Engineering

Technical Guideline

TG 0650 - Tree Clearance and Remediation in Earth Dams

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Significant/Major Changes Incorporated in This Edition

This is the first issue of this Technical Guideline.

Document Controls

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1 Introduction

SA Water is responsible for operation and maintenance of an extensive amount of engineering infrastructure.

This guideline has been developed to assist in the design, maintenance, construction, and management of this infrastructure.

1.1 Purpose

The purpose of this guideline is to detail minimum requirements to ensure that assets covered by the scope of this guideline are constructed and maintained to consistent standards and attain the required asset life.

1.2 Glossary

The following glossary items are used in this document:

Term	Description
ANCOLD	Australian National Committee on Large Dams
ASDSO	Association of State Dam Safety Officials (of United States of America)
DEW	Department of Environment and Water, South Australia
DELWP	Department of Environment, Land, Water and Planning, Victoria
DPIPWE	Department of Primary Industries, Water and Environment, Tasmania
EBS	Earth Bank Storage
FEMA	Federal Emergency Management Agency (of United States of America)
NRM	Natural Resources Management Board
SA Water	South Australian Water Corporation
SRZ	Structural Root Zone
TG	SA Water Technical Guideline
TPZ	Tree Protection Zone
TS	SA Water Technical Standard
USBR	United States Bureau of Reclamation

1.3 References

1.3.1 Australian and International

The following table identifies Australian and International standards and other similar documents referenced in this document:

Number	Title
ANCOLD Guidelines	The suite of ANCOLD Guidelines, applicable to the design and safety assessments of earth and embankment dams
ASDSO (2018a)	Dam Ownership Fact Sheet – Internal Erosion of Earth Dams
ASDSO (2018b)	Dam Ownership Fact Sheet – Trees and Brush
DEW (2018)	Department for Environment and Water: Private Dam Maintenance and Management in Emergencies
DELWP (2018)	Your Dam, Your Responsibility – A Guide to Managing the Safety of Small Dams
NRM (2011)	Eyre Peninsula Natural Resources Management Board (NRM): Farm Dams – A Guide to Siting, Design, Construction and Management on Eyre Peninsula
Fell et al. (2015)	Fell, R., MacGregor, P., Stapledon, D., Bell G., and Foster, M., Geotechnical Engineering of Dams, 2nd Edition, CRC Press/ Balkema
FEMA (2005)	Technical Manual for Dam Owners – Impacts of Plants on Earth Dams, FEMA 534
Melbourne Water (2016)	Retarding Basin Design and Assessment Guideline
SA Water (2019)	Incident Management Adjacent Trees SOP
DPIPWE (2008)	Guidelines for the Construction of Earthfill Dams
USBR (2017)	Canal Operation and Maintenance - Vegetation
USBR (1987)	Design of Small Dams, Rev. 3

1.3.2 SA Water Documents

The following table identifies the SA Water standards and other similar documents referenced in this document:

Number	Title
TG 0641	Technical Guideline - General Technical Information for Geotechnical Design - Earth Dams, Rev. 2, October 2020

1.4 Definitions

The following definitions are applicable to this document:

Term	Description
SA Water's Representative	The SA Water representative with delegated authority under a Contract or engagement, including (as applicable): • Superintendent's Representative (e.g. AS 4300 & AS 2124 etc.) • SA Water Project Manager • SA Water nominated contact person
Responsible Discipline Lead	The engineering discipline expert responsible for TG 0650 defined on page 3 (via SA Water's Representative)

2 Scope

The scope of this document is to provide guidelines on geotechnical dams engineering aspects of the tree clearance and required remediation works associated with the tree removal in the vicinity of existing earth dams and earth bank storages for SA Water infrastructure.

A literature review and further discussions and recommendations are provided in this Technical Guideline to determine a specified clearance for trees from earthfill dam embankments and spillways, and appropriate methods for removing the concerning trees.

3 Introduction

Trees and vegetation are highly valuable assets for SA Water sites. They provide habitats for native flora and fauna, manage upstream sedimentation, reduce wind loads and improve the aesthetics of our land sites. Where used correctly, vegetation can also provide a dam safety benefit, where on the downstream slope of an earthfill embankment, well maintained grass can prevent erosion.

