Meeting the challenge of managing tree roots & infrastructure

ABSTRACT

The successful retention of city trees is being pressured by infill development; and a reduction of the space provided for new trees to grow successfully. At the same time, Utilities and City managers are seeking solutions that reduce the historic costs of ongoing repairs and maintenance; and that also address the hazards/risks that damaged roads and hardstands create for the people that use them.

In seeking solutions, the majority of the decision making information on hand is a trail of damages caused by tree roots (quantified by the cyclic costs of ongoing repairs), and the promises of newly engineered structures such as structural soils and structural cells that can convert the space beneath hardstands, parking bays, roads and crossovers, into rootable soil spaces or stormwater water harvesting zone.

However, without a better understanding of the capacities of roots to enter and grow within and beyond these newly engineered spaces; and without an understanding of the tolerances of roots in occupying these and other spaces, it is difficult for engineers to design rootable soil volumes into these city infrastructure regions without there being a high risk of repeating the mistakes of the past; that result in infrastructure damage.

Through some 30 years of observing and trialling root behaviour in the coastal sands of Perth's urban growth, it is clear that there is enough qualitative data from rudimentary evidence of root growth habits and soil characteristics, that can better enable decision makers to more purposefully engineer tree roots into the landscape; rather than ignoring their needs, or excluding tree roots from sharing these urban infrastructure zones.

The observations and trials discussed have led to some low cost innovations that can be incorporated into Perth's current development practices with only minor construction modification and include:-

i. Spray-on root barrier (Camilaflex SORB); that can inhibit roots from entering the regions that cause most of the kerb and road damage;
ii. Compacted road base trenches at strategic alignments that interlock with surface treatments, and with the joints sealed have been shown to prevent root ingress;
iii. The creation of sub-terrain aeration in the preservation of existing trees within developments;
iv. The construction of root canals to purposefully direct roots to suitable feeding grounds.

These observations are provided as a guide to where further research and trialling is needed to meet the challenge of better managing tree roots in city precincts.

INTRODUCTION

The damage caused to infrastructure by tree roots; is an everyday observation for most tree managers and tree owners.

The problem does not seem to be going away, despite enormous advancement in our knowledge and understanding of trees; the elevated appreciation of their importance; the vastly improved ways we manage and maintain them as an urban asset; and our ever improving knowledge of tree root biology, genetics, physiology and morphology.

Why not?

Essentially, the behaviour of mature and maturing roots within Perth's disturbed urban soils is poorly understood, and the factors of influence are highly complex. None the less, there appears to be a number of features within the sub-terrain regions that are having a macro effect on the pattern of tree root behaviour in Perth's coastal sands.

Appreciating these macro-patterns of behaviour, along with the micro-level of detail required in the construction of sub-terrain infrastructure which address potential conflict zones, appears to be providing solutions that coalesce with engineering needs.

This paper takes a firsthand look at our 'Perth Experiences', in discovering where root systems tend to develop in its urban sands (with some reference to heavier soils); observation and understandings for their purposeful migration through the various soils; and how we at Arbor Centre have gone about creating solutions across common scenarios.

Images and explanatory drawings include a brief summary of our observations and case study data relating to measures that have been applied to:-

- Mitigate root damage to hardstands, roads and kerbs;
- Better protect below ground services;
- Restricting roots from occupying certain soil spaces;
- Taking advantage of root behaviour, to effectively direct them to places of convenience within the landscape (other than immediately around the tree);
- And examples of the level of design and engineering detail required for successful outcomes (includes the utilisation of structural cells and soils).

Common Understanding

The variables and interaction between roots and soils are loaded with highly complex and inter-dependent systems that can change with circumstance and soil type [Craul 2006]. The objective of this paper is to target the general morphology of roots and their physical responses to urbanisation in Perth's coastal sands and somewhat reframe the way we consider root systems (For a summary of the types of coastal sands, Refer Appendix 1 for a general description of the predominant sands of the Swan Coastal Plain).

In order to establish a common baseline from which to interpret how root growth and development impacts on our urban infrastructure, a model of common root descriptors has been developed to help visualise the general behaviour of the different types of roots; that together make up the root system; and how roots go about distributing themselves within the natural and un-natural soil profiles we find in urban spaces (refer Figure 1).

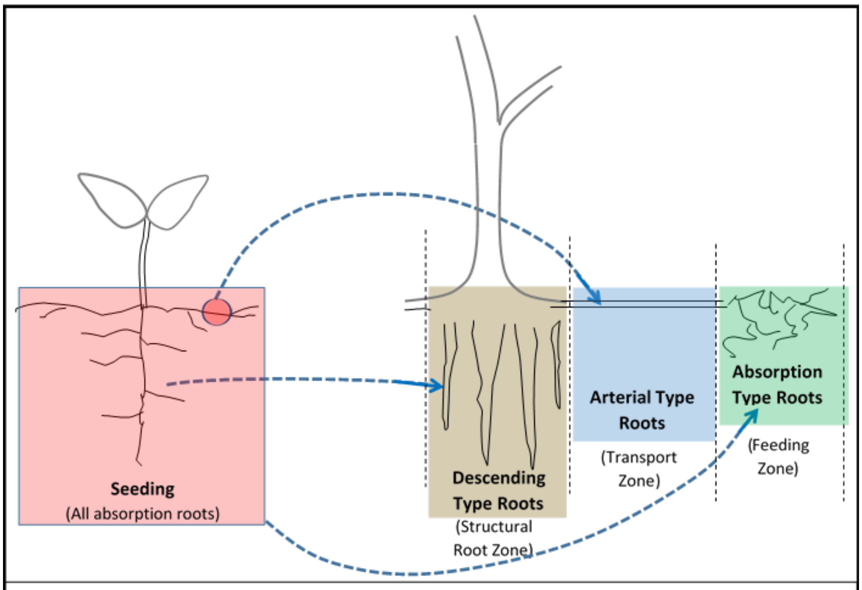


Figure 1:- A model of typical root types in Perth's Coastal Sands

Descending Type Roots (Within Structural Root Zone)

Within the zone of rapid taper [Wilson 1964 cited in Day S D, E Wiseman, S B Dickinson and J R Harris 2010 p150], the descending and lateral arterial roots are subject to the loadings associated with the mass of the tree and the mechanical forces being endured by the above ground parts to provide anchorage [Mattheck 1991cited in Day S D, E Wiseman, S B Dickinson and J R Harris 2010 p150].

In Perth's undisturbed coastal sands we find the majority of anchorage type roots that provide tree stability, generally grow vertically and tend to only develop within the Structural Root Zone (SRZ) as described in the tree protection guidelines of AS 4970 – 2009 Protection of trees on development sites. However, in heavier mediums such as loams and lateritic soils, smaller but similar descending roots can develop from lateral arterial roots (Refer Figure 2).

Figure 2:- Typical Marri (*Corymbia calophylla*) root system growing in heavy soil (Forrestfield) showing Anchorage Type roots (Vertical Roots, Sinker Roots) within the SRZ and smaller versions descending from arterial laterals beyond the SRZ --- Image property of Arbor Centre

With phreatophytes such as Marri (*Corymbia calophylla*), Flooded Gum (*Eucalyptus rudis*) and Jarrah (*Eucalyptus marginata*) that are growing in natural and undisturbed sand, these vertical "descending" roots can venture to water bodies that have been recorded to 15 m depths (CSIRO studies by Jacobs (1955), Kimber (1980), Carbon Etal (1980) and Dell et al (1983) in WA). In Bassendean sands, limestone and lateritic soils, it appears that remnant fossil roots can also provide corridors for the next generation of trees to take advantage of in reaching these depths - personal observation.

<u>Noteworthy characteristics of descending roots in Perth's Coastal Sands</u>

- In meeting the mechanical forces that strongly influence how the tree anchors itself to achieve stability as it matures over time in Perth's sandy soils, the descending roots within the SRZ commonly range in depth from 1.5 m to 5 m; and for many species, develop a feathering of roots toward the lower potions of these descending roots – personal observation (Refer Figure 3).

Figure 3:- Images of a Norfolk Island Pine (*Araucaria heterophylla*) as a 20 year old specimen (LHS image) and a close-up of the early stage of descending roots development within the Structural Root Zone (Circled) --- Image property of Arbor Centre.

- One of the primary governing factors in disturbed urban soils appears to be the nature of the layers (Horizons) that exist within the soil profile of Perth's coastal sands, and the moisture gradients that these layers create – personal observation.

  A compacted subsoil layer can also govern the depth of anchorage type roots (Refer Figure 4).

Figure 4:- Spotted Gum (*Corymbia maculata*) within median of Nicholson Rd, Cannington that has been planted over road base at 600mm depth. Image A showing top of root plate. Image B showing the flat bottom of the root plate…. Images property of Arbor Centre

- Water bodies also provide natural barriers to vertical root growth [Craul 2006]. In Perth's coastal sands many plant species can establish the majority of their primary root system within the seasonal fluctuation zone of these water bodies (e.g. Paperbarks (*Melaleuca rhaphiophylla and M.preissiana*) – personal observation (Refer Figure 5).

Figure 5:- Showing the primary absorption root zone of a Paperbark (*Melaleuca rhaphiophylla*) in the fluctuation zone of the water table…. Image property of Arbor Centre

- The development of vertical and horizontal roots in the structural root zone of Perth's coastal sands often create soil compaction forces that push the whole tree upwards as it matures [Craul 2006]. For large growing tree species, such as *Corymbia maculata, C.calophylla, C.citriodora, Eucalyptus.rudis, E.grandis, E.gomphocephylla and E.maginata,* a 30 cm rise at the base of the tree had occurred within 15 years of planting a 2 year old specimens in Perth's urban regions – personal observation (Refer Figure 6).

Figure 6:- A Flooded Gum (*Eucalyptus rudis*) showing the result of root mass within the structural root zone causing it to rise some 700mm over 40 years when growing in deep Bassendean Sands (A), and a close up (B) of the exposed lateral roots – Images property of Arbor Centre

- A common occurrence for these larger growing trees in Perth's undisturbed coastal sands, is the development of arterial roots that are perpendicular to the descending roots, at 0.8 m – 1.5m depth; without there being an observable change in the soil structure above or below where these roots originate from – personal observation (Refer Figure 7).

