Root excavation of *Salix matsudana × alba* 'Moutere' willow on the Hutt River, Wellington, New Zealand and on the Rangitikei River, Ohakea, New Zealand

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Summary

Willows were excavated from the Hutt River and from the Rangitikei River to better understand the root structure in the various sediment layers (silt, sand and gravel). Roots were prominent in the surface silt and deep gravel layers but sparse and of small size in intermediate layers (a mixture of sediments, predominantly sand). This is considered to be an effect caused by water deficit in the intermediate layer when river flows are low, which likely coincides with the latter part of the growing season. Trees originating from poles planted to depths close to the summer water table had thick roots growing form the bottom of the pole, and were considered well-anchored within the deep gravel layer. These trees are considered to remain stable in high river flows and able to stabilise the river bank. The tree planted only to the depth of the sand layer was deficient in roots from the bottom of the planting material and was not well anchored. Trees grown from shallow-planted poles are considered to be vulnerable to dislodging in high river flows and unlikely to stabilise the river bank.

Key words willow roots, river sediments, pole, root development, fine root

Introduction

The primary implication of the physical and ecological importance of floods on a wide range of river types is that rivers must be managed and restored for process rather than form, and process includes floods. Restoring form without process by engineering a specific channel configuration that cannot be maintained over a period of decades or longer by the existing flow regime, for example, is likely to require continual, expensive artificial maintenance and is unlikely to replicate the conditions necessary for a fully functional river ecosystem (Kondolf et al., 2001; Wohl et al., 2005). Flood prevention is a difficult matter. Given the inevitability of floods, the most effective management strategies will be those that restore and maintain a nearly natural flow regime and sediment supply, and permit the river to adjust to fluctuations in water and sediment discharge within a riverine corridor that has the minimum possible structural constraints (Jaquette et al., 2005).

Impacts of vegetation on mass failure can be divided into mechanical and hydrological effects, some of which are positive in terms of their impact on bank stability and some of which are negative. The most important mechanical effect that vegetation has on slope stability is the increase in soil strength induced by the presence of the root system. In terms of river bank hydrology, three main factors are a) interception, b) infiltration, c) evapotranspiration. However, the rate and amount by which plants alter the water content distribution within a river bank depend on a great many factors related to vegetation type, soil characteristics, seasonal variations, and climatic conditions of the region. All these are difficult to quantify. Van De Wiel and Darby (2004) demonstrated that reach-scale variations in bed topography induced by the presence of bank vegetation influences local river bank retreat in a spatially variable manner. The variations can be induced by vegetation assemblages located on the banks in reaches upstream and downstream so that at-a –site analysis by itself is not always sufficient to determine the net beneficial or adverse impact on bank stability of a specific assemblage of riparian vegetation. Discontinuous vegetation may also direct flow towards the opposite bank and promote meandering.

Willows are considered to be effective by river engineers and their use is widespread in most regions in New Zealand as front line defences for river control works. Where bank erosion is required to be controlled, it is achieved with either structural measures (concrete structures or rip rap (large boulders)) or by planting trees at the river edge or on the banks. Vegetation is widely accepted as a key factor in contributing to a stream's bank stability. In general terms, vegetation roots increase bank stability by protecting soils against entrainment from flood flows, and root mass and density provide soil shear strength and thereby protect against gravity collapse of undercut banks (Phillips & Daly, 2008).

The root systems of willows used in river control works can be sometimes exposed in severe floods where high flows generate higher than normal rates of erosion. In these situations the willows may be considered to have failed, as indeed they have. However, it is not always clear where the failure lies. Failure may be contributed by 1) river control works being overwhelmed by the superior forces generated by the high water flow, or 2) the willows being weakened by age, disease or pests, or 3) weakness in the underlying sediment structure in that section of the river, or 4) physical alterations upstream of the river.

However, little is known of tree willow rooting behaviour in river bank sediments, and how the nature of the sediments and the depth to which the material is planted influence root growth. Hence a field study was initiated to test the hypotheses that willow root growth will differ in different sediments.