However, in some scenarios, larger vegetation (specifically trees) can pose significant risks to the dam's safety. Tree roots can destabilise soil in dam embankments and abutments and if they penetrate far enough, they could create a flow-path which can result in internal erosion or piping along the roots. The tree roots whilst the tree is still alive and healthy may not destabilise the soil enough to cause internal erosion or piping, but if the tree dies the roots shrink, and then piping of the embankment could initiate. Upstream of spillways, large trees may become dislodged and obstruct flow through the spillway, thereby reducing the capacity of the spillway and risking overtopping of the dam. Additionally, trees can obscure the ability to inspect embankments, abutments and the reservoir rim if not properly monitored. Also trees can discourage the growth of grasses beneath their canopy. This could cause local erosion of the embankment.

While these are known and understood concerns, and any impact of vegetation deemed to be unsafe is noted in inspections and action is taken against this, there exists a gap in the standard procedure for identifying trees of concern and appropriate removal methods. While any vegetation concerns are generally addressed proactively, the subjective nature of the current inspection and maintenance requirements leaves the potential for trees of concern to remain unaddressed. This Technical Guideline is prepared to review and assess the existing information on required clearances and removal procedures for trees of concern and provide recommendations on future actions for inspection and maintenance in SA Water dams assets.

4 Overview

4.1 Benefits of trees and vegetation near dams

Vegetation has several benefits near and surrounding dams. Upstream of a reservoir, and back from the reservoir rim, trees and vegetation contribute to the ecological health of the area, both providing shelter and feeding areas for fish and other wildlife, and in reducing sediment runoff flowing into the reservoir (NRM, 2011). Removal of trees near the inlet and within the reservoir catchment can affect the hydrology and salt movement into the reservoir. A cover of trees on the opposite side of the reservoir to the dam can provide windbreaks and consequently reduce wave actions and bank erosion and can also decrease the evaporation where trees can safely grow.

In *Design of Small Dams* (1987), USBR further specify that any vegetation that does not need to be removed for any reason should be preserved, and any vegetation that is inadvertently

destroyed during construction should be reinstated. Any reinstatement should be in accordance with appropriate environmental advice and specifications.

Vegetation can also be highly useful on dam embankments and abutments. A cover of topsoil and dense, well maintained short grass along an embankment is an appropriate cover for the downstream face of dam embankments (Fell et al., 2015). FEMA (2005) also states a consistent layer of low-cut grass further allows the full embankment to be accessed for inspections and provides visibility to inspect the condition of the embankment. The condition of the grass cover can also indicate the health of the dam; areas where the grass is growing significantly faster or dying can indicate higher or lower volumes of water on that face.

4.2 Issues and concerns regarding trees near dams

Despite the aforementioned benefits of trees near dams, there are a number of issues with trees growing in an unsafe location on or near the dam embankment, spillway, and reservoir rim. FEMA (2005) notes that the most prevalent issue with trees on dams is the lack of education by dam owners; this is demonstrated by the statistic that some US states estimate that 90 to 95% of dams in their state have trees on the downstream face. The most common issues that trees cause in and around dams can be split into 3 categories:

- Inability to inspect assets,
- Damage due to trunks and branches, and
- Damage due to roots.

Each of these issues are described in the sections below.

4.2.1 Inability to inspect assets

Trees, and other dense woody vegetation, can obscure signs of potential issues on an embankment or spillway, or prevent inspection altogether (ASDSO, 2018). Where a consistent, well maintained grass cover allows access to all areas of the embankment, and allows identification of issues from visual inspection, tall dense vegetation and trees can prevent this. Some of the issues that dense or woody vegetation can obscure include seepage, cracking, boils, sinkholes, slumping, settlement, deflection, displacement, animal burrows and other signs of stress. Even tall, poorly maintained grass cover can prevent identification of cracks and seepage. Trees and tall vegetation can provide shelter for burrowing animals, and the canopy of trees can hinder the growth of a consistent grass cover across the dam, which in turn could contribute to surface erosion.