Figure 7:- Exposed root bole of mature Flooded Gum (*Eucalyptus rudis*) showing an arterial root perpendicular to the descending root at 1.2 m (circled) … Image property of Arbor Centre

- In undisturbed regions that experience long dry periods (that include Perth's coastal sands, the Pilbara to the north of Perth and the Goldfields to the east), it is common to observe some species of native trees having their root flare commence at approximately 300 mm below natural soil level. However, the same species planted and grown to maturity in irrigated sites rarely exhibit this characteristic - personal observation (Refer Figure 8).

Figure 8:- Exposed root bole of mature Jarrah (*Eucalyptus marginata*) at Dawesville, showing a 400mm depth from natural ground level to root flare … Image property of Arbor Centre

Arterial Type Roots (Transport Zone)

As the absorption roots lead the way through the soil and put on secondary growth, they effectively leave behind a network of living conduits (woody arterial roots) that transport the water solute and metabolites provided by the absorption roots through the xylem vessels to other parts of the tree, as well as transporting resources generated from the canopy of the tree, to expand the root system [Campbell 2011].

Some species appear to develop an entwined network of both arterial conduits and absorption roots (regardless of soil type -- e.g. Elms (*Ulmus sps*) – Refer Figure 9).

Figure 9:- English Elm (*Ulmus procera*) at Waite Arboretum SA, showing the matted network of both arterial 'transport' and absorption 'feeder' roots radiating from the trunk. --- Image property of Arbor Centre

However, for many of WA's mature native species, it may only be the arterial 'transport' roots that radiate from the tree (often 10's of metres) before 'absorption' roots are found (Refer Figure 10). This phenomena appears to more common in sandy soils than heavier soils - personal observation.

Another common trait of many WA native species growing in sandy soils is the development of small 'island' like clusters of 'absorption' roots at 2m to 5m spacing's along smaller arterial 'transport' roots (Refer Figure 11).

Figure 11:- Coolabah (*Eucalyptus microtheca*) in Kings Park, showing a cluster of absorption roots growing from a lateral arterial 'transport' root. These clusters appeared at 2m to 5m spacings along the arterial root.--- Image property of Arbor Centre

Figure 10:- Jarrah (*Eucalyptus marginata*) showing the radial length of an arterial 'transport' root prior to any 'absorption' root development . --- Images property of Arbor Centre.

NOTE:- Roots at the persons feet belong to an adjacent tree and not the Jarrah.

Typical and Noteworthy Characteristics of arterial roots within Perth's Coastal Plain

- Once established, the transport roots of most tree species in Perth's coastal sands have shown that they can withstand high levels of soil compaction and modest restrictions to radial expansion – personal observation.

- The radial expansion of these arterial conduits causes natural compaction of the surrounding soil [Taiz – 2010]. It is these secondary growth phases of root expansion that most commonly causes damage to urban infrastructure such as roads, kerbs footings and paths – personal observation.

- Beyond the anchorage zone the arterial (transport) roots are less subject to the mechanics of tree stability and anatomically change the arrangements of the cells and fibres to give them rope-like qualities of high tensile strength while also having comparatively high flexibility that is most obvious toward the network of absorption roots where they are less woody [Moore 2013].

Absorption Type Roots (Feeding Zone)

In Perth's coastal sands, absorption roots growing within in the sands beneath the organic layer ('O' horizon) are observed to occupy soil space differently than when growing in the clay or lateritic soils of the Swan Coastal Plain. In these sands the absorption root network tend to distribute itself more spaciously across a larger area than those growing in clay or lateritic soils where the absorption root network is more compact and the roots are comparatively finer in diameter than in the sands – personal observation (Refer Figure 12).

Further, these absorption root networks have been observed to have a strong correlation with:-

- Moisture Gradients (that arise via condensation, soil hydrology, natural or purposeful runoff, or a seasonal or supplementary watering regimes) ,
- Aerated Zones (usually associated with sands that are disturbed or less compacted than elsewhere), and
- Soil Profile Characteristics (i.e. the nature of the soil types and their location within the Soil Profile).

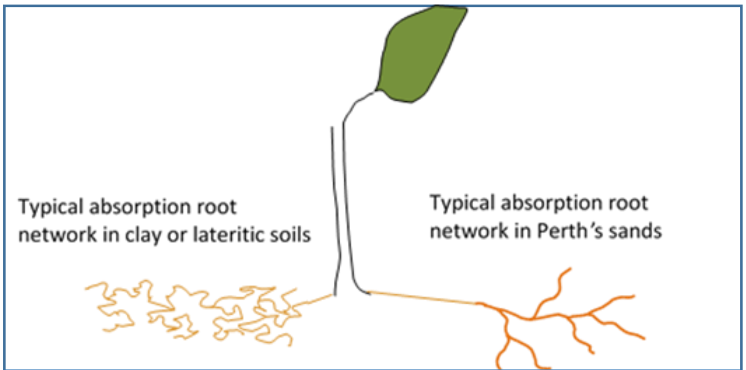


Figure 12:- Showing the distribution of absorption roots in Perth's sands compared with Clay and Lateritic soils in the Swan Coastal Plain – Diagram property of Arbor Centre

Typical and Noteworthy Characteristics of absorption roots within Perth's Coastal Plain

- Absorption roots proliferate in the upper regions of the soil where air, moisture and nutrients are most freely available [Craul 2006, Harris 1999, Urban 2008, Watson 2008].

- Beyond the SRZ of trees growing over Perth's undisturbed sands, absorption roots are observed to quickly graduate to being mainly present in the top 200 mm of sandy soil; in lateritic soils to 800 mm; in highly organic soils to <500 mm - personal observation.

- To the extent that soil compaction is the enemy of absorption roots [Harris 1999, Watson 2008]; it can also be a natural way of influencing where absorption roots grow – personal observation.

- For many of our mature native species growing in undisturbed natural sands, the highest concentration of absorption roots is beyond the canopy of the tree – personal observation (e.g. mature Jarrah (*Eucalyptus marginata* – refer Figure 5).

- The practice of placing a layer of fertile and high organic soil within a strata of the 'A' horizon of the soil profile, in the common belief that it will attract roots and keep them away from other zones, has rarely been observed as successful beyond a 6 to 12 month period in Perth's urbanised coastal sands. The above factors commonly have a stronger influence as the trees become established and mature - personal observation.

Common Tree Root Networks

Common network of arterial 'transport' roots and absorption roots as a mature tree

(Perth observations)

Typical Species:- Most deciduous species, Magnolia sps, Ficus sps many of the large growing native tree species in heavy soils (Includes - *C.calaphylla, E.guilfoylei, C.ficifolia*)

Characteristics:-

1. Majority of absorption roots trend towards being within the canopy drip line in heavy soils but less so in sands
2. Aligns with AS 4970 – 2009 Protection of trees on building sites, guide lines but subject to site and soil circumstances
3. All zones cope poorly with compaction

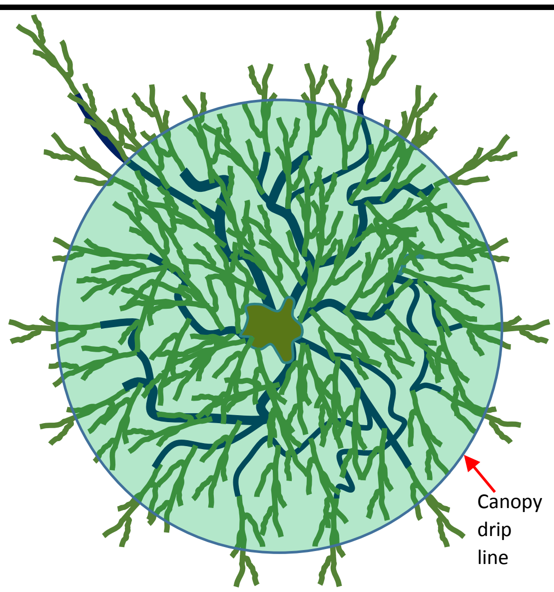


Figure 13:- Diagrammatic representation of the common network of arterial and absorption roots as a mature tree, typical species and characteristics; with an image showing an example Elm (*Ulmus procera)* and the typically matted network of both arterial 'transport' and 'absorption' roots radiating from the trunk. --- Image property of Arbor Centre

Absorption roots predominantly found beyond the canopy drip line of mature trees

(Perth observations)

Typical Species:- Many large growing native tree species growing in sandy soils (includes *E. marginata, E. gomphocephala, C. maculata, C. citriodora*)

Characteristics:-

4. Only arterial roots within the canopy drip line
5. Absorption roots are beyond the canopy drip line
6. Tend to cope with hardstand when there is minimal root zone disturbance
7. Does not align with AS 4970 – 2009 Protection of trees on building sites, guide lines .
8. Zones within the tree canopy cope well with soil compaction

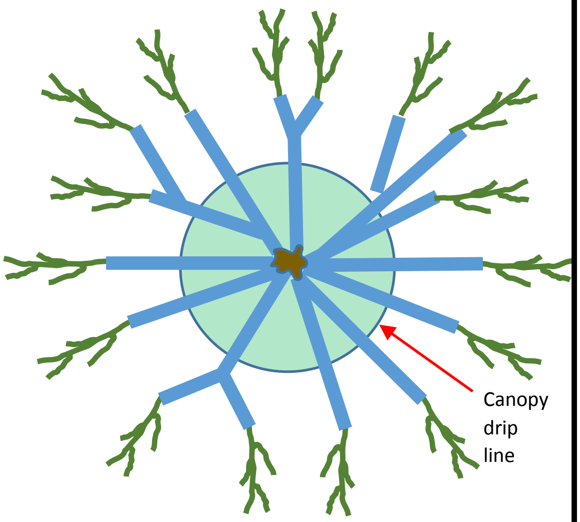


Figure 5:- Diagrammatic representation of absorption roots predominantly found beyond the canopy drip line as a mature tree, typical species and characteristics; with an image showing an example Jarrah (*Eucalyptus marginata*) showing the radial length of an arterial 'transport' root prior to any 'absorption' root development . --- Images property of Arbor Centre.

NOTE:- Roots at the persons feet belong to an adjacent tree and not the Jarrah.