Method

Location of excavated trees

Tree 1 was located on the western side of the Hutt River. We excavated a tree nearest to the river in a row of trees planted. Trees planted along the river bank were arranged in rows, at spacings 3 m apart within the rows and 5 m apart between rows. Rows ran upwards from the edge of the active riverbed with the trailing edge adjacent to the riverbed. The 'soil' was a mixture of large and small boulders, sand and silt. Understorey vegetation was grass. The active riverbed was below the grass ~2 m from the trunk of the lowest tree. There was a silt layer extending from 0- 0.3 m, below which the sediment was dominated by stones interspersed with silt and sand. Most trees had three leaders since trees had been coppiced to provide a continuous supply of poles for riverbank stabilisation. Tree height was 5.6 m. The original pole was planted to 2.8 m depth. Water was reached at a depth of ~ 3 m and clean water drained into the hole from above the hole on the land side, and also filled from the river side. A hard pan was reached at ~ 3.2 m.

Tree 2 and tree 3 were on the eastern side of the river 200 m upstream from tree 1. Tree planting arrangement was the same as that for trees in tree 1 location. A tree was excavated further up the row (tree 5) in the expectation that the silt layer was likely to be deeper and the influence of this would alter the root pattern. This tree was at a higher elevation than the lowest tree in the row by 0.4 m.

The pole was planted to 3.4 m. The bottom of the pole showed evidence that it had been submerged up to 0.6 m frequently (blackened appearance), though there was no rot. Tree 2 was a similar size to tree 1 (Tables 1, 2).

Tree 4, a 'Moutere' willow, was in a willow nursery on the western bank of the Rangitikei River below the Kakariki Bridge. It was planted as a stake at a depth of 0.75 m, the depth matching the depth of the silt layer. There was no evidence from the root or stake appearance that the water table reached the bottom of the original stake.

Trees 1, 2 and 4 were excavated in 2018. Tree 3 was excavated in 2014 and findings for tree 3 were reported previously.

Excavation approach

A mechanical digger excavated the soil along one side of the tree excavating between the rows. As the hole got deeper sediment fell into the hole exposing the tree root system. The turf held together but the deeper sediments did not, being dominated by stones. The tree was anchored by roots extended opposite to where the digger was excavating until total collapse was achieved. At this point the tree was lifted out of the hole intact, laid flat across the bucket of the digger, and measurements were made. The root system was not able to be maintained intact, various sections of roots being cut through by the digger and others broken in the extraction of the intact tree, so measurements (diameter at trunk, position along trunk, length of root and diameter of distal end of root) were made for the 5 dominant roots in each section of the trunk (or less where there were less than 5 roots present). Trunk diameter was measured at the root transition points. For trees 1 and 2 root samples were collected from within the different trunk sections, and the roots separated according to diameter classes, their length and dry mass recorded and their specific root length calculated. Measurements were made on site for tree 3 but no root samples were collected.

Results

Measurements of root parameters were made for all trees except for tree 4. Data for trees 1 and 2 are given in tables 1 and 2. For tree 1 large diameter roots were found at two depths, 0 – 0.3 m and 1.5 – 1.8 m. The soil at the shallow depth was silt, and at the deeper depth was gravel boulders with a small amount of finer material (sand, silt). From 0.3-1.5 m the soil was mostly sand, varying slightly in depth for the different tree positions. For tree 2 proximal root diameters were comparable with those for tree 1 but depths at which they occurred differed.

Table 1. Tree 1 trunk below ground separated into zones based on relative root development with some root measurements taken within each zone (see text).

Trunk Section below surface m	0 – 0.3	0.3 – 1.5	1.5 - 1.8	1.8 – 2.6	2.6 – 2.8
Proximal Root diameters mm	17, 14, 15, 13, 17	13, 12, 6, 6, 9	20, 20, 19, 27, 15	10, 4, 8, 7, 9	2, 2, 2, 1, 2
Root lengths m	1.6, 2.8, 1.4	1, 1	06, 0.9, 1, 1	0.9, 0.9	0.2, 0.25
Distal root diameters mm	6, 3, 4	2, 2	24, 12, 25, 24	2, 2	1, 1
Trunk diameter cm	15.5	14.4	12.2	12.2	10.8

Table 2. Tree 2 trunk below ground separated into zones based on relative root development with some root measurements taken within each zone.

