factors affecting cost such as property type, access, depth of underpin, underpin method, transitions , preliminaries, consequential damage such as internal floors or features etc and the effect on occupants. Each project would require costing on an individual basis.

It was suggested by Driscoll and Crilly (Driscoll & Crilly, 2000) that a typical underpin scheme costs upwards of £10,000 (corrected to £17,200 at current prices assuming average inflation 2.8%).

While no cost figures are available Table 6.6 considers the main characteristics of a root barrier vs underpin and each consideration has an impact on cost.

Table 6.6 Characteristics of Underpinning and root barriers compared

Characteristic	Underpinning	Root Barrier
Type of intervention (direct or indirect).	Direct intervention upon foundations of the property with consequent disruption to features, fittings etc.	Indirect intervention upon tree roots not the building with consequent disruption to services only.
Effect on occupants.	Significant effect on occupants, often requiring alternative accommodation.	Minimal effect on occupants, not usually requiring alternative accommodation.
Transitioning	Construction of the building affected. Transition bays required with traditional underpin to prevent damage to non-underpinned sections of the building. (Driscoll & Skinner, 2007, p. 51). Transitioning for piled schemes requires careful consideration.	No transitioning required as the solution does not directly affect the building foundation.
Duration of the works.	Underpinning schemes take longer on site, typically 4 weeks on site for 10m length of underpinning. *see Note 1 below	By comparison root barriers can be installed in a shorter timeframe. Case 3 barrier took 2 days to install and case 32 3 days on site.
Depth of underpinning and root barrier.	Traditional underpin may be carried out at depths up to 3m however where desiccation occurs below this depth piled schemes are usually considered.	Root barriers typically installed at 4m depth therefore method not influenced by depth of desiccation.
Neighbour concerns	Underpinning will usually require Party Wall agreements with neighbours that can be costly and time consuming.	Root barriers may require co-operation when the root barrier encroaches neighbour's property.
Long term effects	Long term effects of underpinning not known however there is evidence to suggest that repeat underpinning cases are growing in number. (Driscoll & Crilly, 2000, p. 9)	Long terms effects not known, as per underpin.

Note to Table 10m length of underpin = 10 pins of 1m length, Preparatory site work (3 days), excavate and underpin 3 pins (4 days), allow to set (2 days), excavate and construct 3 pins (4 days) allow to set (2 days), excavate and construct 4 pins (5 days) and set (3 days). Total duration =23 working days.

Table 6.6 summarises the main differences between root barriers and underpinning demonstrating that underpinning tends to be more complex and involved compared with installing a root barrier. Although case studies did not identify the comparative cost of underpinning in many cases participants advised that the root barrier was installed because it was more cost effective than underpinning.

The complexity of underpinning, time taken to complete and direct intervention on the property tends to make it more expensive than an equivalent repair using a root barrier.

6.7.3 The Cost of Tree Removal or Pruning

The average or typical cost of tree removal is required to inform cost effectiveness considerations. Data concerning the cost of tree works was not obtained during case study as a root barrier was due to be installed.

It is difficult to obtain precise costs for tree removal as there are many variables such as tree height, species, girth, location, site constraints, services, nearby roads, waste removal, stump retention etc. Tree surgeons would tend to quote on a job specific basis and any firm quotes would depend on timescales and availability.

Notwithstanding the above an estimation of the cost of tree works is sufficient for cost effectiveness considerations without significantly affecting the main argument.

To estimate the cost of tree works an online search was undertaken. Most websites required site-specific information before quotes could be obtained. A particularly useful website was identified that provided indicative costs for various projects, including tree works. (Prices, 2019). The indicative costs including VAT were:-

- removal of a large oak in the rear garden with difficult access expect to pay a tree surgeon around £3000
- remove 2 x 30ft multi-stem trees with good access and dispose of waste £750
- day rate £950

In addition to the above, the 2018-2019 claim analysis by Property Risk Inspection (Lawson & Wennyi, 2019, p. 18) confirmed the cost of tree works in 73% of 2000 clay shrinkage cases was less than £1,000 and in 85% or fewer cases £1,500 or under.

Based upon the above information and experience for the purposes of value for money considerations, the average indicative cost of tree removal to resolve a clay shrinkage subsidence claim would reasonably be £1250.

6.7.4 Valuing Trees

In Chapter 2 the CAVAT method of tree valuation was proposed, and this is now introduced in relation to calculating the value of trees which effectively equates to the monetary loss or cost incurred if a tree is removed.

Questionnaire questions 5, 6 and 7 determined perceptions of certain trees' value but first determined how did these values compare to calculated values using CAVAT?

A spreadsheet was set up and using the simple method. The base value was multiplied by tree diameter for the three trees in the questionnaire. The calculation determined the value of each tree.

The trees within the questionnaire are located in outer London with associated 150% increase in base value due to population density. The trees are assumed in good condition.

The CAVAT valuation of a tree is heavily influenced by the trunk diameter and not the species, therefore, to calculate values for the trees in the three questions diameters of 110cm, 10cm and 30cm have been used.

The oak assumed longevity >80 years, tree 2, 30 years, retaining 80% of the full value and tree 3, 80+ years.

The assumptions and factors used are shown in Table 6.7 and Table 6.8.

Table 6.7 CAVAT values of questionnaire trees

For tree 1 the oak estimated CAVAT value of £226,369.

Trunk diameter (DBH, cm)	Value (£)	Population	Condition	Longevity	Total value
		London	good	>80	
		150%	100%	100%	
110	£150,913	£226,369	£226,369	£226,369	£226,369

For tree 2 (small tree). Maximum CAVAT value £1,497

Trunk diameter (DBH, cm)	Value (£)	Population	Condition	Longevity	Total value
		London	good	30	
		150%	100%	80%	
10	£1,247	£1,871	£1,871	£1,497	£1,497

For tree 3 (medium tree) maximum CAVAT value £16,837

Trunk diameter (DBH, cm)	Value (£)	Population	Condition	Step 7 longevity	Total value
		London	good	>80	
		150%	100%	100%	
30	£11,225	£16,837	£16,837	£16,837	£16,837

The results from the questionnaires are now shown alongside the CAVAT value (calculated in Table 6.7 above) in Table 6.8.

Table 6.8 CAVAT value compared with questionnaire results

	TDAG	Subsidence Forum	CAVAT
Tree 1 oak	£535,714	£361,842	£226,369
Tree 2 small	£145,833	£77,431	£1,497
Tree 3 medium	£279,545	£147,297	£16,837

Table 6.8 demonstrates that respondents all valued the trees more highly than CAVAT; this was particularly the case for the medium size and small tree.

6.7.5 Value for Money Considerations

In order to calculate the value of the trees within the case studies, Figure 6.21 plots the CAVAT value of a tree against diameter based upon 150% community value, 40 to 59 per hectare, 80% functional value and 40-80 years life.

In the absence of detailed information concerning tree diameter or tree condition obtained from the case studies, Figure 6.21 will be used to estimate the value of trees to progress value for money considerations.

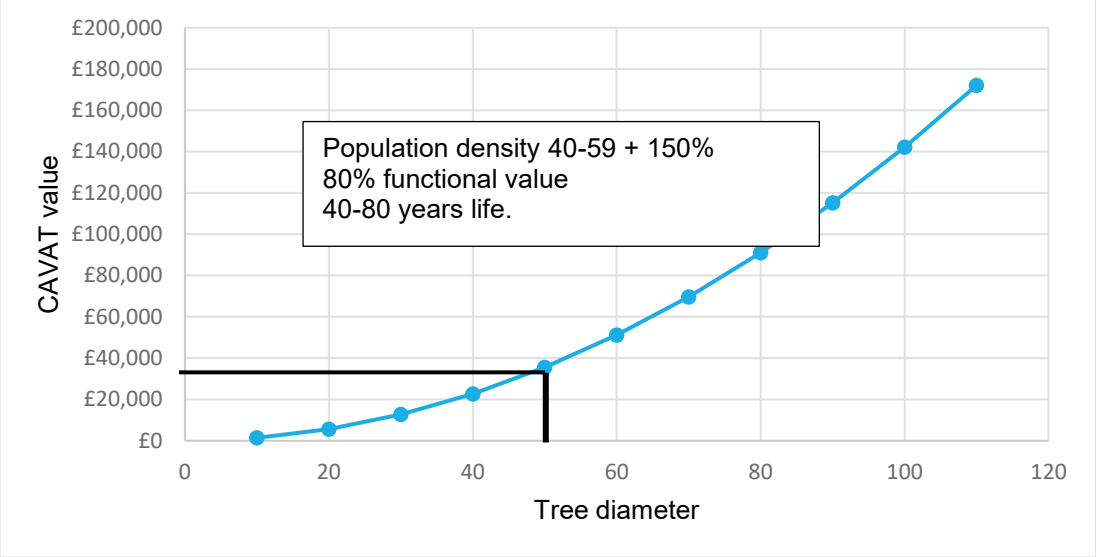


Figure 6.21 CAVAT Tree values

Tree diameter was not specifically measured during case study data collection and an estimate of the diameters of trees significant enough to cause clay shrinkage of 50cm is used. Some trees will be larger and others smaller, but overall, the average calculated figure for multiple trees will be sufficiently accurate and realistic.

50cm diameter equates to an individual tree value of £35,346, as illustrated in Figure 6.21 rounded to £35,000 per tree per claim.

In hindsight, this information regarding trunk diameter and condition could have enhanced the research by obtaining data on the size and condition of the trees in the case studies required to calculate accurate CAVAT values. However, the values

assumed above are considered sufficient for the present purposes of the assessment of value for money and within acceptable tolerances, as will be demonstrated. Table 6.9 lists all the trees within individual case studies saved from removal by the root barrier, together with the calculated value of trees, the cost of the root barrier, less cost of tree removal resulting in overall saving.

Overall saving = value of trees saved - the cost of root barrier + cost tree removal.

Table 6.9 Calculations for overall saving by installing a root barrier

case number	number of trees saved	total value of trees saved per claim	cost of root barrier	cost tree removal	overall saving
1	5	£175,000	£21,600	£6,250	£159,650
2	5	£175,000	£22,800	£6,250	£158,450
3	5	£175,000	£120,000	£6,250	£61,250
4	2	£70,000	£16,800	£2,500	£55,700
5	1	£35,000	£15,798	£1,250	£20,452
6	1	£35,000	£22,291	£1,250	£13,959
7	1	£35,000	£30,174	£1,250	£6,076
8	2	£70,000	£29,682	£2,500	£42,818
9	1	£35,000	£22,362	£1,250	£13,888
10	1	£35,000	£18,883	£1,250	£17,367
11	1	£35,000	£23,520	£1,250	£12,730
12	3	£105,000	£28,440	£3,750	£80,310
13	3	£105,000	£21,480	£3,750	£87,270
14	4	£140,000	£21,474	£5,000	£123,526
15	2	£70,000	£15,612	£2,500	£56,888
16	1	£35,000	£18,752	£1,250	£17,498
17	1	£35,000	£10,014	£1,250	£26,236
18	5	£175,000	£13,800	£6,250	£167,450
19	2	£70,000	£17,962	£2,500	£54,538
20	1	£35,000	£16,502	£1,250	£19,748
21	1	£35,000	£25,386	£1,250	£10,864
22	1	£35,000	£22,878	£1,250	£13,372
23	5	£175,000	£17,400	£6,250	£163,850
24	3	£105,000	£15,000	£3,750	£93,750
25	2	£70,000	£15,602	£2,500	£56,898
26	5	£175,000	£15,120	£6,250	£166,130
27	1	£35,000	£30,182	£1,250	£6,068
28	1	£35,000	£15,468	£1,250	£20,782
29	1	£35,000	£32,160	£1,250	£4,090
30	5	£175,000	£23,640	£6,250	£157,610
31	2	£70,000	£19,591	£2,500	£52,909
TOTALS	74	£2,590,000	£740,373	£92,500	£1,942,127
AVGE	2.4	£83,548	£23,883	£2,984	£62,649

Table 6.9 demonstrates that root barriers save on average £62,600 per case (rounded to nearest £100) when introduced to prevent tree removal assuming average tree value of £35,000.

For the “average” case identified in the final row of Table 6.9 there are 2.4 trees involved valued at £83,548, the root barrier costs £23,883 and assuming cost for tree works of £2,984 a saving of £62,649 per claim results by installing a root barrier.

6.7.6 Summary Value for Money and Cost Consideration

Practitioners may be aware of the root barrier solution and may have used root barriers in the past; however, the cost of installing a root barrier may deter practitioners. The case studies identified the average root barrier installation cost of £23,900 including vat as indicated in Table 6.9

This is not particularly high in the context of clay shrinkage and in many cases from case study results was less expensive than underpinning.

To illustrate the cost-effectiveness of root barriers in specific situations and to assume the average cost of £23,900 for a root barrier then the following savings are achieved: -

Example 1 A single large tree, 50cm trunk, in good condition, CAVAT value £35,000

£35,000 - £23,900 +£1250 = £12,350 saving

Example 2 A very large tree 1.2m trunk diameter, CAVAT value £200,000

£200,000 - £23,900 +£3000= £179,100 saving

Example 3 A small tree, 30cm diameter trunk, in good condition, CAVAT value £16,837

£16,837 < £23,900 (no saving)

Example 4 Two small trees, 30cm diameter trunk, in good condition, individual CAVAT value £16,837. 2 x £16,837 = £33,670

£33670 - £23,900 + £1250 = £11,020

Based upon the examples, single trees of 500mm diameter (average size assumed in calculations) and multiple smaller trees produce savings in the order of £12,000 and £11,000 respectively when a root barrier is installed in preference to tree removal. In cases where there are exceptionally large trees, trunk diameter 1m and above significant savings over £150,000 can be achieved. No savings occur, and root barriers are not demonstrated to be cost-effective when there is a single small tree of trunk diameter 30cm or less, or the tree is in poor condition.

The research has identified the value of trees and the need to consider not just the cost but overall value, especially by balancing the cost of the barrier against losses incurred by tree removal.

It is acknowledged that there are other methods of valuing trees that may produce lower values than CAVAT. Furthermore, the savings are not tangible for insurers or policyholders. The savings are delivered to society by the benefits that trees provide as explained in chapter 1 and therefore difficult to quantify and persuade insurers they are legitimate.

In terms of value for money, design rules established to determine the optimum depth and length of the root barrier enables them to be designed economically reducing costs and increasing acceptability.

6.8 Knowledge Concerns

In Chapter 2, knowledge concerns were encompassing all aspects of practicality, cost, and reliability on the cost quality time theoretical proposition.

Knowledge concerns relate to a lack of published information in the design and construction of root barriers. Alternatively, practitioners may be set in their ways only using solutions that they are familiar with, such as tree removal and pruning.

The case studies demonstrate that the design and construction of root barriers is a specialist operation requiring knowledge of trees, soils, building and construction, health and safety, plant and machinery, buildings, materials performance, drawing, utilities and costs. All these elements combine to determine the successful outcome of this solution.

Knowledge concerns also include the type of company or organisation taking the lead role in the design and construction of root barriers. The questionnaire asked who should take the lead role, and it was identified that according to the questionnaire results, it should be arborists. This would seem appropriate given that the root barrier is dealing with trees, the behaviour of roots growing in the ground and protecting a tree from damage.

An arborist is also well placed to advise on materials that prevent root growth and to calculate the value of a tree and more likely to argue for protecting them than an engineer or loss adjuster would. However, there are aspects to a subsidence claim and installing a root barrier that do not fall directly under the discipline of Arboriculture, such as damage diagnosis, soil mechanics, engineer design, construction, utilities and materials technology.

Importantly, delegates responded that the main difficulty in design and construction of root barriers were practical. Installation was highlighted as a major obstacle and this requires different skill sets. Dealing with services would fall more under this heading than that of an arborist.

The design is important in that relevant properties are collected to determine the correct depth of the barrier. The depth depends on NHBC guidelines the gathering of accurate site information, services, features, paths, walls etc. required to determine location.

If the main difficulty is practical (Q3 in the questionnaire) then this would suggest that the contractors should take the lead role based upon a design by others.

Ultimately it would seem appropriate that the design and construction of root barriers requires close co-operation between consultants and contractors, so that contracting and practical site difficulties are taken fully into consideration.

By involving contractors more in the process, improved construction methods could be adopted to reduce costs, time and disruption on site.

Ultimately, the enhanced design protocol will enhance the profile of root barrier solution providing practitioners with knowledge. The guidelines assist economic and reliable design and encourage innovative and cost-effective construction techniques with suitable materials.

6.9 Reliability Concerns

One of the concerns relating to the use of root barriers was that they do not work or that they are unreliable. This heading is included under perceptions because the opinion may not be based upon evidence or empirical data.

As mentioned earlier in the thesis, insurance companies who fund subsidence work may be unwilling to risk further damage to the building with untried and untested methods. Policyholders will be reluctant to agree to solutions that are thought of as unreliable.

The research has demonstrated however within case studies that root barriers do work and that they can be reliable. The case studies demonstrate how with a planned process, careful choice of barrier material, appropriate construction techniques at suitable depths that the solution is viable. It is accepted that only a limited number of cases have been researched where there has been genuine professional input in planning and construction.

The guidance produced in this thesis in terms of informed design protocol will establish a benchmark to ensure that all the important variables are considered

systematically such as depth, length etc. The informed design protocol provides structure and confidence for consultants and contractors.

The post installation monitoring by participant 2 is a useful indicator of reliability as it demonstrates how the root barrier is reducing the movement of the building.

Safety factors proposed over and above NHBC guidelines provide increased re-assurance regarding reliability, ensuring that the root barrier is constructed at adequate depth to prevent roots from growing under the barrier and reaching the property.

The informed design protocol also includes a flow chart of the design process so that all important matters of design are considered in a logical and consistent manner.

One of the concerns related to reliability was that root barriers are rarely used. Based upon the number of clay shrinkage subsidence claims submitted annually (23,000 in 2018), and if less than 30% result in tree removal, then the proportion of claims resolved by a root barrier instead of tree removal is negligible. This is calculated assuming that the research has identified only 10% of all the root barriers installed in the last 5 years (33x10=330) and that annually 34,500 claims are resolved by tree removal (23,000 x 5 x 0.3). In the same period the percentage resolved by installing a root barrier amounts to only 1% (330/34,500). This confirms the concern that they are rarely used.

As with any solution there is a risk that the root barrier will not resolve the problem, but this is also the case for other solutions. Underpinning usually only has a 10-year guarantee and tree management will not solve the problem if the tree regrows.

It would be important for insurers to understand the risks with root barriers, as with any other solution, so that if damage re-occurs designers will not be concerned by legal action being taken against them. This could form the basis of a warranty like that of an ASUC guarantee whereby an insurance company underwrites a policy.

PART D

INFORMED PROTOCOL,

SUMMARY AND CONCLUSIONS

PART D Informed Protocol, Summary and Conclusions

7.0 The Informed Design Protocol

7.1 Introduction

In Chapter 2 an initial, inaugural design protocol was established from literature, experience and theory. This initial design protocol assisted in development of the case study methods and data collection procedures including results analysis. The process of research has enabled the initial protocol to be developed further into the informed design protocol contained in this chapter achieving the final objective.

The informed design protocol provides a template for the design of root barriers but does not include discussion that has been covered in Chapter 6.

The enhanced protocol involves 13 main stages as follows: -

- general and initial considerations
- input information
- confirmation of cause and implicated trees
- scaled plan of the site showing trees, services, features etc
- justification and cost benefit
- calculate d (t min) minimum distance tree to barrier
- calculate design depth h (des) of the root barrier
- overlay design depth rings or circles on scaled plan
- determine encroachment 45-degree line
- determine barrier length
- choose barrier location on scaled plan
- finalise drawing scaled plan showing barrier depths and dimensions
- site works

7.2 General and Initial Considerations

The information required in the consideration of a root barrier necessarily includes the reports and investigations completed as part of the subsidence claim under investigation. Early involvement is suggested so that the root barrier option is considered as early as possible in the process, after the initial site visit and following receipt of site investigations when the diagnosis has been made concerning the cause of damage to the property.

At the earliest stage personnel with knowledge of root barriers and their benefits with design capability should be involved.

7.3 Input information

The required input information should include:-

- building damage reports
- clay soil properties
- site plan
- site features and services
- site investigation including existing foundation depths and type
- tree species, trunk diameter at 1.5m height, vigour and maturity and location
- tree condition (for valuation)
- monitoring results

7.4 Confirming Causation and Implicated Trees

Due to the potential value of trees and the importance of identifying clay shrinkage as the dominant cause by specific trees, it is proposed that a robust procedure for checking soil desiccation is adopted at the outset before identifying trees for removal or the root barrier solution. The eight desiccation indicators should each be assessed from site investigation to confirm the extent of desiccation, as shown in Table 7.1.

Table 7.1 Indicators re-affirming clay shrinkage

	Measure	**Desiccation level**	
		TP/BH1	**TP/BH2**
1	Moisture content	Complete for each trial hole and for each measure with a clear assessment on the extent of desiccation observed.	
2	Strength tests		
3	Moisture content compared with Atterberg limits		
4	Oedometer		
5	Soil Suctions by filter paper tests		
6	Root identification		
7	Root activity depth		
8	Soil descriptions		

Each indicator would need to be assessed in terms of the degree of desiccation and the positive link between this desiccation and specific trees.

7.5 Scaled Plan of the Site

A scaled plan should be drawn of the site, including all implicated trees, sizes and location relative to the building and the area of damage to the building. The drawing should show the services to include all drains, pipes, cables, site features such as fences, paths, patios, that would be relevant in terms of positioning the root barrier. It is important to emphasise that the survey should include full and detailed assessment of the underground services, location depth and type.

7.6 Value of Trees Calculation to Justify Root Barrier Method

To justify the root barrier option, it is proposed to value the trees planned for removal using CAVAT and complete a cost-benefit exercise.

Note that the research has identified that in cases where there is a single, large tree (0.5m trunk diameter) in good condition, irrespective of species, a root barrier will usually be cost-effective.

In cases where there is a significant large tree, of say 1.2m trunk diameter the savings by installing a root barrier are significant. In cases where there is a single tree, either of small size (0.3m or less trunk diameter) or not in good condition a root barrier would not usually be cost-effective.

Various graphs can be produced, an example of which is shown in Figure 7.1, plotting tree value assessment using CAVAT. Figure 7.1 is based upon a spreadsheet and uses the published base tree value and calculates tree value for various tree diameters. The base cost is adjusted in accordance with population density, condition and age range.

Three ranges of population density apply, moderate, high and very high.

Table 7.2 Population density adjustment

Population density	% increase	Classification	Example area
40 – 59	150	Moderate	Eg Luton (47), Leicester (45) Urban
60 – 79	175	High	Eg Outer London
80 – 99	200	Very High	Eg Hackney Inner London

Various websites provide population densities if exact figures are required for a specific area, for example. (Plot, 2019)

Figure 7.1 plots values for moderate population density (40-59 people per hectare) for three conditions, average, good and excellent, representing 50%, 75% and 90% adjustments, respectively.

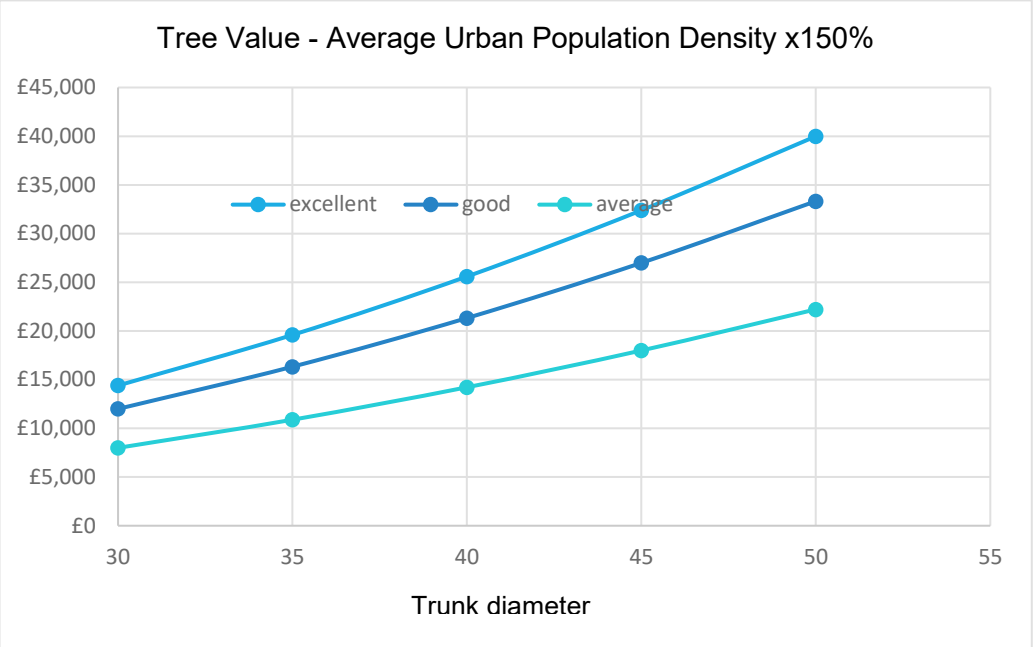


Figure 7.1 Tree value

In Figure 7.1 the tree age has been taken as 95% (40-80 years remaining life).

If the cost of tree works were obtained for individual claims the cost savings could be more accurately obtained using Equation 7-1.

Cost saving = value of trees removed – root barrier cost + cost tree removal

Equation 7-1 calculated cost saving using a root barrier

7.7 Notation

The notation is unchanged from the original protocol.

d (t min) minimum distance between root barrier and tree

d (b min) minimum distance between building and root barrier

d installed distance between root barrier and tree (actual)

D overall distance between tree and building

h (des) designed depth of root barrier including F of S at desired location

h (b) existing foundation depth

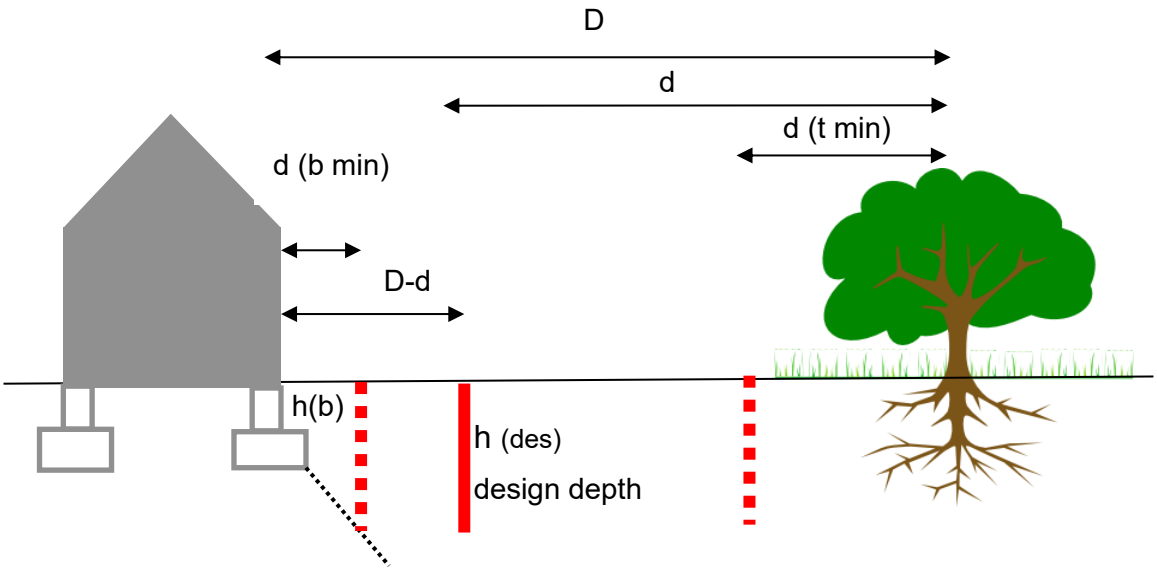


Figure 7.2 Notation defined (Source Author)

Figure 7.2 also demonstrates potential locations of a root barrier in terms of distance from the tree d (t min) and from the property d (b min).

7.8 Calculate Minimum Distance Between Barrier and Tree d (t min)

To prevent damage to the tree the barrier must be positioned a minimum distance from the tree. This is calculated by referring to BS5837, Damage to Trees by Construction Work.

Progress as per initial design protocol see section 2.16.6.

7.9 Calculate Barrier Depth at Various Distances

The root barrier must be constructed at adequate depth to prevent roots passing underneath. This should be calculated using NHBC guidelines with a FoS applied (line 2 very conservative).

In section 6.2.3 the design depth of the root barrier was determined by Equation 7-2.

Design depth (root barrier) = -0.04 x distance + 4.4m

Equation 7-2 Design depth

A table should be prepared based upon Equation 7-2 showing the design depth required at say 2m intervals as shown in Table 7.3.

Table 7.3 Example tabulated design depths h(des)

	Tree 1				
		F of S	% increase	6%	
		F of S	addn depth	0.8	m
Distance	4	6	8	10	12
design depth h (des)	4.14	4.06	3.98	3.9	3.82

The first distance (4m in the example Table 7.3) equates to the minimum distance tree to barrier (as the barrier cannot be placed closer to the tree than this distance) and the furthest distance (10m) represents the total distance to the building.

The designer should determine the appropriate FoS being used and identify this in the calculation, as indicated above.

7.10 Prepare Depth Rings on Scaled Plan

The design depths h (des) previously calculated at pre-set 2m intervals are now added to the scaled plan for all trees.

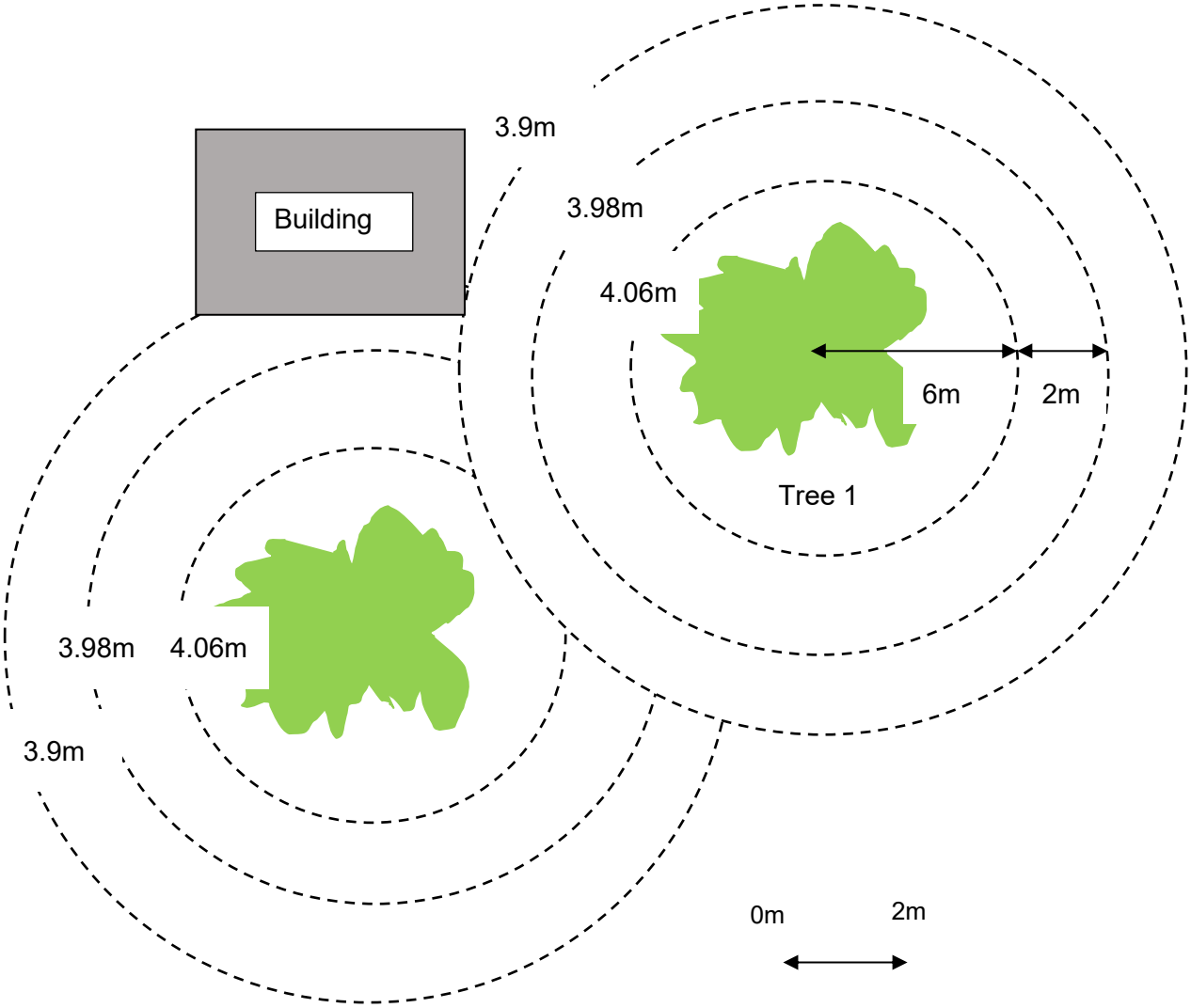


Figure 7.3 Concentric circles with design depths shown (Source Author)

In Figure 7.3, 2 trees are shown with design depths h (des) indicated based upon the tables previously prepared by the designer which include the FoS.

7.11 Encroachment 45-Degree Line

Next determine the encroachment zone so that the drawing is marked showing the depths at which encroachment would occur, assuming 1m foundation depth. The first is drawn 2m from the building and equates to “no encroachment” for a 3m deep barrier. The next at 3m distant provides for a 4m deep barrier (no encroachment). This stage identifies if the barrier undermines foundations and informs the choice of backfill and need for sequencing.

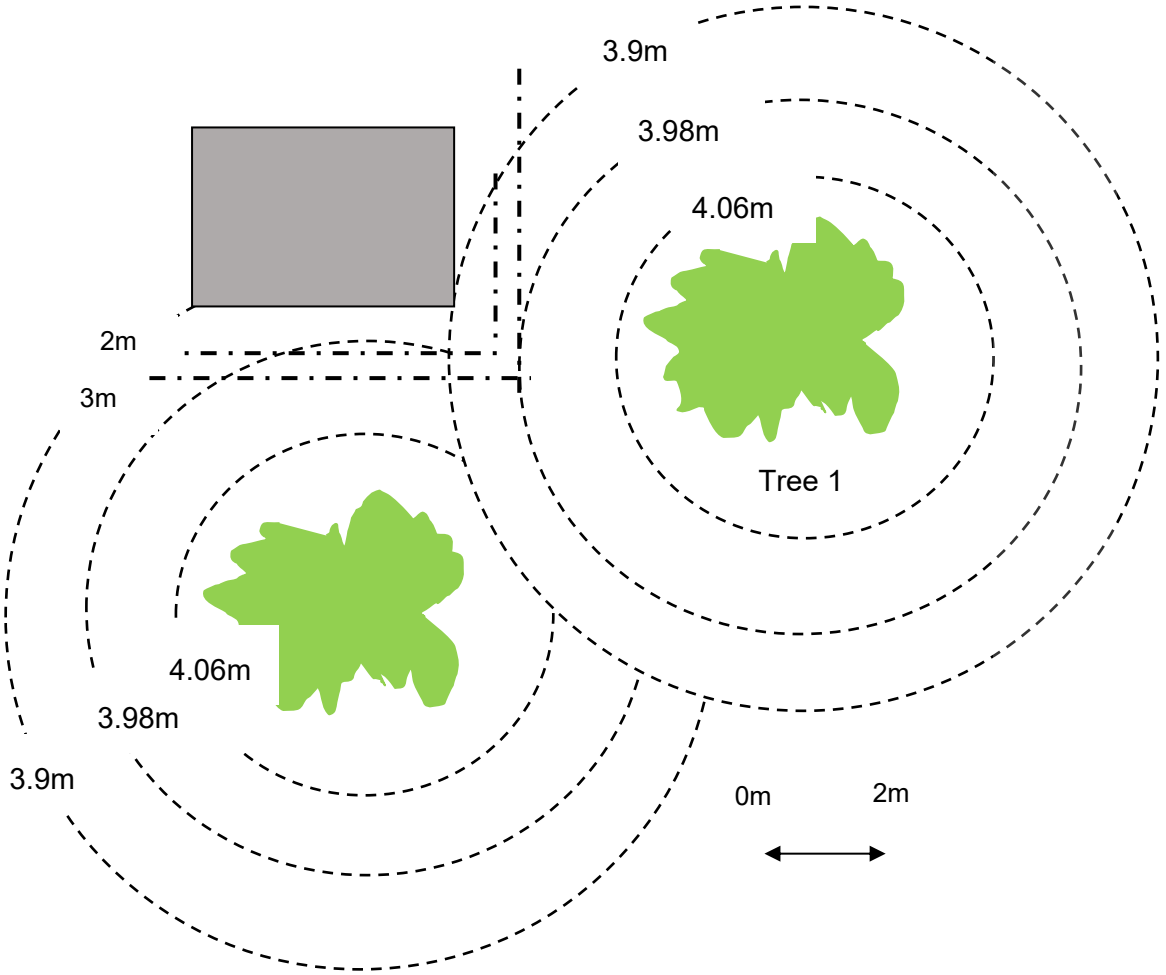


Figure 7.4 Encroachment zones 45-degree

7.12 Length of the Barrier lb

The next stage determines the barrier length and overlap.

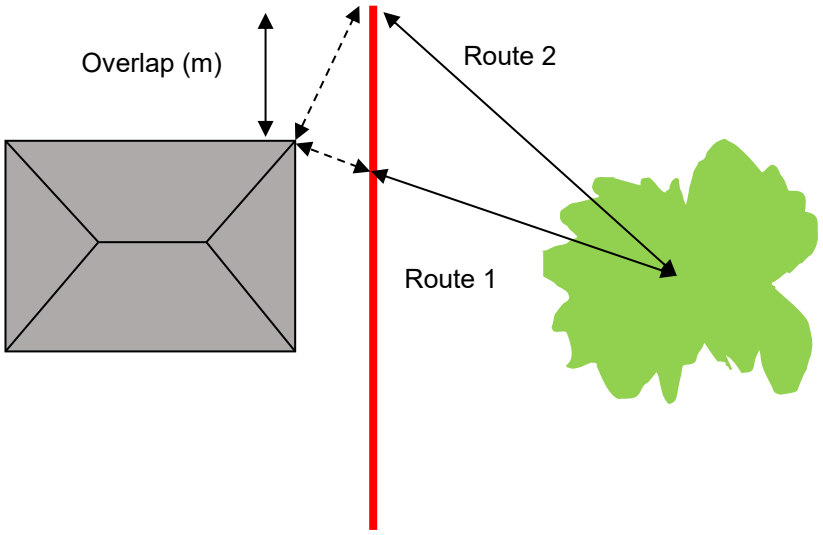


Figure 7.5 Partial barrier

The length of the root barrier may be governed by site features and boundaries but it should extend beyond the area of damage, termed the overlap.

This overlap distance should ideally be at least 2m. In addition, the length calculated for route 2, as shown in Figure 7.5 should be greater than the maximum tree to building distances or provide adequate foundation depth (based upon the actual length of line 2) using NHBC.

In some cases, site constraints will limit the length of the barrier and it may not meet the above requirements resulting in increased risk that roots will travel around the barrier.

The designer should specify the overlap distance used in the design.

7.13 Choose Barrier Location

The next stage involves determining the best location for the root barrier based upon design depths required with consideration to the site features, boundaries, obstacles and services.

This is to some extent a matter of judgement balancing the depth, which is directly related to cost, and avoiding services, features and boundaries.

This process will also determine whether foundations are undermined.

In the example illustrated in Figure 7.7 it would be simpler to construct the barrier outside 45-degree line as shown, so that foundations are not undermined and services avoided. However, if necessary, the barrier may be located closer and encroach upon the 45-degree load spread which requires concrete backfill and constructing the barrier in short lengths.

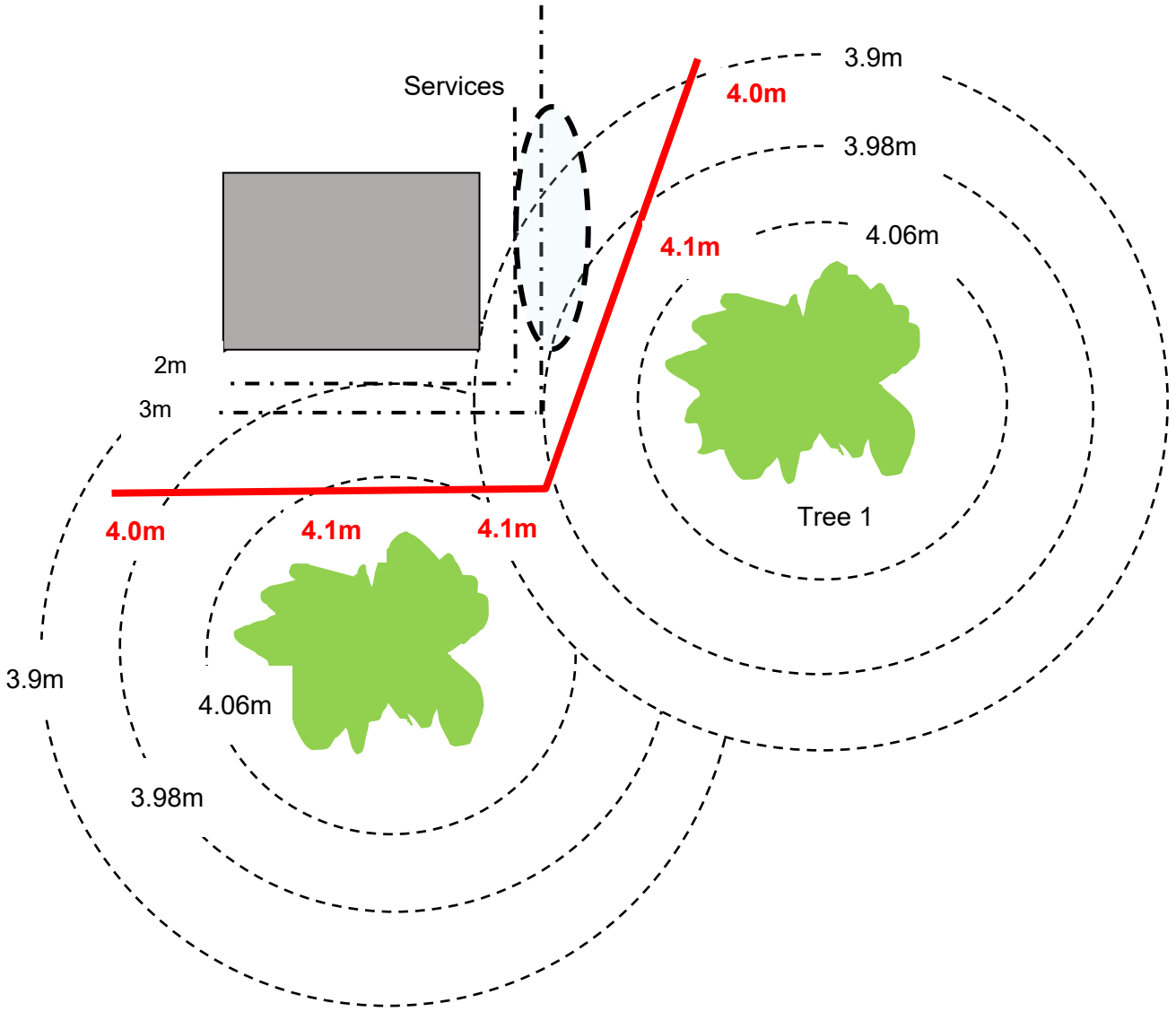


Figure 7.7 Determine location and depth of root barrier (Source Author)

The design depths of the barrier shown in Figure 7.7 are in red bold type e.g., **4.1m**

Note in Figure 7.7 that the depth varies from 4.1m maximum to 4.0m minimum. In practice the barrier may be installed at a constant depth of 4.1m, as evidenced from case studies.

7.14 Finalise Scaled Plan

Finalise the scaled drawing showing the location of the barrier, with dimensions indicating the depths of the barrier at each position. The drawing is required to show all features, services and would include reinstatement work required. Dimensions and depths should be shown sufficient for the contractor to set out the work on site.

7.15 Alternative for One Tree (Spreadsheet Calculation)

The spreadsheet calculation in Chapter 2 for one tree would be sufficient for one tree in straightforward cases as opposed to drawing concentric circles.

The spreadsheet calculation summarised within Table 7.4 includes a logical calculation in the final column checking the 45-degree encroachment criteria and providing a false or not false statement regarding suitability.

Table 7.4 Calculations within alternative spreadsheet design (Source Author)

inputs	**min dist. tree to barrier**	**d (t min)**	**4**	**m**
	foundation depth	**h (f)**	**1.2**	**m**
	distance tree to building	**D**	**12**	**m**
distance tree to root barrier	**distance building to root barrier**	**Design depth of barrier NHBC + FoS**	**check on suitability**	
d	**D-d**	**h**	**h (f)+(D-d)>h**	
4	8	4.14	ok	
5	7	4.10	ok	
6	6	4.06	ok	
7	5	4.02	ok	
8	4	3.98	ok	
9	3	3.94	ok	
10	2	3.9	FALSE	
	=	calculated value		
	=	input values		

In this example the barrier may be placed at 9m distant from the tree at a depth of 3.94m without encroachment. Similarly, there is a range of locations at which the barrier may be placed from 4m to 9m distant at the depths shown.

7.16 Additional Information

The documents and drawings should indicate the materials used in the construction of the barrier and include a method statement explaining how the barrier will be constructed. This information may include a cross section through the barrier, especially if services are affected, and sequencing where the 45-degree line is encroached.

This stage would include preparation of work schedules, tender documents, health and safety risk assessments and the contract for the work.

7.17 Site Works

Site works involve construction of the barrier and reinstatement.

At all stages of the site work the contractor should check the location, depth and type of services using CAT scan and other detection equipment. It is proposed that specialist contractors are used for this important task.

Root samples should be taken during construction to check and ensure the barrier depth is at least 500mm below the lowest tree roots level.

Where the barrier is outside 45-degree load spread then flexible backfill may be used and the root barrier completed in one operation. Where 45-degree encroachment occurs then construct with rigid (concrete) backfill and in stages.

Post-installation level monitoring provides useful feedback identifying how the root barrier has reduced or eliminated the building's movement.

The flow chart of the informed design protocol is illustrated in Figure 7.8.