Mature Jarrah and the arterial root with no absorption roots

Clumps of absorption roots sparsely scattered within the canopy drip line of mature trees with the majority being beyond the canopy **(Perth observations)**

Typical Species:- Many small growing native tree species growing in sandy soils, many Mallee's and WA Goldfield natives (includes *E. erythrocorys, E.drummondii, E.microtheca, Santalum sps)*

Characteristics:-

11. Mainly arterial roots within the canopy drip line
12. Absorption roots mostly beyond the canopy drip line
13. Does not align very well with AS 4970 – 2009 Protection of trees on building sites, guide lines .
14. Zones within the tree canopy cope reasonably with soil compaction

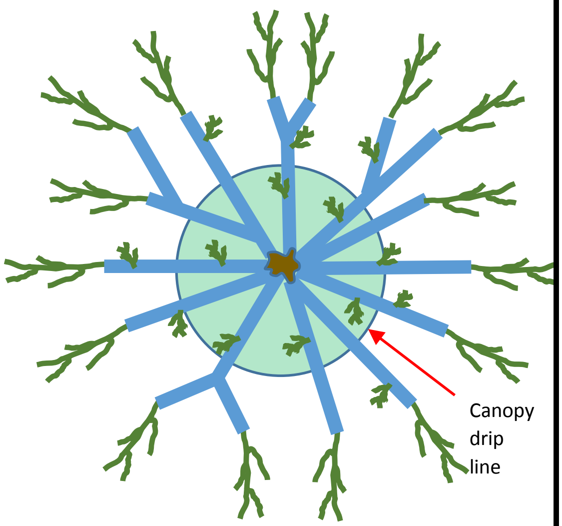


Figure 6:- Diagrammatic representation of clumps of absorption roots sparsely scattered within the drip line of a mature tree with the majority of absorption roots being beyond the canopy, typical species and characteristics; with an image showing an example Coolabah (*Eucalyptus microtheca*) showing a cluster of absorption roots growing from a lateral arterial 'transport' root. These clusters appeared at 2m to 5m spacings along the arterial root.--- Images property of Arbor Centre

Natural Soil Profiles in Perth's coastal sands

The root zones of trees adapt differently to the natural soil profiles that exist in the Swan Coastal Plain. Examples include the differing root characteristics and distribution of a Marri (*Corymbia calophylla*) when grown in natural Spearwood sands (Figure 16) compared to the lateritic soils of Perth's foothill (Figure 17); and the adaptive qualities of Paperbarks growing in natural wetlands (Figure 18).

Figure 16:- Image showing upper region of typical soil profile in Spearwood sands adjacent a Marri (*Corymbia calophylla*)

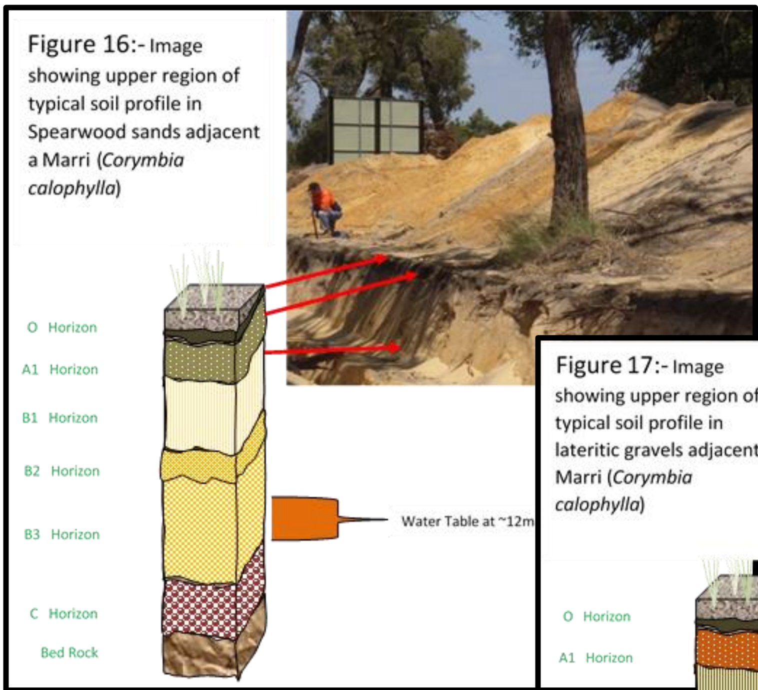


Figure 17:- Image showing upper region of typical soil profile in lateritic gravels adjacent a Marri (*Corymbia calophylla*)

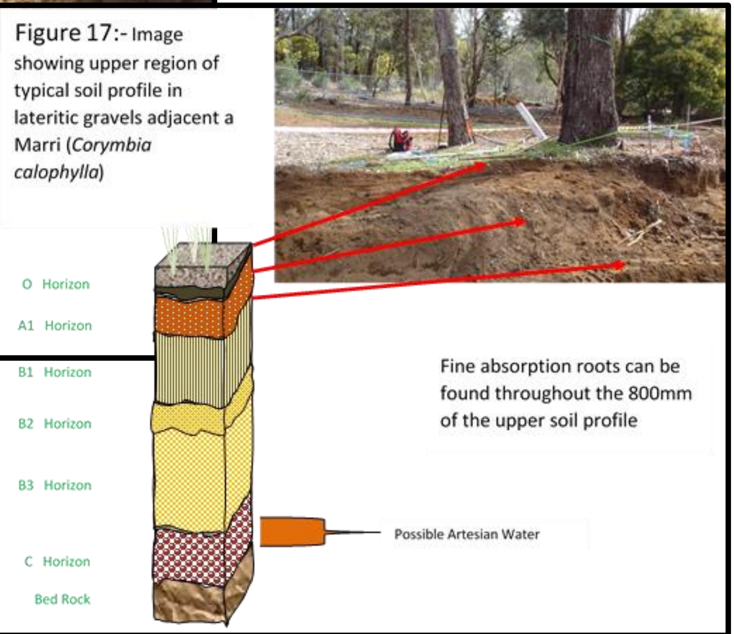
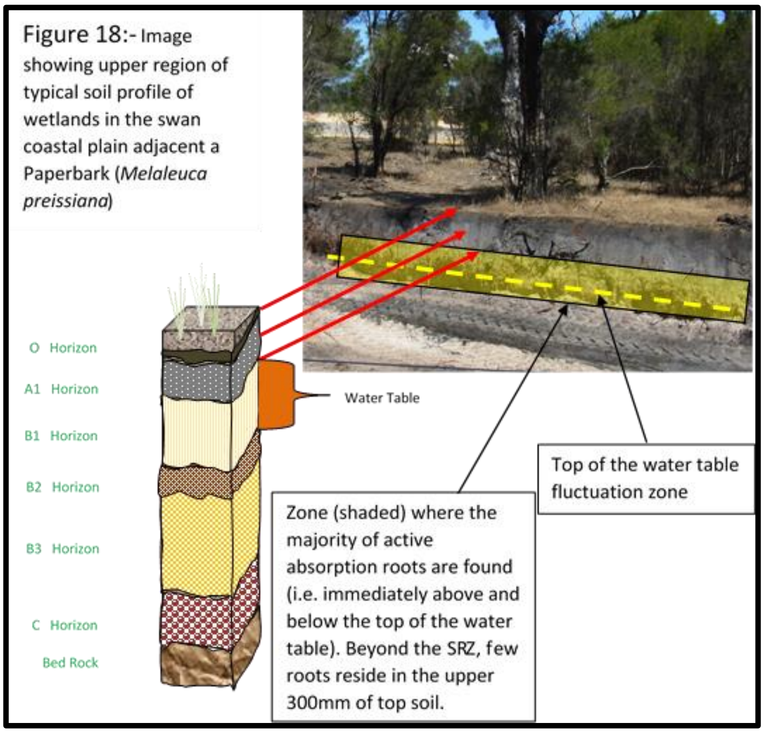
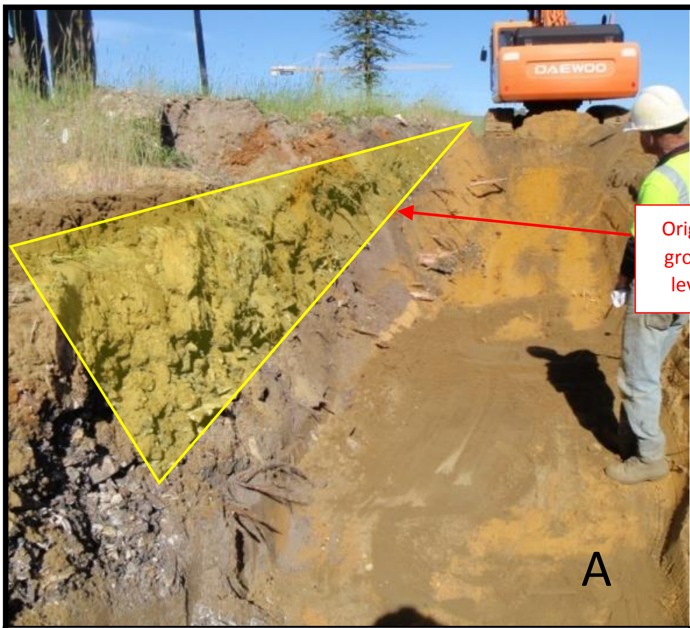


Figure 18:- Image showing upper region of typical soil profile of wetlands in the swan coastal plain adjacent a Paperbark (*Melaleuca preissiana*)



Un- Natural Soil Profiles in Perth's coastal sands

The majority of development across Perth's coastal sands has resulted in varying degrees of sand and soil disturbance. The most common of these being the introduction of cut and fill operations during the civil stage of development that result in layers of mixed local sands, compacted layers and foreign materials being the inherited origin of the majority of the past and current landscape (Refer Figures 19 & 20).



