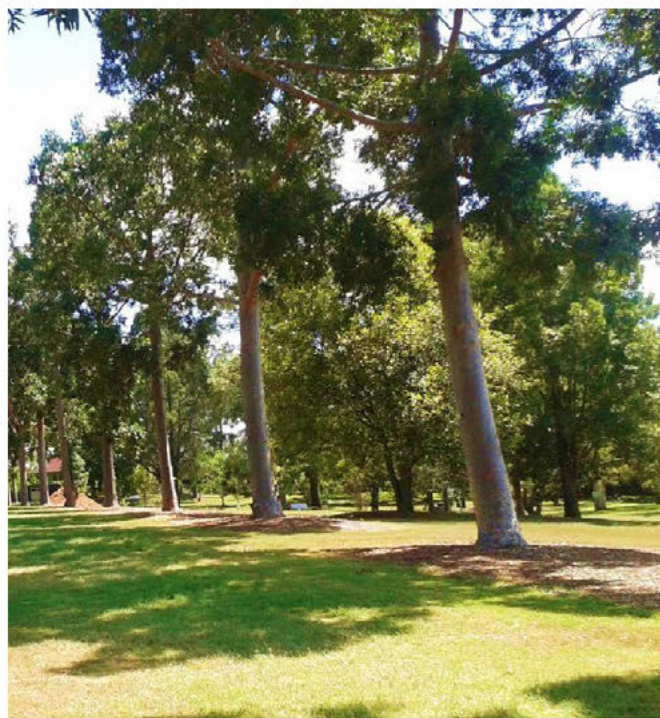


Sherwood Arboretum Kauri Pine Decline

Review and Options Paper

Water Management Team
Parks Policy & Planning and Public Space Operations
CA23/686640

April 2024



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Executive summary

The Sherwood Arboretum (Arboretum) was formed from a community and Council collaboration nearly a century ago. The Arboretum opening saw the planting of over 72 Kauri Pines by dignitaries along the Sir Matthew Nathan Avenue. The Avenue to this day presents significant cultural heritage that Council wishes to continue. Unfortunately, within the first year of planting, poor health for a significant portion of the Avenue was observed including multiple tree deaths.

The underlying conditions of the site as a wetland, have proven to be largely unsuitable for successful growth of the Kauri Pines. While the northern end of the Avenue supports well established and thriving Kauri Pines, the lower and southern side of the Avenue has resulted in poor health and several deaths over the course of time.

Due to the significance of Sherwood Arboretum, and the Kauri Avenue, Council has undertaken numerous investigations, reports, and studies to try and prevent the decline and death of the Kauri Pines in sections of the Avenue. This report brings together the results of multiple investigations and studies into the cause of the continued decline of the Kauri Pines. The main issues identified from these findings are unfavourable soil conditions including soil compaction, waterlogging and poor drainage. These problems are complicated by additional soil and groundwater imbalances that are generally not suitable for many tree species including Kauri Pines.

Three options to improve the health and vitality of the Avenue are presented that incorporate previous recommendations and contemporary understanding of the site conditions. Options include Option 1, reinstatement of the dying Kauri Pines with another juvenile Kauri Pines 4-6m. Option 2, remediation to improve the soil and drainage and support the existing stands of Kauri Pines. Option 3, mounding of the Kauri Pines was a trial started in 2014, this option is not considered a viable long-term option. Option 4, selection of a replacement species. Hoop Pine, a close relative of the Kauri Pine, is currently being investigated due to the species physical similarities with the Kauri Pine. Other potential replacement species that deserve further investigation include (but not limited to) Weeping Paperbark (*Melaleuca leucadendra*), Swamp mahogany (*Eucalyptus robusta*), or Norfolk Island Pine (*Araucaria heterophylla*).

In an effort to find a suitable new species, a healthy stand of Hoop Pines has been studied at a near-by site that has many similar historic flood episodes and soil – groundwater characteristics. Hoop Pines were once found in abundance adjacent to the Brisbane River and were logged due to their favourable timber. The form of Hoop Pines is similar to Kauri Pines, with the potential to recreate the intent of the avenue.

To remediate the land in a way that supports Kauri Pines to be healthy presents numerous risks, challenges and costs. The research indicates that even with significant soil remediation and drainage infrastructure, there is still a high risk that Kauri Pines will not thrive in some locations of the Avenue. For these reasons, this report concludes that replacing Kauri Pines when at the end of life with another species presents the best option for the Avenue. Species replacement provides an opportunity for continued scientific observation and learning of other species to adapt to the Avenue's conditions.

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1. Introduction

1.1 Background

The Sherwood Arboretum has had areas of poor health and dying Kauri Pines over its nearly 100-year history. Numerous investigations and trials have taken place to understand the decline of the Kauri Pines and options to improve their health. Soil, water and natural events including flooding appear to have impacts to the health of the Kauri Pines and have been investigated in detailed studies over numerous years. Flooding events appear to coincide with many of these events impacting the health of the Kauri Pines. Some works have been trialled including raising the Kauri Pines on mounds above the natural soil level to improve drainage in 2014.

Despite on-ground efforts to improve the Kauri Pines health, they continue to decline. Council is striving to understand the site conditions that are causing the declines, and to provide a long-term cost-effective solution.

1.2 Scope

This report aims to provide an overview of the long history of Kauri Pine decline at Arboretum, and the numerous investigations that have been conducted, summarising the possible causes of the declines and the proposed solutions. It will also provide information on the heritage considerations, which are a critical component of the final outcomes. This report can be utilised to plan actions to save, or replace the existing Kauri Pines, source budget, and seek approval from stakeholders on the recommended actions.

The outline for this work is as follows:

- Understand heritage considerations
- Understand the site context and condition
- Undertake a review of existing documentation and reports and compile into a brief summary noting the work, its outcomes and impacts
- Prepare a high level summary of actions undertaken by Council to date to manage the Avenue
- Provide management options that consider the future of Kauri Pines at the site (Figure 1) including:
 - Reinstatement of the dying Kauri Pine with another Kauri Pine
 - Remediation to improve the soil and drainage and support the existing stands of Kauri Pines (includes drainage channels, soil replacement and mounding)
 - Replacing the Kauri Pines with a different species of tree.

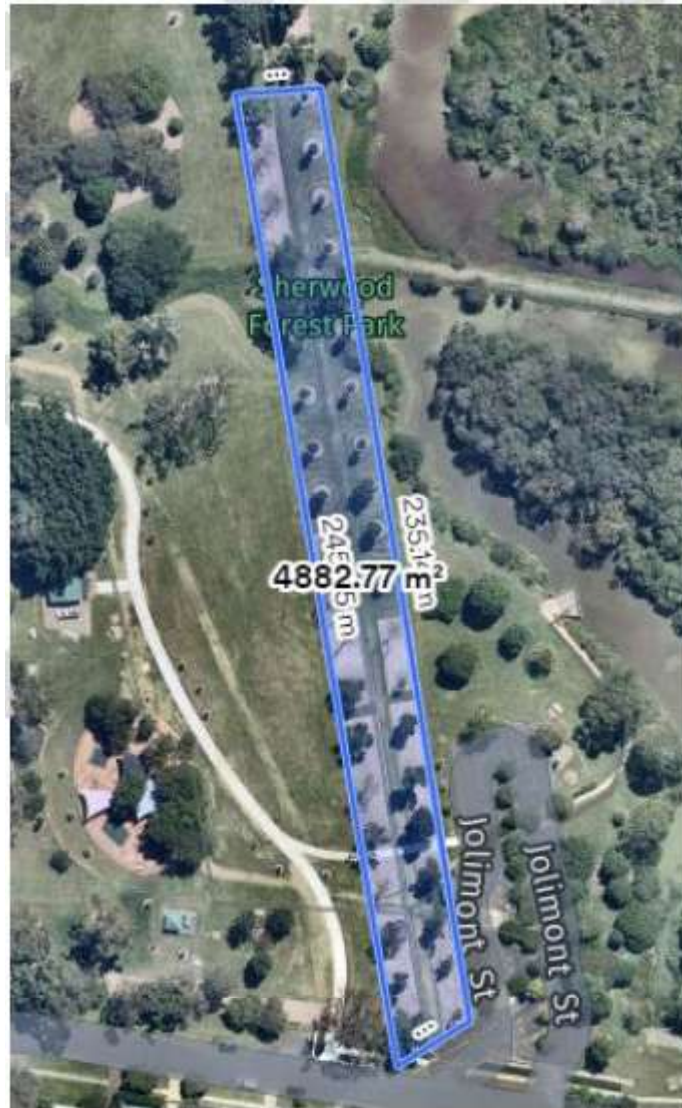


Figure 1 Map showing the remediation area.

1.3 Methodology

This paper reviews the decline of the Kauri Pines, the conditions of the site, and the relationship of these conditions and how they impact on the Kauri Avenue. As the decline is not a new problem at the Arboretum this paper has reviewed, analysed and referenced all previous studies and reports, along with updated investigations, to obtain a full and complete picture of the Avenue and what options are possible to mitigate the deaths of some of the Kauri Pines, particularly in the southern section of the Avenue.

A brief outline of the site context and conditions, including potential causes to the decline of the Kauri Pines, is presented in Section 2. The studies and reports undertaken to the site conditions are detailed in Section 3. A summary of the findings will follow in section 4 with options presented in Section 5. Section 6 will present the recommended Strategies and Actions.

The costs of the on-ground works for the investigations will not be examined as part of this report.

2. Site considerations and conditions

2.1 Considerations

The main site considerations identified include:

- Site history
- Flooding
- Species type
- Site soil conditions and groundwater
- Stakeholder consultation
- Public Utilities

Heritage values of a highly significant site, such as Sherwood Arboretum and the Kauri Avenue, is an important consideration and Council will be guided by the Conservation Management Plan (CMP), consultation with Department of Environment Science and Innovation (DESI), and the supported recommendation to preserve the Avenue. Any decisions made on the Kauri Pines need to involve consultation between Council and stakeholders including DESI, community groups and various Council departments.

The species grown in the Avenue has to be suitable for the site conditions and respect the heritage significance of the site. The species selection also needs to provide a cost-effective long-term solution to maintain the significance of the Avenue.

The site's physical constraints include existing soil properties, flooding, climatic and groundwater conditions. These conditions play a major role in the species selection and the future of the Avenue.

Public utilities are identified in the site adjacent to the Kauri Pines in the Arboretum. Figure 2 shows the public utilities within Sherwood Arboretum, where sewer (orange) approaches the Avenue in the south and water (blue) passes through in the north (Figure 2). The sewer is listed as asbestos cement with an invert level of approximately RL 3 m AHD (Relative Level (RL) of height using Australian Height Datum (AHD)) and average depth of 3.5 m. Its location would need consideration if any earthworks were planned.



Figure 2: Surrounding Utilities (BCC Gecko) – Blue = Water main, Orange = Sewer

2.2 Historical Perspective

The Arboretum was established in 1925 through a community and Council collaboration to provide a place, 'where the growth of native and other trees could be studied'. It is Brisbane's third Botanic Garden. The collection predominantly contains species from northern, central, southeast Queensland and northern New South Wales. The opening of the Arboretum saw the planting of an Avenue of Kauri Pines (*Agathis robusta*). The CMP provides a detailed historical timeline which includes any changes to the Arboretum, such as the impact of the floods. The impact of flooding at the site since the 1970's is briefly reviewed below.

The 72 trees planted along the Avenue, named after the Governor of the day, Sir Matthew Nathan, were planted by a number of dignitaries, including the Governor himself (Figure 3).

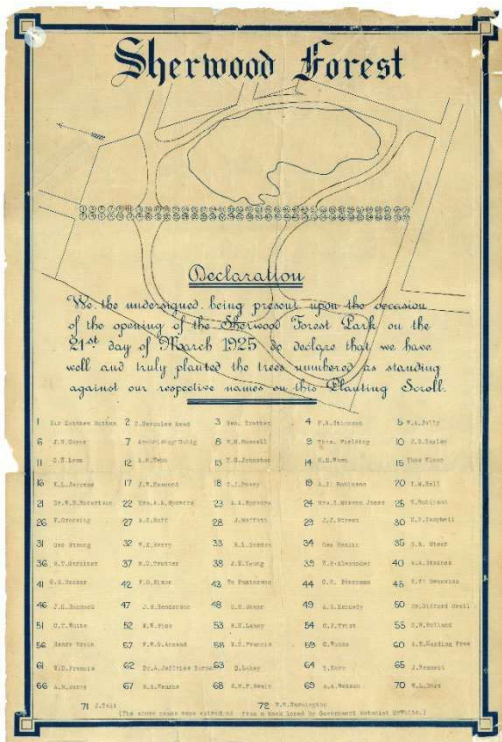


Figure 3: 'Planting Scroll' listing the people who planted the Avenue in 1925.

"A TREE PLANTING TRAGEDY."

In the Sherwood district he met much disappointment. Firstly, the newly created arboretum adjacent to the river might be aptly described as a tree planting tragedy. Nathan-avenue was the chief feature, being planted with pines throughout, two-thirds of which were dead. Between 200 and 300 trees apparently had been planted, the greater number of which were dead, whilst the remainder were just existing. No supports had been provided for the trees, some of which were 2ft. high, with stems not much thicker than a wooden match. These were blown about in all directions by the wind, and the wonder was that any were alive. The planting apparently had taken place during wet weather, with the result that the soil had set like cement around the

Figure 4 Extract from the Brisbane Courier, 29/10/1925, page 16, reporting on Mr Moore's inspection of Sherwood Arboretum.

Within the same year the Kauri Pines were planted, a newspaper article identified at least two thirds of the trees at the Arboretum had died (Figure 4). The article also noted that the trees had been planted in wet weather, and the soil around the trees had 'set like cement'.

While there was no flood recorded that year, the impact of wet weather on the site, that was mapped as a Swamp¹, was evident through the decline of a great number of trees across the Arboretum. Early mapping from 1924 shows the current wetland area as a 'Swamp' (Figure 5).

¹ The historical Swamp will be referred to as the wetland throughout this report.

2.3 Avenue Condition

The Kauri Pines at the Arboretum showed decline within the first year of being planted and their lack of suitability was even noted by the then Curator, Ernest Walter Bick. Unfortunately, a tally of the total number of Kauri Pines that have been replaced over the life of the Arboretum has not been recorded.

The declines have included the trees displaying a general lack of vigour, with reduced crown growth. The image of the dying trees in (Figure 6) is representative of the current declines including the two most recent declines that have occurred on the elevated section of the southern Avenue next to the car park.



