LIVING STREAM LITE

SUMMARY REPORT

PIPPA CONSTABLE

NATURELINK INTERN

2022

Living Stream Lite: Summary Report

Acknowledgements

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Cover Images: Pippa Constable, 2022
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1. SUPPORT TOOL REFERENCE GUIDE

This summary report has been developed in association with support tools to enable the implementation of the proposed design 'Living Stream Lite'. This document provides an in-detail review of the design and available literature that supports the information and advice supplied in these tools.

The supplementary documents are:

- *Living Stream Lite: Information Support Tool (Part 1)*
- *Living Stream Lite: Practical Support Tool (Part 2)*

Provided here is a reference guide to assist in locating the relevant contextual information for the support tools throughout this report.

LIVING STREAM LITE: INFORMATION SUPPORT TOOL (PART 1)

LIVING STREAM LITE
Information Support Tool

PART 1 OF 2

PURPOSE

In light of escalating climate change, increasing pressure from urbanisation, and accelerated loss of both biodiversity and natural green spaces in Perth city, there has never been a more crucial time to explore and rapidly execute blue-green initiatives. A fast and efficient solution is broad scale tree planting within existing stormwater drains to establish native tree canopy. The Living Stream Lite design simplifies existing revegetation processes to the planting of a single species, the native swamp paperbark (*Melaleuca rhaphiophylla*) along open stormwater drains. The aim of this project is to expedite positive environmental outcomes for biodiversity, connectivity, urban heat, and human health, while continuing to support the primary function of drainage systems across Perth and preserve the potential for future comprehensive living stream conversions. This information support tool, jointly developed by the Water Corporation and NatureLink Perth, presents the environmental context and design considerations that support the implementation of Living Stream Lite tree planting projects in suitable Water Corporation assets, and should be paired with the Living Stream Lite: Practical Support Tool document.

BACKGROUND

In the context of global climate change and urbanisation driven by migration towards urban centres, it is unsurprising that the population of Western Australia is rapidly growing, with much of this growth occurring in the greater Perth region. Unfortunately, the necessary development required to accommodate this expanding population is driving a loss of biodiversity in this global biodiversity hotspot, as natural habitats are degraded and significantly fragmented through land use changes. In conjunction, increased anthropogenic activity in the urban landscape is contributing to increased climate impacts that negatively influence both the unique local ecosystems, and the liveability of these built environments. The detrimental changes that are occurring include:

- Loss of critical habitat and connectivity of fauna refuges
- Loss of ecosystem balance resulting in increased presence of invasive species that outcompete or negatively impact native and endemic species
- Presence of weed species that disrupt the functioning of built infrastructure like drainage systems and reduced community aesthetics (e.g., algal blooms)
- Increased urban heat island effect, resulting in increased water, surface and air temperatures throughout built environments due to a lack of shade and heat absorption from vegetation
- Frequent and more destructive weather events, which negatively affect built infrastructure like drains through increased erosion and structural damage
- Increased pollutants emitted in urban centres, and increased carbon emissions globally
- Impaired hydrological cycling and reduced water quality due to increased impervious surfaces in urban landscapes
- Loss of human connection to the environment, leading to reduced health and wellbeing outcomes
- Increased negative health outcomes relating to climate change (especially temperature related)

ACRONYMS

WC - Water Corporation BAL - Bushfire Attack Level EOL - End of Life
LG - Local Government DPLH - Department of Planning, Lands and Heritage

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SECTION 3.1 & 3.2, INTRODUCTION, PG. 8

BENEFITS

The Living Stream Lite design maximises environmental benefits while minimising the time taken to achieve those benefits. This lite version of living stream revegetation retains many of its comprehensive counterparts ecological, climate and community services, as well as providing value to the functioning of stormwater drainage systems.

Ecological

- Increases biodiversity and rebuilds connectivity between urban green spaces, facilitating the movement and survival of local flora and fauna
- Provides refuge, habitat and resources for native aquatic and terrestrial species
- Contributes to nutrient cycling and promotes soil biodiversity and health through increasing available organic matter
- Reduces growth of weed species via shading of stream bank and watercourse

Community

- Improves community health and wellbeing through people's interaction with nature and proximity to green space.
- Buffers local urban climate change impacts (especially reduced heat) to reduce negative health outcomes in the community
- Improves aesthetics of urban spaces

Environmental

- Increases capacity for carbon sequestration and contributes to filtration of air pollutants
- Increases urban cooling effects through shading of water and ground surfaces and transpiration (reducing water, surface, and above ground air temperatures)
- Increases infiltration and canopy interception of precipitation to promote a slower, more natural hydrological cycle, reducing impact of extreme events, erosion and improving water quality
- Contributes to improving water quality of stormwater runoff through trapping or removing pollutants

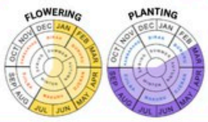
Logistic

- Provide erosion control and bank stabilisation
- Reduce weed infestations that limit drain operability

SWAMP PAPERBARK

Southwest WA's endemic *Melaleuca rhaphiophylla* (Noongar: Bibool Boorn, Yowarl, or Yiembak) has been carefully selected for Living Stream Lite for its wide-ranging ecological values and its low impact structure.

SALINITY TOLERANT ☑
FLOOD TOLERANT ☑
NON-INVASIVE ROOT SYSTEM ☑
EVERGREEN ☑



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SECTION 6.1, BENEFITS OF LIVING STREAM LITE, PG. 22

SECTION 6.1d, LOGISTICS, PG. 28

DESIGN CONSIDERATIONS

Maintain Function of Drain

The primary purpose of stormwater drainage systems is to protect housing and infrastructure up to the 1:10 year storm event (noting that local governments are responsible for protection above this level and sometimes this is achieved through the same drainage corridor). The planting of trees should not directly compromise the flood protection provided, nor should the presence of trees impact the structure or function of the drainage system in the short or long-term.

Maintain Safe and Efficient Serviceability

To ensure that stormwater systems can function to their full capacity when required, the Water Corporation requires access to maintain the hydraulic capacity of these systems. The planting of trees should not compromise the ability for this maintenance work to be carried out safely and efficiently.

Manage Land Agreements and Insurance Risk

The Water Corporation's land portfolio is composed of Crown land, freehold land and land owned by another agencies with easement rights provided. The appropriate access arrangements are therefore required to allow local government access to sites for planting and ongoing maintenance requirements. Access agreements for planting and maintenance, as well as risk and insurance responsibilities, should be clearly defined prior to the planting of trees.

When considering land matters in the context of this initiative, land may be categorised to the following agreement negotiation effort level:

1. Low: Land with which the LG already has access
2. Medium: Land that this currently owned by WC (freehold)
3. High: Crown land with which the local government has no current access rights to (requires approval through DPLH, with a processing time of approximately 12-24 months)

Engage Community

While there is a strong argument in favour of tree planting, and the beneficial ecosystem services they provide, it is noted that local governments are closest to their communities and are best placed to make decisions on their behalf, for what are socially acceptable locations for tree planting. Wherever possible, tree planting should take into consideration the concerns and requirements of the local community and adjacent land holders.

Protect Existing Assets

The Water Corporation owns and maintains both below and above ground assets that provide critical services to the local community, including drinking water, wastewater removal and stormwater conveyance. The planting of trees should not compromise the structure or function of any existing assets or impede the safe and efficient replacement of these assets at EOL.

Manage Safety

The existing risk profile of the drain should be maintained to ensure the safety of existing assets and the local community. This includes consideration of fire risk within the system, BAL rating implications for neighbouring infrastructure, and CPTED requirements. The planting of trees should not alter the risk profile of Water Corporation owned or managed land, and trees should be maintained to preserve this risk profile over time.

Maintain Trees

Trees have maintenance requirements to ensure their establishment and longevity, in addition to those for the mitigation of safety risks. The location of trees, once planted, should be logged for periodic assessment and maintenance. The responsibility for the tree and its maintenance falls with the local government and should be carried out as per the management guidelines for street trees under their administration.

All information provided in this support tool was sourced from *Living Stream Lite: Summary Report* (Constable, 2022)
Image credit: Pippa Constable 2022

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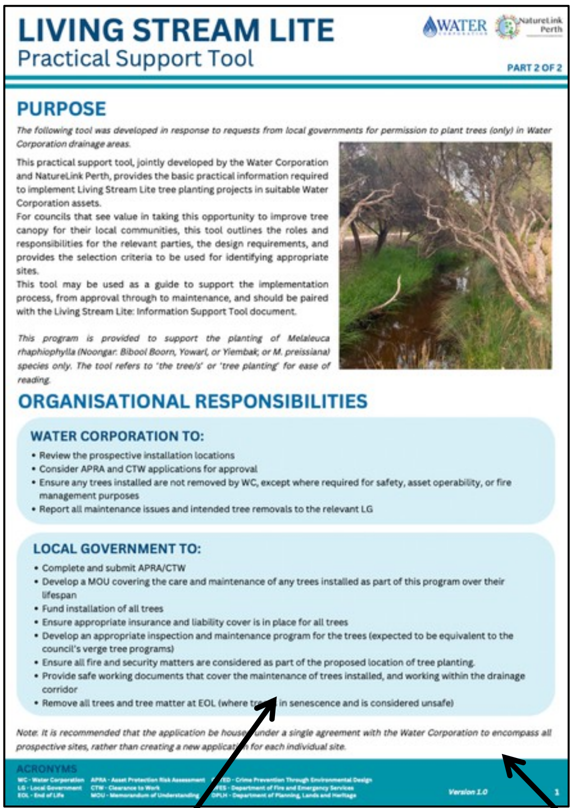
SECTION 4.3, DESIGN CONSIDERATIONS, PG. 14

LIVING STREAM LITE: PRACTICAL SUPPORT TOOL (PART 2)



LIVING STREAM LITE
Practical Support Tool

PART 2 OF 2

PURPOSE

The following tool was developed in response to requests from local governments for permission to plant trees (only) in Water Corporation drainage areas.

This practical support tool, jointly developed by the Water Corporation and NatureLink Perth, provides the basic practical information required to implement Living Stream Lite tree planting projects in suitable Water Corporation assets.

For councils that see value in taking this opportunity to improve tree canopy for their local communities, this tool outlines the roles and responsibilities for the relevant parties, the design requirements, and provides the selection criteria to be used for identifying appropriate sites.

This tool may be used as a guide to support the implementation process, from approval through to maintenance, and should be paired with the Living Stream Lite: Information Support Tool document.

This program is provided to support the planting of Melaleuca rhaphiophylla (Noongar: Bibool Boorn, Yowarl, or Yiembak; or M. preissiana) species only. The tool refers to 'the tree/s' or 'tree planting' for ease of reading.

ORGANISATIONAL RESPONSIBILITIES

WATER CORPORATION TO:

- Review the prospective installation locations
- Consider APRA and CTW applications for approval
- Ensure any trees installed are not removed by WC, except where required for safety, asset operability, or fire management purposes
- Report all maintenance issues and intended tree removals to the relevant LG

LOCAL GOVERNMENT TO:

- Complete and submit APRA/CTW
- Develop a MOU covering the care and maintenance of any trees installed as part of this program over their lifespan
- Fund installation of all trees
- Ensure appropriate insurance and liability cover is in place for all trees
- Develop an appropriate inspection and maintenance program for the trees (expected to be equivalent to the council's verge tree programs)
- Ensure all fire and security matters are considered as part of the proposed location of tree planting.
- Provide safe working documents that cover the maintenance of trees installed, and working within the drainage corridor
- Remove all trees and tree matter at EOL (where tree is in senescence and is considered unsafe)

Note: It is recommended that the application be housed under a single agreement with the Water Corporation to encompass all prospective sites, rather than creating a new application for each individual site.

ACRONYMS
WC - Water Corporation | APRA - Asset Protection Risk Assessment | CPTED - Crime Prevention Through Environmental Design
LG - Local Government | CTW - Clearance to Work | DFES - Department of Fire and Emergency Services
EOL - End of Life | MOU - Memorandum of Understanding | DPLH - Department of Planning, Lands and Heritage

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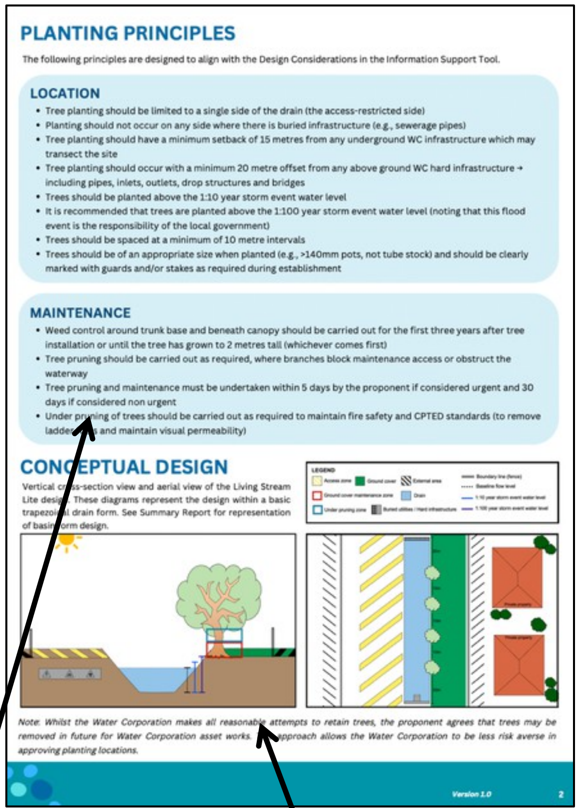

PLANTING PRINCIPLES

The following principles are designed to align with the Design Considerations in the Information Support Tool.