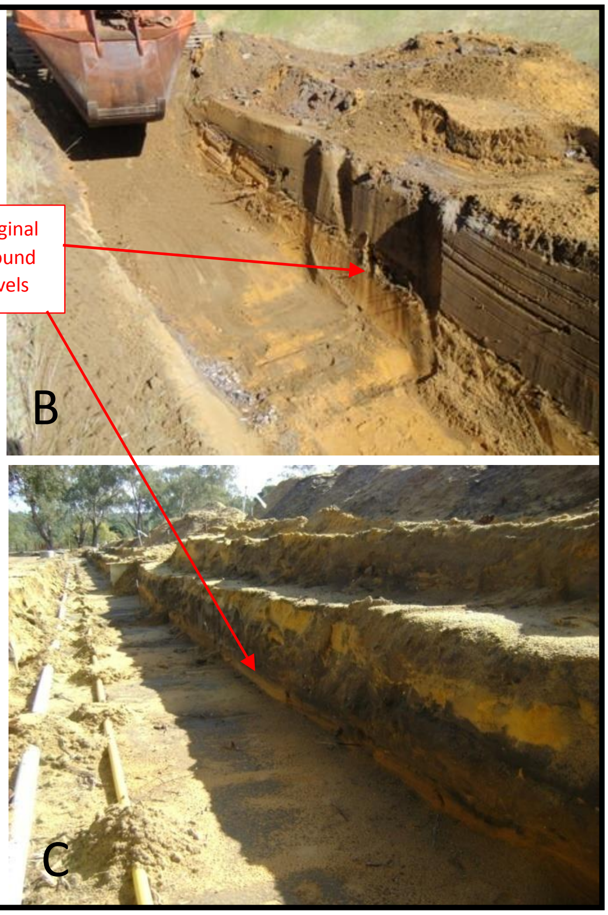


Figure 19:- Un-natural soil profiles in Perth's coastal sands. Image A showing gradation of rubble as fill (highlighted) over the original soil that the adjacent Marri's (*Corymbia calophylla*) have grown into. Image B is at the other side of the trench (where the man is standing) showing that the fill over the original soil has changed to highly alkaline construction sand that the tree roots have avoided. Image C is at Perry Lakes showing 5 layers of various sands that this new inner city estate is being built on….. Image property of Arbor Centre

The combination of the differing qualities of these layers in the preferred zone for tree roots to grow (i.e. the array of various physical qualities, potential hydrogen (pH), hydraulic conductivity, moisture gradients, organic content, nutritional status, compaction levels ---etc) has a significant bearing on the capacity of tree roots to perform as they would in "natural" soil profiles. In most instances it is impossible for them to do so [Craul 2006].

Essentially, the reasonably assumed behaviour of roots in their natural environs are significantly constrained by the urban soil profiles that we create or that we inherit in Perth's urbanised metropolis. In many instances, these changed circumstances are so vastly different to the natural soil profile that endemic vegetation has adapted to, that they are often the least able to successfully cope with the change – personal observation.

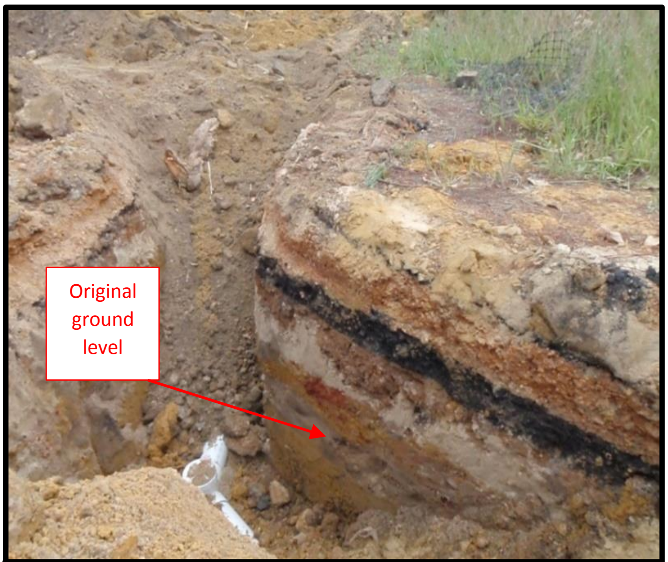


Figure 20:- Typical soil profile in the Midland area where numerous layers of various fill materials have been placed over the original top soils…. Image property of Arbor Centre

Common Tree Root Problems

Kerbs, footpaths, crossovers and footings are the common problem areas (refer Figure 21b). These are also the linear areas where higher moisture gradients periodically arise and persist longer in the soil than in other/adjacent areas (i.e. absorption roots historically grow and survive longer within these zones than in other zones). These periodic moisture gradients also commonly persist within the upper soil zone (to 500mm depth in sandy soils) that is the favoured place for absorption roots to grow – personal observation.

These moisture zones can occur either by design; in the case of kerbs (used to capture and divert storm water), or by default (for in-ground structures that induce condensation at their soil contact surfaces &/or that rain or irrigation water is naturally directed to ---e.g. a vertical wall collects and directs the water to its base).

It has also been our observation that where these structures and below ground services are installed following disturbance of the soil (modified to achieve new levels or excavated for services or footing installations), the soil within these backfilled areas is usually an aerated form of the blended site soils. For sandy soils, this blending of the top 200mm of organic soil with free draining sub soil sands, usually makes for a better root zone environment than the adjacent undisturbed soils and explains why these corridors are a common preference for root growth – personal observation.

Figure 21a:- Showing arterial roots within a service conduit ------Image property of Arbor Centre

Below ground services are claimed by some to be at great risk from such tree roots however, roots are rarely found to be the primary cause of breakage. Our only two circumstances (in the past 30 years), where roots have been the primary cause of damage have been extraordinary (not typical). One being where roots had grown within a service conduit that constrained arterial root expansion and resulted in the irrigation pipes being squashed (refer Image 21a). The other being where roots had grown between a footing and a service that was running against the footing. Other than these exceptions, our investigations have shown that it is mostly the failure of a join or a mechanical break in the service that has created soil moisture conditions that are better than elsewhere in the soil profile; and that over time, roots that happened to be present in the affected area, took advantage of the improved conditions provided.

It seems that it is by association that roots are often wrongfully argued as being the primary cause of the damage. None the less, their presence tends to compound the problem and their continued expansion into the favoured zone usually make matters worse in the case of below ground services, or can provide improvement in the case of retaining; where the presence of roots provides sand stabilisation - personal observation.

By incorporating measures that acknowledge root behaviour into design and construction, most of these kinds of root problems can be adequately mitigated to meet the intended design limitations of the structure.

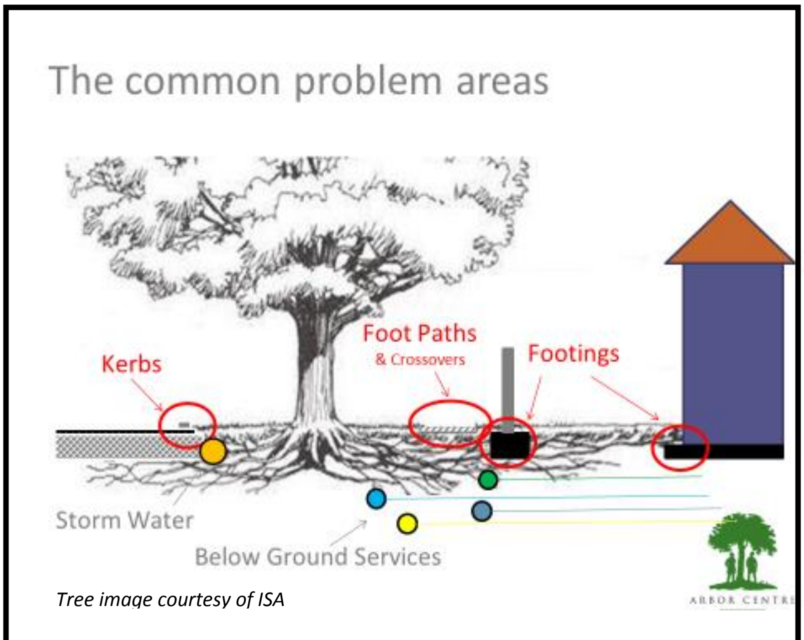


Figure 21b:- Showing the areas where roots common impact with urban infrastructure that are seen as problematic…. Image Property of Arbor Centre

Overview of common problem areas (Kerbs, Footpaths & Crossovers and Footings)

In Perth's coastal sands, water capturing areas like kerbs, the edges of footpaths, crossovers and footings, all have primary root ingress points that are at the interfaces between the layers created during construction. It is at these interfaces that moisture gradients arise and persist for longer than elsewhere as a result of condensation (between mediums of differing bulk densities), or the hydraulic conductivity variations between each of the soil profile layers – personal observation.

Through many years of trialling an array of ways to seal off these potential root ingress points in Perth's coastal sands, a suitable base product was found, and the manufacturer able to modify its characteristics, such that it could provide an effective 'spray-on' root barrier (Camilaflex SORB), capable of adhering to most of the surfaces encountered in road and civil construction; and when applied correctly, provides a seal that has both the strength and elasticity to potentially retain the seal for some decades (Refer Appendix 2b – Product information - Camilaflex)).

In conjunction with innovations such as compaction trenching, the protection of urban infrastructure can be afforded two principle tools of root management that can close off many of the root ingress zones that cause the infrastructure damage that is commonly observed.

Drawings explain the basic level of detail required to appreciate where the root ingress point are found and methods of protecting the likes of Kerbs, Footpaths & Crossovers and Footings that have proved successful in Perth's coastal sands. These can be found in Appendix's 2a, 2b & 3.

Other measures for managing roots in Perth's coastal sands

It is important to note that the hydraulic conductivity of Perth's coastal sands is very high [Samala] and the climate in Perth has high temperatures with relatively low humidity and a rainfall pattern that has 80% of its annual 800mm precipitation occurring in the winter months [Dixon 1997]. It is these combination of factors that appear to have facilitated the success of the root management measures being described below. For example, the practice of raising soil levels around trees has <u>very</u> limited 'fill depth' tolerances for most tree species where the backfill soils are not as free draining– personal observation.

<u>Road base compaction trenches</u>

Investigations and trials carried out by Arbor Centre on the installation of various conventional root barrier products (e.g. Vertical root barrier, Tree root deflectors – etc) has shown that they have limited success in Perth's coastal sands and that in most instances, the installation of the products usually attracts roots to the zones that the product was intended to protect (Refer Figure 22).

