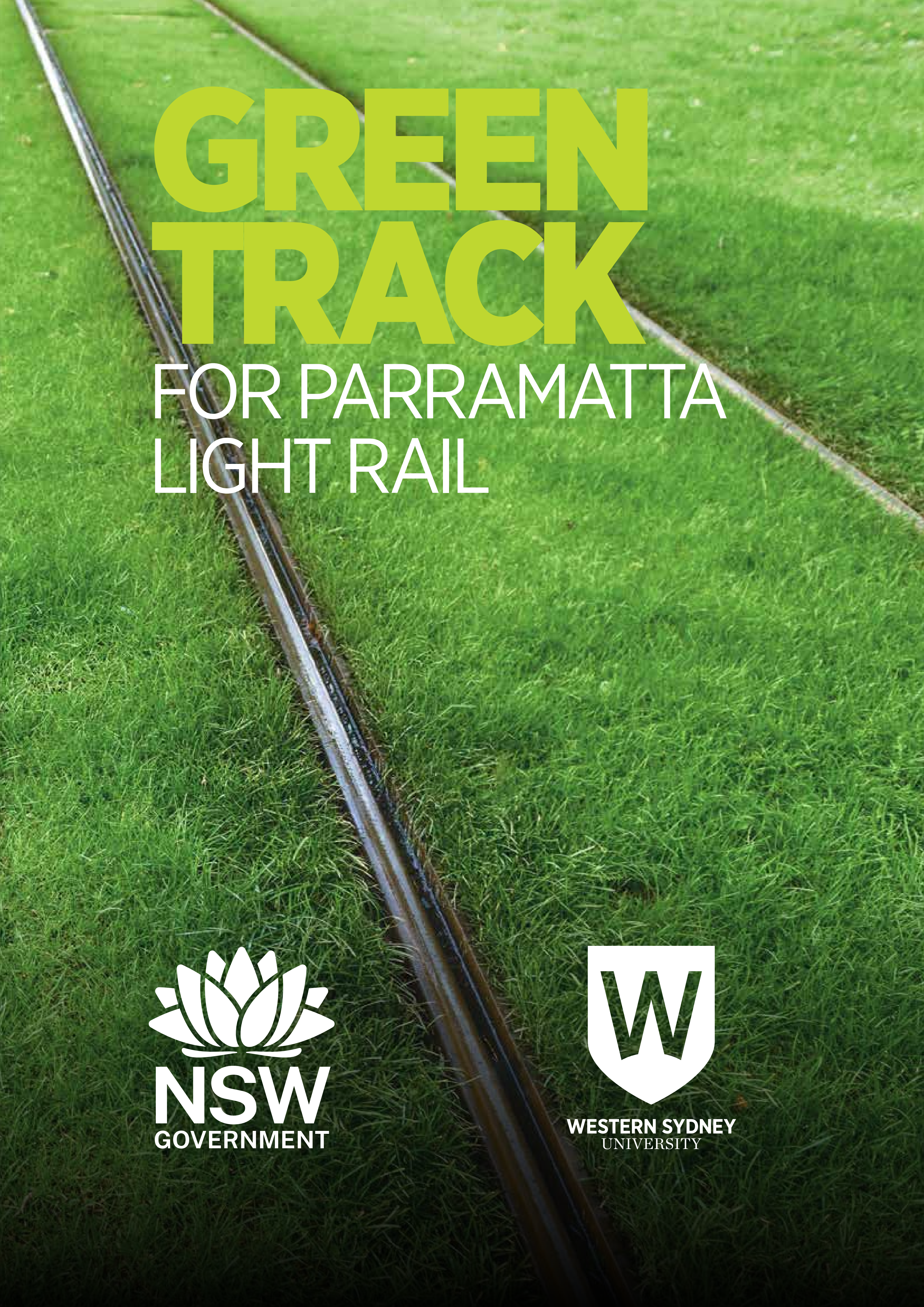
GREEN TRACK

FOR PARRAMATTA LIGHT RAIL



NSW GOVERNMENT

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CONTENTS

LIST OF FIGURES

EXECUTIVE SUMMARY

This review assesses the viability of establishing green track as part of the Parramatta Light Rail project by Transport for New South Wales (TfNSW). Green track is anticipated to cover more than 900 metres of the new tram line. To date, green track at this scale has not been realised in Australia. The project represents a significant opportunity to demonstrate how responsible urban design can be implemented to simultaneously enhance local mobility and environmental sustainability. This document assists decision-making processes towards successful construction and operation of green track in Parramatta.

KEY FINDINGS

» **Green track will perform environmental functions that improve the amenity and ecology of Parramatta.**
Vegetated tracks help improve urban life through reduction of rail noise, evaporative cooling from vegetated tracks, binding of particulate matter, production of oxygen, providing habitat and biodiversity, filtering pollutants from runoff and regulating stormwater drainage (Chapter 1).

» **Green track is possible in the prevalent and anticipated climate of the Parramatta region.**
This finding is supported by a review of climate change predictions for the Greater Sydney Basin and a comprehensive climate analysis, using meteorological data from cities around the world that operate light rail on green tracks (Chapter 2).

» **Use of compacted sub-grade is preferred.**
Compared to concrete, compacted materials will not increase soil pH and therefore plant nutrient availability. Organic acids leached from plants and top soil will not cause aggressive corrosion. Compacted sub-grade may provide additional (although limited) draining benefits, and comes at a lower cost and most likely at a lower carbon footprint compared to concrete (Chapter 3).

» **Multiple species are suitable for green track in Parramatta, including groundcovers and grasses.**
A number of native grasses and groundcovers have been identified against a comprehensive list of technical and ecological criteria to provide a Top-10 list (Chapter 3).

» **Green track in Parramatta will need irrigation to maintain visual appeal and provide environmental functions.**
This finding is based on (1) the observed weak negative relationship between average amounts of summer rainfall and geographic location of other green track systems, and (2) the high evaporation rates commonly observed in the summer climate of the Greater Sydney Basin (Chapter 4).

» **A hybrid irrigation system is most efficient in delivering water.**
It was found that using a hybrid system between drip lines and irrigation mats, installed at 100-150 mm depth will provide the necessary volume of water to plant roots (Chapter 4).

- **A parallel grade beam track, with a minimum depth of 250 mm top soil and a filter layer of 100 mm is suitable to operate green track in Parramatta.** The irrigation system will decouple plant water uptake from natural rainfall. It follows that top soil only needs to be sufficiently deep to support plants and retain some rain and irrigation water. A filter layer that contains drainage piping will divert excess volumes of water away from track beds (Chapter 5).

All findings of this review are the result of a thorough assessment of existing information from a wide range of sources. It will be necessary to further evaluate the feasibility of green track in Parramatta through impartial and rigorous testing under field conditions using a green track prototype. Tests using this prototype must include:

- Studies of soil properties, including soil structure and water holding capacity.
- Identification of optimal planting systems (direct seeding or new grass-tile technology) and plant species.
- Determination of optimal irrigation and fertilization regimes for individual plant species.
- Assessment of maintenance regimes, including mowing, weeding and track cleaning.
- Optimum plant species performance in relation to the above variables.

Scientific experiments that systematically manipulate growing conditions and analyse their effects will be necessary to identify the best species suited for green track under current and anticipated climate of Parramatta, including optimal care and maintenance. Field testing can further be used to provide valuable information on some of the environmental functions of green track, particularly its capacity to reduce greenhouse gas emissions by replacing concrete surface with vegetation, mitigate urban heat and sequester carbon.

Building and operating green track along the new Parramatta light rail line has great potential to become a stellar example for successful implementation of progressive urban development and a valuable model to inform other green track projects in NSW and Australia.

INTRODUCTION

1.1 WHAT IS GREEN TRACK?

Green track is a vegetative layer composed of turf, grasses or groundcovers, planted into (i.e. between and parallel) light rail track beds. The most widespread forms of vegetation used in track greening can be divided by plant type and track type. For plants the following two systems can be used: (a) track beds covered with different species of grass and (b) track beds covered with sedum species (Figure 1.1). The latter are a variety of flowering species of the family Crassulaceae, which are predominately succulents, also known as 'stonecrops'.

Grass track beds are the most common form of track vegetation systems and are found in almost all central European countries. These track bed systems are often created using roll-out turf or self-seeding grass types. Grass track beds are ideally composed of a relatively dense vegetation layer where grasses are the dominant part of the vegetation, limiting the capacity of weeds and other unwanted plant species (also known as spontaneous vegetation) to establish. Grass track systems generally require some level of management such as wmowing, fertilisation and irrigation.

Grass tracks can differ in the way rails and vegetation are arranged. Most common is to plant the vegetation layer at a height that will allow a level finish of vegetation and rail head. This design is termed 'top-of-rail', or 'high-level vegetation'. This track bed system provides improved noise reduction by fully enclosing the rails. Further, it allows good integration of the green track into the existing urban matrix and presents the least trip hazard. Maintenance such as mowing can be carried out with ease and the low-lying rails are unlikely to catch debris and rubbish, allowing a clean, uniform visual

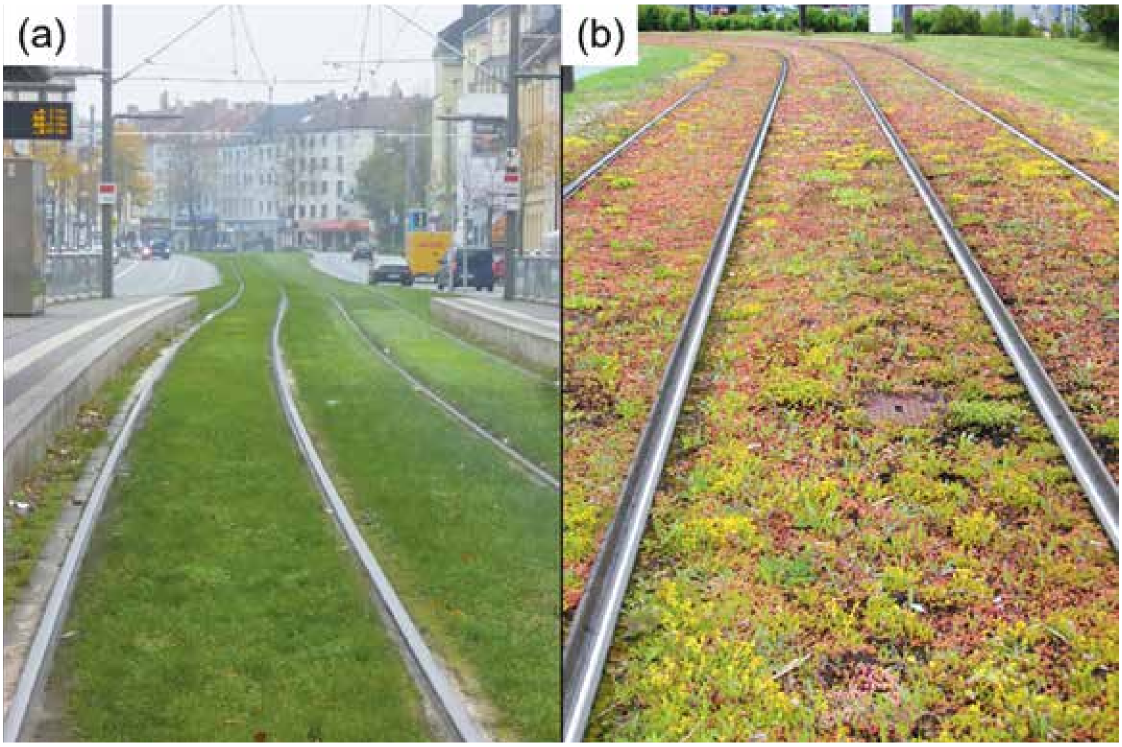


FIGURE 1.1: The two major types of green track beds. (a) Track bed covered with grass. (b) Track bed covered with Sedum species. Both depicted systems are high-level systems where vegetation reaches to or above the head of rails. Vignole rails are used in (a), whereas grooved rails are used in (b). (Image source: (a) Dortmunder Stadtwerke AG, (b) Picssr.com)

appeal. For completion, other track bed systems are listed in Appendix 1 of this review.

The world-first sedum tracks were built in Germany in the 1990's. Sedum track beds can be constructed using pre-cultivated vegetation mats or small bales of sedum sprouts. The level of maintenance and management of sedum track beds is less compared to grass track beds. Mowing is not required since the plants generally only reach a low height (Kappis et al. 2010). In addition, sedum species display a range of colours and flowers during the vegetative period, adding texture and aesthetic value. However, these vegetation systems are not shade tolerant or tread-proof, which limits their implementation. The natural distribution of Sedum species is limited to the northern hemisphere with high species diversity concentrated in the Mediterranean region, the Himalaya and Mexico (Figure 1.2). It thus seems unlikely that species of this genus will play any important role for establishment of green track beds in Australia in the foreseeable future.

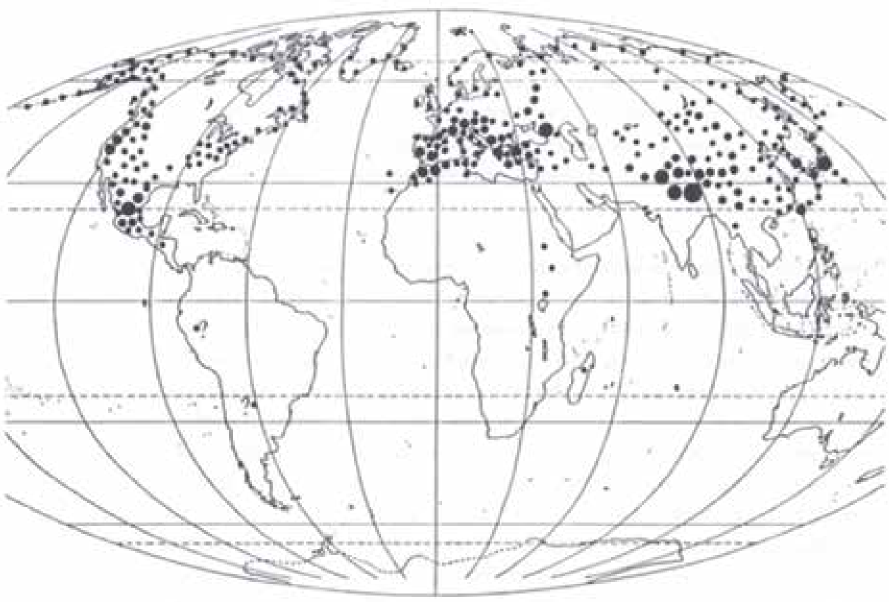


FIGURE 1.2: Natural global distribution of Sedum species. (Image source: Stephenson 1999)

1.2 ADVANTAGES AND BENEFITS

Light rail and tram tracks have an ever-present visual impact on city landscapes and therefore play an important role in urban planning. A major benefit of green tracks is the aesthetic improvement of the track area compared to ballasted and embedded track (Kappis & Schreiter 2016). This is particularly important in urban space that is generally deprived of foliage and other green infrastructure. Thus, green track beds represent a positive enhancement of concrete and asphalt-laden streetscapes, and are recognized as an expression of responsible urban design. In addition, green tracks can result in better acceptance of tram schemes by the public and positively impact the reputation of the operating authorities and local governments. Moreover, green track systems can become a location factor that attracts business and result in increased property value.