LOCATION

- Tree planting should be limited to a single side of the drain (the access-restricted side)
- Planting should not occur on any side where there is buried infrastructure (e.g., sewerage pipes)
- Tree planting should have a minimum setback of 15 metres from any underground WC infrastructure which may transect the site
- Tree planting should occur with a minimum 20 metre offset from any above ground WC hard infrastructure → including pipes, inlets, outlets, drop structures and bridges
- Trees should be planted above the 1:10 year storm event water level
- It is recommended that trees are planted above the 1:100 year storm event water level (noting that this flood event is the responsibility of the local government)
- Trees should be spaced at a minimum of 10 metre intervals
- Trees should be of an appropriate size when planted (e.g., >140mm pots, not tube stock) and should be clearly marked with guards and/or stakes as required during establishment

MAINTENANCE

- Weed control around trunk base and beneath canopy should be carried out for the first three years after tree installation or until the tree has grown to 2 metres tall (whichever comes first)
- Tree pruning should be carried out as required, where branches block maintenance access or obstruct the waterway
- Tree pruning and maintenance must be undertaken within 5 days by the proponent if considered urgent and 30 days if considered non urgent
- Under pruning of trees should be carried out as required to maintain fire safety and CPTED standards (to remove ladder fuels and maintain visual permeability)

CONCEPTUAL DESIGN

Vertical cross-section view and aerial view of the Living Stream Lite design. These diagrams represent the design within a basic trapezoidal drain form. See Summary Report for representation of basin form design.

Note: Whilst the Water Corporation makes all reasonable attempts to retain trees, the proponent agrees that trees may be removed in future for Water Corporation asset works. This approach allows the Water Corporation to be less risk averse in approving planting locations.

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SECTION 4.1, LIVING STREAM LITE, PG. 11

SECTION 4.3, DESIGN CONSIDERATIONS, PG. 14

SECTION 4.2, CONCEPTUAL DESIGN, PG. 12

SITE GRADING SYSTEM

SIMPLE
Drains that possess **no or few** elements of complexity, that require no additional planning or consideration. These drains can be considered directly suitable for this program.

MODERATE
Drains that possess **some** elements of complexity, and require some additional planning or consideration. These drains can be considered suitable for this program where additional issues are addressed.

COMPLEX
Drains that possess **many** elements of complexity, that require much additional planning and consideration. These drains would not be considered suitable for this program.

EXAMPLE SITES

SIMPLE

SIMPLE

MODERATE

COMPLEX

*Note: This tool does not replace the local government seeking advice from the Drainage for Liveability Team. The local government is still required to seek the following where applicable: **1)** APRA, **2)** CTW approval, **3)** Land Agreement to use and access Water Corporation land, **4)** other local, state, or federal approvals as required by regulations and laws.*

Use of this tool assumes the local government is confident it has the capacity and capability to partner in the program.

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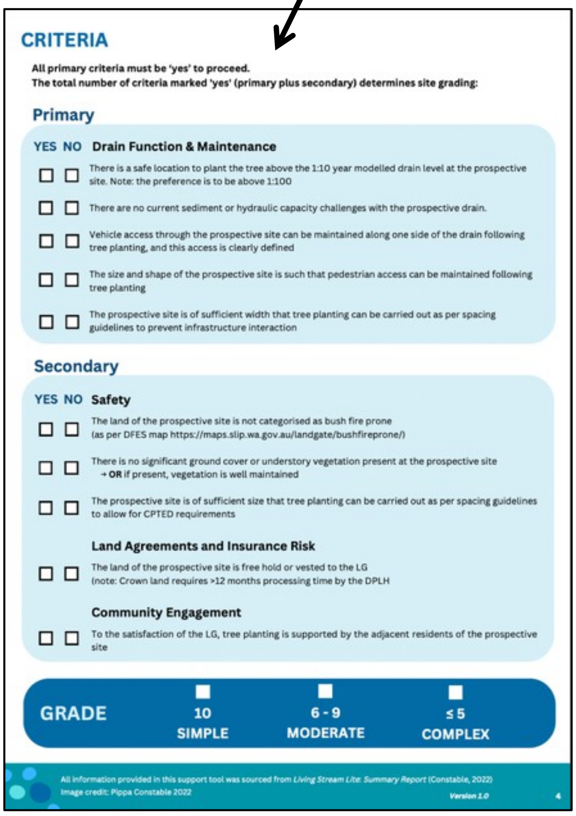

CRITERIA

All primary criteria must be 'yes' to proceed.
The total number of criteria marked 'yes' (primary plus secondary) determines site grading:

Primary

YES	NO	Drain Function & Maintenance
☐	☐	There is a safe location to plant the tree above the 1:10 year modelled drain level at the prospective site. Note: the preference is to be above 1:100
☐	☐	There are no current sediment or hydraulic capacity challenges with the prospective drain.
☐	☐	Vehicle access through the prospective site can be maintained along one side of the drain following tree planting, and this access is clearly defined
☐	☐	The size and shape of the prospective site is such that pedestrian access can be maintained following tree planting
☐	☐	The prospective site is of sufficient width that tree planting can be carried out as per spacing guidelines to prevent infrastructure interaction

Secondary

YES	NO	Safety
☐	☐	The land of the prospective site is not categorised as bush fire prone (as per DFES map https://maps.slip.wa.gov.au/landgate/bushfireprone/)
☐	☐	There is no significant ground cover or understory vegetation present at the prospective site → **OR** if present, vegetation is well maintained
☐	☐	The prospective site is of sufficient size that tree planting can be carried out as per spacing guidelines to allow for CPTED requirements
		Land Agreements and Insurance Risk
☐	☐	The land of the prospective site is free hold or vested to the LG (note: Crown land requires >12 months processing time by the DPLH
		Community Engagement
☐	☐	To the satisfaction of the LG, tree planting is supported by the adjacent residents of the prospective site

GRADE	☐ 10 SIMPLE	☐ 6 - 9 MODERATE	☐ ≤ 5 COMPLEX

All information provided in this support tool was sourced from *Living Stream Lite: Summary Report* (Constable, 2022)
Image credit: Pippa Constable 2022

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2. EXECUTIVE SUMMARY

Urbanisation is driving significant loss of biodiversity through habitat destruction and fragmentation, both globally and locally. Simultaneously, escalating anthropogenic activity is contributing significantly to climate change, resulting in negative outcomes for ecosystems and people. Considering the acute nature of these issues, there has never been a more important time to consider rapid greening initiatives to buffer these impacts, support our local biodiversity and combat climate change. For example, blue-green infrastructure, which falls under the umbrella of water sensitive urban design, is an increasingly attractive solution that can be employed in urban settings to combat these growing issues. By integrating natural and designed elements of the urban landscape, including water bodies and green and open spaces, this solution facilitates adaptive urban water management, while actively contributing environmental benefits such as improvements in air and water quality, aesthetics, urban cooling, and biodiversity.

The open stormwater drainage systems found across the greater Perth region present an opportunity to address these issues. The ecological value of riparian vegetation is well documented, playing a major role in the healthy functioning of water systems, and whose benefits can extend beyond waterways. As such, the conversion of urban drains into living streams is the paragon of water sensitive design. Unfortunately, full scale conversions can be complex and lengthy, and in the current environmental context, delays in solutions are increasingly undesirable. Consequently, there is immense value in exploring and implementing provisional measures, to achieve rapid climate change adaptation.

This report outlines the contextual knowledge that supports the implementation of a proposed blue-green solution: Living Stream Lite (LSL). This initiative is a stripped back version of traditional living stream conversions, focusing on a single basic element: riparian trees. Through the planting of locally endemic *Melaleuca rhaphiophylla* (swamp paperbark, Noongar: Bibool Boorn, Yowarl, or Yiembak) across suitable drain sites, considerable ecological, environmental, and social benefits can be gained. As an intermediary solution, this initiative aims to produce rapid benefits in a straightforward and cost-effective manner, while ensuring drains can retain the potential to be developed into full-scale living streams in the future.

This report has been produced in conjunction with two support tools designed to facilitate the implementation of LSL. The Information Support Tool (Part 1) provides a condensed summary of the need for rapid blue-green initiatives and the Practical Support Tool (Part 2) provides practical guidelines for implementation and appropriate site selection.

3. INTRODUCTION

3.1 GLOBAL CONTEXT

Urbanisation is one of the foremost destructive and persistent anthropogenic pressures faced by natural ecosystems, and it is escalating at an unprecedented rate (Garden *et al.,* 2006; Seto *et al.,* 2012).The number of people living in high-density urban settings globally more than doubled between 1975 and 2015, increasing to 3.5 billion inhabitants. With no signs of slowing, the number of people living in cities is projected to reach almost 55% of the population (5 billion) by the year 2050 (OECD European Commission, 2020). As urban populations continue to expand, so too do demands for residential, recreational, and industrial land use, driving the spread of urbanisation.

Urban expansion is a primary contributor to natural ecosystem degradation and results in severe environmental impacts. These include land use shifts leading to habitat loss and fragmentation with implications for biodiversity, disrupted hydrological systems, polluted air and waterways, disturbed local and regional climate, increased pests and disease, as well as a loss of invaluable ecosystem services (Scanes, 2018; Kelobonye *et al.,* 2019). As a consequence of rapid urban growth, anthropogenic activity is concentrated in urban centres, and as such has become a significant driver of climate change. This in turn has created a cyclical vulnerability of urban landscapes to the consequences of climate change, including extreme and unpredictable weather conditions, including flooding, wildfires, and heat waves (Maheshwari *et al.,* 2020).

3.2 LOCAL CONTEXT

The city of Perth, Western Australia is a prime example of centralised urbanisation, with 85% of the state's population residing in the greater Perth region (Wilkinson III *et al.,* 2022). This urban primacy is expected to increase due to accelerated urbanisation and increased migration to urban centres over the coming decades (Hiller *et al.,* 2013). The challenges of Perth's urban sprawl are further exacerbated by demand for land from Perth's rapidly growing population, along with its unique geographical, social, and cultural framework (Hiller *et al.,* 2013).

As a globally recognised biodiversity hotspot within the state's south-west region, Perth has a rich and unique biodiversity that is critically threatened by urbanisation and climate change (Hopper & Gioia, 2004). Through habitat destruction and fragmentation, urban sprawl contributes to increasing pollution, presence of invasive species and disease, inappropriate fire regimes, changes to hydrology and increased wildlife mortality through anthropogenic interactions (Australian Conservation Foundation, 2020). This has resulted in a loss of critical habitats, and a decline in the quality and connectivity of the habitat patches that remain

(Garden *et al.,* 2006). Consequently, there has been a significant loss of biodiversity within the city's urban matrix, and increasing local extinctions (Australian Conservation Foundation, 2020). The negative outcomes of habitat loss are exacerbated by the effects of climate change, including extreme temperatures, unpredictable weather, acute air and water pollution and disrupted ecosystem services. While these directly impact local biodiversity and the capacity of native species to persist in urban centres, they also significantly affect local communities. Poor environmental conditions and loss of urban green spaces detrimentally impact health outcomes and diminish the liveability of urban regions (Jabbar *et al.,* 2021).

To address the pressing liveability and sustainability challenges they face, cities like Perth need to proactively employ conscious urban planning and design, become more resilient to climate impacts, and improve their ecological footprint (Newton & Rogers, 2020). Doing so will produce numerous environmental benefits while also directly supporting local communities in the short and long term.

3.3 BLUE-GREEN URBAN DESIGN

In recent decades, urban planning has shifted towards 'green infrastructure', stressing the importance of connecting natural systems within and between urban landscapes, to preserve ecosystem function and value, and maximise positive social outcomes (Perini & Sabbion, 2016). Building from this, blue-green urban design calls for inclusive management of water, wastewater, and stormwater in connection with green spaces. These systems holistically provide high level services that supply and protect communities, facilitate climate change resilience, and ensure the health of local aquatic and terrestrial ecosystems (Brears, 2018). This approach is driving a departure from traditional urban water management, which has historically relied on hard grey infrastructure including dams and levees as the fundamental solution for risk mitigation. These traditional systems, while fulfilling their primary function, are non-adaptive, and often have concerning environmental and even economic implications, including deterioration of local hydrological cycles, negative downstream impacts, and degraded water quality (Perini & Sabbion, 2016; Brears, 2018). Even more pressing is the risk of out-dated infrastructure failing under the accelerating pressure of extreme weather events resulting from climate change (Brears, 2018).