The primary reasons for roots being drawn to the conventional root barrier zones is the soil aeration that takes place during installation excavations and the 'practical' difficulty in re-compacting them. To add to the problem, the unsightliness of the products in high traffic areas is usually addressed by covering over the top portions of them during ongoing maintenance; providing an immediate pathway for roots to access their preferred growing spaces beyond the barrier (usually beneath the adjacent mulch).

Most root barrier products fail to achieve their intended purpose in Perth's coastal sands

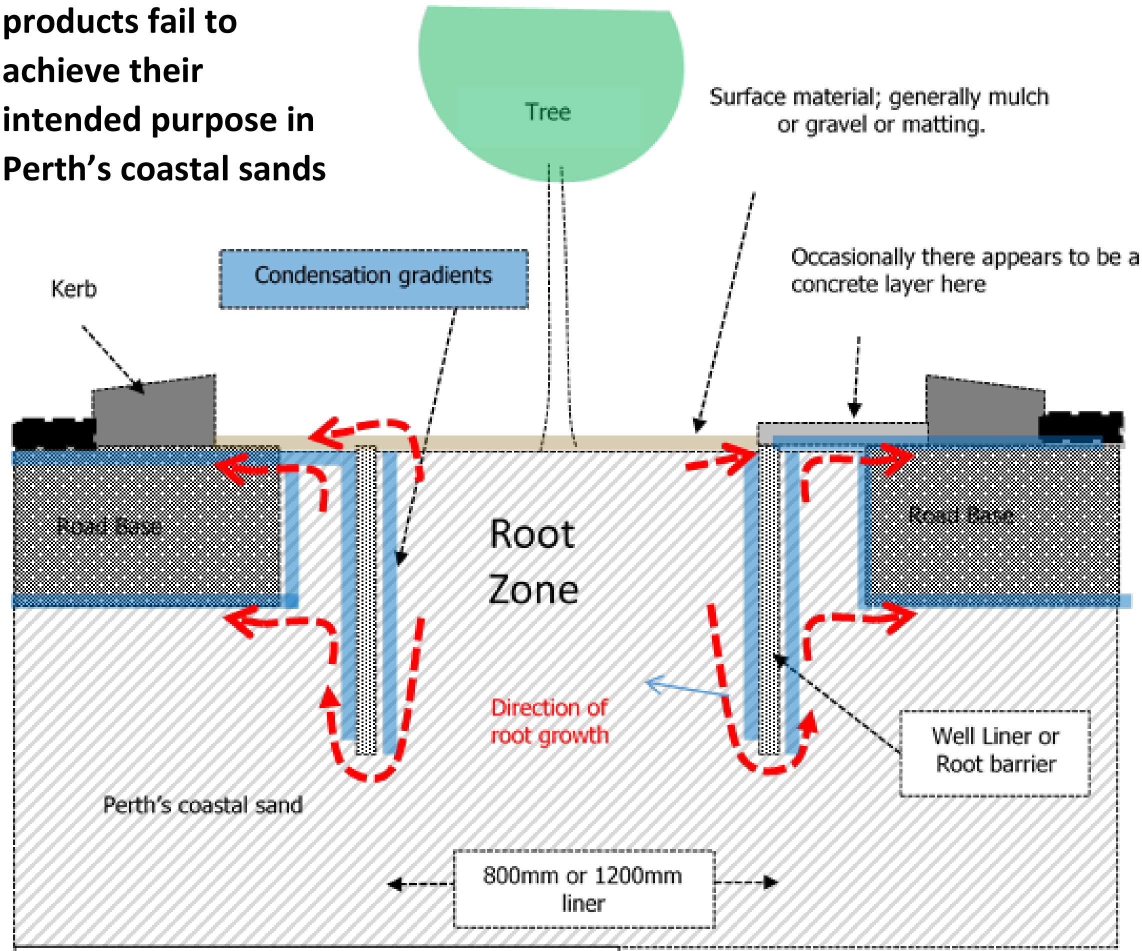


Figure 22:- Typical root barrier installation showing where roots are drawn to and then escape from the barrier… Property of Arbor Centre

Further to the application of 'spray-on' root barriers (as shown in Appendix's 2a, 2b &3), a successful approach for many situations in Perth's coastal sands, has been the introduction of compacted trenches of road base type material that is interlocked with the edge of hardstand and the interface joints sealed.

This approach creates secondary compaction of the sands immediately adjacent the road base as it is being compacted (Refer Figure 23).

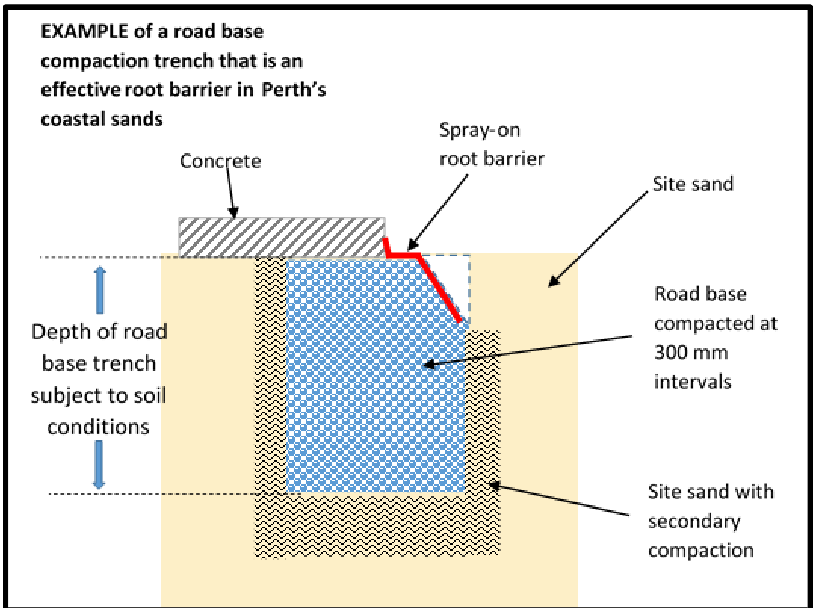


Figure 23:- Road base compaction barrier- property of Arbor Centre

Root Canals

From the observations of tree root behaviour (growth and distribution habits) in Perth's coastal sands; and the strong influences that disturbed sands have on tree root behaviour, it is evident that the structural root zone (or the zone of rapid taper as described by Wilson 1964) should remain a critical focus for tree managers to ensure that tree stability is well catered for. However, beyond the SRZ of most tree species growing in Perth's coastal sands, there is opportunity to purposefully manage root behaviour by taking advantage of the characteristics being observed (Refer Figure 24).

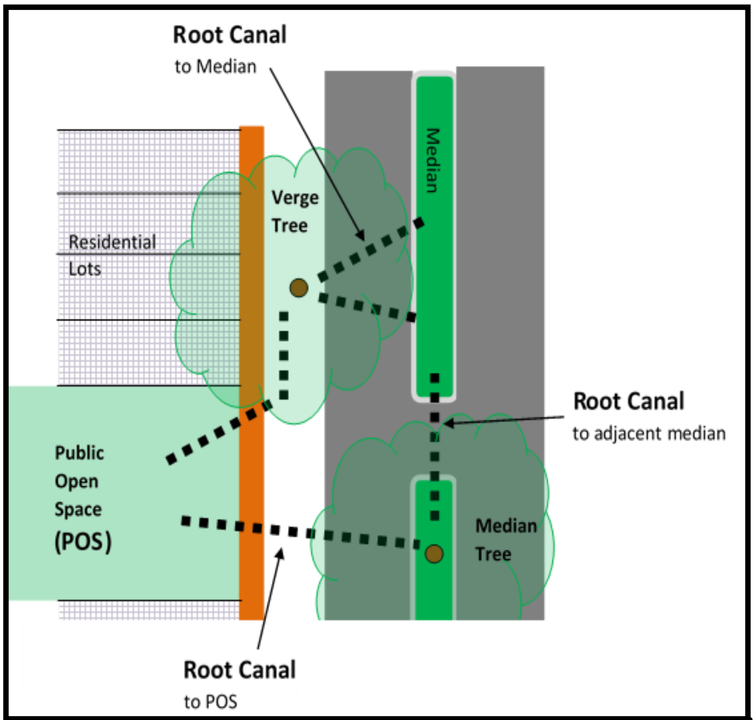


Figure 24:- Showing root canal possibilities to consider in urban design - property of Arbor Centre

With the propensity of many of Western Australia's tree species to naturally develop absorption root zones beyond the canopy of the tree (and that this propensity is accentuated by the disturbed nature of Perth's urban sands), there is sound reason to consider providing purpose built 'root canals' that provide corridors to selected feeding sites that are beyond the structural root zone of the trees. Some of the issues that we often associate with 'problems' are also evidence that tree roots are happy to utilise such canals.

Tree roots can be encouraged to travel at appropriate depths beneath roads, paths and hardstand when we provide the conduits they can utilise --- City trees, like city people, can also enjoy dining out in public places.

The construction required for providing these transport root conduits (root canals) in Perth's coastal sands, can be engineered to avoid conflict with other important urban infrastructure when designing new sub-divisions (Refer Figure 25).

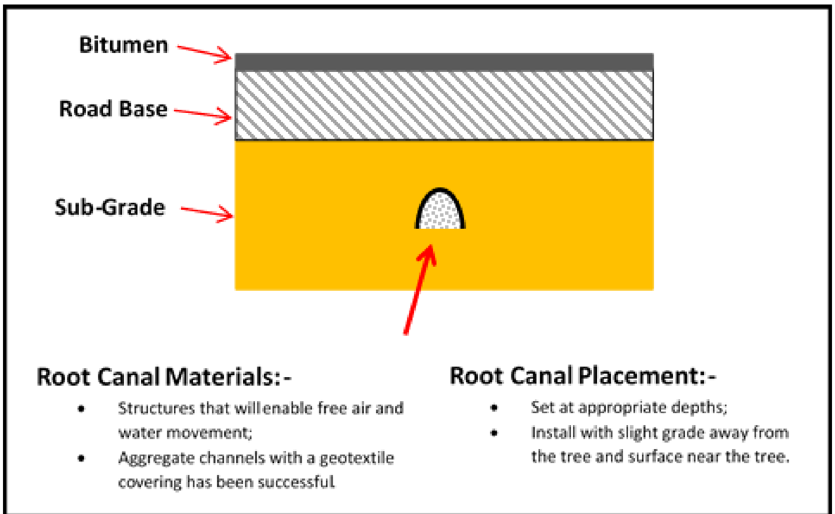


Figure 25:- Example showing root canal placement and construction beneath a road in Perth's coastal sands – image property of Arbor Centre

Aeration Layers and Pitching

Aeration layers can be 'root canals' arranged radially around affected areas of the root zone that require fill, or by creating a skirt around the tree (Refer Figure 26) using washed and screened aggregate (5mm – 20mm grades), covered with geotextile; for placement over the natural contours of an existing root zone where fill operations are going to occur. It has been our experience that they are effective when:-

- The aggregate is free of fines and organic material. (*Washed and screened basalt aggregate is commonly used*)
- Measures are taken to prevent siltation in and above the aggregate layer. Such measures need to be part of designing its application into the landscape. Geotextiles can cause silting over time and impact adversely on the soil's hydraulic conductivity.
- The aggregate layer provides the capacity for water and air to move easily through the aggregate layer for a period of years provided there are entry and exit points that avoid sumping.