FIGURE 1.3: Water retention capacity of green track. Precipitation and run-off volumes are given in l m^{-2}. Water storage capacity of the soil (also known as field capacity) is given as proportion of the maximum storage capacity (%FC). Before the rainstorm, soils had a %FC of 40%, whereas after the event they were at full capacity. High water absorption rates by the soil resulted in very small volumes of run-off. (Image source: Grüngleis Netzwerk 2012)

Ecological benefits of green track beds include carbon sequestration, potential for a reduced carbon footprint by replacing concrete, retention of stormwater within the track bed, mitigation of urban heat, absorption and retention of pollutants (heavy metals, hydrocarbons and nutrients) by the soil, noise reduction and an increase of biodiversity (Monteiro 2017). For example, 50-70% of stormwater can be retained by green track beds (e.g. Henze et al. 2003; Siegl et al. 2010). For an area like Parramatta, where annual rainfall is 960 mm, this would equate to an average annual stormwater retention of 480-670 litres for each m^2 of green track. The remaining runoff from stormwater will be released more uniformly and will contain less pollutants, compared to runoff from impervious surfaces. Water retention effects of green track have been studied (e.g. Henze et al. 2003), demonstrating high retention and minimal run-off after a heavy rain event (Figure 1.3). To benefit from this effect most, it is important to build green track using soils with optimal balance between retention of water and provision of moisture to plants. These are counteracting forces, where highly plastic clay soils can hold water well and freely draining sandy soils allow plants easy uptake of moisture.

Increasing the spatial extent of vegetated surfaces has been demonstrated to reduce urban heat in Western Sydney, including Parramatta (Santamouris et al. 2017). Stored soil water will be transpired by vegetation, and associated evaporative cooling will reduce local air temperatures. Siegl et al. (2010) has calculated that 10 ha green track can cool 8.8 billion m^3 of air by 10 K per year when evaporation is 440 L m^{-2}. This equates to an annual energy amount of 27.6 million kWh and based on an energy price of Euro 0.2 kWh^{-1}, an energy value of Euro 5.52 million per year. Also, the lower capacity for absorption and radiation of electromagnetic radiation of green vegetation compared to concrete or asphalt will provide further cooling benefits for urban spaces. Vegetation systems also cool down faster during the night compared to concrete or asphalt. In particular, high-level vegetation systems (those that reach to or above the head of the rail) limit the exposed area of the rail and thus help reducing rail temperature particularly on hot days, further quenching local heat island effects (Schreiter 2016). These benefits are particularly interesting for a city like Parramatta where summer heat and more general heat island effects are of concern for public health and integrity of infrastructure.

Light rail tracks are often situated along major roads, which are sources of urban air pollution that negatively affects humans and infrastructure. Light rail traffic itself is a source of particulate matter emissions that originate from abrasion of breaks, wheels, rails and overhead contact lines. Driving over uncovered surface with light rail vehicles also creates eddies that are a source of throw up dust dispersion within the track area. Airborne particulate matter and other pollution can be bound or absorbed by urban vegetation. This capacity increases with greater roughness of the vegetation surface but is also species dependent. Hence, and in addition to the production of oxygen, green track systems can assist in producing cleaner air with a positive effect on local air quality.

An important benefit of green track beds for residents is noise reduction (Novales and Conles 2012). Green track assists in the reduction of noise emissions particularly with high-level vegetation systems. Noise reduction of up to 3 dB (A) has been recorded, compared to optimised ballasted track (Kappis 2016). The German Traffic Noise Ordinance lists noise reduction benefits for systems embedded in asphalt/slab track (ST) and two different green track bed systems. System 1 is a green track bed with low low-level vegetation (FOR), and system 2 contains high-level vegetation (TOR). Noise emission from these systems are compared to those emitted by conventional ballasted tracks (Figure 1.4). Results from standardized laboratory tests clearly indicate the superior performance of green track systems over conventional ballasted or embedded track systems. Particularly high-level vegetation seem to provide the greatest noise reduction benefits. The superior performance originates from the capacity of vegetation to absorb horizontally propagating noise emission from the web and foot of rails.

Health benefits and general well-being are derived from the positive effects of green track as a result of the above-mentioned ecological benefits on health (noise reduction, absorption of fine dust, cooling effect etc.). A close link between provision of green space and the levels of respiratory and heart problems indicate the significance of green areas and the positive effect of greenery on social and mental well-being in increasingly dense and fast-growing cities.

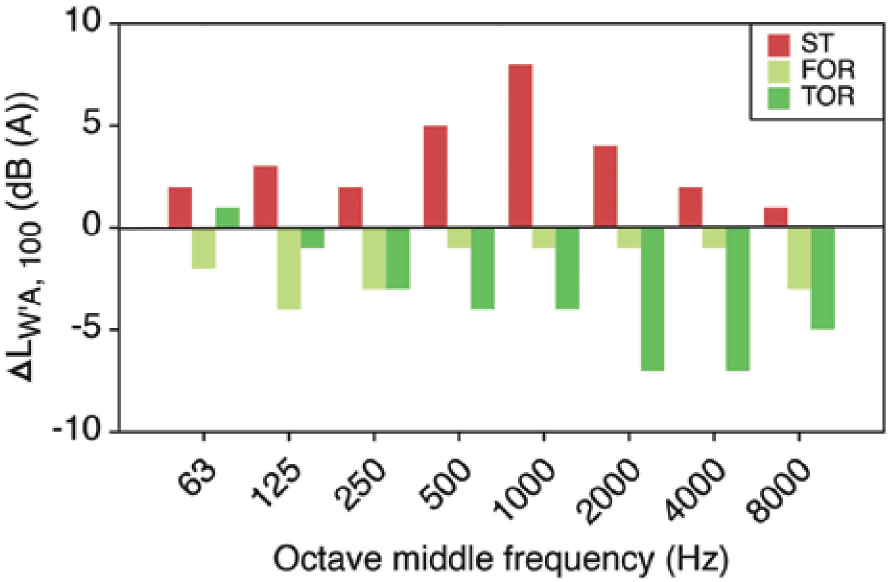


FIGURE 1.4: Difference in linear noise emissions from three different track systems compared to conventional ballasted track. ST: slab track, including systems embedded in concrete or asphalt; FOR: foot of rail, low-level vegetation green track where plants reach to the foot of the rail; TOR: top of rail, high-level vegetation green track where plants reach to the top of the rail head. Data adopted from Kappis and Schreiter (2016).

1.3 CLIMATE CHANGE

The global climate is changing, and will continue to do so. These changes will affect planning of day to day operations of businesses, government agencies and other organisations. The manifestations of climate change include higher temperatures, altered rainfall patterns, and more frequent and intense extreme events such as heatwaves, drought and storms (Department of Environment and Heritage 2006). While weather varies on a daily and seasonal basis, rapid and progressive changes in climate as documented over the past four decades have produced unprecedented environmental conditions that pose significant challenges for public life that often manifest at local scales (Table 1.1).

Australia has already been witnessing increased frequency and severity of extreme heatwaves in its major cities, and climate change is expected to further exacerbate impacts and the ability of vulnerable urban dwellers to cope and adapt to such events (Zografos, Anguelovski & Grigorova 2016).

TABLE 1.1: Risks arising from climate change. Adapted from the Department of Environment & Heritage, Australian Greenhouse Office (2006).

1	For urban planners, more frequent heatwaves may increase the stress on emergency services and hospitals while more intense and rising sea levels may increase the vulnerability of coastal housing, infrastructure and transport.
2	For the electricity sector, an increase in the number of days over 35°C and over 40°C would further stimulate air-conditioning demand. Increased peak demands on generation and distribution systems will challenge system reliability. Since investment needs are strongly driven by peak demand rather than average levels of consumption, the per unit cost of electricity can be expected to increase in response to the increased demand.
3	For local government, climate change may affect the economic base of the local region, for instance, by reducing the viability of pasture growth and therefore carrying capacity or perhaps causing the southward spread of pests and diseases previously limited to tropical areas. Climate change may also create new demands for services, for instance, due to more frequent heatwave conditions. Thus, some local governments may be faced with a reduced ability to raise income accompanied by increased demands for services, ranging from transport, healthcare to emergency services.

While this review does not assess impacts of climate change on TfNSW, key elements of the organisation may be affected, including light rail infrastructure and operation, and of course maintenance of green track beds. Particularly the selection of suitable plant species may change over the lifetime of tracks. Yet, thermal stress on established green track beds and related irrigation operations can be expected to need regular reassessment.

1.4 CLIMATE PROJECTIONS

1.4.1 Climate Change in New South Wales

Situated in the mid-latitudes of eastern Australia, NSW covers an area of 809,444 km^2, with just over 2,000 km of coastline. From the mountainous region of the Great Diving Range the coastal rivers flow eastward to the sea. These rivers are short and subject to flooding during high rainfall periods. This is particularly common in the Parramatta River area. With an anticipated increase in severity of heavy rain events, this risk can be expected to rise.

According to long-term (1910-2013) observations, air temperatures have been increasing since the 1950's, with the highest temperatures on record being experienced in the past decade. The rate of change has also increased, with mean temperatures rising by 0.5 °C per decade since 1990, compared to about 0.1 °C per decade during the 1950's to 1980's. The state of NSW is projected to continue to warm in the near future (2020-2039) and far future (2060-2079). Warming is projected to average 0.7 °C per decade in the near future, increasing to 2.1 °C per decade in the far future (Adapt NSW 2018).

1.4.2 Climate Change in the Sydney Basin

The 2016-2017 summer was Sydney's hottest on record with temperatures reaching 47 °C in the Greater Sydney Basin. The Greater Sydney Basin is warming as a result of the combined effects of climate change and rapid urbanisation and associated transition away from green space. The City of Parramatta has experienced 14 days above 35 °C in 2013. This number has increased to 17 in 2017 and is expected to rise further. Urban areas like the Parramatta are hotter than surrounding peri- (semi- or sub-) urban areas. This is a result of replacing vegetation and pervious surfaces with buildings and transport infrastructure that absorb and radiate solar radiation at a greater rate. Particularly during night, when buildings and roads continue to radiate energy back into urban space, do heat island effects impact public health and increase power consumption (City of Sydney 2018).

The urban heat island effect is especially striking in Western Sydney. Its unique geography and lack of sea-breeze results in an increasing number of hot and very hot days along a prevalent east-west gradient. It is projected that by 2030, the number of very hot days will rise by an additional 5-10 days (WSROC 2018). NSW Office of Environment and Heritage (2014) predicts that conversion of forests, woodlands and grasslands to new urban development in the north-west and south-west of the Greater Sydney Basin could potentially double projected temperature increases that would result from climate change alone.

As climate in the region of Parramatta continues to change, pre-emptive long-term management strategies for native vegetation, including grasses and groundcovers will become increasingly important (Gallagher et al. 2012). Hotter temperatures and extended dry spells will have a marked effect on management of green track beds. However, as outlined above, well-maintained green track beds can, especially during hot and dry summer periods, provide meaningful contributions to reduce local heat island effects.

1.5 GREEN TRACK IN PARRAMATTA

TfNSW has announced the construction of a new, 12 km long light rail line that runs from Westmead to Carlingford via Parramatta CBD, Camellia, Rydalmere, Dundas and Telopea. Climate of Parramatta and most parts of the Greater Sydney Basin is classified as humid sub-tropical with very hot summers and extended dry spells in summer and winter months. It is currently unknown how green track could successfully be established and maintained under these demanding conditions.

Five sections of the new tram line have been identified as potential sites for green track (Figure 1.5). These sites include highly developed streetscapes (Hawkesbury Road, Church Street North), semi natural urbanscapes (Robin Thomas Reserve) as well as native bushland (Parramatta North Urban Transformation Area). along the proposed light rail line appears feasible if appropriate plant species are selected for each section of the five priority sites (Figure 2.28).

The urban design place objectives of the Parramatta Light Rail project declare that green track must ensure positive impact on significant existing urban space, such as the Cumberland Hospital site and the large parklands near the Parramatta River. It is essential that these places remain attractive and memorable public spaces that are better utilised by the communities after construction is complete (TfNSW 2017).

Green track beds can help achieve these place-making objectives. The following benefits of green track for Parramatta Light Rail have been suggested by project managers:

FIGURE 1.4: Draft map of the proposed light rail line across the local government area of Parramatta. The map depicts the location of five priority and three potential extension sections for green track beds. (Image source: TfNSW 2018).

- **It looks good.** Green track can visually integrate light rail into parks and neighbourhoods where grass is common. Equally, green track provides an important visual softening in dense urban environments where vegetation is sparse.
- **It makes a cooler and quieter city.** Green tracks absorb and radiate less heat compared to impervious surfaces. Their capacity to absorb noise would be particularly beneficial in residential areas and around the Westmead Hospital Complex.
- **Improves water and air quality.** Green tracks can help filter dust out of the air and pollutants out of stormwater, improving the quality of both for people and the environment.
- **It defines light rail environments.** Green track separates road space from light rail environment. This important characteristic can reduce the chances of conflict between light rail vehicles and other modes of transport and/or pedestrians.

To achieve a desirable outcome for green track along the Parramatta Light Rail line, TfNSW has defined the following performance requirements for vegetation cover, vegetation base soil and drainage (as per Contract Requirements Summary – Draft 2018):

a. Provide a minimum of 500 mm of good quality soil (as defined in RMS Specification R178 Vegetation).

b. This layer should consist of a minimum topsoil depth of 300 mm, and a minimum 100 mm drainage profile.

c. Each grass surface of all grass track is a minimum of 1 m wide between rails.

It is expected that these conditions ensure that the vegetation layer remains dense, healthy and of uniform green colour; green track sections must be cut cleanly and vegetation height of less than 10 cm should be maintained uniformly and flush with surrounding ground. Actions must be taken immediately to remediate patches of bare soil. If and how these requirements can be met remains unknown.

1.6 AIMS

This review represents the first systematic assessment of available literature and other sources on green tracks in Australia and overseas. It is designed to inform planning and management of potential green track beds along the new Parramatta Light Rail line and assess if the outcomes specified above can be met.

While reflecting on a range of successful examples of green track bed from around the globe, emphasis is placed on assessing existing green track beds in Melbourne and Adelaide. In doing so, it provides insight why building green track beds in Parramatta will be different from other Australian green tracks. Importantly, it offers recommendations how to solve the associated challenges, particularly those associated with extreme summer heat.

The comprehensive list of potential plant species represents a novel and highly valuable source of information as selection also takes current and projected climatic conditions into account. Plant growth characteristics and other species-specific technical information is offered to facilitate an informed selection of growth media and effective preparation of planting beds.