As such, blue-green infrastructure (BGI) is an alternative that redefines the existing structural framework, integrating natural and semi-natural spaces that capitalise on ecosystem processes to provide social services and protect biodiversity (Brears, 2018). This ties directly into the approach of Water Sensitive Urban Design (WSUD), which incorporates a broader range of environmental and social objectives into urban planning and integrates nature-inspired concepts into the design of the built environment. Prior implementations of WSUD have emphasised the value of stormwater, through mechanisms that minimise runoff and supporting natural hydrological cycling, rather than focusing on conveyance and disposal like in traditional systems (Department of Water and Environmental Regulation, 2004; Brear, 2018)

3.4 OPPORTUNITIES

Stormwater drainage systems in Perth have been constructed over time as a combination of underground pipes and engineered linear overland flow paths to prevent flooding and support land development across the greater Perth region (Department of Water and Environmental Regulation, 2004). Kilometres of undeveloped open stormwater drains across Perth present a key opportunity to implement BGI initiatives, with increasing awareness of the management needs of stormwater systems and increasing recognition of the potential role these systems can play as environmental assets (Department of Water and Environmental Regulation, 2006). Over the last decade, the contemporary preference for land use in Perth has been shifting away from single function and moving towards flexible and multipurpose utility. This receptive socio-economic climate provides the opportunity to explore multi-functional approaches to management that can achieve more than just flood mitigation (Department of Water and Environmental Regulation, 2006). Stormwater drains are sites of relative permanence within urban matrices due to their fixed hydrological function, and therefore have the potential to support long-term sustainability strategies and maximise environmental and social benefits over time. This report explores a new, simple blue-green initiative: Living Stream Lite, that can capitalise on this land use opportunity and facilitate rapid climate change adaptation. The design is evaluated alongside comparative alternatives, considers long-term benefits and risks, and identifies potential future developments and research. The information presented within this report has been used to develop practical and informative support tools to facilitate the implementation of this initiative.

4. PROPOSED INITIATIVE

4.1 LIVING STREAM LITE

Living Stream Lite (LSL) is a blue-green initiative in which local governments across Perth can rapidly contribute positive environmental action through planting native *Melaleuca rhaphiophylla* (swamp paperbark, Noongar: Yowarl, Bibool Boorn or Yiembak) in simple open stormwater drains. In prescribing the framework of native tree planting, this initiative can expedite high ecological benefits, in a way that minimises risk of impediment to the functioning of the drain. Similar to full living stream conversions (via the Drainage for Liveability program), this project is designed to capitalise on the opportunity of available urban land presented by open stormwater drains. The difference, however, is that LSL is an accelerated, simplified version of the original living stream design that can be rapidly implemented across the Perth metropolitan region. The intention for this solution is not to replace full scale living stream conversions, but rather in act in a two-fold capacity to both 1) be a simple and rapid solution where the need for environmental action is pressing, and 2) to be a solution to fill opportunities where living stream conversions are unsuitable.

Given pressing climate change concerns, local governments have expressed a need for rapid and effective green initiatives. By focusing on a single core aspect of living streams, increasing riparian tree canopy in drainage systems, the complexity of the design and implementation process is significantly reduced, resulting in an initiative that is faster and simpler to execute. Specifically, LSL uses swamp paperbark trees, as they are a cornerstone of wetlands across the Swan Coastal Plain and have an immense capacity to produce ecological and environmental benefits (Pen & Hutchison, 1999; Powell, 1990). As such, they are perfectly placed to optimise the value of revegetation action and can be integrated independently into drainage systems.

Another critical aspect of this initiative is refining and expediting the site selection process in order to assist with balancing the need for acceptable flood management against the contemporary environmental threats faced by cities. Not all sites are appropriate for blue-green enhancement, due to a variety of both intrinsic and extrinsic factors and determining a suitable site can therefore be a complex and time-consuming process. As a result, a framework to facilitate appropriate site selection has been developed to assist the execution of LSL in a fast and effective manner. A series of simple site criteria have been composed to allow the ‘low hanging’ sites to be easily identified, and the complex sites to be flagged. Ultimately this can expedite projects through the identification and approval process, for both local councils and the Water Corporation.

4.2 CONCEPTUAL DESIGN

LSL has been designed to ensure three key factors:

1. The implementation process is simple and rapid.
2. The function of the drainage asset is upheld throughout the lifetime of the tree.
3. The maximum ecological and environmental benefits can be achieved from the tree installation given the above limitations.

Existing tree planting procedures and mechanisms necessitate a tailored approach for each drainage site. By contrast, LSL identifies the fundamental aspects for tree planting in drains without compromising hydraulic function, so they can be implemented broadly. As such, many of the design features are conservative, to ensure prompt approval and simple installation. Living Stream Lite has also been designed with the future prospects of drain sites in mind, and has attempted to minimise any potential impediments to future developments from tree installation.

The basic design elements are outlined below:

TREE

- Tree species to be used is *Melaleuca rhaphiophylla* (though *Melaleuca preissiana* has been deemed equivalent and potentially suitable where replacement is required).
- Trees to be planted should be of an appropriate size for establishment (e.g., >140mm pots, not tube stock).
- Trees should be clearly marked with guards and/or stakes as required during establishment.

LOCATION

- Tree planting should be limited to a single side of the drain (the access-limited side), to ensure there is always safe and easy access to the drain for maintenance purposes.
- Planting should not occur on any side where there is buried infrastructure (e.g., sewerage pipes).
- Tree planting should have a minimum setback of 15-metres from any underground infrastructure that may transect the site.
- Tree planting should occur with a minimum 20-metre offset from any above ground hard infrastructure (this includes all pipes, inlets, outlets, drop structures and bridges that comprise the drainage asset).
- Trees should be planted above the 1:10 year storm event water level (it is recommended that trees are planted above the 1:100 year storm event water level, as this flood level is the responsibility of the local government).
- Trees should be spaced at a minimum of 10-metre intervals, to allow for a minimum 5-metre interval between canopies at maturity.

MAINTENANCE

- Weed control should be carried out surrounding and beneath tree canopies for the first three years after tree installation, or until trees have grown to a height of 2 metres (whichever comes first).
- Tree pruning should be carried out as required, where branches block maintenance access or obstruct the waterway. This includes removing large debris that causes actual or potential impediment to the functioning of the system. Tree pruning and maintenance when requested must be undertaken within 5 days by the proponent if considered urgent and 30 days if considered non-urgent.
- Under pruning of trees should be carried out as required to maintain fire safety and Crime Prevention Through Environmental Design (CPTED) standards (including the removal of ladder fuels and pruning to maintain visual permeability through and between trees).

The following diagrams illustrate the proposed design of LSL within two basic drain forms:

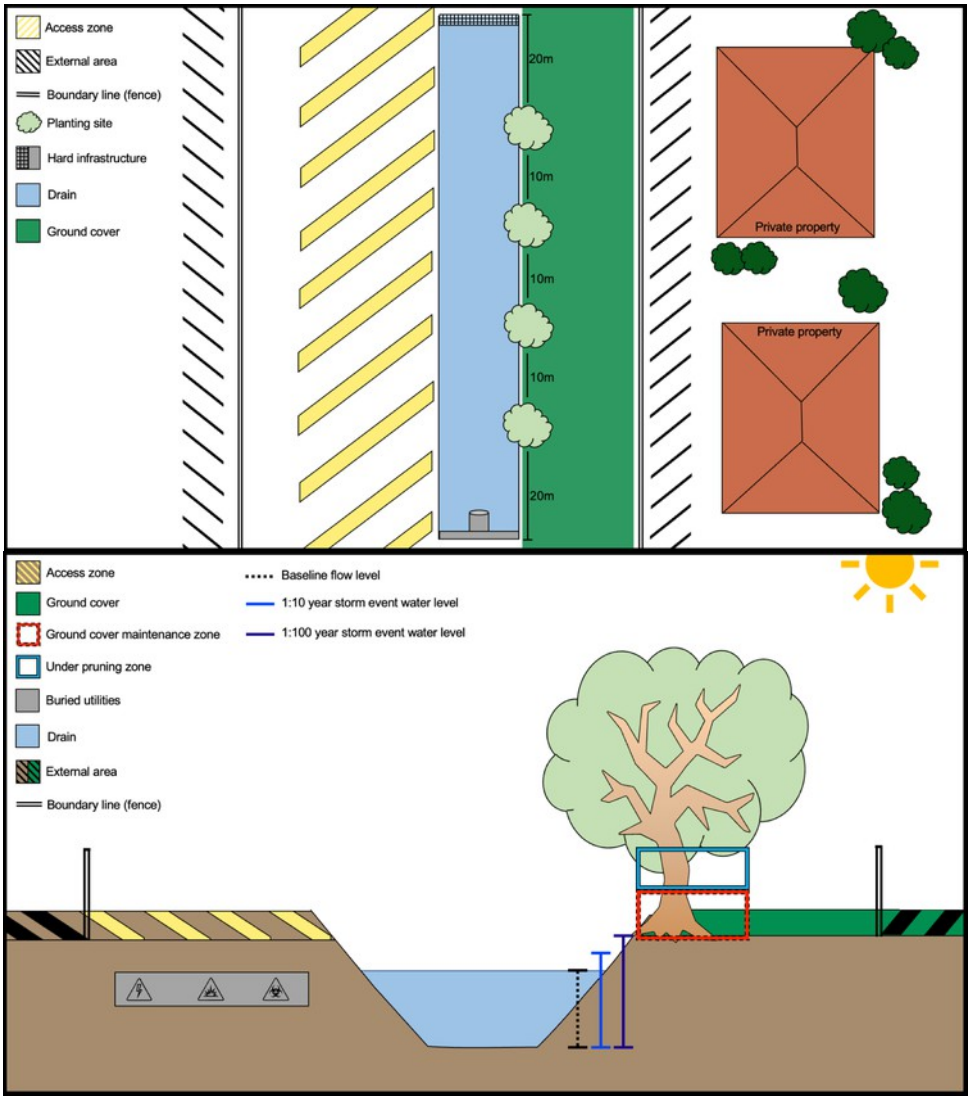

Figure 1. Aerial view and vertical cross section of a typical drain, illustrating the basic conceptual design to be implemented for this structural form.

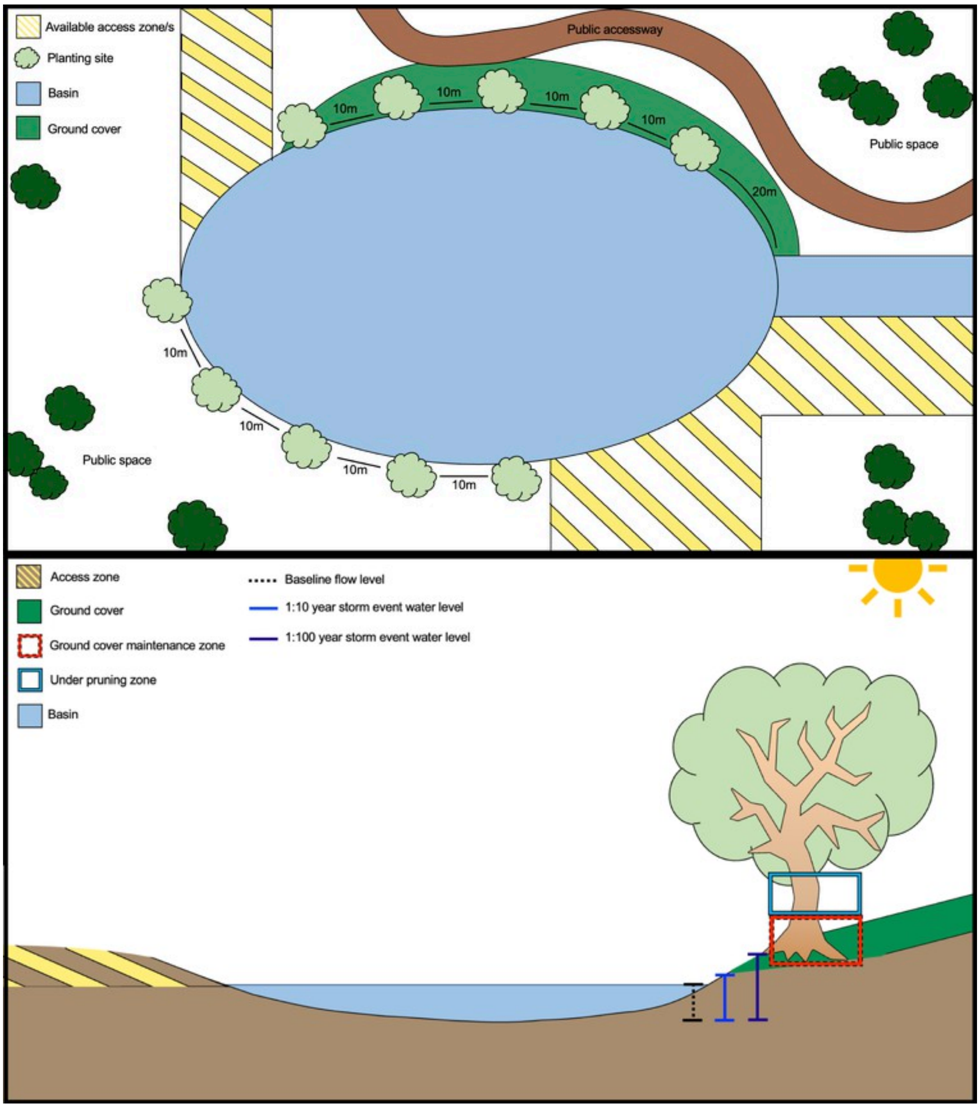

Figure 2. Aerial view and vertical cross section of a typical basin, illustrating the basic conceptual design to be implemented for this structural form.