Figure 26:- Showing the aeration layer and pitching around the trunk of a Flooded gum (*Eucalyptus rudis*) in Midland, prior to the placement of geotextile and subsequent backfilling of an embankment in 2007 and shows no signs of decline (2015). Image property of Arbor Centre

In Perth's coastal sands, aeration layers have been shown to be an effective way of providing the 5 to 10 year time frame many trees require to re-adjust to soil level changes. This re-adjustment is through roots being able to grow into the new soil environment (subject to aggregate layer depth), &/or in helping existing roots to support the trees needs long enough for new roots to develop elsewhere beyond the fill – personal observation.

In conjunction with the installation of an aeration layer over the root zone, it is often necessary to also provide pitching around the trunk of the tree when new soil levels surround the tree's trunk (Refer Figure 26). As well as the above points for success, we have also learnt that it is important that the size of the aggregate and the radius of pitching is proportional to the depth of fill (the deeper the fill the larger the aggregate and the wider the aggregate collar); that it is important for fines and organic matter to be restricted from entering the pitched zone; and that the pitched zone has good drainage (Irrigation can induce problematic factors) – personal observation.

Aeration layers under paving

Where washed and screened aggregate layers are introduced immediately beneath hardstand surfaces (in Perth's coastal sands), the root growth is usually restricted to the bottom of the aggregate layer. The only observed exceptions being where the aggregate has been contaminated with introduced soils or sands during construction (refer Figure 27).

Figure 27:- Showing exploratory excavation site and the 3.5 years of new root growth from the adjacent *Pinus pinaster*, at Edith Cowan University, WA, remaining below the aggregate layer. Inset showing a design section. - Images property of Arbor Centre

It has been our experience that they are effective when:-

- The edge treatments specifications take into account the site soil conditions and the root ingress points that require sealing.

  Note:- *The edge treatment of combining weed-mat and cement as an edge treatment at ECU, failed at joins of the weed-mat. Roots from the adjacent Pines (Pinus pinaster) entered via the joins and developed alone the interface between the weed-mat and the cement haunch.*

- The pavers are placed directly on the aggregate; and in which case it is important to select a practical size of aggregate that is appropriate for the paver size (i.e. 5mm for small pavers and can be up to 20mm for large slabs).

- The aggregate layer being installed directly over the sub-grade sands or road base.

  Note:- *In Perth sands, the introduction of a geotextile layer can act as a wick and provide a moisture gradient for roots to follow. Should a geotextile be required for sub-soil stability, it has proven best to confine its use to being within the edges of the aggregate layer.*

- To be effective in restricting root growth within the aggregate layer, it is imperative that the aggregate is washed and screened to the required size (avoid mixing sizes), and that it is kept free of sand or soil during construction.

Figure 28:- Showing 2 years of Pinus pinaster root growth remaining beneath the road base; but within the sub-grade of contaminated railway ballast beneath the subgrade - Image property of Arbor Centre

For pavements carrying light vehicular traffic, a trial was also carried out with the aggregate layer beneath the paving being deepened to 150mm depth (with the inclusion of geo-cells to improve stability), where this was placed directly onto a compacted road base

(200mm depth), that was constructed over a 200mm layer of Railway ballast. Exploratory excavation 2 years after installation showed that the subgrade of railway ballast had mixed with the Spearwood sand below and the road base above, to provide a favourable rooting medium that created minor undulations to the finished pavement surface in some parts of the paving (Refer Figure 28).

The challenge for tree managers is ensuring that the construction of edge treatment meets the level of detail prescribed in the construction drawings. Initially, this requires on site supervision until contractors become familiar with the site hygiene and quality control issues that make a difference to the outcome.

Structural Soils and Structural Cells

With cities imposing more hardstand and minimising natural open ground for trees to grow, the creation of sub-terrain rootable soil spaces beneath hardstand has been a welcomed innovation as a way of meeting engineering requirements for roads and other trafficked areas; while potentially catering for tree roots. These engineered solutions are primarily by way of “structural soils” and “structural cells”.

Structural Soils

The “structural soil” referred to here means the use of large structural objects, such as rock, that interlock under specified compaction loads while leaving macro spaces which are <50% occupied by a filler soil in which roots can grow [Pers. Com, May, P 2011] (Refer Figure 29).

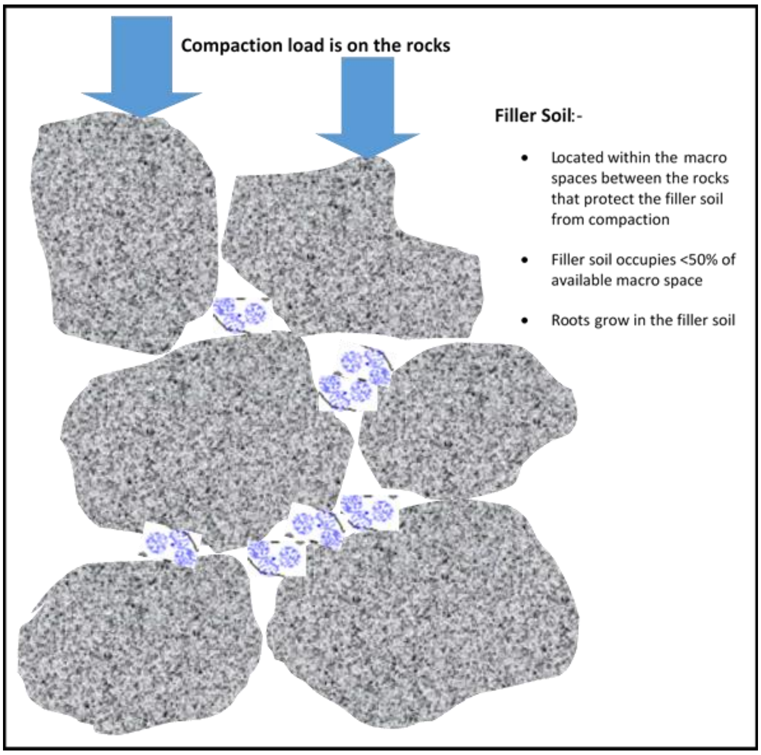


Figure 29:- Typical structural soil make up showing filler soil within macro spaces of the rocks – Image property of Arbor Centre.

Details of specifications, uses and applications can be found at the Horticulture Institute, Cornell University, NY, USA or Sydney Environmental & Soil Laboratory (SESL).

While focus has primarily been on the attributes of the structural soil and its abilities to support root growth to varying depths and how to introduce roots into the medium, limited research has been undertaken on how roots grow and distribute themselves beyond the confines of the structural soil zones provided.

Because successful structural soils are often costly to produce, handle and install in Perth (personal experience), the structural soil spaces afforded trees is often kept to a minimum and only caters for a marginal portion of the trees total rootable soil volume needs over coming years. Regardless of the volume of structural soil space provided, it has been our experience that roots migrate beyond these designated structural soil zones and behave in the same fashion as described previously (i.e. roots rarely remain confined to the constructed space provided ---- in effect, the introduction of structural soils tends to invite tree roots to continue beyond the installation and impact on infrastructure as described above (Tree Root Problems) – personal observation (Refer Figure 30).

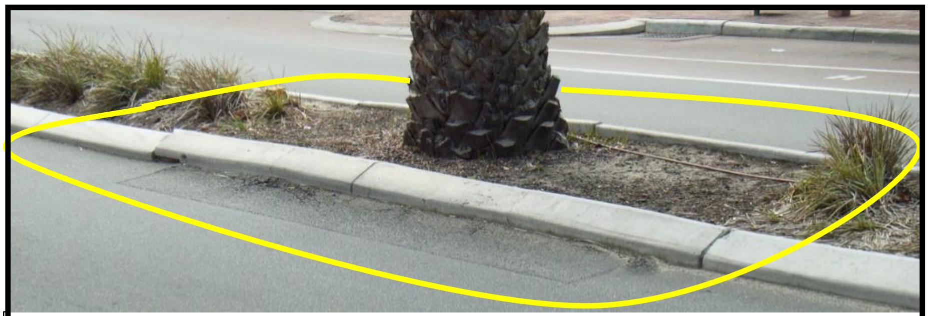


Figure 30:- Showing the zone where structural soil was utilised to 1.2 m depth around a date palm (*Phoenix canariensis*) in Midland and provided a much better rooting environment than the surrounding clay soils; causing road and kerb repairs every 2 to 3 years after planting – Image property of Arbor Centre

Being able to interpret the makeup of the surrounding soil profile and the influencing factors for root growth and development over time is a critical part of these kinds of installations.

Structural Cells

Structural cells also provide an excellent way of creating rootable soil space beneath hardstand however, it is beyond the structural cells that little if any, root management consideration is given to how roots will grow and distribute themselves.