Trunk Section below surface m	0 – 0.15	0.15 -0.6	0.6 – 1.2	1.2 -1.6	1.6 – 2.8	2.8 – 3.2	3.2 – 3.4

Proximal Root diameters mm	15, 16, 16, 9, 9	4, 2	25, 14, 17, 13, 14	2, 2, 2	24, 28, 17, 23, 15	3, 4, 3, 5, 3	8, 12, 9, 5, 7
Root lengths m	0.6, 0.5, 0.4	0.3, 0.2	1.5, 1.05, 1.2, 0.95	0.5	1.2, 0.8, 1.2, 0.5, 0.6, 0.5	0.5, 0.4	0.6, 0.65
Distal root diameters mm	2, 2, 1		16, 12, 14, 11	<1	19, 33, 19, 15, 17, 16	<1, <1	7, 4
Trunk diameter cm	14.2		14.7	12.3	12.3	10.3	10.7

Figure 1. Root presence along the length of the pole for Tree 1

Figures 1 – 6 show how the root development differed along the pole, and also how it varied between trees 1 and 2 in the angle with which the roots grew.

Figure 2. Section of trunk of Tree 1 at 1.6 - 1.8 m (L), and at 1.9 - 2.1 m (R), showing the differences observed in the root development at different parts of the pole.

Figure 3. Various views of the soil profile where Tree 1 was excavated, showing water table (top left), presence of root at the different tiers, nature of soil in the top 0.3 m (lower left) and location of thicker roots in the profile (lower right).

Figure 4. Root growth in Tree 2 was obliquely downwards, in contrast to Tree 1. Soil profile was comparable for the two sites.

Figure 5. Very little sediment attached to the roots of tree 1.

Figure 6. The bottom of the pole was in a saturated soil zone restricting root growth.

Table 1. Root length distribution (m) for roots of trees 1 and 2 sampled at different depths

		Root diameter mm						
Tree	Depth m	<1	1<2	2<5	5<10	10<20	>20	Total length m
1	0-0.3	16.80	3.33	4.33	0.91	0	0	2.537
	0.3-1.5	5.63	0	2.23	0.23	0	0	0.809
	1.5-1.8	4.57	0.56	0.09	0	0	0.85	0.590
	1.8-2.4	4.45	0.63	1.24	0	0	0	0.634
2	0.1	27.37	4.73	2.23	0.61	0.13	0	3.485
	0.3	6.58	2.83	2.02	0.51	0	0	1.274
	2.4	4.34	0	0	1.30	0	0	0.564

Table 2. Root mass distribution (g) for roots of trees 1 and 2 sampled at different depths.

		Root diameter mm						
Tree	Depth m	<1	1<2	2<5	5<10	10<20	>20	Total mass g
1	0-0.3	5.2	2.45	12.52	12.70	0	0	32.9
	0.3-1.5	1.56	1.58	1.54		0	0	4.7
	1.5-1.8	1.73	0.15	0.16	0	0	84.09	86.1
	1.8-2.4	1.24	0.35	3.9	0	0	0	5.5
2	0.1	11.9	4.17	10.36	13.85	6.86	0	47.1
	0.3	3.36	1.88	5.56	3.8	0	0	14.6
	2.4	1.17	0	0	18.02	0	0	19.2

Figure 7. Roots were long with little side-branching of structural roots.

Table 3 Specific root length (SRL; m/g^{-1}) of the different root diameters at the sampled depths

		Root diameter mm					
Tree	Depth m	<1	1<2	2<5	5<10	10<20	>20
1	0-0.3	3.23	1.36	0.35	0.07		
	0.3-1.5	3.61	0.0	1.45			
	1.5-1.8	2.64	3.40	0.56			0.01
	1.8-2.4	3.59	1.89	0.32			
2	0.1	2.30	1.08	0.22	0.04	0.02	
	0.3	2.20	1.51	0.36	0.13		
	2.4	3.71			0.07		

Figure 8. Tree 3 from Rangitikei River showing root development down the stake. The prominent lateral root is at 0.5 m depth. Note changes in diameter of the original stake showing where growth has occurred. Changes in diameter are always associated with root activity. The remains where some large roots broke off can be seen ~20 cm up from the bottom of the stake.