Figure 6: Image of Typical Poor Condition Kauri Pine Tree in Sherwood Arboretum Avenue (2017)

A map is shown below in with the areas of Kauri trees healthy and in decline. Individual trees within the declining area are delineated between those that have died and those that are showing signs of stress. A larger version of the map is available in Appendix A1.

In 2014, a temporary measure, designed by Council's arborists, was to elevate the replacement trees in 'boxing' 400mm high. The boxing was removed in 2016, and the trees were placed in one metre mounds, to raise them above natural soil level (Figure 7). A total of 11 mounds were installed.



Figure 7 Trees in one metre mounds on southern lying lowing section of the Avenue.

When the Avenue is viewed from an aerial perspective, some patterns can be observed relating to the health of the Kauri Pines (Figure 8). Kauri Pines in the northern portion of the Avenue above RL 6 m AHD, and up to approximately RL 9.5 m, appear in good health as shown by the green polygon and green circles around the trees in Figure 8. In contrast, most of the trees in the southern portion are in poor condition or dead, indicated by the orange and red circles in Figure 8. The measure of elevation is therefore not a critical factor in Kauri Pine decline as declining trees in the southern portion of the Avenue are above RL 6 m, as are healthy trees in the northern portion of the Avenue.

Two Kauri Pines on either side of the northern drainage channel marker in are in relatively good health, despite being in a low-lying area. They are sited at approximately RL 5 m and have a channel to the west that may be creating locally improved drainage and / or altered groundwater conditions.

The southern most portion appear to have declined relatively recently as viewed from aerial imagery. These specimens are located at approximately RL 7 – 7.5 m.



Figure 8 Map showing the extent of Kauri Pine decline. Red indicates dead trees, unhealthy trees in orange, and healthy specimens in green (October 2023).

2.4 Flooding

The floods have brought both water and silt to the site, which, when combined with the compact soil conditions, have had a major influence on the trees in the Avenue at the Arboretum. However, these impacts have mostly been restricted to the southern end. The photo below (Figure 9) from 1976 shows the healthy northern end of the Avenue after the major 1974 flood, however not the same can be said for the southern part of the Avenue shown in the photo below in the same year (Figure 10).



Figure 9 Northern end of Sir Matthew Nathan Avenue (mid to back left of photo) in 1976 showing healthy trees.



Figure 10 Dead and dying Kauri Pines behind the wetland weir in 1976.

The tree deaths in 1976 were most likely linked to the 1974 flood. Permanent wetlands were created during 1975-76 in an area of the Arboretum that was a low-lying wetland as indicated on the 1924 map of the Arboretum area (Figure 5).

In 1997 a master plan identified the low-lying area of the Avenue had four trees that needed replacing and an additional seven that had already been removed due to poor condition.

The next major impact came from flooding in 2011. This flood saw the low-lying areas of the Arboretum inundated for six days with a metre of silt and debris being deposited across the site. This event resulted in the death, and subsequent removal of eight Kauri Pine trees. Heavy machinery was employed to remove the silt and debris.

In 2017, following cyclone 'Debbie', the area was flooded again (Figure 11). An additional Kauri Pine declined and needed to be replaced as a result. This pine was replaced as a mounded tree in 2018, bringing the total number of mounded pines to 12.

The most recent flood in 2022 saw the Arboretum inundated up to a depth of 3m over a few days. A total of seven Kauri Pines have shown decline following this flood. Above average rainfall both before and following this flood, have led to more Kauri Pines declining.

In late October 2023, 8 dead Kauri Pines were replaced, to improve the presentation of the Avenue.



Figure 11 Low lying area of the Avenue during the 2017 flood (Source: Andrew Benison, FOSA).

A summary of the extents of the 3 largest floods is presented in Figure 12. The 1974 flood is recorded having the largest extent, followed by 2011 and 2022, all of which inundated the whole of the Avenue including the healthy stand reaching an RL of approximately 10m AHD.

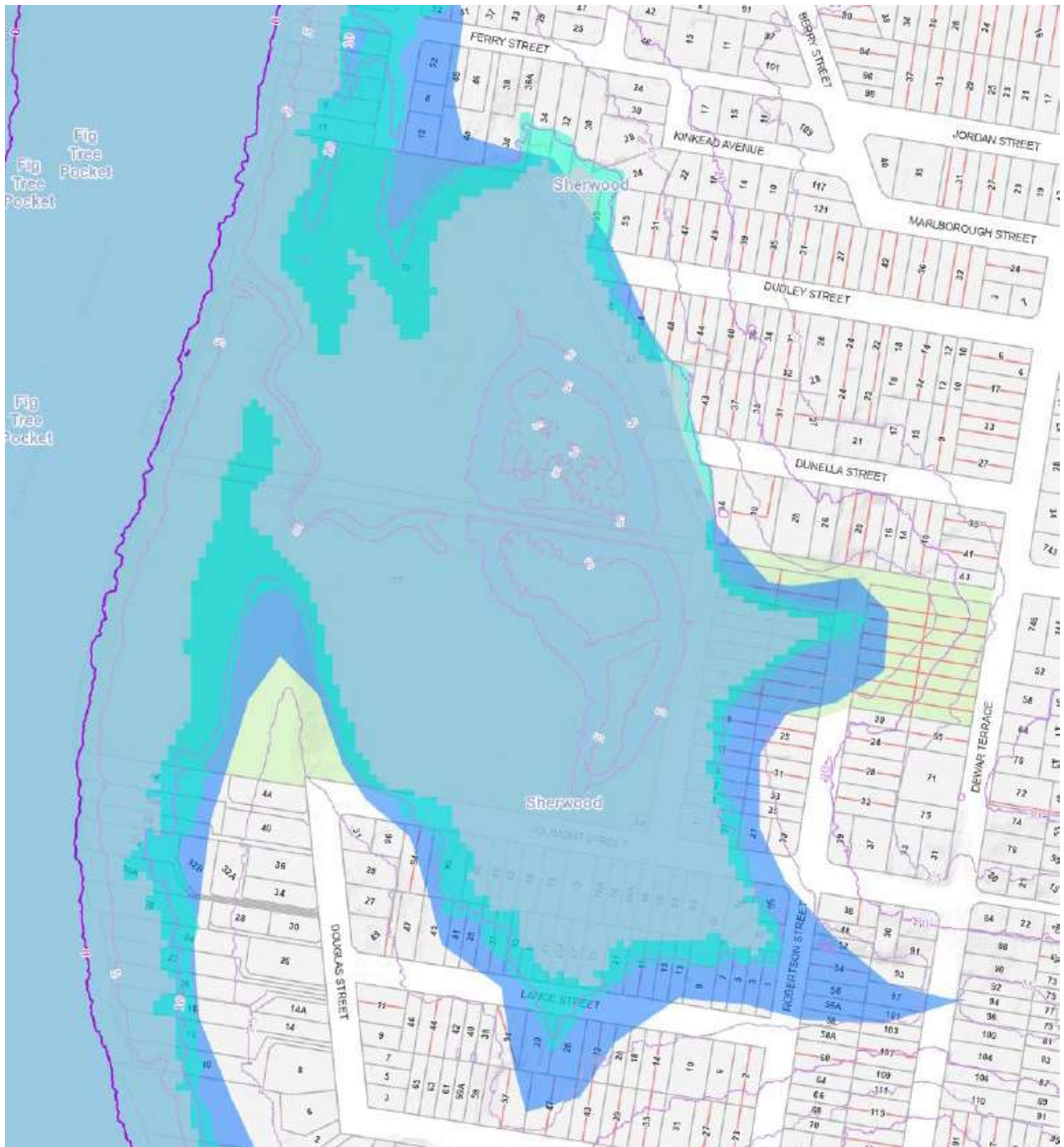


Figure 12: Major Historic Flood Events (Largest to smallest - 1974, 2011, 2022)

3. Site Investigation Literature Review

3.1 Background

Technical studies have been commissioned since 2015 to understand the underlying issues causing the decline in health of the Kauri Pines. The studies have been reviewed and summarised in this report under two broad categories:

- Horticultural and Arboricultural Science investigations focusing on assessing the health and management of the Kauri Pines; and
- Soil and Ground Water studies investigating soil chemistry, geotechnical borelogs and groundwater levels and chemistry.

While the declines of Kauri Pines have been observed for decades, the first on-site remediation trials were undertaken with boxing and mounding in 2014 and 2016. The first iteration of the trial began with the Kauri Pines in 'boxes'. A more aesthetic solution was to place the trees in mounds that could then be turfed. Around the time of these trials, investigations into the trees' health and soil conditions commenced.

Previous reports and background studies have been reviewed and used in the preparation of this paper. Those studies form a vital part of the analysis of the Arboretum and provide an understanding of the issues, risks and opportunities that support the options presented in this paper.

Additional documents briefly reviewed but not summarised are provided below for reference only.

1. Sherwood Waterbody Management Plan – CPO 2021 - [PD21/75954](#)
2. Sherwood Forest – Opportunities plan – CPO 2022 - [CA22/769892](#)

3.2 Horticulture and Arboriculture Reports

Horticulture and arboriculture reports have been commissioned to analyse the health of the Kauri Pines. Summaries of the following reports are presented in relation to Tree Condition and Management Actions in the following section. The reports summarised are:

1. 2015 – Asset Horticultural Consultants – *Soil Test Results and Recommendations: Sherwood Arboretum* – [CA22/1249352](#)
2. 2017 - ENSPEC Environment & Risk - *Ground Penetrating Radar Report – Sherwood Arboretum* – [CA22/1249369](#)
3. 2022 – The Tree Doctor – *Tree Inspection Report* – [CA22/1247945](#)

3.2.1 Tree Condition

Each of the reports concluded that the southern half of the Avenue had trees in poor health with reduced canopy. Several types of root rot and collar rot were identified. In the Tree Doctor (2022), five trees were found to be in severe decline with symptoms that show vascular wilt infections, i.e., necrotic (dying), marcescent (withering) and epinastic (bent) foliage.

The symptoms demonstrated by the unhealthiest trees are consistent with root rot. *Phytophthora* root rot was found in the roots of the Kauri Pines (Asset Horticultural Consultants, 2015) which are known to be prone to this disease, but is generally not a problem in well drained soils.

Other types of root rot may also be present, although the test kits have not identified a particular fungal species, however it is most probably cinnamon fungus (*P. cinnamomi*), common in Brisbane soils (Asset Horticultural Consultants, 2015). In New Zealand, trial work is being carried out using injections of phosphorous acid to

control a similar disease in *Agathis* plantations. In Australia, tree injection is common practice in fruit orchards and is very successful. Soil treatment using specific fungicides is also effective. With both methods, treatment is ongoing.

Collar rot was evident from increased soil levels due to excess mulch, flood alluvium and excess water (The Tree Doctor, 2022).

Ground Penetrating Radar analysis was undertaken in 2017 by ENSPEC who surveyed 6 trees (ENSPEC Environment and Risk, 2017). The number of trees surveyed was limited due to unfavourable weather conditions at the time. The survey focused on the trees in the lower section of the Avenue just north of the gully on the west side (Figure 13) and identified:

- The trees had roots at 5 cm to 65 cm depth that were less than 10 cm in diameter
- The roots did not extend more than 3 - 4 metres from the centre of the tree.

Without comparative results from within the healthy stand, limited conclusions can be drawn about how the tree roots are impacted by the ground conditions. An Arborist was not able to provide any conclusions from this information, however, provided general advice to indicate that the extent of the roots is perhaps limited based on the size of the tree.



Figure 13: Area surveyed using Ground Penetrating Radar

Figure 14 shows an extract of the outputs of the radar. The image shows roots between 5 – 65 cm below for trees 5 (Left) and 4 (Right). Most of the roots are less than 5 cm (Green), whilst some are 10 cm (Yellow).

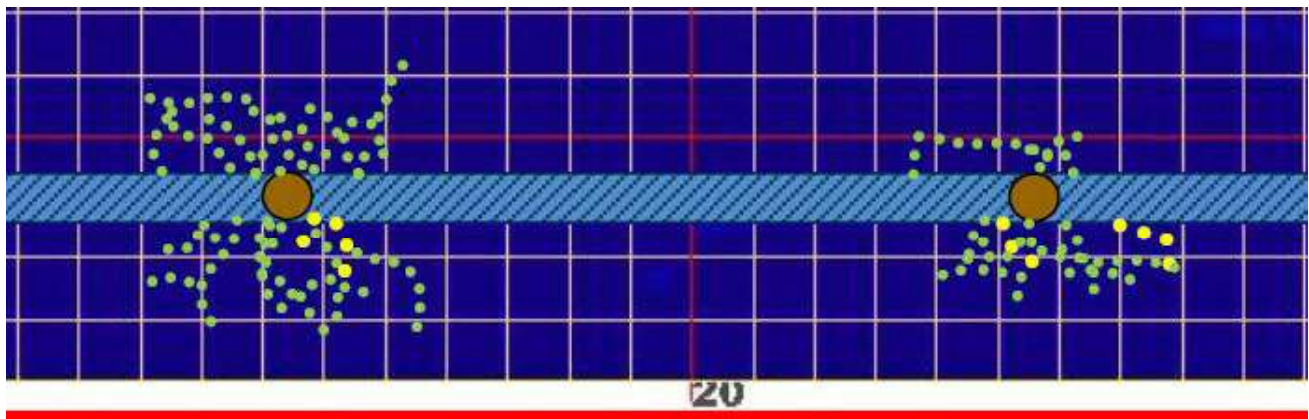


Figure 14: Typical results showing roots between 5-65 cm with an average size of 5 cm (Green), and some at 10 cm (Yellow). Grid size is 1 m.

3.2.2 Soil Conditions

The Tree Doctor (2022) identified two main problems associated with mulch and drainage. The report's findings and recommendations advised:

- Mulch based on Eucalyptus and hardwoods should not exceed 50-75 mm as this has been found to be detrimental for soil and tree health
- Mulch used on site should be coarse with a particle size of 25 mm
- The mulch around the root crown was excessively deep and very wet and black in colour – appears to be applied to schedule rather than as required
- Design and install an effective positive flow subsurface drainage system – to efficiently remove excess water and improve soil aeration
- Adjust levels around all Kauri Pines, where required, to remove all soil and mulch to expose root crowns at natural level to a minimum 500 mm radius. Works should be performed using an 'Air Spade' mechanical excavation will result in damage to the root crown and inner root system
- Do not plant replacements until the drainage issues are resolved
- Do not apply additional mulch- let mulch decay (only remove if necessary) aerating mulch with an 'air spade' could provide benefit
- Do not apply fertilisers - tests show no significant deficiencies. Excessive nutrients (particularly nitrogen) will benefit anaerobic pathogens and water moulds, e.g. vascular wilts.