The collective knowledge provided forms a guide to the successful implementation of green track in Parramatta. Information provided here will help reducing the risk of plant failure and associated financial and PR repercussions. To further limit such undesirable outcomes, it is highly recommended to validate findings of this review under real-world conditions. An outline for the necessary experimental work using a green track prototype is provided towards the end of the review.

GREEN TRACKS AROUND THE WORLD

Green track finishes can include turf, native grasses and groundcovers. These 'green' finishes provide an attractive alternative to concrete or unit paving track bed materials in areas where trafficable surface materials are not needed for either pedestrian, cycle or vehicular traffic (Cox Richardson 2015). As a result of the many benefits of green track, local governments around the world have established green tracks in cities, towns and peri-urban areas where they enhance ecological values, provide permeable surfaces and aesthetic benefits.

A survey carried out in 2009 found that there were more than 425 kilometers (km) of green track in Germany (IASP 2009). A similar survey in 2015 (IASP 2015) indicated rapid growth in the extent of green track in Germany, listing a total of 565 km. By the end of 2017 more than 600 km of light rail track provided 155 ha additional green space and related benefits to cities in Germany (www.gruengleisnetzwerk.de).

The combined length of global green track is currently unknown. However, due to the popularity of green track across a large number of countries, this chapter explores green track projects from around the world. Although visually similar, these projects are found in cities with varying climate envelops. These envelops or zones include temperate, sub-tropical and Mediterranean climate characteristics where plants used for track greening will have to cope with a range of temperature and precipitation regimes.

As climate zones of cities with green track can vary largely, it is important to identify cities with similar climates using an internationally accepted climate classification system. The Köppen Climate Classification (Peel, Finlayson & McMahon 2007) serves this purpose. It allows grouping of cities and distil climate trends that may be relevant, favourable or limiting for the establishment and maintenance of green tracks. A range of successful green track projects has been evaluated for similarities and differences amongst each other to deduct useful insights as to what role climate and maintenance characteristics play for making green track a success.

This knowledge has been used to analyse differences of green track projects in three Australian cities, namely Melbourne, Adelaide and Sydney, with special emphasis on current and anticipated climatic conditions in Greater Western Sydney (GWS) area. The resulting refined understanding of climatic trends and conditions and their potential impact on green tracks in the GWS region are discussed, taking anticipated changes in local climate into account.

It is also important to note, that this analysis does not consider cultural, economic or political conditions that may limit the development of green tracks. For example, the lack of green tracks in tropical Africa may not be a result of lacking suitable plant species, but rather be the result of missing infrastructure investment and general low economic productivity and associated development.

2.1 THE KÖPPEN CLIMATE CLASSIFICATION SYSTEM

Developed by German botanist-climatologist Wladimir Köppen more than a century ago, the Köppen Climate Classification (KCC) is an internationally accepted system to define climatic boundaries largely based on dominant vegetation patterns, termed **biomes** (Arnfield 2009). Refined versions are used today, that next biomes also consider distribution patterns of soil types (ISC Audubon 2018).

In this context, climate is the characteristic, long-term weather condition (more than 30 years) of the troposphere at a given location on the Earth's surface. Two of the most important factors determining climate are air temperature and precipitation. The Köppen Climate Classification system recognises five major climate types and additional sub-classifications based on annual and monthly averages of temperature and precipitation. The resulting 3-letter code represents a detailed description of dominant seasonal climate patterns (Figure 2.1). A detailed legend of the classification codes is provided at the end of this report (see Appendix 2).

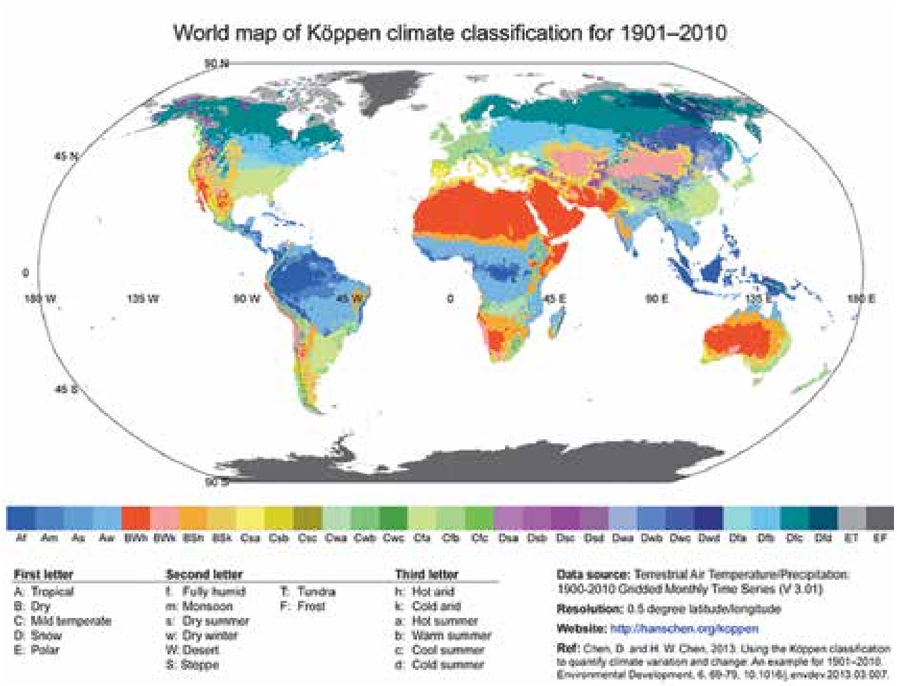


FIGURE 2.1: The Köppen climate classification map. The major climatic types are based on patterns of average precipitation, average temperature, and dominant natural vegetation. (Source: Peel et al. 2007).

2.2 CLIMATE ANALYSIS

The cities identified in this literature review were chosen for their location (both northern and southern hemispheres), climate zones (temperate, sub-tropical, tropical and Mediterranean) and availability of meteorological data. These data were gathered from the World Meteorological Organisation and other sources, including local government departments.

Using the mean air temperature of the four months of summer, it was possible to identify 16 cities around the world that successfully operate light rail on green tracks within the above-mentioned climate zones (Table 2.1).

Location	Köppen Climate Classification	Mean Summer Temperature (°C)	Mean Annual Precipitation (mm)	Mean Summer Precipitation (mm)
Temperate Zone				
Basel, Switzerland	Cfb	23.5 (1.91)	784	88.00
Bilbao, Spain		24.8 (1.26)	1174	71.75
Bordeaux, France		25.5 (1.73)	931	66.75
Karlsruhe, Germany		24.3 (2.36)	728	70.50
Paris, France		23.5 (1.91)	637	54.00
Sofia, Bulgaria		26.0 (2.45)	581	53.75
Sub-tropical Zone				
Baltimore, USA	Cfa	29.8 (2.22)	1035	97.28
Guangzhou, China		33.5 (0.58)	1720	233.50
Kagoshima, Japan		27.8 (2.23)	2300	295.00
New Orleans, USA		32.5 (1.00)	1613	156.97
Turin, Italy		25.8 (2.22)	994	74.50
Mediterranean Zone				
Athens, Greece	Cfa	30.8 (2.06)	1033	71.75
Barcelona, Spain		28.5 (1.73)	658	52.00
Madrid, Spain		29.3 (2.45)	412	17.97
Portland, USA	Cfb	25.0 (1.83)	932	115.82
Porto, Portugal		19.5 (1.29)	1267	38.75

TABLE 2.1: Climate indices of selected cities around the world that maintain green track. Mean summer indices were calculated from long-term mean monthly measurements for the four months of summer (June-September in the northern hemisphere, November-February in the southern hemisphere). Parenthesis show ±1 Standard deviation of means.

Summers in the Mediterranean climate zone can differ markedly. The climate classification system code Csa is used for regions where summers are hot and dry (e.g. Madrid and Athens), whereas Csb is ascribed to regions where summers are cool and dry. Portland, Oregon usually has a very dry summer, and substantial rain may only occur in September, leaving the biased impression of a relatively wet summer.

Within Australia, green tracks are either operated or anticipated in three climate zones, where temperate climate is prevalent in Melbourne, Mediterranean climate in Adelaide and sub-tropical climate in Parramatta (Table 2.2).

Location	Köppen Climate Classification	Mean Summer Temperature (°C)	Mean Annual Precipitation (mm)	Mean Summer Precipitation (mm)
Temperate Zone				
Melbourne, Victoria	Cfb	26.0 (1.15)	650	51.00
Mediterranean Zone				
Adelaide, South Australia	Cfb	26.8 (1.50)	546	22.75
Sub-tropical Zone				
Parramatta, New South Wales	Cfa	27.5 (1.29)	962	102.00

TABLE 2.2: Climate indices for Melbourne, Adelaide and Parramatta. Mean summer indices were calculated from long-term mean monthly measurements for the four months of summer (November-February). Parenthesis show ±1 Standard deviation of means.

When plotting the relationship between the geographical location of cities that operate green tracks and their mean annual summer temperatures (Figure 2.2a), a pronounced negative trend emerges ($r^2 = 0.69$). With increasing mean annual summer temperatures, the likelihood of green track declines. Green track locations were concentrated between 30° and 50° northern and southern latitude (i.e. temperate climate zones). No cities with green track could be located between 0° and 20° southern and northern latitude (tropical climate zone). Similarly, no green track projects could be found pole-wards above 50° latitude. As mentioned earlier, several reasons could be responsible for the absence of green track from the specified latitudes. These are likely a combination of economic and climatic origin.

A less pronounced trend explains the relationship between latitudinal location and mean summer precipitation ($r^2 = 0.37$; Figure 2.2b). Most cities in this analysis cluster around 50-100 mm summer rainfall, with Parramatta sitting on top of this cluster at 102 mm rainfall during the summer months. Only three cities receive more than 150 mm rain during this season. Like Parramatta, all three cities fall into the sub-tropical climate zone (Guangzhou, Kagoshima, New Orleans).

Importantly, several cities were identified where average summer temperatures were hotter and rainfall was significantly lower compared to the climate indices of Parramatta (e.g. Athens, Barcelona and Madrid). This result of the climate analysis clearly indicates that there are no real climatic barriers for successful establishment of green track beds in Parramatta. Moreover, the relatively weak relationship between latitudinal location and summer precipitation indicates that additional watering through irrigation systems provides independence from low water availability during summer.

Overall, the climate analysis reveals that mean summer temperatures and their variability are somewhat similar among the three Australian cities. However, clear differences exist in the amount of precipitation that each city is likely to receive in summer. While mean summer rainfall in the temperate climate of Melbourne amounts to 50 mm, Adelaide receives just 23 mm during the same time. These amounts of rainfall represent 50 % (Melbourne) and 20 % of rainfall that Parramatta is likely to receive between November and February. Parramatta received on average more than 100 mm rainfall in summer, which is similar to Baltimore in the United States and Basel in Switzerland, although the latter has markedly cooler temperatures.

It must be noted that in comparison to Melbourne and Adelaide, the high summer precipitation in Parramatta also comes with the highest mean temperatures, which will cause high rates of evaporation and associated risks for periodic water deficits. Nevertheless, using the estimates that green track beds can store up to 70 % precipitation (see Chapter 1.2), about 70 L m^{-2} of summer rainfall could be stored in vegetation base soil and used to support transpiration and health of plants in Parramatta.

Taken together, the climate analysis presented here clearly documents that successful establishment of green track beds in Parramatta is not restricted because of predominant climatic conditions during summer. Several cities with much less rainfall or higher temperatures have successfully managed to maintain green track beds, highlighting the importance, yet also the dependence of green track on irrigation.

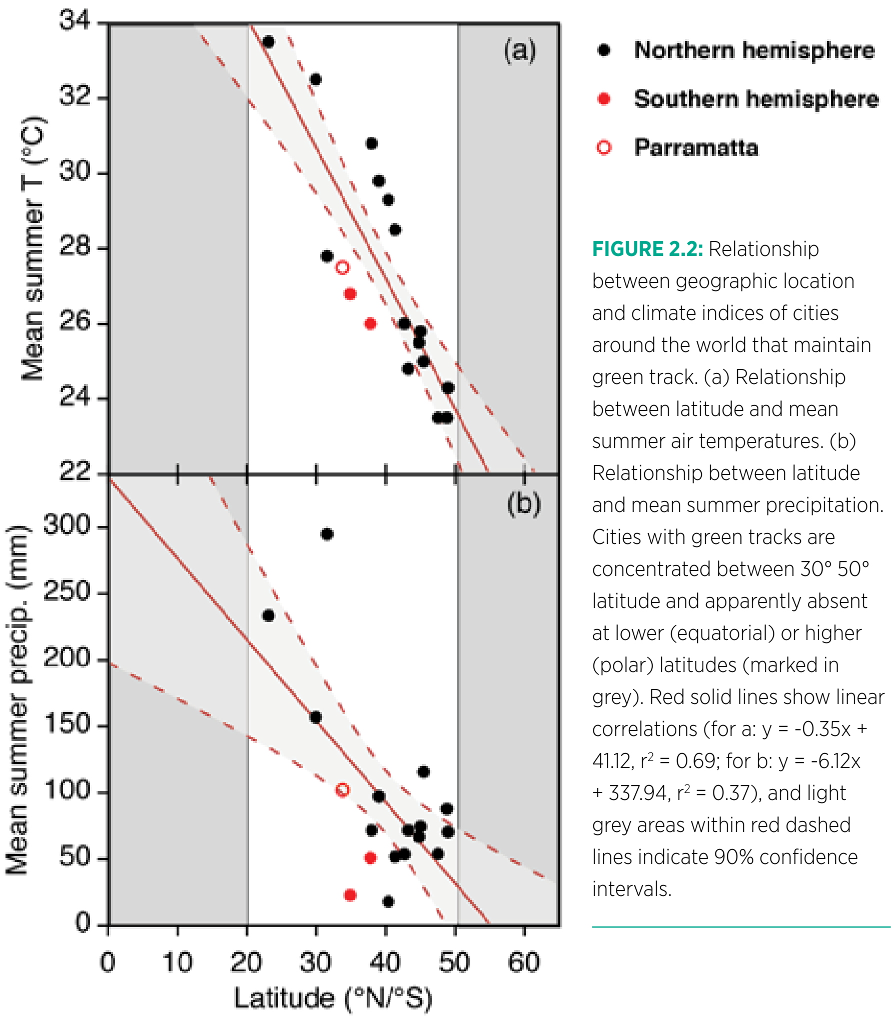


FIGURE 2.2: Relationship between geographic location and climate indices of cities around the world that maintain green track. (a) Relationship between latitude and mean summer air temperatures. (b) Relationship between latitude and mean summer precipitation. Cities with green tracks are concentrated between 30° 50° latitude and apparently absent at lower (equatorial) or higher (polar) latitudes (marked in grey). Red solid lines show linear correlations (for a: y = -0.35x + 41.12, r^2 = 0.69; for b: y = -6.12x + 337.94, r^2 = 0.37), and light grey areas within red dashed lines indicate 90% confidence intervals.