Figure 9. Soil profile at Rangitikei river site

Root development for tree 3 was largely lateral (Figure 8). Root data for tree 3 are given in table 3.

Figure 10. Another view of the root allocation for the ‘Moutere’ willow at Rangitikei river.

Discussion

Learnings from in-situ excavation

Roots were extensive in the silt-dominated topsoil. Tree root growth was typically prominent in the top 0.4 m where the soil was finer in texture, rich in nutrients and air, and with the capacity to hold water. A high proportion of fine roots were found in this layer, but root extension was moderate. Larger roots with significant root extension occurred deeper in the soil profile for all excavated trees (see Appendix 1, 2). This was gravel (Hutt River) and silt (Rangitikei River). There was an important difference in root initiation and extension between the two environments. A readily observable section of the pole growing in gravel had few and small roots. This gravel zone sits well above the water table and the natural drainage channels through which water enters the river, and has insufficient water holding capacity to sustain plant roots. The presence of some roots suggests that there are times, probably in winter, where there is sufficient moisture to sustain root growth. The small size and short length of these roots suggests they are short lived. Roots were absent from such a section for the tree excavated in 2014 (Appendix 1).

The root distribution along the buried length of the pole was similar for both trees 1 and 2. The soil profile was similar with the top 0.3 m being principally silt, and below 0.3 m dominated by stones of various sizes with small amounts of silt and sand. Below the silt layer water storage capacity is extremely low in both summer and winter. Significant root development is seen at depths where water is presumed to be constantly available to the many small roots growing off the main roots.

The roots at depth in the gravel are thick and extend a long way from the trunk. They were growing between the stones, some of which were very large, and importantly they are adding to the shear strength of the soil/plant association to resist erosion in high river flows. In particular these roots resist erosion at depth, which is not true for trees where the mass of the large roots are growing in silt where hydrological erosive forces can act to undermine them.

The size (3 m) and the placement (down to the water table) of the planting material appear to be important factors in developing a root system dominated by large diameter roots at depths close to the winter water table.

The observations of dead and small roots near the bottom of the pole for the deep planted trees indicates that survival of these roots, particularly the finest roots, depends on the height of the water table. During periods of low river flow, when the roots are well aerated, they will be active in water absorption and some mineral uptake, and during periods of high flow the anoxic environment will lead to fine root dieback. There was no evidence that the large roots are affected adversely by periods of normal high flow, or of periodic flood inundations.

Why are willows effective in holding river edges? Willows are effective in holding river edges when they are planted deep and their large structural roots are deep in the soil profile and entwined in the sediment, and the combined shear strength of the root/soil complex exceeds the erosive forces generated by the river flow. Gravel and boulders being uneven in size and heavy have high shear strength. A grass covering also protects the silt from surface erosion, as does the dense network of fine roots.

When are willows ineffective in holding river edges? Willows are ineffective in holding river edges when they are planted shallow, the bulk of soil is silt, the silt is not protected with grass, the tree roots acquire all the tree's needs from the silt layer, and there is little root development into gravel layers. This was apparent for the tree excavated on the Rangitikei River. In this situation, the gravel root/soil complex has a lower shear strength requiring smaller erosive forces to dislodge it. While the silt root/soil complex has increased shear strength than silt alone the silt is easier to separate from the roots than is the gravel because of the relatively even particle size and erosive forces weaken the soil/ root complex through undermining and dislodging of soil particles. In contrast, the trees on the Hutt River planted deeper and with access to the water table continuously developed large roots in the deep gravel that both anchor the tree in floods and sustain the moisture requirements of the tree during periods of surface water stress.