4.3 DESIGN CONSIDERATIONS

In determining an appropriate design for this initiative, various departments of the Water Corporation were interviewed to develop a comprehensive understanding of the structural and functional needs of typical drainage assets, along with long-term requirements that would influence the establishment and success of LSL. These components have been distilled to define both the responsibilities and the principles of the design, as listed below.

ORGANISATIONAL RESPONSIBILITIES

The responsibilities of LSL fall to both the relevant local councils undertaking the project, and the Water Corporation in charge of the drainage asset.

Local Government

Prior to any work taking place at the selected site, the local government would be required to complete and submit an Asset Protection Risk Assessment (APRA), as well as request a Clearance to Work (CTW) as is standard for working with Water Corporation assets. During the approval process, a memorandum of understanding should be developed between the two parties that covers the care and maintenance of trees installed over their lifetime, placing this responsibility with the local government. The local government will also be responsible for funding the project in full and must ensure that the appropriate insurance and liability cover is in place for all trees that are installed. Following their instalment, an appropriate inspection and maintenance program should be initiated, which is expected to be similar to the local councils' verge tree maintenance programs. The local government must also provide safe working documentation for the execution of tree installation, maintenance work and working within the drainage corridor. Finally, the local government will be responsible for the removal of all trees and tree matter at tree end of life (EOL; where the tree is in senescence and is considered unsafe to remain in situ).

It is recommended that local governments house their applications under a single agreement with the Water Corporation to encompass all prospective sites, rather than creating an application for each individual site.

Water Corporation

The Water Corporation would be responsible for reviewing all prospective installation sites that are put forward by local governments. Following submission of APRA and CTW applications, the Water Corporation would be responsible for considering the installation projects for approval. Following their installation, the Water Corporation should ensure that trees are not removed, except for circumstances where the removal is required for safety, operability, or fire management purposes. The Water Corporation would be responsible for reporting all apparent maintenance issues that are noted during their asset monitoring to the relevant local government, as well as any planned tree removals.

DESIGN CONSIDERATIONS

Maintain Function of Drain

The Economic Regulation Authority (ERA) manages the drainage licence that defines the drainage service standards under which the Water Corporation operates. This was established in response to ineffective historical management of drains transecting multiple administrative districts, to centralise drainage management under one authority, the Water Corporation. The drainage service standards set the following flood management objectives (Economic Regulation Authority, 2021):

- *Urban drainage will protect against peak flows of stormwater runoff from rainfall events with intensities up to 5-year average rainfall for residential areas, and 10 year rainfall for commercial areas.*

- *Rural drainage will be managed so that the maximum period of inundation should not exceed 72 hours.*

Therefore, the Water Corporation is responsible for maintaining drainage infrastructure that protects housing and infrastructure from flooding up to the 1:10 flood level. Beyond this, it is understood that the local government is responsible for managing rainfall events above this level, as it is more appropriate to manage these types of rainfall events through town planning and local civil engineering solutions. As such, it is critical that the installation of vegetation, in this case the planting of trees, does not directly compromise the flood protection that is provided by the drain. The installation of trees should not impact the structure or function of the drainage system in the short or long-term.

Maintain Safe and Efficient Serviceability

The Water Corporation requires clear and open access to drains to be able to maintain the hydraulic capacity of these systems and ensure that these stormwater systems can function to their full capacity when they are required to. As such, the installation of trees should not compromise the ability for any variety of maintenance work to be carried out safely and efficiently.

Manage Land Agreements and Insurance Risk

The Water Corporations land portfolio is composed of Crown land, freehold land and land owned by another agency with easement rights provided. The appropriate access arrangements are therefore required to allow local government access to sites for planting and ongoing maintenance requirements. Access agreements for planting and maintenance, as well as risk and insurance responsibilities should be clearly defined prior to the planting of trees.

When considering land matters in the context of this initiative, agreement negotiation may vary in complexity depending on the status of the land. As such, the effort required for these negotiations may be categorised to the following levels:

1. *Low*: where site is on land already freely accessible by the local government, no negotiations of access are required.
2. *Medium*: where site is on land currently owned by the Water Corporation (freehold), some negotiations regarding access and maintenance arrangements are required.
3. *High*: where site is on Crown land, and the local government has no current access rights, more complex access negotiations are required, along with approval through the Department of Planning, Lands and Heritage, which has a processing time of approximately 12-24 months.

Engage Community

Local governments are positioned closest to their communities and are best placed to make decision on their behalf. While there is a strong argument in favour of tree planting in urban settings, due to the beneficial ecosystem services they provide, local governments will best determine what is suitable and socially beneficial for their community in terms of execution. Wherever possible, tree planting should take into consideration the concerns and requirements of the local community.

Tree Management

Whilst trees in a natural wetland context generally do not require maintenance, trees in urban centres and public spaces do require forestry management. In response to increasing awareness of this need, local governments are improving their capacity and capability to meet it. This also applies to trees planted near infrastructure assets and public places for safety and the prevention of unintended assets failures. This overarching tree management fall into three specific categories as below:

Protect Existing Assets

The Water Corporation owns and maintains a variety of below-ground and above-ground assets that provide critical services to the local community. These include the provision of drinking water, the removal of wastewater and stormwater conveyance. The location of these assets should be evaluated, and the installation of trees should not compromise the structure or function of any existing assets or impede the safe and efficient replacement of these assets at EOL. Trees should be maintained to prevent damage or unintended failure of assets in proximity to trees.

Manage Safety

The existing risk profile of the drain should be maintained to ensure the safety of existing assets and the local community. This includes consideration of the fire risk within the system, BAL rating implications for neighbouring infrastructure, and CPTED requirements. The planting of trees should not alter the risk profile of Water Corporation owned or managed land, and trees should be maintained to preserve this risk profile over time.

Maintain Tree Health

Trees have maintenance requirements to ensure their establishment and longevity in urban environments, in addition to those required to mitigate safety risks. The location of trees, once planted, should be logged for periodic assessment and maintenance. The responsibility for the tree and its maintenance falls with the local government and should be carried out as per the management guidelines for street trees under their administration.

5. EXISTING ALTERNATIVES

Under the umbrella of WSUD, there are many emerging retrofitting techniques and devices that can be implemented to improve traditional stormwater management, and both restore and conserve environmental conditions (Department of Water and Environmental Regulation, 2006). These include structural controls like storage, infiltration, conveyance, and detention systems, as well as non-structural controls like construction and maintenance practices and education. These controls can be employed at various of scales including at a lot, neighbourhood, and catchment level (Department of Water and Environmental Regulation, 2006; Department of Water and Environmental Regulation, 2005). Though these controls can be executed independent of other measures, best practice for achieving functional, environmental, and social objectives is likely a multifaceted ‘treatment train’ approach that combines at-source, in-system, and end-of- catchment measures (Department of Water and Environmental Regulation, 2006). While there is significant value to be gained by considering diverse controls, for the purposes of this exploring the value of Living Stream Lite, only two alternative options will be addressed in this report. These are alternatives that exist on opposing ends of the spectrum when compared to LSL, and act as effective examples of 1) negative (or neutral) action and 2) positive action towards maintaining and adding benefits to traditional drainage. This section provides a brief overview of each alternative, to give context for comparison to Living Stream Lite.

5.1 NO INTERVENTION (CURRENT STATE)

Urban stormwater infrastructure in Perth is considerably varied in its structural form, age, and condition, and eight successive agencies have managed these drainage services in the last century (Williams, 2019). Over this period, the primary focus of stormwater management has been to mitigate potential damage to property and the risk posed to human life (Environment and Communications References Committee, 2015). Historically, this was achieved by transporting stormwater away from urban areas as rapidly as possible, conveying it to the nearest waterway. Such approaches can be seen across many Australian cities, with nearly 90 percent of rainfall ending up transported through 'hard drainage systems' to receiving waterways without treatment, and with little consideration for the consequences of this approach (Environment and Communications References Committee, 2015; Department of Water and Environmental Regulation, 2004). While WSUD was first integrated into urban planning and stormwater management in the late 1980s, much of Perth’s drainage infrastructure remains outdated (Department of Water and Environmental Regulation, 2004; Williams, 2019).

Stormwater systems in Perth consequently have varying degrees of hard infrastructure present, with morphology that often presents hazards to public safety. This includes steep designs of trapezoidal drains and the presence of detention basins and sumps. As a result, these types of infrastructure often require protective measures to exclude the public and maintain safety. (Department of Water and Environmental Regulation, 2004; Williams, 2019). Open stormwater drains are typically bare of native vegetation, with a predominance of weedy ground cover species growing across available soil surfaces. In some cases, other vegetation types are present, where they have opportunistically self-seeded in the system (these can be a range of native Western Australian, native Australian and exotic species). Where self-seeding has occurred, vegetation is generally located haphazardly throughout the drain. Aquatic weed species are also present in many of these drains with varying extents of proliferation.

Figure 3. Examples of traditional open stormwater drain systems within the Perth metropolitan area, that have no invention applied.

5.2 LIVING STREAM CONVERSIONS

Living stream conversions are a form of structural retrofitting that transforms traditional open stormwater drains to mimic the characteristics of natural streams, developing healthy living waterways, and improving the overall management of stormwater in that location. Existing open stormwater conveyance channels can be converted to living streams through physical remodelling that builds key characteristics of natural streams, including the structural morphology of streams, as well as their vegetative structure. This allows the system to replicate both the hydrological and ecological functioning of a natural system (Department of Water, 2011; Department of Water and Environmental Regulation, 2007).

For stormwater assets maintained by the Water Corporation, living stream conversions in Perth are managed through the 'Drainage for Liveability' program jointly partnered with the Department of Water and Environmental Regulation. This program is focused on promoting stormwater management systems that integrate with urban landscapes (Department of Water and Environmental Regulation, 2018). These conversions are often collaborative initiatives that involve interested community groups, local industry, and authorities to enhance benefits to the local community and the environment.

Living streams are most often installed in appropriate areas where the natural system has been degraded, and where there is opportunity to adapt traditional trapezoidal open stormwater drains, as well as in regions to replace piped drainage, and locations with both ephemeral and permanent water regimes (Department of Water and Environmental Regulation, 2007). There are many design considerations required for living stream conversions to ensure ecological and hydrologic functions are met, and these include appropriate site selection, channel design, and vegetation management. Living stream designs generally comprise of broad meandering U-shaped channels that mimic natural streams containing pools, riffles and large woody debris that convey frequent low flows and create diverse habitat conditions. They also often include a floodway to maximise storage of stormwater produced by high flows following larger rainfall events (Department of Water and Environmental Regulation, 2007).

Figure 4. Examples of retrofitted open stormwater drain systems within the Perth metropolitan area. Living stream conversions have been completed to varying levels at these sites.

6. RATIONALE

6.1 BENEFITS OF LIVING STREAM LITE

This section focuses on the rationale behind the implementation of the Living Stream Lite design, including the benefits (both broadly and specifically relating to *Melaleuca rhaphiophylla*), as well potential risks and ways to mitigate them. It also briefly covers the comparable benefits and risks of the previously defined alternatives of 'no intervention' or full-scale 'living stream conversions'. When discussing the benefits of the overall design and the selected species, it is important at the outset to consider that the proposed value will vary, as there may be disparate outcomes across different sites based on differences in site structure, and that not all benefits will be applicable to all sites (Quinn *et al.,* 2001).

6.1a ECOLOGY

Biodiversity and Connectivity

Melaleuca rhaphiophylla (swamp paperbark) has an immense capacity to increase the biodiversity of the urban landscape when installed in open stormwater drains, by supporting a vast number of native Western Australian species that persist with Perth's urban matrix. Planting this species in urban drainage systems can increase and support local ecosystem biodiversity by improving habitat availability over the lifetime of the trees. Similarly, by establishing riparian vegetation corridors through tree planting amongst urban infrastructure, linkages between landscapes and conservation areas (Naturelinks) can be developed (Department of Water and Environmental Regulation, 2006). This will improve outcomes for wildlife populations by providing access to critical habitat and resources, as well as safe corridors for movement and protection (Douglas, 2020; NatureLink Perth)

Habitat Provision

There is a diverse range of associated fauna that rely on the flowers, foliage, bark, and structural characteristics of the swamp paperbark. The foliage, trunk hollows and shedding bark create optimal roosting habitat for multiple bat species (Hosken, 1996; Atlas of living Australia, n.d.; Andrew, 2015). Mature trees provide both protection from both hot and wet weather, as they remain drier and cooler than other trees (Hosken, 1996). This species provides nesting and feeding habitat for a multitude of native waterbirds (Balla, 1994; Watkins *et al.,* 1987), many that preferentially choose it over other *Melaleuca* species due to its location on wetland banks (Powell, 1990). Some birds take advantage of tree characteristics like multiple trunks, or trunks that contain hollows for nesting, while others prefer to roost and nest in the horizontal forks in branches of the tree (Powell, 1990). Many terrestrial bird species are also known to be associated with *Melaleuca* spp. habitat throughout remnant native vegetation in the Perth urban landscape (Davis *et al.,* 2013). While it is important to note that riparian zones function best with a rich and complex matrix of species, mature trees are a central and critical element for bird species (Wenger *et al.,* n.d). Tree presence, irrespective of landscape context, has been shown to positively influence bird species abundance within riparian zones (Martin *et al.,* 2006).

