A review of current research relating to domestic building subsidence in the UK: what price tree retention?

Abstract

The Association of British Insurers reports that UK domestic property insurers receive around 35 000 domestic subsidence claims in a normal year, and settle them at a cost of around £250 million. In a hot, dry year, the number of claims can increase significantly. These are termed 'event' years. For example, in 2003 the claim count exceeded 55 000 and costs increased to £400 million – an increase of just over 60%. It is estimated that vegetation (primarily trees) accounts for 70% of valid claims in event years.

Unfortunately, there is often conflict between municipal arborists charged with administering statutorily controlled trees in the urban environment and the insurers of houses built on a clay sub-soil. The perceived threat of subsidence leads to polarised views from the various parties, stakeholders and interest groups.

Insurers may seek tree removal as a permanent and economic claim resolution. The Local Authority Arboricultural Officer may prefer insurers to pay for the house foundations to be deepened and implicated trees left in place. As this debate continues, on occasion ending in legal action, the homeowner can feel sidelined, watching their home deteriorate as the various interest groups take their stand. With this conflict in mind, how do concerned parties address the vision of the Mayor of London that seeks to expand London's tree cover 5% by 2025? Can insurers be seen as a force for good in contributing to maintaining urban greening?

Current research being undertaken by the Clay Research Group (CRG) and OCA UK Ltd seeks to contribute to a balanced resolution to this problem. The CRG, by linking with academics from various disciplines, has several studies under way to test new methods of undertaking the investigation and repair of subsidence damaged houses. It is anticipated that data collected can be used to support those wishing to retain trees in the urban environment.

This paper concludes by exploring the need for a policy framework built between the Association of British Insurers (ABI), Local Government Association (LGA), The Public Risk Management Association (ALARM), Communities and Local Government (CLG), Trees and Design Action Group (TDAG), Subsidence Forum and research bodies such as the CRG and OCA, so that innovation and a collaborative approach to solving those occasions when trees are implicated in indirect property damage can be established.

Introduction

The Lord Mayor has suggested that London will need more trees to be planted by 2025 in order to mitigate the 'urban heat island effect'. It is estimated that there are *c.* 6 million trees in the London Boroughs, providing around 20% of canopy cover by total geographical area. The proposed increase adds 5% extra canopy cover, which equates to around 2 million extra trees planted.

The pursuit of sustainable urban greening is a concept supported by all political parties. Ebenezer Howard (1902) believed fervently that the best attributes of town and country life could be joined in the Garden City. He hoped that both 'may be secured in perfect combination'. We know the vision of Howard to establish and sustain tree-lined streets in Letchworth and Welwyn was not new. Planners and other groups have been striving to sustain trees and beautify our urban areas for more than a century.

Keywords:

climate change adaptation, environment, subsidence, sustainability, urban heat island, urban greening

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Insurers have an interest in this proposal as around 70% of domestic subsidence claims are attributable to vegetation-induced clay shrinkage (Driscoll and Skinner, 2007). The number varies considerably with temperature and location and will be higher in long, dry summers, reducing in mild years. There will be a greater proportion of such claims in areas where there are shrinkable clay soils, good tree cover and a mature housing stock. Ward (1947) reported that 'The majority of claims occur in London due to the high density of houses with shallow foundations built on highly shrinkable clay soils.'

Domestic property insurers have an interest in any significant increase in the urban tree population and need to be part of the development of a policy led approach which ensures that tree cover is maintained and increased responsibly. For balance, we must also recognise the myriad of other reasons which lead our municipal authorities to remove trees and which apparently have caused a far greater numerical loss of canopy than tree loss related to subsidence claims.

The London Assembly's (2007) review of their street trees in May 2007 provided the emotively titled *Chainsaw Massacre* and this was widely disseminated as an anti-insurer piece of work. In fact, from the population of trees felled over a five-year period only 5% were felled because they were implicated in causing damage to domestic properties. The majority of trees were felled to comply with Health & Safety requirements:

- trees removed over the previous five years 39 924
- trees removed because of subsidence claims 2034

This conflict is an inappropriate way of resolving differences when seeking to retain such a valuable asset. The benefits and attributes of trees in our cities in helping to combat the urban heat island effect are well recognised and agreed by all.

This debate continues against a backdrop of climate change. Certain species of tree will suffer more from an increase in temperature and soil drying than others. Those that survive may do so by increasing their rooting zone, drawing moisture from a wider area, thus threatening more buildings.

The Clay Research Group's (CRG) current research programme is directed towards resolving this debate by exploring a variety of techniques that will allow trees to be retained and to reduce the threat of root-induced clay shrinkage in certain instances. The project has two elements. First, determining the spatial distribution and the depth of moisture uptake of mature trees. The second is the installation of harvesting chambers to reduce water demand by combining a variety of techniques including partial root drying (PRD), which is aimed at triggering the production of hormones combined with simple rehydration of the soil.