Drainage notes were provided that included;

- Poorly drained in the lower area of the Avenue – most probably waterlogged in some places
- Raised water table – potentially the primary cause for this is the water level in the wetlands
- Wetter areas are not the natural profile and are affected by the presence of fill and compaction
- Any subsurface remedial works will be ineffective if the drainage is not corrected
- Aeration of the soil while it is saturated or above field capacity will have no beneficial effect.

Council has been undertaking aeration by air spading since 2015 and will continue this practice. The mulch and fertiliser issues identified in this report are being incorporated into the ongoing maintenance of the Kauri Pines.

3.3 Soil and Groundwater Analysis

Five studies have been undertaken to assess the soil and groundwater conditions between 2017 and 2024. Soil and groundwater have been assessed together. The difference in the health of the Kauri Pines from the southern

to the northern ends of the Avenue reflect the variance in ground conditions. This section will provide a detailed description of the outcomes of the reports undertaken to date.

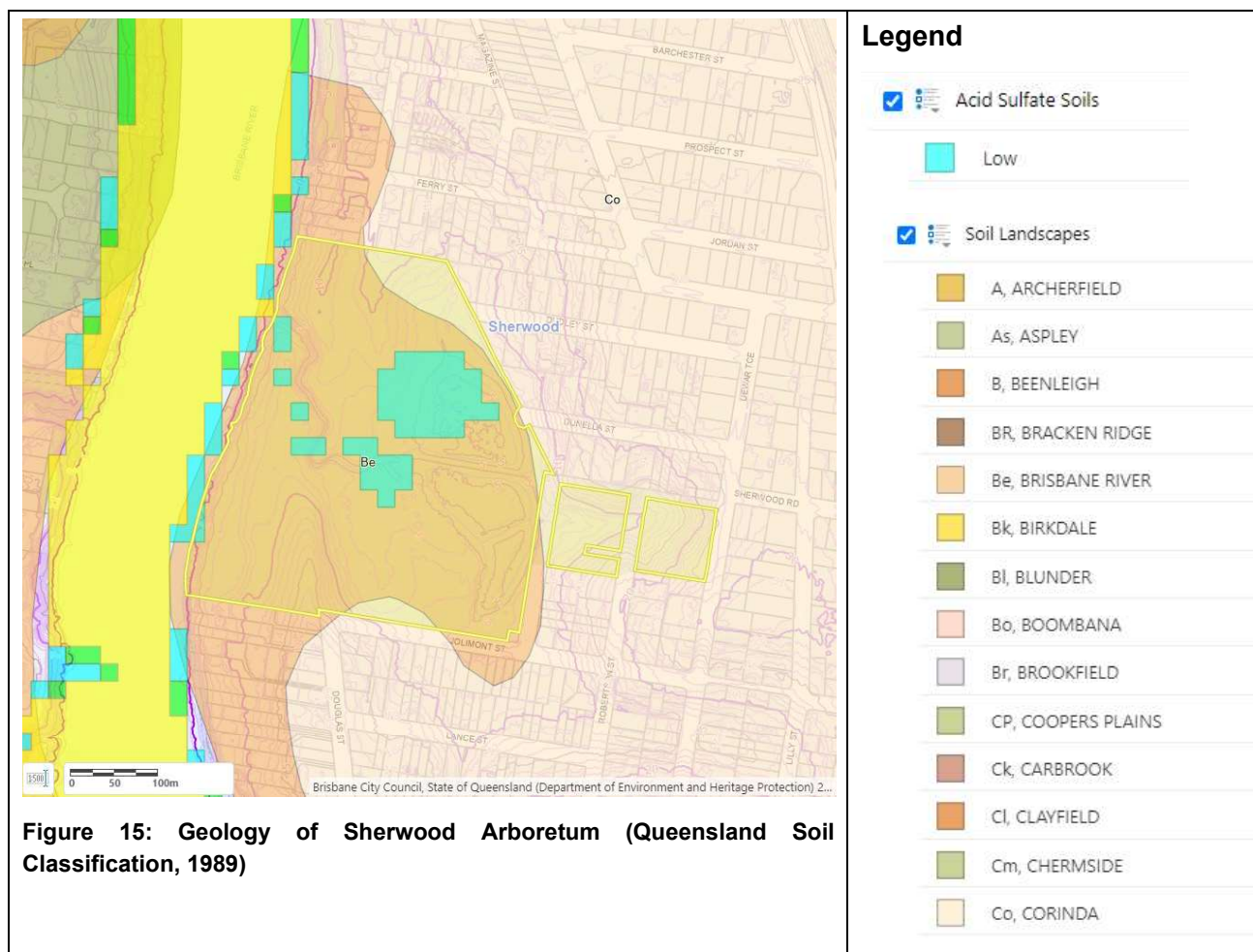
The following reports have been completed for the Sherwood Arboretum.

1. Dec 2015 – *Soil Test Results and Recommendations: Sherwood Arboretum*, Asset Horticultural Consultants. Document Reference: [CA22/1249352](#)
2. May 2017 – *Sherwood Arboretum hydrological characterisation of Soils* – University of Queensland Sustainable Minerals Institute. Document Reference: [CA22/1249338](#)
3. June 2017 – *Sherwood Arboretum Groundwater Characterisation* – BCC, City Projects Office. Document Reference: [CA22/1249362](#) (Appendix B1)
4. June 2022 – *Soil Investigation Report Following Kauri Pine Death* – Sherwood Arboretum, Heritage Tree Care. Document Reference: [CA23/1238901](#)
5. June 2023 – *Factual Report – Monitoring well installation*, Sherwood Arboretum and Oxley Creek Common – BCC, City Projects Office. Document Reference: [CA23/689349](#) (Appendix B2)
6. Feb. 2024 – *Factual Report* – Sherwood Arboretum and Oxley Creek Common groundwater logger and water quality analysis - BCC, City Projects Office. Document Reference: [CA24/315619](#) (Appendix B3)

3.3.1 Site Geology

Queensland geological mapping indicates that the site's underlying geology consists of Holocene aged alluvial deposits. The deposits mainly consist of silt, sand and clay gravel. Many of these deposits are heavily influenced by the Arboretum's location adjacent to the Brisbane River. The area of interest in the Arboretum with poor Kauri health has a RL of around 5 m to 6 m AHD. The mapping also shows areas of Acid Sulphate Soils, particularly where the levels are near 5 m or below (Figure 15). This indicates that the Acid Sulphate Soils have the potential to influence the Kauri Pines in the low-lying areas of the Avenue.

Historical mapping of the area show that the site has long been a wetland (Figure 5). The nature of the wetland was likely to be quite different to the current wetland, however little information was found about this. The wetland was unlikely to have a permanent water body, but rather a low-lying depression based on the map from 1924 (Figure 5).



3.3.2 Soil Results

Borelogs and analyses were undertaken by CPO in 2017 along the Avenue where the Kauri Pines have been in decline. This study provided detailed information about the chemical and physical properties of the soils and groundwater characteristics over a 6-month period. In summary, the results indicate that the soil largely consists of approximately 0.8 m of sandy clay topsoil over alluvium consisting of silty and sandy clays. This is consistent with the Land Zones of Queensland mapping (Figure 15). The full Groundwater Characterisation report from 2017 is provided in Appendix A2 for reference including a map of the borehole locations.

Further soil characterisation was undertaken in 2023 to better understand the differences between the healthy and unhealthy stands of Kauri Pine. Table 1 displays a summary of the field observations indicating that the compositions appear to be physically similar to one another. Borehole BH01/23 was located within in the southern (unhealthy) portion of the Avenue, whilst BH02/23 was located in the northern (healthy) portion of the Avenue. A map of the borelogs can be found in the report in Appendix B1.

Table 1: Soil Field observation summary 2023 (BH01 located in southern portion of Avenue, BH02 located in northern portion)

Borehole / Monitoring well ID	Depth (m BGL)	Material description	Groundwater encountered (m BGL)
BH01 / MW01/23 (Sherwood arboretum)	0 – 0.2	Fill: sandy silt, firm to stiff, dry	
	0.2 – 6.2	Natural: silty clay with organic material, very stiff to hard, dry to moist	6.2
	6.2 – 8.1	Natural: silty clay with jarosite, very stiff to hard, wet layer then moist to end of hole.	
BH02 / MW02/23 (Sherwood arboretum)	0 – 0.3	Fill: sandy silt, firm to stiff, dry	
	0.3 – 4.1	Natural: silty clay with organic material, very stiff to hard, moist	4.1
	4.1 – 6.0	Wet between 4.1 – 4.4	

Soil permeability tests indicate the clay soil found at the site is heavily compacted and has limited soil structure, leaving minimal voids for air and water to pass (Brisbane City Council, CPO, 2017). Due to this, trees find it hard to penetrate as shown by the limited root development in the ground penetrating radar results. Kauri Pines are generally found in deep well drained soils and are therefore not well suited to the hard clay conditions found at the site (The Gymnosperm Database, 2023).

Soil results also present several potential chemical challenges to trees including sodic and acid sulphate soils. Not all the borelogs contained these properties, however several of the lower lying borelogs did (Brisbane City Council, CPO, 2017).

Asset Horticultural Consultants (2015) reported that pH, electrical conductivity (EC), phosphorus, calcium, aluminium, exchangeable sodium and trace elements were all in satisfactory ranges. Some aspects of the soil were not within ideal ranges including organic matter (relatively high in topsoil), low permeability. No treatment to the subsoil was recommended by the consultant based on this testing.

In 2017, the Sustainable Minerals Institute undertook an analysis of the soil to investigate the soil / water relationship. The outcome of the study found that although the soil has a relatively high level of saturation, due to the soil structure the plant effectively finds the soil 'dry'. This is because the soil holds on to the water so tightly the plant can have difficulty extracting it. If drainage was to be installed, there is a risk of making it even drier for the trees. Therefore, to improve the drainage, soil remediation may also be required to achieve the right balance.

Soil tests were undertaken in the healthy and unhealthy tree stands in 2023 to better understand the differences. BH1/23 shows several parameters out of typical ranges, including low calcium, high to very high magnesium, very high sodium levels and strong sodicity. BH2/23 shows more typical ranges for pH, calcium, potassium, sodicity for example. Some soil chemical parameters in the healthy stand are also outside the range of typical soils. For example, similarly high levels of electrical conductivity were found in the healthy and unhealthy stands of trees at a depth of 0.8 m – 1 m. Some key differences of note are the higher exchangeable sodium in BH1 and the presence of higher concentrations of calcium in BH2. Table 2 below presents values at locations BH1 and BH2 compared to guideline values. Further documentation about the recent borelogs and soil information from June 2023 is provided in the Factual Report located in Appendix B1.

Table 2: Soil Analysis Results June 2023

Date	Location	Analyte grouping/Analyte	Unit	06/06/2023 BH01_0.3-0.5	06/06/2023 BH01_0.8-1	06/06/2023 BH01_1.8-2	06/06/2023 BH01_2.3-2.5	06/06/2023 BH02_0.3-0.5	06/06/2023 BH02_0.8-1	06/06/2023 BH02_1.8-2	06/06/2023 BH02_2.8-3	
EA002: pH 1:5 (Soils)												
pH Value			pH Unit	Strongly acid	Strongly acid	Neutral	Mildly alkaline	Slightly saline	Extremely s	Moderately s	Mildly alkaline	
				5.5	5.4	7.1	7.6	7.3	5.8	8.2	7.7	Guideline 5.5-7.5
EA010: Conductivity (1:5)												
Electrical Conductivity @ 25°C			µS/cm	Non saline	Non saline	Moderately s	Highly saline	Slightly saline	Extremely s	Highly saline	Slightly saline	
				61	111	589	986	141	1440	626	217	240-560
ED005: Exchange Acidity												
Exchange Acidity			meq/100g	8.2	5.9	----	----	----	<0.1	----	----	
Exchangeable Aluminium			meq/100g	7	4.5	----	----	----	<0.1	----	----	
EA005: Exchangeable Cations												
Exchangeable Calcium			meq/100g	4.4	2.8	3.4	3.1	16	10.5	10	9.6	Low Ca
Exchangeable Magnesium			meq/100g	7.9	9.7	10	7.1	10	13.3	7.9	6.7	High Mg
Exchangeable Potassium			meq/100g	0.3	0.3	0.2	<0.2	0.4	0.2	0.4	0.6	Low to v low K
Exchangeable Sodium			meq/100g	1.6	2.9	3.1	4.4	3.2	2.8	3.2	1.6	High Na
Cation Exchange Capacity			meq/100g	22.4	21.6	18.6	14.8	29.8	10.5	21.5	18.5	High CEC
Exchangeable Sodium Percent			%	11.5	18.3	0.3	29.7	10.9	0.8	14.9	8.8	Strongly sodic
Calcium/Magnesium Ratio				0.6	0.3	16.9	0.4	1.6	26.8	1.3	1.4	Ca deficient
												Sodic
												Low calciu

Hazelton and Murphy, 2007

3.3.3 Groundwater

Groundwater level and quality was monitored in 2017 over approximately 6 months and again in June 2023 until June 2024. Similar but different locations are used between the two monitoring periods. Monitoring was undertaken by City Projects Office staff. The interactions between the soil, groundwater and Kauri Pines are complex. There are groundwater quality parameters out of range particularly in lower lying areas providing concern for impacts to the health of the Kauri Pines. The following section provides a discussion and summary of the results. Locations of groundwater bores from 2017 are shown in Appendix A1. Groundwater results from 2023 are in Appendix B2.

Ground water levels in 2017 are shown to be approximately 1.5 – 2.5 m below soil surface for the lower and unhealthy sections of the Avenue, whilst closer to the healthy section, levels were approximately 4 m below (Brisbane City Council, CPO, 2017). Locations of groundwater bores from 2017 are shown in Appendix A1. Groundwater levels from June 2023 until February 2024 show ground water levels for the unhealthy stand at approximately 3.7 m below soil surface and 2.5 m below for the healthy section (Refer to Appendix B2). Importantly, the results show that following high rainfall periods in February 2024, the groundwater level does not vary significantly.

When groundwater level and rainfall are juxtaposed in a graph, the levels appear to respond to rainfall (Brisbane City Council, CPO, 2017). Wetland water surface levels mimic fluctuations in groundwater levels, although this is only a correlation and insufficient information to confirm a direct link as both respond to rainfall. Groundwater level was recorded using data loggers.