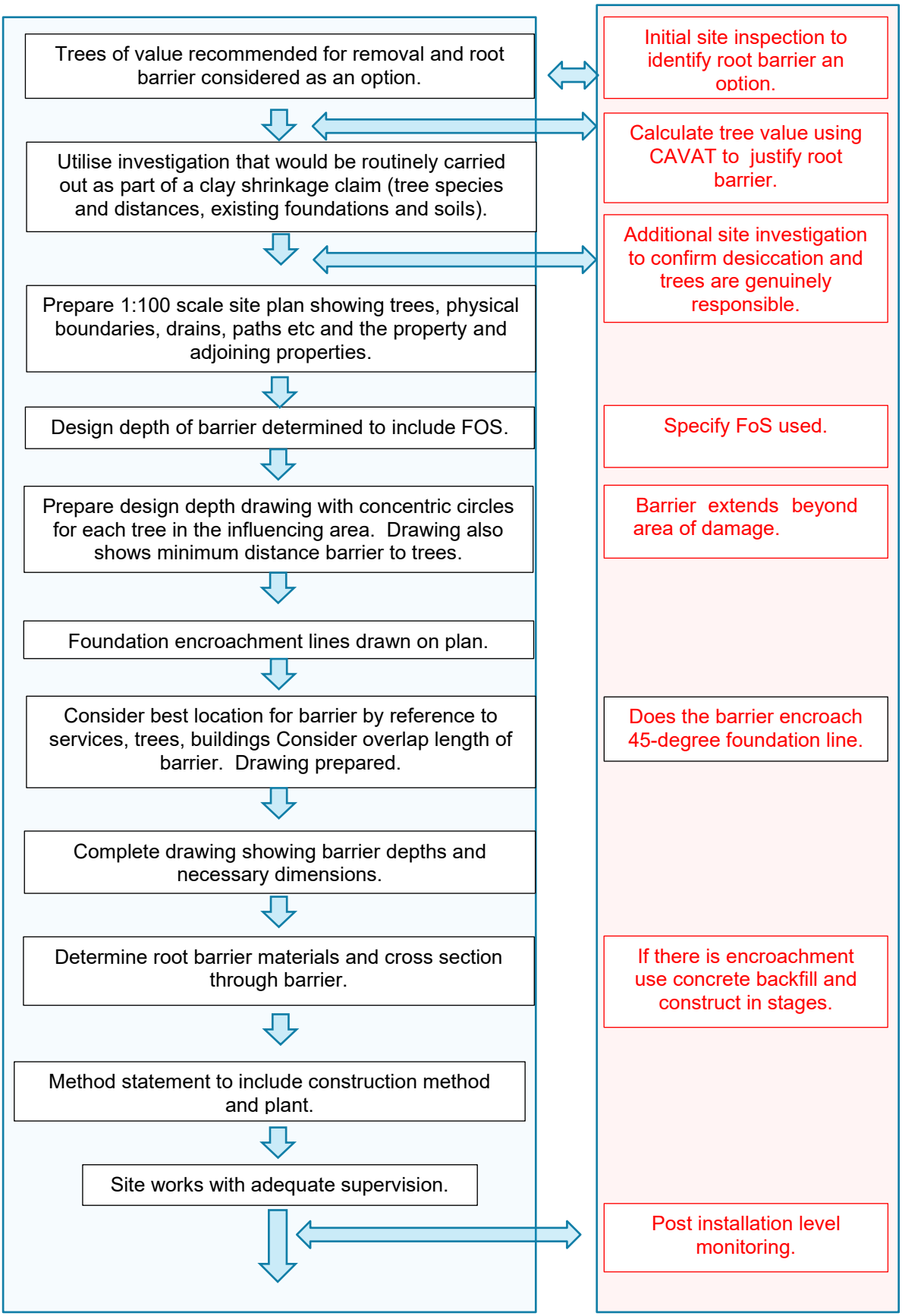


Figure 7.8 Informed design protocol process flow chart (Source Author)

7.18 Example

Figure 7.9 illustrates the type of scaled drawing that would be required for multiple trees around a building showing concentric circles with design depths. The figure has been replicated from case study 33.

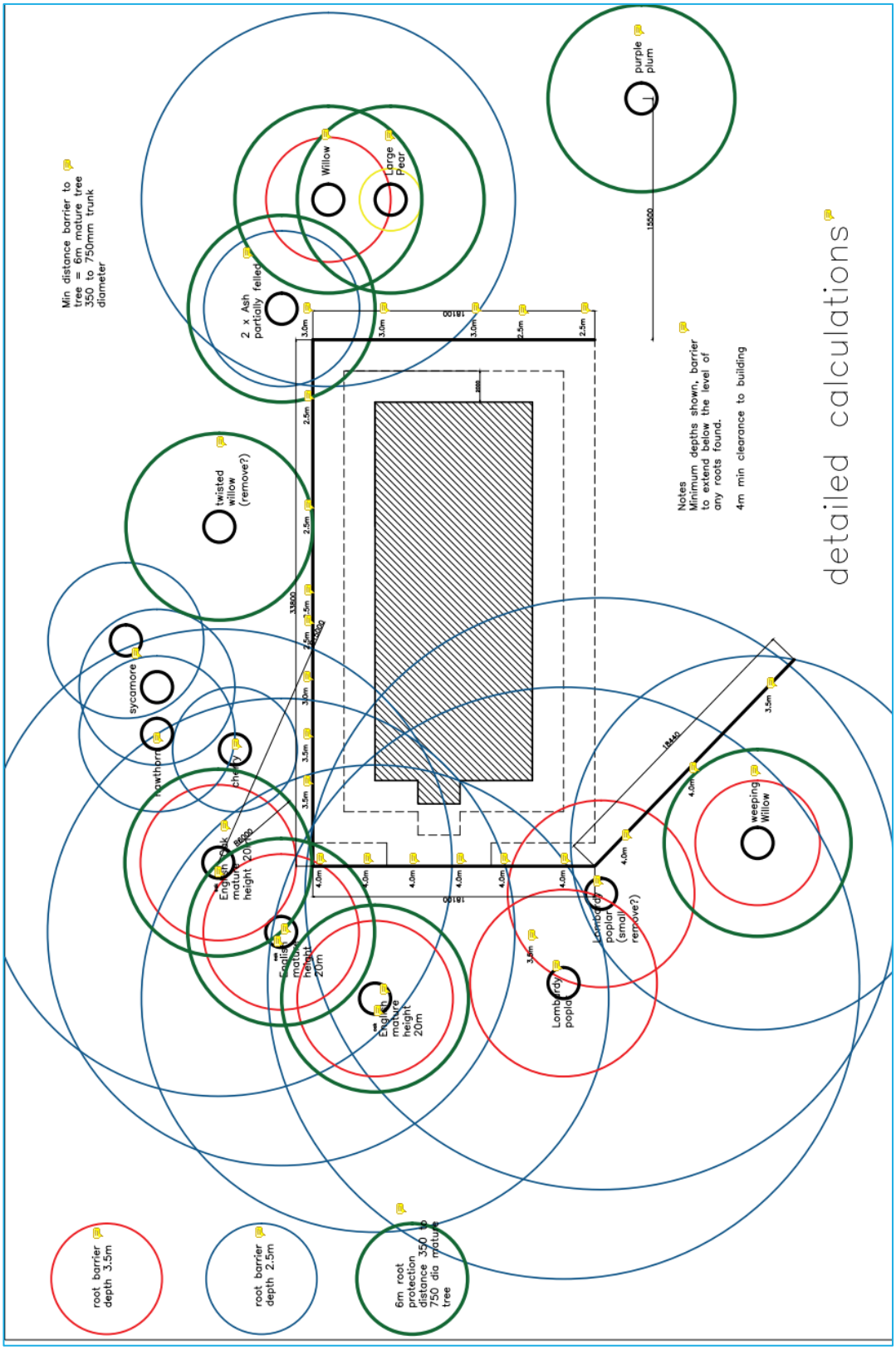


Figure 7.9 Example of barrier around existing trees (Source Author)

8.0 Summary and Conclusions

8.1 General

The research has investigated the practical use of root barriers to resolve clay shrinkage subsidence cases. The research identified the processes and explained the underlying principles involved in clay shrinkage and highlighted its potential to increase due to anticipated global warming bringing wetter winters and longer drier summers.

Current practice determines that tree removal is the preferred and routine solution adopted to resolve clay shrinkage subsidence as it is relatively inexpensive, quick to implement and resolves the problem. Other solutions, such as tree pruning and to a lesser extent underpinning are also utilised. However, underpinning is expensive and tree pruning has been shown to be ineffective and requires continued repeat visits.

In consideration of the above, the research investigated the value of trees and how they provide significant benefits, especially when located in urban areas. Trees' benefits derive from community, environmental, health and financial criteria and these benefits are often not fully appreciated. The value of trees may be calculated in monetary terms by various methods such as CAVAT as used in this thesis. The monetary benefit of an oak tree for example, say 1.2m trunk diameter, located in a very built-up area and in good condition can be up to £450,000 according to CAVAT.

The research then associated the current resolution of clay shrinkage subsidence, (tree removal) and its potential to increase (due to global warming) with tree removal and the losses incurred to society by removal of trees. The alternative solution of a root barrier was presented and justified as a viable alternative to tree removal. A root barrier placed between the damaged building and the tree effectively stops the passage of tree roots resolving the problem whilst retaining valuable trees.

The research identified that the greater the value of a tree in a specific setting the greater the damage that will be caused by its removal. The more valuable trees become, especially urban trees, the more important the research becomes.

The research aims and objectives were presented to examine the root barrier solution in more detail. The aims were: -

- to carry out an in-depth study of the benefits, disbenefits, practical use and perceptions of root barriers relevant to subsidence practitioners
- to develop a framework, or design protocol, to optimise the use of root barriers and prevent the unnecessary loss of valuable trees

Four objectives further refined the above aims and these were: -

- to identify the most important variables that would influence decisions to mitigate clay shrinkage subsidence with reference to the use of a root barrier
- to identify the most important perceptions in the use of root barriers amongst subsidence practitioners
- to analyse the a) variables and b) perceptions that influence the use, effectiveness and reliability of root barriers
- to develop design protocol for the design and construction of root barriers

These four objectives were referred to throughout the thesis as an underlying thread to provide clear focus and direction.

The variables were defined as the more tangible, quantitative aspects of a root barrier such as its depth, length, materials, costs and position in relation to the tree and the building. Perceptions were defined as more qualitative views or perceptions or beliefs concerning the use of root barriers.

Literature searches formed the initial stage of the research and these searches identified that there was minimal published documentation on the practical use of root barriers of the type that would be required to resolve clay shrinkage subsidence. There were no published guides, design rules or technical papers available for consultation.

Available literature from linked disciplines such as clay shrinkage claims guidance, soil mechanics, arboriculture, NHBC, British Standards and shallow root barriers to protect pavements was reviewed together with author's own experience to identify important variables in the design and construction of root barriers and perceptions. The literature identified concerns that root barriers were perceived as unreliable and rarely used.

Following literature review, an inaugural set of initial design rules or protocol was generated that linked the variables and established basic relationships that formed the initial theoretical preposition for the research process.

The perceptions of the use of root barriers were identified under the headings of practical, cost, knowledge and reliability concerns and modelled into a project management type schema of cost, quality and time.

Following the literature review, the overall research design was derived from the basic philosophical underpinnings of ontology, through epistemology, into theoretical perspective to determine the research methodology, as the overarching logic of enquiry. It was determined through this process that the variables would be

researched through case study methodology and that perceptions would follow the route of survey methodology.

These two logics of enquiry, case study and survey were developed into methods (of data collection) for both variables (through case study) and perceptions (through questionnaire). Documents were the main method (of data collection) used to collect variables for case study and questionnaires were used to collect data concerning perceptions.

Variables were analysed in the research using a total of 33 case studies with 22 separate headings/topics using 3 participants. Perceptions were researched by survey questionnaires using 9 pre-defined questions and a total of 90 participants over four events. The method chapter explained how the participants were selected and the precise way the data was collected.

The results of the case studies and questionnaires with appropriate analysis were presented in Chapter 5 and discussed in Chapter 6 resolving the first three objectives to understand relationships, importance, linkages and dependencies between the variables and the perceptions. The most important variables, confirmed because of the research, were: -

- the depth of the root barrier
- length of the root barrier
- positioning of the barrier in relation to tree and the property
- materials used in the construction of the root barrier
- construction method

The main perceptions were similarly considered in relation to the design and construction of root barriers. These were: -

- cost of root barriers and in particular, value for money
- reliability of root barriers
- practicality of site works and installation
- knowledge (holding the above aspects of cost, reliability and practicality together)

The final stage was presentation of the informed design protocol in the use of root barriers, developed throughout the research process and fulfilling objective 4. The informed design protocol identified 13 important stages of the design process incorporating the important variables and dealing with common concerns.

The overall process is summarised in Figure 8.1. (Note V = variables P = perceptions)

No pattern and irregular	
Unrelated to root barriers	Separate out variables and perceptions
No structure	Relate to root barriers
No relative importance	Theorise/order

variables and perceptions with structure
relative importance established
ordered

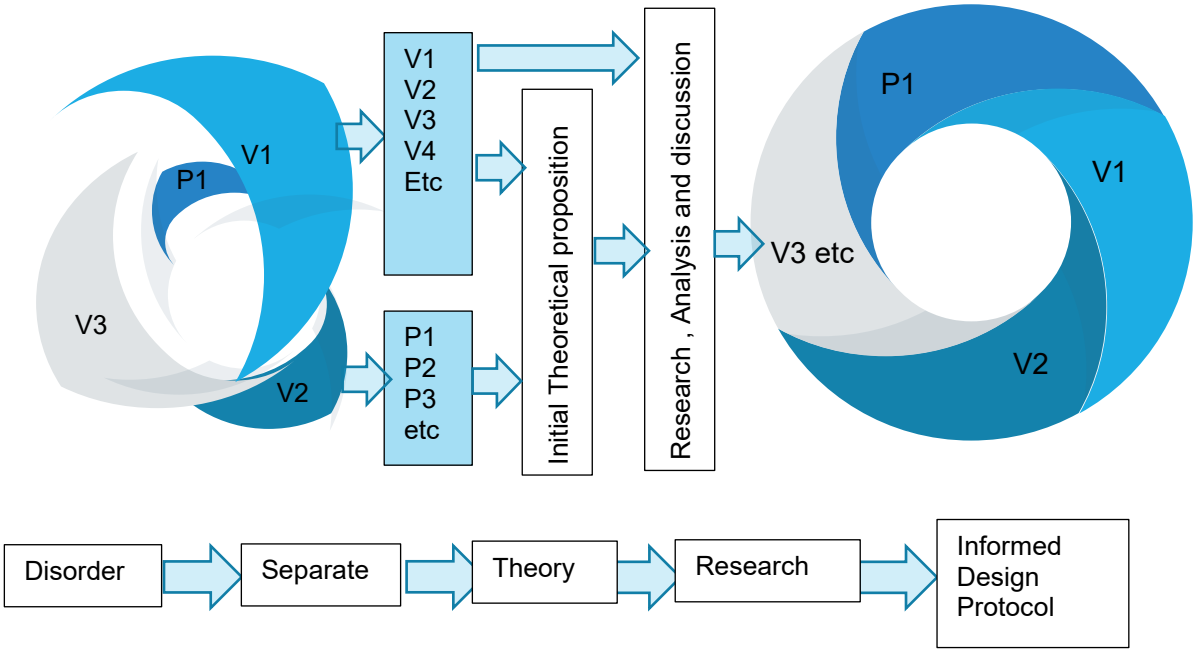


Figure 8.1 Research outline creating order from disorder (Source Author)

Figure 8.1 demonstrates how the research started with fragmented information without order or form. Variables and perceptions were identified and then consolidated and developed into initial theoretical propositions of initial design protocol for the variables and cost, quality time model for the perceptions. The research process resulted in the creation of order from disorder culminating in the preparation of informed design protocol for the practical use of root barriers. Ultimately, because of this research, decisions on whether to use root barriers will be more informed because the choice will be based on knowledge providing greater confidence leading hopefully to increased use and fewer trees removed.

8.2 Overview of the Research

Figure 8.2 illustrates how the research encompasses various threads such as historic solutions, concerns, variables, perceptions, methodology, methods, results, analysis and discussion culminating in the informed design protocol.

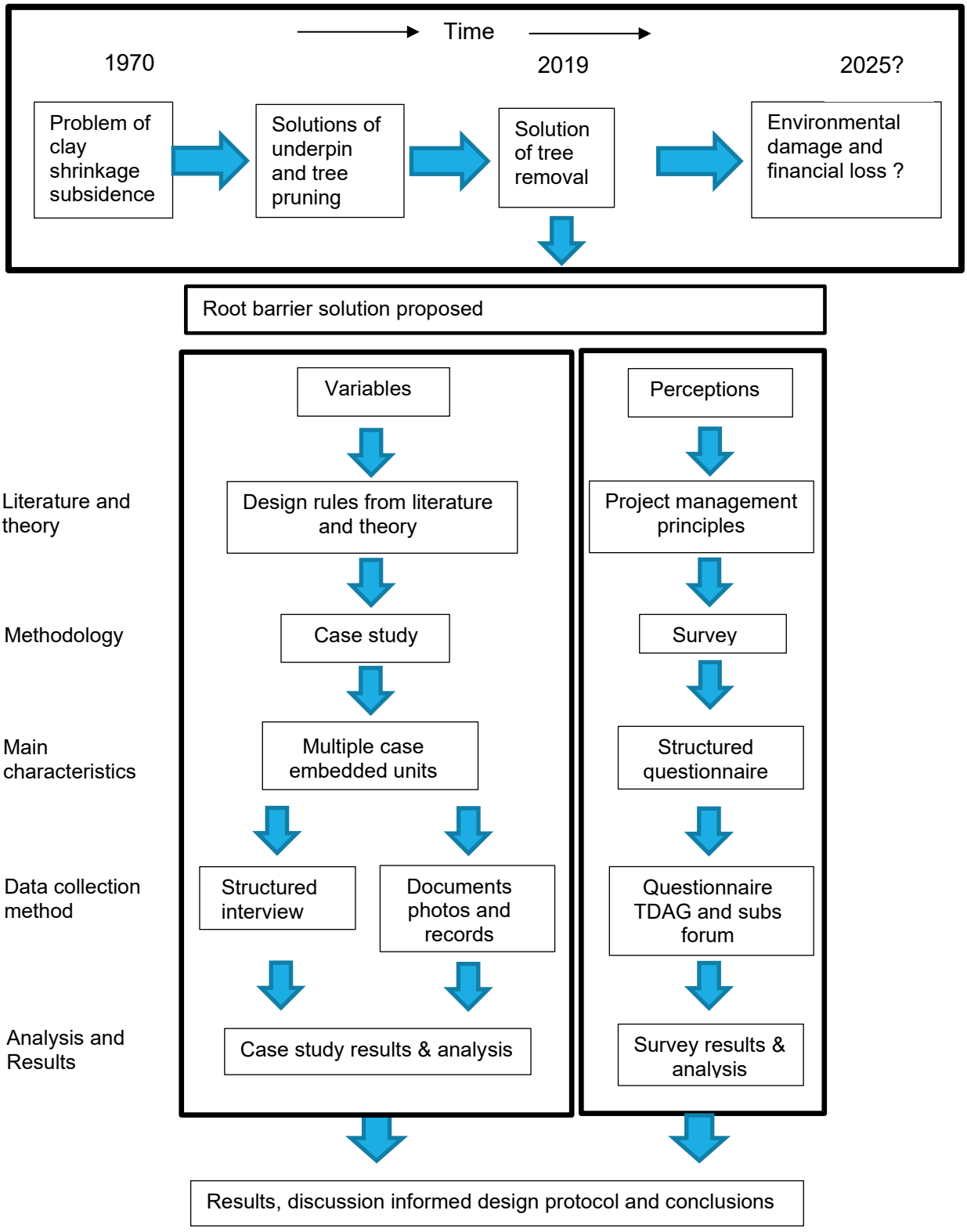


Figure 8.2 Research overview and general structure (Source Author)

8.3 Main Conclusions

The following main conclusions have been derived from the research under the main headings of general conclusions, variables and perceptions.

8.3.1 General

Root barriers are infrequently used and a root barrier installed between a tree and a building presents a viable and realistic solution to resolving damage due to clay shrinkage subsidence.

Root barriers act to prevent roots from reaching the foundations of a building and are effectively the same as tree removal.

Root barriers can overcome tree root trespass and liability problems in that root barriers prevent roots reaching the building and effectively abate the nuisance, potentially relieving tree owners from claims if the tree remains.

8.3.2 Variables

The depth of the barrier is one of the most important variables and the average depth of the root barriers within case studies was 3.9m which was found to be generally higher than would be required by NHBC rules.

NHBC guidelines may be used to determine the depth of a root barrier modified using defined factors of safety. An applied FoS of 0.8m plus 6% x distance can reduce the risk of roots growing under the root barrier by up to a factor of 8 compared with NHBC.

Root barriers may be installed at varying depths according to design, resulting in overall savings per m2 compared with barriers installed at a constant depth.

A graphical method of design and positioning of a root barrier was proposed in the informed design protocol suitable for cases with multiple trees. The graphical method assists in positioning the barrier to avoid services or site features.

With appropriate precautions barriers can be located close to foundations and encroach upon a 45-degree line potentially increasing the number of situations where they may be used.

A method was proposed for determining the length of barrier to avoid roots growing around the barrier.

The research made the positive link between valuing trees using CAVAT and root barriers to resolve clay shrinkage subsidence with a view to considering value for money considerations.

Case studies indicated the most common trees to be saved using a root barrier were Oaks with 33 incidences, across 33 cases. The next highest were maples and London planes (9 and 7 respectively). However, the research emphasizes that the value of a tree using CAVAT derives mainly from the trunk diameter, its location and condition, not its species.

Practitioners tend to value trees more highly in monetary terms when compared with values calculated using the CAVAT method as evidenced from questionnaires.

Practitioners consider loss adjusters, engineers, and arborists to design root barriers with a preference for arborists.

The most adopted construction method within case studies was excavating a trench, inserting a root barrier material and backfill with concrete or gravel. Sheet piles driven in pre-bored holes were also used as an installation method.

Innovative methods of construction were identified in case studies such as vacuum suction in one case.

The materials currently used in constructing root barriers were identified and divided into categories of rigid or flexible, permeable or impermeable, biodegradable and non-biodegradable. Permeable, biodegradable rigid type barriers are suggested for further research using pilot holes to assist construction.

8.3.3 Perceptions

8.3.3.1 Practical concerns

The main concern amongst practitioners was practical difficulties. In particular dealing with obstructions such as services in the ground, obstacles and site features. Practical concerns may be overcome or reduced by considering the methods of installation, materials, depth and length of the barrier, and its location in relation to the building and the tree.

Due to the multiple skills required, multidisciplinary teams are required to deal with design and construction of root barriers.

Root barriers were 100% successful in the case studies that formed the research. In terms of perceptions, over 50% of practitioners confirm that they were successful where they had experience of root barriers.

The informed design protocol established the required depth, length, location in relation to the building and the tree.

Reliability and knowledge concerns can be overcome using the informed design protocol developed by the research.

Post installation monitoring can provide feedback on the effect of a root barrier is having on the property.

8.3.3.2 Cost and value for money

Cost and value for money concerns were listed as the 2nd biggest concern amongst practitioners.

The research provided average costs for root barrier installation of £300 per square metre that can be used for initial pricing and to compare with calculated tree values and demonstrate value for money using Equation 8-1

Cost saving = value of trees removed – root barrier cost + cost tree removal

Equation 8-1 Calculation for determining cost effectiveness of a root barrier

Root barriers are a cost-effective solution and provide excellent value for money when compared with the losses incurred using CAVAT when trees are removed. Savings on average £62,500 for each of 33 case studies were identified by installing a root barrier.

Based upon the four examples in 6.7.6 referring to value for money considerations using CAVAT values and data from case studies it was identified that:-

- In cases where there are single trees of 500mm diameter (average size assumed in calculations) savings in the order of £12,000 are achieved when a root barrier is installed in preference to tree removal.
- In cases where there are two smaller trees (300mm diameter) savings in the order of £11,000 are achieved by installing a root barrier compared to tree removal.
- In cases where there are exceptionally large trees, trunk diameter 1m and above significant savings in excess of over £150,000 are achieved.
- No savings occur and root barriers are not demonstrated to be cost effective when there is a small single tree of trunk diameter 30cm or less or the tree is larger but in poor condition.

8.3.3.3 Knowledge Concerns

Overall, there was a negative perception of root barriers amongst practitioners with neutral or negative accounting for 74% of respondents in the subsidence forum.

Nearly half (46%) within the subsidence industry indicate that they are not yet ready to consider root barriers as a solution to clay shrinkage subsidence. The results demonstrate a willingness however amongst practitioners to consider the root barrier option even where there were no objections to tree removal. i.e., 50/50 split.

The informed design protocol brings the research to conclusion resolving many knowledge concerns through a 13-stage design process.

8.4 Future Research

The research has identified two areas in particular that would benefit from further research appropriate to progress the root barrier option.

The actual growth of roots in the ground around deep fixed barriers is not well understood. The effects of a barrier can be realized by monitoring the movement of the building acting in response to a root barrier in the presence of trees. Also, field measurements of soil moisture deficit around a deep barrier would provide essential information concerning the growth of roots and moisture extraction. Incomplete barriers allow roots to grow around the barrier. Research into root growth around barriers would be of benefit, especially concerning the likely responses of roots to impenetrable barriers. (Roberts, et al., 2006)

Case studies have identified difficulties encountered when installing root barriers, in particular practical concerns. In terms of construction, from a practical viewpoint, there are significant benefits that could be achieved by installing rigid type, environmentally friendly, interlocking sheets within thin pre-cut trenches as an alternative to wider trenches that require backfilling. The author is particularly interested in plant that acts as a large chain saw. These devices are currently used to construct trenches at short depths of about 2m (See Figure 6.17) and could be modified to achieve 4m or 5m depths.

In order to progress innovative methods it will be necessary to work with manufacturers to develop materials, plant and machinery capable of constructing thin trenches up to 5m deep in clays soils. And through these innovative methods and materials, could the cost of installing barriers be reduced to make the option more financially attractive?

8.5 Advancing the Root Barrier Solution

In this section, the necessary policy or strategic changes that need to occur, from my experience and based upon the research, are presented alongside implementation required to advance the root barrier solution.

8.5.1 Policy or Strategic Changes

There needs to be a paradigm shift in the way trees are viewed if alternatives such as a root barrier are to be considered. Many practitioners start from the premise that trees are not valuable in monetary terms. There must be increased awareness, by the “non-arborist” community of stakeholders, concerning the high value of trees, identified by the CAVAT method described in Section 2.12.2. The arguments favoring retaining urban trees need to be emphasised and their true value and importance realised in practice.

Increased protection for urban trees in addition to those described in Section 1.6.6 would be most beneficial (such as used for listed or local heritage buildings) would encourage stakeholders to invest and encourage alternatives to tree removal as a solution to clay shrinkage subsidence. If London becomes a national park city, mentioned in Section 1.6.4.4, all trees would automatically be protected in law. This increased protection would have enormous implications for those dealing with subsidence claims and wishing to remove trees because of the additional restrictions that would operate. In addition, should there be 'a locally significant private trees' audit and valuation by local authorities - to complement the listing of nationally protected and public trees?

Insurers are already aware of the implications of climate change on their business. With regard to subsidence, there is likely to be an increase in claims, as outlined in Section 1.6.3. An event year usually focuses attention on clay shrinkage subsidence and if an event does occur in the near future the concerns highlighted with regard to loss of trees in Section 1.6.4.2 would become more apparent. Insurers may be required at this time to invest in alternatives to tree removal, such as root barriers, to deal with high claim numbers and alleviate the adverse effects of excessive tree removal.

In my experience insurers, who fund subsidence work, are often quite removed from the activity and delegate day to day claim management to other stakeholders such as specialist loss adjusters or engineers. If these outside agencies are driven primarily by reducing claim cost, then alternatives such as root barriers will not be considered as root barriers cost more to install than removing trees. Root barriers are shown however to be cost effective by this research (see Section 6.7) when the value of the tree is included. To overcome this barrier, insurers could be more

directly involved in claims as they appreciate that loss of trees can lead to increased crime, poor health, flooding and more accidents for example, events for which they also provide insurance. Alternatively, insurers could provide direct incentives to practitioners employed by them to retain trees or encourage them to invest in developing alternatives such as root barrier.

In Chapter 1, I introduced Figure 1.25 (page 80) illustrating how knowledge sharing and collaboration help to develop the body of knowledge. I would hope to encourage the open, interactive approach through this research where new ideas are shared so that the body of knowledge concerning design and construction of root barriers grows, enabling improved solutions to be developed.

8.5.2 Implementation

This section considers how the findings of the research may be implemented and progressed. It is first necessary to identify the main stakeholders, identified through the research as insurers, loss adjusters, arborists, local authority tree officers, contractors and subsidence engineers.

The “onion ring” Figure 2.14 on page 127 demonstrated a unique method of explaining how the research into root barriers aims to encourage practitioners to move from an entrenched central position of tree removal to considering alternatives, such as a root barrier, by overcoming certain obstacles and concerns such as cost, quality and time.

The literature review and research in general, has identified that root barrier design and construction is a specialist area. Loss adjusters and engineers dealing with claims would benefit from using the design protocol contained in Chapter 7 culminating in a flow chart for design Figure 7.8 Informed design protocol process flow chart” as a template for root barrier design.

The questionnaires demonstrate that arborists tend to value trees highly (see Section 5.3.9) and this stakeholder group are encouraged to highlight the value of trees being removed to other practitioners when dealing with subsidence claims.

Beyond London's proposed national park status, is there an accompanying role for local authority officers to further protect trees, given the variety of local policies and strategies that seek greater sustainability, and liveability, such as local plans, air - quality management, climate emergency strategies?

The current research will be published as a first stage in engagement with stakeholders, as the design protocol. This may be supplemented with further presentations and seminars on the root barrier solution or by publishing in relevant Journals.

An alliance between local tree and planning officers, arborists, subsidence engineers, contractors and insurers is needed to facilitate adoption and further development of the root barrier design protocol. My involvement as a champion would begin with interested stakeholders or ICE with funding and training opportunities assisting with research and development into new methods of construction and materials. Further research into construction methods and materials would assist implementation by reducing the installation costs and enabling them to be constructed in more challenging situations such as around services and restricted sites.

In addition, insurers should ideally take a more holistic view of claims and become more involved in claim decisions, not simply delegating the responsibility of dealing with claims to others who may be driven by costs alone. Where insurers pay more to resolve a claim by installing a root barrier, I would argue that they will pay out less in the long term, through insurance claims, by improved health, cleaner air, less crime and the many other benefits described in Section 1.6.4 by saving precious trees.

Ongoing practical involvement as part of my work as a consultant is essential to maintain momentum and provide practical assistance and the author maintains an ongoing interest in root barrier projects, one of which is being completed in Essex.

8.6 Originality and Contribution to Knowledge

Two of the cornerstones of professional doctoral research are the requirements to contribute to knowledge (and professional practice) and demonstrate originality. This section specifically outlines how the author considers that these requirements have been achieved within the thesis.

The requirement to contribute requires firstly to identify a “gap”. In the literature review in Chapter 2 this “gap”, certainly in the case of design and construction of root barriers, was demonstrated to be wide. The author is not aware of any formal research into root barriers to resolve clay shrinkage subsidence claims or design rules. This wide gap had advantages when demonstrating a contribution; however, it also requires originality to fill the gap.

The research identifies genuine concerns regarding routine tree removal for the resolution of clay shrinkage subsidence in terms of sustainability by highlighting the value and importance of trees especially in urban environments. The connection between the value of trees from arboriculture and the resolution of clay shrinkage subsidence is new in terms of justifying the root barrier solution and has been firmly established from this research.

The research first identifies, organises and then researches the main variables in the design and construction of root barriers. The theoretical proposition for variables (initial design rules) was original, developed from individual disparate components and existing, unrelated theories, such as NHBC guidelines, British Standards, Codes, existing practice, arboriculture and experience. The research similarly identifies the perceptions in the use of root barriers from literature and forms them into a theoretical proposition of cost, quality and time.

The knowledge gap was filled by preparation of the initial design rules built in terms of variables, demonstrating originality and culminating in preparing the informed design protocol. The informed design protocol for the use of root barriers is the first such formal published document generating practical design rules in the use of root barriers.

The research contributes by embedding the existing process to calculate the value of trees using CAVAT into subsidence claims management to demonstrate the loss caused when trees are removed and the benefits of alternatives.

The depth of the root barrier was identified as a significant variable and the research established an original procedure for using an FoS when determining the depth based upon existing NHBC guidelines. The method includes an assessment of the confidence that roots would not grow below, compared with NHBC.

The thesis has highlighted existing materials and methods in the use of root barriers and suggested new, innovative methods and construction techniques to improve value for money, reliability and practicality in the use of root barriers.

Whilst it is not suggested that the design protocol is the final product, it is an important starting point and later modification and revision will undoubtedly evolve. However, the informed design protocol does not improve an existing protocol, but an entirely new protocol.

The research should contribute by means of increasing awareness of the value of trees, providing practical guidelines for the use of root barriers, improve confidence, widen the body of knowledge and ultimately enhance the frequency of the use of root barriers with the ultimate aim of protecting valuable trees from unnecessary removal during clay shrinkage subsidence claims.

8.7 Concluding Remarks and Reflections

The material presented in this thesis amounts to a gathering together of the knowledge I have gathered during my years as a subsidence specialist enhanced by this research into the practical use of barriers. The research has been challenging especially when dealing with a rarely utilised solution such as root barrier. The research identified concerns with the common solution of tree removal and the adoption of different remedies such as a root barrier represents a paradigm shift within pre-existing practices. Nevertheless, if a tree's full value is recognised, routine tree removal to resolve clay shrinkage may not be sustainable.

Upon reflection the initial research proposal completed back in 2015 considered only basic methodological considerations such as inductive vs deductive styles and qualitative vs quantitative methods without consideration of some of the deeper issues of ontology, epistemology, theoretical perspectives, paradigms or methodologies. There was no mention of objectivist or constructivist epistemologies or positivist or post positivist theoretical perspectives or of interpretivism as methodology. So, it has been necessary and important for me, and sometimes challenging, as an engineer, to consider these complex topics. This has also led to research into philosophy and philosophers to understand some of the more difficult terms and questions raised. Knowledge is key, and the informed design protocol, it is hoped, will be used as a basis for considering root barriers as a viable alternative to tree removal.

I hope that the research will be further developed serving as a body of knowledge that will further advance our understanding of root barrier design and installation. I am a keen golfer and to use a quote from Ben Hogan in his book entitled The Modern Fundamentals of Golf, “every year we learn a little more (about golf). Each new chunk of valid knowledge paves the way to greater knowledge. (Golf) is like medicine and the other fields of science in this respect”. (Hogan, 1957, p. 109)

This research is not the end of the process but the beginning. The research outcomes and design protocol act as a springboard for further research and development of this innovative approach to resolving clay shrinkage subsidence claims and providing support for companies considering the option.

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http://www.forestry.gov.uk/

The Tree Council

http://treecouncil.org.uk

Trees for Cities

http://www.treesforcities.org/

The Woodland Trust

http://www.woodlandtrust.org.uk

Other online resources

RIBA Urban Forest and Green Infrastructure Knowledge Community

The RIBA hosts a range of knowledge community platforms that are free and open to all. The urban forest and green infrastructure knowledge community can be accessed by signing-up to

http://www.riba-knowledgecommunities.com/

Tree Management Toolkit for Social Landlords

An online resource developed by Neighbourhoods Green

http://www.neighbourhoodsgreen.org.uk/

Other Publications

The benefits of large species trees in urban landscapes; a costing, design and management guide.

A comprehensive guide aimed at the construction industry produced by CIRIA in 2012 available for purchase at

http://www.ciria.org/SERVICE/Home/core/orders/product.aspx?catid=2&prodid=2005

Trees in Towns II. This government commissioned report will be invaluable to those engaged in establishing policies and setting appropriate levels of resources to plan, develop, and manage robust urban tree populations.

The 36-page Executive Summary can be downloaded for free at http://www.communities.gov.uk/documents/planningandbuilding/pdf/treesintownsii.pdf

The full report of some 650 pages, B&W paperback, can be purchased at http://www.lulu.com/content/paperback-book/trees-in-towns-ii/12620931

Trees Matter: Bringing Lasting Benefits to People in Towns.

Produced by the National Urban Forestry Unit and Trees for Cities in 2005 available at

http://www.treesforcities.org/index.php/download_file/502/141/Notes

Trees, People and the Built Environment Conference Report.

The research papers from this ground-breaking conference held in April 2011 in Birmingham are available at

http://www.charteredforesters.org/default.asp?page=166

12 Appendices

12.1 NHBC tables and graphs

TABLE 12

HIGH SHRINKAGE SOILS Plasticity Index greater than 40%

HIGH water demand BROAD LEAF trees including:–

Figures are heights in metres

Elm		Oak		Poplar		Willow	
English	24	English	20	Hybrid black	28	Crack	24
Wheatley	22	Holm	16	Lombardy	25	Weeping	16
Wych	18	Red	24			White	24
Eucalyptus	18	Turkey	24				

Foundation depths (m)

Distance from centre of tree or hedgerow to face of foundation (m)

Mature tree height (m)	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00	9.00	10.00	11.00	12.00	13.00	14.00	15.00	16.00	17.00	18.00	19.00
8	3.25	3.00	2.75	2.50	2.25	2.00	1.75	1.50	1.25	1.00	1.00	1.00							
10	3.30	3.10	2.90	2.70	2.50	2.30	2.10	1.90	1.70	1.50	1.30	1.10	1.00	1.00					
12	3.33	3.17	3.00	2.83	2.67	2.50	2.33	2.17	2.00	1.83	1.67	1.50	1.33	1.17	1.00	1.00	1.00		
14	3.36	3.21	3.07	2.93	2.79	2.64	2.50	2.36	2.21	2.07	1.93	1.79	1.64	1.50	1.36	1.21	1.07	1.00	1.00
16	3.38	3.25	3.13	3.00	2.88	2.75	2.63	2.50	2.38	2.25	2.13	2.00	1.88	1.75	1.63	1.50	1.38	1.25	1.13
18	3.39	3.28	3.17	3.06	2.94	2.83	2.72	2.61	2.50	2.39	2.28	2.17	2.06	1.94	1.83	1.72	1.61	1.50	1.39
20	3.40	3.30	3.20	3.10	3.00	2.90	2.80	2.70	2.60	2.50	2.40	2.30	2.20	2.10	2.00	1.90	1.80	1.70	1.60
22	3.41	3.32	3.23	3.14	3.05	2.95	2.86	2.77	2.68	2.59	2.50	2.41	2.32	2.23	2.14	2.05	1.95	1.86	1.77
24	3.42	3.33	3.25	3.17	3.08	3.00	2.92	2.83	2.75	2.67	2.58	2.50	2.42	2.33	2.25	2.17	2.08	2.00	1.92
26	3.42	3.35	3.27	3.19	3.12	3.04	2.96	2.88	2.81	2.73	2.65	2.58	2.50	2.42	2.35	2.27	2.19	2.12	2.04
28	3.43	3.36	3.29	3.21	3.14	3.07	3.00	2.93	2.86	2.79	2.71	2.64	2.57	2.50	2.43	2.36	2.29	2.21	2.14
30	3.43	3.37	3.30	3.23	3.17	3.10	3.03	2.97	2.90	2.83	2.77	2.70	2.63	2.57	2.50	2.43	2.37	2.30	2.23

TABLE 14

HIGH SHRINKAGE SOILS Plasticity Index greater than 40%

MODERATE water demand BROAD LEAF trees including:–

Figures are heights in metres

Acacia false	18	Cherry		Honey locust	14
Alder	18	Japanese	9	Hornbeam	17
Ash	23	Laurel	8	Horse chestnut	20
Bay Laurel	10	Wild	17	Laburnum	12
Blackthorn	8	Hawthorn	10	Lime	22

Foundation depths (m)

Distance from centre of tree or hedgerow to face of foundation (m)

Mature tree height (m)	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00	9.00	10.00	11.00	12.00	13.00	14.00	15.00	16.00	17.00	18.00	19.00
8	2.17	1.93	1.70	1.47	1.23	1.00	1.00												
10	2.21	2.03	1.84	1.65	1.47	1.28	1.09	1.00											
12	2.24	2.09	1.93	1.78	1.62	1.47	1.31	1.16	1.00	1.00									
14	2.27	2.13	2.00	1.87	1.73	1.60	1.47	1.33	1.20	1.07	1.00								
16	2.28	2.17	2.05	1.93	1.82	1.70	1.58	1.47	1.35	1.23	1.12	1.00	1.00						
18	2.30	2.19	2.09	1.99	1.88	1.78	1.67	1.57	1.47	1.36	1.26	1.16	1.05	1.00					
20	2.31	2.21	2.12	2.03	1.93	1.84	1.75	1.65	1.56	1.47	1.37	1.28	1.19	1.09	1.00	1.00			
22	2.32	2.23	2.15	2.06	1.98	1.89	1.81	1.72	1.64	1.55	1.47	1.38	1.30	1.21	1.13	1.04	1.00		
24	2.32	2.24	2.17	2.09	2.01	1.93	1.86	1.78	1.70	1.62	1.54	1.47	1.39	1.31	1.23	1.16	1.08	1.00	1.00
26	2.33	2.26	2.18	2.11	2.04	1.97	1.90	1.83	1.75	1.68	1.61	1.54	1.47	1.39	1.32	1.25	1.18	1.11	1.04
28	2.33	2.27	2.20	2.13	2.07	2.00	1.93	1.87	1.80	1.73	1.67	1.60	1.53	1.47	1.40	1.33	1.27	1.20	1.13
30	2.34	2.28	2.21	2.15	2.09	2.03	1.96	1.90	1.84	1.78	1.72	1.65	1.59	1.53	1.47	1.40	1.34	1.28	1.22

TABLE 15

HIGH SHRINKAGE SOILS Plasticity Index greater than 40%

MODERATE water demand CONIFEROUS trees including:–

Figures are heights in metres

Cedar	20	Spruce	18
Douglas fir	20	Wellingtonia	30
Pine	20	Yew	12

Foundation depths (m)

Distance from centre of tree or hedgerow to face of foundation (m)

Mature tree height (m)	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00	9.00	10.00	11.00	12.00	13.00	14.00	15.00	16.00	17.00	18.00	19.00
8	1.90	1.40	1.00																
10	2.00	1.60	1.20	1.00															
12	2.07	1.73	1.40	1.07	1.00														
14	2.11	1.83	1.54	1.26	1.00														
16	2.15	1.90	1.65	1.40	1.15	1.00													
18	2.18	1.96	1.73	1.51	1.29	1.07	1.00												
20	2.20	2.00	1.80	1.60	1.40	1.20	1.00												
22	2.22	2.04	1.85	1.67	1.49	1.31	1.13	1.00											
24	2.23	2.07	1.90	1.73	1.57	1.40	1.23	1.07	1.00										
26	2.25	2.09	1.94	1.78	1.63	1.48	1.32	1.17	1.02	1.00									
28	2.26	2.11	1.97	1.83	1.69	1.54	1.40	1.26	1.11	1.00									
30	2.27	2.13	2.00	1.87	1.73	1.60	1.47	1.33	1.20	1.07	1.00								

Guidance

Water demand and mature height of trees

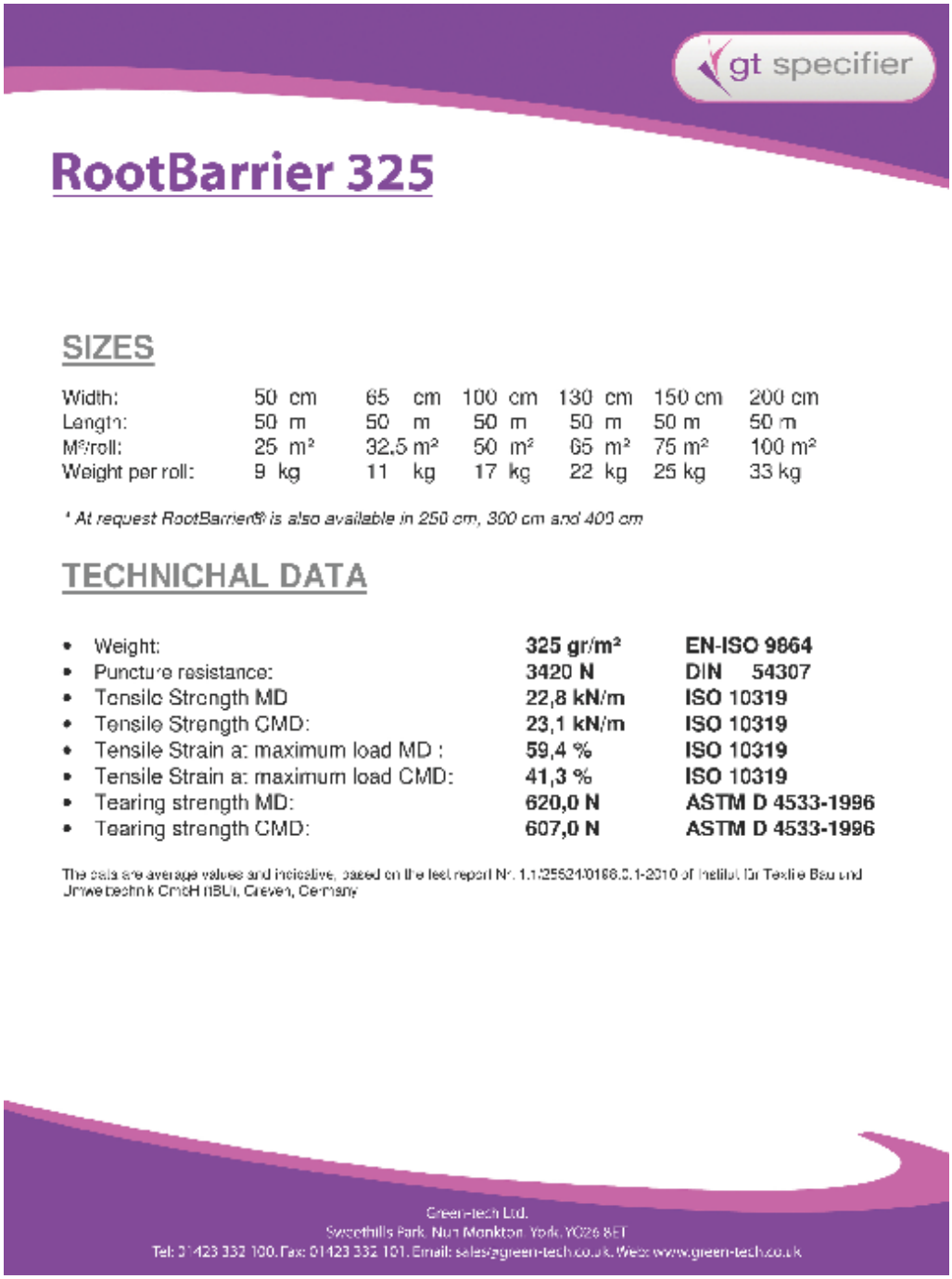
Broad leaved trees			Conifers			Orchard trees (take as broad leaved)		
Water demand	Species	Mature height (m)	Water demand	Species	Mature height (m)	Water demand	Species	Mature height (m)
High	Elm		High	Cypress				
	English	24		Lawson's	18			
	Wheatley	22		Leyland	20			
	Wych	18		Monterey	20			
	Eucalyptus	18						
	Oak							
	English	20						
	Holm	16						
	Red	24						
	Turkey	24						
	Poplar							
	Hybrid black	28						
	Lombardy	25						
	Willow							
	Crack	24						
	Weeping	16						
	White	24						
Moderate	Acacia false	18	Moderate	Cedar	20	Moderate	Apple	9
	Alder	18		Douglas fir	20		Cherry	15
	Ash	23		Pine	20		Pear	12
	Bay Laurel	10		Spruce	18		Plum	10
	Blackthorn	8		Wellingtonia	30			
	Cherry			Yew	12			
	Japanese	9						
	Laurel	8						
	Wild	17						
	Hawthorn	10						
	Honey locust	14						
	Hornbeam	17						
	Horse chestnut	20						
	Laburnum	12						
	Lime	22						
	Maple							
	Japanese	8						
	Norway	18						
	Mountain ash	11						
	Plane	26						
	Sycamore	22						
	Tree of heaven	20						
	Walnut	18						
	Whitebeam	12						
Low	Beech	20						
	Birch	14						
	Holly	12						
	Magnolia	9						
	Mulberry	9						

Note

1. Where hedgerows contain trees, their effects should be assessed separately. In hedgerows, the height of species likely to have the greatest effect should be used.
2. Within the classes of water demand, species are listed alphabetically; the order does not signify any gradation in water demand.
3. When the precise species is unknown the greatest height and highest water demand should be assumed.
4. Further information regarding trees may be obtained from the Arboricultural Association or the Arboricultural Advisory and Information Service (see Appendix 4.2-G).