As background to tree physiology and the hormonal regulation of transpiration the work of Prof. William Davies and his team at Lancaster University has been particularly valuable in explaining the 'root to shoot signalling system' (Wilkinson, 2002). The technique is aimed at raising the pH within the xylem of a tree to promote the effectiveness of abscisic acid (ABA) – a naturally occurring stress hormone triggered by drought conditions – in the leaf apoplast. The function of this hormone is stomatal regulation and the conservation of water.

Whether ABA is effective depends not simply on concentrations but also the pH of the cell, which determines its receptiveness. That is to say, high levels of ABA do not ensure they will be active or effective (Sauter *et al*., 2001; Sharp and Davies, 2009). The objective is to use PRD (Stikic *et al*., 2003) to trigger a reduction of the stomatal aperture in dry periods and the duration of opening, leaving the tree healthy and undamaged whilst reducing transpiration. Carbon fixing takes place over a shorter cycle. PRD is a technique whereby one half of the root system is watered, while the other is not. Stikic cites the work of others (Loveys *et al*., 2000) when he says 'PRD treatment increased xylem sap ABA concentrations and pH, and as a result, stomatal conductance was reduced. In addition, there was a reduction in the cytokinin content in roots, shoot tips and buds'. Cytokinins are a class of hormone known to regulate root and shoot growth. The combined increase in ABA and reduction in cytokinins is therefore favourable in terms of water conservation.

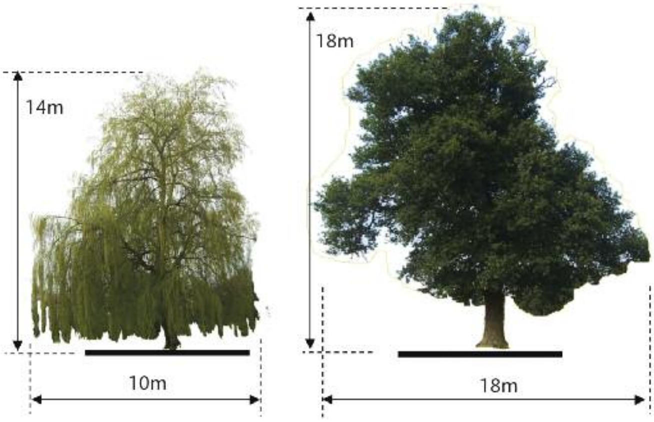
It is suggested that PRD helps when the dry roots produce ABA and the watered zone provides the vehicle to transmit the hormone to the xylem. This is a technique that has been used for crop propagation in dry countries with success. Clearly, however, there is a huge difference between crops grown under propagation conditions and street trees in an urban landscape.

The current research will we hope lead to the retention of the urban street scene and reduce conflict between various interest groups. Any solution has to be sustainable and environmentally acceptable and the cost has to be reasonable in the context of current expenditure resolving this category of claim.

Materials and methods

Data was gathered from a 40.5 ha research site in north London by monitoring ground movement beneath a single mature willow and an oak tree (see Figure 1).

Figure 1 The subject trees and their proportions. Willow (weeping): *Salix x sepulcralis* 'Chrysocoma' and oak : *Quercus robur*. The oak is in a row of similar aged trees at 20 m spacing on a grass playing field. The willow is sited in the garden of a detached house on a gently sloping site in north London. Latitude 51.662 and longitude –0.326.



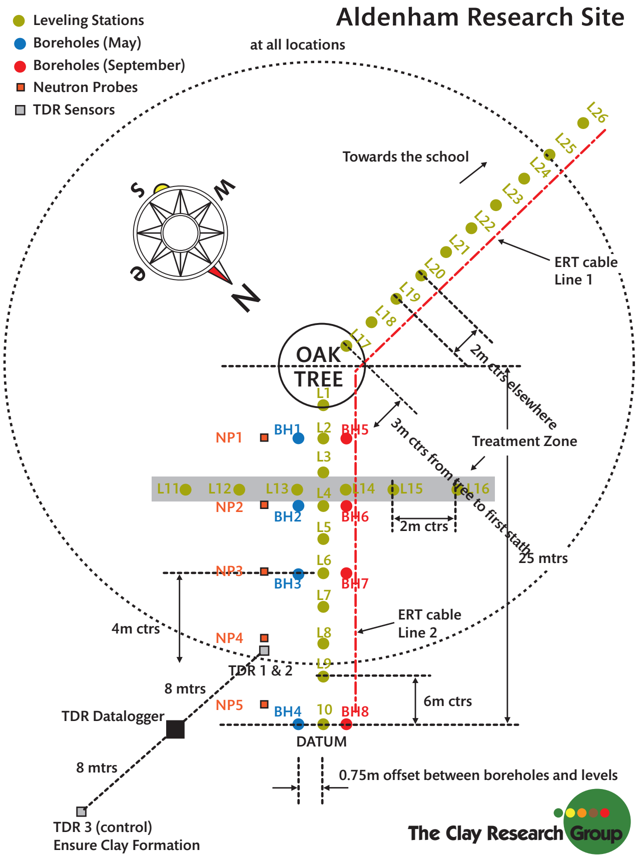
Academics were invited to use the site to complement research that they were undertaking elsewhere and to share any output.