Some borehole locations in 2017 recorded very high electrical conductivity (EC) levels, mainly BH5/16 near the carpark. Similar levels of EC were found in 2023 at BH01/23 at approximately the same location. The EC found in BH5/16 and BH01/23 are 12 times the allowable limits of irrigation waters and are classified as saline. The readings were found to be 30100 $\mu\text{S}/\text{cm}$ (February 2017), 28120 $\mu\text{S}/\text{cm}$ (June 2023) and 33293 $\mu\text{S}/\text{cm}$ (February 2024). Brackish water is generally categorised as between 500 – 30,000 $\mu\text{S}/\text{cm}$. Irrigation water is required to be lower than 2500 $\mu\text{S}/\text{cm}$.

Similar EC levels were recorded in 2017 for areas north of BH05/16 and extending into the healthy stand. BH01/16, BH02/16, and BH03/16 recorded 2980, 4960 and 3960 $\mu\text{S}/\text{cm}$ respectively. These EC levels are therefore still above irrigation water agricultural guideline values for most plants. BH01/16 and BH02/16 are located in the lowest area in the unhealthy stand, and BH03/16 is located in the healthy stand slightly up the hill on the northern side of the avenue. These levels are comparable within healthy and unhealthy stands. Similar results for June 2023 and February 2024 were recorded indicating that EC levels are not significantly changed or impacted by rainfall. A detailed spreadsheet of the results can be found in Appendix B3.

The EC for the wetland was found to be 390 $\mu\text{S}/\text{cm}$, which is well below the irrigation water level of 2500 $\mu\text{S}/\text{cm}$ and is therefore not the source of the issue (Brisbane City Council, CPO, 2017).

High levels (20,400 and 29,300 $\mu\text{S}/\text{cm}$) of EC were also found in the stand of Hoop Pines recently tested at the Oxley Common, Secret Forest Site. This site has been investigated to assess the suitability of Hoop Pines as a potential replacement species. Interestingly, the hoop pines appear to be in good health according to the Heritage Tree Care report (2023). Further to this, the stand appears to be still present in the 1946 aerial (Figure 16). Additional information on this site is provided in Section 3.4.

During prolonged periods of rainfall and flooding situations, the water level in the monitoring wells effectively raises to the surface. Highly saline groundwater could be saturating the soil during very wet times, causing salinity health issues for the Kauri Pines.

There is a potential risk that high EC groundwater migrates up through the soil profile, causing health issues within the unhealthy stand of Kauri Pines. The dense clay soil will limit the migration of groundwater through the soil profile, however, over time the sodium may be transported by wicking up through the profile and deposit in the soil if the rainwater cannot dilute and assist leaching fast enough.

Investigations into the cost of improving both the soil and the drainage was undertaken in 2017 by City Projects Office, Water Management Team. The design proposed several drainage changes including removing the existing culverts between the wetland and the channel, and longitudinal under drainage for the trees. The design also included the remediation of soil. The summary report and design can be found with the following document references.

- WTM Memo – Sherwood Arboretum Concept Environmental Engineering required for tree protection – CPO 2017 [CA22/1312890](#)
- WTM Drawings – Proposed Kauri Avenue drainage design – CPO 2017 [CA22/1312893](#)

The Sherwood Arboretum Groundwater Characterisation Report (2017) also provided remediation recommendations and comments. The report cautioned that the replacement of existing soil with more permeable soil may allow groundwater to rise higher and essentially not result in an effective change of soil moisture. That is, the soil moisture and salinity could wick up into the remediated soil.

These design options would also have very high site impacts. The soil replacement and drainage option would require over 600 truckloads of soil to be moved off, and onto the site. This option presents a high-risk, high cost and high impact design option, and is therefore not viewed as a recommended, cost-effective solution to the issues at the Avenue.

3.4 Oxley Common - Secret Forest Site

An option to mitigate the loss of Kauri Pines is using an alternative species. Hoop Pines have been identified as a potential alternative species to the Kauri Pine. To confirm this, Council has been undertaking soil and groundwater testing at a stand of Hoop Pines located within Oxley Common, known as the Secret Forest. The Secret Forest is located approximately 2.5 km SW of Sherwood Arboretum within a meander of Oxley Creek, refer to Appendix A3 for a map.

Figures 13 and 14 indicate the location of the Hoop pines and show the population has progressed well over the years. The Hoop pines were planted at the site around the same time as the Kauri Pines, but have not shown any losses, despite facing a similar flooding regime as the Arboretum.



Figure 16 Hoop pines at the Oxley 'Secret Forest' in 1946

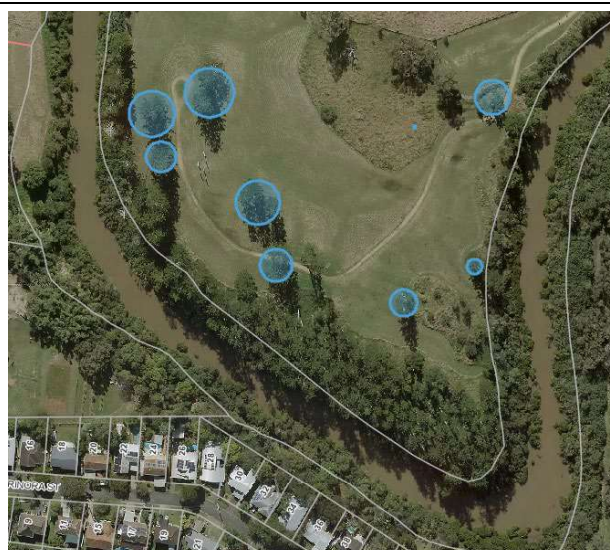


Figure 17 Hoop pines at the Oxley Secret Forest - 2023.

The stand of trees is located adjacent to brackish water, similar to the conditions at the Arboretum. Land elevations are similar but lower to those found at the Arboretum, with surface elevations of between 2 – 4 m AHD, whereas at the Avenue, the elevations range from 5.5 – 7 m within the southern section and up to 9 m AHD in the north.

Studies undertaken include:

1. 2023 - Heritage Tree Care - *Oxley Common Secret Forest* - ([CA23/622129](#)). The report investigates the soil around the Hoop Pines at the Secret Forest and compares them to the soil at the Avenue.
2. 2023 – Brisbane City Council, Contaminated Land Services - *Factual Report – Monitoring well installation, Sherwood Arboretum and Oxley Creek Common* - ([CA23/689349](#)).

In 2023, Heritage Tree Care reported that the Hoop Pines were in good health despite being inundated with similar flood regimes to the Avenue. Reports have confirmed that the trees have “crowns have moderate to full crown size with density ranges from average to dense. No dieback was noticed.”

Soil samples from the Secret Forest were compared to those found at the base of a recent Kauri Pine death (Heritage Tree Care, 2023). High levels of Magnesium, Manganese and Iron were found at both sites. Nitrogen and Phosphorus compounds were found to be similar but below Agricultural ranges. Sodium levels were lower at the Secret Forest resulting in lower EC than around the failed Kauri Pine. The main differences in chemical properties between the two sites is that the Avenue had higher, and out of range elements of Sulphur and Exchangeable Sodium. Table 3, Table 4 and Table 5 show a summary of the results from the Avenue and the Secret Forest.

Table 3: Comparison of main soil parameters (Heritage Tree Care, 2023)

	Sampling date	2021	2023	2022	Agricultural	
		Calculated averages			Guidelines	
Soil Parameters	Units	Sherwood	Secret Forest	Failed Kauri	Light Soil	Heavy soil
Cation Exchange Capacity	cmol+/kg	16.30	25.25	21.00	7.80	20.10
pH	pH units	6.61	6.21	6.70	6.30	6.50
Estimated Organic matter	%OM	4.07	6.44	4.10	3.50	5.50
Conductivity (EC)	dS/m	0.06	0.09	0.46	0.12	0.20

Table 4: Comparison of macro-element contents (Heritage Tree Care, 2023)

		Sampling date	2021	2023	2022	Agricultural	
			Calculated averages			Guidelines	
Macroelements 1/2	Element	Units	Sherwood	Secret Forest	Failed Kauri	Light Soil	Heavy soil
Soluble Calcium	Ca	mg/kg	1197.86	1371.38	1031.00	375.00	1150.00
Soluble Magnesium	Mg	mg/kg	334.76	527.63	518.50	60.00	160.00
Soluble Potassium	K	mg/kg	109.44	95.38	154.00	60.00	112.50
Macroelements 2/2	Element	Units	Sherwood	Secret Forest	Failed Kauri	Light Soil	Heavy soil
Soluble Phosphorus	P	mg/kg	7.42	3.48	10.50	10.00	15.00
Nitrate Nitrogen	NO3-	mg/kg	5.81	4.51	2.04	10.00	15.00
Ammonium Nitrogen	NH4+	mg/kg	2.44	4.29	11.85	15.00	20.00
Sulfur	S	mg/kg	6.47	10.05	37.00	8.00	10.00

Table 5: Comparison of micro-element contents (Heritage Tree Care, 2023)

		Sampling date	2021	2023	2022	<i>Agricultural</i>	
			Calculated averages			<i>Guidelines</i>	
Microelements	Element	Units	Sherwood	Secret Forest	Failed Kauri	Light Soil	Heavy soil
Zinc	Zn	mg/kg	4.86	20.56	3.85	4.00	6.00
Manganese	Mn	mg/kg	21.25	68.50	46.00	18.00	25.00
Iron	Fe	mg/kg	111.06	123.50	176.00	18.00	25.00
Copper	Cu	mg/kg	2.06	3.24	1.35	1.60	2.40
Boron	B	mg/kg	0.91	0.96	0.86	1.40	2.00
Silicon	Si	mg/kg	66.78	72.88	41.00	40.00	50.00
Exchangeable Sodium	Na	mg/kg	61.97	116.13	515.50	51.00	69.00

Results from 2023 have shown that ground water levels at the Arboretum are comparable to those at the Secret Forest. Table 6 displays the Surface Water Level (m) or the meters Below Top Of Casing (mBTC), effectively the distance from the top of the well to the water. The results indicate that Hoop Pines are able to withstand similar groundwater conditions to those found within the Avenue, making them a good replacement species candidate. Further results showing daily recordings in a graph from June until November 2023 can be viewed in Appendix B3.

Table 6: Summary of Standing Water Level (SWL) at times of Monitoring

Well ID	Date	Time	SWL (m BTC) (m)
MW01-23 (Sherwood South)	12/06/2023	12:30	3.69
	25/08/2023	10:00	3.653
MW02-23 (Sherwood - North)	12/06/2023	12:50	1.96
	25/08/2023	10:30	2.075
MW03-23 (Secret Forest East)	12/06/2023	14:30	2.95
	25/08/2023	11:30	1.845
MW04-23 (Secret Forest West)	12/06/2023	14:45	2.99
	25/08/2023	11:45	2.445

4. Summary

The following are key points from the review of the investigations that Council has undertaken:

- There is a clear distinction between the unhealthy and healthy stand of trees shown in the landscape. The issue appears to be related to the soil and the groundwater.
- Unhealthy trees have shown signs of Phytophthora root rot. However, as there is a healthy stand of trees adjacent to the unhealthy, it appears that with suitable conditions, the trees grow to the mature size.
- Tree management practices of providing too much mulch may have impeded the success of the trees but could not be attributable to the overall decline of the trees.
- Most arboricultural studies have assumed that poor soil and drainage have contributed to poor health.
- Kauri Pine trees are unsuited species for regularly inundated areas and those with high water tables. Queensland Kauri Pine trees both in the wild and planted specimens around Brisbane are typically located in higher elevation zones which allow for free draining soils unlike the regularly inundated heavy clay soils found within the lower sections of Sherwood Arboretum.
- Significant differences between the soil and groundwater results were recorded between the stand of healthy and unhealthy Kauri Pines. Further analysis is required by soil scientists.
- The groundwater in the healthy and unhealthy stand were well above irrigation standards for electrical conductivity by up to 15 times. In some areas, the groundwater was found to be saline.
- Ground water conditions at the Secret Forest were also found to have a high electrical conductivity and to be high in sodium. The Hoop Pines at the Secret Forest appear to have remained healthy in similar conditions to those at The Sherwood Arboretum.
- Varying climatic conditions, with wet weather and flooding having been recorded on site is possibly one of the key impacts for the Kauri Pines.
- Drainage options have also been investigated. While drainage alone may reduce waterlogging conditions, without soil remediation no improvement to the health of the Kauri Pines would be expected. Additionally, during drier and drought weather patterns, water would be encouraged to migrate away from the trees, potentially resulting in stress from insufficient water. The impact of draining free water from the soil profile may also increase movement of water from the wetland, a key feature of the Arboretum. This would be a costly option with unpredictable results and broader site impacts.
- Soil remediation and drainage is not a guaranteed to improve the health of the Kauri Pines, comes at a substantial cost, and would have major impacts on the Arboretum and surrounding community.
- Council's arborists have been carefully working to improve the health of the Kauri Pines through their management practices. These actions include:
 - Soil aeration (air spading) since 2015
 - Improving mulching techniques including widening the mulched area to reduce the impact from the mowing equipment
 - Mechanical aeration and top dressing of the Avenue walkway
 - Mounding the Kauri Pines soil decompaction on lower Avenue with VOGT Geo Injector

Council has been managing the Avenue and collection at the Arboretum for almost 100 years. Kauri in the southern section have continued to fail and ultimately die since 1925. With more knowledge of the site conditions, it has been determined that due to the soil and groundwater conditions, Kauri Pines in this section will continually not thrive. The testing has also shown that soil remediation and drainage improvements are not likely to improve the health of the Kauri Pines. These options are also at risk of altering the form, function, and historical value of the Arboretum. There is an opportunity to use years of investigation and management as an educational opportunity at the Arboretum.

5. Options

Engaging with the community and stakeholders will be a critical component to delivering the approved options.

Stakeholders include:

- Department of Environment, Science and Innovation (DESI)
- Friends of Sherwood Arboretum (FOSA)
- Bushcare group
- Public Space Operations
- Council's internal stakeholder teams

A Heritage Exemption will be required for any changes to the Avenue and the Kauri Pine trees.

Based on recent investigations, combined with previous reports and studies regarding the decline of the Kauri Pines, three options are presented to determine and recommend a way forward. In summary, the options are;

Option 1 – Reinstatement of Kauri Pines – This option involves replacing the existing Kauri Pines with new Kauri Pines as they die.