4.2.2 Damage due to tree trunks

Unstable trees can cause damage to the structure of a dam through two methods: via uprooting and exposing the reservoir rim, spillway or downstream face to erosion and seepage; and via blocking the spillway, thus reducing the spillway capacity, and increasing the risk of overtopping.

USBR (2017) states that in high wind or storm events, trees (particularly those dead or dying) are susceptible to falling over. As a tree falls, it also dislodges the root ball and can pull out major structural roots. This creates a hole in the slopes, spillway, or embankment, leaves the soil under the roots exposed and, without the protection of topsoil or grass cover, is susceptible to erosion. This erosion could contribute to slip of the slopes, or failure of the spillway or embankment. Depending on the seepage line, if a hole is created on the downstream slope of an embankment this could provide a location for seepage to surface, encouraging piping erosion.

FEMA (2005) adds if trees are established on an embankment crest, their falling over could create a hole in the crest, thereby reducing the freeboard of the dam and increasing the risk of overtopping, as well as reducing the effective width of the dam.

DEW (2018) further notes that, in high flows trees can become dislodged, and if within or upstream of the spillway, can flow into and block the spillway. Particularly for small spillways or spillways without a trashrack, trees can significantly reduce the spillway capacity and heighten the risk for reducing the freeboard and overtopping.

If the trees flow into the spillway, they can further damage the spillway or outlet works. Trees lodged in a spillway (either standing or fallen over) can also redirect flow, compromising the hydraulic design of the spillway. This can result in turbulence and scouring if the spillway is not concrete lined, and during high flows through the spillway could increase damage to concrete surfaces.

USBR (1987) notes, while trashracks can reduce the risk of this occurrence, the potential for trees flowing into the spillway should still be considered in the management of trees upstream.

4.2.3 Damage due to tree roots

Issues arising from tree roots are often mentioned as the most significant risk of trees on downstream face of an embankment. The most well documented issue of tree roots is that they provide a path for internal erosion through an embankment. When tree roots grow into an embankment, they displace otherwise compacted soils with organic material. Fell et al. (2015) describes that when the tree dies, the roots decay and decompose, leaving soft, uncompacted organic soil to allow for leakage through or collapse of the above soil. As the roots decay they also shrink, leaving air pockets for additional seepage or collapse. FEMA (2005) also notes that as tree roots grow into compacted soil, they loosen the surrounding soil, thus compromising the compaction of the embankment. Additionally, larger trees are more likely to die while growing on an embankment; as they grow into the controlled section of the compacted embankment soils with lower nutrients, the tree will struggle to survive. However, this only occurs once tree roots have penetrated to a dangerous level into the dam, and the dying roots trigger the issues above. The key consequence of this is increasing the risk of piping through the embankment, and ultimately causing failure of the dam due to internal erosion.

Roots of living trees can also be an issue of concern. FEMA (2005) describes that tree roots do not survive in submerged condition (i.e., beneath the line of seepage in an earthfill dam where the moisture content is greater than 40%). However, as trees absorb moisture in the embankment, they could potentially lower the seepage line in the embankment. This can give a false perception of the level and rate of seepage through the embankment. Furthermore, FEMA proposes a scenario in which several trees are established along an embankment. If one tree dies due to some other cause, the same volume of groundwater is no longer being drawn and the seepage line will rise. This could rise to the level of the dead tree's roots and begin piping but could also rise to the level of the roots of other trees, effectively drowning them. This will result in further dead trees with decaying roots, exacerbating the problem.

Tree roots can also damage dam infrastructure including concrete works and pipework (ASDSO, 2018). Tree roots can exhibit significant force while growing, and the impacts of tree roots on concrete infrastructure, foundation rock and pipework is well documented. While tree roots may not create cracks in concrete or pipework, they can grow into existing weaknesses and cracks, and exacerbate the issue. Tree roots can also damage structural works through uplifting or displacement. These issues should continue to be considered in conjunction with the other issues caused by tree roots on dam sites.