2.3 GREEN TRACKS IN TEMPERATE CLIMATES

2.3.1 Sofia, Bulgaria

A 60 m long section of 'green rails' vegetated with turf (TOR system) is maintained at Ruski Pametnik Square in Bulgaria's capital Sofia (Figure 2.3). City planners have installed the green track with the clear aim to reduce traffic noise, improve air quality and mitigate extreme summer heat. Although currently other vehicles transit the square, city authorities plan to convert the area to a pedestrian-only zone and extend the green track along three blocks in the city centre by 2020 (BBC 2015). Note that access to green track is limited by landscaping towards road traffic on the left side and by protective grating on the right side to block pedestrian traffic.

FIGURE 2.3: Green track in Sofia, Bulgaria. The track was opened in August 2015; total length of the track is 60 metres, using a TOR vegetation system in combination with grooved rails. (Image source: BGNES 2015)

2.3.2 Basel, Switzerland

Basel is one of only two places on earth where it is possible to cross an international border using light rail (the other one is a cross-border tram link between Strasbourg in France and Kehl in Germany; Barrow 2017). Several light rail lines in and around Basel contain large sections of green track beds that mostly use high-vegetation, TOR systems.

Operated by the Baselland Transport AG (Tramway Network Agency), Line 10 is one of the longest tram lines in Europe and is entirely made of green track using turf (Fig. 2.4). Opened in 2009, the 26 km long narrow-gauge line stretches from Rodersdorf (Solothurn canton) to Dornach through Basel city and the canton of Basel Landschaft (Nagy 2009). Line 10 crosses the Swiss-French border twice.

FIGURE 2.4: Green track in Basel, Switzerland. (Top): Lawn trackage flanked by privet hedges on Line 8 in. (Bottom): Grass track along Line 6 running through the suburb of Kleinbasel. The two examples depict situations where access to green track is very restricted or freely available. Open access apparently does not lead to degradation of the green cover in the image shown. Rail types used throughout Basel's light rail network. (Image source: Smiler 2001 (top), Siissalo 1999 (bottom))

FIGURE 2.5: A Grass track bed in Karlsruhe, Germany. Typical high-vegetation, TOR system and grooved rails with open access to both sides. Regularly-spaced tree plantings provide good optical separation, while at the same time further increase the amount of urban green infrastructure. (Image source: City of Karlsruhe 2018)

FIGURE 2.6:A tram on grass track in Bilbao, Spain. The track bed features a high-vegetation, TOR system with vignole rails. The green track extends into the tram stop and is only separated from pedestrian and bicycle tracks by boulevard-type plantings of urban trees. (Image source: Soriano 2013)

2.3.3 Karlsruhe, Germany

Green track beds have been installed in Germany for more than 100 years. Today, green tracks are featured in more than 40 German cities and towns. Below is an example from the city of Karlsruhe in Baden-Württemberg, Germany. The ballastless track system is also used in other cities such as Kassel, Dresden, Chemnitz and Berlin in Germany and Szeged in Hungary (Kappis and Schreiter 2016). In Karlsruhe, the green track is implemented along more than 10 km of the cities tram network and was opened in 2003 (Figure 2.5).

2.3.4 Bilbao, Spain

The Eusko Tranbia Bilbao, in northern Spain opened in 2002 and is operated by Basque Railways (Figure 2.6). It is one of two light rail lines operated by Euskotren Tranbia and was designed to improve Bilbao's railway network by servicing suburbs that do not have train stations. The second green track line is in Vitoria-Gasteiz the capital city of Basque country in the province of Araba/Àlava in Northern Spain.

2.3.5 Paris, France

In France, it is official government policy that wherever possible developers should implement green track beds using turf as vegetation surface in the design and implementation of new tramways.

The 3rd Paris Tram Line (T3) has a green track length of over 6 km and was opened in 2006 (Figure 2.7). T3 is part of the long-term strategy for improving public transport as key to reducing road congestion and providing a more walk-friendly cityscape. The features of the T3 are a combination of greenbelt landscape with widened footpaths for pedestrians, cycle paths and more than 1,000 newly-planted trees. Overall, city municipalities redesigned and improved more than 36,000 m² of urban land. The resulting green infrastructure represents not only an improvement in city space and aesthetics, but also delivers a marked amount of noise reduction and improved traffic flow (Hunter Industries 2018).

FIGURE 2.7: Green track in Paris, France. The image shows green track bed along the 3rd Tram Line (T3) and a grassed median strip on a major established road. The track bed utilises a high-vegetation, TOR system and grooved rails without traffic obstruction alongside the track line. An interruption of green track at a nearby tram stop is visible in the background of the image. (Image source: Railway Technology 2006)

2.3.6 Bordeaux, France

In Bordeaux, a historic city in southwestern France, the tramway network consists of three lines. The tracks were opened in 2003 (Figure 2.8). The exceptional historic architecture, consisting mostly of limestone buildings has been recognised by UNESCO as a world heritage site, second only to Paris in the number of protected buildings. The Bordeaux tram system was designed in part to protect and compliment the historic core. The trams trackways are a mix of grassy medians or clearly delineated areas on existing road surfaces (Universal Design Case Studies 2005). Particularly along historic streetscapes and throughout inner-city squares, no overhead conduction lines were use in order to maintain uninterrupted views.

FIGURE 2.8: Green track in Bordeaux, France. The upright plants between tracks are vines, symbolising the strong affiliation with viticulture in the region. The track bed uses a TOR system and grooved rails, delineated by a single line of concrete curb stones, followed by a small banked slope covered with grass. The light rail line is only separated by a second row of shallow curb stones from vehicular traffic to the left and right. (Image source: Smiler 2009)

2.4 GREEN TRACKS IN SUB-TROPICAL CLIMATES

FIGURE 2.9: Green tracks in New Orleans, Louisiana, United States. Top: Streetcar tracks with a concrete pedestrian pathway intersecting the patchy grass track. Bottom: A streetcar on the St. Charles to Lee Circle shuttle. Both images display worn-out patches of grass track bed. (Image source: Devlin 2010 (top); American Public Transport Association 2005 (bottom))

2.4.1 New Orleans, United States

The Canal Street Line is a streetcar system in New Orleans, Louisiana and was opened in 2004 (Figure 2.9). The Canal streetcar line is a historic line currently operated by the New Orleans Regional Transit Authority. It originally ran from 1861 to 1964 and it was redesigned in 2004 after a 40-year hiatus. Large sections of the line are covered by green turf track bed of the TOR type. However, the visual assessment of several images available for this example of green track bed indicate that irrigation systems are not used to support plant health along this tram line.

In New Orleans mean summer temperatures are 5 °C higher compared to Parramatta. And although also summer rainfalls are greater in the capital of the state of Louisiana, vast amounts of soil moisture will be lost due to high rates of evapotranspiration. As can be seen in the images provided, the lack of additional water has resulted in deterioration of the vegetation cover. In many places bare soil and clumped vegetation dominate, reducing the aesthetic appeal and other benefits like noise reduction, binding of air pollutants and dust suppression.

2.4.2 Baltimore, United States

The Maryland Transit Administration in Baltimore city has incorporated green track into two sections of the 'Red' and 'Purple' Lines (Grundahl 2011). Opened in 2013, the green track sections of the light rail lines were modelled on similar projects in Europe where green roof technology was applied to green track construction (NCTCOG 2013). The green tracks pilot project in Maryland was designed to provide new and improved understanding of how widely implemented green roof technology can successfully be used to build green tracks and light rail systems (Figure 2.10).

A study conducted in Baltimore provided a well-researched example of how transport infrastructure can be transformed from grey to green through retrofitting (NCTCOG 2013). More importantly, it highlights the importance of pilot projects in developing best management practices for storm water management and green infrastructure.

FIGURE 2.10: Light rail in Baltimore, Maryland, United States. This green track features Sedum species instead of grasses or turf. The track system is made of embedded concrete slab and grooved rails. (Image source: Mahan Rykiel Associates Inc 2013)

2.4.3 Turin, Italy

Turin, in the Piedmonte region of northern Italy, 195 km of light rail boast 19.2 km of green track, which commenced operations in 1995. The Turin tramway network is large, traversing and connecting all parts of the city. As depicted in Figure 2.11 green tracks are often separated from each other by introducing lines of trees (mostly *Robinia pseudoacaia*, common name is black locust) and travel in segregated kerbside lanes. Turin is considered to be the industrial heart of the country and has been recognised as a trailblazer in application of green track beds in for many years, with an extensive and well-used tramway system (Railway Technologies 2010).

FIGURE 2.11: Green track in Turin, Italy. The image shows an example how rows of urban trees can be used to separate tracks and provide additional greening benefits. While the line shown here uses a high-vegetation, TOR type system, some bare patches can be seen on the left track. The track beds are separated from the roads by protective grating, a necessary precaution as the tram passes densely populated urban streets. (Image source: Smiler 2009)

2.4.4 Kagoshima, Japan

In Kagoshima prefecture on the southern tip of the Kyushu region, a tramline has existed since 1912 and the Kagoshima City Transportation Bureau has operated the trams from 2005. The city of Kagoshima demonstrates some very successful grassed tram tracks and contemporary innovative urban design (Figure 2.12).

Kagoshima has a very convenient tram system and every tram station has grass growing on the tramway. This is one of the city's countermeasures for the urban heat-island effect which was planted in 2006.

2.4.5 Guangzhou, Guangdong Province, China

Guangzhou Trams operates a single line between Canton Tower and Wanshengwei along the northern shore of Haizhu Island. Opened in 2014, the tramway is 18.1 km long with sections of green track (Figure 2.13). A further six additional tram lines are under planning and the tram routes run on reserved grass-bed tracks in the middle of heavily trafficked roads.

FIGURE 2.12: Impressions of green track in Kagoshima, Japan. Top: Additions of flowering plants and landscaped green infrastructure generate a visually pleasing arrangement; the track bed uses a TOR system and vignole rails without grass between rails in tram stops. Bottom: Example of a vibrant grassed track-bed with mixed vegetation height. (Image source: kaorisquarefeet.com 2014 (top); Asian-Pacific City Summit 2011 (bottom)).

FIGURE 2.13: Skytrain station in Guangzhou, China. This image shows a grassed track bed that runs along the light rail tracks inside a tram stop using a TOR vegetation system between embedded concrete slab and grooved rails. (Image source: megapixl.com 2015)

2.5 GREEN TRACKS IN MEDITERRANEAN CLIMATES

2.5.1 Portland, USA

The TriMet's Portland to Milwaukie line in Oregon has a green track area covering more than 375 m^2 and was opened in 2015 (Figure 2.14; Andrews 2015). The green track runs between Portland State University and North Clackamas County and consists of a mix of flowering, low-growing evergreen plants (including sedums) between the tracks. It was the first green trackway constructed in Portland. It has been reported that these plants help enrich the urban experience along the Metropolitan Area Express (MAX) line and reduces train noise and vibration (Ridgway 2015). The MAX line connects Portland city centre with Beaverton, Clackamas, Gresham, Hillsboro, Milwaukie, North/Northeast Portland and Portland International Airport.

FIGURE 2.14: Grassed tracks in Portland, Oregon, United States. Image shows passengers exiting the train during the first ride of the MAX Orange Line for TriMet's Portland-Milwaukie Light Rail Transit Project. Note the inlayed grass sections between a slab track system, representing a rare example of a low-vegetation, FOR-vegetation slab track system where vignole rails, footings and fastening infrastructure is easily accessible. (Image source: TriMet 2015)

FIGURE 2.15: Light rail train in Porto, Portugal. The green track in Porto was installed with the aim to progress urban renewal and regeneration. The image shows that green track (TOR vegetation system with embedded slab and grooved rails) was even established inside of tram stops under filtered light conditions. Turf has been used between the rails and also between and along the tracks, documenting that engineering solutions can be found to maintain dense, healthy grass tracks in difficult situations. (Image source: SENER 2014)

2.5.2 Porto, Portugal

The Porto light rail project, operated by Metro do Porto, created four tram lines with a total of 60 km, comprising of 60 stations above ground and 12 stations below ground (Figure 2.15). The light rail project was completed and opened in 2006. The system connects nine municipalities in the metropolitan area and interconnects with the city's existing bus and railway lines.

The Porto Light Rail Train (LRT) has been awarded the Veronica Rudge Green Prize, granted every two years by the School of Design at Harvard University to projects that stand out for their excellence in sustainable urban planning. From the outset, the system was designed to become a source for urban renewal and regeneration. For this reason, its contribution to the preservation of Porto, a city that is included in UNESCO's list of World Heritage, has been acknowledged. This project has also been recognised previously with the Light Rail Award – Best New System granted by the International Association of Public Transport (UITP) which distinguishes the creativity and design of light rail systems around the world (SENER 2018). A noticeable proportion of the track system is green, with TOR systems dominating the track bed design.

2.5.3 Madrid, Spain

Opened in 2007, the T1 Sanchinarro line, the T2 Pozuelo de Alarcon line and the T3 Boadilla del Monte line cover a distance of 27.8 km. Green track was established along several extended sections of all three lines (Figure 2.16). It is reported that Madrid has now embraced the concept by constructing its own three-line light rail system, imitating the style of other Spanish cities such as Barcelona. The three-line light rail system consists of three routes that run both above and underground providing connections between the end of the extensive metro network and the developing satellite towns that are being built on the edge of the Spanish metropolis. The key is to provide an attractive passenger experience that will accompany future expansion of urban space (Railway Technology 2018).

FIGURE 2.16: Grass track with intersecting pedestrian crossing in Madrid, Spain. The most commonly used green track bed system in Madrid is of the TOR vegetation type. The image depicts a section of green track that is openly accessible by pedestrians and only uses a single line of low-profile curb stones to separate green tracks from roads. (Image source: Railway Technology 2007)

2.5.4 Barcelona, Spain

The Barcelona Metro Line 3 (known as **Green line**) is 18.5 km long and sections of it is in the city's oldest underground railway line originally opening in 1924. Today it runs from the University of Barcelona Zona Universitària campus out to the neighbourhood of Trinitat Nova, featuring large sections of grass-covered green track (Figure 2.17).

FIGURE 2.17: Line 3 of Barcelona Metro, Barcelona, Spain. All green track along this line is using the high-vegetation, TOR vegetation system with grooved rails. Landscaping with additional green infrastructure is enhancing the visual appeal of the green track. (Image source: Inhabitat 2014)

FIGURE 2.18: Light rail with green track in Athens, Greece. The tramway passes through residential area and its visual impact is softened by trees and grass strips. Note the serrated edge of grass on the concrete section of the embedded, grooved rail system. (Image source: Railway Technology 2018)

2.5.5 Athens, Greece

The Athens light rail network is 25.6 km and was opened in 2000 (Figure 2.18). Line 1 (known as the **Green line**) is owned and operated by Athens-Piraeus Electric Railways and runs from Piraeus to Kifissia via Athens. The track bed system used is a slab-track with embedded concrete rail channels and high vegetation base layer.