Appendix 12.2 Root barrier materials and selected technical information
Materials used in root barrier construction.
Data sheets and information

GT Specifier Root Barrier 325



gt specifier

RootBarrier 325

SIZES

Width:	50 cm	65 cm	100 cm	130 cm	150 cm	200 cm
Length:	50 m	50 m	50 m	50 m	50 m	50 m
M²/roll:	25 m²	32.5 m²	50 m²	65 m²	75 m²	100 m²
Weight per roll:	9 kg	11 kg	17 kg	22 kg	25 kg	33 kg

** At request RootBarrier® is also available in 250 cm, 300 cm and 400 cm*

TECHNICHAL DATA

• Weight:	**325 gr/m²**	**EN-ISO 9864**
• Puncture resistance:	**3420 N**	**DIN 54307**
• Tensile Strength MD	**22,8 kN/m**	**ISO 10319**
• Tensile Strength CMD:	**23,1 kN/m**	**ISO 10319**
• Tensile Strain a: maximum load MD :	**59,4 %**	**ISO 10319**
• Tensile Strain a: maximum load CMD:	**41,3 %**	**ISO 10319**
• Tearing strength MD:	**620,0 N**	**ASTM D 4533-1996**
• Tearing strength CMD:	**607,0 N**	**ASTM D 4533-1996**

The data are average values and indicative, based on the test report Nr. 1.1/25524/0168.0.1-2010 of Institut für Textile Bau und Umwelttechnik GmbH (ITU), Greven, Germany

Green-tech Ltd.
Sweethills Park, Nun Monkton, York, YO26 8ET
Tel: 01423 332 100. Fax: 01423 332 101. Email: sales@green-tech.co.uk. Web: www.green-tech.co.uk

http://www.gtspecifier.co.uk/Tree-Pit-Root-Barriers (accessed September 2013)

Geosyn membranes products

Geomembranes

Geomembranes are essentially impermeable lining materials used as fluid or containment barriers.

West Nurseries, Spalding

Since the 1950's engineers have successfully designed systems with a wide range of geomembranes and associated geosynthetic products to protect our environment and water resources in particular.

Geomembranes have proven to be far more effective than traditional products such as concrete, asphalt and compacted clay. They display a wide range of physical, mechanical and chemical resistance properties and can be compounded for greater resistance to ultraviolet light exposure, ozone and micro organisms. Different combinations of these properties exist in various geomembranes allowing the engineer to address a wide spectrum of applications. Thorough knowledge of the application is necessary in order to select the appropriate membrane and design a successful Geosynthetic Containment System.

More economical to install, Geosynthetic Containment Systems are less susceptible to ground movement and are now considered the safest method in the majority of applications.

Geomembranes can be of polymeric or composite construction have smooth or textured surfaces. Textured surfaces provide enhanced friction characteristics which can be important in certain applications.

Advanced products, as well as manufacturing and installation techniques, continue to evolve as the geosynthetic industry steadily improves existing technology and strives to address the future needs of the containment industry.

As you will see on the following pages, Geosynthetics Limited has put together the largest and most comprehensive range of geomembranes available today. Allow us to use our extensive knowledge of products and applications to help you select the best product for you project.

Marie Curie Pond Install, Solihull

Product Range
HDPE Geomembranes

HDPE is recognised by the lining industry as the most durable of impermeable geomembranes, manufactured fr
prime quality raw materials which give it a very high resistance to stress cracking. HDPE is also extremely resista
to most chemicals, this coupled with its excellent physical properties make it the geomembrane of choice.

Geosynthetics HDPE range of products are;

AquaBlock HD

Geosynthetics offer various standard roll sizes for lining and containment applications. Some examples of uses for AquaBlock HD are Heap Leach Pads, Wastewater Treatment Lagoons, Landfill, Leats and Slurry Lagoons.

Banbridge Hydro Scheme

CarbonBlock

Hydrocarbon barrier; Prevents the ingress of latent hydrocarbons into a development. Used on Brownfield and redevelopment sites such as old petrol forecourts.

Madston Gainsborough Site

VoltBlock

Dielectric Geomembrane used extensively on modern electric transport lines. Prevents stray current from transferring to the passenger platforms, approved for use on the Docklands Light railway.

KnotBlock

KnotBlock is a Japanese Knotweed barrier that complies fully with the knotweed code of practice document released by the Environmental Agency. Orginally introduced as an ornamental plant, the Japanese species knotweed has become a nationwide problem due to its virulent invasive nature. Geosynthetics knotblock product is very cost effective due to its very large roll size minimising the need for joints as stated in the Environment Agency's code of practice.

RootBlock

RootBlock is a high performance root barrier developed with a broad spectrum of indigenous trees and shrubs. The product has been specifically designed for use as a root barrier, where an ultra strong, durable, robust membrane is needed. It has been designed and manufactured with the Environment Agencies 'Knotweed Code Practice' as the primary driving force. This ensures that is capable of almost every imaginable use as a root barri

ɾ of geosynthetic materials in the UK

Design service

Onsite support

See all products online at **geosyn.co.uk**

Product data sheet

Landscape – Arboriculture – Invasive weed control
T: 01202 831151
E: sales@pba-solutions.com
W: www.root-barrier.co.uk

pba Solutions Management
London
Midlands
Hampshire
Dorset

Root barrier: Advice, Specification & Sales

PBA Solutions- for informed root barrier sales through dedicated arboricultural and invasive weed consultants.

Product Name	bioroot-barrier x
Classification	Structure: Flexible layered geotextile Permeability: Permeable Function: Biological signal barrier – (A cooper foil is securely bonded between porous geotextile, releasing copper ions and forming copper carbonate (verdigris) that signals an adverse reaction to roots deflecting them away from the barrier. The presence of copper does not constitute an eco-system burden or impact on groundwater)
Description	bioroot-barrier x is a mechanically bonded geocomposite consisting of a copper-foil firmly embedded between 2 layers of geotextile. Specifically used in Arboriculture and Japanese knotweed control where a permeable barrier is required. The biobarrier acts as a signal barrier diverting root growth both biologically and physically.
Product data	Mass per unit area:

Base Layer:	g/m²	100	Woven geotextile
Intermediate layer:	g/m²	100	Copper-foil
Top layer:	g/m²	200	Non woven geotextile
Total Product:	g/m²	450	
Tensile strength MD	kN/m	>12	
Tensile Strength CD	kN/m	>12	
Thickness (2 KpA)	mm	>2.0	
Water permeability (50 Kpa)		>3.3 x 10^{-4} m/s	

Dimensions	Length		100 metres
	Width		5 metres
	Diameter of roll		0.5 metres
	Weight of roll		230 Kg
Transport	As above		

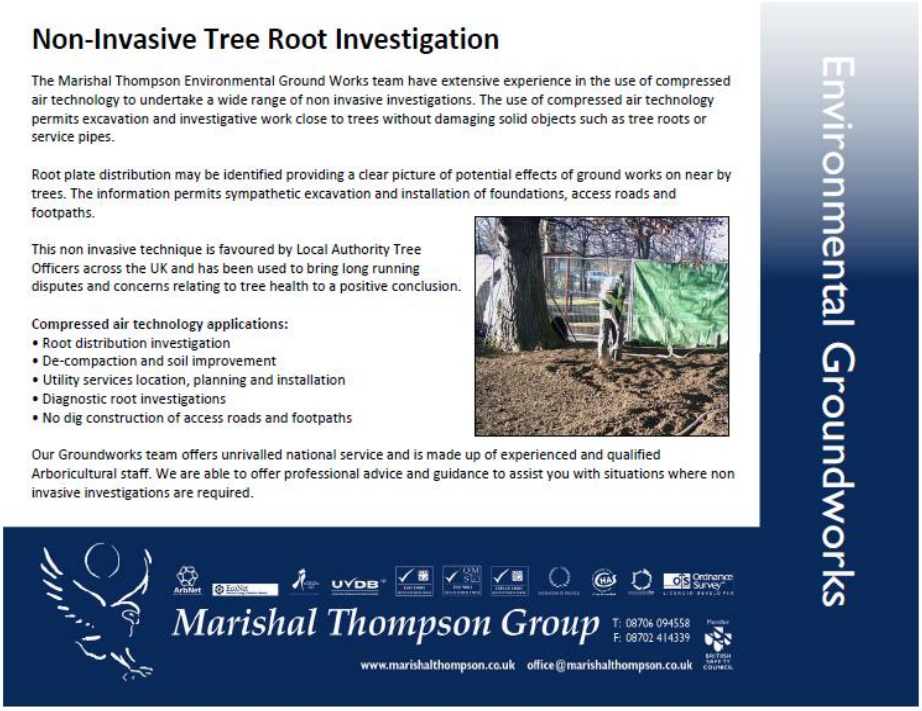
The information contained herein is to the best of our knowledge accurate. However product specifications are subject to change without prior notice. No Warranty or liability is expressed or implied.

UK distribution available on all products within 5 working days. For express delivery call 01202 831151.

PBA Solutions is a trading name of PBA Consulting Partnership LLP (OC308728), registered in England at our head office, Bryn Gardens, Rake Road, Liss, Hants GU33 7HB

http://pba-solutions.com/sites/default/files/Product%20data%20sheet%20-%20bioroot- barrier%20x.pdf
accessed September 2013

Marishall Thompson Air Blade



http://marishalthompson.co.uk/Downloads/AirSpade.pdf (accessed September 2013)

Terram Root Guard

TERRAM

TERRAM ROOTGUARD™

Root control barrier to protect buildings, walls, paths, access roads, drainage pipes and underground cables from root damage.

ROOTGUARD and ROOTGUARD PLUS are used to protect buildings, walls, paths, drainage pipes, cables and lawns from potential damage caused by root development.

Tree roots grow very close to the surface and are the cause of considerable damage. Structures with shallow foundations can be undermined. Damaged pipes, or pipes with faulty joints can become blocked by roots. Root growth is also known to cause desiccation of soils to the extent that soil shrinkage can result in parts of the foundation no longer being supported. When this occurs structures may subside and crack, and in these circumstances expensive underpinning may be the only solution.

The choice of ROOTGUARD product will depend upon the application, specifically whether water needs to pass through the product:

Terram RootGuard - permeable solution

In some instances it may be necessary to have a water-permeable solution e.g. surrounding land drains. Although some permeable barriers may not provide the highest level of protection (see ROOTGUARD PLUS), they still provide excellent resistance.

Terram ROOTGUARD is a geotextile manufactured from polypropylene/polyethylene fibres. It provides excellent resistance to root development; confirmed in numerous trials and commercial projects. Terram ROOTGUARD has high tensile strength, high puncture resistance and is capable of withstanding the differential forces that can develop in clay soils.

Terram RootGuard Plus - impermeable solution

Research has demonstrated that high-density polyethylene (HDPE) can withstand penetration by even the most vigorous of tree roots. Terram ROOTGUARD PLUS - a composite of Terram ROOTGUARD and an HDPE membrane is the choice when there is no requirement for water to pass through the barrier. This product will provide the greatest degree of protection.

Both products are chemically inert to natural soil conditions and resistant to biodegradation.

ROOTGUARD PRODUCT DETAILS

PRODUCT	ROLL SIZE (m)	WEIGHT	CBR PUNCTURE RESISTANCE	COLOUR	MATERIAL	PART NO.
ROOTGUARD	2.25 x 25	260g/m²	3250N	Black	Non Woven PE/PP	081257
ROOTGUARD PLUS	2 x 25	275g/m²	2550N	Black	Non Woven PP HDPE coated	081127

Visit our website for further information on:
Data Sheets, Installation & Design Guidances and Case Studies or call +44 (0) 1621 874200

www.terram.com

Free technical seminars can be arranged to suit your specific area of interest in our product range. Please contact us for further details.

http://www.terram.com/products/geotextiles/rootguard.html (accessed September 2013)

GREENWALL
PVC SHEET PILE

Plastic Piling is extremely versatile and can be used in a number of applications across different industry sectors :

- Riverbank, stream, pond, lake and reservoir bank retention and restoration
- Creating well defined drainage culverts and channels
- Fishing lake and fish farm bank reinforcement
- Anticorrosive covers of sewage and water reservoirs,
- rainage-ditches,
- Elements of retaining wall systems
- Formation elements of green spaces

Resistance of mechanical damage

Weather Resistance

Exceptional durability

Ecological – 100 % recyclable

Resistance to corrosion

Light weight

Easy installation and good performance

No maintenance

Competitive price

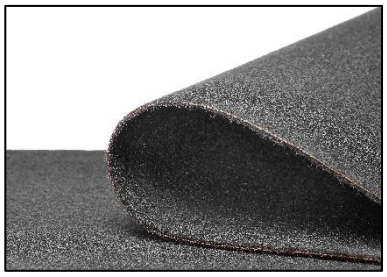
UV Resistance

www.greenwallpvc.com

GEOfabrics®

CuTex

Copper Composite Root Barrier



1. DESCRIPTION A geocomposite root barrier system consisting of a copper sheet mechanically encapsulated between a woven polypropylene geotextile and a high strength nonwoven polypropylene geotextile. The copper acts as a signal layer that all plants avert their growth from. The copper foil only releases minute quantities of the copper ion. These do not constitute an ecosystem burden, or impact on groundwater.

2. APPLICATIONS CuTex geocomposite can provide a direct protection of utilities' infrastructures such as foundations and drains from root intrusion, landfill caps and "green roofs". It will also provide a protection to roads, railways and dams.

3. FEATURES Plant shoot/root primordia (growth tips) are averse to growing into the vicinity of copper concentrations. In essence, the roots/shoots turn their growth in a different direction when confronted with the copper foil. These principles make CuTex a suitable barrier for Japanese Knotweed growth as well as all other plants. The majority of the Japanese Knotweed rhizome exists in the upper layers of topsoil. It has been established that, in an infected area, 14,000kg/ha dry weight of Knotweed may exist in the top 250mm (Brock, 1994).

	Test	Unit	MEAN VALUES
4. MECHANICAL PROPERTIES			
Static puncture (CBR)	EN ISO 12236	kN	2.5
Tensile strength (MD/CMD)	EN ISO 10319	kN/m	20
Tensile elongation (MD/CMD)		%	35
5. FILTER PROPERTIES			
Water permeability v_{H50}	EN ISO 11058	l/(m²·s)	3.10^{-4}
6. PHYSICAL PROPERTIES			
Copper thickness (nominal)	EN ISO 9863-1	µ	18
Carbon black content (geotextile)			1% active carbon black
Standard colour			Black
Polymer			100% virgin polypropylene

Notes:

a) Mean values indicate the arithmetic mean derived from the samples taken for any one test as defined in the standard – usually an overall mean of five samples. Mean values are subject to tolerances based on 95% confidence limits as published on the product CE declaration of performance.
b) Nominal Value (indicates an average manufacturing norm and not a controlled performance parameter).
c) MD: Machine Direction (longitudinal to the roll).
d) CMD: Cross Machine Direction (across the roll).
e) Tensile testing is performed using extensometers.

	Test	VALUES
7. DURABILITY		
Weathering 50 MJ/m² (1 month)	EN ISO 12224	>90% Retained Strength
Microbiological resistance	EN ISO 12225	No loss in strength
Resistance to acids & alkalis	EN ISO 14030	No loss in strength
Oxidation at 112 days (100 years)	EN ISO 13438	>90% Retained Strength

GEOfabrics Limited, Skelton Grange, Stourton, Leeds LS10 1RZ, United Kingdom
T: +44 (0) 113 202 5678 F: +44 (0) 113 202 5655 E: info@geofabrics.com

GEOfabrics®

CuTex
Copper Composite Root Barrier

8. TESTING

All materials are tested every 6000m² in an UKAS accredited ISO 17025 laboratory to all mechanical properties prior to release.

In order to demonstrate the bio-barrier performance of the proprietary CuTex barrier system a laboratory test was undertaken by REC Ltd. The test was performed on a mixture of plant species including mustard, docks, meadow grass and Japanese Knotweed within a peat and compost based soil matrix. The trial was monitored over a duration of six months in which period it was evident that the rhizome fragments of Japanese Knotweed were actively growing beneath the Cutex barrier. The field trial was conducted within a climate controlled environment (20°C) with daily addition of moisture to the surface of the soil.

Upon careful exhumation of the CuTex barrier, it was evident that none of the plants were able to grow through the bio-barrier. Typically, the roots that made their way down to the copper foil were either stopped or took lateral route. None of the rootlets penetrated any of the needlepunched holes, demonstrating the growth inhibited effect caused by the chemical properties of the copper foil insert. It should be noted that the CuTex barrier is a permeable system capable of transferring moisture through the geotextile sandwich and copper foil and therefore not prone to water logging in field conditions. The laboratory trial proved that there was no water logging of the soil above the barrier.

9. STORAGE

The geocomposites are supplied in packaging designed to protect the product from damage during handling, storage and degradation as a result of UV exposure. The product should be kept in appropriate packaging until such time that it is required for installation. The product is clearly and indelibly marked with the product name along the edge of the roll at regular intervals no greater than 5m. The packaging is labelled clearly to identify the product supplied in accordance with EN ISO 10320: Geotextile and Geotextile related products – Identification on site. Use slings where provided. Product weights are given on roll tickets. Use equipment appropriate to weight and dimension. Store and handle in accordance with good occupational hygiene and safety practice.

	Unit	VALUES			
10. DIMENSIONS					
Standard roll length	m	25	25	50	50
Standard roll width	m	2.6	5.2	2.6	5.2
Approximate roll weight	kg	38.5	77	77	154

Flexline 1.5mm

Flexline is a propylene/ethylene copolymer geomembrane produced from a resin formulation designed to provide a premium quality geomembrane, with excellent flexibility, improved elasticity and resistance to puncture. These properties assure maximum multiaxial elongation to accommodate differential settlement. Flexline is ideal for most geomembrane applications and major benefits to installation are provided by a lower coefficient of thermal expansion and a wide temperature-welding window.

Tested Property.	Test Method.		Min. Value.
Nominal Thickness (mm)	ASTM D5199		1.50
Thickness (mm) minimum.	ASTM D751		1.35
Density (g/cm³)	ASTM D792/ 1505 A		0.88
Tensile properties (each direction)	ASTM D638 Type IV Speed 50 mm pm		
Strength at Break (N/mm)			26
Elongation at Break % G L 50mm		960	
Tear Resistance (N)	ASTM D1004		90
Puncture Resistance (N)	ASTMD4833		200

Reference Property.	Test Method.		Nominal Values.
Thickness (mm)	ASTM D5199		1.5
Multi-axial Strain	ASTM D5617		>100
Carbon Black Content (%)	ASTM D1603		3.0
Carbon Black Dispersion	ASTM D5596		Note 1
Dimensional Stability (%)	ASTM D1204	±1.0%	
Low Temperature Brittleness °C	ASTM 746 Condition B		<-40
Melt Flow Index g/10 minutes	ASTM D1238 Cond. 190/2.16		<1.0

Note 1. Dispersion only applies to near spherical agglomerates. 9 of 10 views shall be Category 1 or 2. No more than 1 view from Category 3.

TRANSPORT INFORMATION
Roll width: 5.7m
Roll length: 130m
Roll weight: approx. 1,000kg

Appendix 12.3 Case study proforma

Site Location	
Date installed	
Design of the root barrier	
Barrier material.	
Construction method.	
Plan of the site with location of root barrier.	
Soils information	
Level or crack width monitoring results.	
Extent of repairs to the property carried out	
Cost of the root barrier	
Tree that was saved by introducing root barrier.	
Vegetation remaining.	
Depth of root barrier	
Width of the barrier	
Why in general was the root barrier option chosen over other methods.	
Any difficulties encountered.	
Monitoring after construction.	
Was the solution successful	

Continuation box

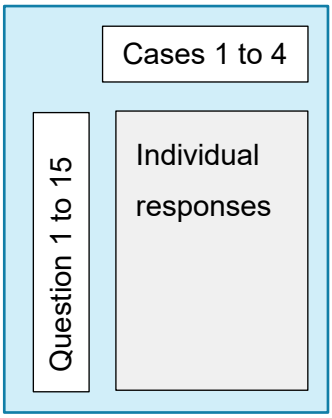
Any other comments

Add photos or drawings details as required.

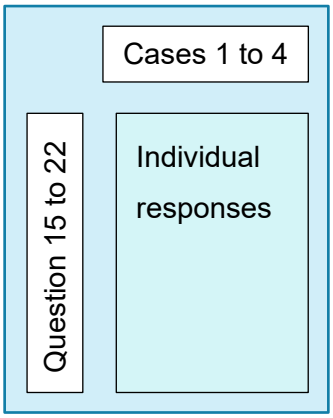
Appendix 12.4

Case Study Full Results

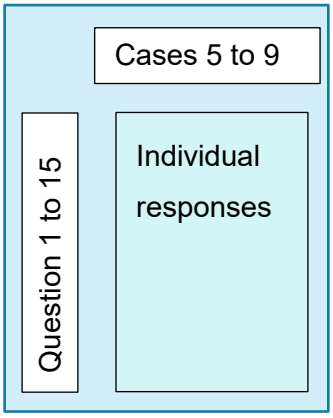
The full case study database results have been transferred to A4 sheets subdivided as indicated below.



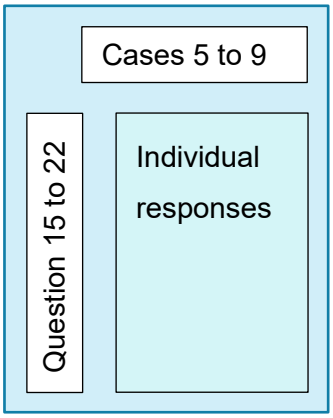
sheet 1 participant 1



sheet 2 participant 1



sheet 3 participant 2



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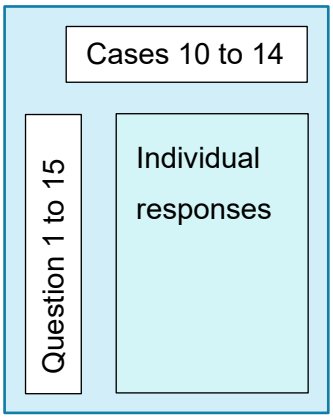
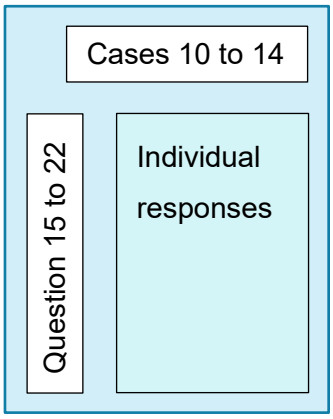
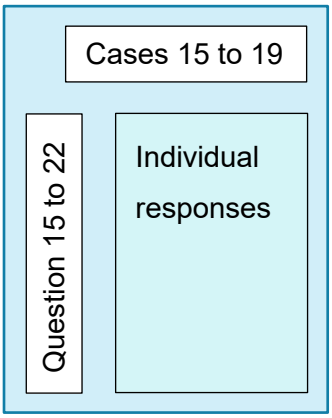


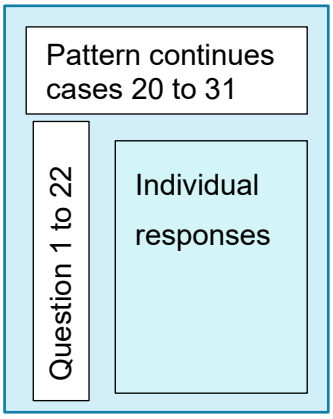
sheet 5 participant 2



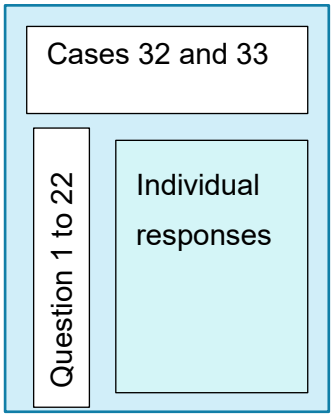
sheet 6 participant 2



sheet 7 participant 2



sheets 8 -14 participant 2



sheet 15 and 16 participant 3

Participant 1 Results

	Question	Participant 1 results Cases			
		1	2	3	4
1	Site Location	Wilburton Ely	Romford Essex	London W11	Eastleigh Hants
2	Postcode				
3	Date Installed	2014	2011	2017	2014
4	Design of the root barrier	None specific detailed procedure prepared.	Yes, NHBC rules for depth required	Yes by others	No specific design
5	Barrier material	steel sheet piles as barrier material.			
6	Construction method	Participant has developed a method of pre-boring and installation of steel sheets as barrier material.			
7	Plan of the site with location of root barrier	yes	yes	yes	yes
8	Soils information, all soils clay but properties noted	Clay soil	Clay soil	London Clay, Roots down to 5m. See S.I report.	Clay soil
9a	Level monitoring	no	no	no	no
9b	Crack monitoring	no	no	no	no
10	Extent of repairs to the property carried out	n/a	n/a	n/a	n/a
11	Cost of the root barrier exc.vat £	18,000	19,000	100,000	14,000
11	cost including vat £	21,600	22,800	12,0000	16,800
12	Tree that was saved by introducing root barrier	1 No 20m Oak	4x Acer	5 No London planes plus addn smaller vegetation	Acer
13	Vegetation remaining	3 No 20m Firs	1x Hornbeam		
14	Depth of the root barrier (m)	4	4	5	4
15	Length of the root barrier	17m	28m	60m	16m

Participant 1 results questions 1 to 15

	Question	Participant 1 results Cases			
		1	2	3	4
16	Why in general was the root barrier option chosen over other methods	Unable to remove trees, in neighbours garden	Lowest cost compared with traditional underpin and shire piles. 3 solutions priced.	Unable to remove 3 No Plane trees. Ongoing damage for over 10 years.	Unable to remove tree.
17	Any particular difficulties encountered	Note the barrier was installed within 1m of the property and restricted by existing scaffolding.	Garage also demolished and rebuilt but on a raft foundation. When rebuilt not aware of need for piles when rebuilding. Good rewards needed.	Length of piles, restricted access. Residents' complaints disruption ground floor. Not all services identified 30 flats affected	none
18	Monitoring Requested	n/a	n/a	n/a	n/a
19	Monitoring after construction	no	no	no	no
20	Was the solution successful? I.e. no record of client reproach				
21	photos additional information	yes	yes	yes	yes
22	Any other comments	Note the barrier was installed within 1m of the property. scaffolding		Time for root barriers. 2 day, but enabling 4 weeks.	

Participant 1 results questions 15 to 22

Participant 2 Results

Participant 2 results includes 27 cases grouped 5 - 9, 10 -14, 15-19, 20-24, 25-29, 30 and 31.

	Question	Participant 2 results Cases				
		5	6	7	8	9
1	Site Location	Woodford Green, Essex	Wicksworth Essex	Tarvers Orchard, Sutton under Brailes	Molehill Road, Chestfield	Stevenage, Hertfordshire
2	Postcode	IG8 9AW	SS12 0DB	OX15 5BH	CT5 3PD	SG2 0HL
3	Date Installed	01/05/2013	26/10/2012	22/07/2013	07/11/2012	09/12/2013
4	Design of the root barrier	Participant 2 own design				
5	Barrier material	WLS Flexline 1.5mm Propylene/ethylene copolymer geomembrane				
6	Construction method	Machine excavated and trench sheets used				
7	Plan of the site with location of root barrier	Not provided by participant however it is assumed that file records would include a plan of the site				
8	Soils information,	Clay, PI 26-50	Clay, PI 45-48	Clay, PI 21-31	Clay, PI 51-58	Clay, PI 30-38
9a	Level monitoring	no	yes	yes	yes	yes
9b	Crack monitoring	no	yes	yes	no	no
10	Extent of repairs	N/A	N/A	N/A	N/A	N/A
11	Cost of the root barrier excluding vat £	13,165	18,576	25,145	24,735	18,635
11	Cost including vat £	15,798	22,291	30,174	29,682	22,362
12	Tree that was saved by introducing root barrier	Oak, 20m high, 20m from property	Oak, 18m high, 27.5m from property	Oak, 17m high, 11m from property	2x Oaks 14&15m high, 12m from property	Oak, 15m high, 10.33m from property
13	Vegetation remaining	No information provided by participant				
14	Depth of the root barrier (m)	4	4	4.5	4.6	4
15	Length of the root barrier	12m	18m	22m	20m	15m

Participant 2 results questions 1 to 15 cases 5 to 9

	Question	Participant 2 results				
		5	**6**	**7**	**8**	**9**
16	Why in general was the root barrier option chosen over other methods?	In general root barrier was chosen in most cases because trees had TPO or root barrier was cheaper than underpinning,				
17	Any particular difficulties encountered?	Services, Fencing & walls, Hard surfacing and hard landscaping, Restricted access, Third party agreement, Restricted space, Storage for trench arisings and gravel, Overhead cables				
18	Monitoring Requested	31/07/2019 chased 11/09/19	15/07/2019 chased 31/07/2019 chased 11/09/19	Received	Received	Received
19	Monitoring after construction?	No	Unknown	No	Yes to 09/14	Yes to 05/14
20	Was the solution successful? i.e. no record of client reproach	Yes	Yes	Yes	Yes	Yes
21	photos additional information					
22	Any other comments					

Participant 2 results questions 16 to 22 cases 5 to 9

	Question	Participant 2 results				
		10	**11**	**12**	**13**	**14**
1	Site Location	Epsom, Surrey	Loughton, Essex	Hotel, Crawley	Leeds, West Yorkshire	Sutton, London
2	Postcode	KT19 8LF	IG10 2HJ	RH11 0JY	LS16 8ES	SM1 3LB
3	Date Installed	07/06/2014	30/06/2014	21/07/2014	25/07/2014	05/09/2014
4	Design of the root barrier	participant 2 own design				
5	Barrier material	WLS Flexline 1.5mm Propylene/ethylene copolymer geomembrane				
6	Construction method	Machine excavated and trench sheets used				
7	Plan of the site with location of root barrier	Not provided by participant however it is assumed that file records would include a plan of the site				
8	Soils information, all soils clay but properties noted	Clay PI 50-54 (TP1) PI 37-50 (TP2)	Clay PI 42-55 (TP1) PI 50-51 (TP2)	Clay, multiple SI reports	Clay, PI 18-22	Clay, PI 48-54
9a	level monitoring	no	yes	yes	no	yes
9b	crack monitoring	no	no	yes	no	no
10	Extent of repairs to the property	N/A	N/A	N/A	N/A	N/A
11	Cost of the root barrier excluding vat	15,736	19,600	23,700	17,900	17,895
11a	Cost including vat	18,883.2	23,520	28,440	21,480	21,474
12	Tree that was saved by introducing root barrier	Oak, unknown height or distance from property	Oak, 15.5m high, 7.5m from property	3x Oaks, 14, 9.5 & 7.5m high, 9, 8 & 8m from property	Oak, Ash, Sycamore, 22, 19 & 17m high, 10, 10 & 11m from property	4x Oaks, 14, 20, 20 & 20m high, 9.6, 10, 11 & 13m from property
13	Vegetation remaining	No information provided by participant				
14	Depth of the barrier (m)	3.5	4	4	4.5	4.5
15	Length of the root barrier	20m	22m	30m	17m	22m

Participant 2 results questions 1 to 15 cases 10 to 14

	Question	Participant 2 results				
		10	**11**	**12**	**13**	**14**
16	Why in general was the root barrier option chosen over other methods?	In general root barrier was chosen in most cases because trees had TPO or root barrier was cheaper than underpinning,				
17	Any particular difficulties encountered?	Services, Fencing & walls, Hard surfacing and hard landscaping, Restricted access, Third party agreement, Restricted space, Storage for trench arisings and gravel, Overhead cables				
18	Monitoring Requested	Other client	Other client	Received	Received	Received
19	Monitoring after construction	N/A	N/A	Yes to 11/14	Only 1 further reading	Only 1 further reading
20	Was the solution successful? i.e. no record of client reproach	Yes	Yes	Yes	Yes	Yes
21	photos additional information					
22	Any other comments				v large rock encountered in the ground	

Participant 2 results questions 16 to 22 cases 10 to 14

	Question	Participant 2 results				
		15	**16**	**17**	**18**	**19**
1	Site Location	Beckenham, Kent	Waltham Abbey, Essex	Witcombe, Bristol	Leadhall Lane, Harrogate	Aldershot, Hampshire
2	Postcode	BR3 5HE	EN9 3AE	BS37 8SA	HG2 9NN	GU11 3SU
3	Date Installed	23/09/2014	14/11/2014	28/11/2014	09/10/2015	14/03/2016
4	Design of the root barrier	participant 2 own design				
5	Barrier material	WLS Flexline 1.5mm Propylene/ethylene copolymer geomembrane				
6	Construction method	Machine excavated and trench sheets used				
7	Plan of the site with location of root barrier	Not provided by participant however it is assumed that file records would include a plan of the site				
8	Soils information, all soils clay but properties noted	Clay, PI 25-32	Clay	Clay, PI 33	Clay PI 24-25 (TP1) PI 23 (TP2)	Clay PI 39-41 (TP1) PI,39-62 (TP2)
9a	level monitoring	yes	no	yes		yes
9b	crack monitoring	no	no	no	yes	no
10	Extent of repairs	N/A	N/A	No	N/A	N/A
11	Cost of the root barrier ex vat	13010	15627	8345	11500	14968
11a	cost including vat	15612	18752.4	10014	13800	17961.6
12	Tree that was saved by introducing root barrier	2x Oaks, 17&18m high, 15&18m from property	Oak, 15-20m high, 20m from property	Acer, 8m high, 6.8m from property	Multiple including Lime, Beech, Cypress and Pine	2x Oaks, 21&18m high, 17&13.5m from property
13	Vegetation remaining	No information provided by participant				
14	Depth of the root barrier (m)	2.5	4.5	3	3.5	4.0m
15	Length of the root barrier	13m	12m	14m	14m	15m

Participant 2 results questions 1 to 15 cases 15 to 19

	Question	Participant 2 results				
		15	**16**	**17**	**18**	**19**
16	Why in general was the root barrier option chosen over other methods	In general root barrier was chosen in most cases because trees had TPO or root barrier was cheaper than underpinning,				
17	Any particular difficulties encountered	Services, Fencing & walls, Hard surfacing and hard landscaping, Restricted access, Third party agreement, Restricted space, Storage for trench arisings and gravel, Overhead cables				
18	Monitoring Requested	Received	None	Received	Received	Received
19	Monitoring after construction	No	No	No	Yes to 03/16	Yes, only 3 further readings
20	Was the solution successful? i.e. no record of client reproach	Yes	Yes	Yes	Yes	Yes
21	photos additional information					
22	Any other comments					

Participant 2 results questions 16 to 22 cases 15 to 19

	Question	Participant 2 results				
		20	21	22	23	24
1	Site Location	Ashleworth, Gloucester	Southgate, London	Stevenage, Hertfordshire	Pulborough	Bristol
2	Postcode	GL19 4JN	N14 7BB	SG2 9XS	RH20 1DD	BS15 9ZB
3	Date	22/02/2016	25/10/2016	09/05/2016	25/07/2016	29/03/2017
4	Design of the root barrier	participant 2 own design				
5	Barrier material	WLS Flexline 1.5mm Propylene/ethylene copolymer geomembrane				
6	Construction method	Machine excavated and trench sheets used				
7	Plan of the site with location	Not provided by participant however it is assumed that file records would include a plan of the site				
8	Soils information, all soils clay	Clay, PI 44-48	Clay, PI 49-58	Clay, PI 22-25	Clay	PI 29-44 (TP1) PI 20-30 (TP2)
9a	level monitoring	yes	yes	yes	no	yes
9b	crack monitoring	no	no	yes	yes	no
10	Extent of repairs	N/A	N/A	N/A	N/A	
11	Cost of the root barrier	13752	21155	19065	14500	12500
11a	cost including vat	16502.4	25386	22878	17400	15000
12	Tree that was saved by introducing root barrier	Oak, 14.5m high, 11m from property	Cedar, 17.5m high, 12m from property	Oak, 25m high, 12m from property	Multiple including Oak, Sweet Chestnut and Field Maple	1x Oak, 2x Lime, 10.3-12.9m high, 7.5-10m from property
13	Vegetation remaining	No information provided by participant				
14	Depth of the root barrier (m)	4.0m	4.0m	4.0m	4.0m	4.0m
15	Length of the root barrier	15m	21m	20m	20m	12m

Participant 2 results questions 1 to 15 cases 20 to 24

	Question	Participant 2 results				
		20	**21**	**22**	**23**	**24**
16	Why in general was the root barrier option chosen over other methods?	In general root barrier was chosen in most cases because trees had TPO or root barrier was cheaper than underpinning,				
17	Any particular difficulties encountered?	Services, Fencing & walls, Hard surfacing and hard landscaping, Restricted access, Third party agreement, Restricted space, Storage for trench arisings and gravel, Overhead cables				
18	Monitoring Requested	Received	Other supplier	Received	Other supplier	Other client
19	Monitoring after construction	Yes, only 3 further readings	N/A	Yes, only 2 further readings	N/A	N/A
20	Was the solution successful? i.e. no record of client reproach	Yes	Yes	Yes	Yes	Yes
21	photos additional information					
22	Any other comments					

Participant 2 results questions 16 to 22 cases 20 to 24

	Question	Participant 2 results				
		25	**26**	**27**	**28**	**29**
1	Site Location	Chessington, Surrey	Allerton Bywater, W Yorkshire	Wray Lane, Reigate	Newbury, Berkshire	Farnham Common, Slough
2	Postcode	KT9 2SP	WF10 2AH	RH2 0HS	RG14 7JP	SL2 3LR
3	Date Installed	22/01/2018	05/01/2018	12/07/2018	11/10/2018	13/11/2018
4	Design of the root barrier	participant 2 own design				
5	Barrier material	WLS Flexline 1.5mm Propylene/ethylene copolymer geomembrane		Copper sheet mechanically encapsulated between a woven polypropylene geotextile and a high strength nonwoven polypropylene geotextile		
6	Construction method	Vacuum suction	Machine excavated Trench sheets used			
7	Plan of the site with location of root barrier	Not provided by participant however it is assumed that file records would include a plan of the site				
8	Soils information, properties noted	PI 31-51 (TP1) PI 39-45 (TP2) PI 18-51 (BH3)	Clay, PI 41 (TP2), 19-31 (BH2), 21-269 (BH3)	Clay, PI 59-69	Clay, PI 23-41 (TP1), 15-28 (BH2)	Clay, 45-54 (TP1), 42-47 (TP2)
9a	level monitoring	yes	yes	yes	yes	yes
9b	crack monitoring	no	no	no	no	no
10	Extent of repairs	No response				
11	Cost of the root barrier	13002	12600	25152	12890	26800
11a	cost including vat	15602.4	15120	30182.4	15468	32160
12	Tree that was saved by introducing root barrier	2x Field Maple, 10&10m high, 7.5&8m from property	Multiple including Oak, Sycamore, Ash and Hawthorn	Copper Beech, 19m high, 10.6m from property	London Plane, 24m high, 14.5m from property	Oak, 19m high, 8m from property
13	Vegetation remaining	No information provided by participant				
14	Depth of the root barrier (m)	4.5m	3.5m	3.5m	2.5m	4.0m
15	Length of the root barrier	8m	21m	25m	16m	18m

Participant 2 results questions 1 to 15 cases 25 to 29

	Question	Participant 2 results				
		25	**26**	**27**	**28**	**29**
16	Why in general was the root barrier option chosen over other methods	In general root barrier was chosen in most cases because trees had TPO or root barrier was cheaper than underpinning,				
17	Any particular difficulties encountered	Services, Fencing & walls, Hard surfacing and hard landscaping, Restricted access, Third party agreement, Restricted space, Storage for trench arisings and gravel, Overhead cables				
18	Monitoring Requested	Received	Received	CET	Received	Received
19	Monitoring after construction	Yes to 12/18	Yes to 06/19	N/A	Yes to 07/19	Yes to 06/19
20	Was the solution successful? i.e. no record of client reproach	Yes	Yes	Yes	Yes	Yes
21	photos additional information					
22	Any other comments					

Participant 2 results questions 16 to 22 cases 25 to 29

	Question	Participant 2 results	
		30	**31**
1	Site Location	Kiln Lane, Tilehurst	Wickford, Essex
2	Postcode	RG31 5UE	SS11 7BJ
3	Date Installed	03/06/2019	24/07/2019
4	Design of the root barrier	participant 2 own design	
5	Barrier material	Copper sheet mechanically encapsulated between a woven polypropylene geotextile and a high strength nonwoven polypropylene geotextile	
6	Construction method	Machine excavated Trench sheets used	
7	Plan of the site with location of root barrier	Not provided by participant however it is assumed that file records would include a plan of the site	
8	Soils information, all soils clay but properties noted	No SI	Clay, PI 41-59
9a	level monitoring	yes	yes
9b	crack monitoring	no	no
10	Extent of repairs to the property carried out		
11	Cost of the root barrier excluding vat	19700	16326
11a	cost including vat	23640	19591.2
12	Tree that was saved by introducing root barrier	Multiple including Oak, Willow and Ash	2x Oaks, 20&18m high, 16&18m from property
13	Vegetation remaining	No information provided by participant	
14	Depth of the root barrier (m)	4.0m	3.5m
15	Length of the root barrier	25m	16m

Participant 2 results questions 1 to 15 cases 30 and 31

	Question	Participant 2 results	
		30	**31**
16	Why in general was the root barrier option chosen over other methods	In general root barrier was chosen in most cases because trees had TPO or root barrier was cheaper than underpinning,	
17	Any particular difficulties encountered	Services, Fencing & walls, Hard surfacing and hard landscaping, Restricted access, Third party agreement, Restricted space, Storage for trench arisings and gravel, Overhead cables	
18	Monitoring Requested	Received	Received
19	Monitoring after construction	Only 1 reading	Only 1 reading
20	Was the solution successful? i.e. no record of client reproach		
21	photos additional information		
22	Any other comments		

Participant 2 results questions 15 to 22 cases 30 and 31

Participant 3 Results

	Question	Participant 3 results	
		32	**33**
1	Site Location	Southend on sea	Pinner, North London
2	Postcode	SS07NE	HA5 4PW
3	Date Installed	2015	Design only
4	Design of the root barrier	Yes	Yes, full design by Author
5	Barrier material	Woven fabric with copper core	Not installed, material not determined
6	Construction method	Trench excavation backfilled with concrete and copper impregnated barrier. Plant used Kubota U27-4	n/a
7	Plan of the site with location of root barrier	Yes see details	Yes
8	Soils information, all soils clay but properties noted	Plane roots under house to 1.6m depth. 600mm foundation depth. Clay soil encountered in desiccated condition	Full site investigation completed, London Clay soils
9a	level monitoring	Yes see results	Yes
9b	crack monitoring	Yes to property	Yes
10	Extent of repairs to the property carried out	Superstructure repairs widespread through property total cost of repairs £30,000	Extensive damage to property. Trees were not the only operating cause.
11	Cost of the root barrier excluding vat	Cost of barrier not known.	Not known but estimated at £40,000
11a	cost including vat	Not known	Not known but estimated at £50,000
12	Tree that was saved by introducing root barrier	London Plane see photos	Pear, Willow, Sycamore, 3 English Oaks, Lombardy Poplar and a Weeping Willow
13	Vegetation remaining	London Plane	As above
14	Depth of the root barrier (m)	2.5m	Varies maximum 4m.
15	Length of the root barrier	14m	90m

Participant 3 results questions 1 to 15 cases 32 and 33

	Question	Participant 3 results	
		32	**33**
16	Why in general was the root barrier option chosen over other methods	To prevent underpinning of the property as root barrier was more cost effective.	To avoid tree removal
17	Any particular difficulties encountered		Barrier not installed.
18	Monitoring Requested	n/a	no
19	Monitoring after construction	Level monitoring after root barrier installation to end of March 2016	no
20	Was the solution successful? i.e. no record of client reproach	Yes, although minor cracking was reported after repairs not related to subsidence damage.	Not installed as claim resolved by alternative methods
21	photos additional information	See attached	appendix
22	Any other comments	When excavating barrier, no significant roots 3 days total. Day 1 and 2 excavate, install barrier and pour concrete. Day 3 reinstate. This was a partial scheme used in conjunction with removal of another nearby tree, see plan.	The root barrier option to resolve the claim served as an opportunity to maintain the trees in place whilst demonstrating that the root barrier could stop roots from reaching the building thus negating the liability attaching to the tree owners for root trespass.

Participant 3 results questions 16 to 22 cases 32 and 33

18/1/18 #1 of 4.

1	Site Location	Wilburton, Ely
2	Date installed	2014
3	Design of the root barrier	None specific detailed procedure prepared.
4	Barrier material.	developed a method of pre-boring and installation of steel sheets as barrier material.
5	Construction method.	
6	Plan of the site with location of root barrier.	Yes provided
7	Soils information	Clay Soil
8	Level or crack width monitoring results.	n/a approached by loss adjusters to install solution.
9	Extent of repairs to the property carried out	n/a
10	Cost of the root barrier	4m depth, 17m length £18k + vat
11	Tree that was saved by introducing root barrier.	1NO 20m Oak 3NO. 20m Firs
12	Vegetation remaining.	Tree at front.
13	Depth of root barrier	4m
14	Width of the barrier	17m
15	Why in general was the root barrier option chosen over other methods.	Unable to remove trees, in neighbours garden.

CS1

16	Any particular difficulties encountered.	Note the barrier was installed within 1m of the property. Scaffolding.
17	Monitoring after construction.	No
18	Was the solution successful	No information provided.

Notes :-

a) Cost of barrier includes cost of site set up, excavation installation of barrier + re-instatement

b) Design Q3 specifically identifies whether there are a set of calculations for design in terms of depth, distances etc.

CS1

ROOT CUT OFF METHODOLOGY:

R S

JOB NUMBER: SS-14-3075
CLIENT:
CLIENT REF:

NOTES:

Procedure for installing Steel Sheet Root Trench.

Remove existing Fence rails and associated posts.
Scan For domestic services, hand excavate and expose same if in the area of root trench.
Mark line of root trench line with site spray paint. (note any nearby services in red paint)
Using a T5000 Small rotary auger rig (1200kgs Mass) auger a series of 300mm diameter holes 4.0m deep (min 50mm Overlap) for entire length of proposed trench. Augers are to be reverse driven forcing excavated material back into holes.
Surplus material (estimated 16 m^3 2 skips) to be removed from site.
Erect mobile tower scaffold and Drive a Single M11 - 4.0m long Steel interlocking trench sheet into ground (initial drive undertaken using a 64kg Rhino Hammer)
Place subsequent steel sheets and drive to refusal.
If sheets are not driven to ground level utilise an Atlus Copco Sheet driver (750kgs) to drive sheets to refusal.
Access to the neighbours drive will be required for this element of the works as a small crane or excavator will be required to lift the hammer onto the sheets.
Cut all sheets off flush 50mm below ground level and reinstate the surface treatments.

Notes for arbolculturalist.

All roots in the area of the trench will be severed during the augering process. No Portland cement will be used on the Tree side of the trench. The sheets have a watertight interlock so no cement grout used the house side will leech into the soils the other side.

CS1

CS1

CS1

#2 of 4 18/1/18

CS2

Site Location	Romford Essex.
Date installed	2011
Design of the root barrier	Yes, NHBC rules for depth required.
Barrier material.	Steel sheet piles
Construction method.	p/e bored 300ø holes
Plan of the site with location of root barrier.	Yes
Soils information	Clay Soil
Level or crack width monitoring results.	n/a
Extent of repairs to the property carried out	n/a
Cost of the root barrier	£19,000 + vat.
Tree that was saved by introducing root barrier.	4 x Acer 1 x Hornbeam
Vegetation remaining.	n/a.
Depth of root barrier	4m.
Width of the barrier	28m
Why in general was the root barrier option chosen over other methods.	Lowest cost compared with traditional underpin and shire piles. 3 Solutions priced.