Fell et al. (2015) also states if trees are allowed to grow sufficiently close to underdrainage systems, there is the potential the roots might grow into and block the underdrainage pipework. It is well documented through issues occurring on gravity sewer mains that tree

roots target sources of water, and due to the lack of pressurisation or protection around many underdrainage systems, tree roots may lodge within underdrainage systems if close enough. This will impair the ability for underdrainage to be measured and identify areas of concern.

5 Allowable Clearance for Trees

It is generally agreed that trees and woody vegetation are not allowed to establish themselves on the embankment of an earthfill dam or in a spillway (Fell et al., 2015). Additionally, any trees that will have a detrimental effect to the operation of the dam (e.g., trees on the approach to the spillway or close to it that may fall over, trees near concrete infrastructure, etc.) shall also be removed or remediated as appropriate. However, trees can also cause some of the above issues while not being on or directly adjacent to the dams or their appurtenant structures. In particular, roots of trees beyond the downstream toe of an embankment can still extend into the embankment, decay, and cause internal erosion.

5.1 Background

There is a lack of consensus regarding the required clearance between trees and earthfill dams, with many dam design guidelines providing generalised recommendations that trees should be kept away from dam infrastructure and/or assessed by a qualified specialist, e.g., Fell et al. (2015) and USBR (1987). As there are several factors which can affect the "safe" clearance for a tree (species of tree, conditions for tree growth, operation and maintenance of the dam, health of the tree), a few different specifications exist for minimum clearance that are reviewed in this section.

FEMA (2005) have recommended the following guidelines:

- Existing trees are to be removed and not be allowed to mature on earthen dams, abutment groins, or around water conveyance structures, in particular on the upstream face, the lower half of the embankment and the downstream toe (piping is less likely to occur from tree roots on the crest and the upper half of the embankment).
- Trees are not to be established downstream of an embankment within half the height of the dam.
- Existing trees should be watched closely until they are removed.
- Grasses and shallow rooted native vegetation are the most desirable surface covering for an earthen dam.

USBR (2017), while not directly applicable to dam embankments, specifies no trees may be established in the canal prism or within 6.1 m of the embankment, that limits the inspection and detection capabilities.

DEW (2018) specifies that if large deep-rooted trees and heavy vegetation are already present on or near the dam, advice should be sought from a suitably qualified and experienced dams engineer about whether they should be removed and the appropriate method.

DPIPWE (2008) specifies that in addition to trees in general, Eucalyptus trees are of particular concern. As a rule of thumb, trees and shrubs should be kept to a minimum distance of 1 ½ times the height of the tree away from the embankment of the dam. This applies especially to Eucalyptus.

Melbourne Water (2016) specifies the minimum clearance between trees and other large or woody vegetation, and areas of concern is 3 m, measured from the canopy of the tree. A summary of Melbourne Water (2016) recommendations is provided in Table 1.

Table 1: Melbourne Water (2016) embankment vegetation guidelines

Embankment Vegetation Guidelines		Established Trees	New Trees/Bushes	Existing Bushes	Slashed Grass	Ground Cover/Non-Slashed Grass
Hazard Rating	Location	Acceptable Vegetation √ Not Accepted x				
High	Constructed Embankment (top and both faces) including abutment region	x	x	x	√	x
	Minimum 3 m Clear of embankment Toe	x	x	x	√	x
	Slope Areas in Cut (non-embankment Areas	√	√	√	√	√
	Floor of Basin (min 3 m clear of embankments/spillway structure)	√	√	√	√	√
	Structures (min 3 m clear of spillway/outlet structures)	x	x	x	√	√
Low	Constructed Embankment (top and both faces) including Abutment region	√	x	x	√	√
	Minimum 3m Clear of embankment Toe	√	x	x	√	√
	Slope Areas in Cut (non-embankment Areas	√	√	x	√	√
	Floor of Basin (min 3 m clear of embankments/spillway structure)	√	√	x	√	√
	Structures (min 3 m clear of spillway/outlet structures)	x	x	x	√	√

DELWP (2018) provides general guidelines related to the clearance of trees from small dams, noting that these are not comprehensively researched specifications. NRM (2011) has also adopted these guidelines for small dams. These guidelines are summarized below:

- Trees are to be set back from the high-water mark.
- Trees should not be allowed to establish within 5 m, or the anticipated height of the mature growth of the tree (whichever is greater), of the dam embankment or spillway.
- The flight path, or line of inlet is to be kept clear of trees.
- During construction, all trees are to be cleared around any embankment, spillway, or other relevant works.