Option 2 – Soil and drainage options to support Kauri Pines.

- Option 2.1 – Drainage Channels – Includes 2m wide soil replacement along the length of the affected Avenue and installation of drainage.
- Option 2.2 – Soil replacement and Drainage channels – Involves a full soil replacement to the width of the affected Avenue of trees and installation of drainage. This option would involve the temporary removal and replacement of trees.

Option 3 – Mounding of Kauri Pines – Involves raising of the trees onto mounds to improve drainage and the immediate soil quality around the trees.

Option 4 – Species Replacement – This option presents a contemporary view of the site by retaining the Avenue through an alternative species.

Option 1 – Reinstatement of Kauri Pine

This option would include the replacement of dead/unhealthy Kauri Pines, with another Kauri Pine, and when a tree dies in the future, another tree would be replanted in its place.

The selection of Kauri Pines for the Avenue has been an ongoing challenge with the failure of trees in the southern end of the Avenue since they were planted in 1925. Council's Curator at the time of the Arboretum's establishment, Ernest Walter Bick, commented that he doubted the ability of the Kauri Pines to survive in the low-lying areas.

Based on recent and previous investigations into tree health, soil conditions and groundwater, evidence shows that due to these conditions there is likely to be continued and repeated poor health, decline and death of Kauri Pines in Avenue. Therefore, like-for-like replacement of the trees is not recommended.

Option 2 – Soil and Drainage Options

Soil compaction and high clay content soils contribute to poor drainage at the site which impacts the health and longevity of the Kauri Pines in the southern section of the avenue. For this reason, a drainage system would need to be considered in conjunction with soil remediation options. The highly impermeable soil also acts to slow down soil water movement from the wetland. Care should be taken to not disturb the hydrology of the wetland when changing the soil or installing drainage.

Two different drainage options identified in section 3.3.3 are outlined below.

Option 2.1 – Two Meter Drainage channels

This option involves the removal of 3 x 2 m wide strips along either side and in the middle of the Avenue in the southern section. Drainage channels would include replaced soil to a depth of 800 mm. At the base of the channels slotted PVC would be placed to carry groundwater down to the discharge point in the channel. Around 1000 m³ of soil would be moved in total with this option.

A soil with good structure and qualities that would support the healthy growth of the Kauri Pines would be selected. This option includes partial soil replacement, but this would not involve removing or disturbing the trees. Tree health would likely improve as the roots are growing in improved soil. There is however a risk that areas not being replaced are sufficiently problematic that the trees still struggle to survive.

Considerations and risks with this option are soil compaction and saltwater contamination. The use of heavy machinery to remove and bring in soil could cause compaction. Additionally, over time the saline groundwater will migrate into the imported new soil, as it is more free draining compared to the in-situ ground. Further, as sodium is highly soluble, it may wash out of the new soil more quickly, however this presents unknown issues with the imported soil media and potential interactions with in-situ soil and groundwater. Works may inadvertently encourage salty groundwater closer to the Kauri Pines.

The plan for this option can be viewed in detail in Appendix C1 - Concept Drainage Plan. [REDACTED]

Option 2.2 – Replacement of soil and Two Meter Drainage channels

This option represents an increased chance of Kauri Pine survival but has the highest cost and changes to the site. The option involves replacement of the soil from the southern section to a depth of 0.8 m and a width of 18 m across the Avenue. It also includes the installation of drainage, as in Option 2.1 and the existing trees would need to be removed and replaced.

Risks associated with this option are based on the solution itself and the nature and extent of the works required to achieve it. A substantial amount of soil (3500 m³) is required to be removed and replaced, which would require an estimated 600 truck movements in and out of the Arboretum. This volume of vehicle movement would impact residents, local roads, cause further compaction of soil and require a detailed traffic management plan for the Arboretum to minimise disruption to the use of the site. At a significantly increased cost, there is still the likelihood that salinity would enter and impact the new soil and with increased permeability, the soil would attract salt. These interactions are displayed in Figure 16. Additionally, with increased drainage, water would not be retained as easily.

There is still a possibility that the underlying soil would continue to create unsuitable conditions for the trees and that the reinstated trees may not survive.

Like Option 2.1, there is a risk associated with saline groundwater entering and interacting with the imported soil.

The plan for this option can be viewed with the in Appendix C3 - Soil Remediation and Drainage Plan. T [REDACTED]

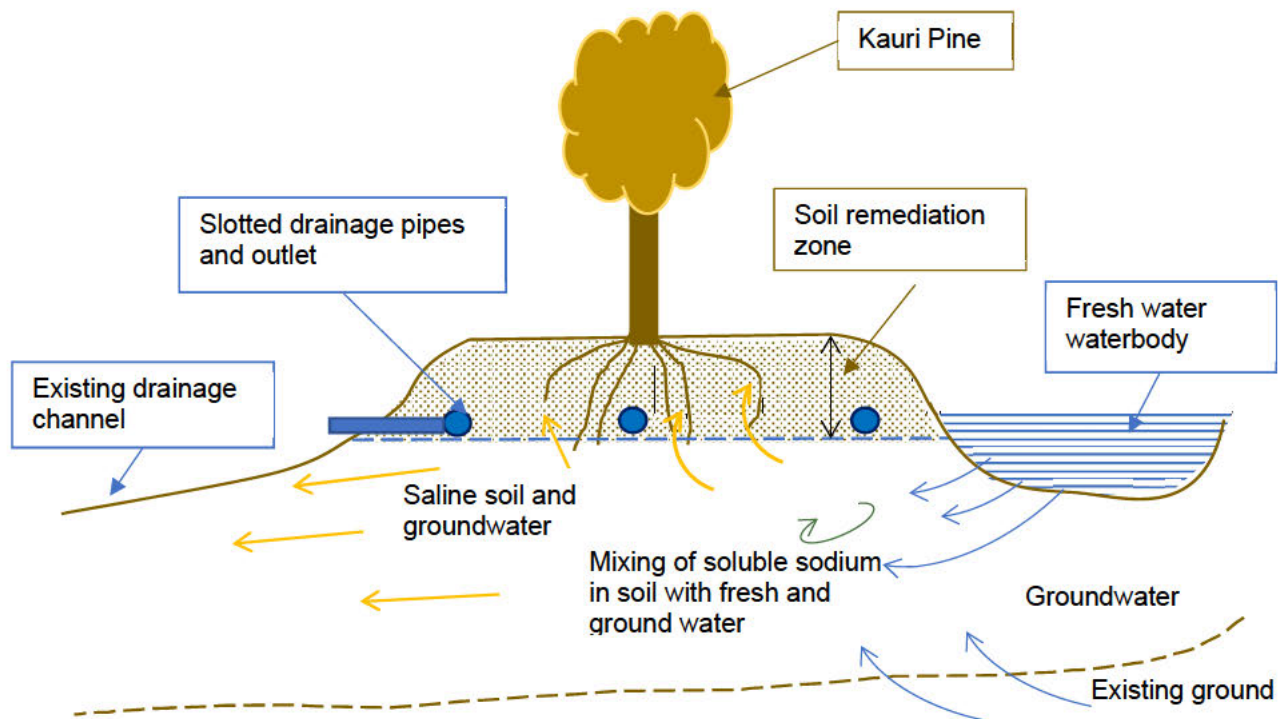


Figure 18: Diagram showing the predicted movement of groundwater and soil interactions.

Option 3 – Mounding of Kauri Pines

Mounding of impacted Kauri Pines commenced as a trial to lift the trees above the natural ground level and soil conditions to determine tree compatibility with the existing conditions. The trial showed that the health and survival rates of the trees were improved when elevated above the ground level and using an imported soil.

Mounding of the Kauri Pines has previously been considered the most cost-effective option for improving the health of the Kauri Pines. As the trees have survived the flood events of the last decade, mounding has been successful.

While mounds have been successful in the early life of the Kauri Pines in the lower southern section of the Avenue, they are not a viable long-term option. As the trees grow and extend their roots, they will encounter the same ground conditions causing the detrimental effects on the Avenue. The trees are also expected to become unstable after 10-15 years.

As recommended in the Policy 22 in the CMP *'The grass mounding of 13 Queensland kauri pines should be removed from Sir Matthew Nathan Avenue'* the mounding has little heritage value and other options need to be found.

Option 4 – Species Replacement

A recent investigation at Oxley Common (the Secret Forest) found that there were some similarities in the soil profile with Arboretum. The location of the stand of Hoop Pines at the Secret Forest has similar physical conditions including flooding events, ground water depths, and soil nutrient profile. The Hoop Pine and the Kauri Pine are shown in Figure 19 and Figure 20. An artist's impression of the Avenue planted with Hoop Pines is shown in Figure 19.

Investigation results suggest the Hoop Pine (*Araucaria cunninghamii*) is a good replacement species candidate to commence a replacement trial. It has a very similar growth form, size and is found in similar soil conditions. Additional species that would also be suited to the site conditions include Weeping Paperbark (*Melaleuca leucadendra*) or Swamp mahogany (*Eucalyptus robusta*), however, their form is noticeably different from the Kauri Pine. An artist's impression of the Weeping Paperbark on the Avenue is presented in Figure 20.

The Norfolk Island Pine (*Araucaria heterophylla*) would also be well suited to the site conditions; however, the Arboretum is almost exclusively Australian native trees. While the Norfolk Island Pine is an external territory, it is represented in other exclusively native botanic gardens including the Australian Botanic Gardens (Canberra) which represents native plants from all parts of Australia.

The CMP identified that the species selection at the Arboretum requires consideration of both the heritage significance of the site and tolerance of potential flood water. The suggested replacement species fit the criteria as well as fitting with the original intent of the Arboretum which was to trial trees endemic to the region for forestry. Additionally, promotion of the trial would align with the educational and scientific intent of the Arboretum. A trial site should include a section of the lower, southern part of the Avenue, where the most declines have been seen.

There is no guarantee that a species replacement will succeed at the Arboretum, and it would require consultation with stakeholders, including DESI for heritage approval. Previously, DESI has supported a species replacement and more recent communications with DESI indicate their continued support of a species change for the Avenue [REDACTED] (Department of Environment and Science), 2023).



Figure 19 Hoop Pine specimen (Heritage Tree Care, 2023).



Figure 20 Kauri Pine specimen (CPO, 2017).



Figure 21 Artist impression of the Avenue planted with Hoop Pines.

5.1 Summary and Recommendations

Table 7 below provides a summary of the options presented above, highlighting the main factors for consideration.

Table 7: Summary of Remediation Options

Option	Description	Benefits	Risk	Recommendation
1 – Reinstatement of Kauri Pine	Replace the Kauri Pines with Kauri Pines	- Low cost - Retains heritage values	- Limited improvement to site - No long term guarantee of success - Continued availability of species stock	This option is not recommended as it does not solve the decline problem.
2.1 - 2 Meter Drainage Channels	Spaced drainage solution (2 m widths) with less soil replacement	- Smaller amount of soil removal and replacement - Retains heritage values - Improves soil drainage	- High cost - Soil would be compacted - Cannot keep salinity from the tree roots	This option is not recommended as it's an uncertain long term option with a number of risks.
2.2 - Replacement of soil and 2 Meter Drainage channels	Replace soil to a depth of 0.8 m for 18 m in the southern Avenue.	- Retains heritage values - New soil with improved drainage	- High cost - Increased heavy vehicle movements in the site - High volume of soil replacement - Impact to users and residents - High risk of compaction – would require additional works to manage this - Complex project delivery and logistics	Not recommended due to uncertain long-term success with a high cost and high level of risk in delivery.
3 - Mounding	Mound Kauris	- Proven to be successful in the short to medium term - Cost are manageable within operational budgets - Low impact to trees - Already in place	- Does not align with heritage values - Interrupts sight lines and views - Inconsistent with the northern end of the Avenue - Tree root growth is limited	Not recommended due to inconsistency with heritage values and not a long term solution.

		- No disruption to service and usability of the site - Easy to deliver	- Tree roots will reach saline soil - Not stable in the long term	
4 - Species replacement	Replace dying Kauris with Hoop Pines or other recommended species	- Aligns with heritage values - Opportunity to promote option as part of the scientific and educational values and intent of the Arboretum - Post approvals and consultation, relatively easy to deliver - Investigations support the potential success of an alternative species - Minimal disruption to the site - Improves the visual amenity and appearance of the Arboretum at the most used entry point - Delivers a quick and cost effective solution with higher likelihood of success	- Alternative species may not live (despite research and investigations) - Potential negative stakeholder feedback - Replacement species stock availability	This is the recommended option – as the new species aligns with the heritage values. Offers research opportunities to reinstate trees in the Avenue more quickly improving the visual amenity and appearance of the Arboretum at the most used entry point. This option has a potentially high level of success.

6. Implementation

This section outlines strategies and actions that could be undertaken to implement the recommended option. It is important to remember that the problems facing this Arboretum, while unique to the site, are often found in other gardens around Australia, and around the world. In the face of a changing climate the *Climate Change Alliance of Botanic Gardens*, is working to help develop strategies and ideas of ways to manage the future of these important botanical institutions. One of the strategies, developed by the Royal Botanical Gardens Victoria, is a Landscape Succession Strategy (LSS).

The LSS is a blueprint for botanic gardens in 'planning the management of their collection and landscape through climate change' (Royal Botanic Gardens Victoria, 2023). Its purpose is to help guide the transition of existing plantings to a collection that is better suited to the projected climate and environmental conditions of 2090. This framework could be used to help guide the species replacement planning at the Arboretum.

6.1 Heritage Considerations

The heritage principles and CMP policies should lead the planning for developing the Kauri Pine strategy. There are multiple policies to consider when considering a Kauri Pine strategy which cover the following significant areas and elements including:

- Elements of Significance
- Conservation of Setting, Views and Fabric
- Landscape Setting of the Avenue and the Kauri Pines
- Landscape Conservation
- Repairs, Alterations, New Work and Maintenance
- Community Engagement and Funding Opportunities

There are specific policies developed to protect the heritage significance of the Kauri Pines and the Avenue however, there are also policies that provide clear direction and guidance on when a new species should be considered. The policies found in the Landscape Conservation section of the CMP recommend that a species should not be replaced like-for-like if it is 'not the most suitable tree for the soil and situation' or 'it is unlikely to thrive/survive in the predicted climate conditions over the next 50-100 years' and it 'will require considerable resources to support' (Policy 52 & 53, CMP, 2021).