Dr Clarke and Dr Smethurst from Southampton University have been researching the impact of climate change by gathering data from stations across the UK. They took periodic measurements of soil moisture from the site of the oak tree using a neutron probe, commencing in August 2006 with a final reading in August 2007. The distribution of the probes is shown in Figure 2. Five probes were installed to a depth of 3.8 m below ground and spaced 5 m apart with the first situated 5 m from the tree.

Dr Cassidy and Dr Jones from Keele University explored the use of electrical resistivity tomography (ERT) to measure moisture change in fine-gained soils (Jones *et al*., 2010). In addition, time domain reflectometry (TDR) sensors were used to measure change in moisture, and data has been wirelessly transmitted to the supervising engineer. TDR sensors measure volumetric moisture content by responding to changes in the dielectric constant of the surrounding soil. These changes are converted to DC voltage virtually proportional to the soil moisture content.

Telemetry – the transmission of data from buried sensors installed on site via the web to the office – avoids the need for frequent and disruptive visits to site.

Figure 2 Layout of instrumentation and levelling stations at the site of the oak tree. ERT cables are shown as red dotted lines, precise level stations are green, neutron probes orange, TDR sensors and dataloggers black and boreholes, red and blue.



A weather station was installed in 2007 to determine the correlation between moisture change and ground movement. Soil moisture deficit (SMD) data was obtained from the Meteorological Office.

Ground movement resulting from moisture content change was measured using precise levelling from over 26 stations situated either side of the oak and willow trees.

Levelling has the advantage of measuring the combined effect of the various elements – climate, trees, soil mineralogy and moisture uptake – over time across the root systems.

Away from the research site, trials on 21 domestic subsidence claims have been established primarily on London Clay soils. All of the claims have been characterised by their complex nature and a history of recurrent problems related to root-induced clay shrinkage. Not all involve the same species of tree but a large proportion was oak.

Water harvesting has been used in each case and has delivered some initially encouraging results. Harvesting takes the form of excavating a trench about 2 m away from the damaged section of the house, to a depth of 1 m.

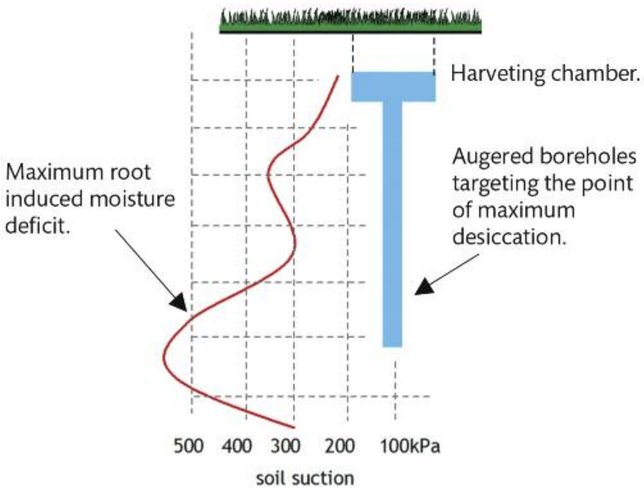
Augered holes are drilled through the bottom of the excavation to target the zone of maximum moisture deficit. This can be determined by a variety of soil testing techniques – see neutron probe data as an example, Figure 6 – or on site using a penetrometer. For mature trees this is usually around 1.8 m below ground but varies with species and climate. The depth is designed to ensure water is deployed at the point where it delivers maximum benefit, avoiding wastage from run-off and loss by evaporation.

The bores were filled with a mixture of clay, sand and lime. This produces a soil with a low plasticity index (the measure of the shrink/swell properties of a clay soil) and regulates the flow of water, avoiding saturation of the surrounding ground, but releasing water as the negative porewater pressures in the soil increase. Lime is added to raise the pH of the soil locally.

Proprietory harvesting chambers are then installed, wrapped in a tough, root-resistant membrane. The general arrangement is shown in Figure 3.

Rainwater is collected from the roof of the damaged property into the harvesting chambers with appropriate measures to cater for overflow and ventilation.

Figure 3 Diagrammatic view of the harvesting chamber feeding a series of augered boreholes that target the zone of maximum root activity. All available rainfall gathered from the rainwater downpipes etc. is fed into the chamber and the drainage is modified to ensure surplus run-off to the main drains to avoid over-flow together with a venting facility.



The project is directed to applying water harvesting in the urban environment with mature trees nearby. The challenge is to understand the benefit over a period of time. How do different species of tree respond for example, and is it a robust and sustainable solution in cases where root-induced clay shrinkage has caused damage to nearby buildings.