As can be seen above, the key discrepancy between resources is the required clearance from areas of concern, in particular the clearance from the downstream toe of the dam. Table 2 summarises the minimum clearances from the downstream toe of the dam based on all reviewed resources.

Table 2: Clearance from the downstream toe of the dam based on different resources

Source	Minimum Clearance
FEMA	0.5 x Height of the embankment
NRM	5 m or the height of the mature tree (whichever is greater)
USBR	6.1 m
DEW	Seek advice
DPIPWE	1.5 x Height of the mature tree
Melbourne Water	3 m (measured from canopy of tree)

Based on this review of different resources, a recommended approach for SA Water assets is provided in Section 5.2.

5.2 Recommended Approach

SA Water has several earthfill dams of different functions, materials, and local environments. Understanding and awareness of the hazards growing on earthfill embankments and within spillways is well documented, and preventive measures, such as regular inspections and maintenance of riprap or grass cover are well established. However, there appears to be a lack of specification in SA Water as to what an acceptable minimum clearance for trees is, and in which circumstances certain remediation is required.

It is accepted and understood by SA Water staff that trees should not be allowed to establish directly on embankments and within spillways. However, based on the information above, it is recommended that trees also be cleared within the approach to the spillway or along the adjacent slopes, i.e., in areas where during high flows the tree might feasibly fall over and flow into the spillway. It is also appropriate to specify a required clearance from areas of concern due to issues relating to roots.

The two key issues arising from tree roots are the risk of internal erosion caused by decaying roots and damage to infrastructure caused by root intrusion. While these have different risks, effects and proposed remediation, the possibility of issues is governed by the extent the roots can reach. FEMA's specification for clearance is based on the height of the embankment, and while this may be appropriate for large dams, this clearance may be insufficient for smaller embankments, and provides no guide for other assets. Additionally, a set distance from the final trunk of the tree does not consider the size of the tree and may either be excessively conservative for small trees or insufficient for large trees. Furthermore, a set distance does not consider the root behaviour of different tree species, such as Eucalypts. Given this, a set distance based on the size, height and/or species would provide the most precise guidelines for the clearance of the tree.

Based on the recommendations above, the specification below is proposed to determine the minimum clearance from the downstream toe of the dams:

For Non-Eucalypts:

$$D \geq \max(0.5H_1, H_2, 5m) \text{ as per Figure 1}$$

For Eucalypts:

$$D \geq \max(0.5H_1, 1.5H_2, 5m) \text{ as per Figure 1}$$

Where: -

- D is the required minimum distance from the toe of the embankment to the edge of the trunk of the tree (in metres)
- H_1 is the height of the embankment (in metres)
- H_2 is the height of the tree (in metres)

Note that over time the size of the trunk and height of the tree will change. Therefore, if there is a partially grown tree or sapling near to this minimum distance, action should be taken to prevent the tree growing to within the minimum distance.