Submerged branches and leaves that are dropped into waterways provide important micro-habitats for a wide range of aquatic species. The tannins that are introduced by the same material also contribute to improving habitat conditions for many species, as the reduction in light penetration shields aquatic animals from sight more effectively (Pen, 1999). Established fringing swamp paperbark is also associated with creating ideal refuge conditions in the sediment beneath the tree for certain freshwater invertebrate assemblages, particularly amphibious species (Strachan *et al.,* 2016). This is due to the higher organic matter content and rougher texture of the sediment that is created beneath these fringing trees, allowing it to retain moisture and dry more slowly. This, in combination with shading, creates a cool refuge for less desiccation-tolerant species, especially over the hot summer months (Strachan *et al.,* 2016).

Resource Provision

In addition to providing habitat, the profuse flowering of swamp paperbark contributes to the food resources of a wide variety of species. Insect species benefit from both pollen and nectar, as do many bird species (APACE, n.d; Powell, 1990). *Melaleuca* trees like swamp paperbark may also contribute to the nectar resources available for nectivorous marsupials like the Honey Possum (*Tarsipes rostratus*) (Russell & Renfree, 1989; Valentine *et al.,* 2009).

Nutrient Cycling

Generally, riparian vegetation participates in actively assimilating soluble nutrients (those that promote algal blooms), while at the same time returning organic nutrients back to the riparian zone through plant death and litterfall (O'Toole *et al.,* 2013). The position of riparian trees allows them to contribute significant organic matter to water systems via the addition of branches and leaf litter, which provides carbon and nutrients into the ecosystem in a slow-release form (Pen, 1999). Although terrestrial carbon may not be a major contributor to stream food webs, it is a basis for many microbial processes (Bunn *et al.,* 1999; Newham *et al.,* 2011). In wetlands, established swamp paperbark has been found to contribute organic matter via litter fall to the system resulting in increased organic matter in the sediment found underneath the trees (Strachan *et al.,* 2016). Swamp paperbark is an evergreen species and therefore will shed both leaves and its papery bark evenly throughout the year which ensures that there are high levels of organic matter being introduced into the system all year round rather than seasonally (Strachan *et al.,* 2016). The specific leaf material contributed by paperbarks to waterways is hard, waxy, and highly resistant to breakdown, with decomposition as slow as 18 months (Pen, 1999). This ensures that invertebrates have time to capitalise on these food resources prior to microbial action that causes decay and helps keep microbial oxygen demand low thereby maintaining oxygenation of the system throughout the year (Pen, 1999).

Invasive Species Control

Pests can create significant problems for the survival of native species (both animal and plant), as they can often outcompete and displace them (Randall, 1996). Tree canopy cover and consequent shade provides a potential mechanism for weed control. By limiting light reaching the water, riparian trees can have an important influence over instream primary production (Newham *et al.,* 2011; Mosisch *et al.,* 2001), and therefore can reduce the growth of various undesirable aquatic species including algae (Pen, 1999; Water and Rivers Commission, 2000). Similarly, the shade provided helps lower the temperature of the water in the drain (Department of Water and Environmental Regulation, 2007), further creating unfavourable conditions for common weedy species. Overall, this is an important mechanism in restoring the ecological balance of the system to favour native and desirable species (Randall, 1996).

The introduction of trees to urban drains also has the potential to impact nuisance vector species like mosquitoes and midges, which has the added benefit of contributing to disease control. The proliferation of these species can be limited by reducing nutrient and pollution levels in stormwater, as well as by the cooling effect on water from shading (Department of Water and Environmental Regulation, 2006). Additionally, by improving infiltration and reducing pooling, there is a decrease in available stagnant water, which inhibits mosquito larval life cycle (Department of Water and Environmental Regulation, 2006).

6.1b CLIMATE

There is a significant body of literature that underscores the benefits of installing trees in the urban landscape to buffer current and projected climate change impacts. They have the potential to both restore and conserve environmental conditions through many mechanisms. In the context of this design, riparian trees like swamp paperbark can fulfil many of these overarching climate and hydrological benefits.

Carbon Sequestration

With the rising concern surrounding carbon emissions and their detrimental impacts on the climate, carbon sequestration is an important area of exploration, and has significant value in the context of urban greening. *Melaleuca* species have been shown, in wetland environments, to have significant capacity to capture and store atmospheric carbon. One study estimated the mean accumulation rate of carbon in their tissue to be 5 ± 2 Mg C y^{-1} ha^{-1} (metric tonnes per year per hectare) and calculated the above ground carbon stocks of this wetland to be 210 ± 60 Mg C ha^{-1} (Adame *et al.,* 2020). Another study has shown the estimated typical carbon content of *Melaleuca* forest leaf litter is between 3.15 and 15.56 tC/ha (tonnes carbon per hectare), indicating similar values of carbon uptake for these trees to maintain productivity (Tran *et al.,* 2013). In the context of the number of swamp paperbark trees planted in drain systems, total carbon sequestration per tree per year is relatively low, however this can be considered over the lifetime of the asset, which is conservatively estimated to be 100 years. While these values will vary between species and habitats, they demonstrate the high capacity of *Melaleuca* trees to actively capture carbon. Moreover, in response to increasing climate change concerns, government-backed carbon credit markets are being formed, making it possible to financially benefit from carbon sequestration.

Air Pollution

Air pollution is an important environmental concern in cities globally, and there has been significant research into the ability of vegetation to capture significant amounts of air pollutants, improving human wellbeing and restoring environmental quality (Nowak *et al.,* 2006). Trees can achieve the removal of air pollutants through a combination of two mechanisms: the uptake of pollutants that are deposited onto plant surfaces (bound or destroyed at the outer surface) or uptake via the stomata (Grote *et al.,* 2016). While the ability for trees to contribute to the removal of atmospheric pollutants may be significant in absolute terms, this removal is often only minimal in the context of the volume of pollution present in urban environments (Blum, 2017).

Temperature Control

Trees fringing watercourses provide shade via overhanging foliage and therefore a mechanism to reduce water temperature (Pen, 1999). Studies have shown generally that streams with trees present in the riparian zone have lower average water temperatures, and reach lower maximum temperatures, than streams without trees present (Bowler *et al.,* 2012). Riparian canopies can absorb some incoming short-wave radiation, preventing heating and therefore lowering maximum water temperatures (Rutherford *et al.,* 1997). However, the effect of shade can be limited, particularly as the ability of riparian trees to shade decreases with increasing stream width, depth, and water velocity (Larson & Larson, 1996). The canopy and shade of established swamp paperbark is associated with reduced surface temperature of dry sediment under the trees (Strachan *et al.,* 2016). As an evergreen species, swamp paperbark retains the capacity to provide this cooling effect year-round (Strachan *et al.,* 2016). Many studies have shown that beneath individual trees, as well as beneath stands of trees, air temperature is cooler than that recorded in non-tree areas in urban spaces (Bowler *et al.,* 2010). Finding temperature reduction solutions is critical for dealing with warming because of climate change, but more specifically, it is vital in the context of urban heat island effect (UHIE). This is the amplified temperature difference seen between urban areas and adjacent rural areas caused by the emission of excess heat and the solar energy trapped by grey infrastructure (Kaluarachichi *et al.*, 2020). Swamp paperbark in urban areas therefore has the potential to be an effective element of WSUD in Perth, and contribute to mitigation of UHIE, via increased vegetation cover to reduce both water, air and surface temperatures in the urban environment (Shiflett *et al.,* 2017), especially when combined with other greening initiatives (Byrne *et al.,* 2019).

Hydrologic Cycle

Green infrastructure, and particularly trees, have a high capacity to support stormwater management, and the restoration of a natural hydrological cycle within the urban landscape of grey infrastructure. Impervious surfaces including roads, paving, and rooftops are pervasive throughout urban landscapes and create a network of 'hardscapes' that interrupt hydrological processes (Berland *et al.,* 2017). These impermeable surfaces diminish the volume of hydrological losses that can occur (e.g., via infiltration and transpiration) as compared to natural landscapes. This results in a runoff occurring at a lower threshold than in natural landscapes, causing greater volumes of water to enter stormwater drainage systems, making stormwater management more challenging (Berland *et al.,* 2017).

In these urban systems where the management of runoff can be complex, trees can contribute solutions by conveying rainfall across various points of the hydrologic cycle (Berland *et al.,* 2017). Tree canopies intercept precipitation and, depending on characteristics like tree morphology, slow the movement of water to the ground, as well as store water on their surfaces that can later evaporate. This canopy interception loss enables trees to notably reduce the volume and speed of stormwater runoff, as well as minimise soil erosion and pollutant washout (Berland *et al*., 2017). Similarly, trees can influence hydrological fluxes through evapotranspiration and infiltration, as both mechanisms independently impact the movement of water. Trees enable evapotranspiration via direct loss of water from tree surface evaporation and the uptake of water from soil and subsequent loss via leaves (Berland *et al*., 2017), while root systems and addition of organic matter modulates soil structure and composition to improve the infiltration of water (Water and Rivers Commission, 1999). These processes can also work in tandem, where soil moisture is substantially reduced by tree transpiration, lowering moisture content between rain events, which promotes higher infiltration rates during subsequent storms (Selbig *et al.*, 2022). These processes facilitate the movement of water naturally through the system and support the reduction of runoff volumes, as well as factors like improvement of water quality, and groundwater recharge (Bartens *et al.,* 2008; Berland *et al*., 2017). Investigation into the capacity of *Melaleuca* species to undertake these functions, as well as their ability to retain water due to their bark morphology, would be beneficial in quantifying the specific benefits of installing these species in urban landscapes.

Water Quality

The addition of trees to stormwater systems can improve water quality by treating stormwater runoff via trapping or removing pollutants (Department of Water and Environmental Regulation, 2006). By increasing infiltration, and reducing surface runoff, the amount of soluble pollutants in waterways is reduced (Water and Rivers Commission, 1999). Additionally, due to their unique position, riparian vegetation can contribute significantly to intercepting dissolved nutrients that are transported via groundwater, as it can often pass through the riparian root zone before reaching the stream channel (Gregory *et al.,* 1991). Consequently, trees can have a large impact on the amount, form and timing of nutrients entering the system (Gregory *et al.,* 1991), and would facilitate improved water quality conditions as compared to unvegetated systems.

6.1c COMMUNITY

Wellbeing

There is a growing body of literature that demonstrates the diverse physical and mental health benefits of green infrastructure (Atiqul *et al.,* 2021; Jabbar *et al.,* 2021; Kendal *et al.,* 2016). Much of this literature describes the benefits of physical interaction with green spaces (recreational and physical activity performed in green spaces), however studies also show that there is a range of positive mental health outcomes associated with being exposed to nature, including having views of natural spaces (Kendal *et al.,* 2016). In a similar manner, vegetated spaces may also have the potential to ameliorate the negative perception of noise pollution in urban environments, and as such, may contribute to reducing the harm noise pollution has on psychological wellbeing (Dzhambov & Dimitrova, 2014). Consequently, even simple revegetation projects, like the addition of swamp paperbark to drains, have the potential to contribute to improved health and wellbeing outcomes for the community, as many of these drains are optimally positioned in areas within close proximity to the local population. This is a benefit that can be gained over the lifetime of the tree, regardless of whether the drain is further developed as a living stream.

Climate Related Health Outcomes

There is emerging evidence to suggest urban greening may have protective effects on wellbeing, by buffering against climate-related health conditions. In many countries, UHIE is recognised as a serious health hazard, and is considered the highest contributing factor for potential fatalities in relation to climate change effects (primarily heat waves) (Piracha & Chaudhary, 2022). In effectively lowering ground surface temperatures, in combination with the cooling effects gained through evapotranspiration, trees have the capacity to reduce the impact of urban heat, therefore reducing the associated negative health outcomes risk like heat stroke (Vandentorren *et al.*, 2006).

Trees in the urban landscape have also been identified as having a higher capacity than the majority of other 'green infrastructure' to uptake urban air pollutants (Jayasooriya *et al*., 2017). There is robust evidence suggesting air pollution and reduced air quality in urban regions contributes to a suite of negative health outcomes, from simply interfering with daily activities and reducing quality of life, to adverse clinical outcomes and increasing mortality (Kjellstrom *et al.*, 2002). Increasing the number of trees within the urban landscape therefore has the potential to reduce the harm that is contributed by air pollution to the population.