Precise levels have provided an assessment of moisture uptake by the tree sufficient to cause ground movement (i.e. ignoring uptake of unbound soil moisture) over time. This has been linked with climate and SMD data and has led to the production of a climate model as well as providing valuable information regarding a possible method of rehydrating desiccated soils.

Results

Water uptake

In contrast to the more usual view of root-induced desiccation where the ground movement assumes a saucer-like profile with maximum movement close to the tree, ground movement profiles of oak and willow at the research site have demonstrated an increased moisture uptake (and hence greater ground movement) some distance from the tree.

The soil directly beneath the canopy dries over time to produce a persistent moisture deficit and the peripheral roots account for the majority of moisture uptake (see Figure 4). Ground movement produces a regular signature in both dry and wet years, varying only by amplitude. In a relatively dry summer (2006 in the example below) movement peaks at 60 mm of subsidence to the right of the image, and reduces to 48 mm in the wetter summer of 2007.

Electrical resistivity tomography (Figure 5) has provided visual evidence of moisture change over time for both the oak and willow (Jones *et al*., 2010). In addition we have data from the unpublished results of an earlier investigation undertaken by Dr Ron Barker at Birmingham University in 2001, showing moisture change beneath a sycamore tree on boulder clay deposits, comparing winter and summer values.

Neutron probe measurements (Figure 6) undertaken by a team from Southampton University have provided important information regarding the depth from which moisture is abstracted.

This data relates to the oak and willow at the research site and provides valuable information for subsidence practitioners in terms of knowing at what depth to target their investigations to obtain evidence of root-induced desiccation. Previously it had been assumed that roots dry soils 'top down'. The neutron probe data (supported by the

Figure 4 Seasonal ground movement (subsidence) at the site of the willow noting the difference in claim notifications between a dry year (2006) and wetter years (2007 and 2008). The profiles reveal increased activity at the root periphery associated with moisture uptake and a regular signature in both wet and dry years which continued to be noted in subsequent years. The x axis represents the distance from the willow (central in all illustrations and marked by dotted line) and the y axis is the amount of ground movement that has taken place in millimetres.

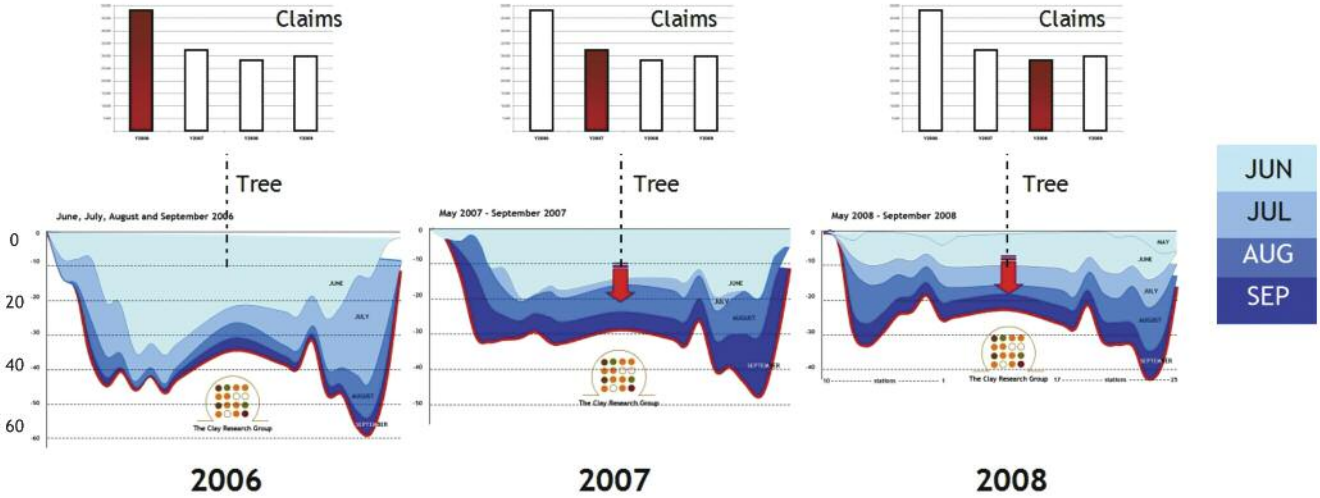


Figure 5 Moisture change beneath an oak tree situated in the Midlands (not from the research site) as revealed by ERT imagery. Changes in moisture content over a few months are clearly illustrated. The zone from which roots are extracting moisture is shallower than in the London Clay at the research site possibly due to the presence of superficial strata of boulder clay overlying the Mercia Mudstone. The lateral extent of drying is approximately equal to the tree height in this instance. Provided by Dr Ron Barker, Birmingham University – personal communication.