Structural cells installations also have the added responsibility of determining and understanding the factors that influence the ability of roots to grow and distribute themselves <u>within</u> the soils provided in the structural cells. In Perth these factors include:-

- ❑ Drainage (at a rate that meets tree species requirement in the given mediums);
- ❑ Awareness of the depth of, and the % of organic matter in planter mix soils and the potential for anaerobic decomposition <u>over time</u>;
- ❑ Aeration and the capacity for air to adequately circulate to meet soil evaporation needs as well as air temperature/ventilation control beneath the hardstand and across the structural cell soil zone;

  Note:- *Beneath metal tree grates at Forrest Place soil temperatures to 100mm recorded temperature above 40C (Refer Figure 31).*
- ❑ Irrigation volumes and frequencies and the method of delivery that will ensure soil function across the whole soil mass, meets expectations;

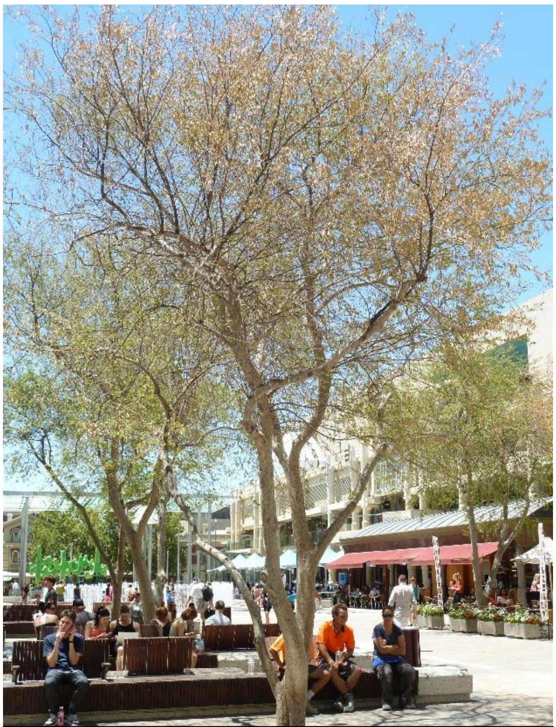


Figure 31:- Showing Elms (*Ulmus parvifolia*) at Forrest Place, Perth CBD, where the soil within the structural cell planter became toxic through anaerobic decomposition, drainage failure (within and beyond the planter) and soil temperatures beneath the steel tree grates exceed 40C during summer – image property of Arbor Centre

- ❑ Determining the soil profile layers that will minimises silting over time, that impedes drainage and can create impermeable zones within the soil profile;
- ❑ Moisture sensors and where they need to be placed (refer Figure 32);
- ❑ Soil contamination provisions (city tree pit are a common wash-down area after midnight);
- ❑ Extreme heat and light radiated from surrounding hardstand;
- ❑ Extreme air temperatures for lengthy periods;
- ❑ Recognising the limitations of the soil space provided;
- ❑ Recognising the limited access to the root zones to modify pre-existing soil conditions;
- ❑ Recognising the extremes of seasonal fluctuations (weather and water table).

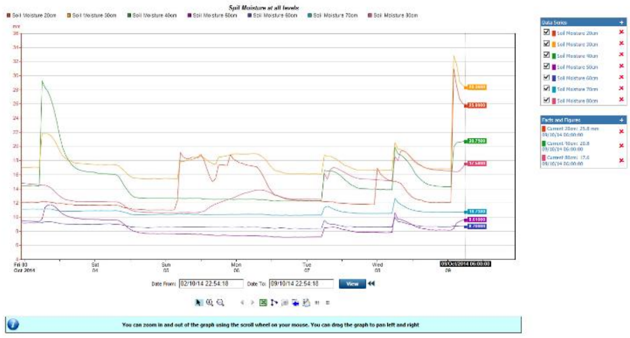


Figure 32:- Showing the moisture sensor data (at 100 mm increments down the soil profile) recorded/logged/transmitted by the 'Hornet' moisture sensor installed at Forrest Place, Perth CBD. – image property of Arbor Centre.

Conclusion

The root systems of trees are as essential to tree life as the above ground parts, and are no less significant in terms of tree management and species selection for the trees we seek to include in our towns and cities.

Tree management also has a breadth of stakeholders that are involved in their selection, planning, planting, aftercare and palliative care. People from many professions, trades, disciplines, communities and government bodies; all have some level of experience or have observed practices in managing (or not managing) tree roots that form the basis of personal views on how they could or should be managed.

Many of these same people are the decision makers that work directly with trees (including the supervisors and the contractors of various trades - including arboriculture), as well as people at higher professional levels (Planners, Landscape Architects, Engineers, City Managers and alike), that provide directives that govern or influence the framework in which tree managers are able to exercise their knowledge and expertise. One of the main challenges faced by tree managers and arborists is to better influence these higher level stakeholders in re-framing their approach and confidence in sound arboricultural practices being exercised within their domains and disciplines.

Recognising and being able to demonstrate the primary causes of the root problems that cause infrastructure damage in Perth's unique coastal sands, has encouraged professions such as Engineers and Landscape Architects in particular, to re-assess the theories and assumptions that have underpinned their previous modelling, and turn their professional skills to re-engage and effectively engineer trees into, rather than out of, the landscape and infrastructure that they are responsible for.

In translating the root behaviours in Perth's coastal sands into the designs of landscape and infrastructure, a great deal of time was also been spent in identifying the level of detail necessary for the development of construction specifications. The ability and willingness of professions to coalesce toward fruitful outcomes was an imperative. Of equal importance was ensuring that the construction detail was interpreted correctly and that there was adequate vigilance in the supervision of contractors as they become familiar with the site hygiene and quality control issues that are essential for successful outcomes.

Being able to interpret the makeup of the surrounding soil profile and the influencing factors for root growth and development over time, has proven itself to being a critical part of root zone management and the kinds of installations discussed.

Overall, the challenge in Perth is providing more quantitative data to support the qualitative observations and comparative data gathered to date. We see this as a challenge for all tree managers and arborists in gaining a better understanding of the below ground circumstances in their domains….. i.e. Digging the holes that verify actual conditions and soil profiles; making time to expose, explore, verify and compare the growth and distribution patterns of root systems, and the peculiar influences that local conditions are having on the common tree species; and determining quantitative measures that can better support the needs of professions that are most instrumental in delivering change.

The circumstances and behaviour of root systems in Perth's unique coastal sands may not be applicable elsewhere however, it is hoped that the issues raised can provide a guide to where further research and trialling is needed to meet the challenge of providing sufficient space and the better management of tree roots within our urban precincts.

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APPENDIX 1

Swan Coastal Plain Sands

Brief Geomorphology

The sands of the Swan coastal plain are made up of three linear geological systems:-

The Quindalup Dune system which fringes most parts of the coast line / foreshore for up to 3 kilometres, is made up of lime and quartz sands as well as lime-based marine deposits which have resulted in it generally having an elevated Potential Hydrogen (pH) that is often >8.5 [Dixon 1996]. The Quindalup sands contain a higher percentage of fine sand particle size and lower course sand than Spearwood or Bassendean system sands; and noticeably slower draining [Salama 1998] .

The Spearwood Dune system which extends from the Quindalup systems (or the coast line in some parts), for a width of further 15 kilometres from the coast where top soils range from 0 – 20 cm over yellow sands with particle sizes having a comparatively higher percentage of medium sand size particles and pH ranging from 4 to 7 (low pH associated with wetlands) [Salama 1998].

The Bassendean Dune system extends from the Spearwood system for a further 15 kilometres to the foothills and is characterised by its comparatively high percentage of course sand size particles, draining more freely than Quindalup or Spearwood sands and having a pH ranging from 2 - 7 (low pH associated with wetlands) [Salama 1998].

The hydraulic conductivity of the Bassendean and Spearwood top soil sands ranges from 0.56m to 2.85 m/day and subsoils range from 3.41 to 6.38 m/day [Salama 1998]

The Urban Soil systems utilised for road construction is sourced primarily from the Quindalup and Spearwood dune systems [Boral 2015] while verge and garden areas are commonly a blend of local subsoil sands with sporadic coverings of manufactured soil mixes with high organic content – personal observation.

The Influence of Ground Water Usage

Of significance also is the increasing use of ground water as part of Perth's domestic supply as well as parks and residential gardens. Being high in carbonates and bicarbonates, the increasing use of these water supplies is incrementally elevating top soil pH [Dixon 1996].

Soil Stability

A chief characteristic of Perth's sands is that they remain relatively stable/consistent in structure when it is either wet or dry and therefore provide better in-ground stability for trees than soils that significantly change structure when wet – personal observation.

APPENDIX 2a

Kerbs:- Where the root problems are in Perth's sandy soils

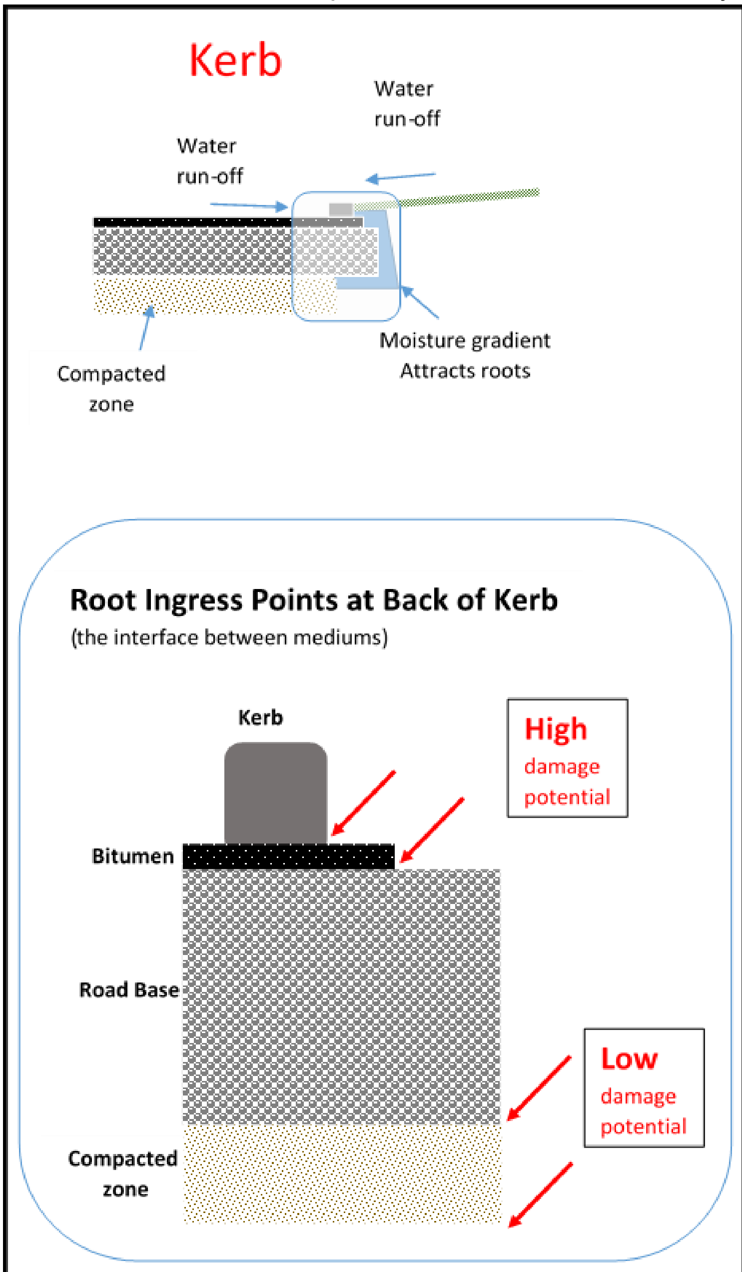

Figure 1:- Typical Kerb Construction and Root Ingress Points in Perth sands

APPENDIX 2b

Kerbs:- <u>Construction required to effectively close off root ingress points</u>