2.6 SIMILARITIES AND DIFFERENCES

The previous section documented a number of green track arrangements across different climate zones and continents. While the climate analysis indicated that green track can successfully be operated in temperate, Mediterranean and also sub-tropical climates, the visual presentation of different systems highlights that green tracks vary greatly in their technical design and how they integrate into the urban fabric.

Similar for all green tracks is the desire to provide a thick, continuous vegetation layer. While selected species to provide this cover will vary by city, country and climate, it is clear that grass species are the most prominently used plants. Resulting green turf is the most common vegetation cover. Our global overview also revealed a dominance of the high-vegetation, or top-of-rail (TOR) vegetation system, where vegetation height reaches or extends over the head of rails. Green track systems seem to rarely employ low-vegetation, or foot-of-rail (FOR) systems. Most likely reason is the superior visual appeal, ease of maintenance, and better noise absorbing characteristics of TOR systems (other reasons have been listed in Table 1.1). Mixed-level vegetation systems seem rare.

Reason for the preference of slab track systems over sleeper and ballast systems when building green track is likely the extended depth of the vegetation base layer (i.e. the amount of soil that can be incorporated into the track bed). Increased thickness of the vegetation base layer has clear advantages in stormwater storage capacity of the track. As the sleeper system is placed on top of the ballast layer, and sleeper bays are subsequently filled with additional ballast up to the top of the sleeper, little space is left for mineral soil as medium to grow vegetation. Commonly, 14.5 cm depth for vignole and up to 20.5 cm for grooved rails are available for soil and vegetation.

On the other hand, slab track systems do not use flexible ballast materials, but use rigid materials like concrete sleepers as support structure for tracks. This allows soil depths of more than 70 cm for the vegetation base layer, depending on the selected system. A much deeper base vegetation layer can have multiple positive effects on plant health and result in extended lifetime of the vegetation layer. A range of variations for both track types are provided in Table 2.3 below. Another clear advantage of any slab track system is the permanence of the rail position, where sleeper and ballast systems may require realignment due to their ‘floating’ properties.

As a rule of thumb, any grass/turf green track system should include a vegetation base layer of at least 15 cm thickness. Depending on permeability of the subbase layer, drainage to divert excess stormwater may be necessary. If drainage infrastructure is provided, a filter layer (geotextile fabric) must be included to prevent clogging and loss of mineral soil. However, if the subbase layer is highly permeable, it can potentially also contribute to water retention characteristics of the vegetation base layer (see also Chapter 3.4).

Differences were also apparent in the measures taken (or not) to restrict pedestrian, bicycle and vehicular traffic. Notably, most of the examples shown use no fencing or other obstructive measures. However, use of vegetation (street trees, low continuous hedge lines) or low-profile curb stones is common to clearly separate green track beds from roads. When green tracks were right next to bicycle lanes or walking tracks, it was more likely that some intervention was in place to minimise accidental entering of the tracks. On the other hand, in situations where single- or multi-lane roads were adjacent to light rail lines, no interventions to limit access (foot traffic in particular) were visible. These observations demonstrate that a variety of options is available to seamlessly integrate green track into existing urban infrastructure.

System	System components	Thickness of vegetation base layer (top-of-rail level)	
Track constructed using a sleeper and ballast system		**Vignole rail profile**	**Grooved rail profile**
Grass track type "Kassel"	Sleepers	10.5-14.5 cm	16.5-20.5 cm
Grass track type "Dresden"	Sleepers	10.0-13.0 cm	15.5 cm
Track constructed using a slab system (permeable subgrade with possible water retaining effect)			
INPLACE	Concrete beams	52.0 cm	58.5 cm
Elastically supported rail base plates	Concrete beams	52.0 cm	58.5 cm
Grass track type "Freiburg"	Concrete beams		40.0-45.0 cm
Grass track type "Bremen"	Sleepers on concrete beams	68.0 cm	74.5 cm
Track panel system type "Güsener Balken"	Pre-fabricated frame	45.0 cm	51.5 cm
Track constructed using a slab system (non-permeable subgrade or with supporting slab)			
SSB grass track	Concrete beams integrated with concrete track slab	25.0 cm	25.0 cm
RHEDA City Green	Sleepers and in-situ concrete slab	10.0-25.0 cm	16.5-31.5 cm
edilon)(sedra SDS-grass track	In-situ concrete slab		19.5-20.5 cm
edilon)(sedra USTS-INFUNDO	Rail channel	15.0 cm	23.0 cm

TABLE 2.3: Common variables for the establishment of vegetation on a sleeper and ballast track or slab system. Information provided was adopted from Kappis and Schreiter (2016).

2.7 GREEN TRACKS IN AUSTRALIA

At the time of this review, only two successful examples of green tracks exist for public light rail systems in Australia. One is located in Box Hill, a suburb of Melbourne in Victoria. Climate of this region is cool temperate with a strong oceanic influence. The other green track is located in Adelaide, South Australia, where climate is considered to be Mediterranean. Both green tracks will be introduced in more detail below.

2.7.1 Box Hill, Melbourne

The Melbourne tram line 109 is operated by Yarra Trams and runs from Box Hill to Port Melbourne. The line begins at the interchange stop in Box Hill and extends west in the middle of Whitehorse Road. 410 m of continuous section of green track can be found at this location (Figure 2.19 top). Operation of this section commenced in the year 2000. Shorter sections extend on Whitehorse Road. The aim of constructing this green track was to beautify the city and create a positive experience for locals and visitors.

It should be noted that the Council of the City of Melbourne is currently reviewing additional options to expand their green track network, focussing on Southbank, a highly frequented entertainment area on the southern bank of the Yarra River. Green track options are developed for streetscapes such as Southbank Boulevard and Dodds Street (Figure 2.19 bottom). Additional track greening (less than 50 m) is anticipated for a location in Stuart Street, near the track turnoff from St. Kilda Road.

FIGURE 2.19: Grass tracks at Box Hill, Melbourne, Australia. Top: The image shows the grass track in 2001, featuring a TOR-type vegetation system between and along an embedded concrete slab track. Bottom: An artist's impression of the proposed green track along Southbank Boulevard. (Image source: TfNSW 2017 (top); City of Melbourne 2018 (bottom))

Two timeseries of images depicting the green track were established for the current review (Figures 2.20 and 2.21). The first time series documents a section of the track near the Interchange at Box Hill. The track is constructed as a slab system with embedded grooved rails in concrete channels. Vegetation type is a TOR system and uses turf as cover. The images show that green cover of the track varies, most likely due to climatic factors, but also as a result of spontaneous vegetation establishing itself in less dense or bare patches. The invasive species *Arcotheca calendula*, also known as cape weed is a major problem in southern Victoria and its yellow flowers can be seen in the centre of the track in September 2014.

Generally, the vegetation cover of this green track section appears less vigorous and green during summer months, indicating that it suffers from water limitation. Although a pop-up sprinkler system was installed during the initial contsruction, water restrictions during the Millennium drought led to abendonment of irrigation and subsequent die-off of the green track. In 2007, the grass cover was reinstalled, yet it is unknown if the operating authorities currently use the irrigation system. Visual impressions provided in the time series suggest otherwise.

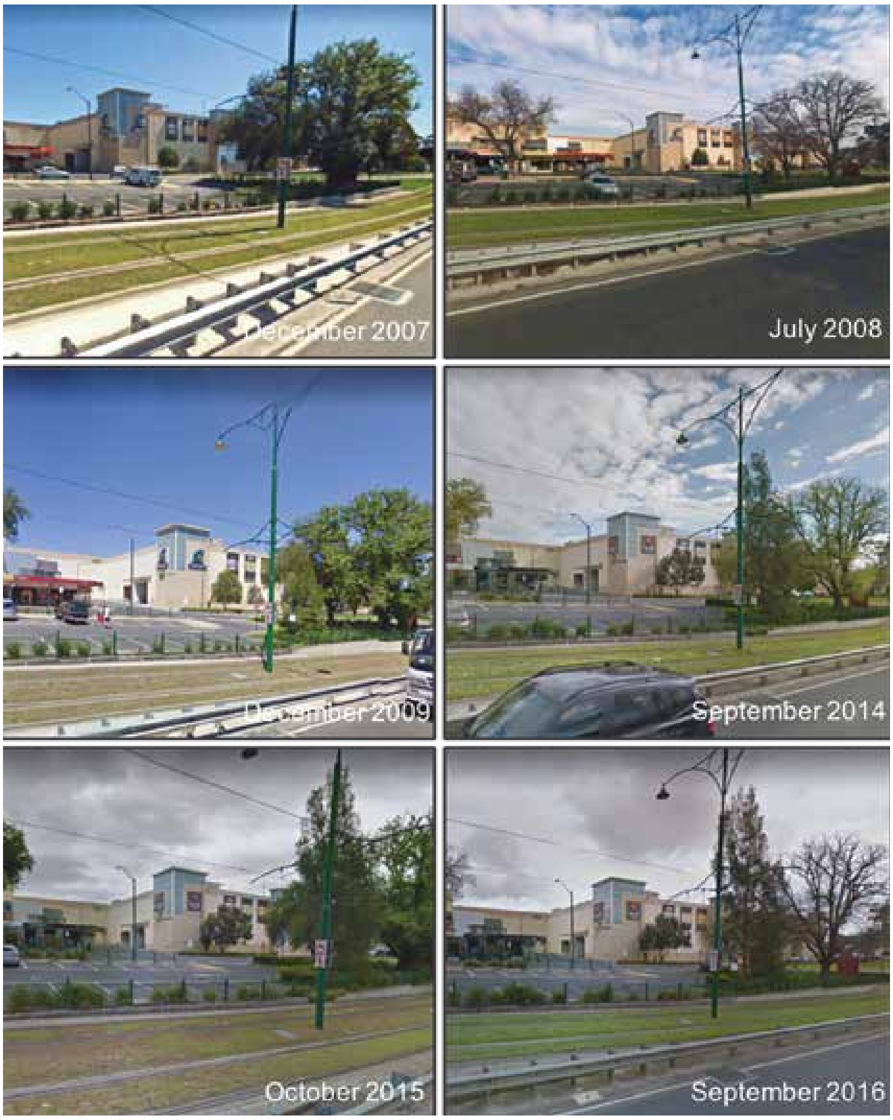


FIGURE 2.20: Timeseries (2007 – 2016) of green track near the Interchange at Box Hill, Melbourne. The series documents varying condition of the green track. As the track is enclosed by fencing and traffic guard railing, deterioration of green cover is unlikely the result of foot traffic. (Image source: Google Maps)

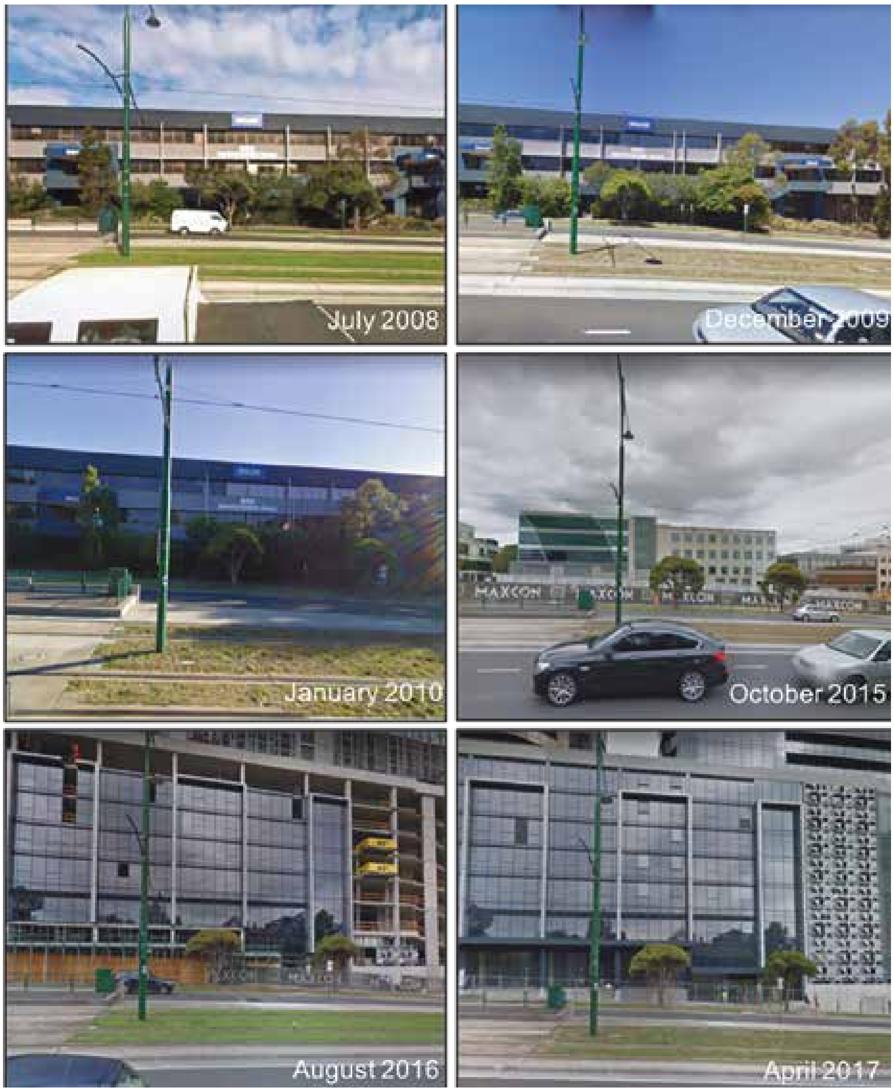


FIGURE 2.21: Timeseries (2008-2017) of green track at the intersection of Whitehorse Road and Nelson Road in Box Hill, Melbourne. (Image source: Google Maps)

The second timeseries reveals similar issues to the first. Seasonal variation in the quality of the vegetation cover is apparent, indicating water limitation issues during summer months. Images taken in December 2009 and January 2010 clearly document the patchiness of the grass and drought-associated discolouration of leaf blades. It is well known that stress-tolerant grass species tend to form tufts that can leave gaps and exposed top soil. Such locations are entry gates for spontaneous vegetation. Sufficient water supply can reduce this negative effect.

2.7.2 Victoria Square, Adelaide

The Capital of South Australia maintains a section of green track in its very centre at Victoria Square (Figure 2.22 top). On the western side of the square, three sections of different length form the border of public space in the centre and the multi-lane road directing traffic northward. The green tracks were opened in 2007 and the longest section extends for 150 metres (Department for Transport, Energy & Infrastructure, 2008). The Adelaide tramline extension from Victoria Square to the University of South Australia City campus is an important part of the vision of the Local Government to further integrate light rail services into the urban transport network.

Similar to Melbourne, the track system used in Adelaide consists of a slab track system with rails embedded in concrete beams and overhead power lines. Green cover is provided by a high-vegetation system of the TOR-type, using Kikuyu grass. Irrigation of the grass is provided through a sub-surface drip line system.