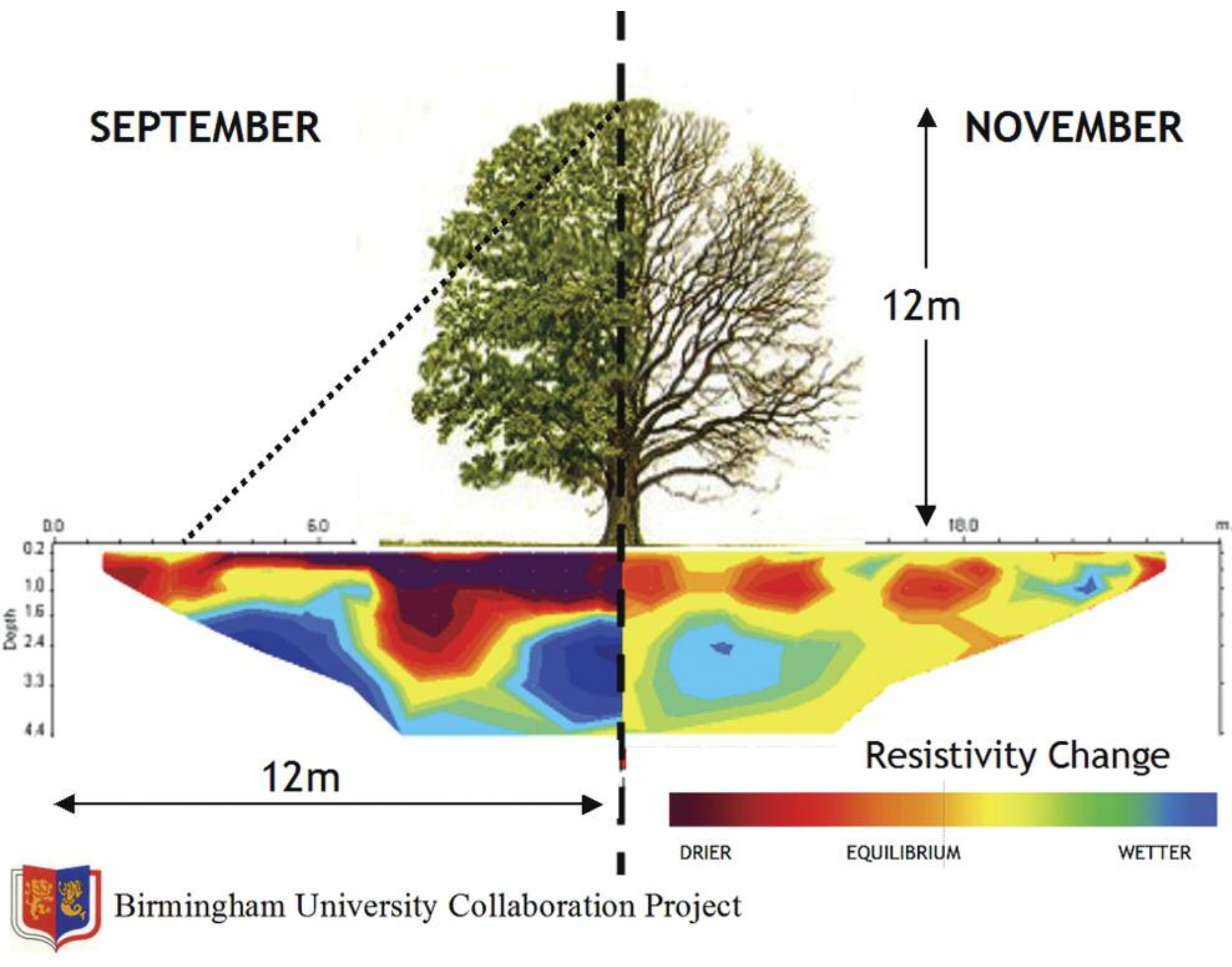
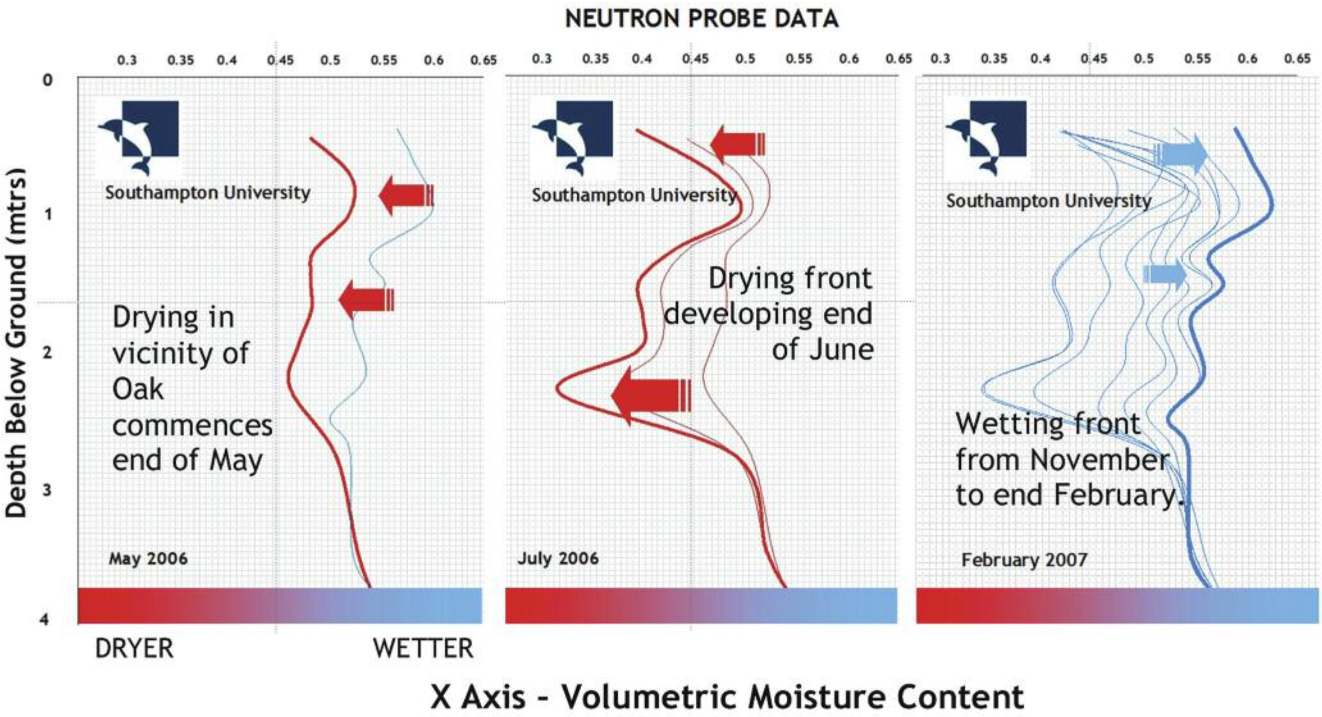