#2 of 4.

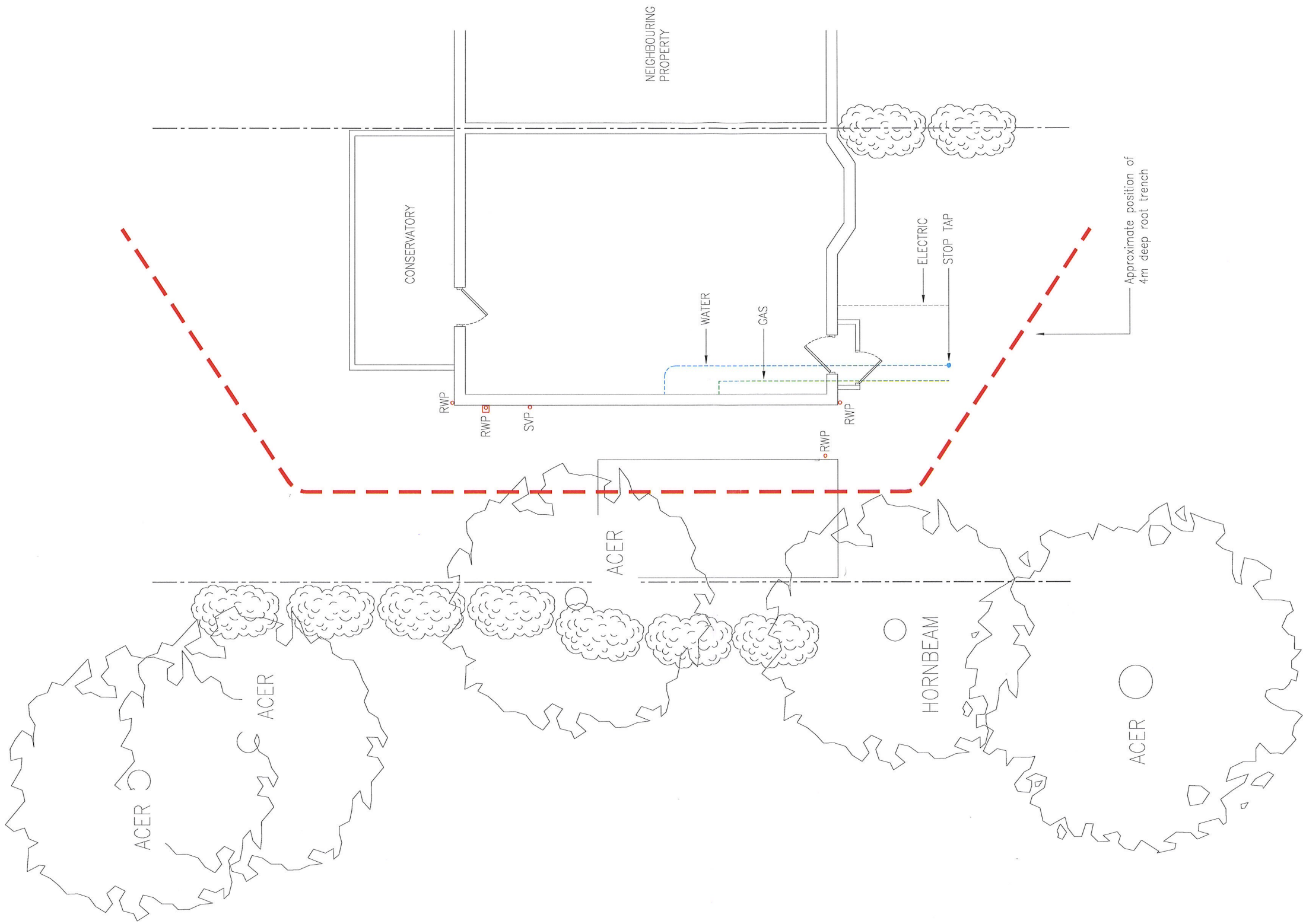
CS2

Any particular difficulties encountered.	garage also demolished + rebuilt but on a raft + failed. When rebuilt not aware of need for piles when rebuilding. Good records needed.
Monitoring after construction.	NO
Was the solution successful	No information provided.

CS2

CS2

CS2



ROOT TRENCH
Scale 1:100 @ A3

ISSUE	DESCRIPTION	BY	DATE
A	PRELIMINARY ISSUE	LM	01.06.11

SCALE AS SHOWN	DRAWN	LM	CHECKED	SC	APPROVED	SC
	DATE	17.05.11	DATE	01.06.11	DATE	01.06.11

ADDRESS

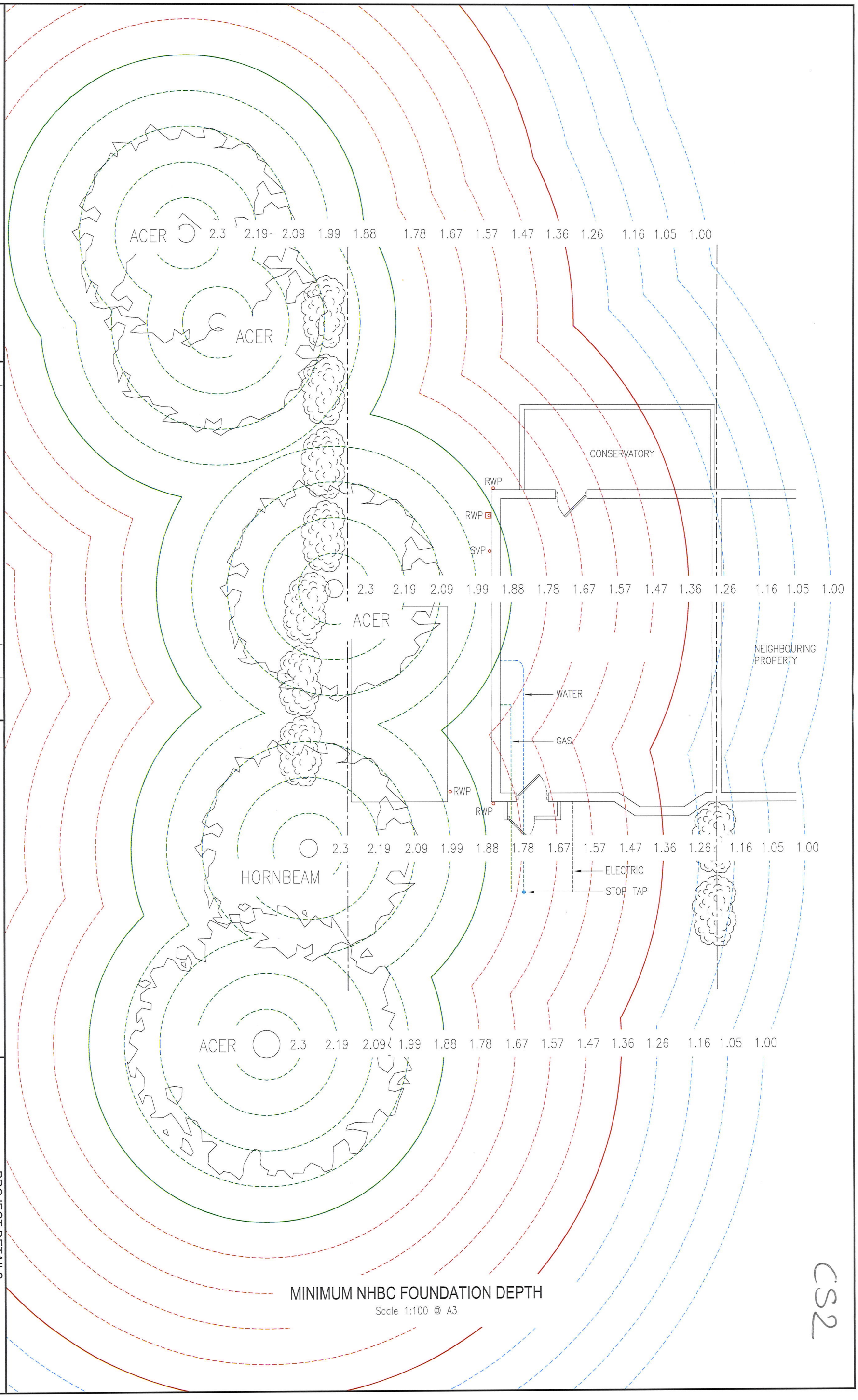
[redacted]
ROMFORD, ESSEX
RM3 0YS

PROJECT DETAILS

CLIENT [redacted]

HOME OWNER

DRG NUMBER A



MINIMUM NHBC FOUNDATION DEPTH

Scale 1:100 @ A3

CS2

7

ISSUE	DESCRIPTION	BY	DATE
A	PRELIMINARY ISSUE	LM	01.06.11

SCALE	DRAWN	CHECKED	APPROVED
AS SHOWN	LM	SC	SC
DATE	17.05.11	01.06.11	01.06.11

ADDRESS

PROJECT DETAILS

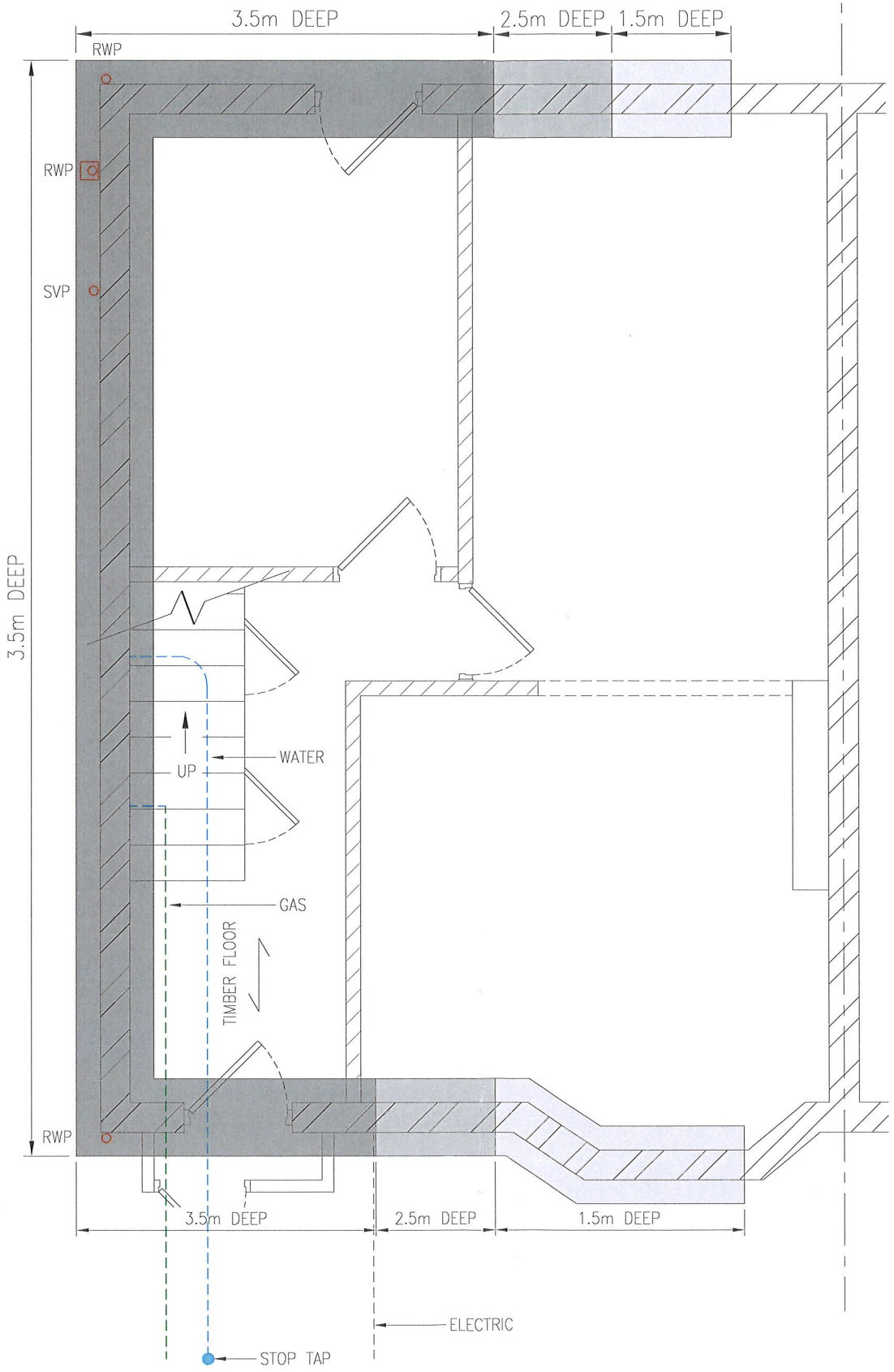
CLIENT

HOME OWNER

DRG NUMBER

REV A

CS2



PRELIMINARY SCHEME
TRADITIONAL UNDER PIN
Scale 1:50 @ A3

ISSUE	DESCRIPTION	BY	DATE
A	PRELIMINARY ISSUE	LM	01.06.11

SCALE AS SHOWN	DRAWN	LM	CHECKED	SC	APPROVED	SC
	DATE	17.05.11	DATE	01.06.11	DATE	01.06.11

ADDRESS

PROJECT DETAILS

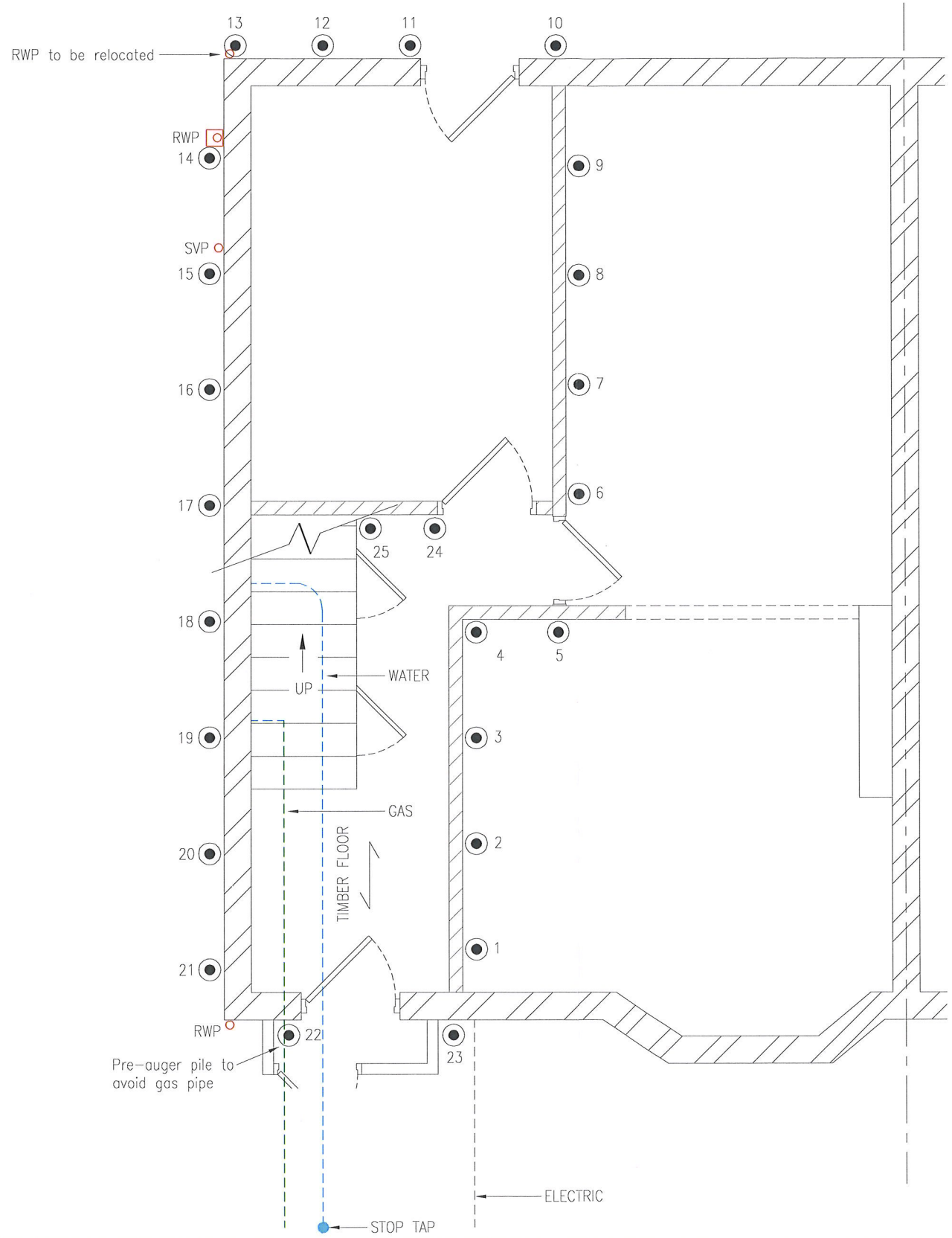
CLIENT: HALIFAX

HOME OWNER: WHITEHEAD - 416050433

DRG NUMBER: SSE-11-130/03

REV: A

CS2



0 1m

● PILE WITHOUT HEAD STRENGTHENING

◉ PILE WITH HEAD STRENGTHENING

PRELIMINARY PILING LAYOUT

Scale 1:50 @ A3

ISSUE	DESCRIPTION	BY	DATE
A	PRELIMINARY ISSUE	LM	01.06.11

SCALE		DRAWN	LM	CHECKED	SC	APPROVED	SC
AS SHOWN		DATE	17.05.11	DATE	01.06.11	DATE	01.06.11

ADDRESS

[redacted]
ROMFORD, ESSEX
RM3 0YS

PROJECT DETAILS

CLIENT

HOME OWNER

DRG NUMBER

REV A

#3 of 4 18/1/18

CS3

Site Location	London W11
Date installed	2017
Design of the root barrier	No calculations
Barrier material.	Steel sheet pile
Construction method.	pre-boring and installation of sheet piles
Plan of the site with location of root barrier.	Provided. Drawings include sections
Soils information	Clay Soil
Level or crack width monitoring results.	n/a
Extent of repairs to the property carried out	n/a
Cost of the root barrier	£100,000
Tree that was saved by introducing root barrier.	5No London Planes plus additional smaller vegetation
Vegetation remaining.	n/a
Depth of root barrier	5m
Width of the barrier	60m
Why in general was the root barrier option chosen over other methods.	Unable to remove Plane Trees.

CS3

Any particular difficulties encountered.	length of piles, restricted access Residents complaints disruption ground floor. Not all services identified.
Monitoring after construction.	NO
Was the solution successful	No information available.

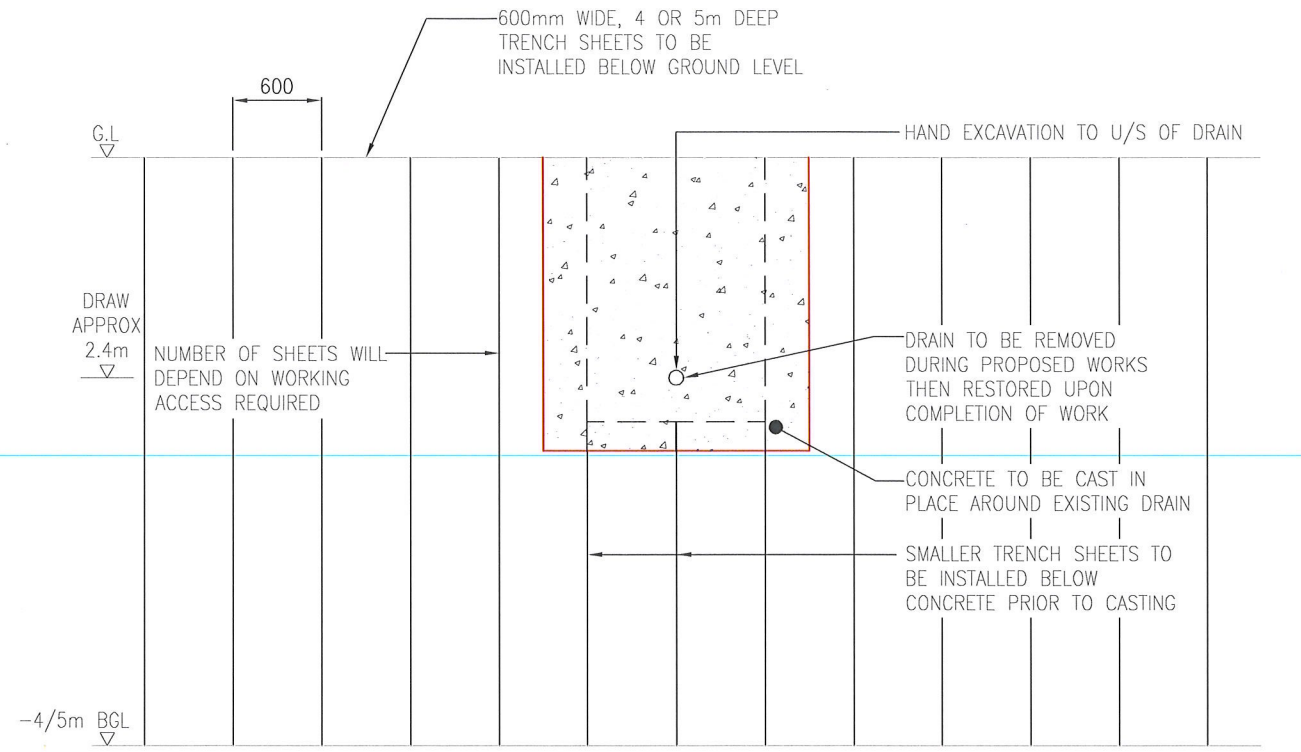
Notes :- prepared a very detailed procedure for installation of sheet pile root barrier.

Date: 16/03/17

Procedure for Installation of Steel Sheet Root Barrier

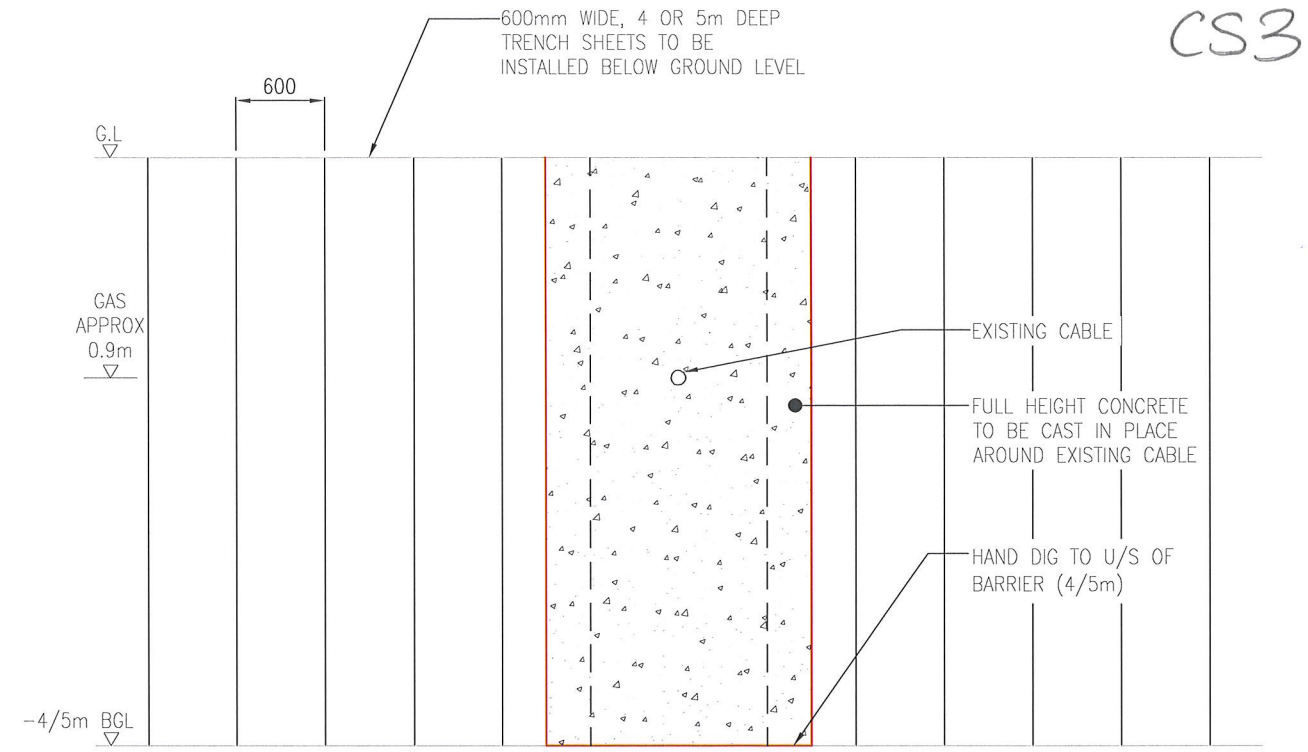
- All preliminaries and site set up to be completed by others
- Scan for domestic services, hand excavate and expose same if around root trench
- Mark line of root trench line with site spray paint
- Using a T5000 small rotary auger rig (1200kgs Mass), auger a series of 300mm diameter holes 4 or 5m deep (min 50mm Overlap) for approximately 1m length of proposed barrier run. Flights to be back spun to force material back into hole as the purpose of the augering is to loosen the ground to enable the driving of the sheets through the clay soils
- Excavate 2m deep trench to allow sheets to be lowered into place
- Lower 4 or 5m long steel sheet into 2m deep hole and then drive the sheet using a 64kg Rhino. Rhino to be either lifted using either a) the excavator on site or b) if access is tight then a tower scaffold is to be erected and the Rhino hand lifted onto the sheets by hand
- Backfill extracted material and compact in layers around the sheets
- Repeat this process, approximately 1m at a time for full length of barrier
- Where drains cross the line of the barrier:
    - Hand dig to the underside of the drain
    - Cut out 1m section of drainage and drive cut down length of sheet to the required depth
    - Reinstate drain using flexible rubber seal couplers
    - Continue to drive full length sheets either side of the drain
    - Cast concrete over drain and between full height sheets to ensure continuity of barrier
- Where services (gas, electric/water) cross the line of the barrier:
    - Hand dig to required depth of root barrier making sure to provide appropriate shoring to excavations (to be advised by engineer) adjacent to previously driven full height sheet
    - Place plastic sleeve over the service (approx. 1m long) and tape up both ends of the sleeve to seal
    - Drive further full height sheet on the other side of the service leaving a gap around the service
    - Cast concrete to full depth to ensure continuity of barrier
- Cut off all sheets flush 200mm below ground level, back fill around the side of the sheets, compact the backfill material to reduce the risk of settlement and reinstate the surfaces
- Cast concrete strip across the top of the sheets 150mm below ground level to allow turf to be laid over (by others)

CS3



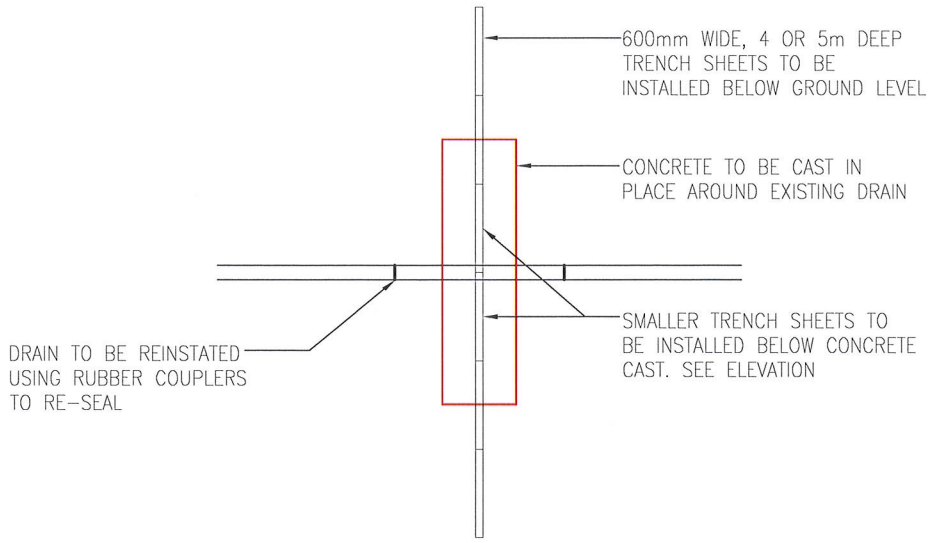
OPTION 1 – DRAIN – FRONT ELEVATION

0 1m
1:50



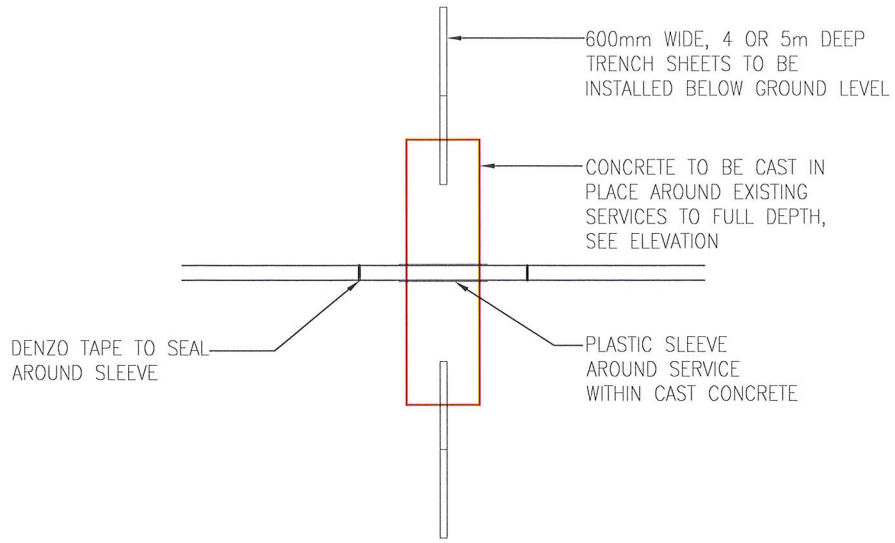
OPTION 2 – GAS/ELECTRIC – FRONT ELEVATION

0 1m
1:50



0 1m
1:50

OPTION 1 – DRAIN – PLAN



0 1m
1:50

OPTION 2 – GAS/ELECTRIC – PLAN

ISSUE	DESCRIPTION	BY	DATE
B	AS BUILT ISSUE	CS	20.06.17
A	ISSUED FOR APPROVAL/CONSTRUCTION	CS	17.03.17

SCALE	DRAWN	CS	CHECKED	DW	APPROVED	DW
AS SHOWN	DATE	17.03.17	DATE	17.03.17	DATE	17.03.17

TITLE
AS BUILT ROOT BARRIER DETAIL

ADDRESS

PROJECT DETAILS

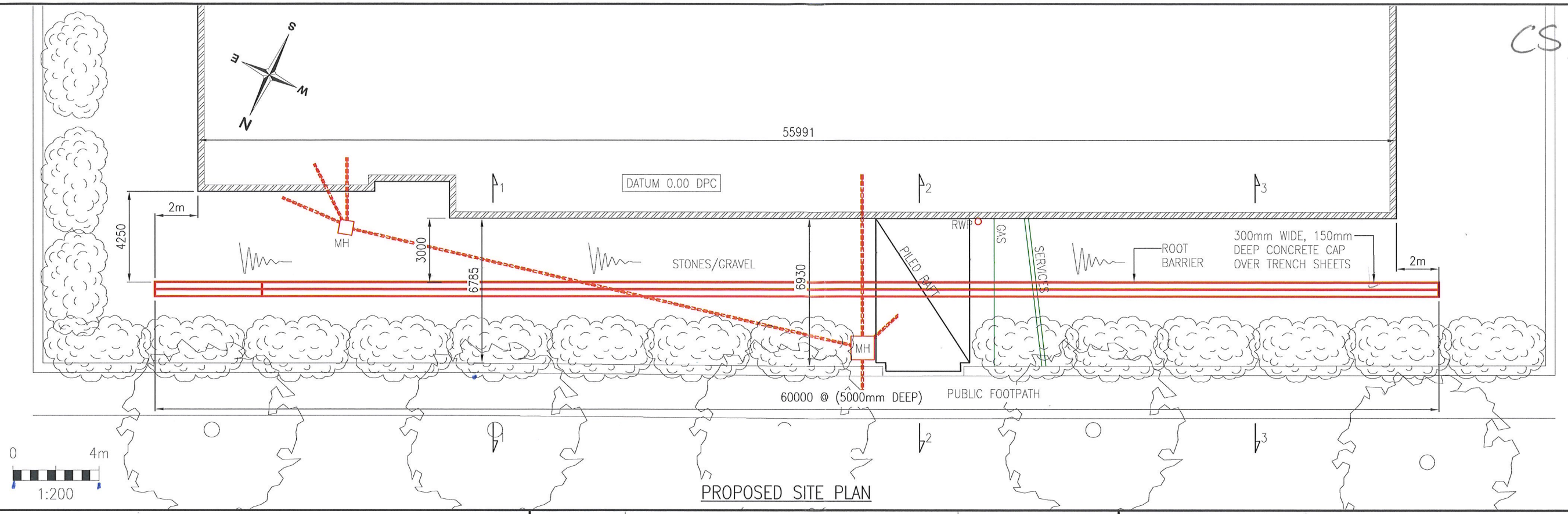
CLIENT

HOME OWNER

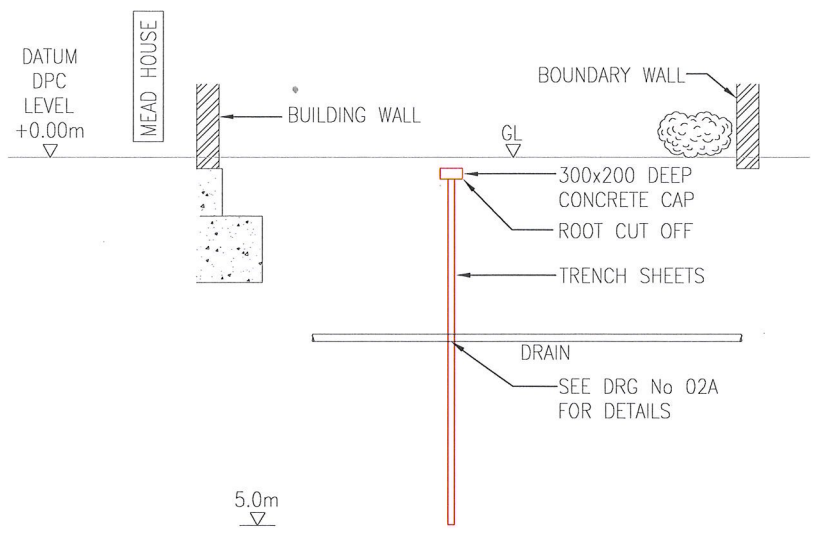
DRG NUMBER

REV **B**

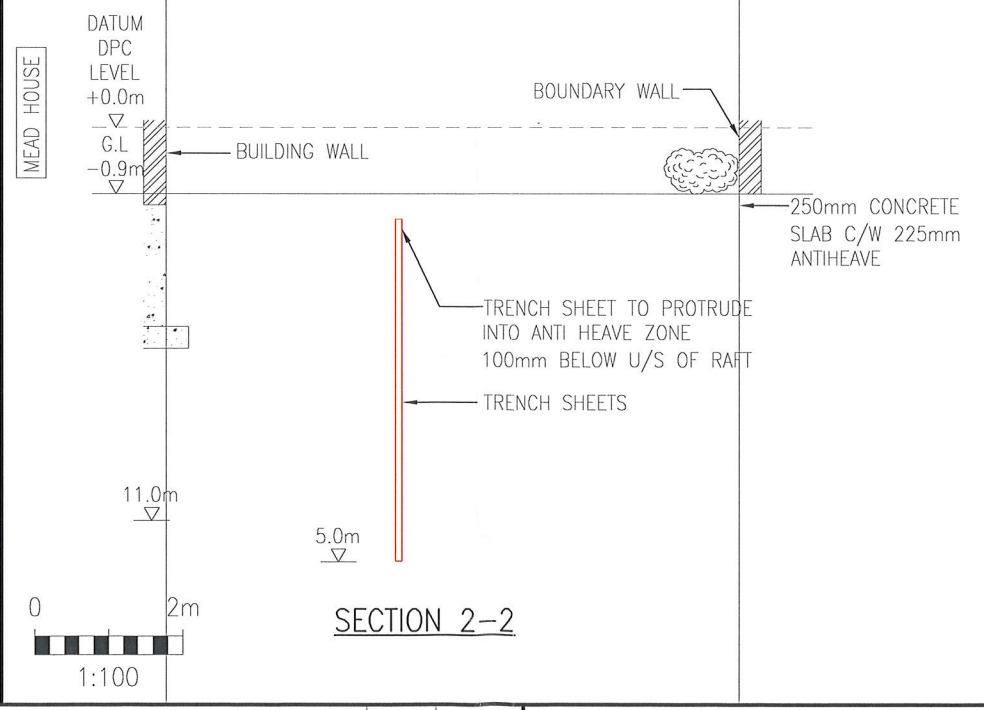
CS3



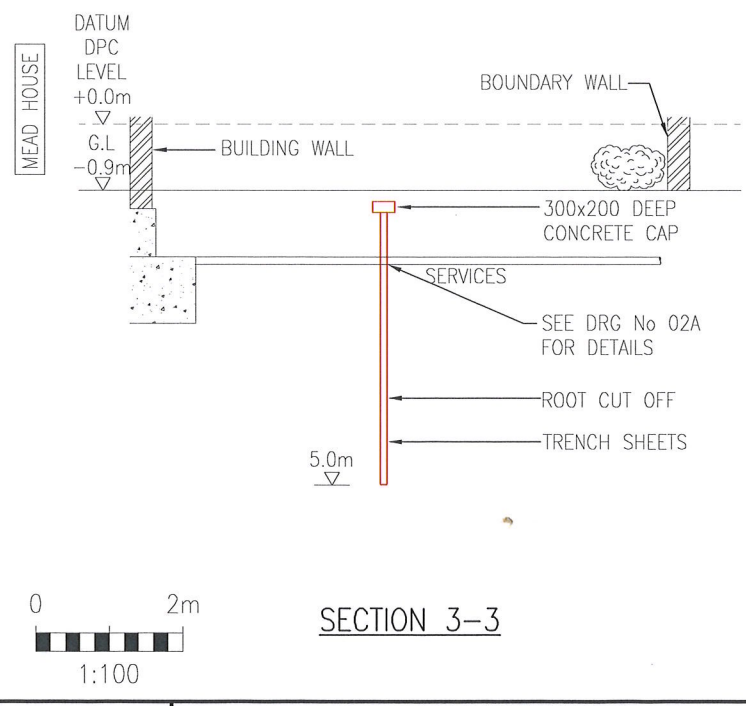
PROPOSED SITE PLAN



SECTION 1–1



SECTION 2–2



SECTION 3–3

ISSUE	DESCRIPTION	BY	DATE
E	AS BUILT ISSUE	TG	06.06.17
D	TRENCH SHEET LOCATION AMENDED	DB	21.03.17
C	TRENCH SHEET LOCATION AMENDED	DB	21.03.17
B	DRAWING AMENDMENTS	DB	20.03.17
A	ISSUED FOR APPROVAL/CONSTRUCTION	CS	17.03.17

SCALE	DRAWN	CS	CHECKED	DW	APPROVED	DW
AS SHOWN	DATE	17.03.17	DATE	17.03.17	DATE	17.03.17

TITLE: AS BUILT SITE PLAN

ADDRESS: [redacted]
LONDON
W11 3PU

PROJECT DETAILS

CLIENT: [redacted]

HOME OWNER

DRG NUMBER

REV E

4 of 4. 18/1/18

CS4

Site Location	Eastleigh Hants
Date installed	2014
Design of the root barrier	No specific design
Barrier material.	Steel sheet pile
Construction method.	pre boring and installation of piles
Plan of the site with location of root barrier.	Provided
Soils information	Clay Soil.
Level or crack width monitoring results.	N/a
Extent of repairs to the property carried out	N/a.
Cost of the root barrier	£14,000
Tree that was saved by introducing root barrier.	Acer
Vegetation remaining.	n/a
Depth of root barrier	4m (tbc)
Width of the barrier	16m
Why in general was the root barrier option chosen over other methods.	Unable to remove tree.

CS4

Any particular difficulties encountered.	None
Monitoring after construction.	
Was the solution successful	

CS4

CS4

CS4

CS4

ROOT TRENCH -16m

REAR OF PROPERTY

Grassed Lawn

Planting

DWARF WALL

ASSUMED DRAINAGE RUN

MH1

MH2

Steps Up

Grassed Lawn

ACER TREE

4.5m Min.

PC SLABS

Planting

DWARF WALL

RWP

DINNING X2

MAX 0.5M PILE SPACINGS

9

8

7

6

5

4

3

2

1

Min.

LOUNGE X2

ROLL BACK CARPET AND PROVIDE ADEQUATE PROTECTION/SCREEN WITHIN HALL & LOUNGE

STAIRS UP

HALL X2

GARAGE X1

PREVIOUSLY UNDERPINNED

ACCESS TO REAR VIA GATE

SHED

FENCE

RWP

PREVIOUSLY PILED

RWP

RWP

FRONT OF PROPERTY

Note:
Existing drainage and service runs to be determined prior to work commencing

0 1m

1:50

Shire Stabiliser, with Head Strengthener

ISSUE	DESCRIPTION	BY	DATE
A	PRELIMINARY ISSUE, FOR INFORMATION ONLY	JB	09.04.2014

SCALE	DRAWN	JB	CHECKED		APPROVED	
AS SHOWN	DATE	09.04.2014	DATE		DATE	

ADDRESS

[redacted]

HANTS
SO50 4SA

PROJECT DETAILS

CLIENT

HOME OWNER

DRG NUMBER

REV A

Questionnaire for knowledgable particants. 18/1/18 At offices of participant 1.

Answer Scale

Strongly disagree Neither agree or disagree Strongly agree
0 1 2 3 4 5 6 7 8 9 10

	Question	Respondent 1 and 2
	Root barriers are rarely used and could be considered in more situations	6
	root barriers are rarely used because practitioners are unaware of the solution being available	5
	root barriers are rarely used because of fear they will not work	2
	root barriers are rarely used because even though they are considered and viable the cost is too high.	5
	root barriers are rarely used because of lack of knowledge/expertise as there is very little published information on the design and construction.	3
	root barriers are rarely used because after consideration the obstacles are difficult to overcome eg services, features and site constraints.	8
	root barriers are rarely used because policyholder/owner wants the tree removed	5
	What would you consider to be the main advantages of root barriers.	Cuts roots and solves problem of the tree
	What would you consider to be the main disadvantages of root barriers.	Site constraints
	Is further research needed	Unable to answer

Comments

GA visited offices of the participant to collect data for case studies. General discussion concerning root barriers. Participant is involved later in the process ie not at investigation stage. Participant have completed approximately 6 root barriers in the last few years. 4 of these selected for case study. The participant have another 5 or 6 cases in progress currently not available for case study process. The questionnaire questions were asked of the participant. The following responses were given

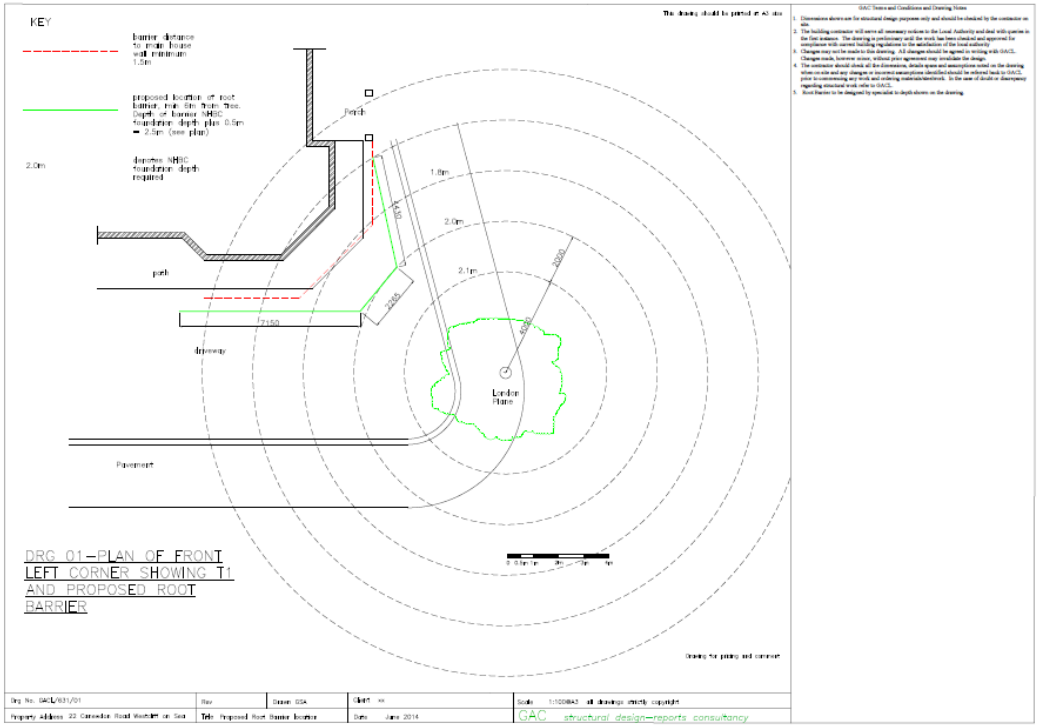
Q1 =A, A
Q2 =B, B
Q3 =A, A
Q4 = A, A
Q5 =A (one respondent declined to provide value as too uncertain)
Q6 =C, C
Q7 =B, B
Q8= A, A
Q9 =A, A

Final remarks. Participant only involved in substructure and root barriers, not repairs to the property. The value of a tree should be considered early in the process.

Appendix 12.6 Participant 3 individual case documents (drawings, notes, photos)

Project Case Study-Southend on Sea		
Item	**Details**	**Additional comments**
Soil type	Shrinkable Clay	
Tree type		
Tree distance to house	See drawing	
Designed barrier	Yes	
Barrier depth	2.5m max	
Barrier distance from tree	See drawing	
Barrier distance from house	See drawing	
Barrier length		
Barrier width	200mm	
Barrier fill	Mass concrete	
Barrier material	Woven fabric with copper core	
Equipment	Kubota U27-4	
Max digging depth	2.8m	
Machine width	1.5m	
Construction information		
Duration on site	3 days total Day 1 and 2 excavate, install barrier and pour concrete Day 3 reinstate	
Additional information	When excavating barrier no significant roots found below about 1m depth.	
	This was a partial scheme used in conjunction with removal of another nearby tree, see plan.	