Aesthetics

The addition of riparian trees to bare and unattractive drain sites would significantly improve their visual appeal and the community perception of the space (Department of Water and Environmental Regulation, 2006). Prior research has demonstrated that people generally show a preference for natural landscapes, and consequently prefer vegetated urban areas over built ones (Kendal *et al.,* 2016). Meta-analysis of urban green space studies has shown that these spaces are perceived by the community to have natural and environmental benefits. Urban residents were shown in many studies to broadly acknowledge the environmental benefits (e.g., climate change mitigation or adaptation) of urban spaces and urban trees, including informal green spaces in their communities (Atiqul *et al.,* 2021). As previously discussed, riparian trees can contribute to reducing weeds and algal growth. By helping prevent or reduce algal blooms, swamp paperbark may contribute to improving community perception of local waterways, as blooms reduce the aesthetics of the local area and are often a nuisance (Rose, 2005; Water and Rivers Commission, 1998).

6.1d LOGISTICS

Tree Characteristics

As a part of creating a simple and effective retrofit design, species selection was critical to ensure that high level benefits could be gained, and that the species was contextually appropriate for the selected sites. *Melaleuca rhaphiophylla* is found extensively throughout the south-west of Western Australia and is endemic to the region (Powell, 1990; Bell, 2012). It is therefore uniquely adapted to the characteristic Mediterranean climate of the region (Hallett *et al.,* 2018). Additionally, swamp paperbark is adapted to the old, highly weathered, and impoverished soils of the region, and uses mechanisms such as nitrate-uptake restraint to maintain phosphorus efficiency in nutrient poor environments (Liu *et al.,* 2022). The species can be found across all major soil types and associations across the Darling Scarp and Swan Coastal Plain (Hollick, 2010; Brophy *et al.,* 2013), and while it prefers waterlogged soils, and is known to be quite tolerant of periods of inundation and dry periods (Chalmers & Wheelers, 1997; Holliday, 2003; Loomes, 2000; Nichol, 2012). Generally, this species is adapted to both freshwater and saline conditions, with research indicating it can endure moderate soil salinity (suggested up to 800 mS/m ECe) (Bicknell & Simons, 2022). These characteristics and the general ecology of the species ensure it is an excellent choice for urban greening initiatives in the greater Perth region, and that it is robust and adaptable enough to be successfully established across a variety of drain site characteristics. Building on this, as a native endemic, the swamp paperbark is already integrated into the existing ecosystems of the Swan Coastal Plain, and is therefore well positioned to support the wide range of native and locally endemic species that can still be found within the urban landscape of Perth.

Lastly, the structural habit of the tree is uniquely suited to the LSL design, providing height and width to fulfil the environmental objectives, while also fulfilling the maintenance and safety requirements that mandate open visible canopies and minimally invasive root structures (as covered below and in the discussion of risks).

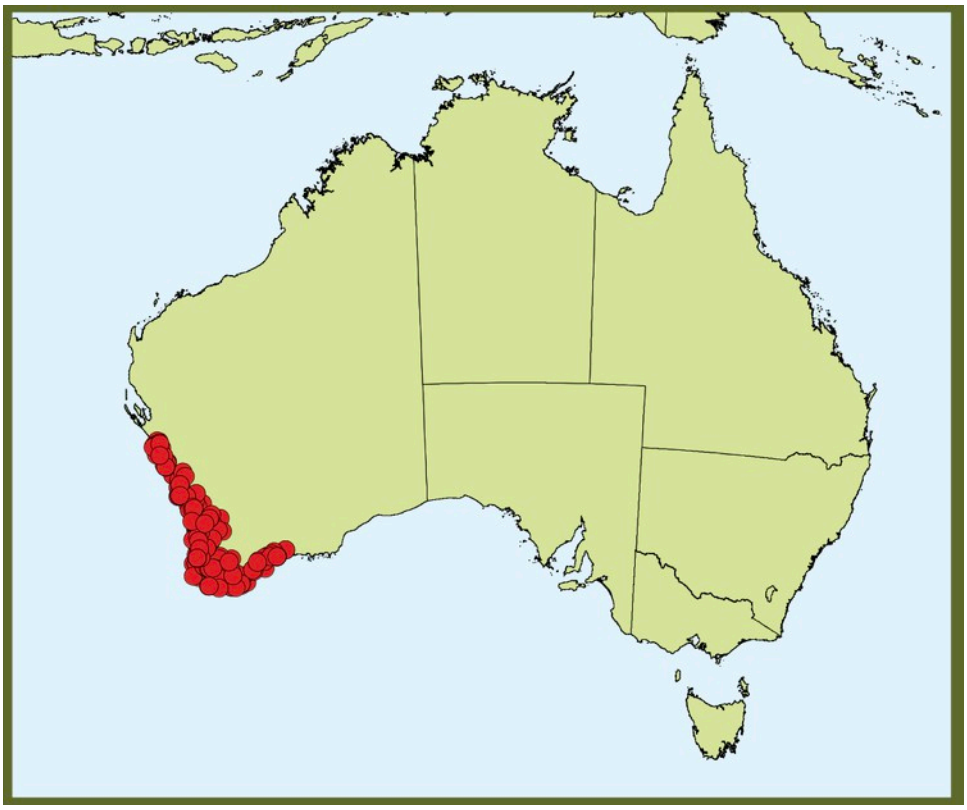

Figure 5. Map of Melaleuca rhaphiophylla distribution, demonstrating endemism to the south-west of Western Australia *(*Brophy *et al.,* 2013)

Maintenance Reduction

Erosion

Banks of waterways that lack riparian vegetation are at increased risk of flood-outs and accelerated bank erosion as vegetation helps to protect and stabilise these zones (Lovett *et al.,* 2004). Riparian trees positively influence slope processes by reinforcing bank sediment via root structures and enhancing bank stability through transpiration and improved drainage (Abernethy & Rutherfurd, 1999). Overall, riparian trees may create up to a ten-fold increase in cohesion in regions of soil close to the trunks. Reinforcement is also improved as trees mature due to the presence of longer, more firmly anchored roots that have greater reinforcement capacity (Abernethy & Rutherfurd, 1999). At maturity, the root structure of swamp paperbark is typically broad and relatively shallow, with roots extending 200cm out from the trunk, and reaching up to 75cm deep, with most of the structure being contained within the top 30 centimetres of soil (Semeniuk, 2007). Cable roots and root stock form the bulk of the root structure, interlaced with many lateral roots and covered in fine root hairs (Semeniuk, 2007). The root structure of swamp paperbark is better suited to the structural needs of the riparian zone than other species (both native and exotic), even some that can already be found in stormwater systems across Perth. Improvements in bank stability have been achieved with a comparable species (*Melaleuca ericifolia*), even with worst-case hydrological and geotechnical parameters, and these improvements are apparent over a range of tree positions in relation to the bank (Abernethy & Rutherfurd, 2000).

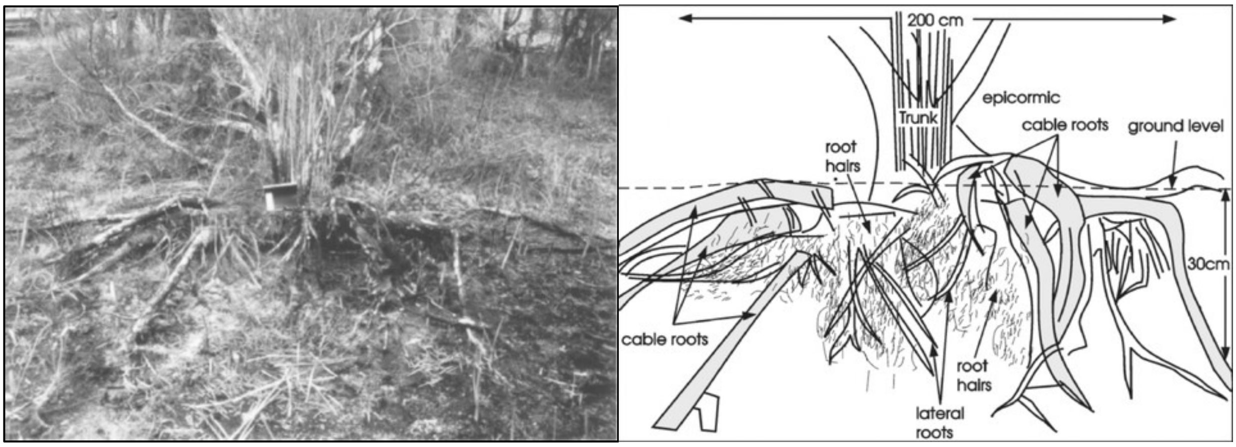

Figure 6: Photo and diagram illustrating the typical root structure of *Melaleuca rhaphiophylla (Semeniuk, 2007).*

Preventing erosion and increasing stability of drain banks should be considered a high priority mechanism to reduce maintenance requirements of drains, as changing weather events resulting from climate change have the potential to significantly erode or destabilise drains. Weather station records indicate that a higher proportion of total annual rainfall in recent decades has come from heavy rain days, with the intensity of extreme, short-duration (hourly) rainfall events increasing by up to ten percent in some regions (Australian Bureau of Meteorology & CSIRO, 2020). This data supports the link between increasing temperatures and heavy rainfall becoming more intense, based on the physical relationship between temperature and the water-holding capacity of the atmosphere (Australian Bureau of Meteorology & CSIRO, 2020). For heavy rain days, total rainfall is expected to increase by approximately seven percent per degree of warming, with the amount of rainfall for short-duration, extreme rainfall events (those associated with flash flooding) expected to increase at an even higher rate (Australian Bureau of Meteorology & CSIRO, 2018). As a result, the pressure on stormwater drains increases during these heavy rainfall events. Stabilising banks therefore will be imperative to ensure longevity and optimal functioning of the systems in the long term. Controlling erosion additionally has the potential to reduce sediment entering the system, and therefore reduce the maintenance costs and requirements for sediment removal (Hoban, 2019).

Weeds

As discussed above, the capacity to shade the waterway enables potential shading out of weed species that have significant impacts on the functionality of the system. Weed grass invasion can be limited by maintaining canopy, as many grasses prefer open sites that receive full sun, and do not establish or compete successfully when shaded (Brown & Brooks, 2003). *Typha* spp., which are known to be a problematic weed in many drain sites across Perth, require high levels of light for germination (Brown & Brooks, 2003). Consequently, a measure that can contribute to reducing *Typha* dominance is establishing and maintaining a cover of native fringing vegetation, as this can keep light levels down and prevent germination of seeds (Brown & Brooks, 2003). This has implications for the maintenance required in these systems, as much of it revolves around weed removal where species have overrun the system to the point where it can no longer function safely. With shading from swamp paperbark, it would be expected that even where weedy species continue to persist, they would not have the ideal conditions to dominate the system as they would in bare drains. It is however important to note that ability to shade instream vegetation decreases as channel width increases, which directly influences ability to exclude weeds (Quinn *et al.,* 2001).

Figure 7. An example of the ability for canopy to shade out weeds within drainage systems, where significant weed invasion is present only in regions where tree canopy is absent.

Conceptual Design

While there is extensive literature on revegetating riparian zones and methods for implementing living stream conversion, the information is not necessarily prescriptive, but rather acts as reference material. When implementing these projects, it is critical that the correct design and methodology is used (including species selection, layout, timing) for each specific site. There may be significant variability between sites selected and there is therefore a risk for poor planning or error in design to lead to suboptimal results. By prescribing the significant elements of LSL and providing a framework from which to select suitable sites, these planning risks can be mitigated.

Through its simplicity, LSL provides a lower cost option than conventional living stream conversions. By centering the design on a single species model, less resources (both labour and materials) are required for implementation, as compared to broad scale conversions. The lower cost of this design may act to incentivise interested parties in executing sustainable initiatives where they may have not previously been able or willing to do so. Similarly, the low complexity of the design allows it to be more time efficient than similar alternatives. This is critically important for securing environmental and ecological outcomes as quickly as possible.

Not only would this design help reduce the planning and approval phase (through its prescriptive outline and clear criteria), but it would also reduce the execution phase (as it has eliminated remodelling requirements). Additionally, with the use of the support tool, time spent locating appropriate sites should be able to be significantly reduced.

Finally, the simplified design of LSL enables it to be applied to a greater variety of land opportunities, particularly those that could not support full scale living stream conversions (without creating unacceptable risks, hydraulic or otherwise). This creates significant flexibility of this initiative, compared to other solutions.