Figure 6 Moisture change measured at the site of the oak tree at the research site in north London by Southampton University using the neutron probe and revealing maximum uptake associated with root activity at around 2 m below ground. Superficial drying due to evaporation is revealed at ground level down to 1 m.



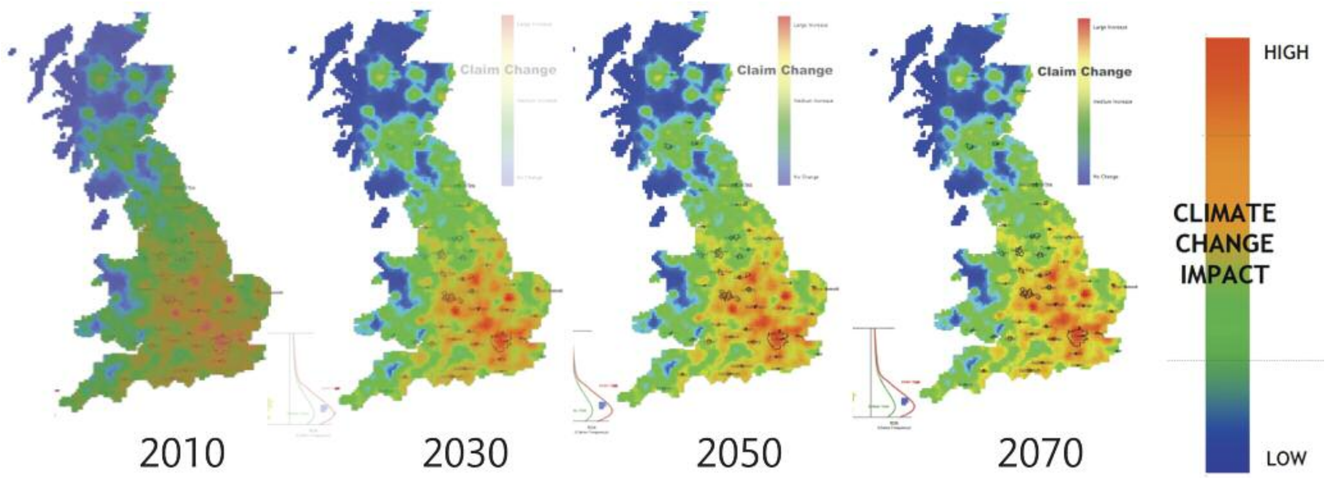
results of actual soil investigations), indicates that soil sampling is likely to deliver better evidence at around 2 to 2.5 m below ground level when investigating mature trees.

Climate

Mapping the geographic distribution and shrink/swell properties of clay soils from site investigations has assisted in producing the maps in Figure 7, which reveal the impact on claim numbers of temperature increases associated with climate change. Root-induced clay shrinkage (as the name indicates) is only a problem where there are shrinkable clay soils.