Additional documents



Drawing

Model			U20-3a	U27-4
Machine weight	Cabin/canopy	kg	2380/2180	2590/2490
Engine	Model		D1105-E2-BH-12	D1105-E4BH-2
	Type		Water cooled, diesel, E-TVCS	Water cooled, diesel, E-TVCS
	Output	PS/rpm	19/22200	21.2/2400
	ISO9249	kW/rpm	14/22200	15.6/2400
	No of cylinders		3	3
Overall length		mm	3850	4190
Overall height	Cabin	mm	2360	2430
	Canopy	mm	2380	2420
Machine width		mm	1300-1500	1500
Hydraulic pumps	P1, P2		Variable displacement pump	Variable displacement pump
	Flow rate	l/min	23 + 23	28.8 + 28.8
	Hydraulic pressure	MPa (kgf/cm²)	21.6 (220)	21.6 (220)
	P3		Gear type	Gear type
	Flow rate	l/min	12.8	19.2
	Hydraulic pressure	MPa (kgf/cm²)	20.6 (210)	17.2 (175)
Max. digging force	Arm	kN (kgf)	13.2 (1350)	12.3 (1260)
	Bucket	kN (kgf)	18.4 (1880)	21 (2140)
Max. digging depth		mm	2820	2820
Auxiliary circuit	Max. Flow rate	l/min	35.8	48
	Hydraulic pressure	MPa (kgf/cm²)	21.6 (210)	17.2 (175)
Hydraulic reservoir		l	22	22
Fuel tank capacity		l	28	33
Max. Travelling speed	Low	km/h	2.2	2.4
	High	km/h	4.2	4.5

Photographs

root barrier depth 3.5m

root barrier depth 2.5m

6m root protection distance 350 to 750 dia mature tree

Min distance barrier to tree = 6m mature tree 350 to 750mm trunk diameter

sycamore

hawthorn

cherry

twisted willow (remove?)

oak English Oak mature height 20m

R6000

R15000

oak English mature height 20m

oak English mature height 20m

2 x Ash partially felled

Willow

Large Pear

33800

3.5m 3.5m 3.0m 2.5m 2.5m 2.5m 2.5m 3.0m

4.0m 4.0m 4.0m 4.0m 4.0m 4.0m 4.0m

18100

2000

3.0m 3.0m 2.5m 2.5m

3.5m

Lombardy poplar

Lombardy poplar (small remove?)

weeping Willow

18440

3.5m

15500

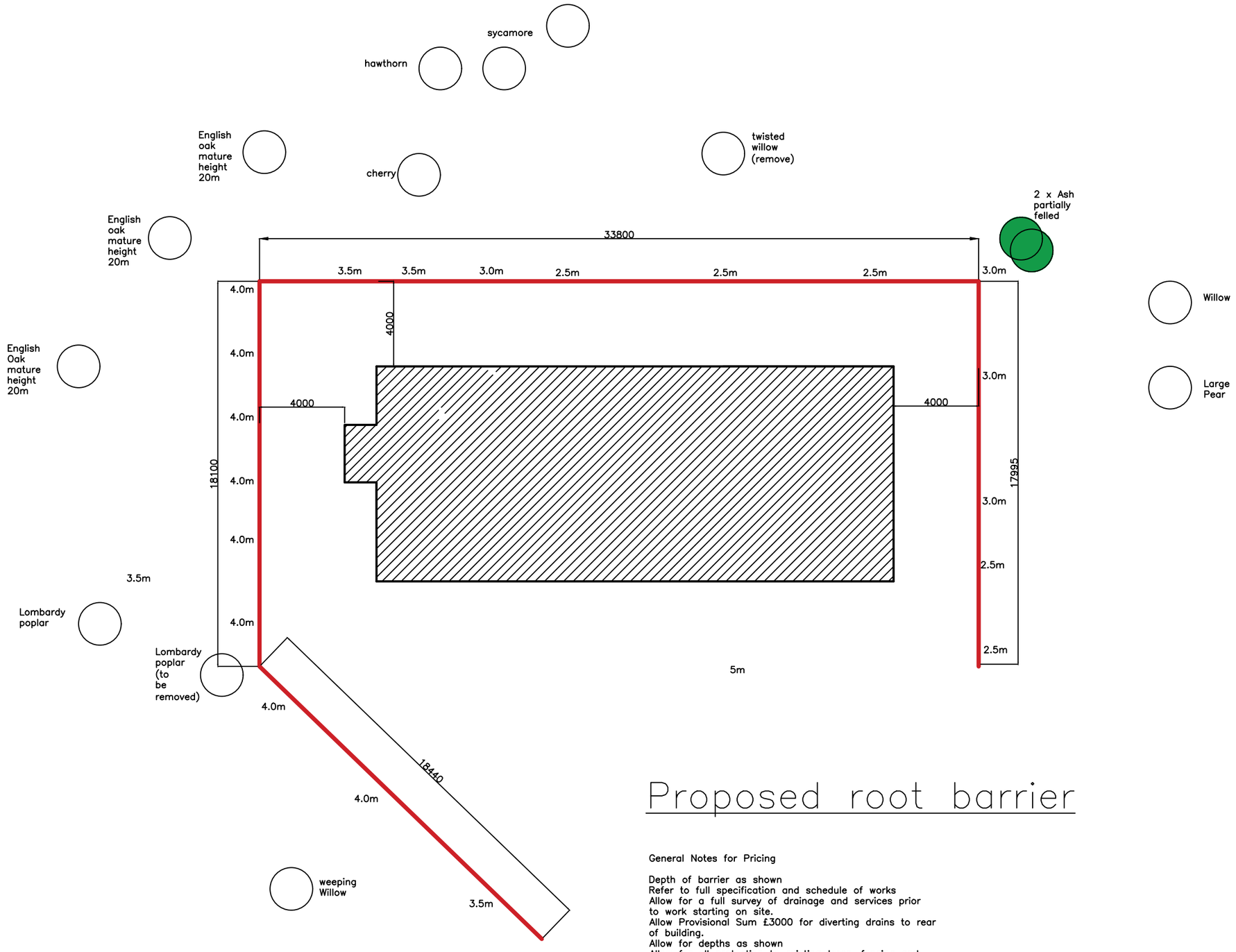
purple plum

Notes
Minimum depths shown, barrier to extend below the level of any roots found.

4m min clearance to building

detailed calculations

Drg No. GACL//01	Rev –	Drawn GSA	Scale	Client xx	(GACL) Structural Engineering
Property Address xx	Title xx			Date x 2018	



Proposed root barrier

General Notes for Pricing

Depth of barrier as shown
Refer to full specification and schedule of works
Allow for a full survey of drainage and services prior to work starting on site.
Allow Provisional Sum £3000 for diverting drains to rear of building.
Allow for depths as shown
Allow for all protection to existing trees, fencing and HS requirements.
Allow for 2.5mm thick flexible propylene geomembrane within 400mm wide trench backfilled within lean mix concrete
Minimum depths shown, barrier to extend below the level of any roots found.
4m min clearance to building
All trees subject to Arborist ID

Assumptions
Tree removals as shown
Min distance barrier to tree = 6m Mature tree 350 to 750mm trunk diameter

Drg No. GACL/907/01	Rev –	Drawn GSA	Scale	Client LBH	(GACL) Structural Engineering
Address Pinner and Grammarians Rugby	Title Root Barrier proposals			Date July 2018	

Appendix 12.7 Ethics Application and Participant consent form

(case studies)

PARTICIPANT CONSENT FORM

To (NAME OF PARTICIPANT):

Title of the project: Root Barriers to resolve Clay Shrinkage Subsidence Cases

Main investigator and contact details: **Graeme Allen**

graeme.allen@student.anglia.ac.uk

Members of the research team: Dr Alan Coday and Dr Yingang Du

- I agree to take part in the above research. I have read the Participant Information Sheet V1.0 dated 24/10/16 for the study.
- I understand what my role will be in this research, and all my questions have been answered to my satisfaction.
- I understand that I am free to withdraw from the research at any time, without giving a reason.
- I am free to ask any questions at any time before and during the study.
- I understand what will happen to the data collected from me for the research.
- I understand that quotes from me may be used in the dissemination of the research but anonymously.
- Researcher to maintain focus on the aims and objectives of the study, i.e. relating only to the use of root barriers to resolve clay shrinkage claims.
- Voluntary participation.
- Researcher to consider carefully how any results are published to maintain anonymity of individual cases (names/addresses/insurers/policyholders/contractors etc.).
- Researcher to maintain confidentiality of privileged company information regarding individual case studies.
- Researcher to maintain objectivity and avoid bias.
- The potential benefits of the study to be explained to participants

Data Protection: I agree to the University processing personal data which I have supplied. I agree to the processing of such data for any purposes connected with the Research Project as outlined to me* “The University” includes Anglia Ruskin University and its Associate Colleges.

Name of participant

(print)……Signed……..…..Date……

PARTICIPANTS MUST BE GIVEN A COPY OF THIS FORM TO KEEP

ADD DATE AND VERSION NUMBER OF CONSENT FORM.

I WISH TO WITHDRAW FROM THIS STUDY.

If you wish to withdraw from the research, please speak to the researcher or email them at graeme.allen@student.anglia.ac.uk stating the title of the research.

You do not have to give a reason for why you would like to withdraw.

Please let the researcher know whether you are/are not happy for them to use any data from you collected to date in the write up and dissemination of the research.

Date 24.10.16

V1.2

Appendix 12.8 The Presentation Delivered Prior to the Questionnaire

The Appendix shows the content of the presentation delivered before the nine questions.

ANGLIA RUSKIN UNIVERSITY

The Use of Root Barriers to Resolve Clay Shrinkage Subsidence

Author: Graeme Allen

Date: October 2016

Anglia Ruskin University

Graeme Allen Consultancy Ltd

Faculty of Science & Technology

Department of the Built Environment

ANGLIA RUSKIN UNIVERSITY

Who am I

- Subsidence Engineer with insurers and loss adjusters
- Structural Engineer at Graeme Allen Consultancy Ltd.
- Masters at Anglia Ruskin University with dissertation on root barriers to resolve clay shrinkage
- Professional Doctorate

Anglia Ruskin University

Graeme Allen Consultancy Ltd

ANGLIA RUSKIN UNIVERSITY

Aims

- To carry out an in depth study of the practical use of root barriers amongst insurance companies and practitioners

Objectives

- Investigate perceptions
- Establish the important variables
- Analyse the variables that influence reliability
- Develop good practice

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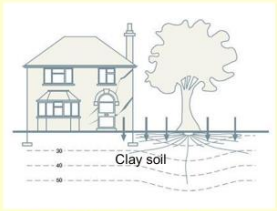
Mechanism



Summer = Shrinkage.

Winter = Swell.

Seasonal movement.

Picture courtesy of Helifix Structural solutions

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Presentation Outline

- Introduction to Clay Shrinkage Subsidence
- Solutions
- Issues
- Alternative solution of a root barrier
- Questions

Anglia Ruskin University

Graeme Allen Consultancy Ltd

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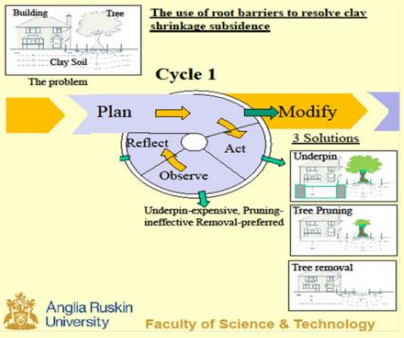
Cycle of Improvement and Reflection

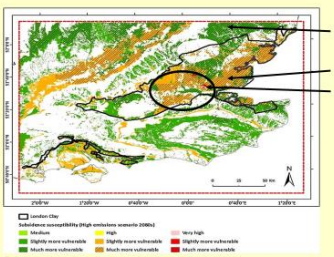


Anglia Ruskin University

Faculty of Science & Technology

ANGLIA RUSKIN UNIVERSITY

Climate Change-Predicted Shrinkage Risk Areas (BGS)



Subsidence susceptibility High emmissions scenario 2080's

Green = Medium

Yellow = High

Red = Very High

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ANGLIA RUSKIN UNIVERSITY

Scale of the Subsidence problem

- Subsidence claims cost insurers many millions £ per year to resolve
- Between 60% & 70% of these claims originated in areas with shrinkable clay soils, i.e., London and the south east
- 60% of the nation's housing stock is built on subsidence prone clay soil
- (Mike Crilly, Geotechnical Officer, Building Research Establishment (BRE) - Personal Communication) (Lawson, 2000)

Anglia Ruskin University

Graeme Allen Consultancy Ltd

Slides 1 to 8 standard presentation

ANGLIA RUSKIN UNIVERSITY

Concerns with Tree Removal

The full value of trees is not always fully realised
Tree removal cannot be reversed
Benefit to future generations
Sustainability

Environmental Benefits of Trees
Reducing effects of climate change (wetter winters and dryer summers), net absorbers of CO_2, provide shade and reduce heat gains, wildlife habitat, absorb pollutants

Social Benefits of Trees
Reduce crime, reduce traffic speed, enhance visual amenity, improve health and well being, improved social cohesion, create landmarks

Economic Benefits of Trees
Reduce crime, increase property values 7-15%, reduce heating and cooling costs of buildings

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Tree Removal Solution

Advantages
- Resolves the claim
- Cheap and relatively easy

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The Trees and Design Action Group (TDAG) formed early in 2007.

"The driving force was a concern that we must act together and promptly if we are to protect and enhance the green legacy in our cities for ourselves and for future generations"

"Trees offer a fascinating insight into looking at urban issues and challenges and it is rewarding to note how often trees appear to provide at least part of the solution"

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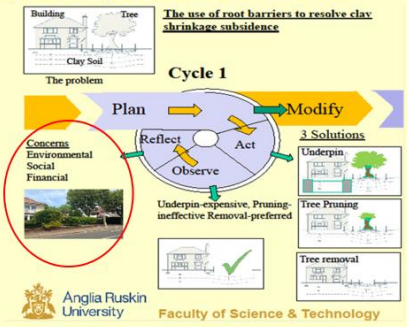
Cycle of Improvement and Reflection



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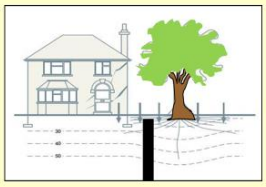
Faculty of Science & Technology

ANGLIA RUSKIN UNIVERSITY

What is a Root Barrier



- Physical barrier
- Same as tree removal
- Used infrequently
- Research on shallow depth barriers up to 1.5m (protect pavements)
- Not much published work on deeper barriers

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Construction of a Root Barrier

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Position of Barrier

- A root barrier should be positioned so that it does not undermine the existing foundations of the building
- 4m deep barrier and 1m deep foundations => 3m (45 degree)
- Positioned a minimum distance from the tree => 6m
- Require <=> 9m between tree and the building to enable a barrier to be installed
- Heave risk when trees are close to a building

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Main Requirements and Considerations using root barriers

- Depth
- Length
- Position of barrier in relation to the tree and building
- Obstructions e.g., services; property boundaries
- Materials
- Construction
- Costs
- Reliability

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Slides 9 to 16 standard presentation

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Case History

- Located on east coast
- Barrier has been installed and the property is still being monitored

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Research Methods

Stage 1 (questionnaire and feedback)

- Identify views and perceptions
- Questionnaire at end of presentation

Stage 2 (volunteer participants)

- Case studies (successes and failures)
- Review of cases obstacles overcome, design issues, materials used (e.g., permeable, impermeable, rigid, flexible), construction methods
- Ethics, protect information, anonymity

Further Research

- How do tree roots actually grow in the ground?
- Best practice guidelines

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Appendix 12.9 Additional literature searches details

Additional details of the literature searches undertaken illustrating the type of results confirming the lack of research on root barriers relevant to the thesis for dealing with cases of clay shrinkage subsidence.

Elsevier Science Direct Root Barrier June 2018

113,808 results

- *Root's barrier*, viscosity solutions of obstacle problems and reflected FBSDEs
- Cerium oxide nanoparticles alter the salt stress tolerance of Brassica napus L. by modifying the formation of *root* apoplastic *barriers*
- Effects of *root* morphology and anatomy on cadmium uptake and translocation in rice (Oryza sativa L.)
- Role of LOTR1 in Nutrient Transport through Organization of Spatial Distribution of *Root* Endodermal *Barriers*
- The *root* of the matter: Linking *root* traits and soil organic matter stabilization processes
- Responses of grapevine rootstocks to drought through altered *root* system architecture and *root* transcriptomic regulations
- Response of two perennial grasses to *root barriers* and fissures
- Signaling Peptides and Receptors Coordinating Plant *Root* Development
- Full linear multistep methods as *root*-finders
- Creation and validation of the *barriers* to alcohol reduction (BAR) scale using classical test theory and item response theory
- Adapting to climate change by water management organizations: Enablers and *barriers*
- Plant Biology: Building *Barriers*… in Roots
- An analysis of *barriers* affecting the implementation of e-waste management practices in India: A novel ISM-DEMATEL approach
- *Barriers* to investment in utility-scale variable renewable electricity (VRE) generation projects

☐ Impact of galactoglucomannan oligosaccharides and Cd stress on maize *root* growth parameters, morphology, and structure

☐ *Barriers* to the Circular Economy: Evidence From the European Union (EU)

☐ Vehicle-to-*barrier* communication during real-world vehicle crash tests

☐ Increased *root* zone oxygen by a capillary *barrier* is beneficial to bell pepper irrigated with brackish water in an arid region

☐ Barrier function-based adaptive sliding mode control

☐ Adherence *barriers* in pediatric epilepsy: From toddlers to young adults

☐ Utilizing the physiological adaptation mechanisms of coastal plants for vegetative restoration of *barrier* islands

☐ Pricing and hedging *barrier* options under a Markov-modulated double exponential jump diffusion-CIR model

☐ The endodermis, a tightly controlled *barrier* for nutrients

☐ Transport *Barriers* and Oncophysics in Cancer Treatment

☐ On the *barrier* graph of an arrangement of ray sensors

“Root barrier” term searched 333 results (June 2018)

Root’s barrier, viscosity solutions of obstacle problems and reflected FBSDEs

Response of two perennial grasses to *root barriers* and fissures

Plant growth patterns in a tripartite strip relay intercrop are shaped by asymmetric above ground competition,

☑ ☐ ☐ Cerium oxide nanoparticles alter the salt stress tolerance of Brassica napus L. by modifying the formation of *root* apoplastic *barriers*

☐ Relationships among Jatropha curcas seed yield and vegetative plant components under different management and cropping systems in Indonesia

☐ A deterministic annealing algorithm for approximating a solution of the max-bisection problem

☐ The effect of using a geotextile in a monolithic (evapotranspiration) alternative landfill cover on the resulting water balance

- [ ] How “green” are the green roofs? Lifecycle analysis of green roof materials
- [ ] Above- and below-ground effects from alfalfa and marsh reedgrass on aspen seedlings
- [ ] Effects of added Cd on Cd uptake by oilseed rape and pai-tsai co-cropping
- [ ] Dissolution of different zinc salts and Zn uptake by Sedum alfredii and maize in mono- and co-cropping under hydroponic culture
- [ ] Combined application of Triton X-100 and Sinorhizobium sp. Pb002 inoculum for the improvement of lead phytoextraction by Brassica juncea in EDTA amended soil
- [ ] Competition for 15N labeled nitrogen in a loblolly pine–cotton alley cropping system in the southeastern United States
- [ ] Above and below ground interactions in agroforestry systems
- [ ] Green roof benefits, opportunities and challenges – A review
- [ ] *Root* interactions between young Eucalyptus deglupta trees and competitive grass species in contour strips
- [ ] Plant Biology: Building *Barriers*… in Roots

Suberization—the second life of an endodermal cell

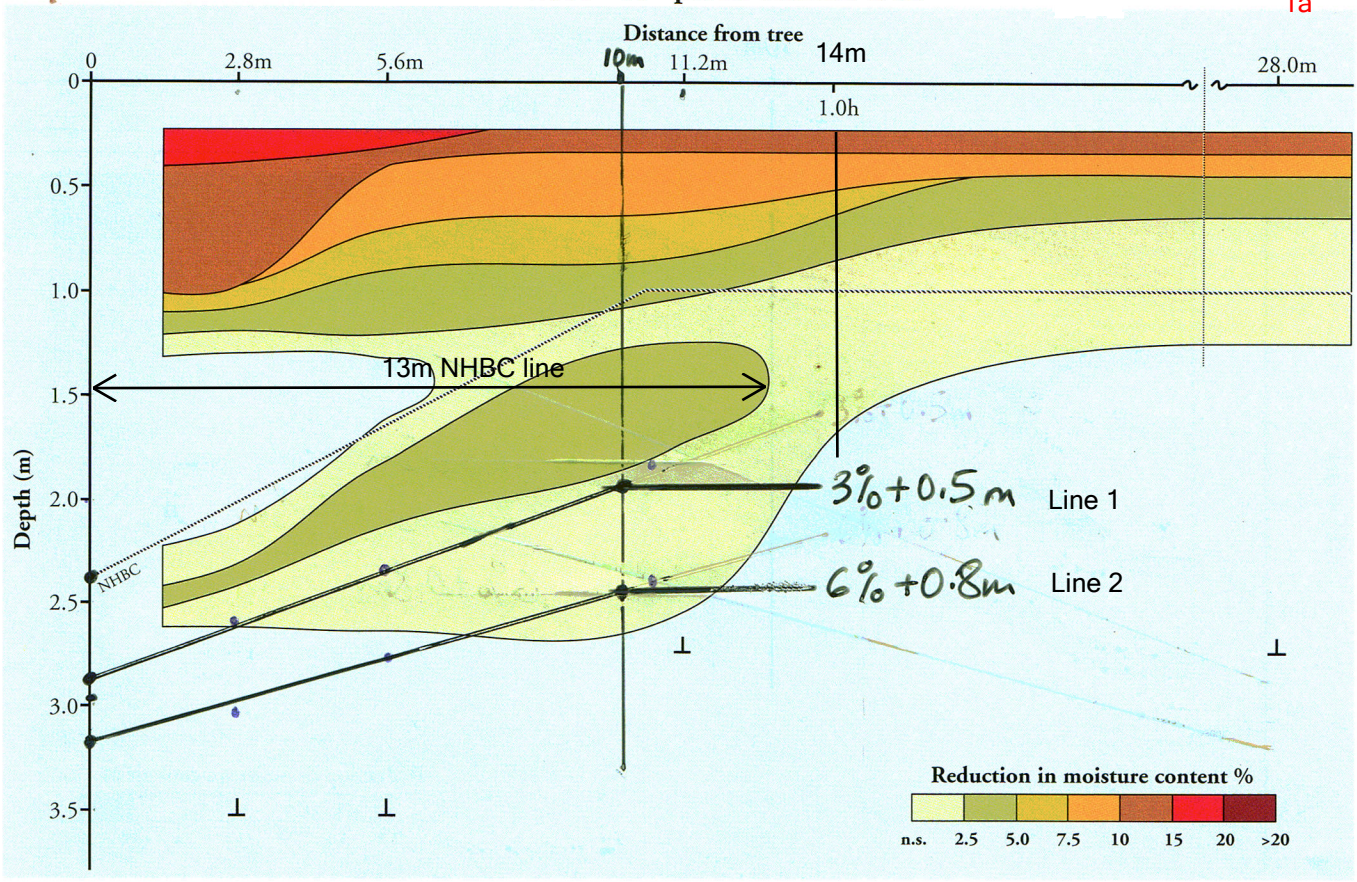
- [ ] Influence of orientation on wheat yield and photosynthetic photon flux density (Qp) at the tree and crop interface in a Paulownia—wheat intercropping system
- [ ] Some European green roof norms and guidelines through the lens of biodiversity: Do ecoregions and plant traits also matter?
- [ ] Chapter 2.3: Green Roofs Classifications, Plant Species, Substrates
- [ ] Thermal inertia assessment of an experimental extensive green roof in summer conditions
- [ ] Life cycle assessment of layers of green roofs
- [ ] Environmental Impact of Green Roofing: The Contribute of a Green Roof to the Sustainable use of Natural Resources in a Life Cycle Approach
- [ ] A review of benefits and challenges in growing street trees in paved urban environments

Appendix 12.10 Biddle Graphs with overlay for 18 trees

The following graphs have been extracted from Volume 2 (Biddle, 1998) with overlays for depth design lines NHBC, Line 1 and Line 2.

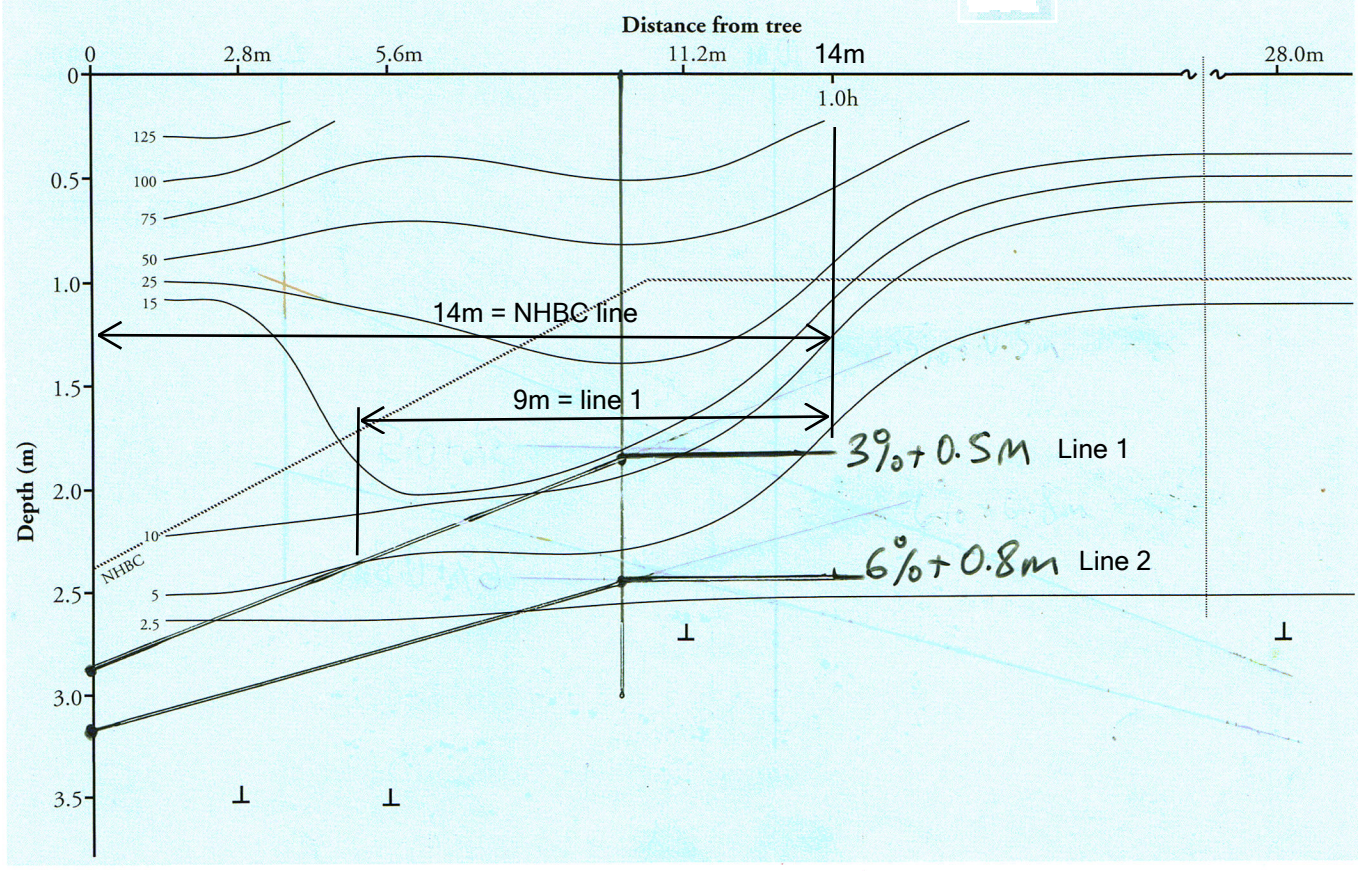
Reduction in soil moisture content on 18/9/84 compared with 21/4/82

1a



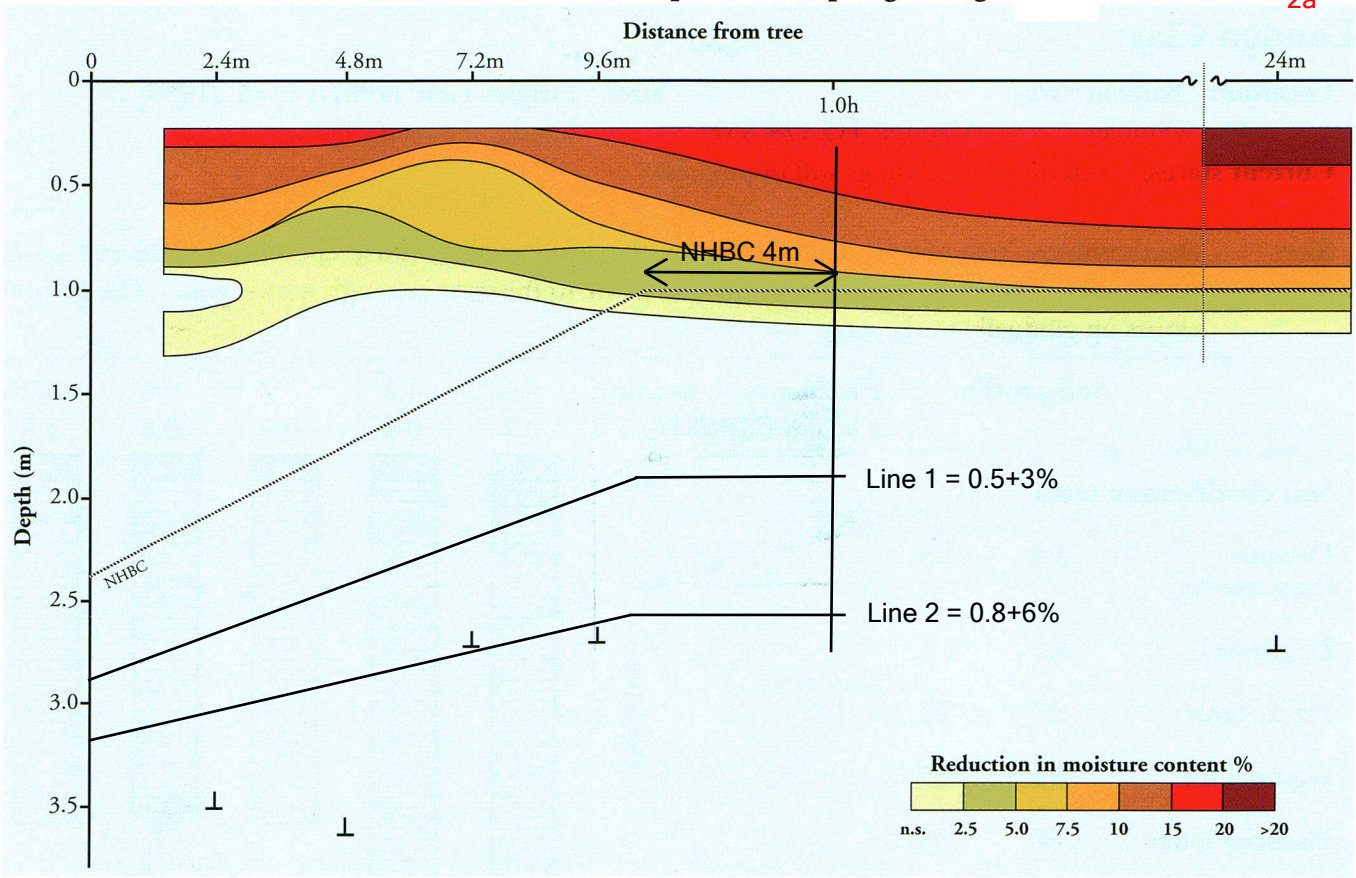
Soil moisture deficit on 18/9/84 compared with 21/4/82

1b



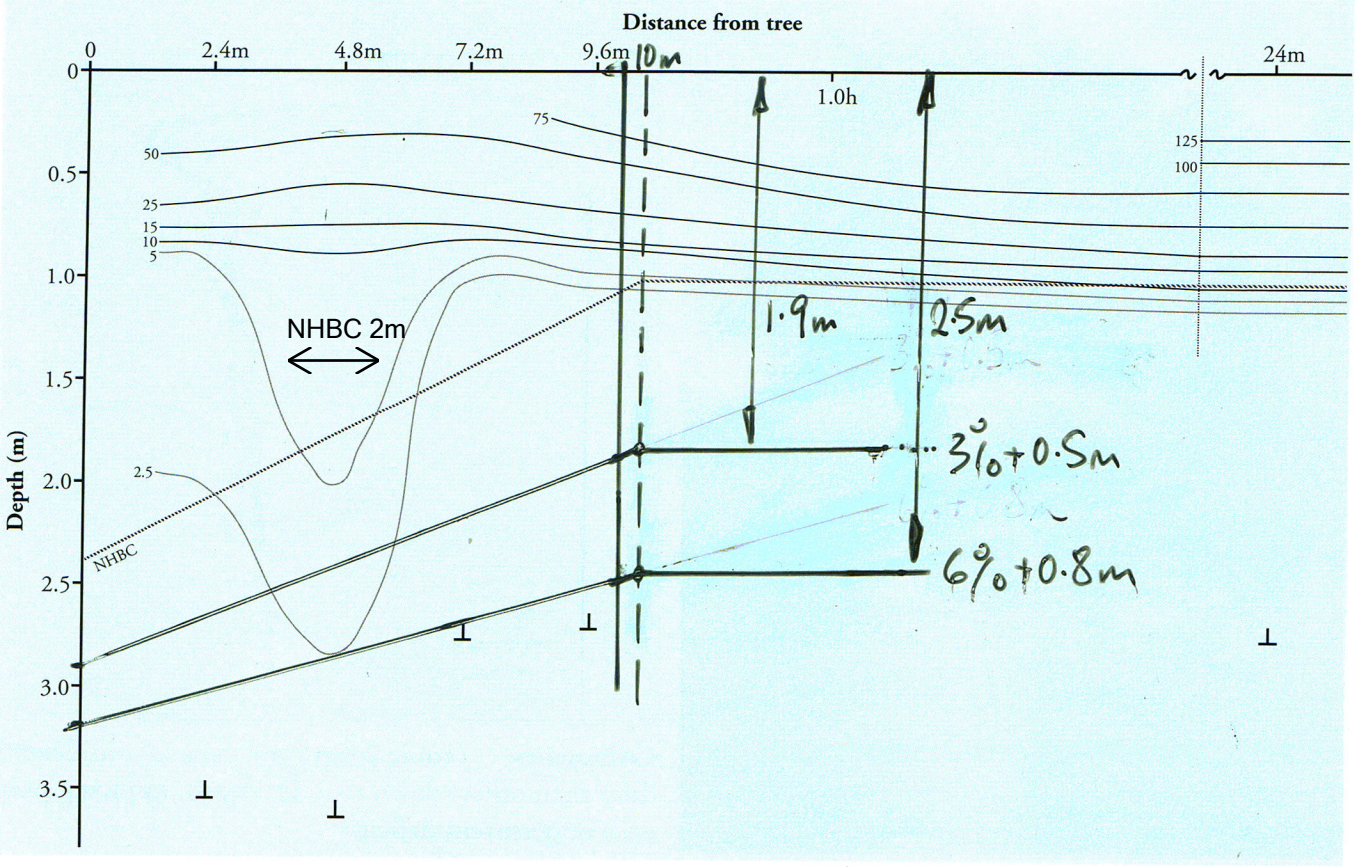
Reduction in soil moisture content on 19/9/89 compared with spring average

2a



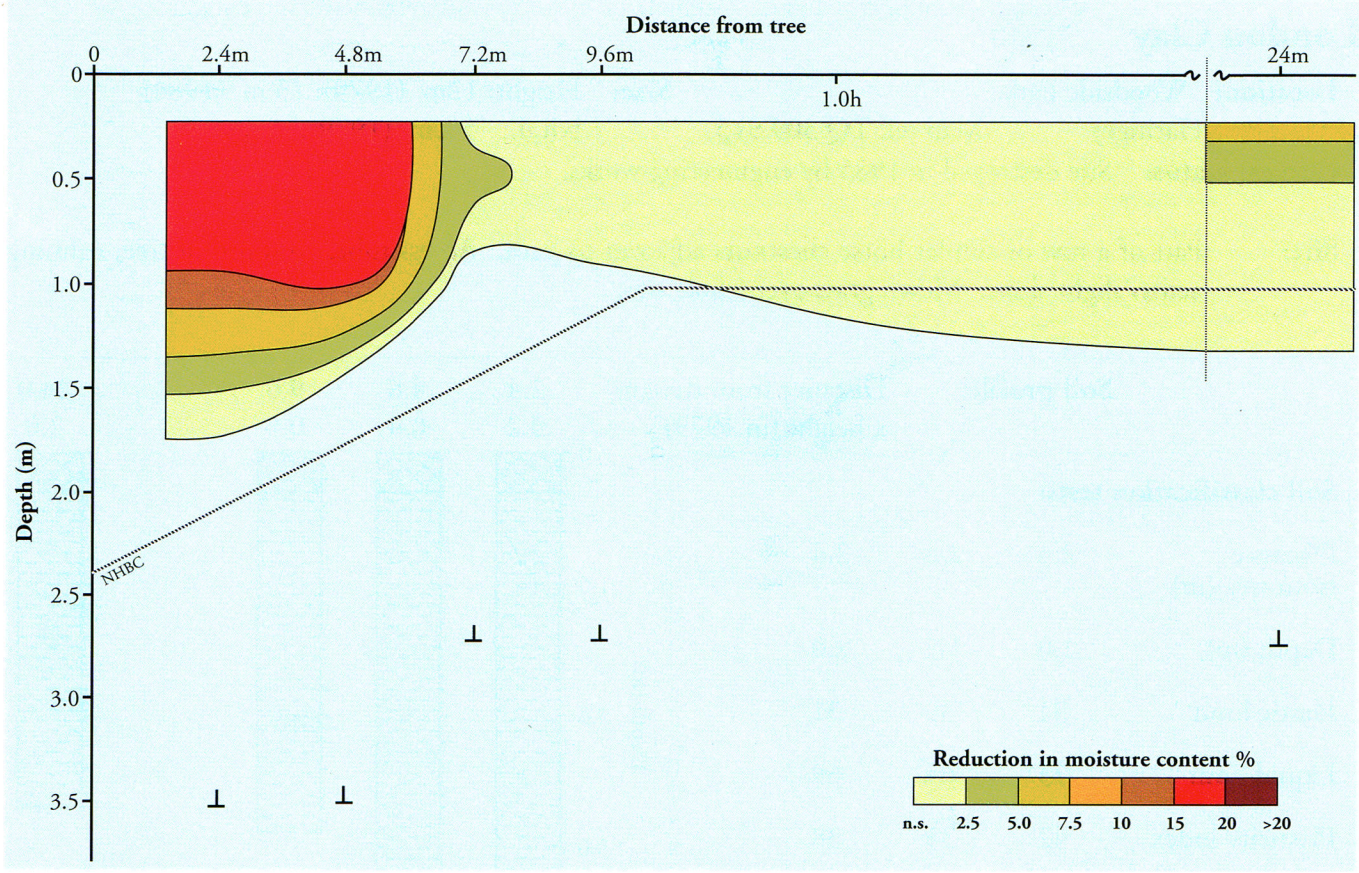
Soil moisture deficit on 19/9/89 compared with spring average

2b



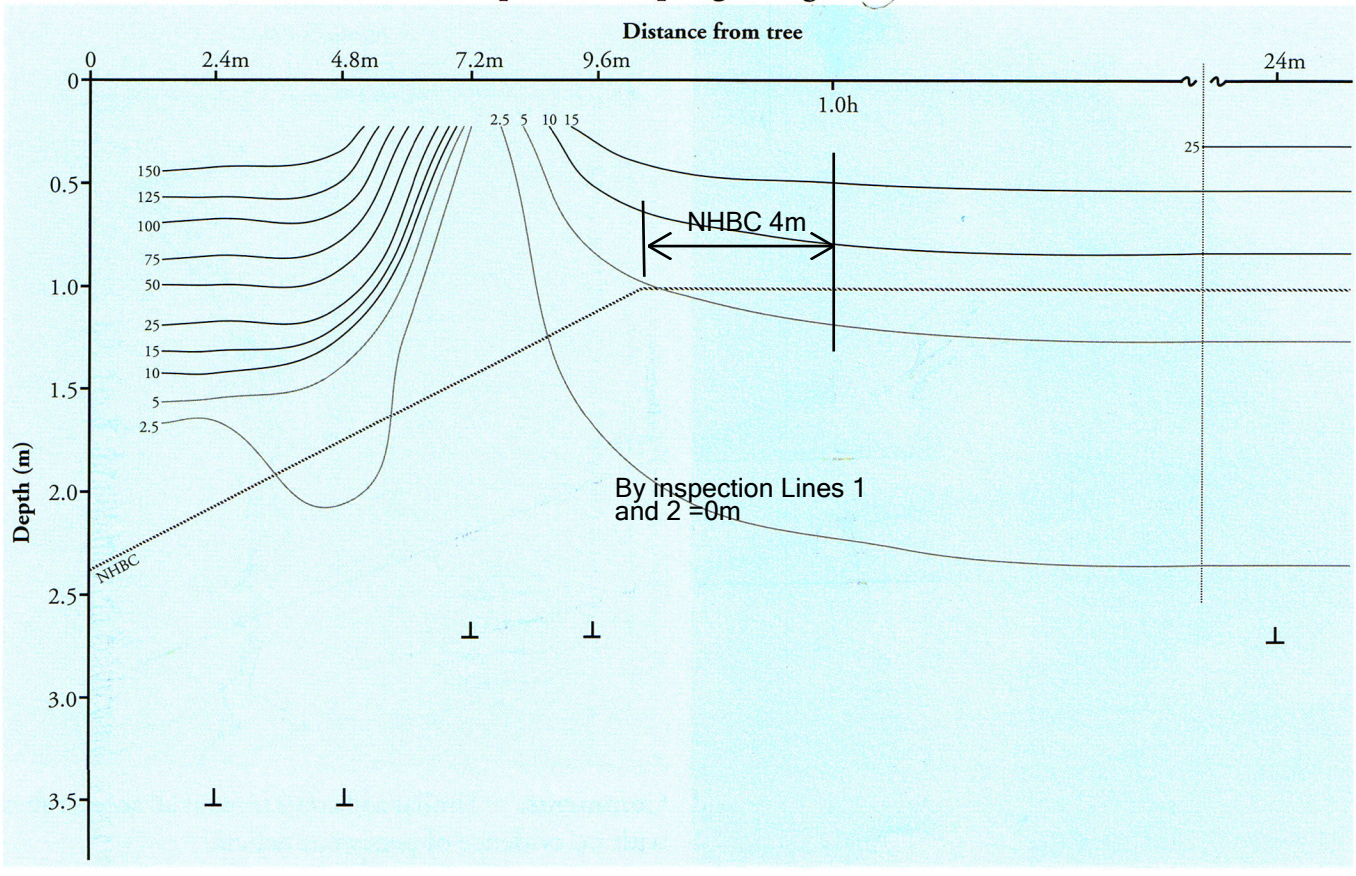
Reduction in soil moisture content on 29/10/91 compared with spring average