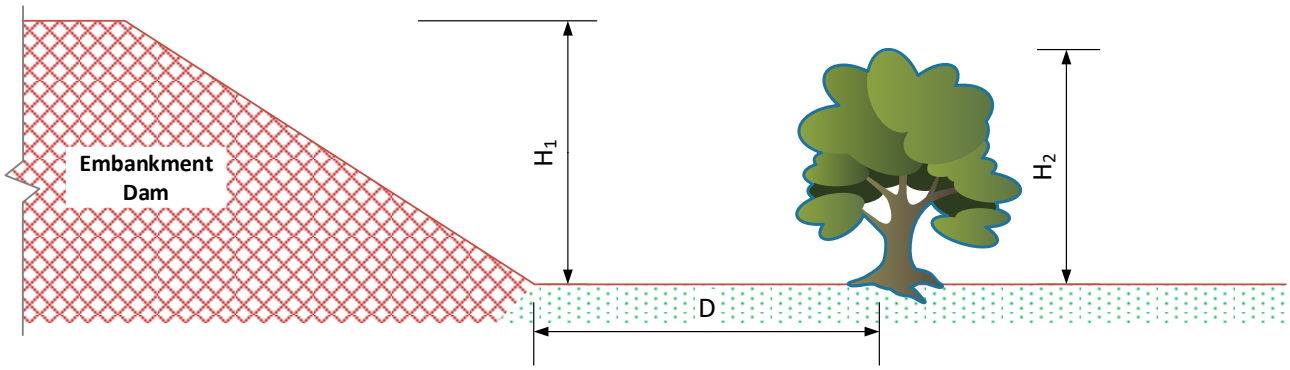

Figure 1: Required parameters to identify tree clearance

6 Tree Remediation Procedure

6.1 Tree remediation

Ideally, trees should not be allowed to establish in areas of concern in the first place. Full removal of the vegetation prior to construction (Fell et al., 2015), as well as regular maintenance of the dam to prevent establishment of large trees and removing the trees when they are small (as specified by ANCOLD guidelines), is the safest and most cost-effective option.

ASDSO (2018) and FEMA (2005) describe a few warning signs which indicate a tree is causing issues. Key indicators include:

- Water discharging near the roots of a living or dead tree.
- Trees that are uprooted on the embankment or abutments or in the valley bottom immediately downstream of the dam.
- Dead trees (the rotting roots of which may become avenues of internal erosion) on the embankment or abutments or in the valley bottom immediately downstream from the embankment.
- Decaying/dead branches, lightning-caused splits, stripping or breakage, leaning/uprooted/blown-down trees, seepage around exposed tree roots.

If trees do become established and pose an issue, there are several options for remediation. It may appear intuitive to immediately cut down or pull out any trees that may be of concern, however DEW (2018) and FEMA (2005) note there are potential issues with these methods if an appropriate procedure is not followed. If trees with potentially decaying roots are cut down without treatment of the stump, this will only expedite the decay, and may cause the seepage line to rise, causing further issue. Furthermore, fully removing the tree and root system without remediation of the surface will leave the area prone to erosion and possibly allow a route for seepage to surface if the excavation is significant.

ASDSO (2018) specifies that herbicides and chemical spraying are not to be used, either for removal of trees or of grass management, on a grass covered embankment. Chemical treatment may be used for management of vegetation within riprap; however, this should be done in conjunction with the appropriate guidelines using approved products. If this treatment is approved for trees, the tree shall be cut down as close to the stump as possible prior to applying treatment.

FEMA (2005) and USBR (2017) describe two typical options for remediation of trees:

- Option 1: Removal of the entire tree, including excavation of the root ball and all significant roots (greater than 12 mm diameter), followed by appropriate reinstatement of ground cover (compaction, topsoil and seeding). In this option, the following procedure should be adopted:
    - The tree should first be stripped of branches and the area be cleared of debris and leaf litter.
    - The tree should then be cut down to 600 mm above ground level. This provides an indication of where the tree is for later excavation and will provide an anchor point for further excavation.
    - If there is significant time after the tree being cut, apply a protective coat to the stump to preserve the moisture in the stump and to prevent root decay in the interim.
    - Tie the stump via a chain or cable to a backhoe and pull out the remaining tree stump and root ball, and any key structural roots.

    - A trench is to be dug to excavate all remaining large roots (greater than 12 mm diameter). This trench should have a flat base and walls at a 3H:1V slope. This excavation should continue until all large roots are removed.
    - The area is to be filled and compacted as per the requirements of the area, then covered with topsoil and revegetated as appropriate.
- Option 2: Removal of tree down to the base stump, to ground surface level, treated to prevent root decay, followed by reinstatement of surface material. In this option, the following procedure should be adopted:
    - The tree should be stripped of branches and the area be cleared of debris and leaf litter.
    - The tree should then be cut down to ground level.
    - If the tree roots may cause some low-level issue, apply a protective coating to prevent decay of the tree root.
    - The area is to be filled and compacted as per the requirements of the area, then covered with topsoil and revegetated as appropriate.