6.2 RISKS OF LIVING STREAM LITE

6.2a FIRE

Vegetation Characteristics

In the Mediterranean climate of the Perth region, there are inherent risks associated with the installation of vegetation and fire. The extent of the risk is, in part, dependent on the specific characteristics of the vegetation in question. Swamp paperbark is not considered a 'low fire risk' species, due to characteristics that increase its flammability, including the oil content of the leaves and the bark morphology (Hollick, 2010; Country Fire Authority, 2021). As a result, trees with these features are considered 'moderately fire wise' and need to be regularly maintained to keep them in a less flammable condition and mitigate the risk of fire (Country Fire Authority, 2021). The flammability of the species can be regulated to some degree by under pruning, to remove ladder materials that contribute to the spread of fire from understory vegetation to canopy. This helps reduce the volume of flammable material available to be burnt. The recommendation would be to prune lower branches and loose bark to a height of two metres from ground level (Department of Planning, Lands and Heritage, 2021) and while this would need to be performed regularly, it would be particularly important to ensure maintenance is carried out during bushfire season (October to April, as per Department of Fire and Emergency Services). Similarly, good maintenance of understory vegetation including clearing, trimming and irrigation would reduce this risk of fire spread.

Bushfire Prone Areas

Bushfire prone areas (BPAs) have been identified by the Department of Fire and Emergency services in Western Australia as areas of land that have the potential to be impacted by bushfires. Where land is designated as a BPA, it triggers a suite of regulations and requirements for the way in which the land can be used, including planning, and building requirements that may apply to development proposals within the area, as well as assessments of bushfire risk into perpetuity for the safety of future developments (Department of Fire and Emergency Services, 2021). To be considered a BPA, land must meet specific criteria that revolve around vegetation class, land size and proximity to other BPAs. As such the addition of vegetation may have the capacity to change the classification of land and subsequently the risk profile of that land, influencing both the way it should be maintained, and its influence on the surrounding land. Some drains, depending on their existing vegetation characteristics and their location may already be classified as BPAs (as per the DFES online *Map of Bushfire Prone Areas;* Department of Fire and Emergency Services, 2021) however, this would be the minority based on their general locality and design. The addition of swamp paperbark trees to drainage systems with little to no existing vegetation is unlikely to alter the classification of these sites. Consequently, to ensure that this retrofit is easily implemented without triggering bushfire regulations or requirements, it is imperative that the proposed design be carried out only in drains that are not already identified as BPAs.

Fuse Formation and Ember Strike

A fire fuse is a linear stretch of vegetation, which can facilitate the spread of fire through regions, acting as a fuse or 'wick' across the landscape and increasing the connectivity of regions (Department of Fire and Emergency Services, 2019). In the urban landscape, vegetated drainage systems, due to their predominantly linear form, may act as fire fuses. As such, planning of the arrangement of vegetation is critical in these systems. The creation of fuse-breaks can improve the ability to contain the spread of a fire. Intentional and pre-defined spacing of swamp paperbark would reduce both direct contact between trees, and connection between trees and contiguous structures. The recommendation would be that tree canopies at maturity would be at least five metres apart to avoid forming a continuous canopy (Department of Planning, Lands and Heritage, 2021). Similarly, thoughtful planting design would additionally help lower the risk of ember strike (Department of Fire and Emergency Services, 2019), by increasing the distance embers must travel to reach each vegetated block. The likelihood of embers occurring can be decreased by reducing the amount of leaf litter present and dead or dried out material on the tree, which can be achieved through regular pruning and removal.

Litter Load

Controlling the available litter load is an important aspect of managing the flammability of vegetation and the risk of fire. Leaf litter is an ignition risk, especially when it consists of vegetation material that is high in oils and the litter has been allowed to dry out (Country Fire Authority, 2021). While the presence of swamp paperbark would increase the litter load of drainage systems, this species is evergreen rather than deciduous, therefore drops leaves regularly and evenly, rather than in a mass dropping event. This ensures there is no period of significant fire risk increase where litter load is higher than usual. Generally, the litter produced by swamp paperbark has higher water content due to its ability to maintain moisture under the canopy (Strachan *et al.,* 2016). This characteristic lessens the fire risk relating to litter loaf produced by these trees. Despite this, a robust maintenance regime would help mitigate this risk posed by litter load, to ensure excessive material, where created, is removed from the system.

6.2b SAFETY

Vegetation Density and Screening

Vegetation in urban spaces has been linked with a perceived risk to the safety of the local community, as visibility can be reduced by dense vegetation, which increases the potential for unlawful activity and triggers heightened fear of crime (Mahrous *et al.,* 2018). This perception of danger is most often correlated with vegetation habit and arrangement that creates a visually impermeable screen (Baran *et al.,* 2018) which both enables prohibited activity and inhibits victims' ability to escape (Wolfe & Mennis, 2012). While this perception of danger is prevalent among urban communities globally, there is very little evidence to support the idea that vegetated spaces facilitate increased criminal activity. In fact, there are studies that have shown the opposite is true of urban parks, where vegetation abundance is associated with lower rates of crimes like assault, robbery, and burglary (Wolfe & Mennis, 2012). It has also been suggested that moderate density of vegetation provides the ideal amount of visual variation to a space to increase the attractiveness of that space, while maintaining appropriate levels of visual permeability fostering a sense of safety (Mahrous *et al.,* 2018; Herzog & Bryce, 2007). Despite this, it is important to acknowledge perceived risk to safety, and ensure community members feel comfortable and secure within and near urban green spaces. Consequently, this greening initiative applies CPTED strategies to address these issues. Swamp paperbark is an appropriate species for this design as it is unlikely to create significant screening due to its open, branching habit at maturity, that provides good visibility. This permeability can also be encouraged in early growth years with appropriate arboriculture maintenance to keep the canopy permeable. The recommended spacing of trees within drains promoted by LSL to maintain an open canopy would reduce the capacity to evoke fear of crime through vegetative screening.

Property Damage

Tall vegetation like trees can also pose a risk to private property and infrastructure, as well as the risk of causing personal injury (Pokorny, 2003). Trees or parts of trees can be subject to structural failure that can cause damage or injury, most commonly during natural loading events (including severe wind and storms)(Pokorny, 2003). The kinds of failures that are seen both across whole trees or just in tree limbs are generally predictable, detectable, and most importantly, preventable (Pokorny, 2003). This risk can be mitigated in part by careful species selection. Swamp paperbark is a small to medium sized tree, rarely exceeding ten metres tall. Compared to eucalypt species that grow to heights more than 30 metres, using a small tree considerably reduces the potential to damage neighbouring property. Regular inspection and maintenance of trees would additionally reduce this risk, as it would keep them in at optimal health and allow early identification of faults. It would be expected that trees planted in drainage systems could be managed in the same way as trees in public open spaces by local government agencies. Lastly, maintaining a prescribed distance from adjacent built structures would also reduce the potential for damage, as trees would not be in an immediate vicinity of structures and therefore are less likely to damage property.

6.2c MAINTENANCE AND HYDRAULIC FUNCTION

Infrastructure Damage

Trees have the capacity to damage the infrastructure of the drain systems via root growth as well as tree or branch failure (Taguchi *et al.,* 2020). Tree root intrusion can impact buried infrastructure like storm water pipes by affecting the hydraulic capacity of the pipes resulting in a reduced level of service (Coombes *et al.,* 2002). Above ground structures may be damaged both by root infiltration or tree and branch failures, requiring maintenance repairs and resulting in a potential loss of function of the system. Living Stream Lite specifies that planting would only occur in regions without buried infrastructure, so the risk of damage is easily mitigated. The risk of damage to above ground structures would be reduced by the specification of minimum distances of trees to these structures. Swamp paperbark anecdotally does not have an invasive root structure, and there are many sites across Perth that show limited interaction or destruction of adjacent infrastructure, however there is a lack of available scientific literature to validate this.

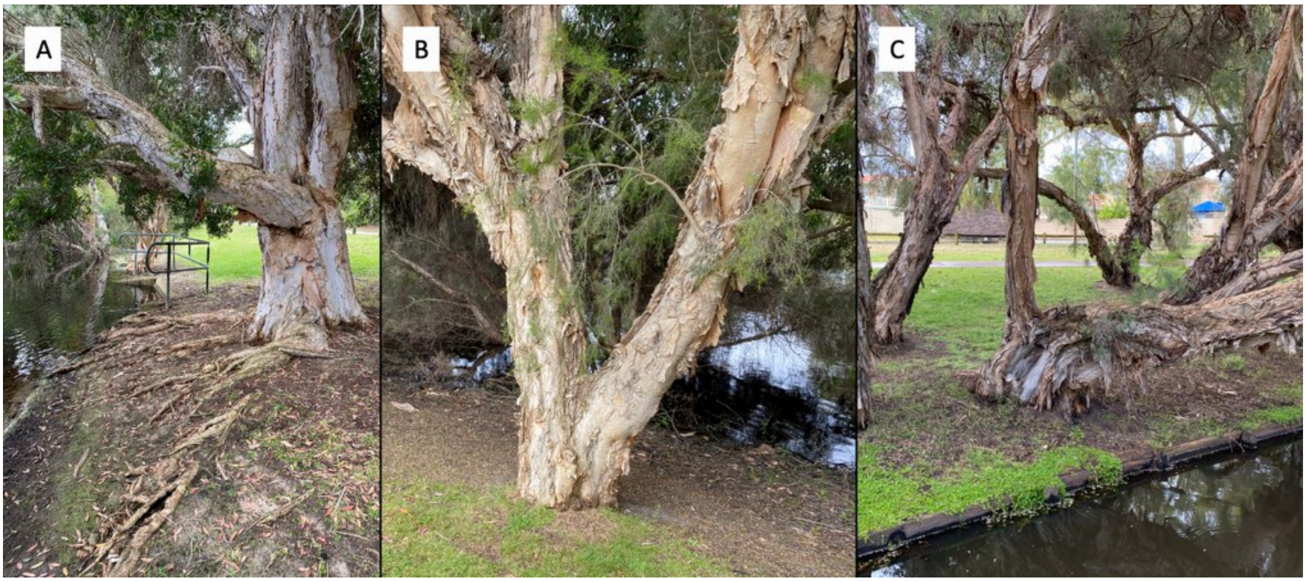

Figure 8. Invasive and damaging roots of a mature introduced paperbark species (Melaleuca quinquenervia)(A) that can be obviously seen across the soil surface, compared to examples of mature *Melaleuca rhaphiophylla (B, C) where no invasive roots can be seen.*

Impediment to Function

In addition to impacting operability via structural damage, trees may also interrupt the primary function of drain systems in other ways. One mechanism that may impact function is the increase of debris load in the system, because of leaf litter and branch debris (Weeks *et al.,* 2013). While swamp paperbark does have the potential to contribute blocking matter (twigs, and even branches) to drainage systems, it may have a much lower capacity to contribute bridging matter. Swamp paperbark has a fine needle-like leaf morphology that has a much smaller surface area as compared to other species. As bridging matter is critical in establishing blockages (Weeks *et al.,* 2013), the overall likelihood of blocking drains may be lower for this species than for other vegetation types in drains. Investigation into the capacity of fine needle leaf litter to bridge blockages would be valuable to support the optimisation of this design. Ultimately, any vegetation increases risk of high debris loads in drains (Weeks *et al.,* 2013), however this could be adequately managed by active maintenance and clearing of litter to remove excess prior to it entering the system. Debris load may also be reduced by active under pruning over the lifespan of the tree.

Access

Mature trees may impede access to drains over time, reducing the ability to maintain the system. Strategic design would ensure that trees are only planted along one aspect of the drain, therefore preserving maintenance access along the opposing aspect. Adequate spacing of trees would also enable necessary access for maintenance if required, and this would also allow sufficient room for maintaining the trees to a high level.

6.2d LAND AGREEMENTS, INSURANCE AND MANAGEMENT

Land Ownership

Varied land ownership may pose complications in relation to the arrangement of access and maintenance of trees in drainage systems. Negotiating long term agreements for access to these systems may be difficult where the land is under Crown reserve tenure, rather than freehold tenure.

Management

As previously noted, regular and thorough maintenance of trees planted within drainage systems is a key factor in seeing the success of this type of green initiative. Good maintenance will ensure both optimal tree health and preservation of operability. Determining the maintenance requirements and defining roles and responsibilities between organisations may be a complicated process. This may centre on the costs of ongoing maintenance.

6.3 BENEFITS AND RISKS OF ALTERNATIVES

Here, the benefits and risks of the two identified alternatives are discussed. These are discussed firstly in the context of the above benefits and risks, where they have equivalent traits or will achieve the same outcomes. Building upon this, the additional benefits and risks for these alternatives are discussed, those that are greater or distinctive as compared to what is outlined above for LSL.

6.3a LIVING STREAM CONVERSIONS

Analogous benefits

Many of the baseline benefits to be gained from living stream conversions are equivalent to those previously outlined for the LSL initiative. By creating a living stream from a conventional drain, complex ecosystems within urban settings can be restored, which both support a wide range of native plant and animal species and create a more visually attractive landscape for the local community. This type of composite revegetation also contributes to bank stabilisation, reduction of both air and water pollutants, carbon sequestration, urban cooling, and improved water infiltration (SERCUL, n.d.). Overall living streams provide rehabilitation of degraded waterways while effectively fulfilling their primary role in conveying flood waters. (Department of Water and Environmental Regulation, 2007).