When assessing the grass cover of Adelaide's green track over time, it is important to note that no season or year can be identified where the quality of the green cover is suffering (Figure 2.23). Although some problems with continuous irrigation seem to have led to reduced coverage of grass in the summer of 2007, these issues must have been resolved by September 2008 where the grass cover appears healthy and dense. From 2008 onwards, the green track appears thick, spongy and in very good health throughout the year. No weeds can be

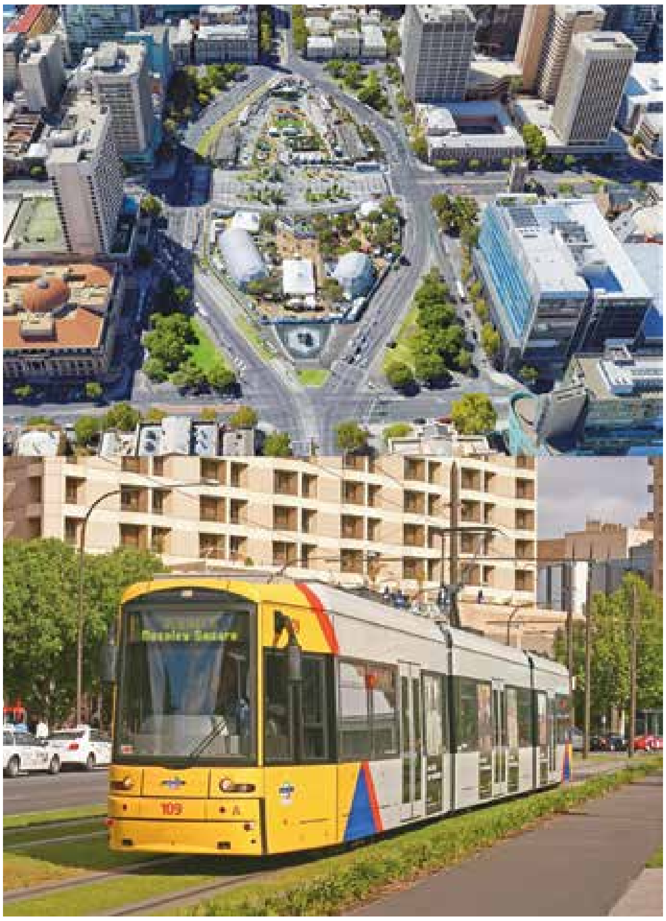


FIGURE 2.22: Green track in Adelaide, Australia. Top: Aerial view of Victoria Square with green track sections visible on the western side. Bottom: Adelaide's Tram service (Image source: Google Earth 2018 (top); southernthunderer.com 2018 (bottom))

spotted. This stands in contrast to the green track at Box Hill, where patchy vegetation cover and flowering invasive weeds could be seen (see Figures 2.20 and 2.21).

Given the very low summer precipitation of 23 mm received between November and February, and the overall lowest annual precipitation of all three Australian cities that maintain or seek green track (see Table 2.2), it is highly likely that the water requirements of green tracks in Adelaide are supplemented by subsurface irrigation. Unfortunately, it was impossible to receive this information from city officials to include further details in this review. It is highly advisable that TfNSW establishes communication with their counterparts in South Australia to receive relevant information and short-track the development of a sub-surface irrigation system, based on valuable experience from Adelaide.

FIGURE 2.23: Time series of green track in Adelaide. Lush green track beds are maintained using a sub-surface drip-line irrigation system. (Image source: Google Maps 2018)

FIGURE 2.24: The Portland Cable Tram. This tramway operates as a tourist destination at the western end of the Great Ocean Road (NRMA 2018) in the town of Portland. An odd exception of grass track bed.

2.8 *Odd* Green Tracks in Australia

In addition to the two light rail systems that contain short sections of green tracks in Box Hill, Melbourne and Victoria Square, Adelaide, there is the odd exception of green track that can be found in a range of locations (historic and contemporary).

The Portland Cable Tram (Figure 2.24) is a restoration project that has been operating since 1996 as a tourist destination, around 350 km west of Melbourne. The line was established with the aim to commemorate the 100th anniversary of cable trams in this former industrial centre of southern Victoria. Grass-covered section of the rail network visually blends the track bed into surrounding vegetation along the shore of Port Phillip Bay.

Historically, it is evident that green track was abundant in Australian cities. The Tramway Museum in St. Kilda, Adelaide features operational historic trams from Adelaide, Melbourne, Sydney and Ballarat for tourists to ride. The museum holds a collection of historical photos where green track can be seen. For example, the Kensington Gardens line in Adelaids was a short section of 'reserve track' that ran though the Eastern Parklands at Rymill Park on an embankment (Figure 2.25). The entire line was covered by green track throughout its operation from 1952 until closure in 1957 (Tramway Museum, St Kilda Adelaide, 2018). Other historical examples of green track operating in Australian cities is shown below (Figure 2.26 and 2.27).

FIGURE 2.25: Historic tramway in Adelaide. (Image source: Tramway Museum, St Kilda S.A 2018)

FIGURE 2.26: Historic green track in Sydney. An image from 1947, the La Perouse via Botany Bay tram line in Sydney operating and surrounded by green track. Clearly visible is the poor performance of the grass cover between the rails where little top soil was available over the ballasted track bed to retain any plant-available water. (La Perouse.info 2018)

FIGURE 2.27: A historical tram at the Sydney Tramway Museum. Notably this green track lacks irrigation with the result of poor grass cover. (Image source: Destination NSW 2018)

The Sydney Tramway Museum provides a nostalgic and educational insight into the Light Rail systems during the 100-year period of tram operations in Sydney from 1861 to 1961. The museum has trams running, plus restoration works-in-progress, exhibits and photos depicting the development and operation of tramways. Trams carry passengers towards Sutherland and to the Royal National Park along the former railway line (two kilometres) which run on areas of green track.

PLANTS FOR GREEN TRACKS

Green track bed finishes on existing light rail projects around the world have included synthetic turf, self-seeding turf, exotic and native grasses and groundcovers. Here, species suitable for priority green track sections of the proposed Parramatta Light Rail line, potential maintenance issues and alternatives will be discussed.

A ‘top ten’ list of suitable plant species, including species-specific technical information is provided. This technical information aims to guide decision-making processes of whether turf sod, inlay systems or direct planting into the track beds is desirable.

3.1 BACKGROUND

Steckler and colleagues (2012) found that challenges experienced by plants on a light rail track related to the physical and chemical traits of the supporting soil (e.g. grain, size, water holding capacity, compaction by trampling or vehicles) and differ widely from site to site. Light rail track systems are mostly open, unshaded habitats characterised by heat and frequent passing of trams that generate gusts of wind. This enhances the dangers of plant dehydration and impedes the development of high flowering stems of plants within tracks. Vehicles may also influence pollinating insects that are necessary to guarantee on-site seed production of flowering plants.

3.2 MAINTENANCE OF VEGETATION

A continuous, thick and healthy cover of vegetation within the track bed, whether it is turf, grasses or groundcovers, will require periodic maintenance. According to Kappis and Schreiter (2016), a visually appealing, uniform cover will have at least 90 % of the area dominated by a single species of turf or groundcover and only a maximum of 2 % spontaneous vegetation. With the correct species selection (i.e. species resilient to local climatic conditions such as frost or prolonged periods of drought) maintenance might be limited to periodic mowing (Cox Richardson 2015).

Adapting new practices

Grass maintenance requires location-specific risk assessments and working procedures that maintain safe operations and minimise impacts on adjacent land-uses, particularly in residential areas (TfNSW 2017). Some grass sections of the green track may require replacement as realised at the Box Hill system after periods of drought.

Plant establishment

Green track requires some attention during the establishment phase, and periodic maintenance through its operational life. Plants will be fully established 6-8 weeks after planting. During this time, it may be necessary to apply water on a daily basis. Further, applications of additional soil and fertiliser may be necessary.

Periodic maintenance

Following the process of mowing, care must be taken to remove debris from rail grooves or tracks. Cutting to keep the grass/groundcovers thick and free of thatch is estimated to be necessary once or twice annually. Tables 3.1 and 3.2 provide more technical information on species-specific requirements for maintenance, including mowing and fertilization. Live vegetation should also be kept away from the rail running surface (Transit Cooperative Research Program 2012). Issues related to live or cut vegetation can potentially become a serious hazard once debris is mixed with residual break sand, lubricating the wheel/rail interface and create problems with traction and braking (Novales and Conles 2012).

Depending on site and plant requirements, irrigation and fertigation might be necessary to ensure plant health. Once vehicular traffic (e.g. emergency services) has damaged the track bed, immediate repairs will be necessary to ensure fast recovery and closure of the plant cover. This will limit also the risk of spontaneous vegetation taking hold in the vegetated track bed. Detailed recommendations for the maintenance of the ‘top 10’ species suitable for track greening in Parramatta will be provided in Chapter 5 – *Design Recommendations for Parramatta.*

3.3 LIGHT RAIL STOPS

Grass track bed finishes might be unsuitable for light rail stops, depending on the design of the station (e.g. blocking of pedestrian crossing), the track system (e.g. FOR or TOR system, see Appendix 1), the vehicle used (e.g. venting of hot air at the base) and mean residence time of the vehicle in the station. The low visual appeal of dead grass track in stations is shown in and example from Frankfurt, Germany in Figure 3.1. However, several cities have been identified in Chapter 2 that operate green tracks in stops successfully (see images provided in Section 2 from Bilbao, Guangzhou, Kagishima, Portland and Potro). Selecting plant species that can tolerate frequent foot traffic and installation of obstacles that minimize such traffic (e.g. low fence between tracks or elevation of platforms) will help keep green track in stop areas appealing.

FIGURE 3.1: Dehydrated grass track at a stop in Frankfurt, Germany. (Image source: Cox Richardson 2015)

3.4 TOPSOIL DEPTH FOR VEGETATED TRACKS

Topsoil (also termed *vegetation base layer*) and subsoils act as primary water storages for plants. As a general rule, the deeper the vegetation base layer, the more water is potentially available for plants. Stored water below the root zone of plants can be wicked upwards by capillary forces where is becomes plant-available. A low watering frequency and associated costs are highly desirable maintenance and budgetary targets for operation of green track. Depending on physical characteristics of sub-soil/base material, deeper soil layers may also be available for storage of access rain or irrigation water.

Depending on the construction profile of slab track systems, depth of soil will vary (see Table 2.3). For example, if a slab foundation is used to support rail columns, depth of topsoil may be less than 300 mm deep (Cox Richardson 2015). When using such a system, additional drainage must be provided to prevent saturating or flooding of soil with irrigation or stormwater. A track system that only uses a parallel beam track, where concrete beams rest on compacted sub-grade material may also require drainage infrastructure as natural seepage of access water into deeper soil layers may be limited. Structural integrity of the track system may be compromised if excess water remains on or in the sub-grade for extended periods of time. These considerations are important factors when matching the design of prospective green track with environmental conditions.

European green track experts suggest an overall soil depth to a minimum of 350 mm, with a minimum thickness of the vegetation base layer of 250 mm (Kappis and Schreiter 2016). This recommendation represents a good compromise between limiting excavation work and providing sufficient depth to ensure good plant establishment and some soil water retention. Given that it will be unavoidable to include an irrigation system into green tracks of the Parramatta Light Rail line to maintain plant health during periods of low or no rainfall (summer and winter), additional water can be supplied at any time. The suggested soil depth allows installation of the irrigation system at ideal depth for shallow-rooting plant species (100-150 mm, see Chapter 4).

It is important to highlight the consequence of including a geotextile layer between the top soil and filter layer. Including such a layer will minimize loss of soil and associated declines in drainage capacity. Selecting the correct mesh size of the geotextile will require expert advice. A visual representation of the different elements involved (i.e. vegetation cover, top soil, geotextile, filter layer) is given in Figure 3.2.

When selecting soil for the vegetation base layer, initial tests are of great value. These tests can help identify desired soil properties prior to ordering soil from contractors. Specific soil tests are outlined in *Section 6 – Conclusions and Outlook*. When ordering soil from a contractor, it is important to request a soil certificate.

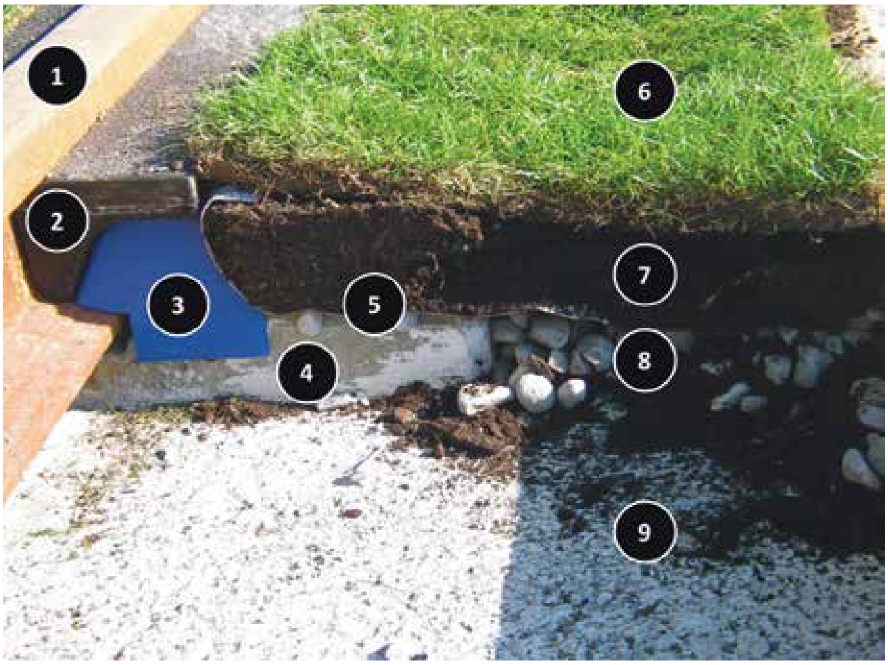


FIGURE 3.2: Green track profile. 1: rail, 2: 2rail insulation, 3: rail fastening insulation, 4: reinforced concrete filler block, 5: geotextile layer, 6: turf, 7: vegetation base layer, 8: filter layer, 9: concrete base slab. (Image modified from Corsi 2017)

FIGURE 3.3: Water thirsty and high maintenance Kikuyu grass used in Victoria Square, Adelaide as a track bed. (Image source: Marne Valley Turf 2009)

This certificate should include information on nutrient status, structure/grain size distribution, water holding characteristics, air space and pore volume, content of organic matter, pH value and should confirm that the soil material is free from contamination. Soil samples should be provided. It is also advisable to collect and test soil samples during the early stages of track operation to detect any changes in soil chemistry or structure that could impact plant health and drainage performance.