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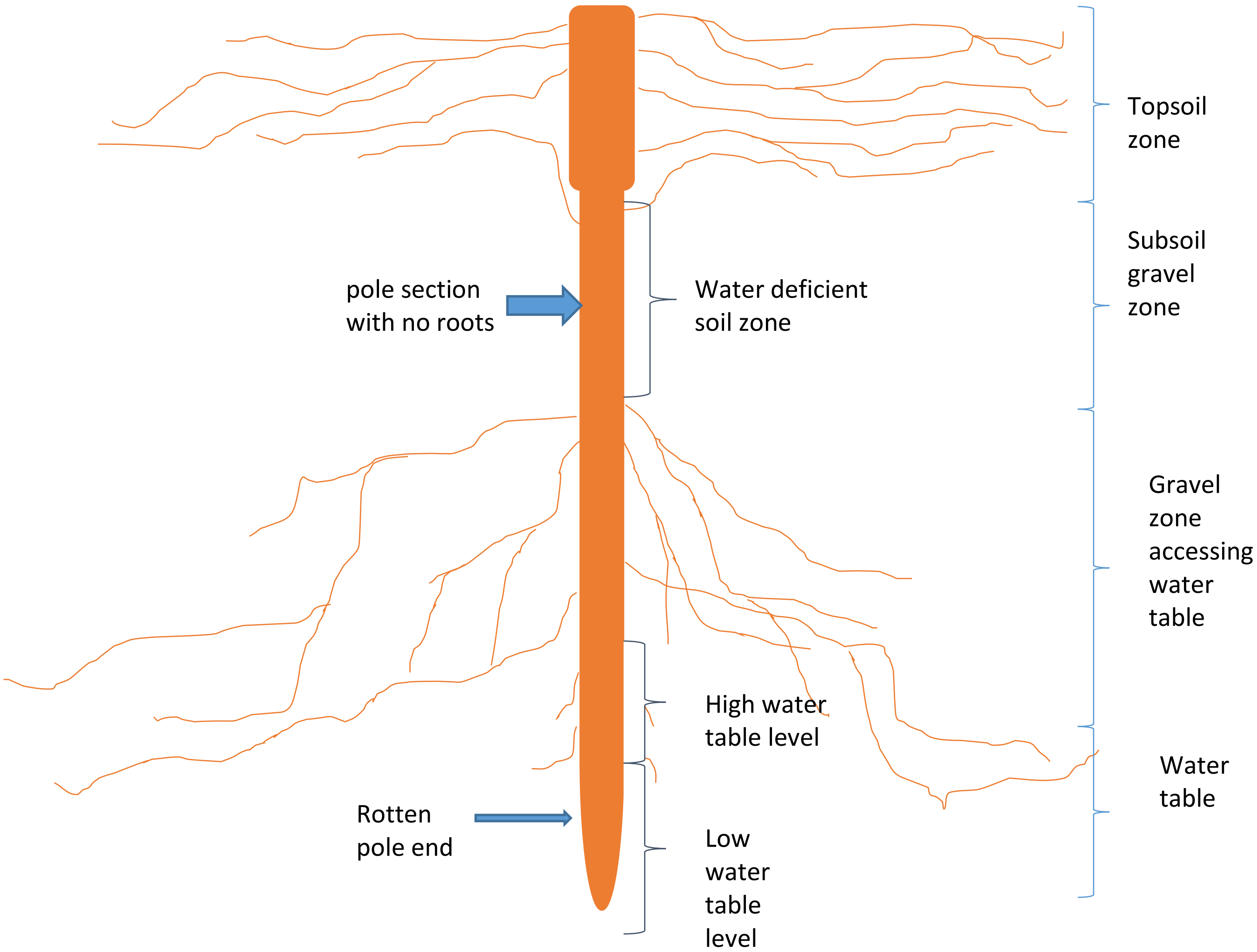
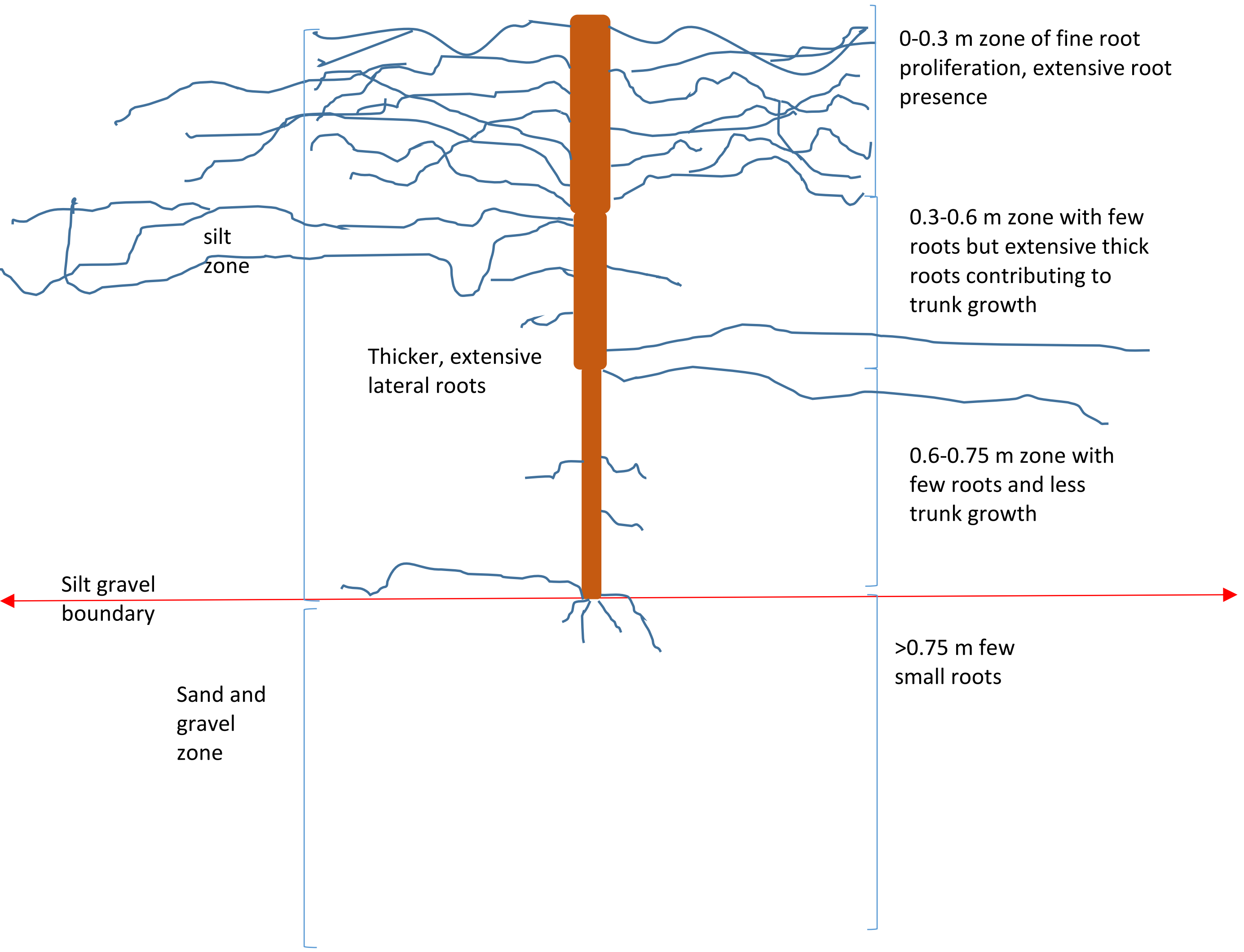
Diagram 1 (representation of root growth for trees at Hutt River), and **Diagram 2** (representation of root growth for the tree at Rangitikei River) are overleaf


Topsoil zone
Subsoil gravel zone
pole section with no roots
Water deficient soil zone
Gravel zone accessing water table
High water table level
Water table
Rotten pole end
Low water table level


0-0.3 m zone of fine root proliferation, extensive root presence
0.3-0.6 m zone with few roots but extensive thick roots contributing to trunk growth
silt zone
Thicker, extensive lateral roots
0.6-0.75 m zone with few roots and less trunk growth
Silt gravel boundary
>0.75 m few small roots
Sand and gravel zone