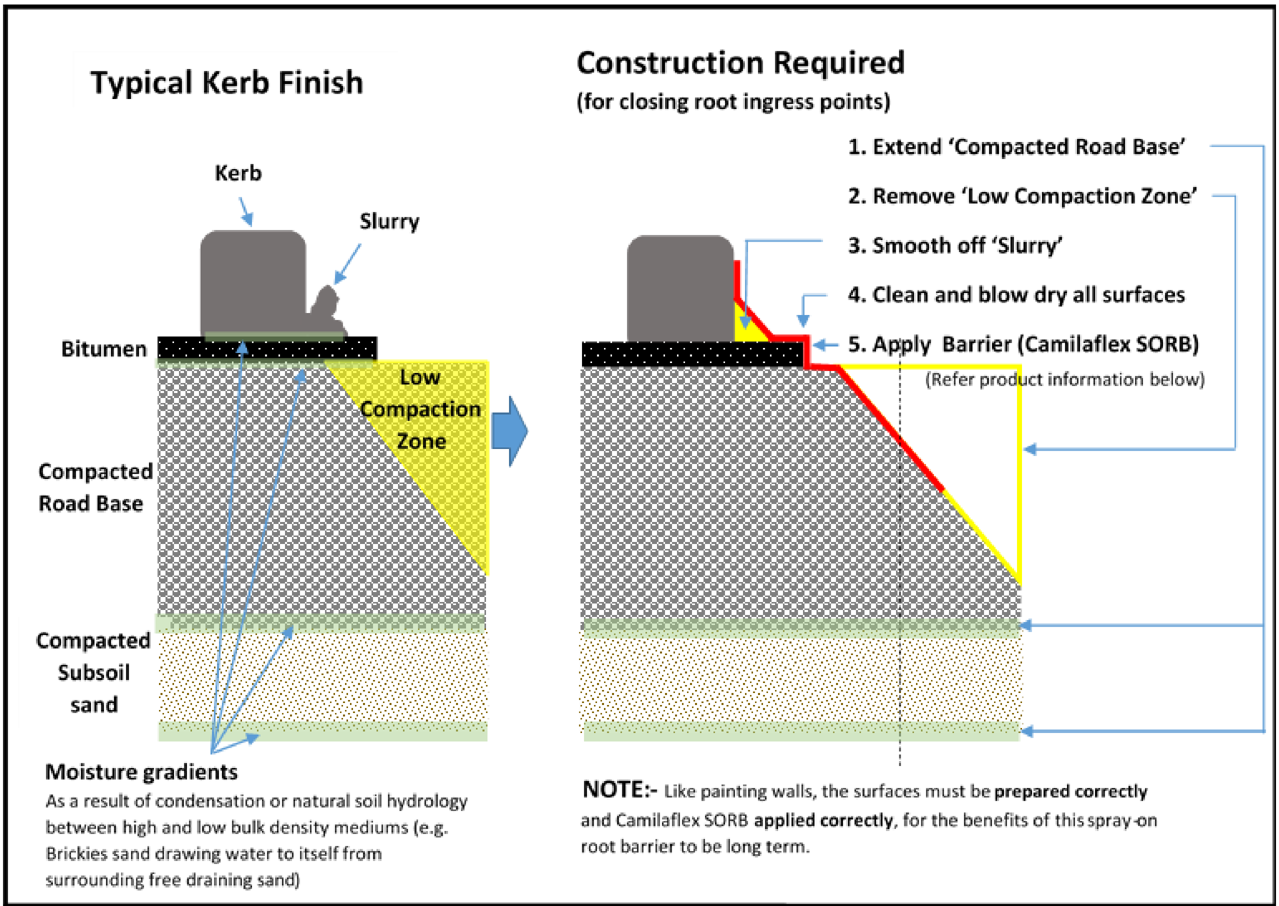

Figure 1:- Typical Kerb Construction Required for Root Ingress Protection in Perth sands

Product Information (Camilaflex)

The liquid (Spray-on) root barrier (Camilaflex SORB) has been purposefully developed by the manufacturer following field trials carried out by Arbor Centre over an 8 year period. It is the only product Arbor Centre has found that when applied as a minimum 500 micron thick continuous coating over correctly prepared surfaces, can:-

- Successfully adhere to a broad range of surfaces that include concrete, bitumen and compacted road base materials;
- Provide the 400% elasticity required to reasonably hold the structural integrity of the coating over cracks to 2 mm, and minor movements that commonly occur at roadside edges;
- Holds its elasticity and structural integrity for up to 10 years in full sun (manufacturers warranty); and potentially decades in ground.

Applying the barrier does not protect the kerb from the horizontal forces that could be applied over time as a result of root mass build up adjacent the back of kerb, or that could result from the radial expansion of arterial roots located along the back of kerb. Other measures need to be implemented if root occupation immediately adjacent back of kerb is to be minimised.

APPENDIX 3

Foot Paths & Crossovers:- <u>Where the root problems are in sandy soils and the construction required to close off the root ingress points</u>

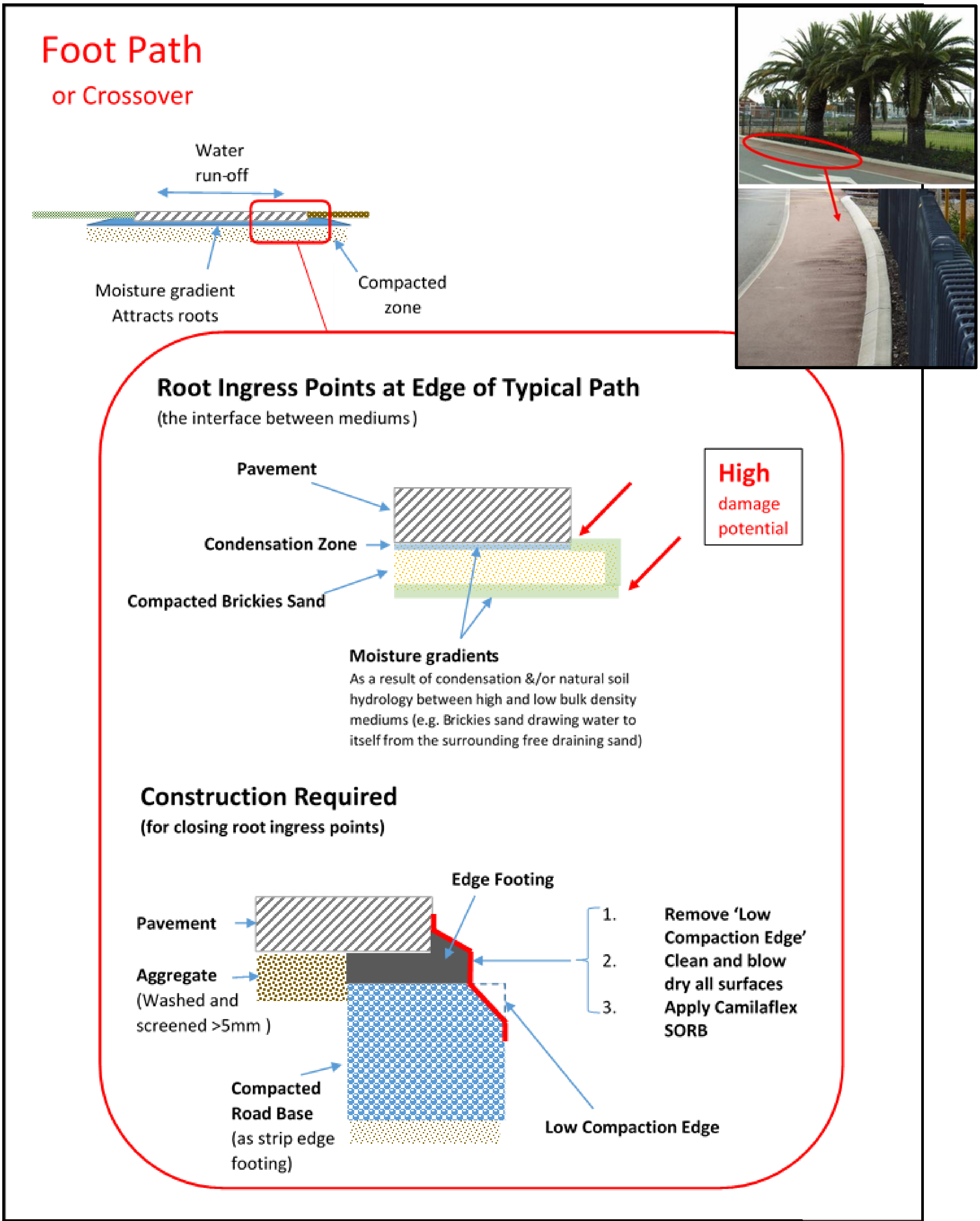

Figure 1:- Typical Foot Path or Crossover Construction Required for Root Ingress Protection in Perth's sands