Additional Benefits

Full-scale conversions have significant supplementary benefits beyond those established through the LSL design. Through structurally altering drain forms to create more natural stream morphology, more diverse and effective habitats can be established for both the aquatic and terrestrial species that use these systems, including frogs, fish, and waterbirds (Department of Water and Environmental Regulation, 2007). The simplified LSL retrofit unfortunately cannot achieve this level of habitat development as it lacks the structural remodelling required to emulate natural systems (including modification of the channel shape, bed form, slope, and alignment) (Department of Water and Environmental Regulation, 2007). This, along with the increased number of plant species introduced into the system intentionally, enables living streams to support abundant biodiversity.

The diversity in habitat structure similarly increases the capacity of living streams to buffer climate change impacts on a greater scale than for the proposed LSL design. Generally, the different species present would be able to contribute different buffering mechanisms, and therefore cumulative benefits would be achieved. Trees in these systems will generally contribute the same benefits as swamp paperbark, however the addition of macrophytes and shrubs will have additional benefits like further improving water infiltration and quality, and reducing erosion and sediment (Department of Water and Environmental Regulation, 2007).

Living stream conversions can create considerable community benefits, on a larger scale than LSL. Through restructuring the drain form, these streams can be integrated into community spaces and be designed for public recreation and enjoyment, while maintaining operability (SERCUL, n.d.). They can contribute environmental education opportunities for local institutions, as well as opportunities to research various anthropogenic interactions with plants and animals in urban contexts. They provide a safe setting for local community members to explore and observe natural environments and wildlife within living streams, and can expand the recreation, including bird watching and bush walking, and provide places to relax and exercise (SERCUL, n.d.).

Living streams have also been shown to provide increased value to the land and surrounding areas. A case study in Perth found that the value of homes situated within 200 metres of a living stream restoration site increased by 4.7% (once the restoration area was fully established, controlling for other factors) (Polyakov *et al.,* 2017). This highlights the potential for revegetation activity to increase the marketability of surrounding developments and increase property values over the lifetime of the project. The LSL design may attain this characteristic to some degree however, it would necessarily be less than living streams due to the restricted ability to engage the community and lesser aesthetic outcomes.

Analogous Risks

Most of the risks occurring for living stream conversions parallel those outlined for the proposed LSL design. Where full scale conversion does not include the addition of trees, the risks may diverge slightly, as there is less risk imposed to property and infrastructure.

Additional Risks

As an open public space with the potential for high community interaction, there are additional risks relating to living stream conversions and the way they are used by the local community. This may include risk of injury to people or property. These would be similar to the risks that occur in other public open spaces like park land.

Living stream conversions carry a higher cost than LSL, which would be a significant disadvantage. This is due to the significant resource requirements for living stream conversions, along with the substantial remodelling and structural work that is often required. It is important to note however that it is fallacious to reason that natural assets should intrinsically cost less or should receive less investment than other initiatives, especially when their costs are generally lower than those for hard assets (which see immense investment). While ecosystem services provided by natural systems are free, when these ecological communities are disrupted or removed due to the demands of urbanisation, the only way to reinstate these free services in urban landscapes is through capital reinvestment.

Similarly, these full-scale conversions may be notably slower in both reaching an approval stage and being fully implemented. They generally require extensive planning, engineering, evaluation, and authorisation, and are significantly more complex to practically carry out than the LSL design. There is also the additional risk, though likely small, that this kind of large and complex initiative is incorrectly planned or implemented (which may relate to poor design, inappropriate species selection or poor site choice among other factors). This kind of risk is mitigated in the LSL design due to its prescriptive nature and simple framework.

Similarly, full-scale conversions may be limited in their application, as they do not have significant flexibility in their design to be accommodated within a variety existing drain forms or land opportunities.

6.3b NO INTERVENTION (CURRENT STATE)

Analogous Benefits

There are very few equivalent benefits between revegetating drainage sites or keeping sites in a current, bare state. Taking no action ensures that no additional environmental benefits can be acquired through these systems, unless there is some level of naturally occurring vegetation that has been able to establish itself independently (though as mentioned below, the presence of this type of vegetation may not necessarily benefit the system overall). Additionally, leaving these sites untouched ensures that the long-term functioning of the site cannot be enhanced.

Additional Benefits

Taking no action to revegetate or otherwise develop drainage systems across Perth has the benefit of conserving their relative low-cost maintenance structure, which is currently reactive maintenance where the system is allowed to devolve over time. Revegetating these systems will unavoidably change their maintenance requirements and may consequently change their overall annual cost.

Left in their current state, there is also the benefit of maintaining their current risk profile. While these risk profiles may not be ‘low’ at every site, the risk will not be intentionally increased by altering their design, structure, or composition. Conserving the risk profile ensures that no additional maintenance surrounding safety is required, and that costs surrounding safety issues are preserved over the long-term.

Analogous Risks

If there is vegetation present that has established itself independently, the system would be expected to have similar bushfire, safety and functional impediment risks as would occur in intentionally vegetated systems. Generally, however, there are few overlapping risks between rehabilitated drains and untouched drains.

Additional Risks

These systems would be at risk of increased erosion, as compared with the revegetated sites, as they have little or no vegetation present to stabilise the banks. There is additional risk posed by the presence of independently established non-native or inappropriate species in these systems. Where species are not uniquely suited to the conditions, they can increase risk to the structure and function of drains. These plants may grow in unfavourable areas where they may be at higher risk of damaging structures or adjacent private property.

Due to the lack of canopy cover, there is very little capacity to naturally combat invasion of weed species in these systems. This means that weeds can proliferate and ultimately deteriorate the functioning of drains when they become infested. These weeds then often require either physically demanding or environmentally harmful methods of removal to be carried out.

Unvegetated, fenced drains have poor aesthetic value and community perception of these systems is poor. These sites are at risk of poor perception, as they may be negatively viewed due to their lack of visual interest, unkempt or weed infested condition, or even presence of anthropogenic refuse. In their current state, many drains negatively impact the aesthetics of their local area and the community view of these assets.

7. FUTURE CONSIDERATIONS

7.1 KNOWLEDGE GAPS

Following the conceptualisation of Living Stream Lite, the original intention of this research was to demonstrate the ecosystem services benefits of the design, and the tree itself, within a business case. Whilst the value of the design is intuitive, the research process revealed that there is limited literature in evidence of these benefits, and consequently a greater depth of research is required to bridge these knowledge gaps.

MELALEUCA RHAPHIOPHYLLA

Climate Impacts

(Carbon Sequestration, Canopy Interception and Air Filtration Capacity)

Targeted research surrounding the carbon uptake and storage capacity of these native paperbarks would be valuable for future environmental and urban planning. There is no current published literature on the accumulation rate of carbon by swamp paperbark. Information on the specific uptake capacity in natural wetland habitats and urban settings would be invaluable to future urban greening initiatives. This information could help quantify both the utility of this species in urban spaces, as well as the economic value of the tree. Having this information would help local governing bodies make more informed decisions and improve their capacity to support local biodiversity, as well as the climate and local communities. Research into the direct capacity of swamp paperbark to capture other atmospheric pollutants would also be useful. Having a deeper understanding of the trees specific ability to filter pollutants that are pervasive in the urban environment would enable more informed planning and decision-making in regard to combating issues of urban pollution. Similarly, no studies have directly examined the capacity of swamp paperbark canopy to intercept precipitation. This information would help inform decisions about appropriate locations for this tree, where it could contribute best to reducing stormwater run-off. With increased knowledge of this species, local governments could make better decisions in the context of urban greening, where they can select the most appropriate species to have the greatest overall benefit, and reduce the likelihood that resources are lost to poorly planned projects.

Weed Control

Research (including case studies or pilot programs) on the effectiveness of swamp paperbark at shading out problematic *Typha* spp. would provide indispensable knowledge for future planning and drainage management. Without a body of data to evidence the relationship between shading and *Typha* spp. presence or dominance, it is difficult for local institutions to choose alternative weed control options. Having a better understanding of this ecosystem interaction could provide evidence to support natural weed control initiatives that also support local biodiversity.

Root Interactions & Bridging Matter

Further research into the root structure and interactions of swamp paperbark would be invaluable for further developing this planting initiative. With a clearer understanding of the common root morphology, and the way it interacts with soil and surrounding structures, more precise decisions could be made regarding tree placement. This would also facilitate a greater confidence in understanding the level of risk posed to existing infrastructure. Similarly, research into the capacity of swamp paperbark fine-needle leaf litter to act as bridging matter in drainage systems would contribute to informing decisions regarding tree utility and placement within drains.

COMMUNITY

Community engagement is an important element of urban sustainability projects, and therefore research into understanding the community perspective of blue-green initiatives in general, as well as the specific details of this design would be valuable for future planning and adaptation. Local Perth communities could be surveyed to quantify their perception of:

1. Urban greening and installing native vegetation.
2. Crime and safety in association with vegetation and green spaces.
3. Environmental activity occurring in their local areas (and their desire for this action).

This kind of research would provide information needed to tailor initiatives towards unique community perspectives, better understand the needs, fears and desires of the local community and provide an understanding of gaps in community knowledge where relevant education would be useful.

7.2 FUTURE DEVELOPMENT

FUTURE LIVING STREAM CONVERSIONS

In most scenarios, living stream conversions are the primary end-goal, as they optimise environmental impact, biodiversity outcomes, and key functional outcomes of drainage systems. Living stream conversions should be possible at all appropriate sites, regardless of whether LSL has been previously implemented. Considerations should be made for future planning or development of this design to ensure that potential living stream conversions are not impeded by the presence of swamp paperbark. This issue may become more complex with the increased complexity of drain form, and the amount of structural remodelling that is required for conversions. A proposed option that could be considered is planting trees into wells or depressions that would more closely represent the state of the drain following bank battering that might take place during conversions. Overall, the likelihood of future living stream conversions at all sites should be considered, and mechanisms should be in place to ensure that environmental benefits are not undone by activity in the short or long term.

EXPANSION OF BIODIVERSITY

To achieve a simple, lower cost design, LSL uses only swamp paperbark, reinstating these trees to watercourses where they are naturally found across the Swan Coastal Plain. While this single species has a suite of biodiversity and environmental benefits that it can impart upon these urban systems, the fact remains that increased species diversity would ultimately have a greater benefit. The practice of planting a single species would not normally be promoted by standard forestry practice due to the susceptibility of monocultures to pests and disease. Consequently, there is value in exploring the expansion of this design to include one or several other comparable tree species that have similar morphology, ecology, or environmental benefits. It would be important, however, to ensure that this kind of expansion does not significantly influence the complexity of the design, and therefore reduce its function as a rapid and simple intermediary initiative for blue-green action.

7.3 EVALUATION

PILOT TRIALS

Small-scale trials of the methods and procedures outlined for Living Stream Lite would be valuable in refining each element of the project design prior to the implementation of the design on a larger scale. This could be carried out at a single test site, or selected sites across a representative range of drain forms.

MONITORING

For the long-term success of this proposed design, there needs to be robust monitoring and maintenance in place. This would ensure the safety of the community, the maintained operability of the drain and longevity of trees installed. It is recommended there be a memorandum of understanding in place to ensure all trees to be monitored to EOL, and maintained in an effective way to:

1. Preserve the hydraulic function of drain.
2. Protect the health of the tree.
3. Reduce litter load and fire risk.
4. Ensure CPTED requirements are being fulfilled.
5. Measure the success of the design.

When planted, tree locations should be logged so they can be reviewed periodically and following storm events to address any failures. It is also recommended that maintenance agreements account for the removal of trees where required for drain maintenance, optimal drain function and at EOL.

8. CONCLUSION

In light of escalating climate change, increasing pressure from urbanisation, and accelerated loss of both biodiversity and natural green spaces, there has never been a more crucial time to explore and rapidly execute blue-green initiatives. Through blue-green infrastructure, services that supply and protect local communities can be provide in a manner that integrates climate change resilience and ensures the long-term health of local aquatic and terrestrial ecosystems. In the context of the vast urban sprawl of Perth, in Western Australia, there are significant opportunities for reclaiming lost ecosystem services through stormwater drains, by returning native wetland vegetation to the system. This report proposes a solution to capitalise on this opportunity in the form of Living Stream Lite (LSL). This initiative seeks to expedite positive environmental outcomes, using a single-species method of stormwater drain revegetation. This report has demonstrated the numerous ecological, environmental, community and practical benefits that vegetation, and in particular native swamp paperbark trees (*Melaleuca rhaphiophylla*), can impart in an urban landscape. The LSL design has been developed to maximise the value gained from living stream conversions while minimising the effort and complexity that is usually associated with these initiatives. Similarly, LSL has been specifically designed to conserve the structure and function of stormwater drainage systems, ensuring their capacity to service local communities is retained. Risks of LSL, including safety and fire risk, have also been addressed. Where available, mitigants and solutions have been outlined to ensure that drainage systems suffer no structural or functional impacts. Living Stream Lite has significant potential to increase the ability of local governments to participate in rapid climate change action, protect communities and increase local biodiversity. With research into elements where knowledge is still limited, and evaluation and improvement of this design through pilot trial and over long-term monitoring, Living Stream Lite has a promising future as a blue-green initiative in Perth’s urban landscape.

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