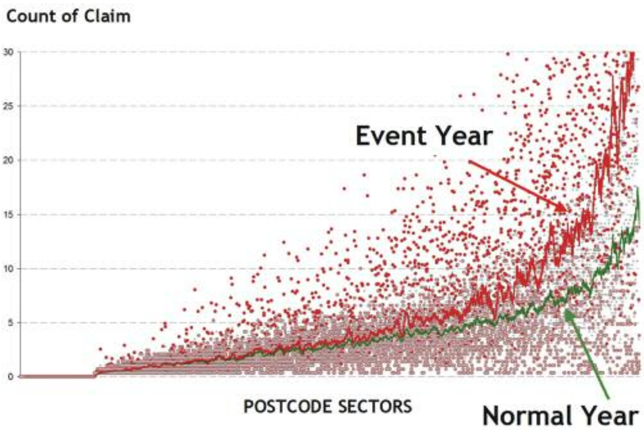
This qualitative view of the UK indicates where trees are likely to cause damage and can be adjusted by actual temperature increases to deliver estimates of claim numbers by comparing an event year with a normal year.

Figure 7 CRG model of climate change impact in relation to root-induced clay shrinkage subsidence claims.



Matching claim numbers (see Figure 8) with temperature anomaly data (see Figure 9) provides some indication of the effect that temperature increases and reduced rainfall may bring. Figure 8 illustrates that numbers increased where there are clay soils, and the greater the shrink/swell potential, the greater the difference between the profiles.

Figure 8 Taking industry figures of subsidence claim notifications and plotting them against postcode sectors, the difference between what insurers regard as 'normal' and 'event' years can be related to changes in temperature and rainfall to model future trends resulting from climate change. Around 20% of postcode sectors lie on shrinkable clay (these are identified by the divergence in numbers to the right of the graph) and they are the areas where trees are more likely to cause damage.



Anomaly data (see Figure 9) uses 2007 as a baseline for a normal claims year and plots the anomaly in temperature and rainfall with 2006 (an intermediate year for claims) and 2003 – an event year.

Discussion

This study explores some of the work currently undertaken to improve our understanding of the interaction between clay soils, trees and climate in relation to domestic subsidence in the UK.

Water uptake

We have an improved understanding of how roots from mature trees can exert an influence at a distance away from the tree and the depth from which moisture is drawn. The suggestion that ground movement increases with distance, as has been demonstrated in this study, is new.

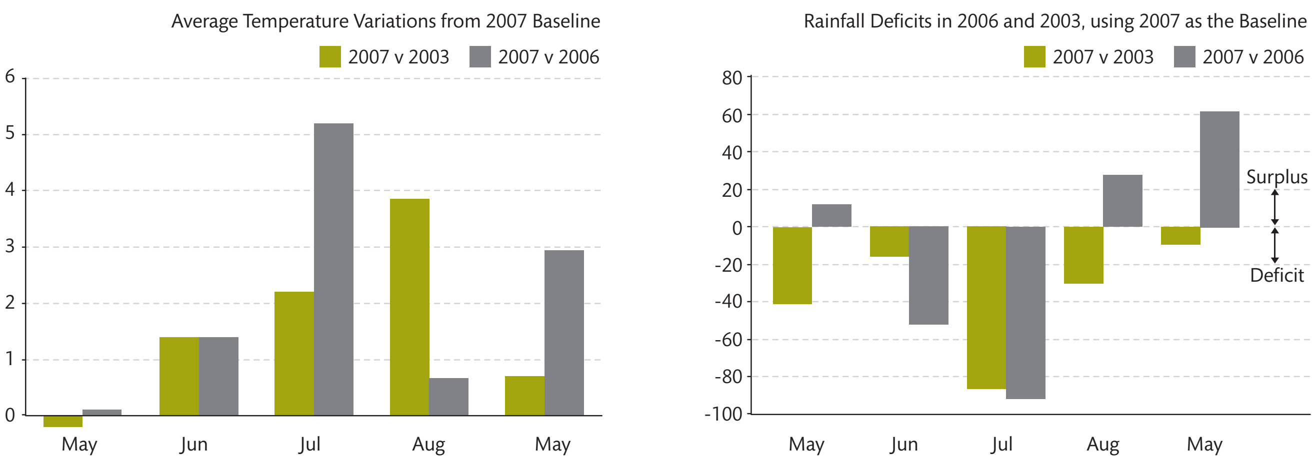
This provides valuable information to engineers when investigating cases of root nuisance regarding understanding the pattern of distress and the depth from which samples are to be extracted – that is, testing soils at 1 m below ground is less likely to deliver a result than testing at 2 m. It is also important in designing any form of soil intervention technique.

An improved understanding of root activity determined by precise levelling has provided guidance on where to target the 'water injection' from the harvesting chambers and with regards to subsidence, if the trials are successful, it will have a beneficial impact not only for insurers, but also homeowners and local authorities.