Additionally, the Arboretum was created to study the growth of native species. It could be presumed the Kauri Pines featured in this report have indeed been well studied. It is recommended that now is the time to put the learnings into action.

6.2 Action Plan

Planning for the implementation of the declining Kauri Pine solution will require careful consideration. The next steps for Council to move through the decision-making process on the Kauri Pines is presented in Table 3. Internal discussions on the future of the Kauri Pines should be the first step.

Table 8: Summary of actions/next steps

Item	Description	Responsibility
Stakeholder Briefings and Feedback	Council departments	NEWS / PPI / PSO
Stakeholder Engagement and Consultation	State Government - DESI	PSO
Community Engagement and Consultation	FOSA, Bushcare group	PSO
Project Planning	Lay out the steps required to implement selected option to address Kauri Pine decline (includes approvals and budget sourcing).	City Standards
Communication Plan	Communicate option and timeframe for delivery	City Standards

6.3 Stakeholder Engagement

While it is Council's responsibility to manage the Avenue and the Arboretum, this is a responsibility Council undertakes in consultation and engagement with numerous stakeholders

State Heritage – Department of Environment, Science and Innovation (DESI)

The heritage values of the site, in accordance with the listing on the Queensland Heritage Register are and important consideration. This means continuing the conversation about the future of the Avenue with the State DESI. To date, the State has been supportive of a species change. A plan for the trial of a new species would need to be prepared for the State to consider.

Friends of the Arboretum (FOSA) and Bushcare

The FOSA is a not-for-profit, voluntary community association who have worked in partnership with Council since 1986 (CMP, 2021). They provide a hands-on approach in the management of the Arboretum. FOSA's involvement continues the community's contribution to the park that saw its creation back in 1925. FOSA members work closely with Council in the promotion, preservation and maintenance of the Arboretum. Invested in the history and future of the site, FOSA share a keen interest in the outcome of the Kauri Avenue options. It is intended that once approved, the recommended option will be supported, promoted and optimised by FOSA.

Based on the recommendation in this report, there are educational and learning opportunities that can be leveraged by FOSA to be communicated to Arboretum visitors.

7. Conclusion

This report has outlined the decline of the Kauri Pine species in the southern section of the Avenue since the opening of the Arboretum. Scientific investigations and analysis of soil and groundwater conditions indicate several conditions that are likely to lead to the decline of the Kauri Pine. Ground conditions consist of compacted clayey sodic soils that create poor drainage and complex nutrient imbalances in whole of the Avenue. However, there are notable differences in the level of exchangeable sodium and other nutrients, between the northern and southern sections of the Avenue. Further analysis by an experienced soil scientist is recommended to better understand the significance of the imbalances.

In addition to technical data, the report has referenced the Conservation Management Plan for the site, which provides policies and guidance on how to manage the issue of the Kauri Pine declines.

Three options to improve the health and vitality of the Avenue are presented that incorporate previous recommendations and contemporary understanding of the site conditions. These include;

- Option 1 - reinstatement of declining Kauri Pine with another Kauri Pine
- Option 2 - remediation of the soil and drainage improvements
- Option 3 - mounding of the Kauri Pines
- Option 4 - selection of a replacement species.

To remediate the land in a way that supports Kauri Pines to be healthy presents numerous risks, challenges and costs. The research indicates that even with significant soil remediation and drainage infrastructure, there is still a high risk that Kauri Pines will not thrive in some locations of the Avenue. For these reasons, this report concludes that replacing Kauri Pines when at the end of life with another species presents the best option for the Avenue. Species replacement provides an opportunity for continued scientific observation and learning of other species to adapt to the Avenue's conditions.

The recommended option in this report is a trial of a new species that will revitalise the Avenue, improve the presentation of the main entry of the Arboretum and align with heritage values. It also presents an opportunity to promote and educate the community about the recommended option, which is part of the intention and purpose of the Arboretum.

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9. Appendices

Appendix A Maps

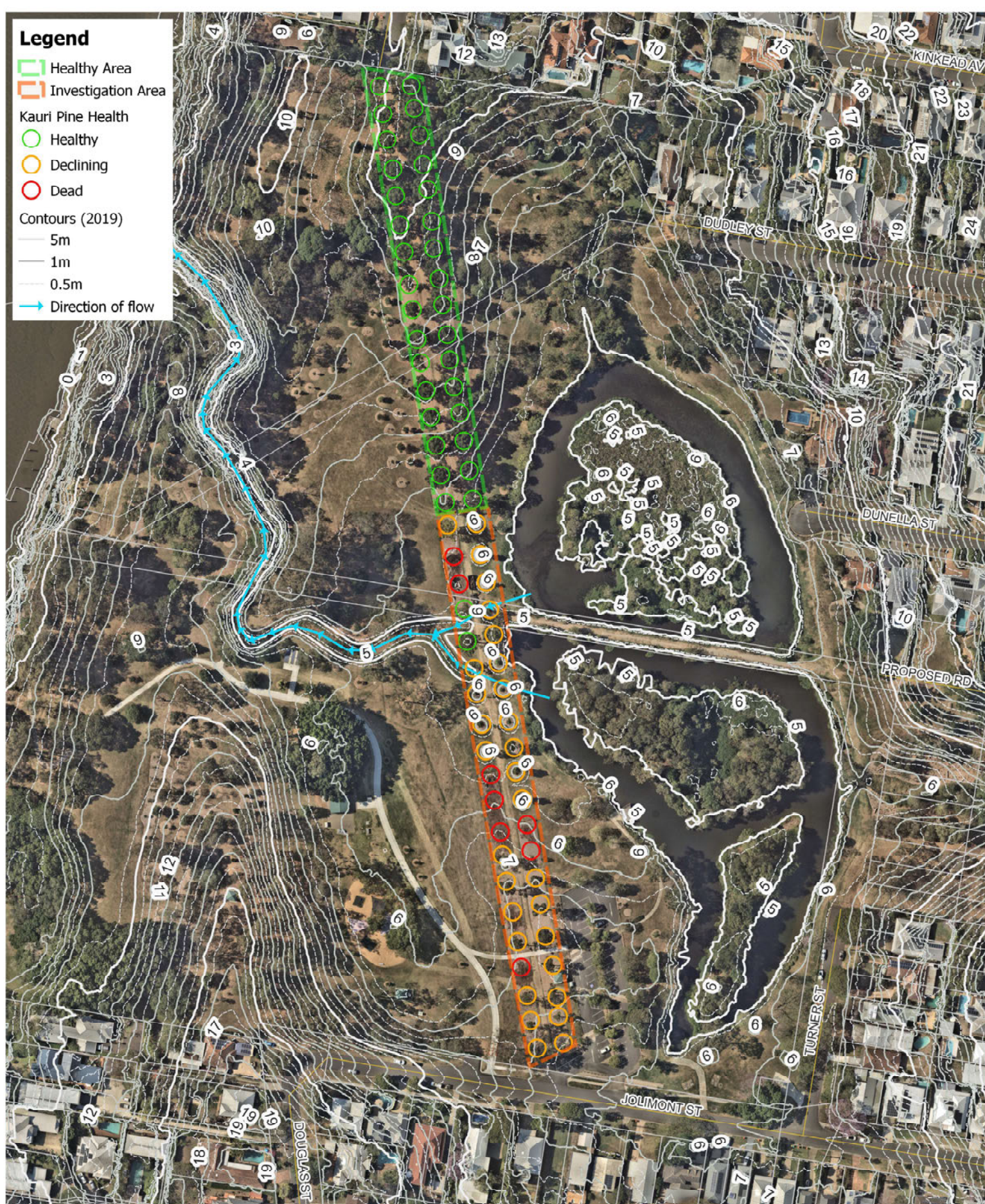
- A1 Map of Kauri Pine Status
- A2 Map of Ground Water Bores - 2017
- A3 Map of Ground Water Bores – Sherwood Arboretum and Secret Forest – 2023
- A4 Map of Ground Water Bores – Sherwood Arboretum - 2023
- A5 Map of Ground Water Bores – Oxley Common – Secret Forest – 2023

Appendix A **Soil Analysis Information**

A1 Map of Kauri Pine Status

Legend

- Healthy Area
- Investigation Area
- Kauri Pine Health**
- Healthy
- Declining
- Dead
- Contours (2019)**
- 5m
- 1m
- 0.5m
- Direction of flow



Brisbane City Council
City Projects Office
Water Management Team

Sherwood Arboretum - Kauri Pine Options Assessment

Figure: Kauri Pine Avenue Health Summary



For more information
visit www.brisbane.qld.gov.au
or call (07) 3403 8888

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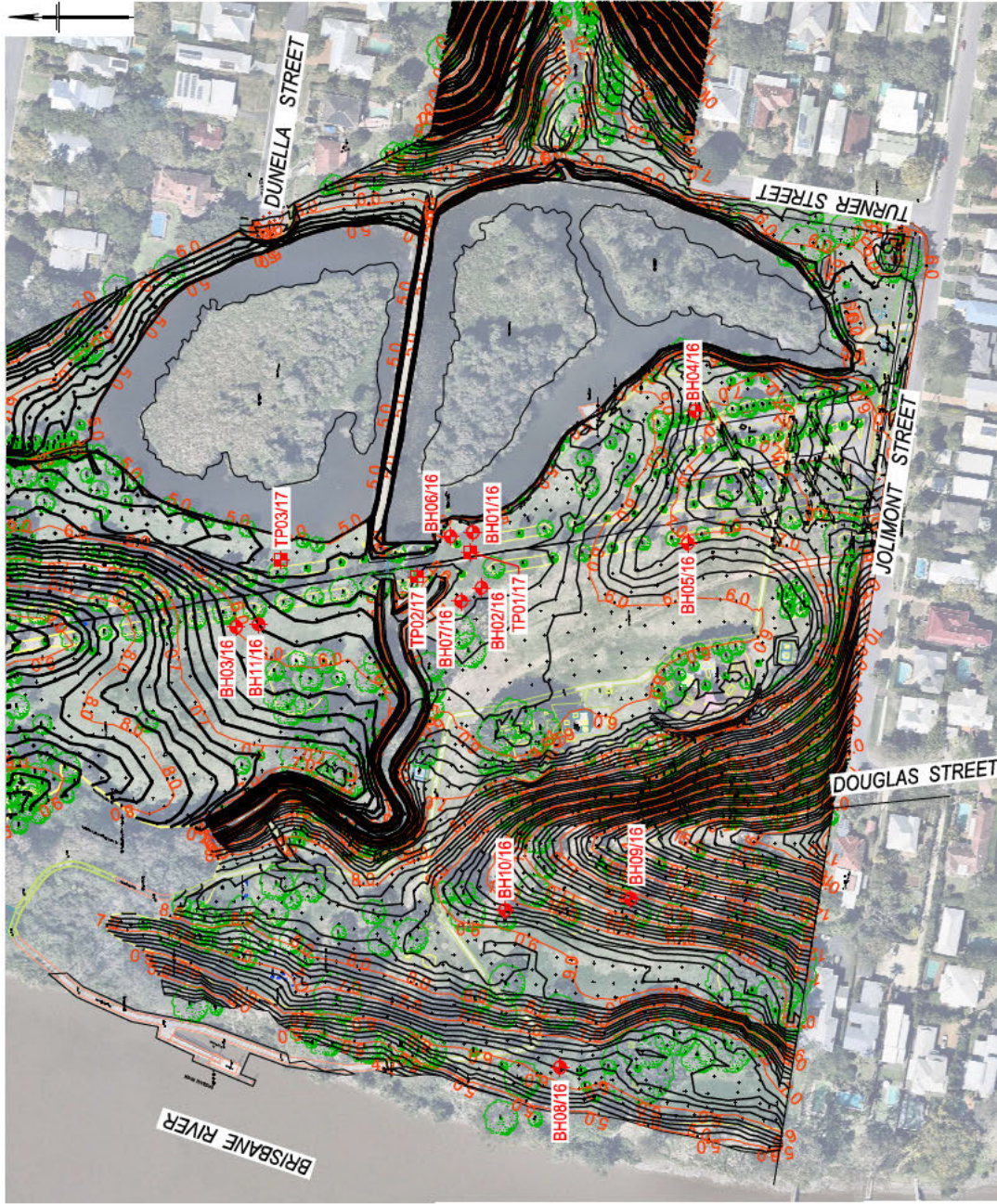
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0 0.02 0.04 0.06 0.08 0.1 km

Scale @ A3: 1:1,500

A2 Map of Ground Water Bores - 2017

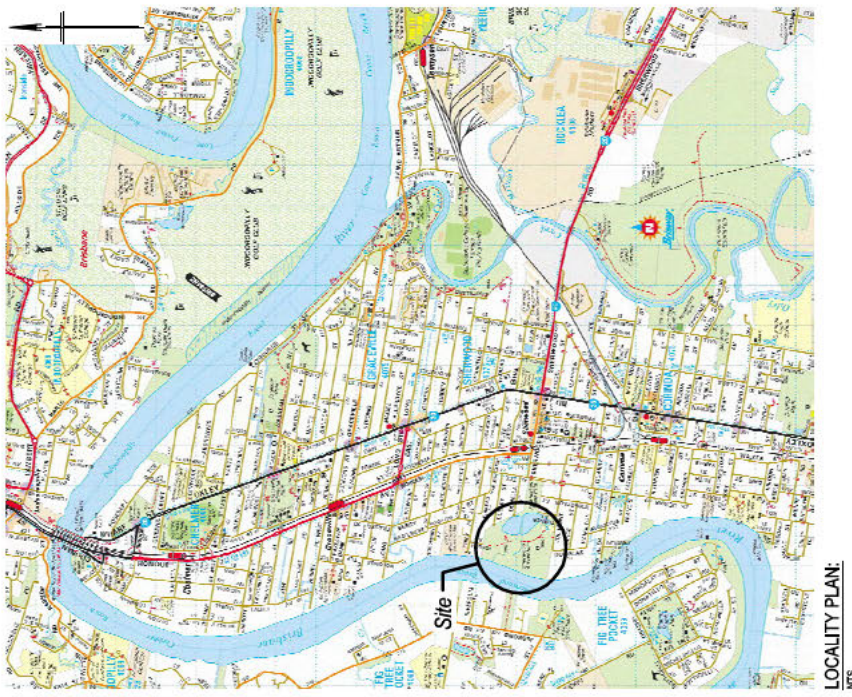


LEGEND:

- BOREHOLE LOCATION
- TEST PIT LOCATION
- 29/03/2017

SCALE 1 : 2000 AT A3

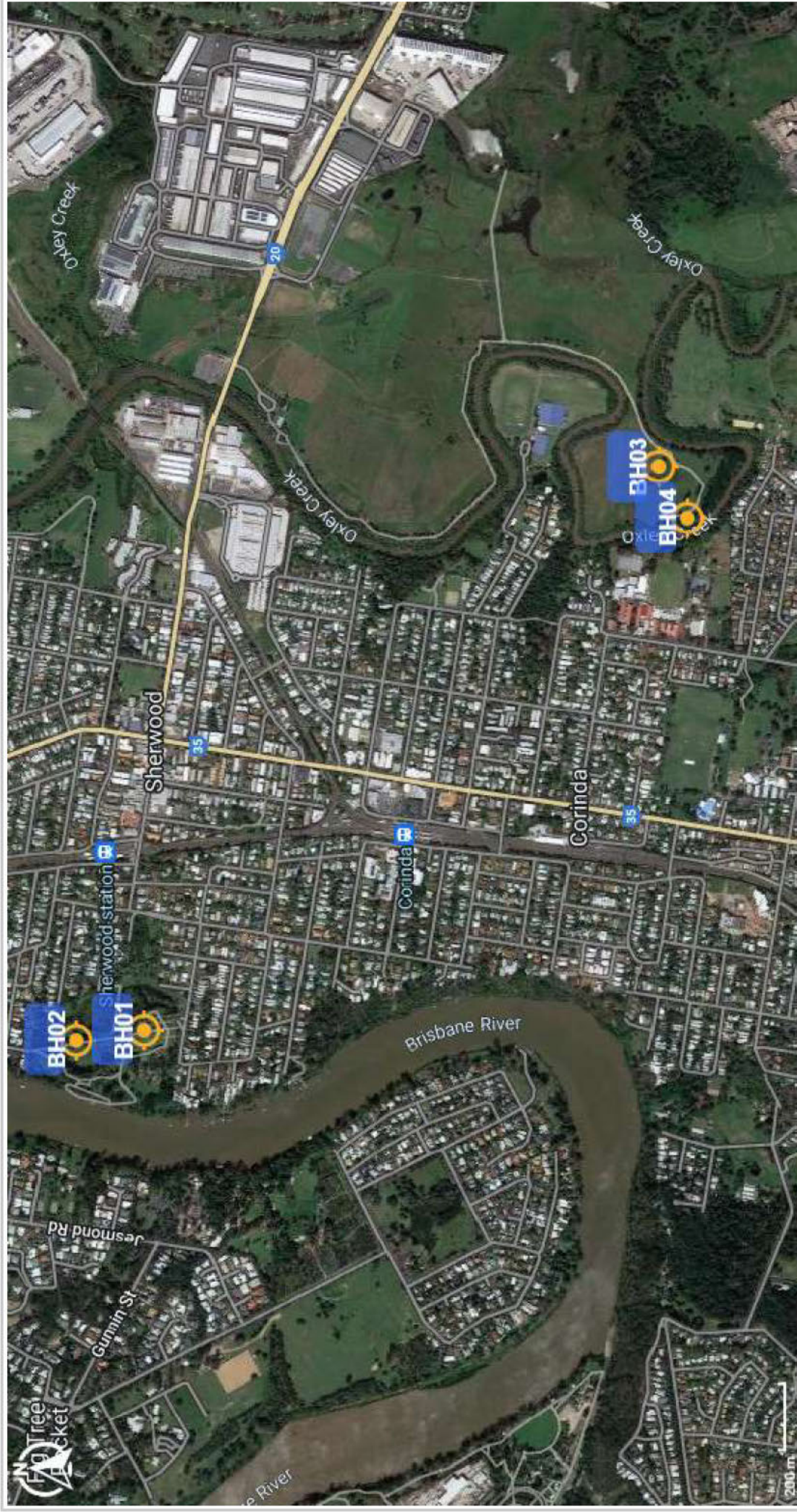
0 50 100 150 200 METRES



LOCALITY PLAN:
NTS

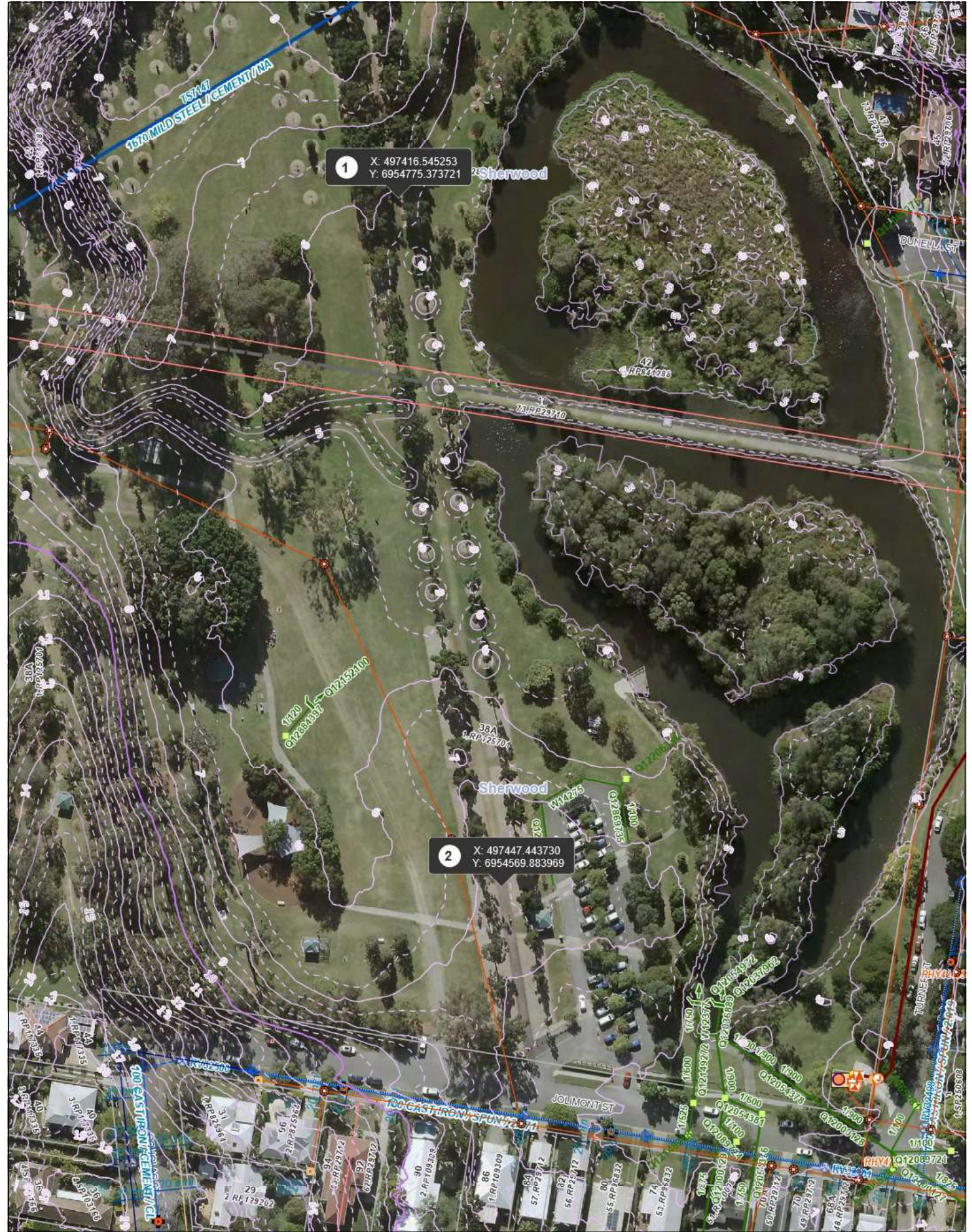
BRISBANE CITY COUNCIL CITY PROJECTS OFFICE The Engineering Group - Ground Engineering Report Reference No. GE/160725 PR001A Rev. 1		LANDSCAPE ARCHITECTURE GROUND WATER CHARACTERISATION SHERWOOD ARBORETUM BOREHOLE AND TEST PIT LOCATIONS		FIG. 1
DRAWN E. Polichronis June 2017		CHECKED B. Chessman June 2017		SCALE As Shown A3
AUTHORISED FOR ISSUE		BRISBANE CITY COUNCIL CITY PROJECTS OFFICE The Engineering Group - Ground Engineering Report Reference No. GE/160725 PR001A Rev. 1		FIG. 1

A3 Map of Ground Water Bores – Sherwood Arboretum and Secret Forest – 2023



  +61 734 038 888  266 George St, Brisbane City QLD 4000, Australia  info@brisbane.qld.gov.au		Map description Sherwood Arboretum & Oxley Common Secret Forest - Monitoring Well Installation	
Site location Sherwood Arboretum & Secret Forest		Client Brisbane City Council	
Project name Sherwood Arboretum & Secret Forest		Project No GK15	
		Scale Not to scale	

A4 Map of Ground Water Bores – Sherwood Arboretum - 2023



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2009 Aerial Imagery © 2009 AAMHatch Pty Limited
2007 Aerial Imagery © 2007 Fugro Spatial Solutions
2005 Aerial Imagery © 2005 QASCO Contours © 2009 AAMHatch



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Notes: Locations of boreholes with monitoring