3a

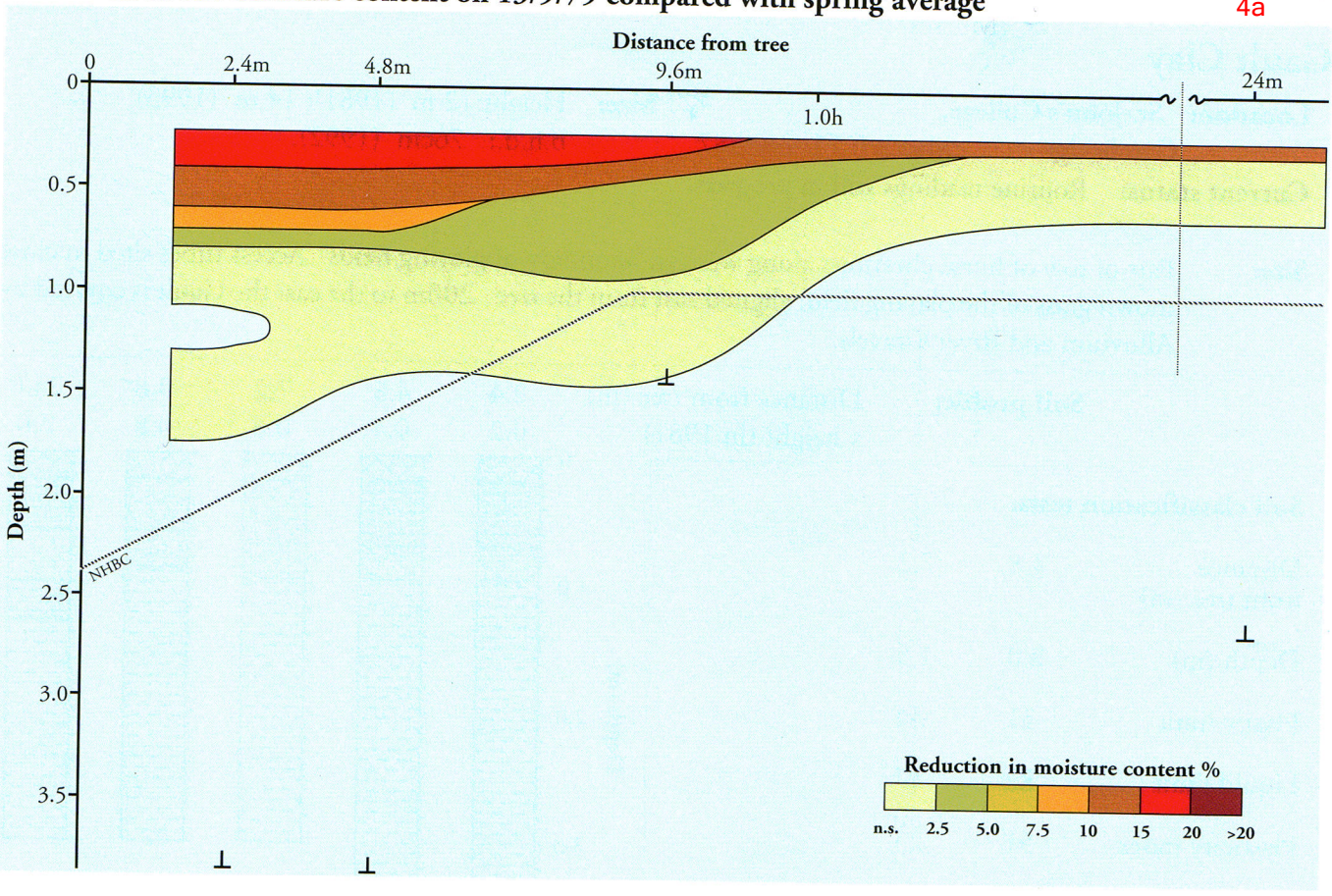


Soil moisture deficit on 29/10/91 compared with spring average

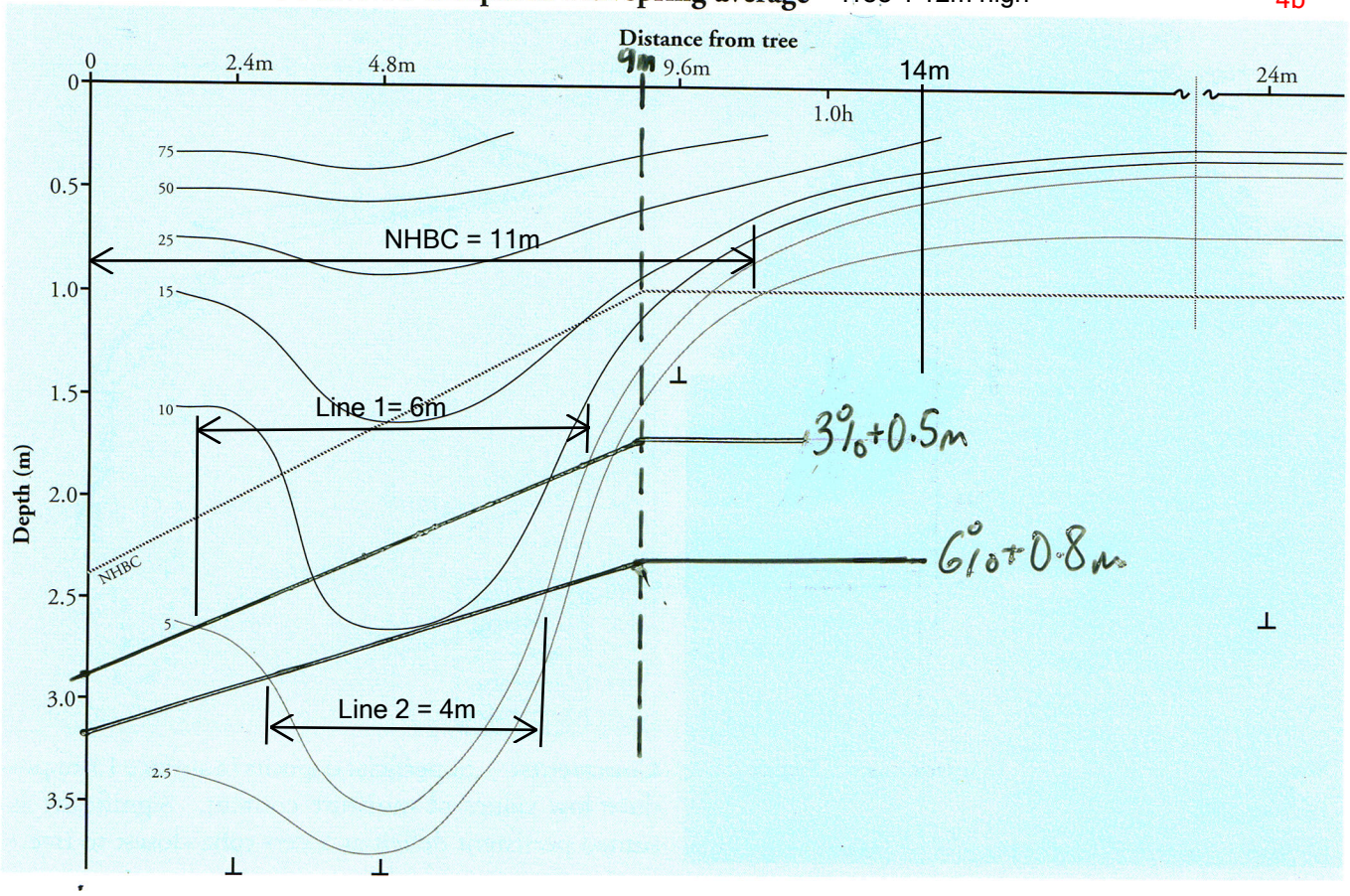
3b



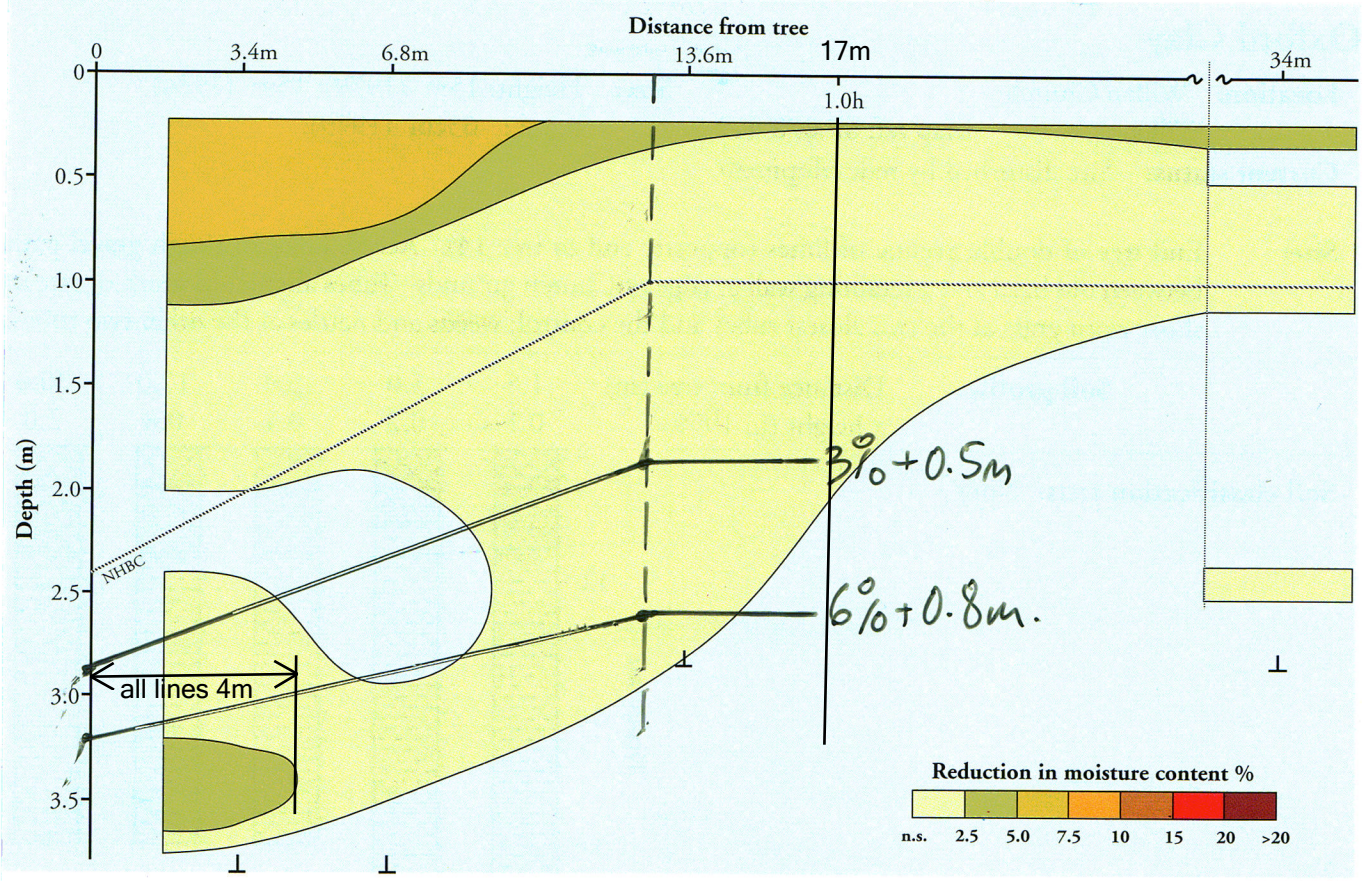
Reduction in soil moisture content on 13/9/79 compared with spring average 4a



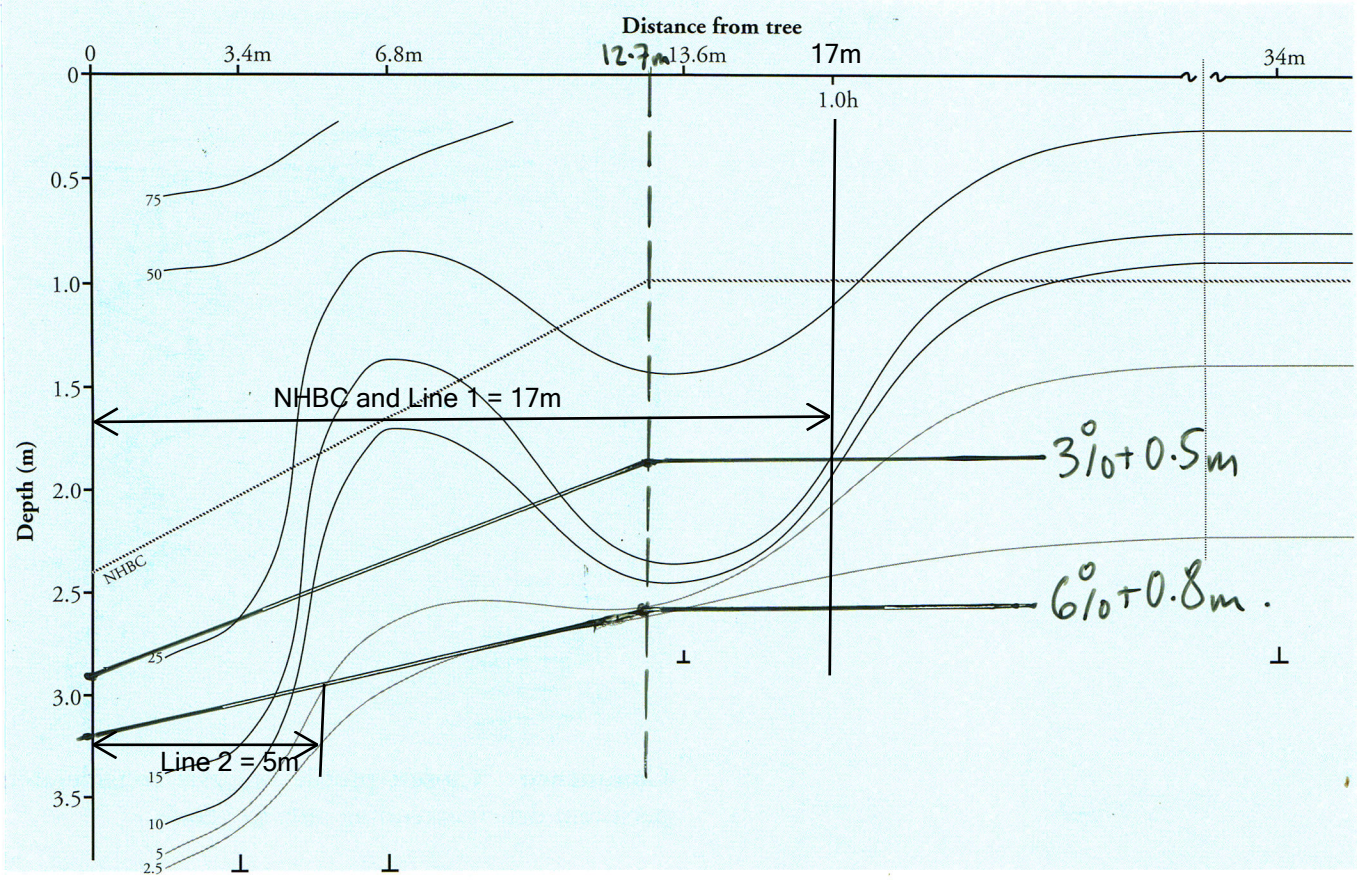
Soil moisture deficit on 13/9/79 compared with spring average Tree 4 12m high 4b



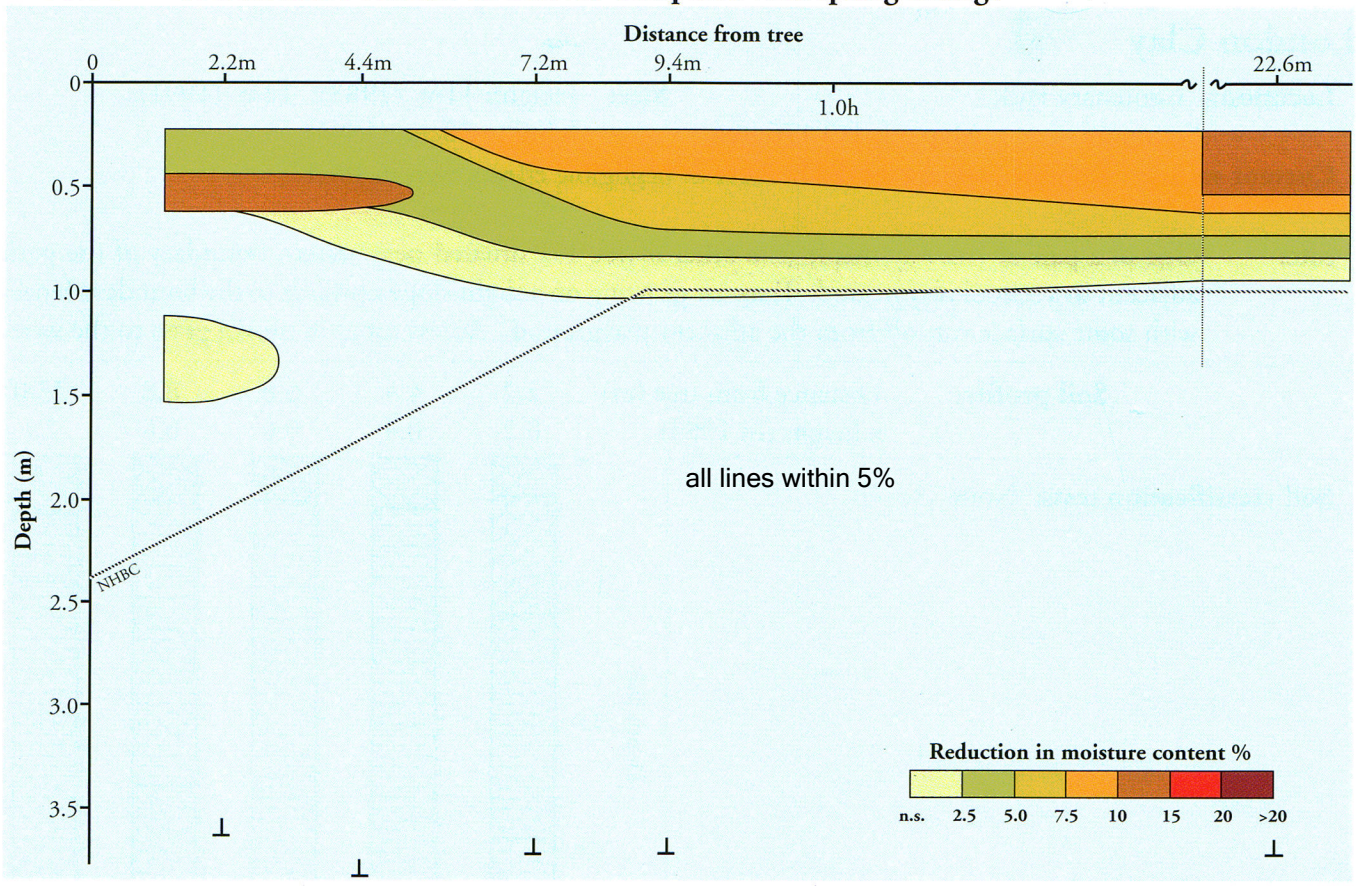
Reduction in soil moisture content on 27/9/84 compared with spring average Tree 12 = 17m high 12a



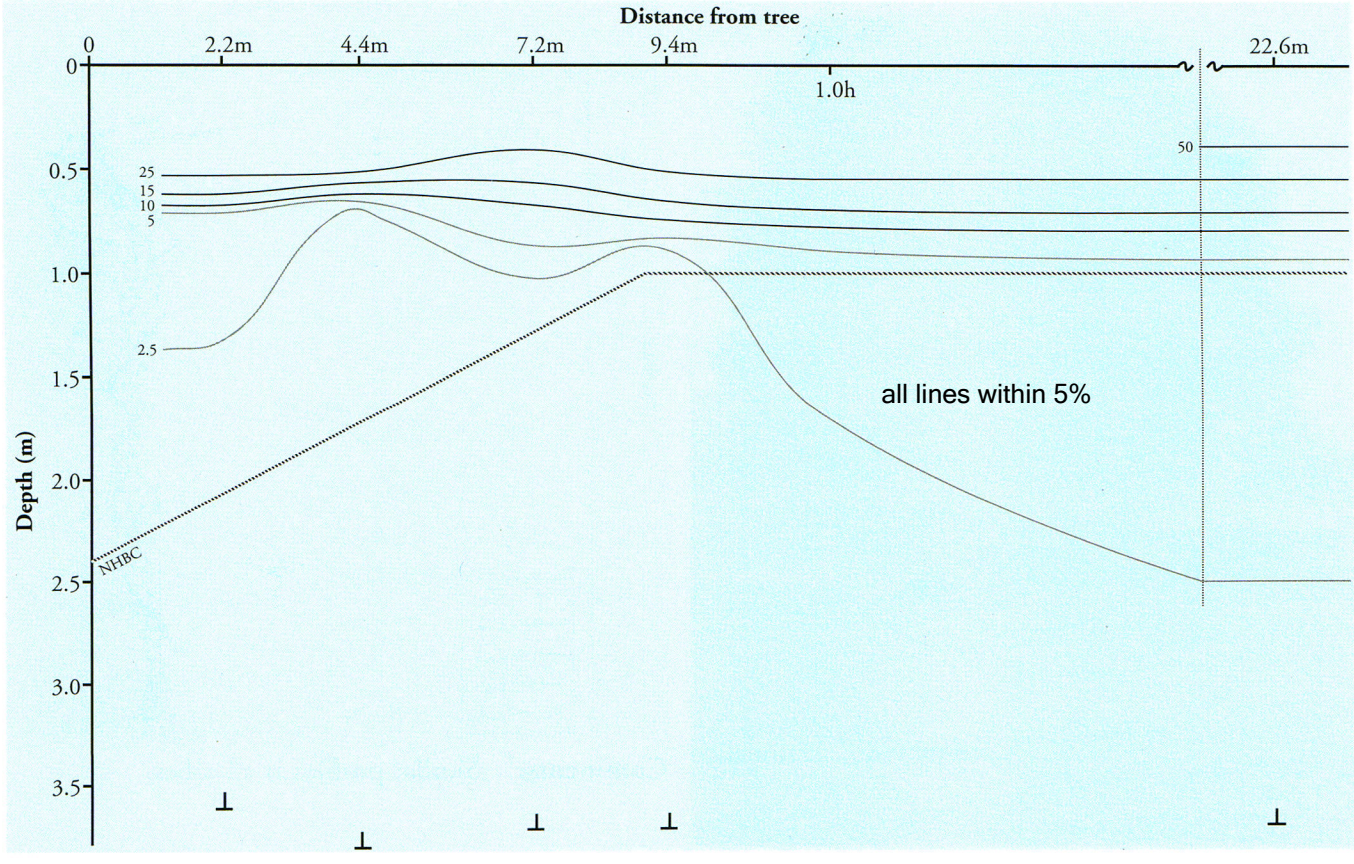
Soil moisture deficit on 27/9/84 compared with spring average 12b



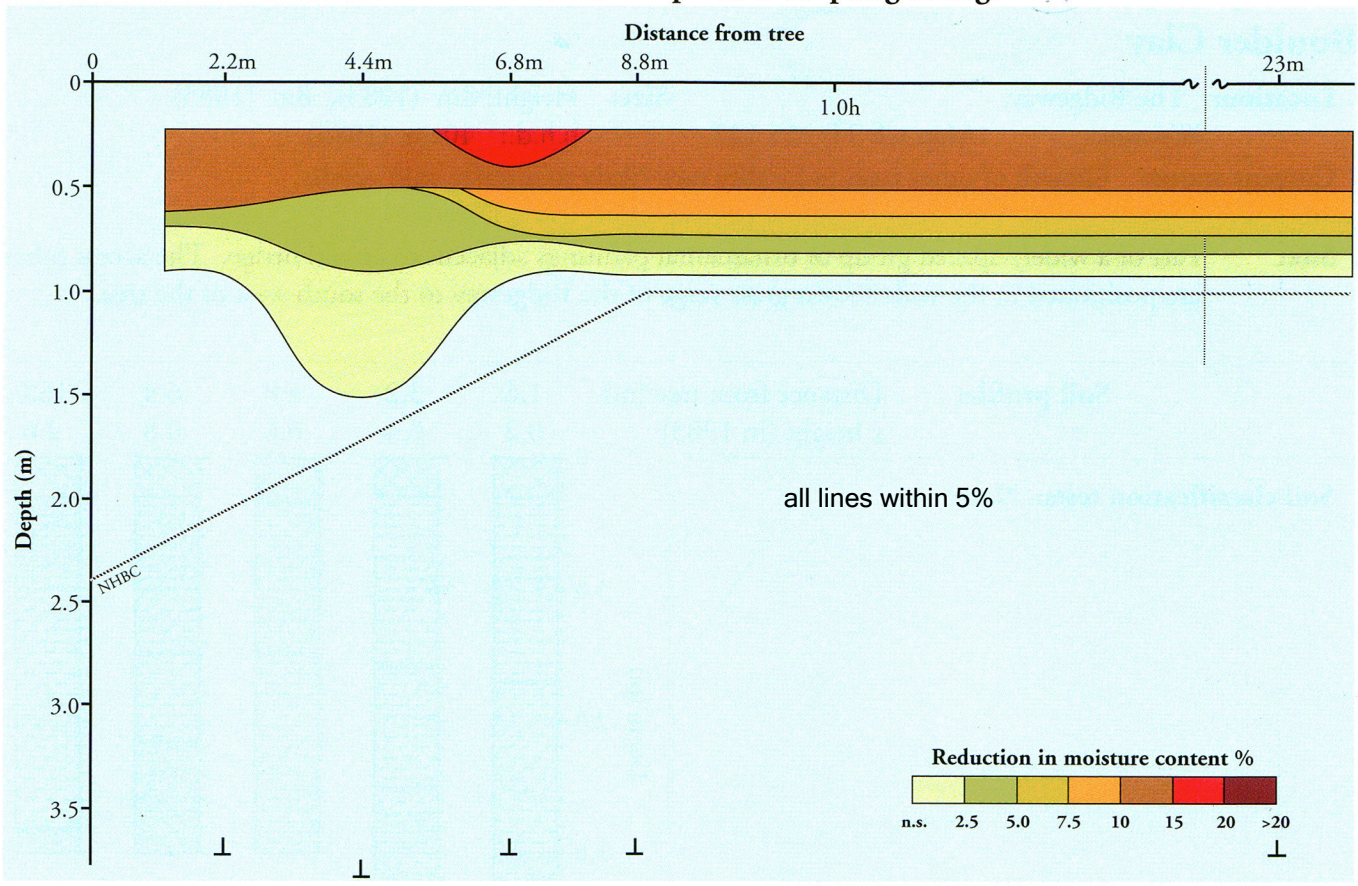
Reduction in soil moisture content on 20/9/89 compared with spring average 17a



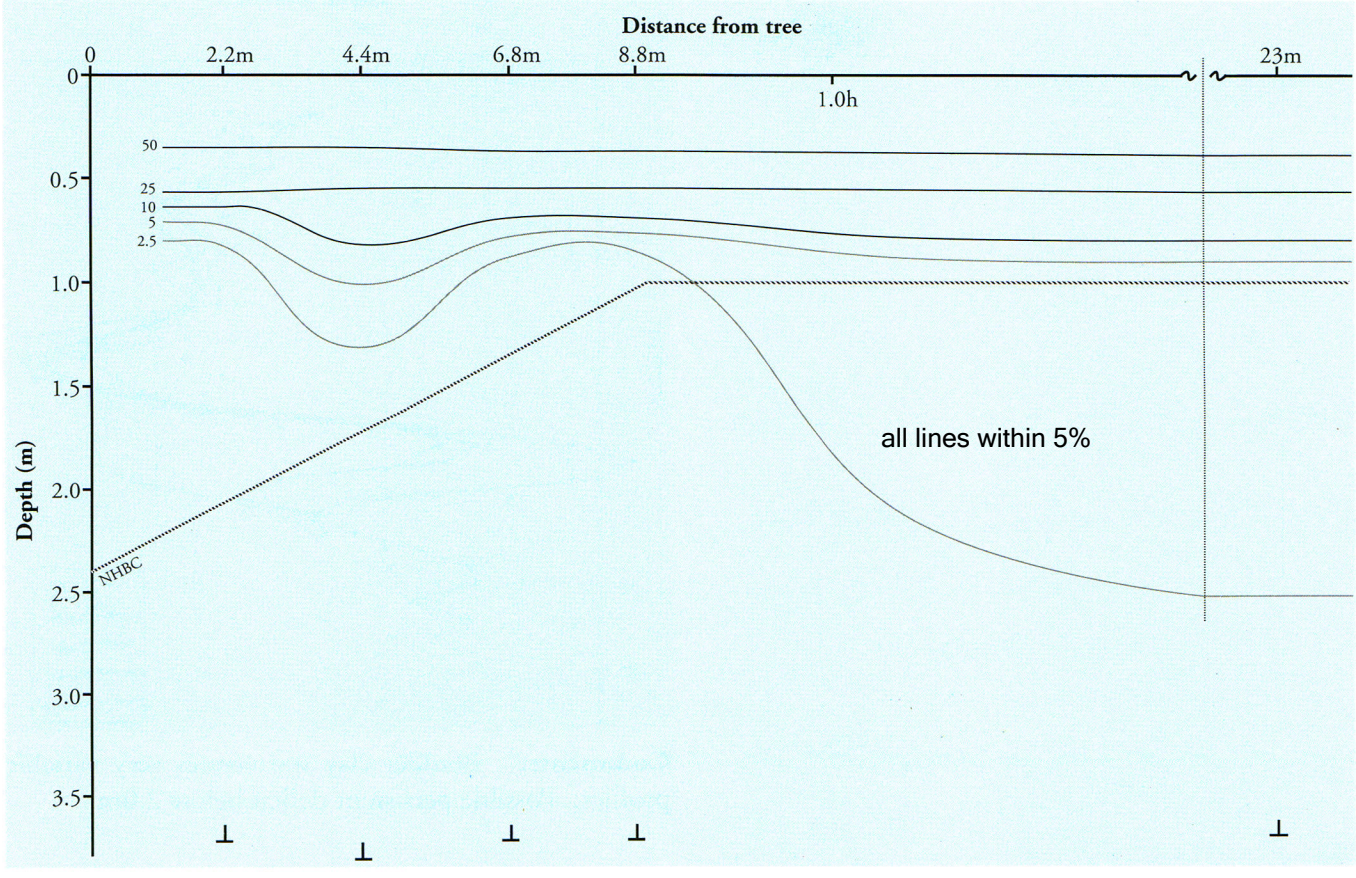
Soil moisture deficit on 20/9/89 compared with spring average 17b



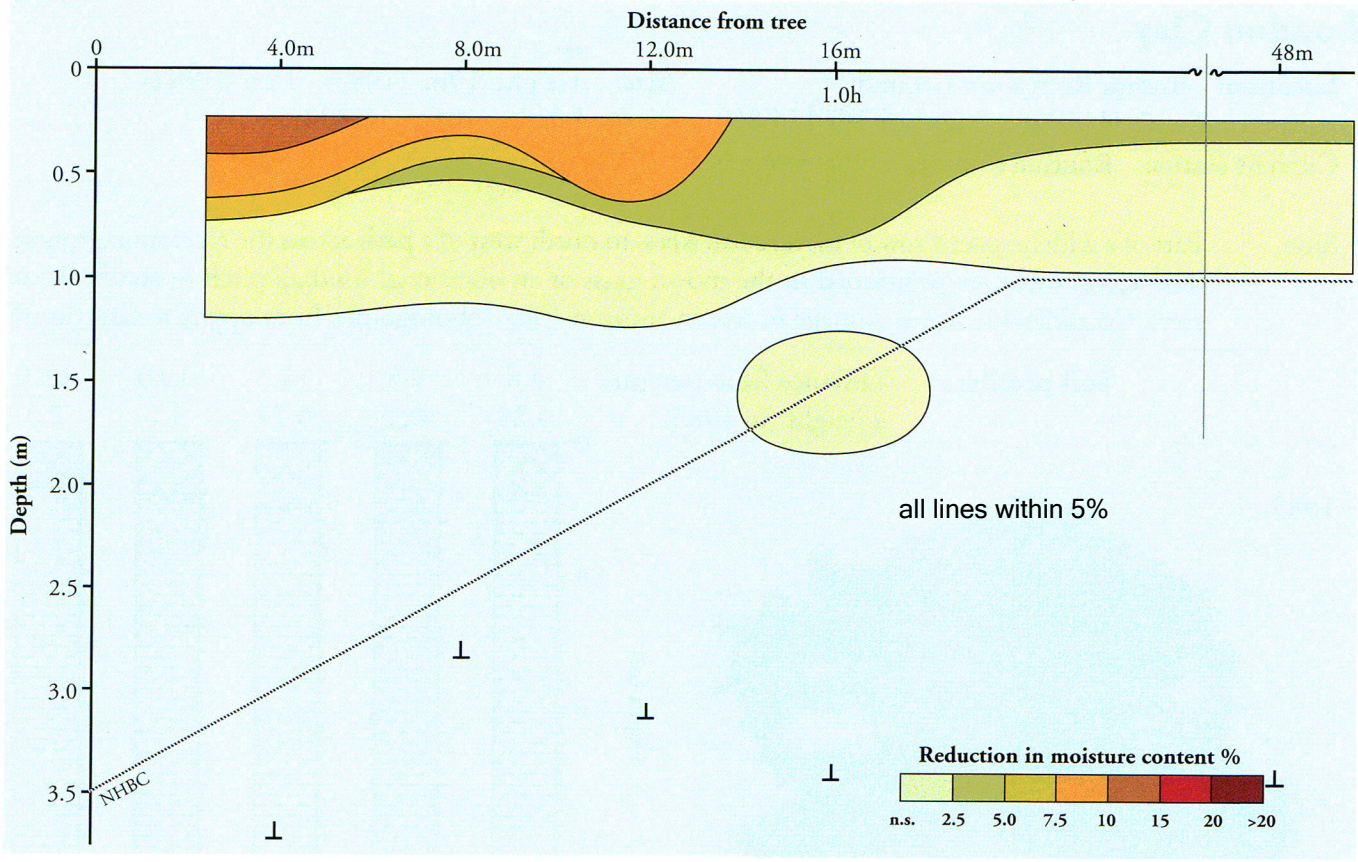
Reduction in soil moisture content on 20/9/89 compared with spring average 18a



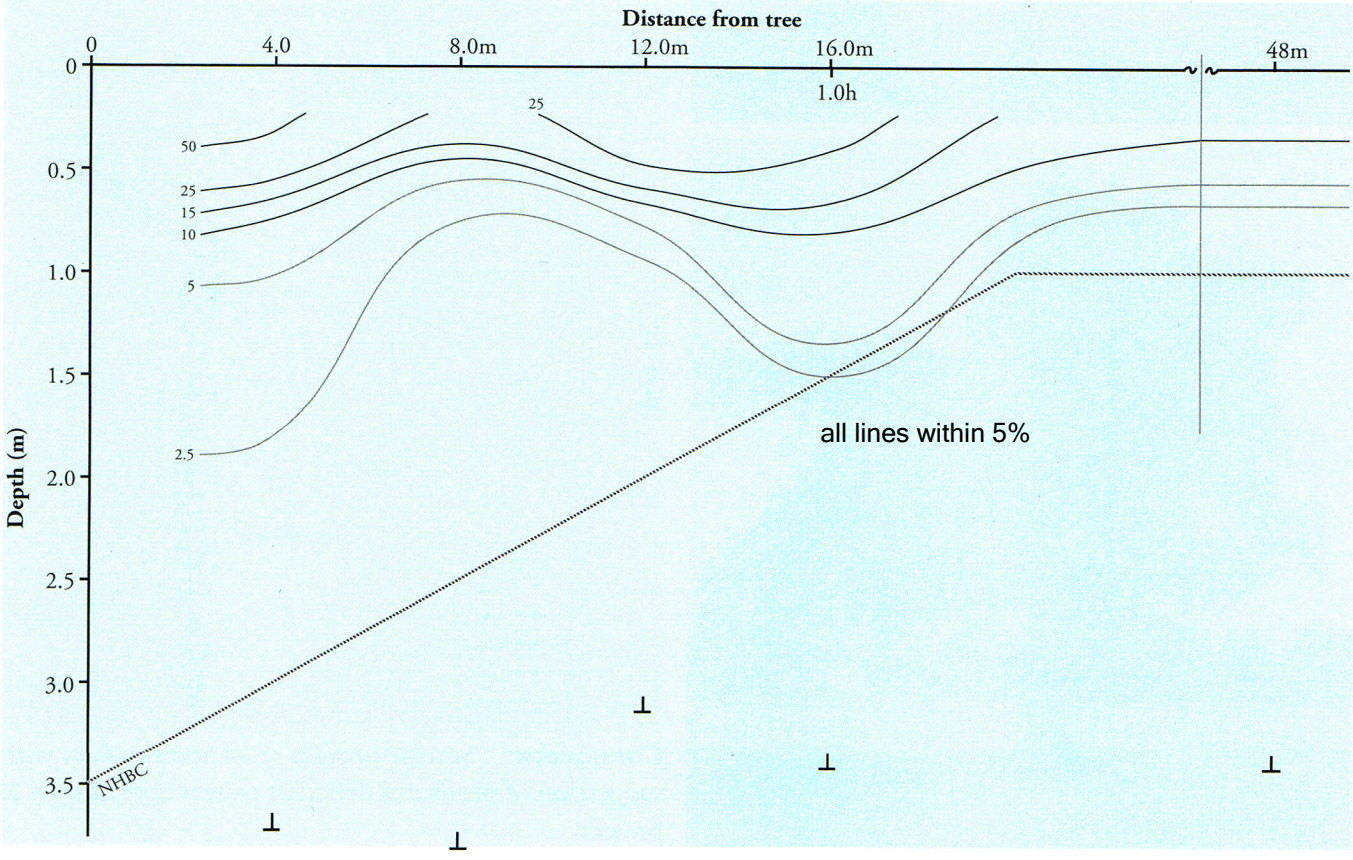
Soil moisture deficit on 20/9/89 compared with spring average 18b



Reduction in soil moisture content on 20/9/94 compared with spring average 21a

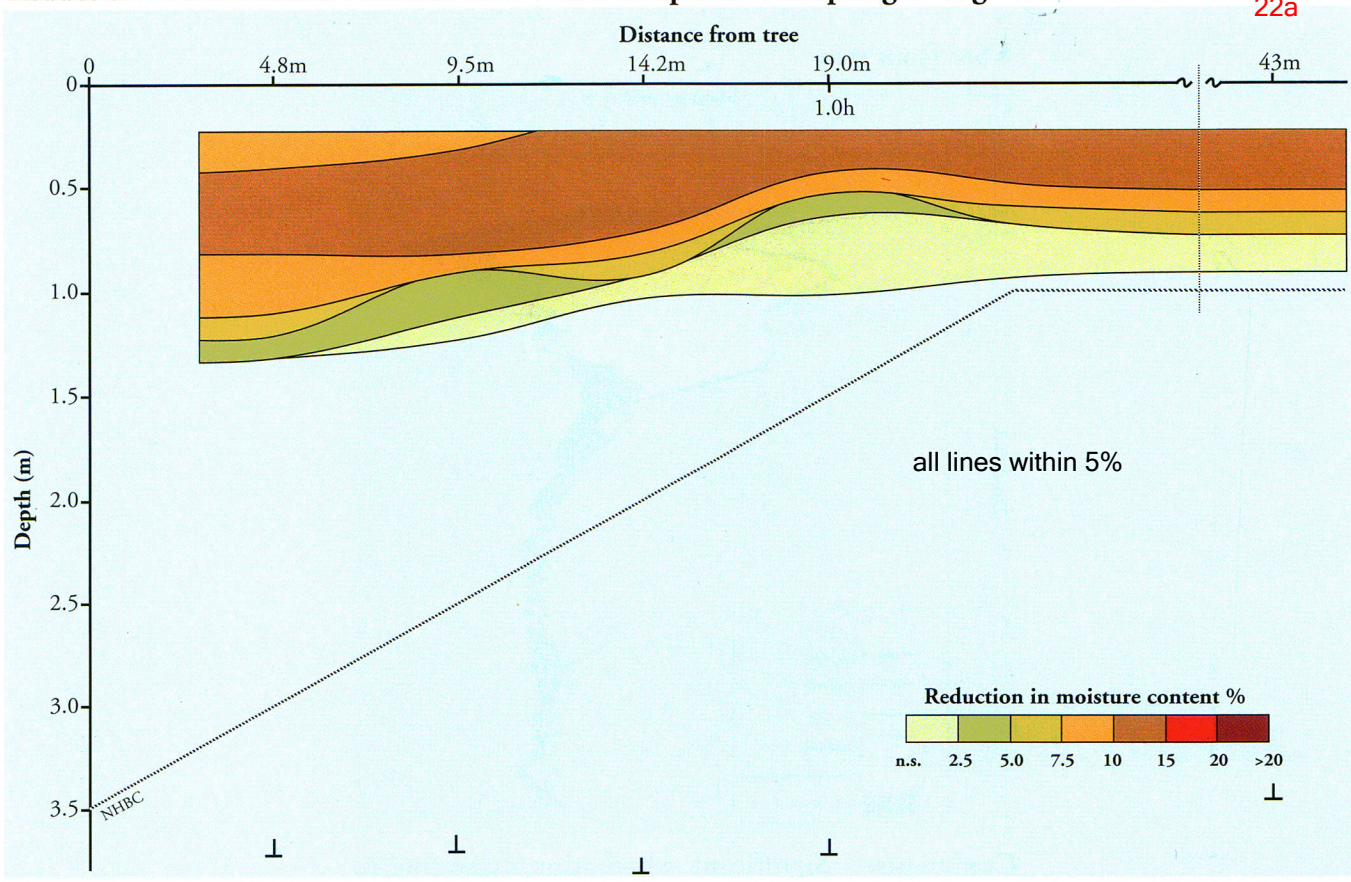


Soil moisture deficit on 20/9/94 compared with spring average 21b



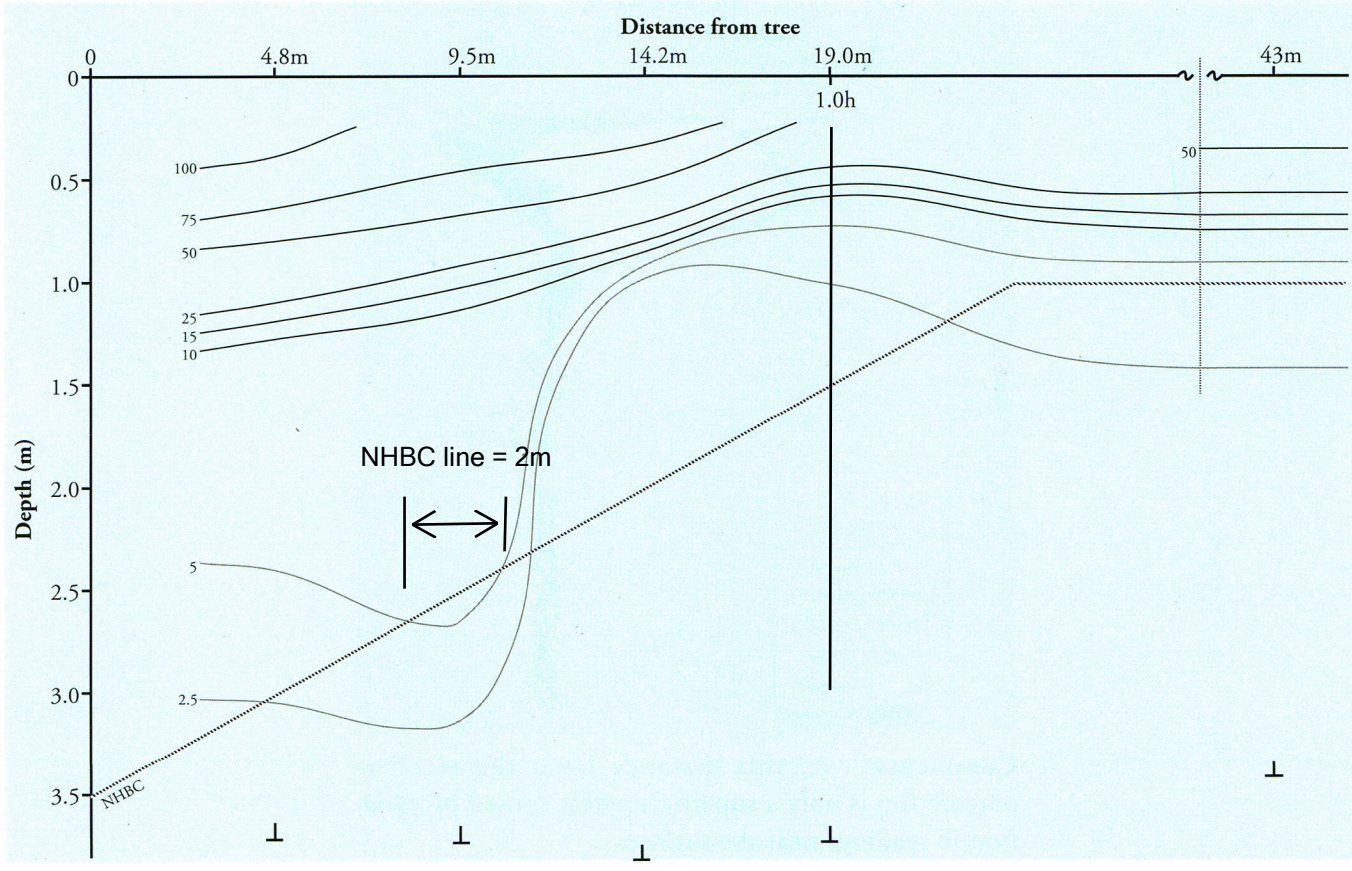
Reduction in soil moisture content on 17/9/84 compared with spring average

22a



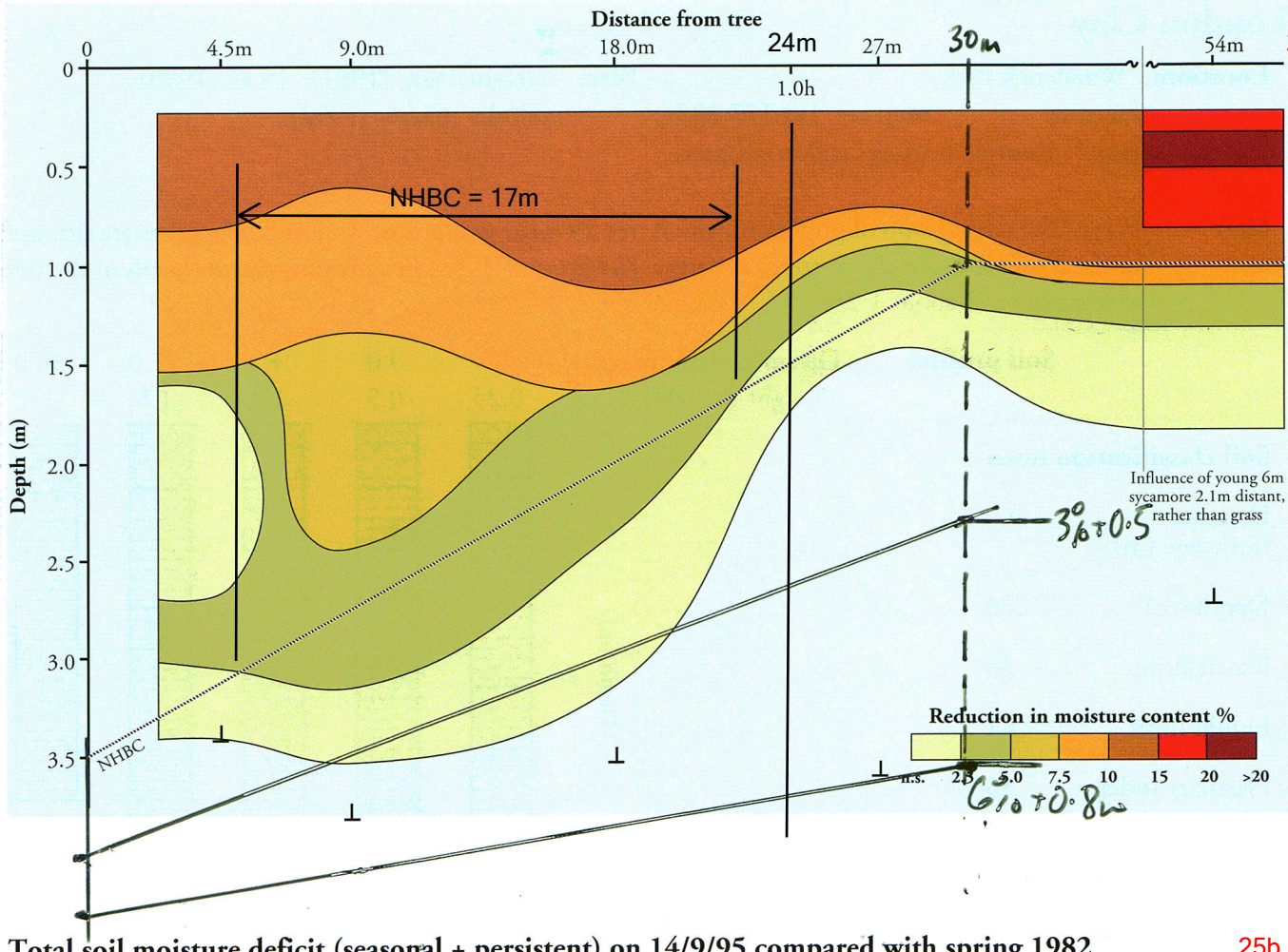
22b

Soil moisture deficit on 17/9/84 compared with spring average



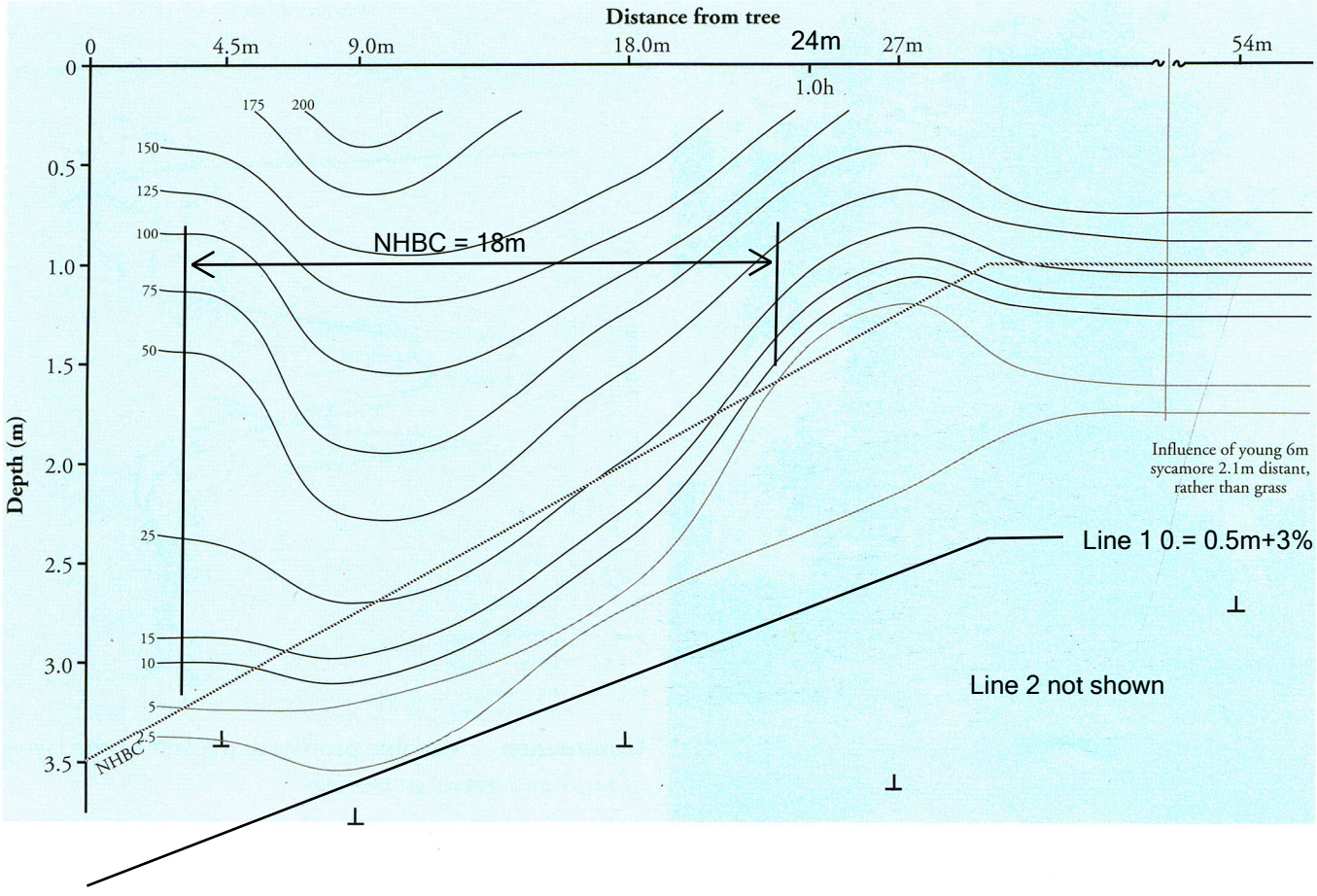
Total reduction in soil moisture content (seasonal + persistent) on 14/9/95 compared with spring 1982