Climate

The research has produced a climate model that will assist insurers and others to develop a strategy for the future. It improves our understanding of where claims are likely to

Figure 9 Temperature and rainfall anomaly data using 2007 as a baseline for a normal claims years and plotting change for two event years, 2003 and 2006.



arise geographically, and the influence of temperature and rainfall on claim numbers and indemnity spend.

By modelling the change in claim numbers resulting from an increase in temperature, we can begin to understand the impact on housing stock of a tree planting regime. As we reported in the introduction, the increase in subsidence claim numbers in dry years is associated with the presence of trees on clay soils and an increase in the tree population will have a bearing on costs to insurers, homeowners and local authorities.

Clarke *et al.* (2006) suggest that 'in 50 years time, every summer day will replicate the conditions we see now in an event year'. By adding 5% (the planned increase in tree canopy planned as part of the urban greening programme) we can model the financial impact over time.

Ground treatment

This improved understanding of the distribution of rooting, ground movement and depth of moisture abstraction described leads to the current phase of research involving the installation of harvesting chambers that might allow tree retention in certain cases. The technique, if successful, will allow the prompt settlement of some domestic subsidence claims for a relatively modest sum of money.

Water harvesting has been installed on a total of 21 houses that have suffered damage resulting from root-induced clay shrinkage. Many had suffered recurring damage linked to a variety of mature trees, predominantly oak. Water harvesting was applied on the first claim early in 2008 and, so far, there has been no notified recurrence of damage at any of the sites.

Hydrating a small section of the root zone while another portion is growing in dry soils beneath impervious tarmac and paving, replicates (in part) a technique known as partial root drying (PRD). This method, used primarily for fruit production, is also thought to enhance the effectiveness of the hormone ABA.

The objective of alleviating root-induced clay shrinkage damage to domestic dwellings using water harvesting is not to satisfy the water demand of the tree. Water harvesting has been installed to reduce the water deficit in the vicinity of damage. Watering-in offers multiple benefits. The obvious ones are (a) adding moisture to the soil causing it to recover to its former level, (b) raising the pH of the water in the xylem which in turn (c) increases the effectiveness of ABA at the apoplast. This leads to closure of the stoma and a reduction in transpiration.

The more traditional approach to raise the soil pH would be to add lime to the soil. Harvesting offers the potential (but as yet unproven) advantage of delivering water quickly and efficiently to the desiccated soil. Adding lime to the soil without watering would not help in dry weather and would provide little benefit in terms of rehydrating a desiccated soil 2 m below ground level.

Rehydration using harvested water does not have to return the soil to field capacity in the summer. It has to be sufficient to emulate a SMD accompanying what insurers regard as a 'normal' year for subsidence claim numbers. For example, if the SMD for grass cover is 120 mm in a dry year with a high claims frequency, the harvesting chambers would have to provide sufficient water to reduce this by 15–20% to emulate a 'normal' claims year. The harvested water is directed to a specific location and has to reduce desiccation – not remove it altogether. The available water is increased by a factor of 4 (i.e. the average area of the roof compared with that of the harvesting chamber) for the average domestic dwelling in the area of desiccation by diverting roof rainwater run-off into the chambers. The objective is to reassure the homeowner by providing a robust and lasting solution whilst reducing the likelihood of litigation between insurers and local authorities.

The study has provided information on how much water is consumed by mature trees by using volumetric estimates based on ground movement by month. It has identified (a) the ground movement that takes place as a result of moisture loss, (b) the differences between dry and wet summers and (c) the depth that any treatment has to be applied to deliver maximum benefit, quickly.

The project is at an early stage. Measuring change produced by mature trees is a much slower process than work in the field of crop science. The genetic factors determining the influence of hormones individually or in combination will almost certainly be very different. The involvement of physiologists from the biosciences to measure tree water uptake over a period of time and any associated hormonal production would be invaluable.

Conclusions

Britain's Victorian legacy of tree-lined streets continue to survive pressures applied by a wide variety of operators opening up our public footpaths as well as our demands for the information technology super highway being readily available.

The pressure from subsidence-related insurance claims is relatively small compared to the extent of utility excavations permitted. Nonetheless, insurers have a financial and environmental interest and should be allowed a voice in developing the strategy for London greening.

The CRG and OCA UK Ltd will continue to research the interaction between vegetation and fine-grained soils under different climatic conditions and share data and resources with other interest groups in this important area of asset/liability land management.

The various bodies who are doing significant work in their own interest areas should join together with the ABI, the Subsidence Forum and LGA to establish a joint approach to formulating a comprehensive pan-sector Code of Practice covering claims of the sort described. Innovation and co-operation between interested parties will help to resolve any conflicts and should be based on sound scientific peer-reviewed research in relation to the influence of trees on their surroundings.

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