Projection:
Web Mercator Auxiliary Sphere
Print Date:
3/05/2023 - 3:37 PM

Sherwood Arboretum Soil and Groundwater Investigation

50.0 0 25.0 37.5 50.0

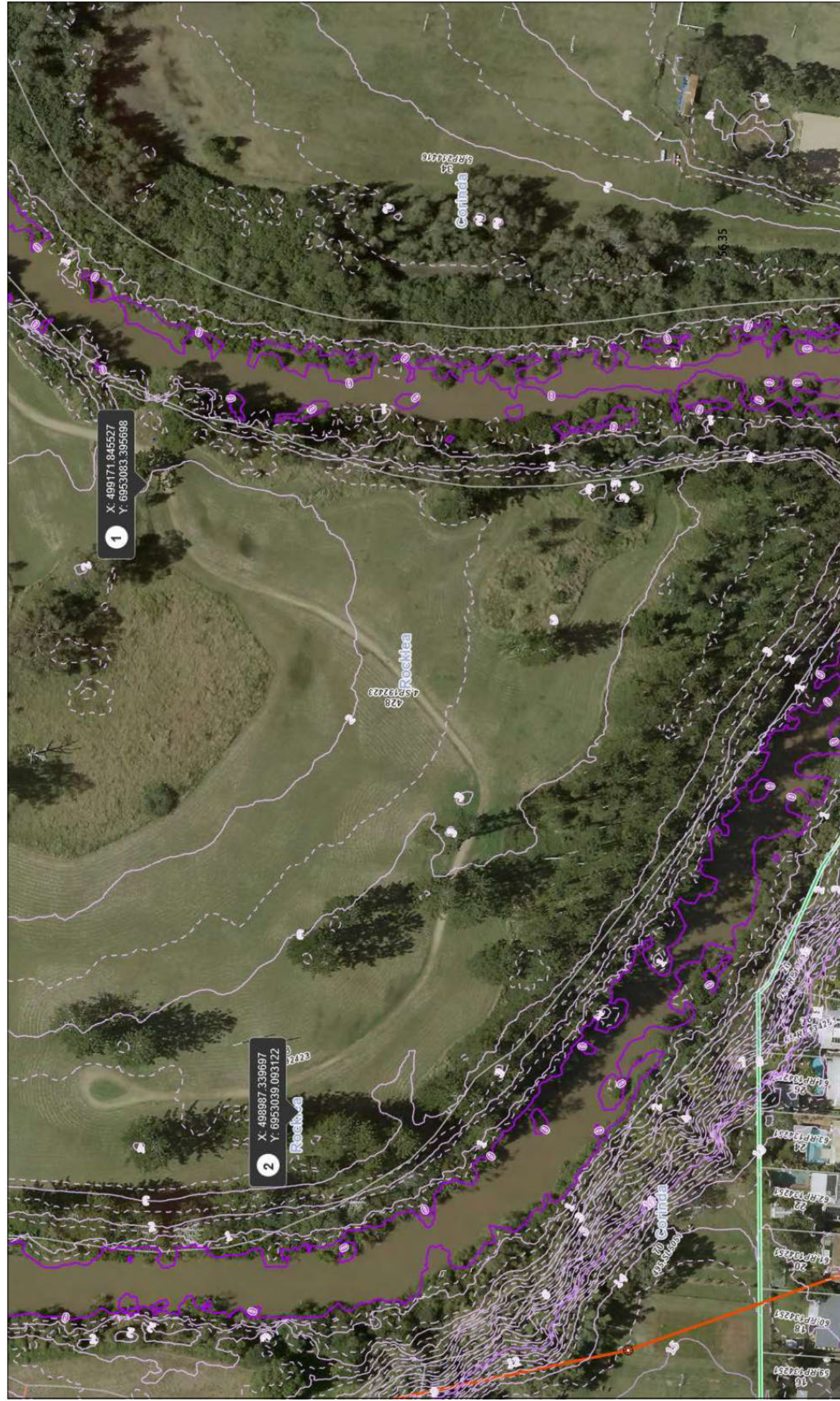
Metres

Scale: 1: 1,000

Legend

Suburb Boundaries 1m Contour (2019) 50m Contour 10m Contour 5m Contour 1m Contour 50cm Contour (2019) Local Distribution Transmission Lines BP Gas Pipeline Murarrie Gas Pipeline Roma-Brisbane Gas Pipeline Moonie Oil Pipeline Energex Sites Substations High Voltage Switching Site Towers other Energex Streetlights Council Maintained Energex Maintained (BCC) Energex Maintained (Other) Other Government Entities Energex Watchman Energex Streetlight Network Energex Low Voltage Network Energex 11kv Network Energex 33kv Network Energex 110kv Network Energex Pilot cables Powerlink Sites 110kv Network Above Ground Underground 275kv Network 500kv Network Recycled Water Device Pressure Gauge Flow Meter Level Sensor Pressure Gauge - Offline Flow Meter - Offline Level Sensor - Offline <all other values> Recycled Water Fitting Bend End Cap Cross Joint Gibault Joint Tapping Band Tapping Reducer Wye Tee Reservoir Inlet Scour Outlet Pigging Point Sampling Station Chemical Injection Point <all other values> Recycled Water Structures Anchor Block Concrete Stop Head Wall Pier Pipe Bridge <all other values> Recycled Water Chamber Recycled Network Structure Boundary Recycled Water Hydrant Inground Hydrant Pillar Hydrant Recycled Water Control Valve Reflux Scour Air Pressure Sustaining Pressure Reducing Altitude Flow Control Reflux - Offline Scour Offline Air - Offline Pressure Sustaining - Offline	Open <all other values> Recycled Water - Reservoirs Reservoir Reservoir - Offline Recycled Water Network Structure Treatment Plant Filling Station Recycled Water Pump Stations Pump Station Pump Station - Offline Recycled Water Network Structure Boundary Recycled Water Pumps Booster Pump Lift Pump Booster Pump - Offline Lift Pump - Offline Recycled Vertical Pressure Main Recycled Water Pressure Main Model Link Reticulation Main Trunk Main Scour Main Reticulation Main - Offline Trunk Main - Offline Scour Main - Offline Recycled Water Service Service Model Link Common Service Sewer Chamber Chamber Chamber - Offline Sewer Fitting End Flushing Point Inline Flushing Point Vacuum Lift Joint Rodding Joint Property Connection Boundary Hunction End Cap Bend Wye Tee Reducer Gibault Joint Cross Inlet Outlet <all other values> Sewer Structure Concrete Stop Pipe Bridge Anchor Block Headwall Pier Sewer Support Structure Boundary Sewer Manholes Manhole Manhole - Offline End Flume Pit <all other values> Sewer Manhole Stub Sewer Control Valve Air Scour Vacuum Reflux Air - Offline Scour - Offline Vacuum - Offline Reflux - Offline Sewer System Valve Sewer Door Gate Butterfly Sewer Door - Offline Gate - Offline Butterfly - Offline <all other values> Sewer Network Structure - All Other Structures Treatment Plant Storage Facility	Wet Well - Offline Sewer Pump Station Pump Station Pump Station - Offline Sewer Network Structure Boundary Sewer Vertical Gravity Main Sewer Vertical Pressure Main Sewer Gravity Main - by Type Syphon Discharge Trunk Main Reticulation Main Overflow Main Model Link Syphon - Offline Discharge - Offline Trunk Main - Offline Reticulation Main - Offline Overflow Main - Offline Model Link - Offline <all other values> Sewer Pressure Main - by Type Model Link Low Pressure Main Rising Main Vacuum Main Model Link - Offline Low Pressure Main - Offline Rising Main - Offline Vacuum Main - Offline Sewer Service Model Link Service <all other values> Sewer Reticulation Area Design Plan Proposed Declare Gully - Stormwater Existing Backflow Prevention Device - Stormwater Existing SQID - Stormwater Existing Waterbody - Stormwater Existing Artesian Well - Existing Detention Basin - Existing Lake - Existing End Structure - Stormwater Existing End Cap - Existing Flood Gate - Existing Pipe End Outlet - Existing Culvert - Stormwater Existing Surface Drain - Stormwater Existing Pipe - Stormwater Existing Drain - Existing Gully Connect - Existing Foul Water - Existing Roof Water - Existing Rising Main - Existing Communication Tower Fibre Optic Device Loop Joint Above Ground Joint Below Ground Pit Fibre Optic Cable Water Device Flow Meter Pressure Gauge Level Sensor Flow Meter - Offline Pressure Gauge - Offline Level Sensor - Offline <all other values> Water Fitting Bend Pigging Point End Cap Cross Joint Gibault Joint Tapping Band Tapping Reducer Wye Tee Reservoir Inlet
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A5 Map of Ground Water Bores – Oxley Common – Secret Forest
– 2023



Legend

Suburb Boundaries	Anchor Block	End Flushing Point	Sewer Vertical Pressure Main	Flow Meter - Offline
1m Contour (2019)	Concrete Stop	Infine Flushing Point	Sewer Gravity Main - by Type	Pressure Gauge - Offline
50m Contour	Head Wall	Vacuum Lift	Syphon	Level Sensor - Offline
10m Contour	Pier	Joint	Discharge	<all other values>
5m Contour	Pipe Bridge	Rodding Joint	Trunk Main	Water Fitting
1m Contour	<all other values>	Property Connection Boundary	Reticalation Main	Bend
Recycled Water Chamber	Recycled Water Chamber	Hunction	Over-flow Main	Pigging Point
Local Distribution	Recycled Water Hydrant	End Cap	Model Link	End Cap
Transmission Lines	Inground Hydrant	Bend	Syphon - Offline	Cross
BP Gas Pipeline	Pillar Hydrant	Wye	Discharge - Offline	Joint
Muarine Gas Pipeline	Recycled Water Control Valve	Tee	Trunk Main - Offline	Chasult Joint
Moonie Oil Pipeline	Reflex	Reducer	Reticalation Main - Offline	Tapping Band
Energex Sites	Scour	Gbasult Joint	Over-flow Main - Offline	Tapping
Substations	Air	Cross	Model Link - Offline	Reducer
High Voltage Switching Site	Pressure Sustaining	Inlet	<all other values>	Wye
Towers	Pressure Reducing	Outlet	Sewer Pressure Main - by Type	Tee
other	Altitude	<all other values>	Model Link	Reservoir Inlet
Energex Streetlights	Flow Control	Sewer Structure	Low Pressure Main	Reservoir Outlet
Council Maintained	Reflex - Offline	Concrete Stop	Rising Main	Scour Outlet
Energex Maintained (BCO)	Scour - Offline	Pipe Bridge	Vacuum Main	Chemical Injection Point
Energex Maintained (Other)	Air - Offline	Anchor Block	Model Link - Offline	Sampling Station
Other Government Entities	Pressure Sustaining - Offline	Headwall	Low Pressure Main - Offline	<all other values>
Energex Watchman	Pressure Reducing - Offline	Pier	Rising Main - Offline	Water Structures
Energex Streetlight Network	Altitude - Offline	Manhole	Vacuum Main - Offline	Anchor Block
Energex Low Voltage Network	Flow Control - Offline	Manhole - Offline	Sewer Service	Pipe Bridge
Energex 11kv Network	Recycled Water System Valve	End	Model Link	Concrete Stop
Energex 33kv Network	Closed	Flume Pit	Service	Headwall
Energex 110kv Network	Open	<all other values>	<all other values>	Pier
Energex Pilot cables	Recycled Water- Reservoirs	Sewer Manhole Stub	Sewer Reticulation Area	<all other values>
Powerlink Sites	Reservoir	Sewer Control Valve	Design Plan	Water Chamber
110kv Network	Reservoir - Offline	Air	Proposed	Water Hydrant
Above Ground	Recycled Water Network Structu	Scour	Decline	Pillar Hydrant
Underground	Treatment Plant	Vacuum	Gully - Stormwater Existing	Inground Hydrant
275kv Network	Filling Station	Reflex	Backflow Prevention Device - Stk	<all other values>
500kv Network	Pump Station	Scour - Offline	SQID - Stormwater Existing	Water System Valve
Pressure Gauge	Pump Station - Offline	Reflex - Offline	Waterbody - Stormwater Existing	Gate - Open
Flow Meter	Recycled Water Pump Stations	Sewer Door	Detention Basin - Existing	Gate - Closed
Level Sensor	Recycled Water Network Structu	Gate	Lake - Existing	Butterfly - Open
Pressure Gauge - Offline	Booster Pump	Butterfly	End Structure - Stormwater Exist	Flow Control - Open
Flow Meter - Offline	Lift Pump	Gate - Offline	End Cap - Existing	<all other values>
Level Sensor - Offline	Lift Pump - Offline	Butterfly - Offline	Flood Gate - Existing	Service Valve - Open
<all other values>	Recycled Vertical Pressure Main	<all other values>	Pipe End Outlet - Existing	Service Valve - Closed
Recycled Water Fitting	Recycled Water Pressure Main	Sewer Network Structure - All Ot	Cuvert - Stormwater Existing	Water Network Structure - Reser
Bend	Reliculation Main	Treatment Plant	Surface Drain - Stormwater Exist	QUU
End Cap	Trunk Main	Storage Facility	Drain - Existing	SEQWATER
Cross	Scour Main	Odour Control	Gully Connect - Existing	Private
Joint	Reliculation Main - Offline	Wet Well	-4% Foul Water - Existing	QUU - Non Portable
Gbasult Joint	Trunk Main - Offline	Treatment Plant - Offline	-0% Roof Water - Existing	SEQ - Non Portable
Tapping Band	Scour Main - Offline	Storage Facility - Offline	Rising Main - Existing	Private - Non Portable
Tapping	Reliculation Main - Offline	Odour Control - Offline	Communication Tower	QUU - Offline
Reducer	Trunk Main - Offline	Wet Well - Offline	Fibre Optic Device	SEQ - Offline
Wye	Scour Main - Offline	Treatment Plant - Offline	Loop	Private - Offline
Tee	Service	Storage Facility - Offline	Joint Above Ground	Water Pump Stations
Scour Outlet	Common Service	Odour Control - Offline	Pit	QUU
Pigging Point	Sewer Chamber	Wet Well - Offline	Fibre Optic Cable	SEQWATER
Sampling Station	Chamber	Pump Station	Water Device	Private
Chemical Injection Point	Chamber - Offline	Pump Station - Offline	Flow Meter	QUU - Offline
<all other values>	Sewer Fitting	Sewer Network Structure Boundt	Pressure Gauge	SEQWATER - Offline
Recycled Water Structures		Sewer Vertical Gravity Main	Level Sensor	Private - Offline
				<all other values>

Appendix B **Soil Analysis Information**

- B1 Factual Report – Sherwood Arboretum Soil and Groundwater Characterisation - 2017
- B2 Factual Report - Sherwood Arboretum Soil and Groundwater Characterisation - 2023
- B3 Results – Soil – Chemical Analysis – 2023
- B4 Results – Ground Water levels – 2023-2024
- B5 Results – Ground Water - Chemical Analysis – 2023
- B6 Results - Ground Water - Chemical Analysis – 2024
- B7 Results - Ground Water – Slug Test

Appendix B Soil Analysis Information

B1 Factual Report – Sherwood Arboretum Soil and Groundwater
Characterisation – 2017

city projects office

**Landscape Architecture
Built & Natural Environment**

**Sherwood Arboretum
Groundwater Characterisation**

June 2017

Prepared by:
*City Projects Office
Ground Engineering*

Prepared for:
*City Projects Office
Landscape Architecture*

Reference:
160725PR001Abac

Date of Issue:
June 2017

ground engineering



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1.0	Introduction	1
2.0	Project Background	1
3.0	Site Geology	2
4.0	Field Investigation	2
5.0	Field Investigation Findings	3
6.0	Groundwater Monitoring	5
7.0	Laboratory Testing	6
8.0	Hydrological Characterisation Study	6
9.0	Discussion and Recommendations	7

Figure 1 Borehole and Test Pit Locations

Attachment “Important Information about your Geotechnical Report”

Appendix A Explanation Sheets
 Borehole Records
 Test Pit Records

Appendix B Groundwater Monitoring Data

Appendix C Laboratory Testing

Appendix D Sherwood Arboretum Hydrological Characterisation of Soils – The
 Sustainable Minerals Institute – University of Queensland

1.0 Introduction

Ground Engineering was commissioned by Landscape Architecture to undertake an appraisal of the subsurface geology and groundwater conditions at Sherwood Arboretum as part of a study to assess the rehabilitation of an avenue of Queensland Kauri Pines.

This report presents the findings of the ground investigation with results of the groundwater monitoring, laboratory testing as well as a hydrological characterisation report. Recommendations pertaining to the geotechnical and groundwater considerations for the rehabilitation study are also provided.

2.0 Project Background

Brisbane City Council arborists identified that up to fourteen Queensland Kauri Pines forming the Matthew Nathan Avenue in the central and lowest part of Sherwood Arboretum are in poor health or have died. Waterlogging of the near surface materials (200-400mm) has been observed to the low lying area and the adjacent man-made pond may be contributing to the soil-water hydrology.

The subject area was inundated in the January 2011 floods for a number of days with up to a metre of silt deposited over the area, which may have contributed further to the poor health of the Kauri Pines. It has also been identified that the presence of Phytophthora or root rot may be a considerable contributing factor to the poor health of the trees.

As a temporary measure, eleven trees have been replaced and planted on elevated mounds above ground level. As part of the study Landscape Architecture is looking to develop a scheme to restore healthy trees to the Matthew Nathan Avenue. The scheme requires consideration by Department of Environment and Heritage Protection.

It is understood that a key aspect for the study and the rehabilitation options for the area is to reduce waterlogging to the tree root zone, predominately a soil depth of 800 mm below ground surface level.

3.0 Site Geology

The Queensland geology GIS dataset, based on the Department of Natural Resources and Mines hard copy Queensland Geology 1:100,000 published in 1986, indicates that the surface geology within the park consists of **Holocene aged Alluvial Deposits**, comprising silt, sand and clay gravel. The south and south-western margin of the site area indicates surface geology of the **Devonian age Neranleigh-Fernvale Beds**, comprising mudstone, shale and arenite.

4.0 Field Investigation

The ground investigation comprised three stages between November 2016 and March 2017. Each stage provided information and basis for further investigation.

The first stage comprised the drilling of boreholes adjacent to the tree avenue to install groundwater monitoring loggers. Following the monitoring of groundwater levels and review of data a second stage of boreholes was carried out drilled to investigate higher levels of the park area. A third stage of test pitting was undertaken to provide samples for a hydrological characterisation study of the near surface soils in the subject area of trees with poor health. The hydrological characterisation study was undertaken with assistance from the Sustainable Minerals Institute of the University of Queensland (SMI).

The first stage of the ground investigation was undertaken on 04 November 2016 comprising the drilling of three boreholes, BH01/16, BH02/16 and BH03/16. Boreholes were drilled to depths between 4.45 m and 5.95 m below ground level. BH01/16 and BH02/16 were drilled at the lowest elevation of the tree lined avenue adjacent to the pond. The boreholes were located to assess subsurface conditions and monitor groundwater levels relative to the pond water levels. BH03/16 was located adjacent to healthy trees of the avenue in order to investigate background information for the assessment. Groundwater dataloggers were installed in all three boreholes to allow for remote groundwater level monitoring.

Following the review of the groundwater data, the second stage of the ground investigation was undertaken on 05 December 2016 to obtain soil samples for laboratory testing. Eight boreholes, BH04/16 to BH11/16, were drilled at various locations across the Arboretum to depths of between 2.50 m and 7.00 m below ground level. Boreholes BH06/16, BH07/16 and BH11/16 were located adjacent to BH01/16, BH02/16 and BH03/17 to obtain soil samples for environmental testing.