ASDSO (2018) also describes a slight variant on Option 2, whereby the stump is cut to 150 mm below ground level.

In general, Option 1 should be used where the tree is causing significant issue, or there are large roots that are currently, or are likely to, cause seepage or damage of assets (as in Clause 4.2.3). Option 2 may be used where the primary concern is the lack of visibility or access to the area, or the risk of damage due to uprooting and consequent damage by the main trunk of the tree. Each tree should be assessed as a unique scenario, and trees of particular concern should be assessed by a qualified specialist, however the conditions below serve as a guide whether Option 1 or Option 2 is more appropriate.

Option 1 should be used where:

- Trees are on the upstream face of the embankment.
- Trees are on the crest or upper $^1/_3$ of the embankment with a trunk diameter greater than 200 mm.
- Trees are on the lower $^2/_3$ or beyond the downstream toe of the embankment with a trunk diameter greater than 100 mm.
- Tree roots are the cause of concern, and decay of tree roots will contribute to the issue.
- Any other circumstance requires the tree to be fully removed, or there is sufficient concern for the tree to be fully removed.

Option 2 should be used where:

- Trees are obstructing the ability to inspect assets, but otherwise are no cause for concern.
- Trees are at risk of falling over and causing damage, but the decay of roots is not expected to cause an issue.
- Trees are at risk of falling over and causing blockage of spillway.
- Trees are on the crest or upper $^1/_3$ of the embankment with a trunk diameter less than 200 mm.
- Trees are on the lower $^2/_3$ or beyond the downstream toe of the embankment with a trunk diameter less than 100 mm.

FEMA (2005) further acknowledges that external factors and stakeholders may influence details of the appropriate remediation and should be considered.

FEMA (2005) also states that the reason for removal is identified. For instance, weeds and tall grasses on an embankment will hinder the ability to inspect the surface, however the roots will

not affect the structural integrity. By contrast, woody vegetation in the same area may affect the structural integrity.

6.2 Ongoing Preventive Measures

Once appropriate removal and remediation has been completed, ongoing maintenance and preventive measures should be considered. As an alternative to the allowance of trees or woody vegetation being allowed to grow in undesirable areas, Fell et al. (2015) suggests a well-maintained grass cover be established, cut regularly, and kept cut lower than 150 mm. This is also consistent with recommendations of SA Water's TG0641. USBR (1987) suggests, due to the uncertainty of applying adequate vegetative cover, cobble or rock protection is generally preferred. Grasses should be appropriate to local conditions, and only if maintained appropriately can be effective.

Additionally, FEMA (2005) notes that many trees perform better in loosely compacted soils, as dense soils require additional work for trees and often have less available pore water and oxygen. Therefore, one of the best ways to prevent trees establishing is to ensure the embankment fill is well compacted. A proper compaction will still allow grasses to grow to protect the embankment as their roots only penetrate topsoil.

There are several other options to further prevent the establishment of large vegetation, including:

- Establishing minimum clearances as specified in other sections.
- Intelligent design, minimising available soil material faults and tree root spaces, to prevent trees being able to establish.
- Root Kill Zones to prevent the spread of the tree. Note this option may kill the tree, and as such should not be used where the death of the tree will cause ongoing issues. Any chemicals used in root kill zones shall be approved and re-establishment of any grass cover shall be used afterwards.
- Maintenance mowing to ensure the grass cover is suitably maintained.
- Root barriers to control the growth and expansion of a tree. This can include air-gap systems, as well as root traps/deflectors, containment devices, metals, screens, plastics, paints, and inhibitors.
- Lining of the storage to prevent intrusion or seepage. This is appropriate for smaller embankments, such as EBSs.
- Directed Growth systems to guide roots away from areas of concern. Directed growth consists of creating preferential and non-preferential environments for vegetation to attract, deflect, channel or lead roots in certain directions. In this case, desirable environmental conditions could be created away from dam assets to encourage roots to avoid dam and its infrastructure.
- Selection of species of vegetation that are unlikely to cause issues.