25a

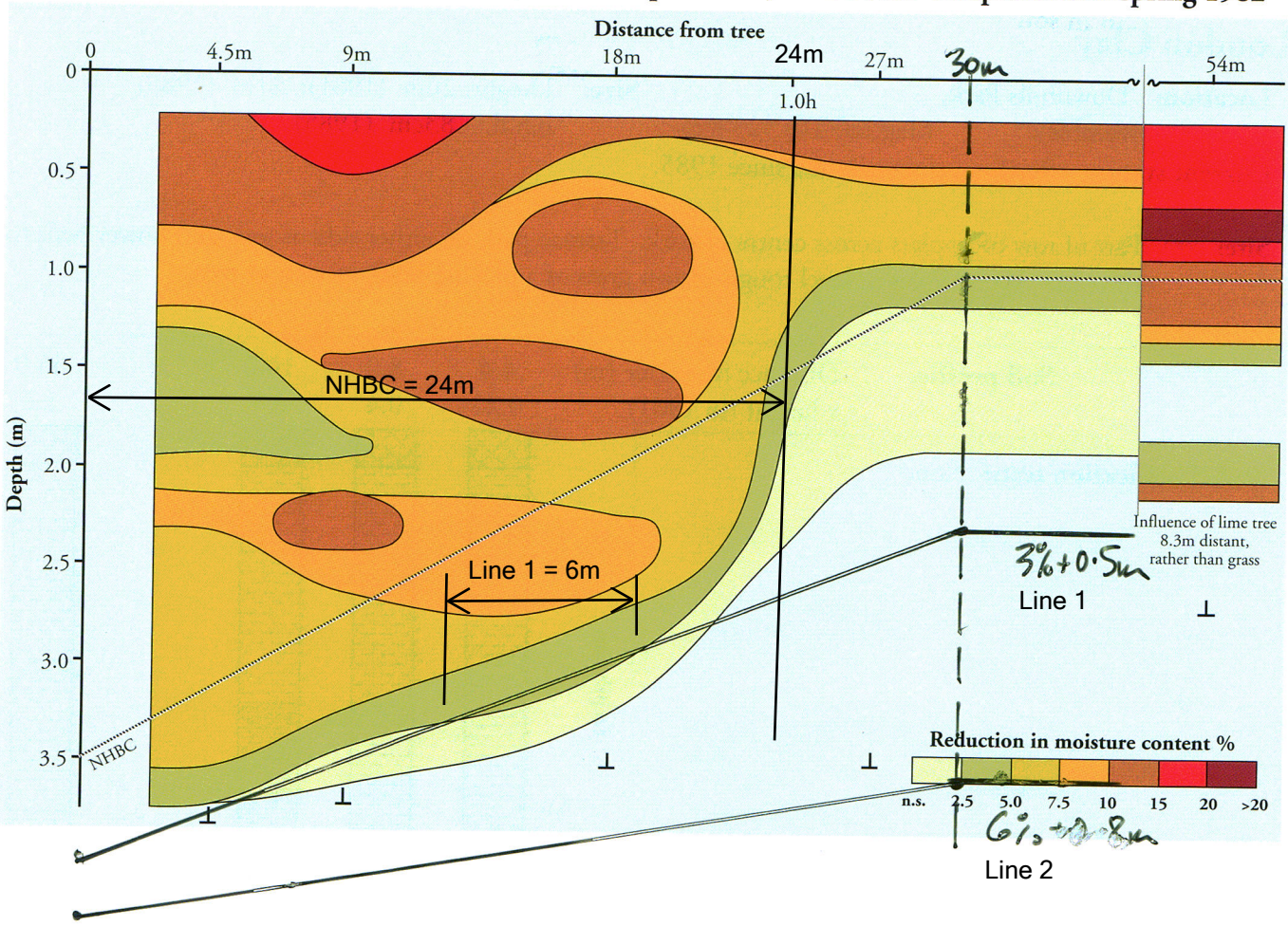


Total soil moisture deficit (seasonal + persistent) on 14/9/95 compared with spring 1982

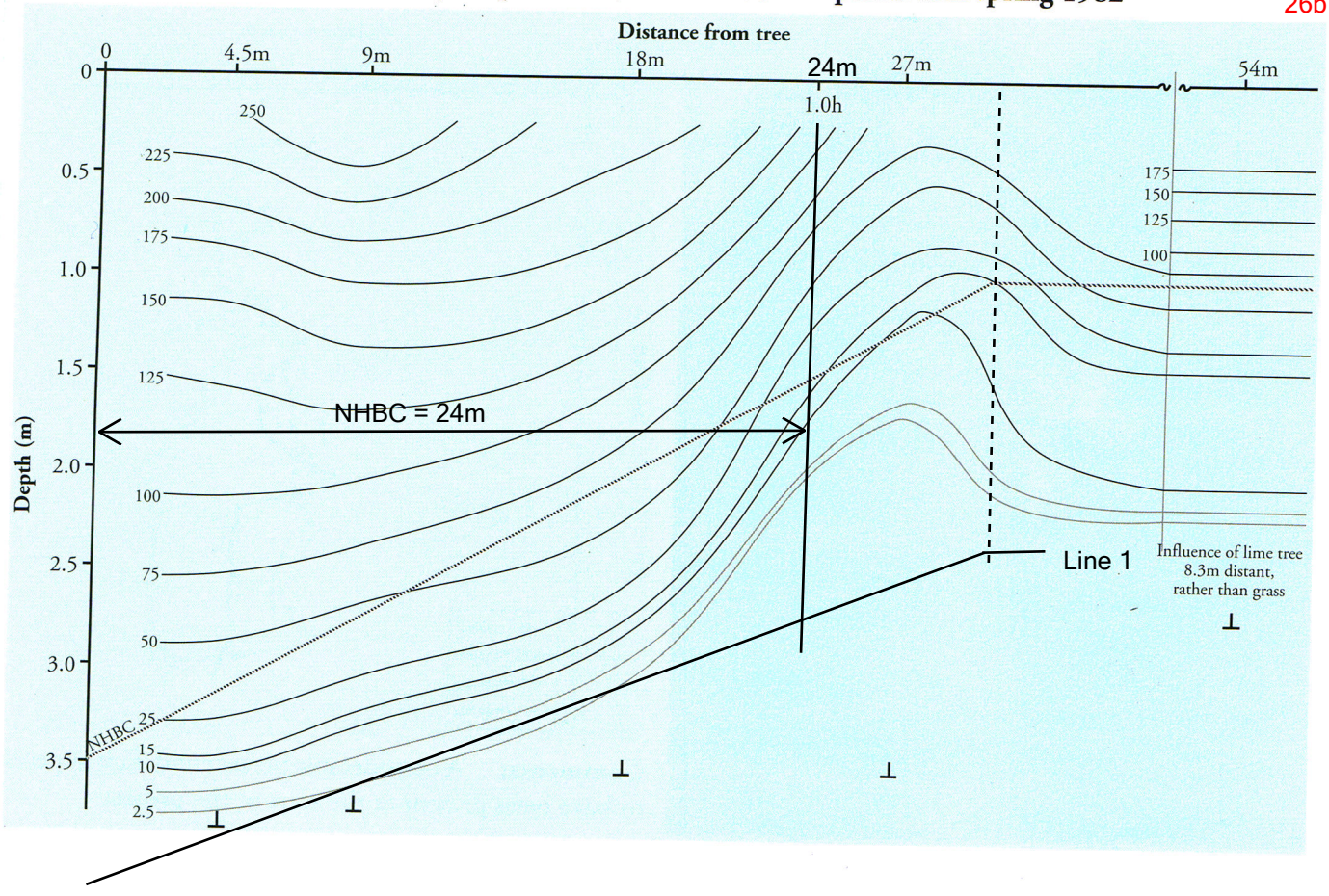
25b



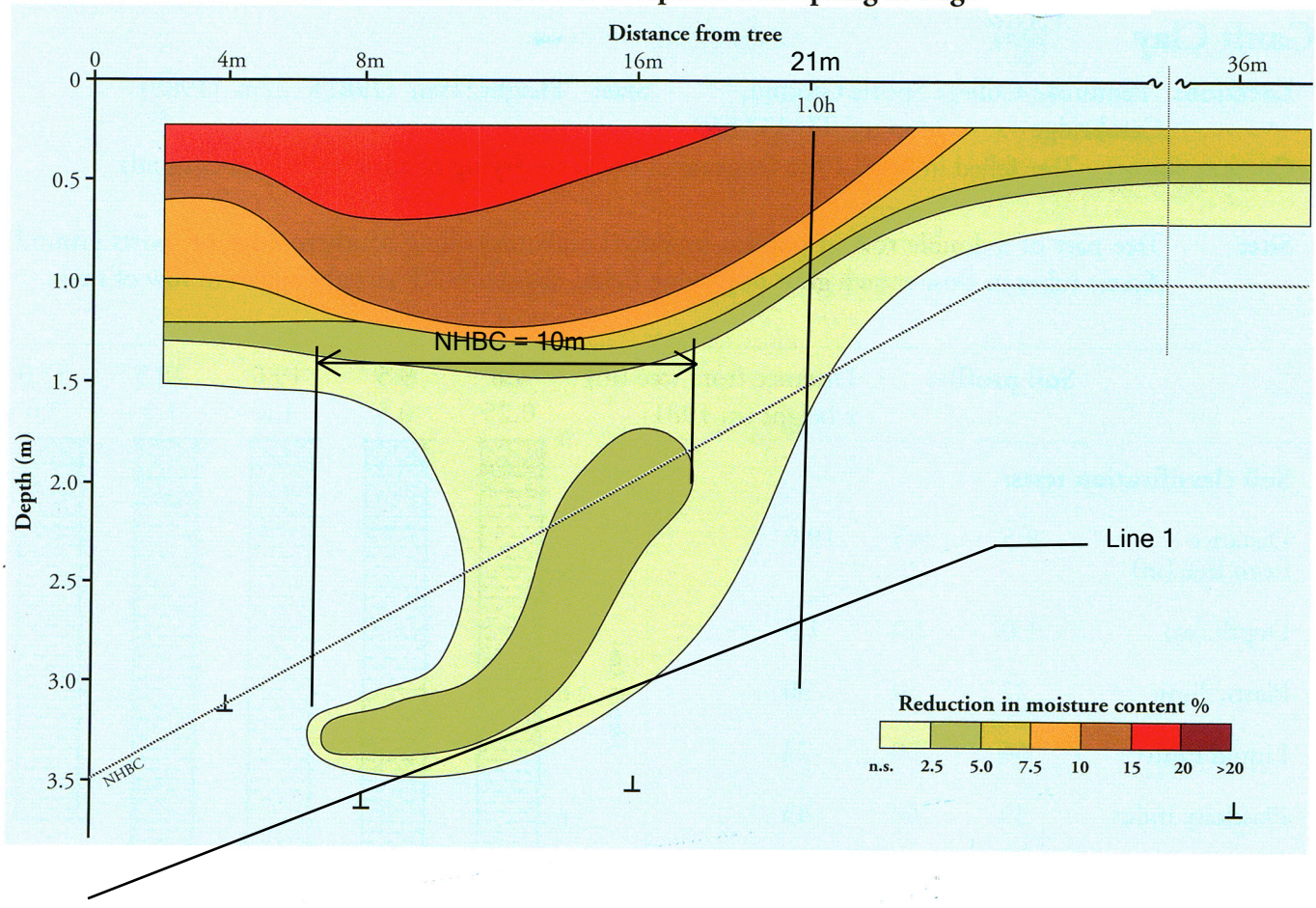
Total reduction in soil moisture content (seasonal + persistent) on 14/9/95 compared with spring 1982 26a



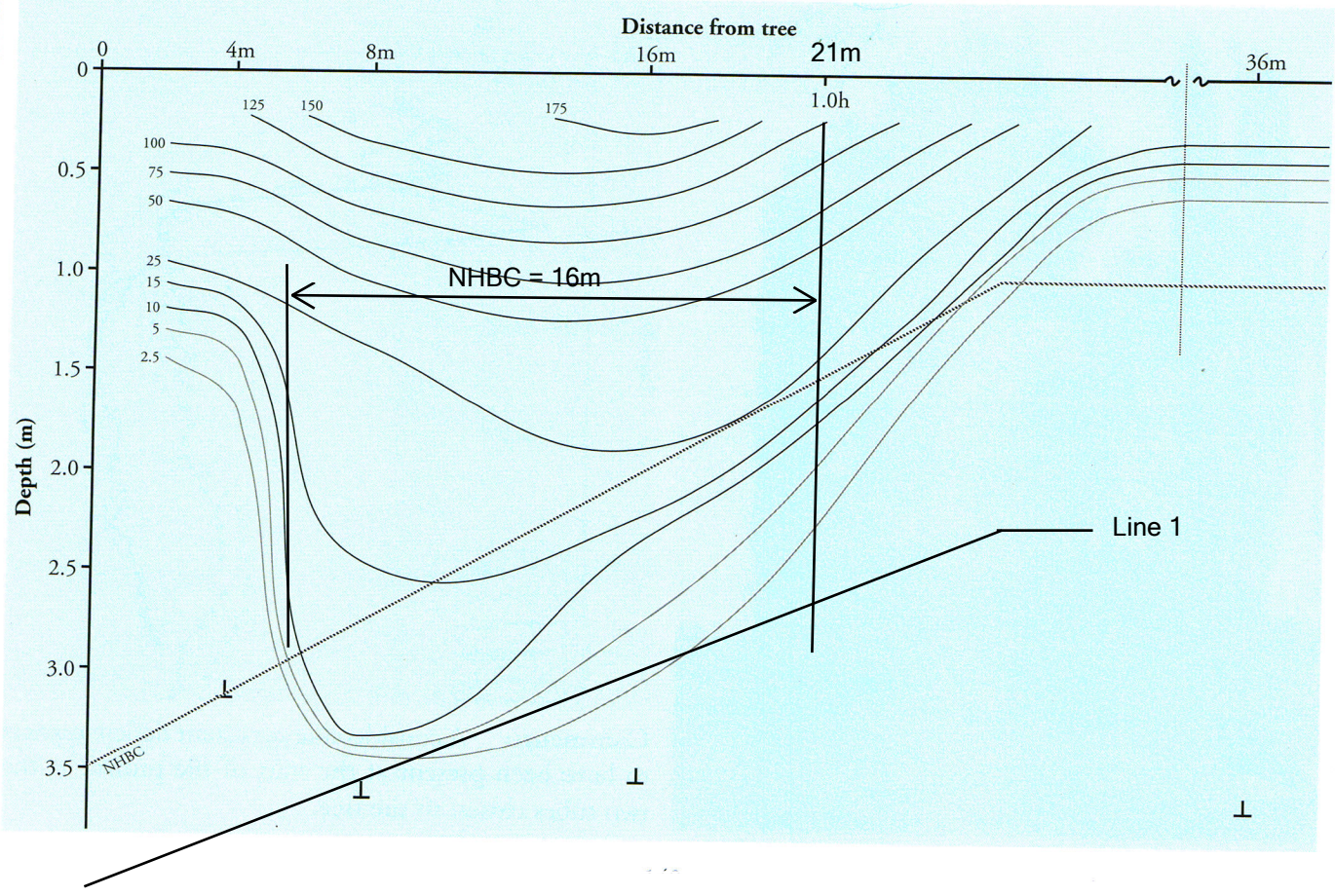
Total soil moisture deficit (seasonal + persistent) on 14/9/95 compared with spring 1982 26b



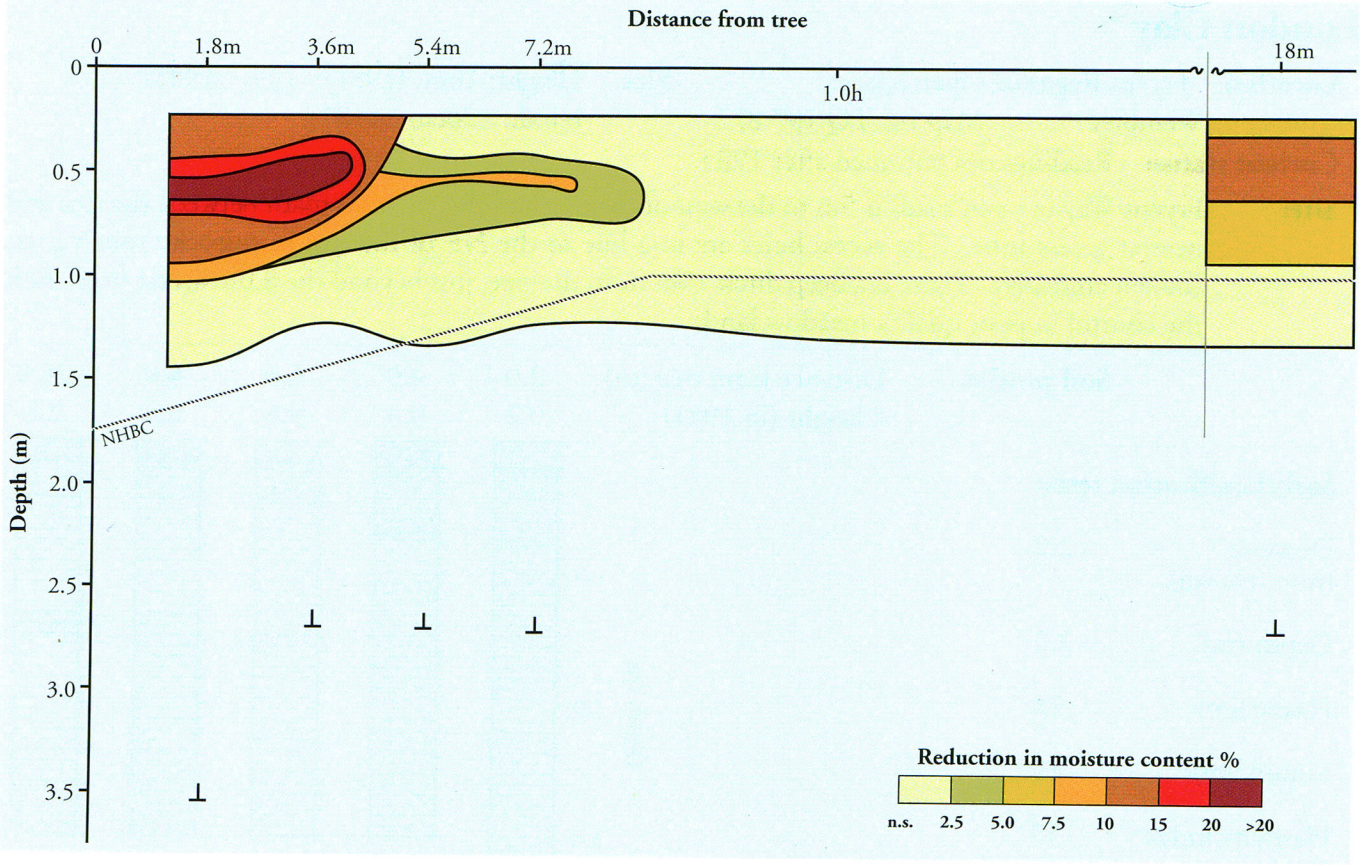
Reduction in soil moisture content on 25/9/85 compared with spring average 27a



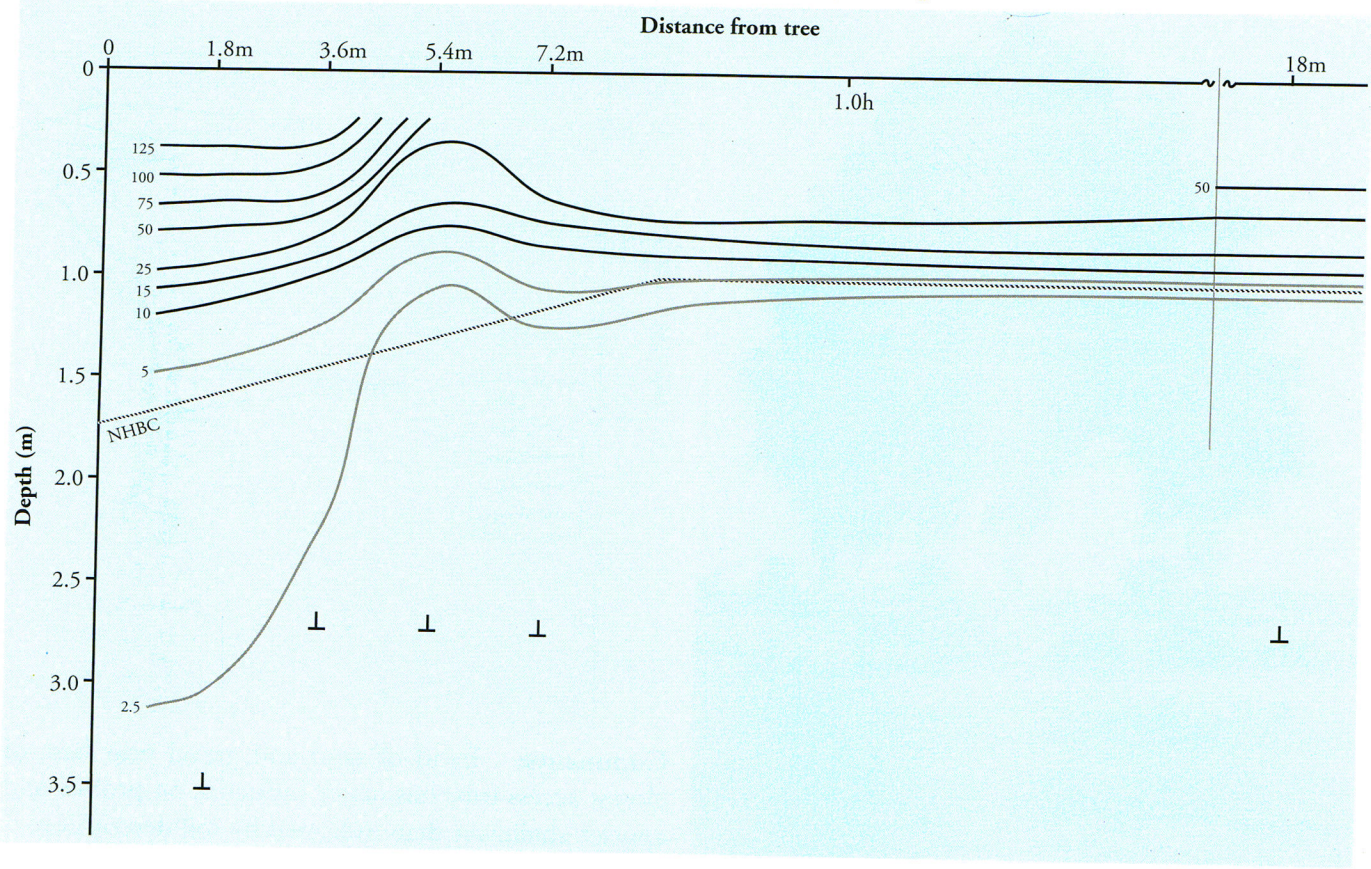
Soil moisture deficit on 25/9/85 compared with spring average 27b



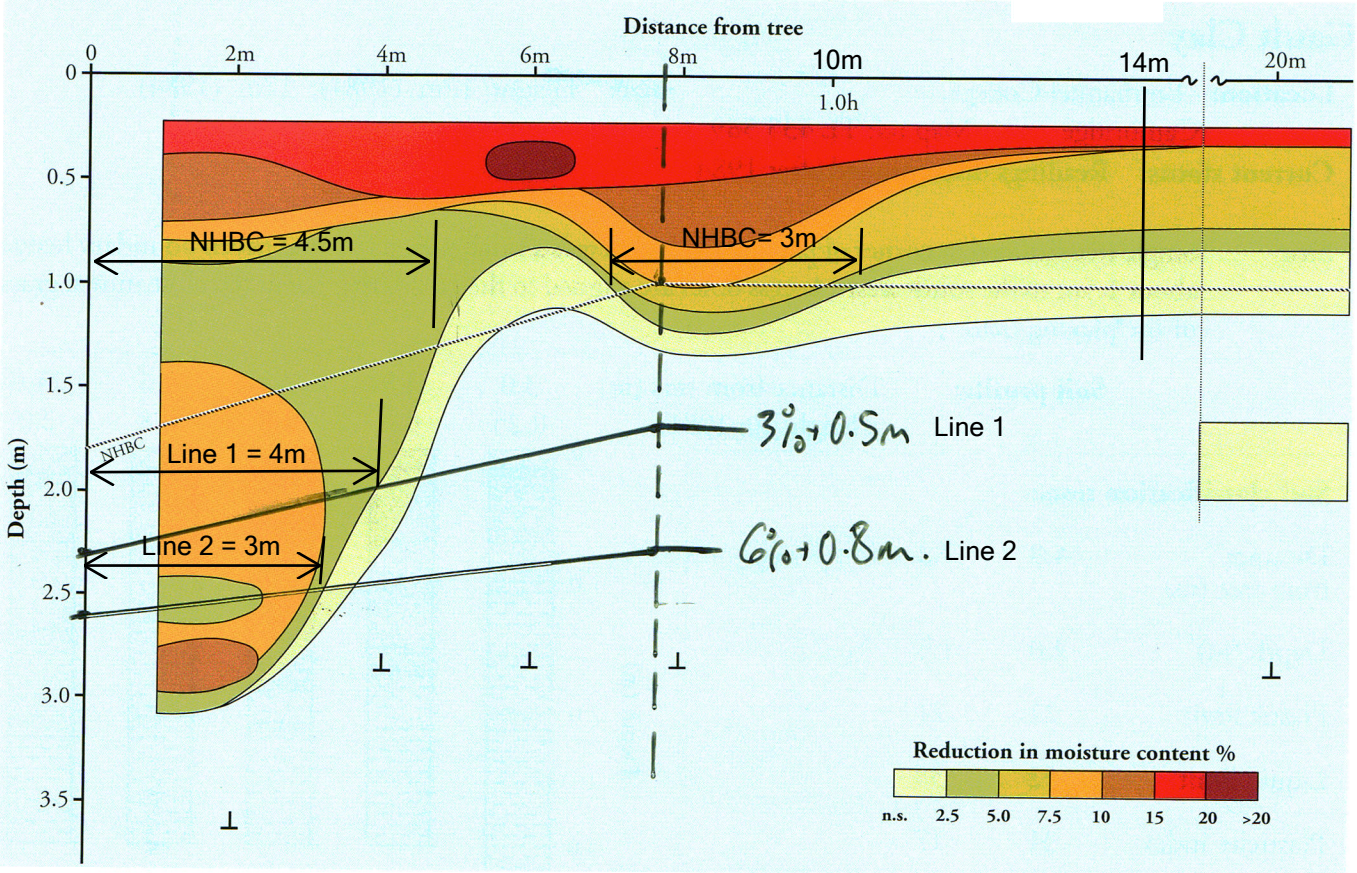
Seasonal reduction in soil moisture content on 16/9/94 compared with spring average 35a



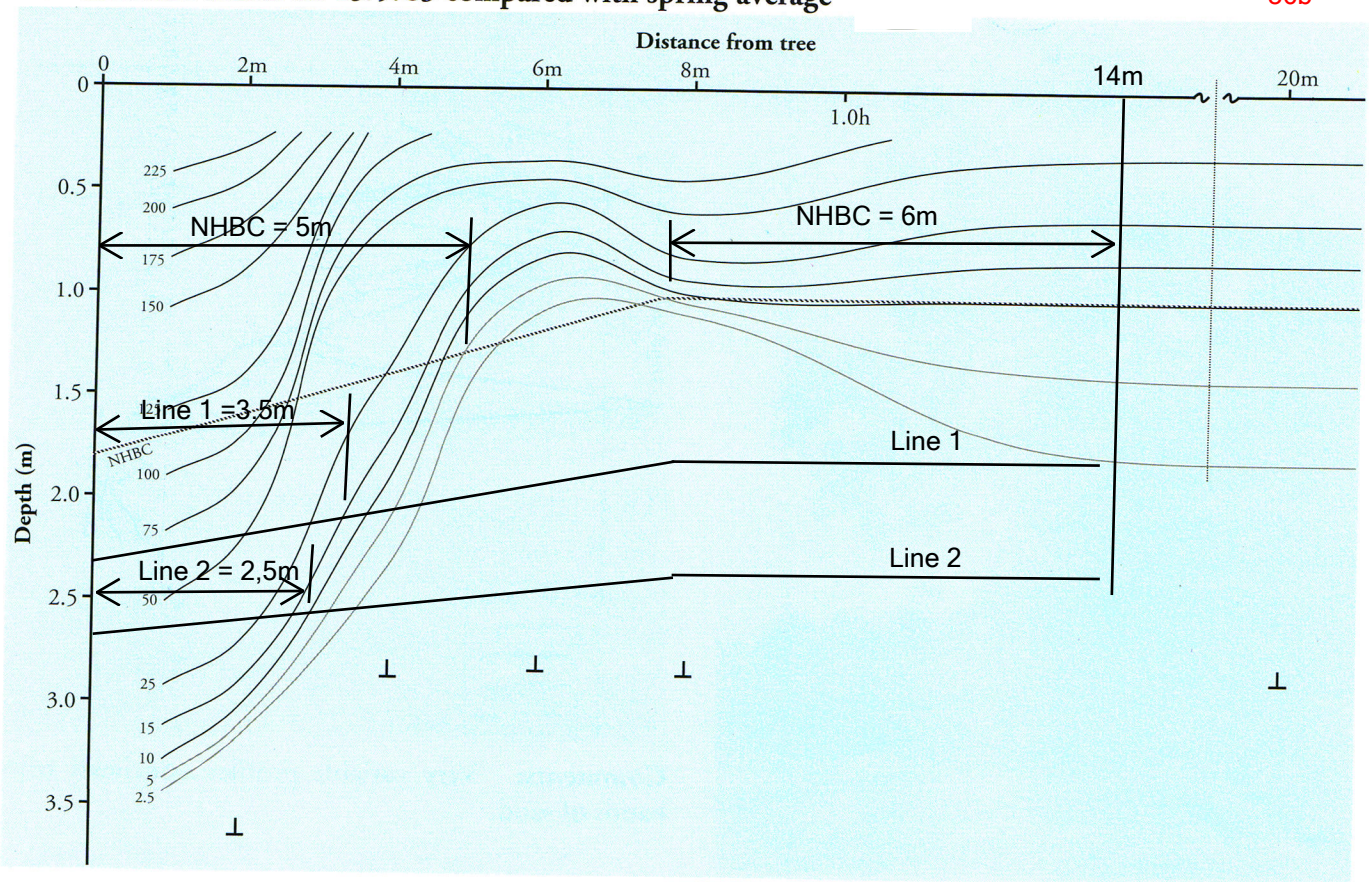
Seasonal soil moisture deficit on 16/9/94 compared with spring average 35b



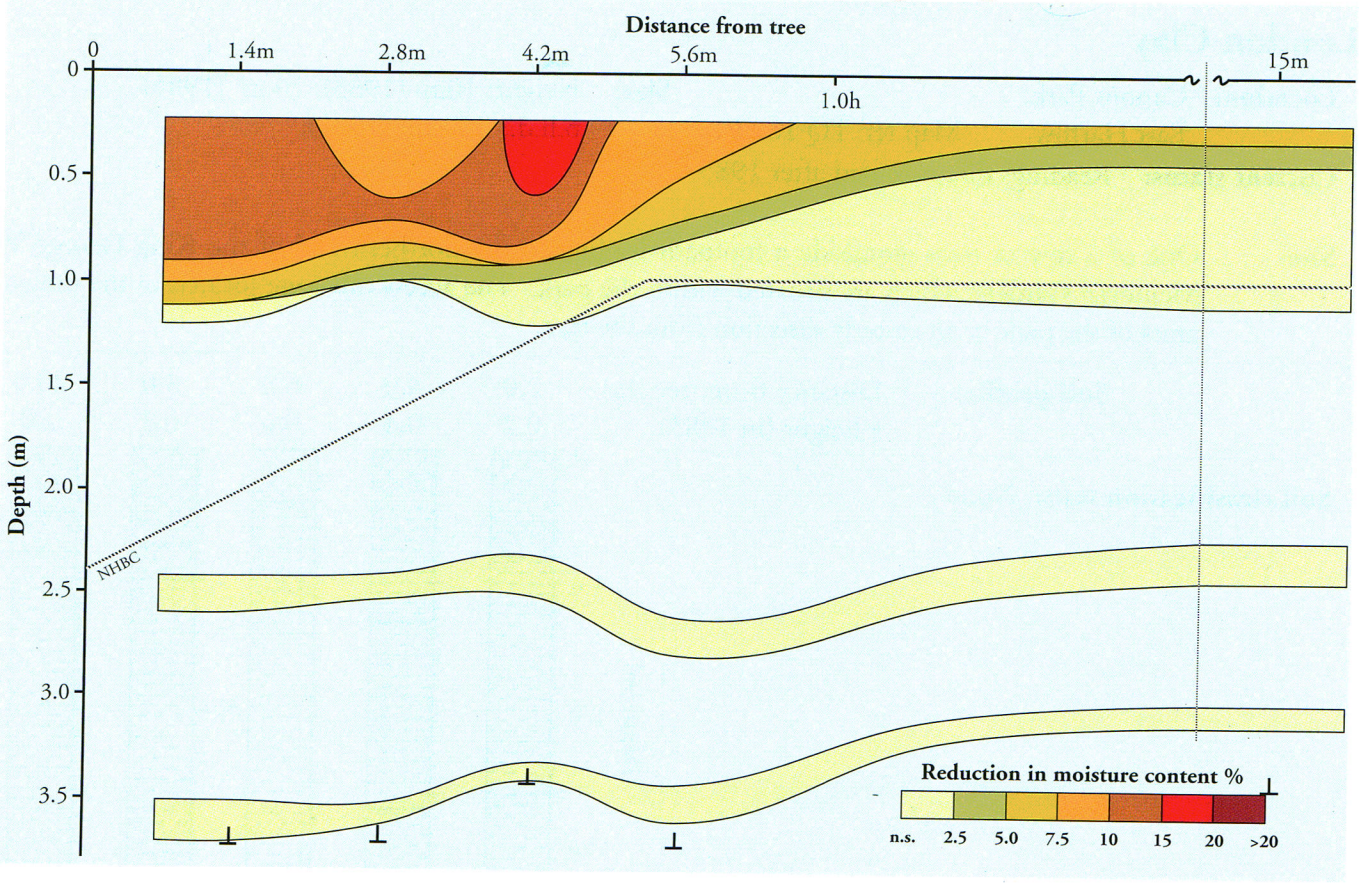
Reduction in soil moisture content on 13/9/83 compared with spring average 36a



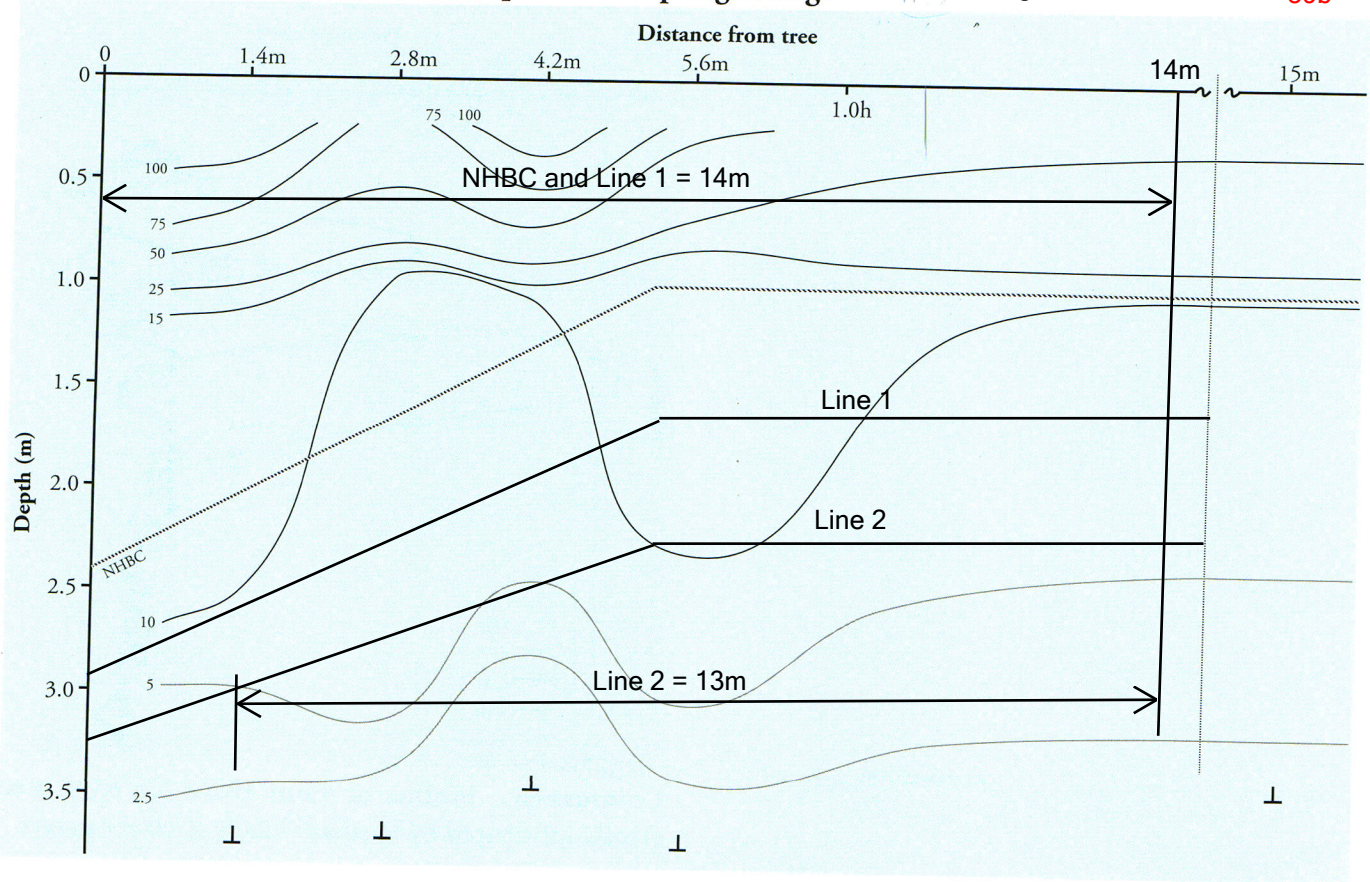
Soil moisture deficit on 13/9/83 compared with spring average 36b



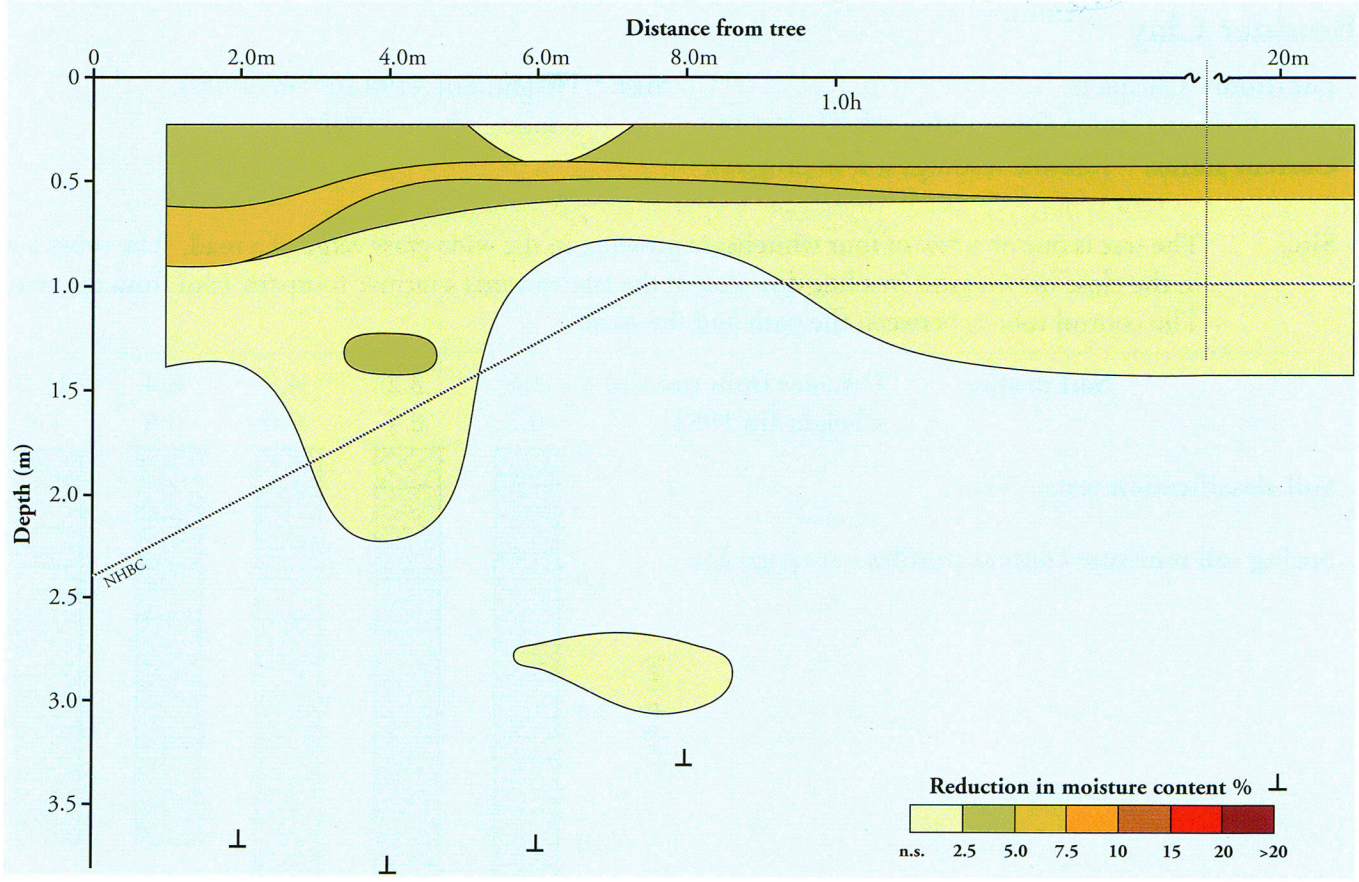
Reduction in soil moisture content on 19/9/83 compared with spring average 39a



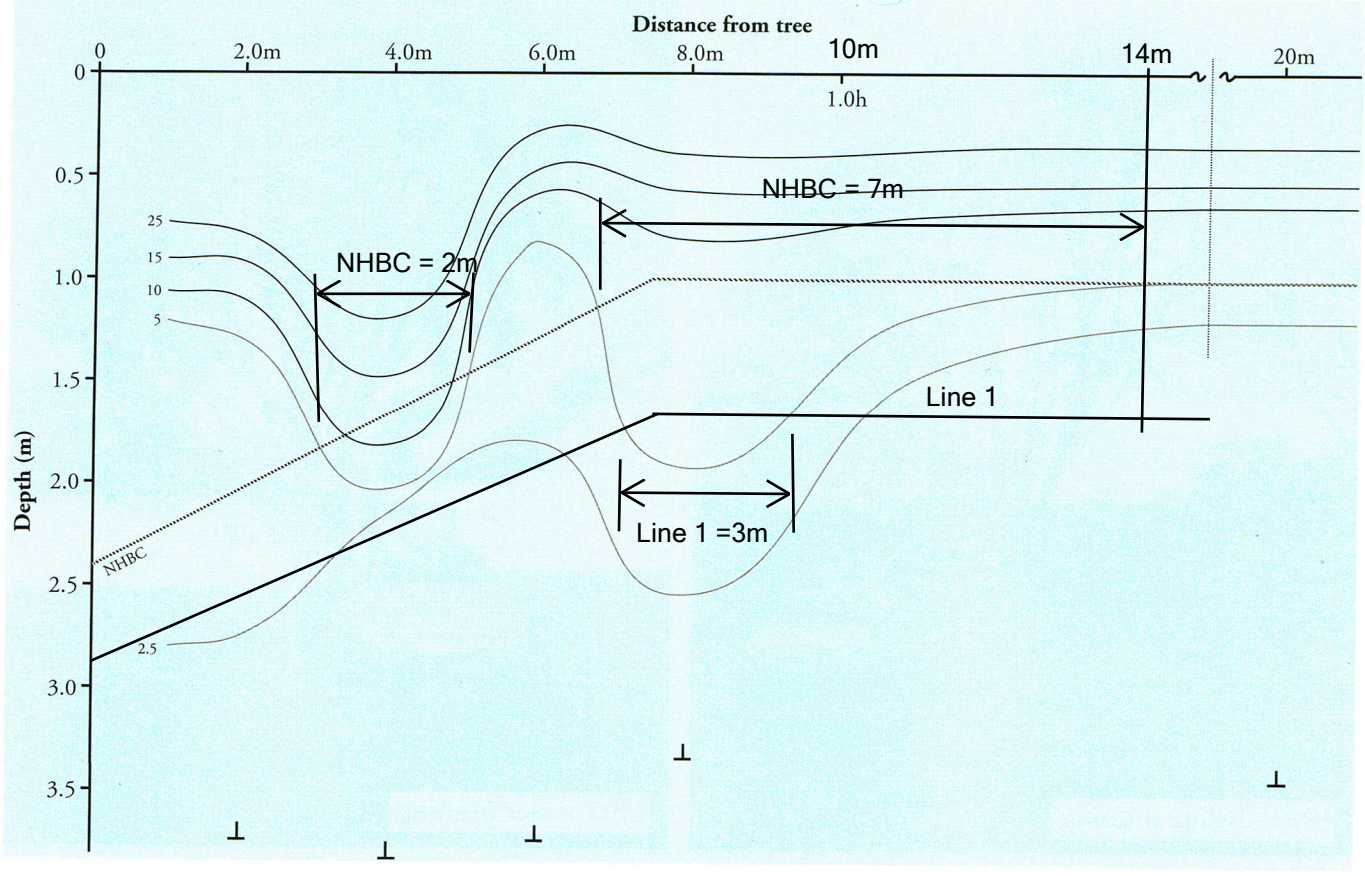
Soil moisture deficit on 19/9/83 compared with spring average Tree 39 height = 8m 39b