Equally important are considerations about the selection of materials for the base layer below the top soil and filter layers. Light rail tracks can be established on compacted sub-grade or concrete slab. In the absence of green track, selection of base material may be influenced by economic reasons or the structural morphology of underlying soil layers and bedrock. However, when building green track beds, it is important to consider vegetation-specific effects on the materials used for the base layer. Plants require nutrients in the form of salts. These are provided either by natural decomposition processes in soils or through application of fertilizers. If salts are present in amounts that exceed plant uptake capacity, they will be leached into the filter layer where they become unavailable for plants and potentially damaging for concrete slabs. The associated deterioration of concrete is known as Salt Damp Attack. The process can be described as follows: "This mechanism concerns the internal creation of crystalline ettringite and gypsum in a complex chemical reaction between the tricalcium aluminate (C_3A) in the cement and invasive sulphate salts forming calcium sulphoaluminate (CSA). The ettringite and gypsum cause a volume increase which ultimately leads to break-up of the mix from within" (*sensu* Goldfinch 2003). It is thus necessary to ensure isolation of concrete from soil surfaces and appropriate drainage to remove excess water and nutrients.

Most plant species suitable for track greening (see Table 3.1 further below) require a neutral or slightly acidic soil pH. Two effects may become problematic to maintain both track integrity and plant health. Track integrity can suffer if organic compounds, fatty acids and other substances are leached from plant roots and top soil onto concrete surfaces where they can cause aggressive corrosion (e.g. de Belie et al. 1996). On the other hand, concrete is highly alkaline (pH of 13 when new). The extreme alkalinity of the composite material originates from the use of ingredients with high calcium concentration, such as lime. Over time, concrete that is in contact with water will leach calcium carbonate into surrounding soil, and thereby increasing soil pH. This process of alkalinisation will lead to plant stress as essential soil nutrients are bound to soil colloids and become unavailable to plants. This process can be restricted by isolating concrete structures from the surrounding environment. However, such precautions come at additional costs for epoxy-type coatings.

Using compacted sub-grade materials such as crushed sandstone or manufactured aggregate will not impact soil pH like concrete slabs. However, this is only the case if materials used do not contain recycled materials, as they are likely to include concrete. In addition, compacted sub-grade can provide additional benefits, such as drainage (although possibly limited), a quickly workable, planar surface, lower construction cost and a smaller carbon footprint compared to concrete slab.

3.5 ISSUES AND PRECAUTIONS

Turf cover seems ideally suited for locations where adjacent road traffic is high, causing continuous wind suction and associated evaporative water loss. Hence, species selection should not only be informed by local environmental climate of soil conditions, but also consider what other types of disturbance regimes might be presence at the site of greening.

The green track section at Box Hill was constructed on a concrete base, made from levelled, compacted sand. It has a skeleton framework of reinforced concrete slabs laid out to fasten the rails and cross-bearers at set intervals. Spaces between concrete slabs were infilled with 150-200 mm top soil and covered with a native grass species. Species selection was guided by plant drought tolerance and also to meet the operator's commitment to improving the environment and using a native species in their greening process (Railpage 2009).

Key issues associated with Box Hill grass track relate to irrigation and access restrictions. The track was watered using a pop-up sprinkler system. Irrigation was scheduled for early morning hours when no service was using the track. However, water restrictions were imposed on Melbourne during the peak of the Millennium drought from 2005-2008. Once irrigation ceased, the grass died.

Although emergency service vehicles could drive along the tram tracks, the grassed areas were only able to take the weight of small vehicles without undue damage. Grassed track beds are not suitable for driving on with a heavy vehicle such as a fire truck or van. Given public safety priorities, substantial costs would incur when driving and operating heavy emergency service vehicles on green track beds.

Little details are known about the construction of the green track in Adelaide. It is assumed that a minimum of 150 mm topsoil was spread over compacted fill. Irrigation (sub-surface drip lines) and drainage systems were approved by Adelaide City Council, which is also responsible for track maintenance (Colling 2004). Kikuyu grass was used for greening (Figure 3.3). This species has high water demand and is watered twice weekly, incurring considerable water costs.

Due to good water supply, the green cover displays vigorous growth and must be mowed fortnightly. This involves a sit-on mover, line trimmer and blower, lasting for approximately 1.5 hours for three staff. Unfortunately, maintenance of the green track can only take place when trams are not operating. Currently this work takes place during 4 and 7 am on Sundays, much to the dismay of local residents.

3.6 PLANT SPECIES SUITABLE FOR GREEN TRACK IN PARRAMATTA

Western Sydney lies in an enormous basin composed of deeply weathered clay soils derived from Wianamatta Shale and the Parramatta area's vegetation type is classified as *Cumberland Plain Woodland* (clay soils and alluviums of the Cumberland Plain). Parramatta's inland location means that the rainfall is lower than on the coast, although the clay soils retain moisture better than the surrounding sandy soils. Within the area of the proposed Parramatta Light Rail line are soils of the Birrong, Glenorie and Gymea formation. The original ground cover was mainly native grasses with scattered shrubs. Now introduced grasses and opportunistic shrubs dominate the area (Robinson 2003).

Local practical plant knowledge was applied to identify suitable plant species and provide selection criteria for green track beds along the proposed Parramatta Light Rail line. The following selection criteria were applied to identify the most suitable plant species for green track in Parramatta:

- » Growth height;
- » Width of plant growth;
- » Flowering periods in the Parramatta local area;
- » Appropriateness to the humid sub-tropical climate zone in Parramatta;
- » Light conditions;
- » Growth habit;
- » Lifespan of the species;
- » Soil moisture required to sustain optimal growth and green appearance;
- » Propagation methods;
- » Frost tolerance;
- » Similar usage in urban landscape design;
- » Tolerance to high foot traffic; and
- » Weed suppression.

GROUNDCOVERS

1. *Pratia pedunculata* 'Trailing Pratia'
Groundcover, clumping perennial
Image source: GardensOnline

DESCRIPTION	» A dainty looking plant which spreads to form a carpet of green. » Has masses of small starry white to pale mauve-blue flowers in spring and summer
GROWING CONDITIONS	» Good for full sun to partial shade, and is best with regular moisture » Soil type: loam, sandy loam, clay loam, potting mix pH: acid, neutral
BENEFITS	» Ideal for planting in between pavers or edging paths, or as a low traffic lawn substitute » It roots at the nodes, so forms a mat of growth » Can be divided to propagate » Low maintenance » Erosion control » Fast growing » 'Playground friendly'
DISADVANTAGES	» Frost tender

2. *Dichondra repens* 'Kidney Weed'
Groundcover, clumping perennial
Image source: semillasdalmau.com

DESCRIPTION	» A creeping plant that spreads from underground stolons, making it a good ground cover » Naturally grows across Australia » Insignificant green-yellow flowers at all times of the year
GROWING CONDITIONS	» Grows best in light shade » Will grow in sunny spots if sufficient water is provided Soil Type: clay, loam, sandy loam, clay loam, poor soil pH: acid, neutral, alkaline
BENEFITS	» Tolerates light frost » Fast growing » 'Playground friendly' » Lawn alternative
DISADVANTAGES	» Unknown

3. *Viola hederacea* 'Viola Aussie Carpet', 'Native Violet'
Groundcover, clumping perennial
Image source: GardensOnline

DESCRIPTION	» A spreading groundcover with kidney shaped leaves » Produces a carpet of mauve and white flowers
GROWING CONDITIONS	» Best for part shade but will tolerate sunnier spots » Doesn't need much care but will appreciate some liquid fertilizer in spring Soil Type: sandy clay, loam, potting mix pH: acid, neutral
BENEFITS	» Flowers mostly spring and summer with spot flowers the rest of the year » 'Playground friendly' » Reliable long flowering
DISADVANTAGES	» May require some light pruning after flowering to promote fresh new growth » Can sometimes invade areas where not wanted but is easy to control if necessary

TABLE 3.1: Species description list of both groundcovers and grasses suitable for green track in Parramatta.

4. *Pratia puberula* 'Pratia Blue Stars', 'Alpine Pratia' Groundcover, clumping Perennial
Image source: GardensOnline

DESCRIPTION
- A moss-like ground cover with tiny, pale blue flowers
- A thick mat of foliage can be almost completely covered by a mass of blue star-like flowers in late spring through to autumn

GROWING CONDITIONS
- Prefers semi shaded areas

Soil Type: loam
pH: acid, neutral

BENEFITS
- A vigorous growing perennial that will spread over large areas
- Evergreen
- Flat growing weed suppressor and helpful in erosion control

DISADVANTAGES
- May require regular feed with a liquid fertilizer
- Can become invasive
- Keep well-watered in summer

5. *Goodenia hederacea* 'Ivy Goodenia'
Groundcover, clumping Perennial
Image source: GardeningWithAngus.com.au

DESCRIPTION
- Attractive and prostrate
- Hardy and long flowering
- Creeping ground cover
- Small yellow flowers

GROWING CONDITIONS
- Best in partial shade with some soil moisture
- Light shade

Soil Type: sand, clay, loam, potting mix, poor soil
pH: acid, neutral, alkaline

BENEFITS
- Useful in landscaping
- Suits most soils
- Low maintenance
- Pipe and drain friendly
- Playground friendly

DISADVANTAGES
- May require mowing

6. *Scaevola albida* 'White Carpet', 'Fan Flower'
Groundcover, clumping perennial
Image source: GardeningWithAngus.com.au

DESCRIPTION
- A vigorous and relatively long-lived soft-wooded ground cover with small leaves
- Small white flower size
- Extremely floriferous habit

GROWING CONDITIONS
- Full sun to light shade positions

Soil Type: loam, sandy loam, potting mix
pH: acid, neutral

BENEFITS
- Long-lived
- Fast growing
- Hardy ground cover
- Provides reliable drainage

DISADVANTAGES
- Annual fertilizing with Blood & Bone

GROUNDCOVERS

7. *Isotoma fluviatilis* 'Fill the gaps', 'Swamp isotome', 'Blue stat creeper'

Groundcover, clumping perennial

Image source: Piergrossi

DESCRIPTION	» Prostrate perennial herb, often mat-forming, usually pubescent or sometimes glabrous » Flowers in summer months producing a flat carpet of tiny green leaves and white/blue star-shaped flowers	
GROWING CONDITIONS	» Grows commonly in South Eastern Australia » Full sun or partial shade Soil Type: moist sand or mud, on edges of seepage areas pH: neutral, alkaline, acid	
BENEFITS	» Ideal groundcover in rockeries and between paving stones » Good lawn substitute » Worth growing as an annual in cold-winter regions » Tolerant of high foot traffic » Medium growth rate	
DISADVANTAGES	» Unknown	

GRASSES

1. *Zoysia tenuifolia*

Image source: Plant Tiles Australia

DESCRIPTION	» A perennial low growing grass originating from South East Asia » A fine textured leaf	
GROWING CONDITIONS	» Slow growing » Fine bladed » Deep green leaves Soil Type: clay, rock, salty and poor soil pH: neutral, alkaline	
BENEFITS	» No mowing required » Low maintenance » Low to medium water usage » Moderate drought & light frost tolerance » Tolerates hot humid climates » Will grow in shadier areas where other grass species struggle	
DISADVANTAGES	» Develops an extensive root system	

2. *Microlaena stipoides* 'Ehrharta stipoides', 'Weeping Rice Grass', 'Weeping grass'

Image source: Native Seeds

DESCRIPTION	» A small slender grass, usually with nodding spikelets » This single species is native to the Sydney Basin
GROWING CONDITIONS	» Occurs naturally throughout NSW, » Known to be moderately drought, frost and wind tolerant Soil Type: poor soil, clay loam, sandy loam pH: neutral to acidic (less than 5.5)
BENEFITS	» Drought tolerant » Produces year-round green growth » Ideal for use on roadsides, parks and golf courses » Low maintenance
DISADVANTAGES	» The seed heads are weeping and mowing is required

3. *Oplismenus aemulus* 'Basket grass' (Grass, Clumping Perennial)

Image source: Tann

DESCRIPTION	» A small trailing herbaceous grass with sprawling or ascending stems and short, broad leaves
GROWING CONDITIONS	» Common in shady places » Can tolerate hot overhead sun to warm low sun Soil Type: clay, sand, loam pH: neutral to alkaline (6-7)
BENEFITS	» Used as a lawn grass » Locally naturally occurring » Requires not much watering
DISADVANTAGES	» Can become invasive

TABLE 3.1: Species description list of both groundcovers and grasses suitable for green trach in Parramatta.

Table 3.2 provides further details of the ten groundcovers and grasses suitable for the climate in the greater Western Sydney area. These are presented as a useful guide to compare and contrast with species used on existing Australia green track systems (such as Kikuyu and Couch grass species). The selected plant species are native to the area and thus adapted to local environmental conditions.

(a) Groundcovers

Species	Height (m)	Width (m)	Flowering Time in Parramatta	Light Requirements	Growth Habit	Propagation Method
Pratia pedunculata	0.1 – 0.2	0.5 – 1	Spring, Summer	Sunny, light shade	Spreading evergreen, dense open foliage	Seed
Dichondra repens	0.1 – 0.3	1 – 5	All year round	Sunny, light shade, partial shade	Evergreen, spreading	Division
Viola hederacea	0.2 – 0.3	1 – 2	All year round	Light shade, partial shade	Dense foliage	Spreads widely by means of trailing stolons that root at the nodes
Pratia puberula	0.1 – 0.2	2 – 4	Late spring to Autumn	Full sun & shade	Very fast-growing evergreen	Roots at the stems & can be spread over large areas
Goodenia hederacea	0.2 – 0.8	0.5 – 1	Spring, Autumn & Winter	Light shade & partial shade	Evergreen	Soft cutting, semi hardwood cutting
Scaevola albida	0.1 – 0.2	0.5 – 2	Spring, Summer	Sunny, light shade	Evergreen, spreading, mound shaped	Germinates readily from seed & also strikes from cuttings
Isotoma fluviatilis	0.1 – 0.2	0.5 – 1	Late Spring to Summer	Sunny, light shade/ partial shade	Spreading evergreen, dense open foliage	Roots at nodes, easily ripped apart into smaller pieces to make new plantings in early spring
Zoysia tenuifolia	0.1 – 0.2	0.5 – 2	Winter	Shade tolerant to full sun	Spreading low levels of thatch	Vegetatively & by seed
Microlaena stipoides	0.1 – 0.5	2 – 5	Most of the year	Sunny, light shade/ partial shade	Evergreen, shallow & spreading root system	Sowing seed, Germination may take place from 10-14 days
Oplismenus aemulus	0.1 – 0.3	2 – 5	Most of the year	Sun & shade	Evergreen	Direct seeding, stems trail along the ground & can root at nodes

TABLE 3.2: Technical information about selected plant species. All propagation methods will require some manual labor.

(b) Grasses

The selection of plants suggested was subject to their availability during the time period preparing this review. Examples of all species were sourced from local nurseries and businesses in Greater Western Sydney area (Table 3.3).