6.3 Recommended Approach

Removal of trees before they are established is also well understood and managed by SA Water Operations staff. As such, established trees of concern do not regularly need to be remediated, as they are removed proactively. However, in cases where trees are of concern, there is no standard documentation for the safe removal of this tree. Options 1 and 2 provided in Section 4.1 appear to address the key points of concern and may be beneficial as a guide in the development of a standard tree removal procedure.

Post-remediation, there are a wide range of maintenance and prevention measures proposed. Given SA Water's current practice of maintenance of the downstream face and installing a liner or other protection on the upstream face, many of these options may not be

relevant. As SA Water's embankments are well constructed and generally well maintained, and there is generally no need to preserve trees where they are causing issue, use of remediation measures to preserve a tree whilst managing problem roots is unlikely to be a regular occurrence. As such, the preferred options in preventing tree growth in problem areas appear to be regular maintenance of riprap or grass cover (and the downstream face in general), removal of trees before they establish in problem areas, and maintenance of the upstream lining/protection and embankment compaction. Any other forms of remediations may be used on a case-by-case basis.

SA Water has collected data about extent of tree roots in investigations into sewer main blockages. In the internal SA Water document Incident Management Adjacent Trees SOP, the tree protection zone (TPZ, i.e., the extent of tree roots which govern the health of the tree) is defined as a function of the tree trunk circumference. Table 3 represents these values.

Table 3: Typical Tree circumference and Tree Protection Zone

Tree Size (circumference in m)	Radius of SRZ (m)	Radius of TPZ (m)
1	2	3.8
1.5	2.4	5.7
3	2.7	7.6
2.5	3	9.5
3	3.2	11.5
3.5	3.5	13.4
4	3.8	15

This information can also be used to understand how far the tree roots might extend around the main trunk.

7 Summary

Trees and vegetation on dam sites can provide several benefits to reservoirs and earthfill embankments, including providing shelter and feeding areas for fish and other wildlife, managing sediment flowing from upstream and acting as windbreaks to reduce erosion. However, issues have been identified in trees and woody vegetation growing in problem areas and potentially contributing to dam safety concerns. These include:

- Obstruction of the ability to access and inspect earthfill embankments and other areas of the dam,
- Damage caused by trees falling and uprooting,
- Blockage of the Spillway as felled trees flow into the spillway path,
- Internal erosion caused by tree roots in embankments,
- Structural damage caused by tree roots.

As such several clearance requirements are specified in the literature:

- No Trees allowed to grow on a Dam embankment or Spillway.
- No Trees allowed to grow along spillway approach.
- No Trees allowed to grow within a specified clearance downstream of the embankment, or from other structural works.
- Advice to be sought for trees of concern on a case-by-case basis.

The required clearance of the trees from the earthfill dams is specified in Section 5.2. This clearance depends on the height of the dam, height of the tree, and type of the tree.

While it is recommended these guidelines are adhered to, there may exist situations where a tree has been allowed to establish in an area of concern and will need to be removed. Two Options for tree removal are presented:

1. Removal of the entire tree, including excavation of the root ball and all significant roots (greater than 12 mm diameter), followed by appropriate reinstatement of ground cover (compaction, topsoil and seeding). This is recommended where the tree is causing significant issues, or the decay of roots is likely to cause further issues.

2. Removal of tree down to the base stump, to 150 mm below the surface, treated to prevent root decay, followed by reinstatement of surface material. This is recommended in cases where the tree roots are not causing issues or are unlikely to cause future issues.

SA Water Dams Engineering or Asset Management Dams Surveillance team should be consulted any time that any digging occurs, or any tree is earmarked for removal from an earthen embankment dam.

After a tree has been removed, several preventive measures may be proposed, these include:

- Regular maintenance of riprap or grass cover (and the downstream face in general),
- Removal of trees before they establish in problem areas and maintenance of the specified minimum clearances,
- Maintenance of the upstream lining/protection and embankment compaction,
- Establishment of root kill or exclusion zones,
- Installation of root barrier systems.