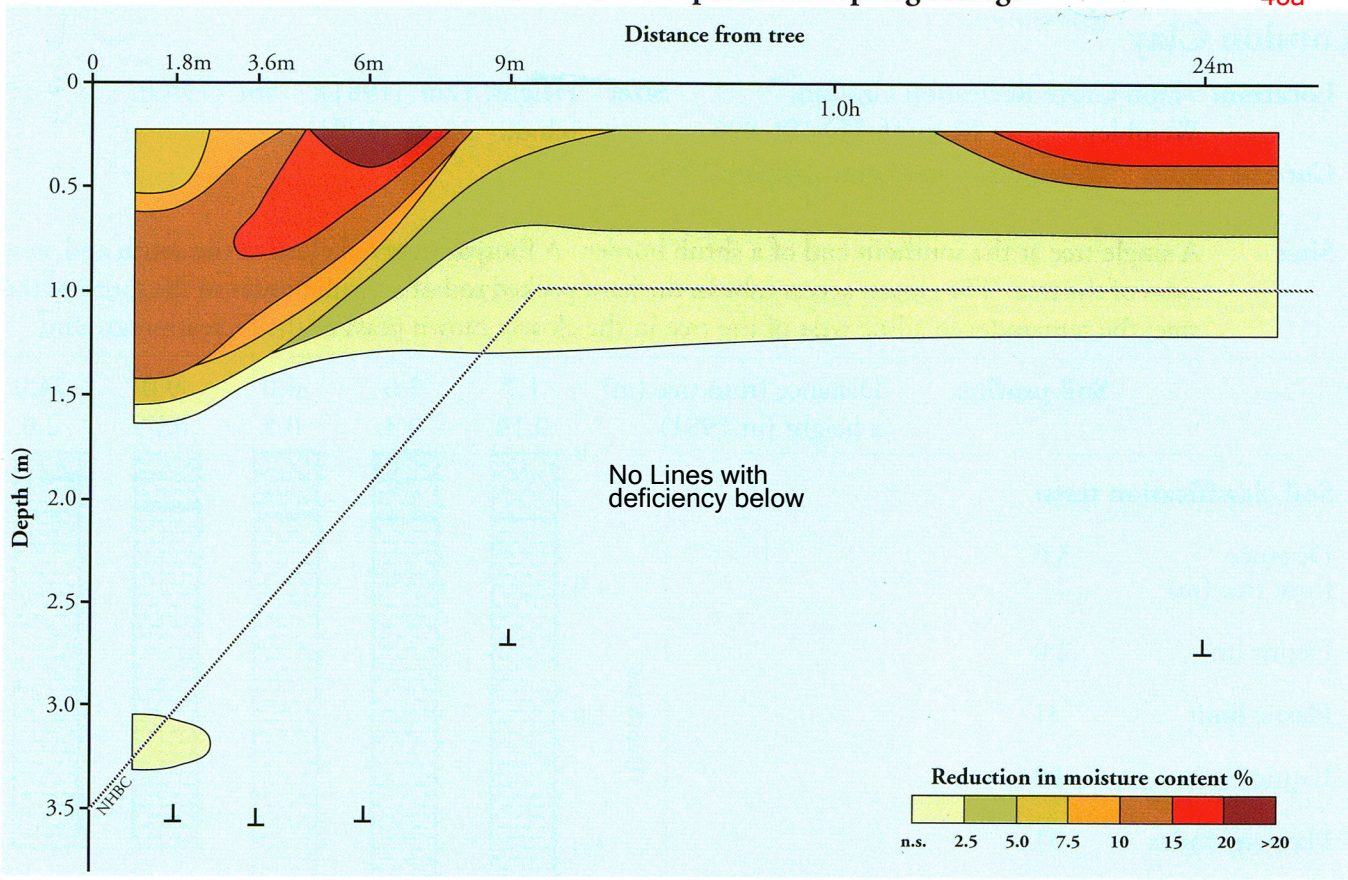
Reduction in soil moisture content on 19/9/83 compared with spring average 40a



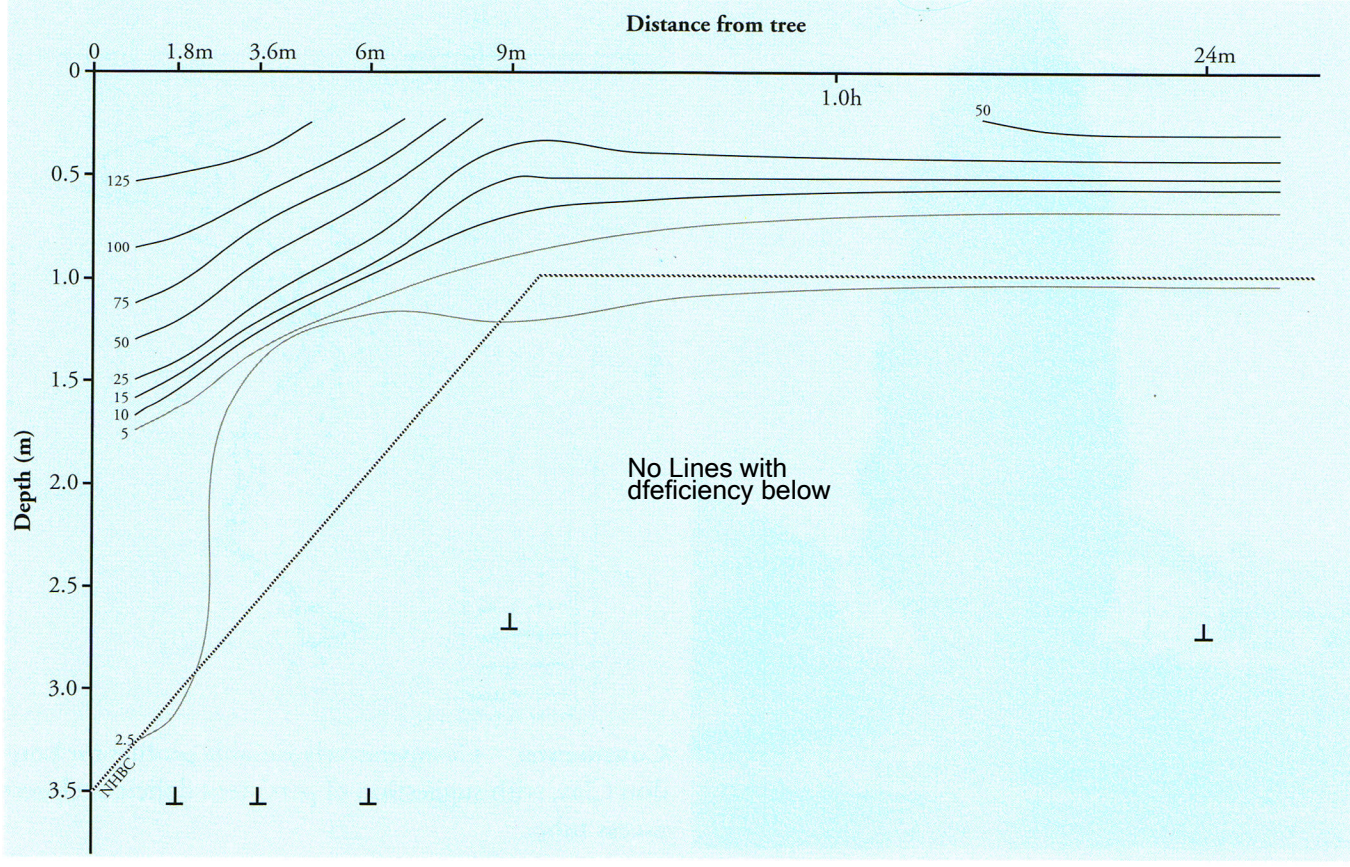
Soil moisture deficit on 19/9/83 compared with spring average 40b



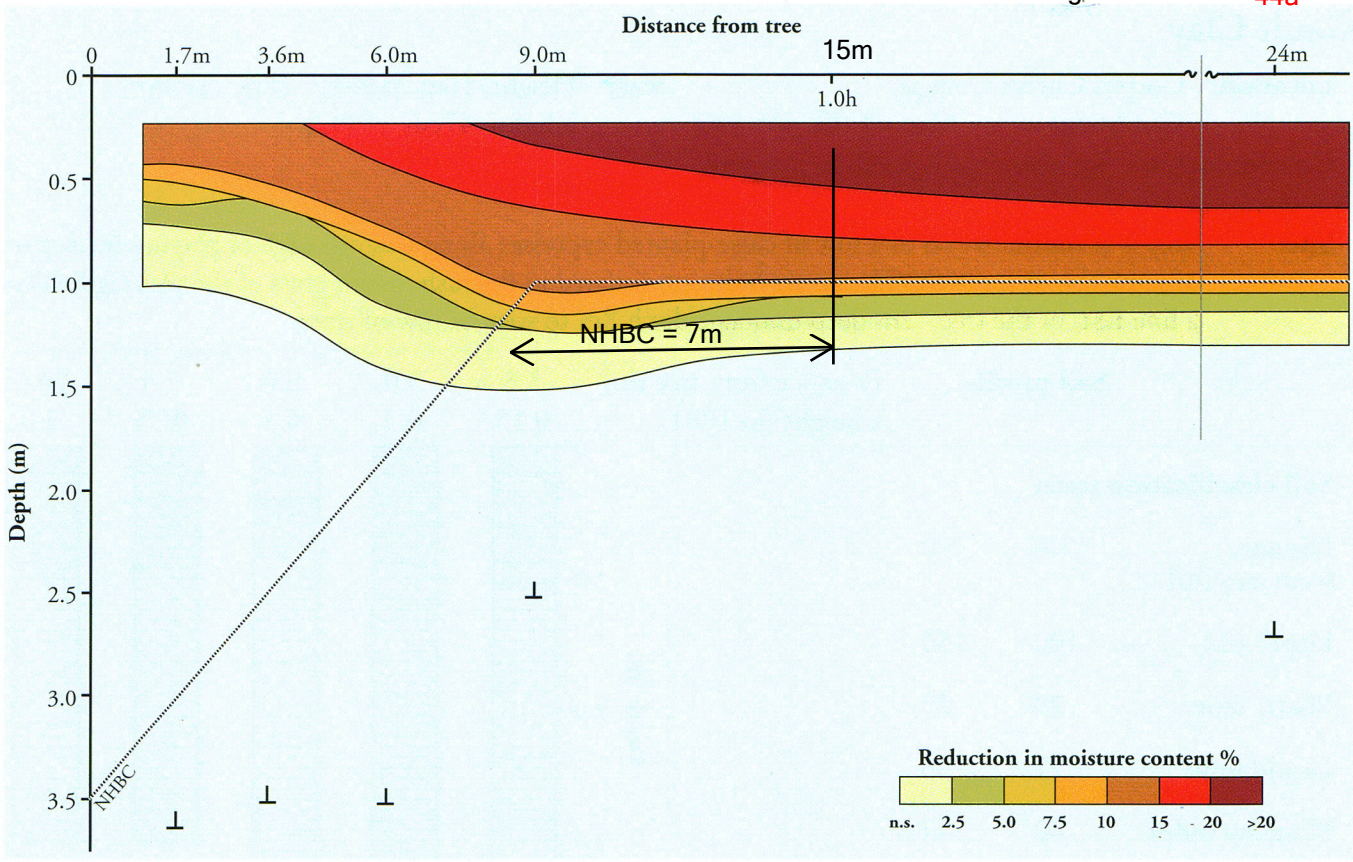
Reduction in soil moisture content on 31/10/91 compared with spring average 43a



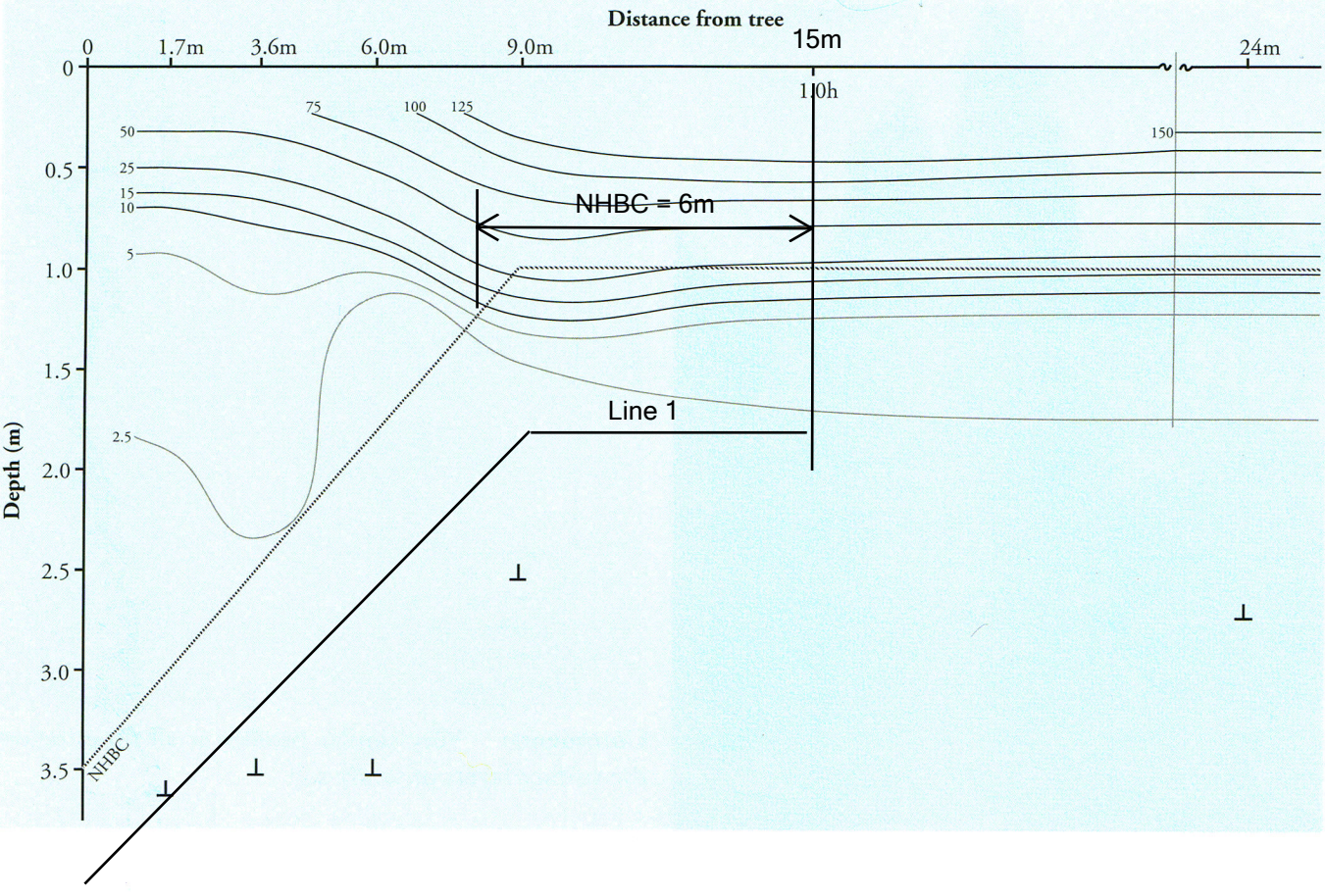
Soil moisture deficit on 31/10/91 compared with spring average 43b



Reduction in soil moisture content on 20/9/89 compared with spring average height = 15m 44a

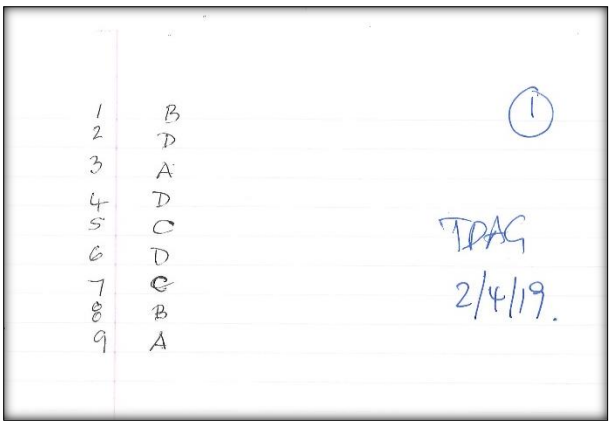


Soil moisture deficit on 20/9/89 compared with spring average 44b

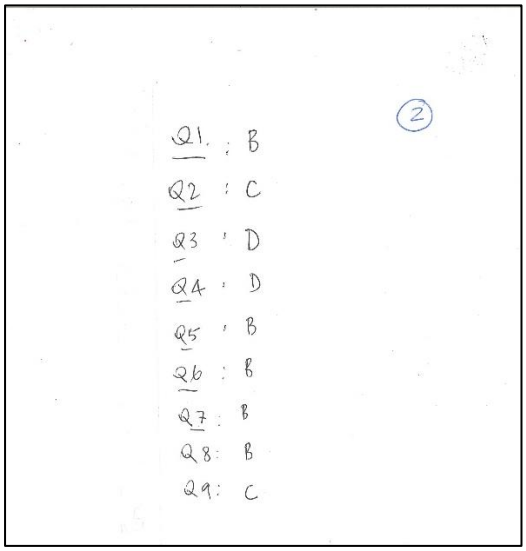


Appendix 12.11 Questionnaire Results TDAG (Raw data)

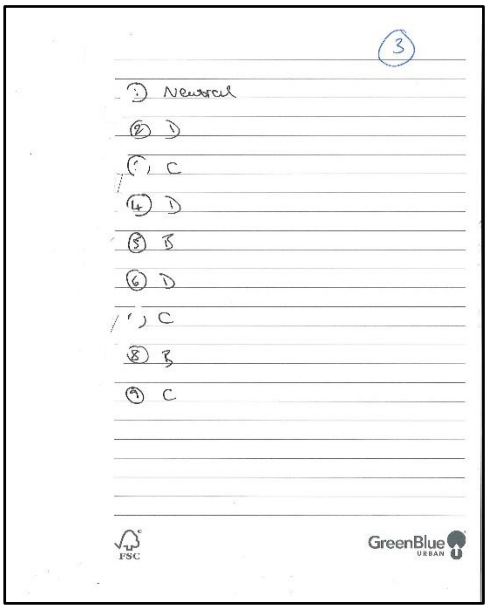
Respondent 1



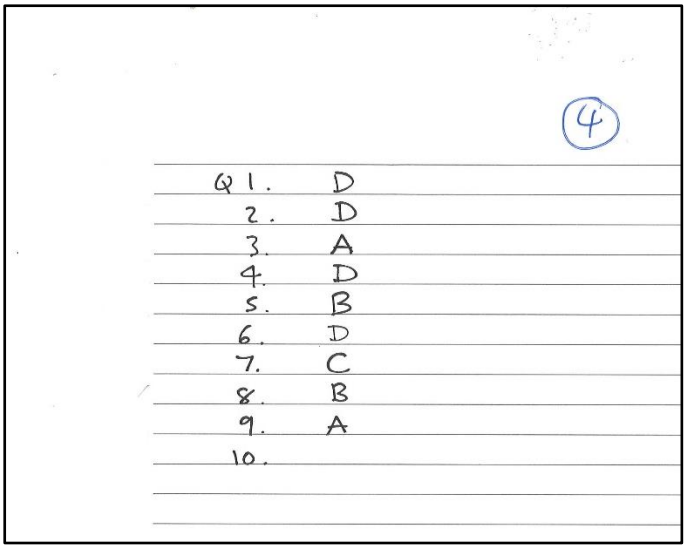
Respondent 2



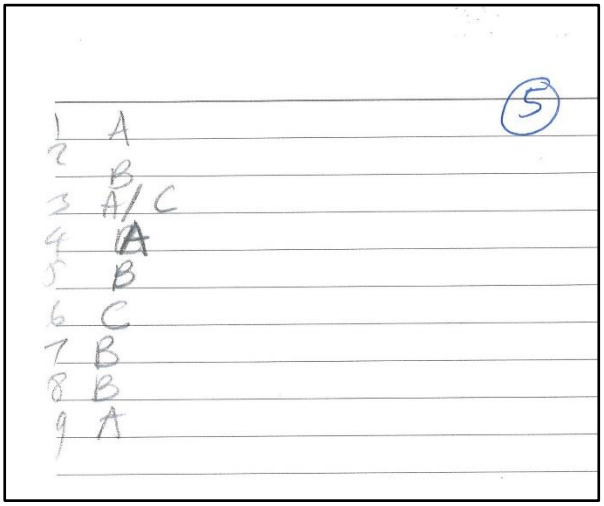
Respondent 3



Respondent 4



Respondent 5



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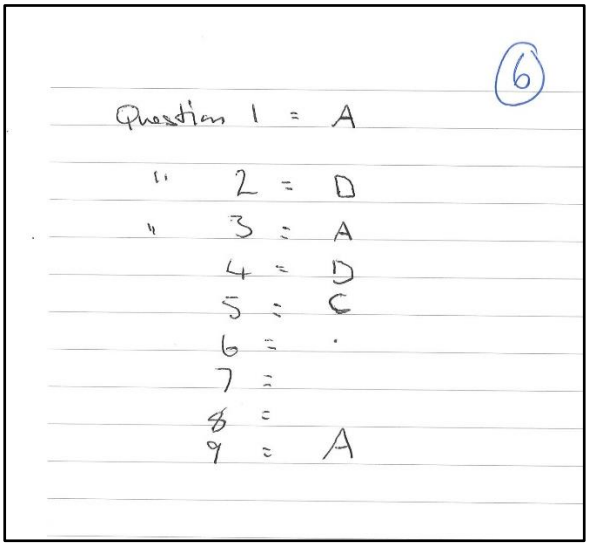
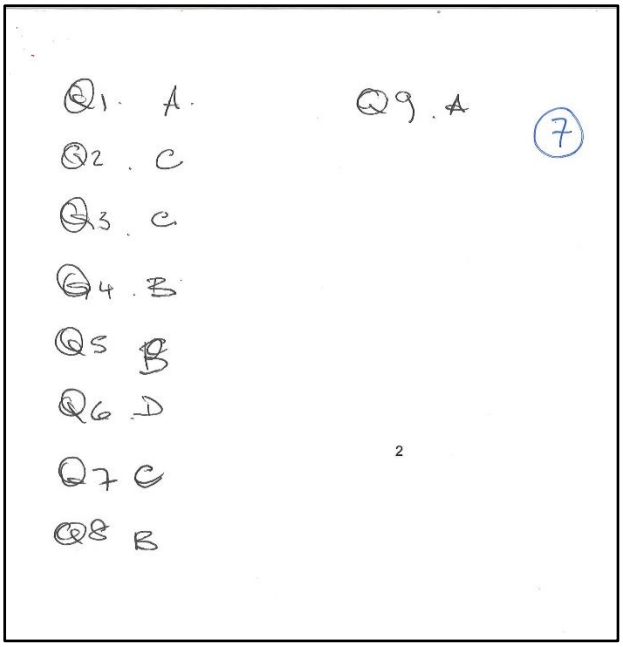


Respondent 7



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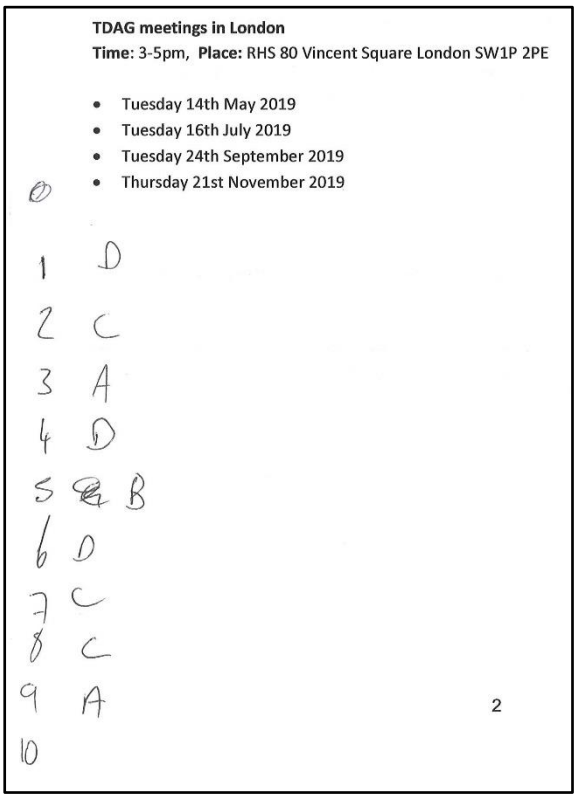
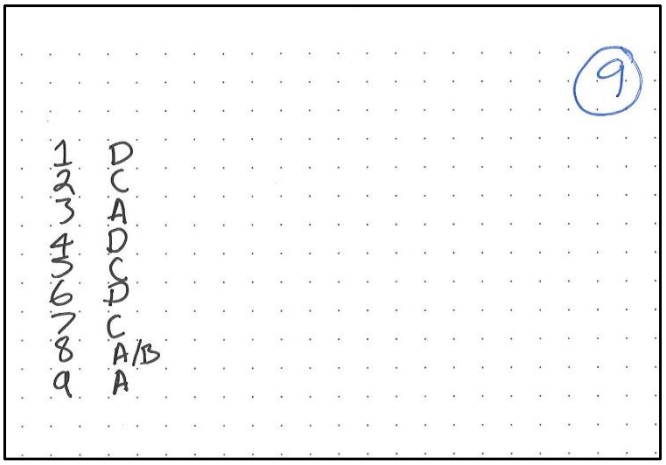
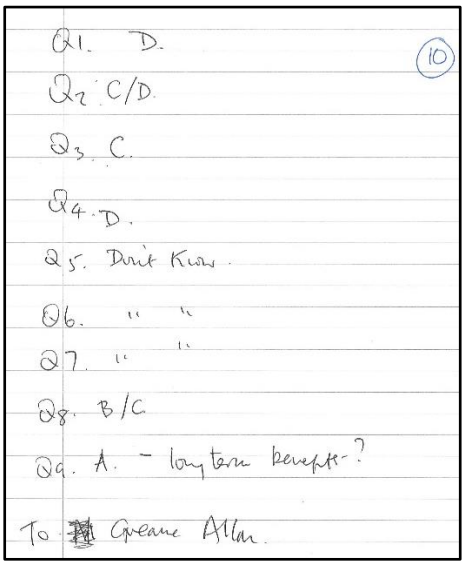


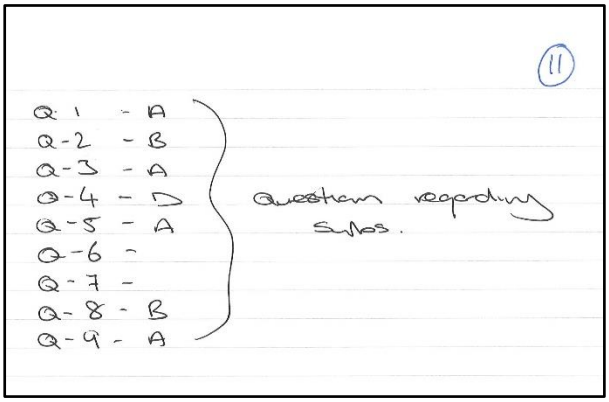
Respondent 9



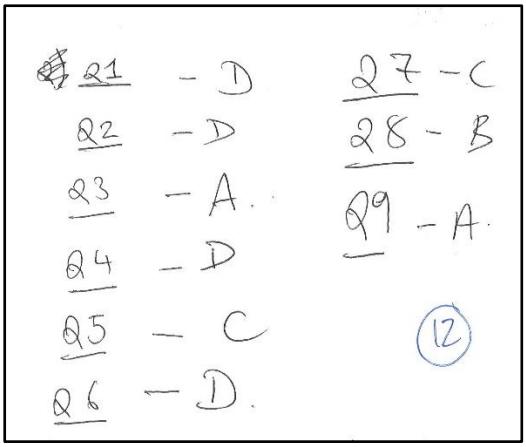
Respondent 10



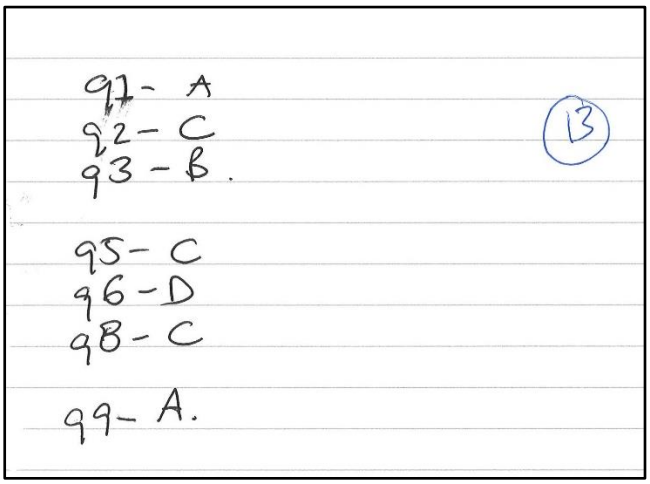
Respondent 11



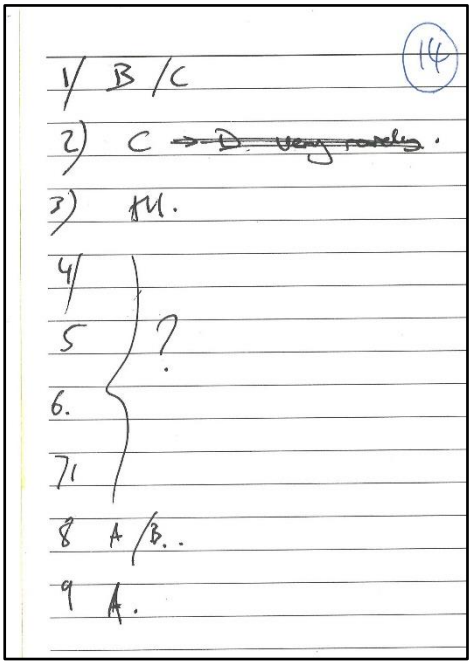
Respondent 12



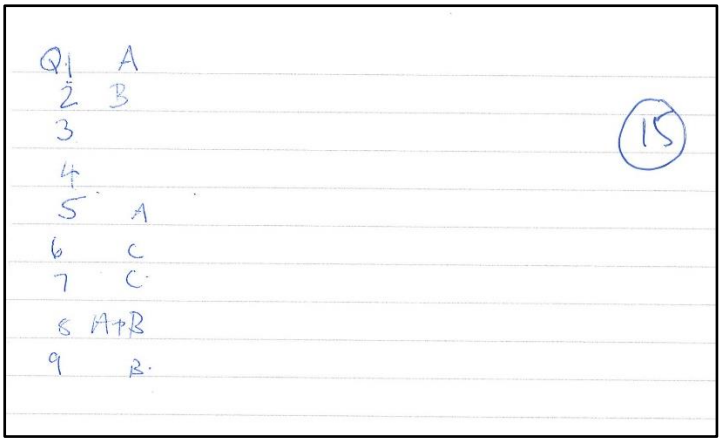
Respondent 13



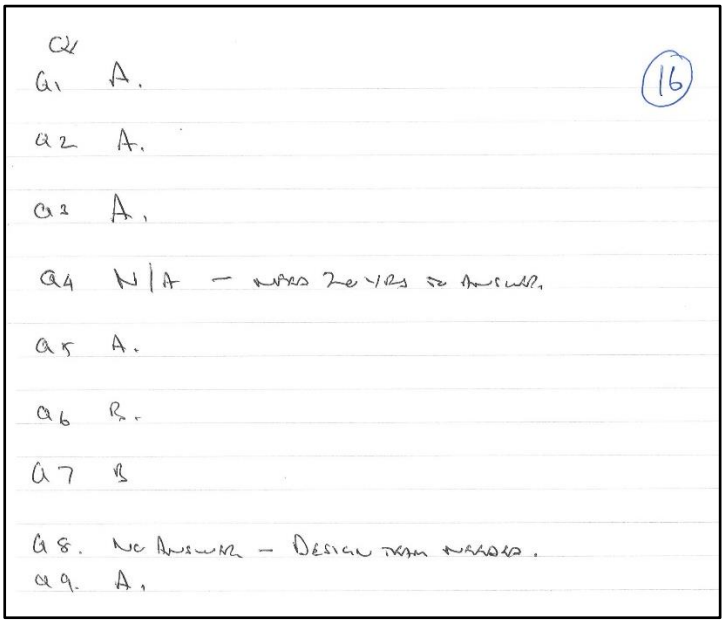
Respondent 14



Respondent 15



Respondent 16



Appendix 12.11 Questionnaire results (Subsidence Forum)

The following pages demonstrate the raw data results for the questionnaire at the Subsidence Forum.

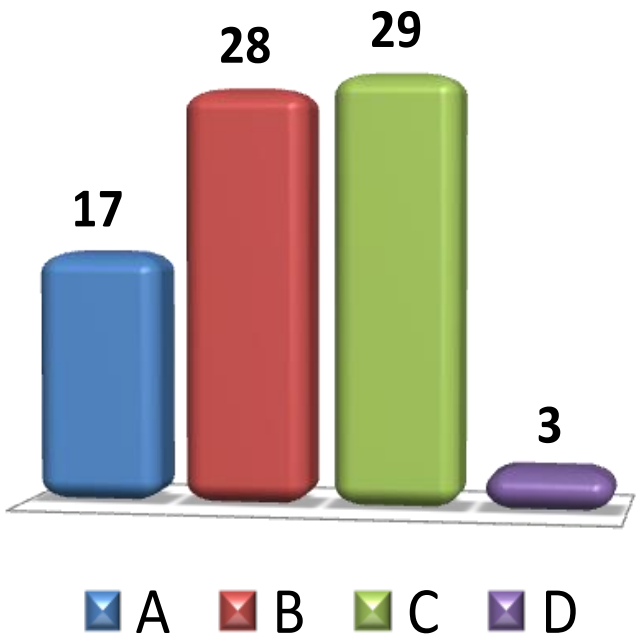
What is the general perception on the use of root barriers to resolve clay shrinkage subsidence claims?

A) **Positive** (would usually consider root barriers)

B) **Neutral** (would sometimes consider root barriers)

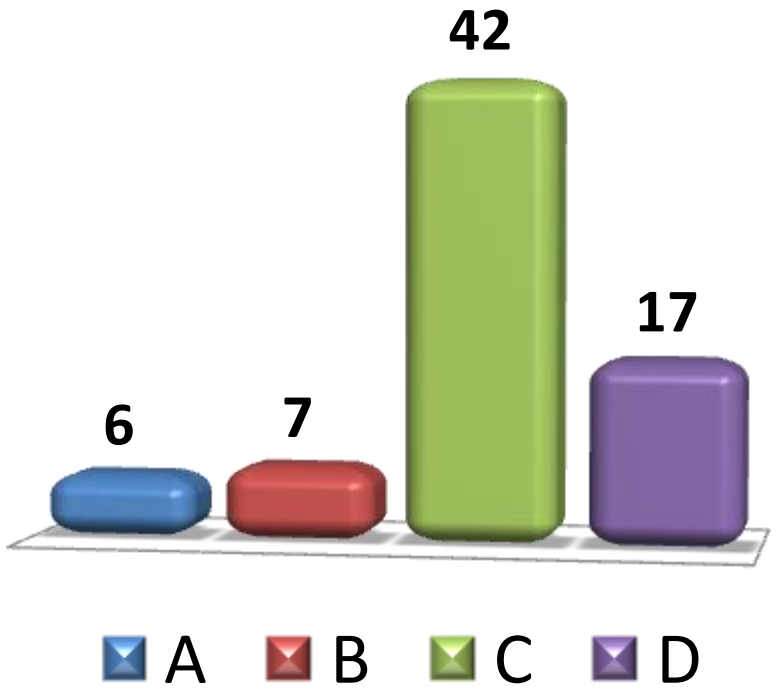
C) **Negative** (would rarely consider root barriers)

D) **No view on root barriers**



How often are root barriers considered (not used) when dealing with clay shrinkage in your experience. This includes cases where they are only considered but not necessarily used?

A) More than 75% of cases
B) Between 75% and 25% cases
C) Less than 25% cases
D) Don't know



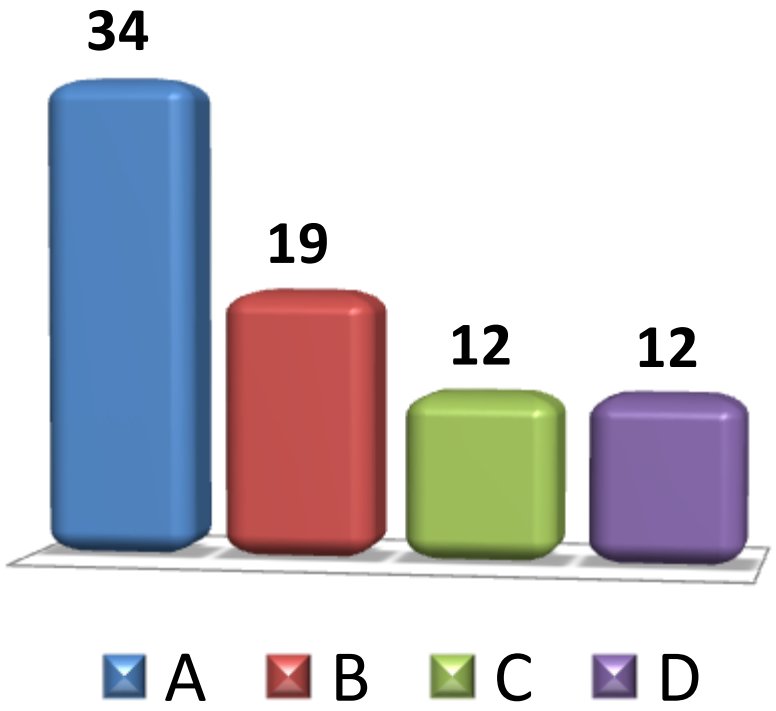
What would you consider to be the main difficulty with the root barrier solution?

A) Practical difficulties eg. services or installation

B) Cost when compared with tree removal

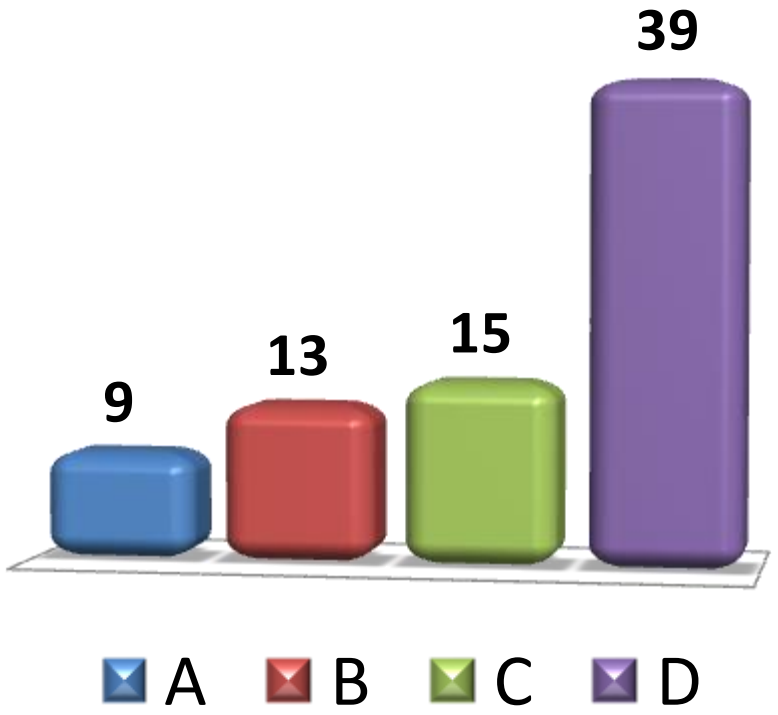
C) Lack of understanding/ design rules

D) Unreliable



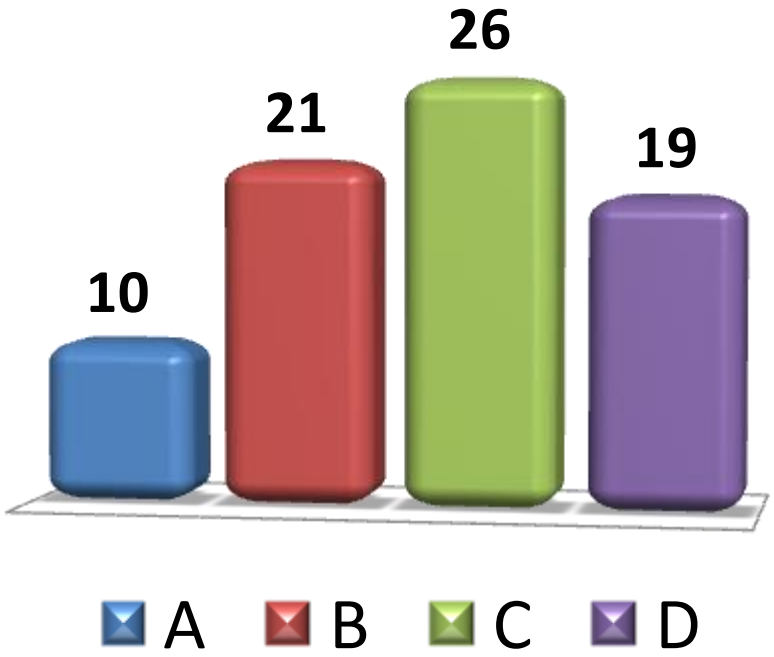
If you have installed root barriers, in your opinion have they been successful?

A) All of the time (100%)
B) Most of the time (>75%)
C) Some of the time (<75%)
D) No experience of their use



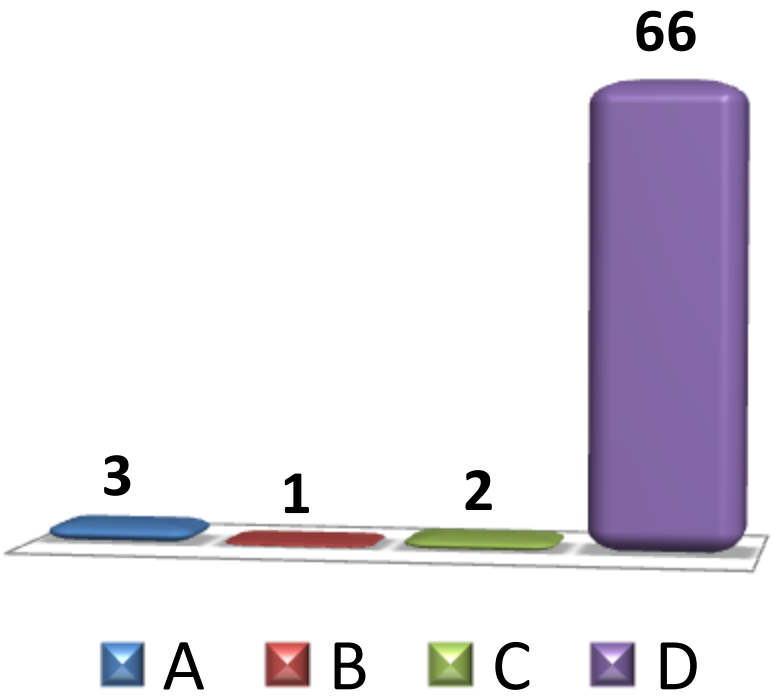
What in your view is the value of this tree over a 30 year period?

A) Over £1,000,000
B) Between £1m and £250,000
C) Between £250,000 and £50,000
D) Less than £50,000



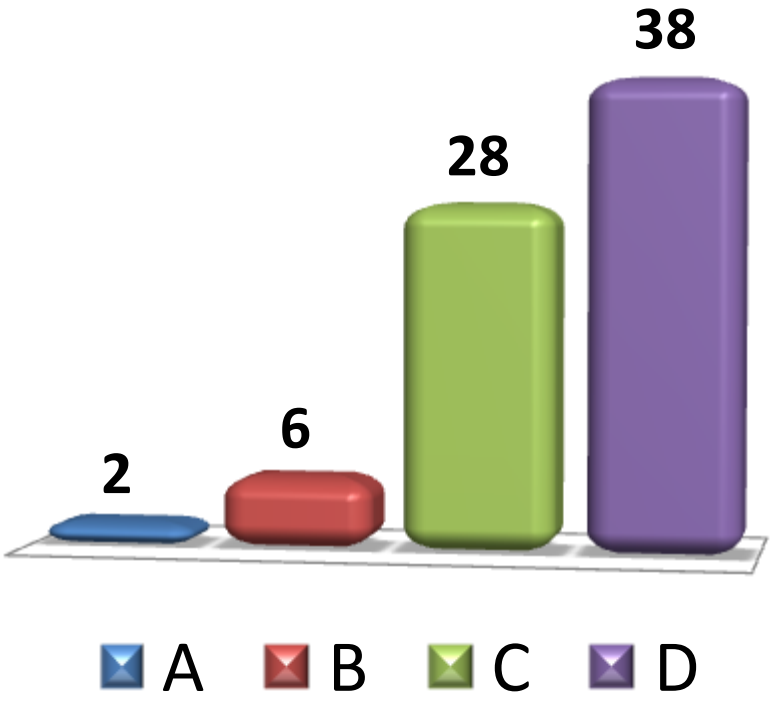
Value of this tree over a 30 year period?

A) Over £1,000,000
B) Between £1m and £250,000
C) Between £250,000 and £50,000
D) Less than £50,000



£1,000,000 over 30 years = £33,000 per year
£250,000 over 30 years = £ 8,300 per year

Value of this tree over a 30 year period?



A) Over £100,000

B) Between £1m & £250,000

C) Between £250,000 & £50,000

D) Less than £50,000

£1,000,000 over 30 years = £33,000 per year

£250,000 over 30 years = £8,300 per year

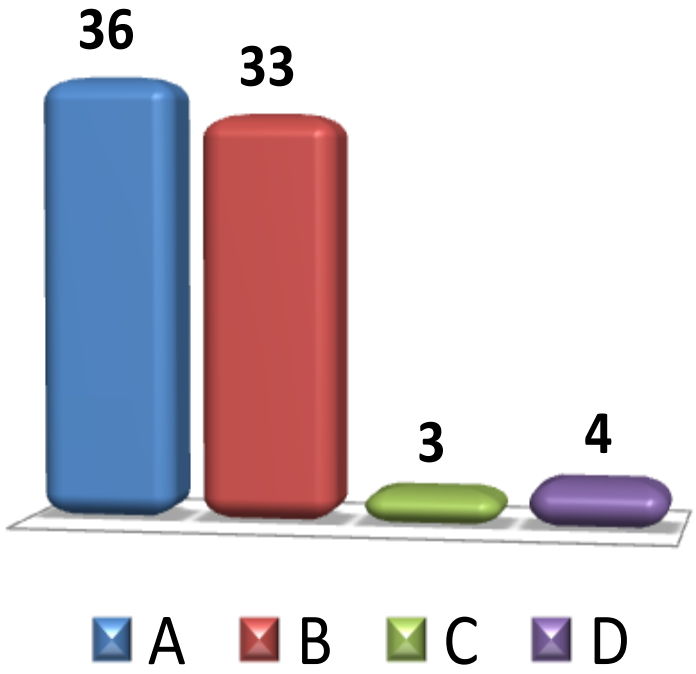
Who should specify and take the lead role in the use of root barriers?

A) Loss adjusters/Engineers

B) Arborists

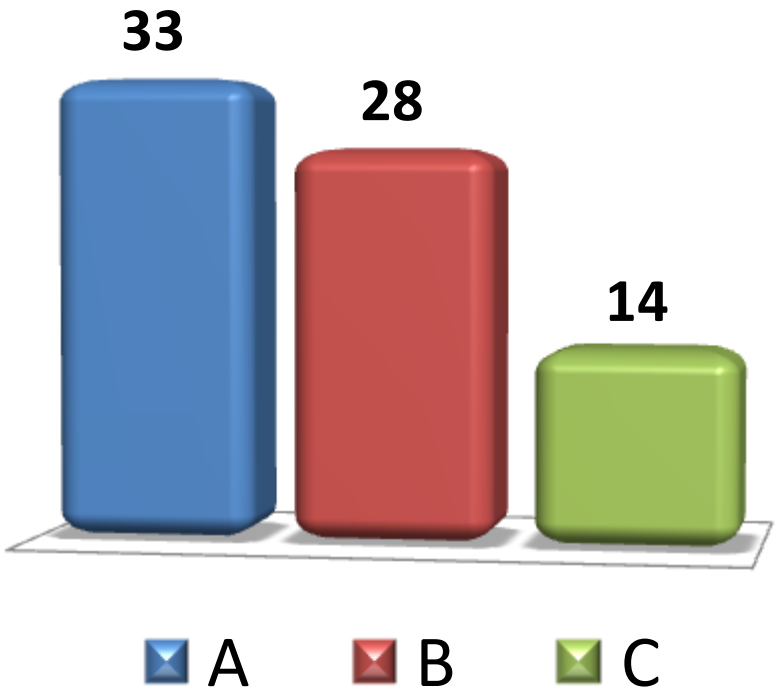
C) Contractors

D) Don't Know



Would you consider a root barrier even if there were no objections to tree removal?

A) YES

B) NO

C) No experience of using root barriers