SPECIES	NURSEY/BUSINESS LOCATION
Pratia pedunculata	Abundantly available from Bunnings
Dichondra repens	Abundantly available from Bunnings
Viola hederacea	Abundantly available from Bunnings
Pratia puberula	Abundantly available from Bunnings
Goodenia hederacea	Greening Australia, WSU Hawkesbury campus
Scaevola albida	Plants Plus, Cumberland State Forest, West Pennant Hills
Isotoma fluviatilis	Abundantly available from Bunnings
Zoysia tenuifolia	Plants Plus, Cumberland State Forest, West Pennant Hills
Microlaena stipoides	Hawkesbury City Council Community Nursery, Mulgrave
Oplismenus aemulus	Grows naturally in the Greater Western Sydney area

TABLE 3.3: Plant species and nursery locations.

The native grass cultivar, *Zoysia macrantha* 'Nara' was recommended by Greening Australia as a suitable species for green track in Western Sydney. It is suited to local conditions, is considered relatively heat, salt and drought tolerant and is noted as requiring less maintenance than typical park turf. However, *Z. macrantha* has potential disadvantages compared to the other ten identified plants species. It is not very shade tolerant and dies back during winter months in Western Sydney (Loch, Simon and Poulter 2005). *Z. macrantha* also requires regular mowing, fertilising and watering. It can be slow growing compared to other groundcovers and grasses and can be invaded by weeds upon establishment. This cultivar becomes dormant over winter in the Greater Western Sydney area.

Nara preferers to be planted when the climatic conditions are not too cold. Installation of the species should be avoided between the 15th May – 15th August (All About Turf 2015). Nara™ Native Turf is trademarked by *Ozbreed* Pty Ltd (Layt 2012) and protected by the Australian Plant Breeder's Rights. It has also been recognised as new cultivar by the Australian Cultivar Registration Authority (ACRA) in November 2017. Nara is an Australian native species of turf currently supplied by breeders for large scale government landscape project. Site visits to Abulk Turf Farm at Corn Wallis in Western Sydney revealed that this local supplier (and surrounding turf businesses) did not have adequate supply of turf sods available for a commercial, large-scale application like the proposed green track for the Parramatta Light Rail line. The above information is provided with the intention to raise awareness of potential issues related to plant availability and planting success.

It is highly recommended to assess performance of any species (and planting system, see Chapter 3.7) selected to feature as green track vegetation is rigorously field-tested and monitored to clearly assess their viability for large-scale planting. Requirements and suggestions for relevant experimental and manipulative work are detailed in Chapter 6 – *Conclusions and Outlook*.

FIGURE 3.4: Pre-cultivated *Dichondra repens* plant tiles. (Image source: unknown)

3.7 GREEN TILE TECHNOLOGY

As an alternative to direct planting on-site and waiting 6-8 weeks for the establishment of grass, there are 'ready to go' installations regularly used in construction of green roofs and walls. A range of species can be used for green tile technology, including turf and other groundcovers. In 2018, a group of turf farmers in Brisbane started a new company called *Plant Tiles* Pty Ltd. This company pioneered an instant, no-mow, ground cover 'carpet tile' to be laid wherever a green floor is needed. Long-term success of these tiles strongly depends on soil preparation (Powell 2018).

Standard size of the tiles is 330 x 330 mm with a height of 22 mm (Figure 3.4). The product can be cut/grown to specified size requirements. Plant Tiles Pty Ltd provides tiles containing three of the *top ten* species described above, namely *Dichondra repens,* native violets and Zoysia, which in tile form creates velvety mounds of very fine grass. These plant tiles are reported as being durable to high foot traffic – as they have been tested in several childcare centres in Brisbane.

Several species of *Zoysia* exist, however *Zoysia tenuifolia* has the finest textured leaf and is the only variety that is considered a to be a no-mow landscaping alternative (Figure 3.5). It grows very slowly and only to about 10 cm in height making it ideal for green track beds.

Z. tenuifolia requires low maintenance and has low to medium water use once established. It tolerates shade, moderate drought and some frost. It grows readily in hot humid areas and develops an extensive root system, making it a highly suitable species for the climate of Parramatta. When established in a 100-200 mm vegetation base layer of well-draining top soil, *Z. tenuifolia* handles moderate traffic well. It is proclaimed that under such conditions the species will become lower and from a denser cover (Plant Tiles Australia 2018), making it a suitable target species for green track in Parramatta.

FIGURE 3.5: *Zoysia tenuifolia* used as infill between pavers. (Image source: Plant Tiles Australia 2018)

The advantages of pre-cultivated, off-site produced 'replace as you go' native ground cover, grass or turf tiles is that they can easily be removed and replaced when needed. This ensures the grass track is dense and has a healthy, uniform appearance throughout time. Any potential scalping can be eliminated promptly by replacing affected tiles.

IRRIGATION OF GREEN TRACKS

4.1 BACKGROUND

Urban development leads to increases in the area of impervious surfaces, which reduce the ability of urban soils to intercept and store rainwater. Consequently, accumulative volumes of stormwater runoff require appropriate infrastructure to minimize the risk of local flooding (Shepherd 2006). The risk of flash flooding is anticipated to amplify through the effects of climate warming and associated increases in the intensity of heavy rain events (Zölch, Henze, Keilholz & Pauleit 2017). These predictions also apply to the Greater Sydney Basin. Permeable surfaces such as grass track beds for light rail systems can assist in mitigating some local impacts as the open surface will allow stormwater to infiltrate into the soil.

An added benefit of this process is the removal of access nutrients and contaminants from stormwater (Fam et al. 2008), thereby improving quality of runoff (Beard & Green 1994; Carpenter et al. 1998; Gross 1990). In addition to stormwater uptake, evapotranspiration from green track vegetation helps reducing urban heat. However, this positive effect is minimal if soils dry out, which is regularly the case during summer when the additional cooling is most needed in build urban space (Gill, Rahman, Handley & Ennos 2013). During this time, evaporative water losses are significantly greater than recharge of soil moisture through rainfall (Figure 4.1). On the other hand, soils can also dry out in cooler months, where monthly rainfall can be as low as 50 mm. Extended dry periods during winter months are experienced in the Parramatta Region, and are predicted to increase in frequency with continuing environmental change.

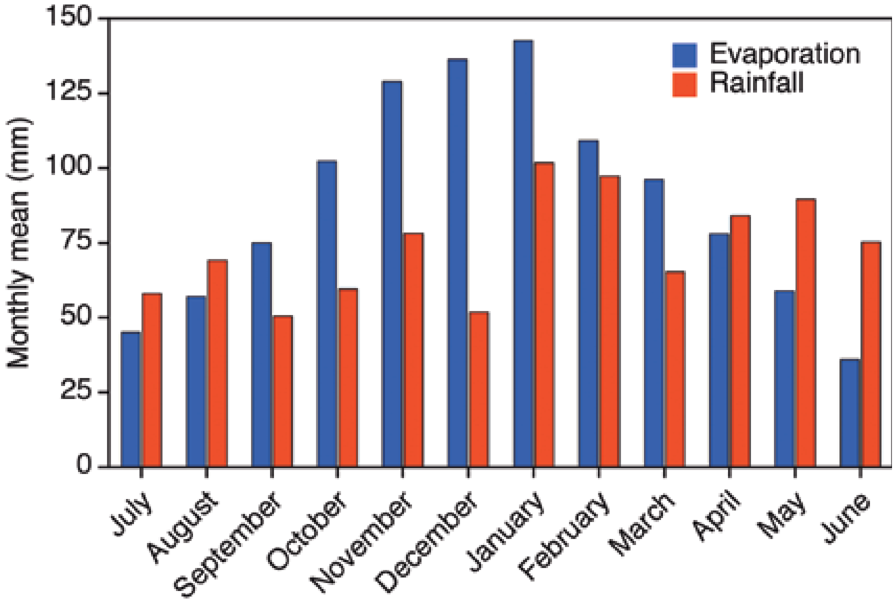


FIGURE 4.1: Long-term average rainfall and evapotranspiration at Sydney Olympic Park.

The common cycle of water on green track can be separated into four processes that often occur synchronous:

1. Rain recharges soil moisture.
2. Once soil reaches field capacity (i.e. maximum water holding capacity), excess water drains away.
3. Capillary forces draw stored soil moisture upwards in the soil profile (direction from wet to dry); this moisture can evaporate if it reaches the interface between soil and atmosphere.
4. Plants take up soil moisture and transpire it back into the atmosphere, whereby the process of evaporation and transpiration of water provides cooling.

The magnitude of these individual processes determines when plants become water limited. During cooler months, when rainfall is higher and rates of evapotranspiration are low, stored soil moisture can be accessed by plants through capillary lift from lower to shallow soil depths and access water can drain out of the filter layer (Figure 4.2a). The specifications listed in the Green Track Discussion Paper (Draft 3, TfNSW 2018) requests a soil layer (total) of at least 500 mm thickness, composed of a vegetation base layer of at least 300 mm and a filter layer of at least 100 mm thickness (Track type 1 in Fig. 4.2). While plants could access stored soil moisture under these design specifications during cool and wet months (Figure 4.2a), they might

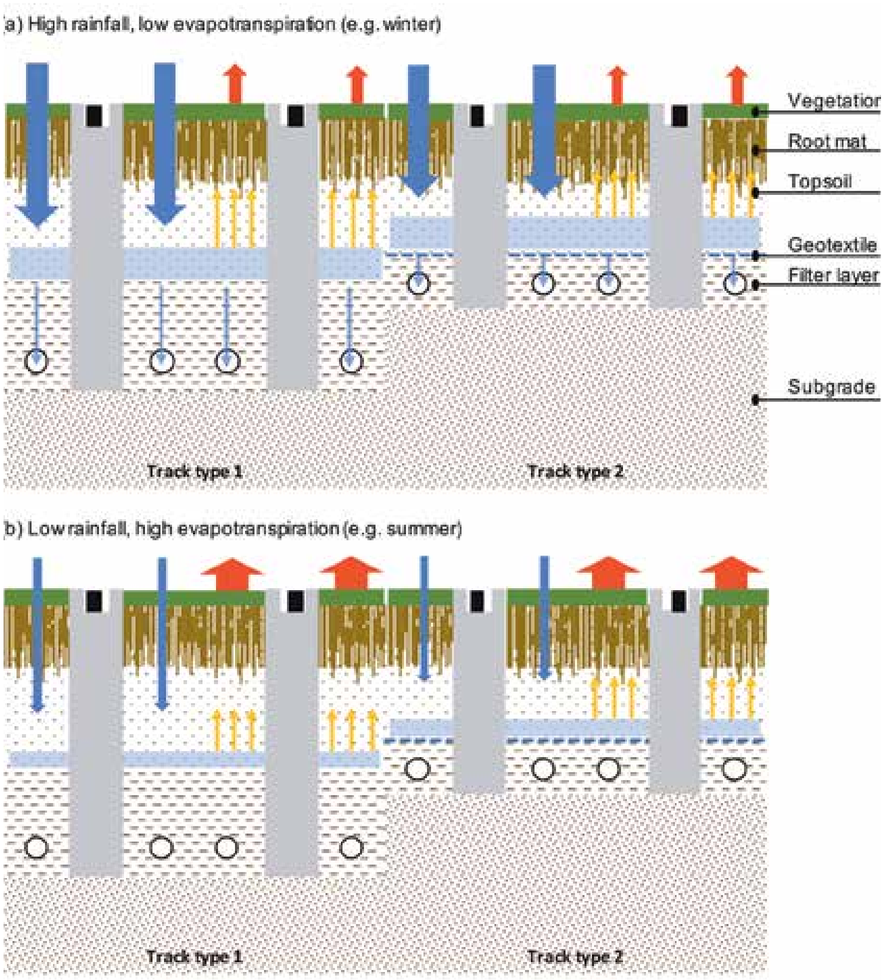


FIGURE 4.2: Seasonal soil moisture dynamics for two different track types. Both track types have identical vegetation cover and root mat thickness. Track type 1 is constructed according to draft contract requirements (TfNSW 2018): 300 mm topsoil and 200 mm filter material. Track type 2 is an optimized design, based on findings of this review: 250 mm topsoil, 100 mm filter material, separated by a geotextile. Solid blue arrow: rainfall; solid red arrow: evapotranspiration; solid yellow arrow: capillary rise of soil moisture; transparent blue layer: soil moisture; transparent blue arrow: draining soil water; circles: drainage pipes. See text for detailed explanation.

not be able to do so when soil moisture becomes limited and capillary forces are not sufficiently strong to lift water into the root zone of plants (Figure 4.2b). Avoiding this situation under the given specifications will lead to higher rates of irrigation, associated higher rates of water losses through drainage and an increased risk of standing water to concrete infrastructure.

Reducing the thickness of the soil layer (total) to 350 mm (250 mm vegetation base later, 100 mm filter layer) seems thus beneficial (Track type 2 in Figure 4.2). During times of high rainfall and low rates of evaporation, excess soil water can still drain out of the track bed. Reduced thickness of the vegetation base layer will optimise irrigation management and water availability during times where rainfall is low and rate of evaporation are high. Under these conditions, irrigation water can be accessed by plants at all times, while capillary forces remain sufficiently strong to lift stored soil moisture into shallow soil depths where it can be taken up by plants. This modification will help reducing the aforementioned risks for water losses and damage to track infrastructure. Including a geotextile layer in the optimised track design seems highly desirable. The textile will act like a filter that prevents downward transport of soil particles, reduced drainage capacity of the filter layer and risk of blockage of drainage pipes. In extreme cases these effects can lead to flooding of the track bed, as well as extended damage to vegetation and track infrastructure.

For these reasons, it is inevitable that green track beds must receive additional water to remain healthy. Furthermore, ground vegetation with short root depth will be the first to suffer from low soil moisture availability, including those species used for green tracks. Mindful irrigation of green tracks and other urban green infrastructure can help alleviate this issue, and the process of irrigation itself becomes part of integrated urban water management (Broadbent et al. 2018).

This chapter focuses on irrigation systems suitable for green track beds by examining current and emerging technologies that meet requirements of the proposed Parramatta Light Rail green track. Pop-up sprinkler systems, driplines and irrigation mats will be explained. Additionally, this chapter provides up-to-date information on a potential 'package system' for irrigation.

4.2 THE IMPORTANCE OF IRRIGATION

Irrigation is required during all three phases of green track maintenance. Phase one can be termed 'Establishment Period', where irrigation, fertilization and cutting ensures good ground cover with plants sprouting from direct seeding. If roll-out turf is used, irrigating will be required to ensure fast growth of plant roots into top soil. Irrigation requirements will differ according to species used, seed germination rates and environmental conditions. Under optimal management and environmental conditions, the maintenance period should last no longer than two months.

A 'good soaking' of at least one-third of the vegetation base layer during the establishment period will encourage root growth into deeper soil layers – a very important process that will provide an improved capacity of the vegetation to access deeper soil water during times where surface layers may become water limited. Soils will reach this undesired state faster if permeability of the top soil is high and thickness of the vegetation base layer is decreasing.

The second phase, termed 'Rectification Period', commences once plant roots have bonded with the vegetation base layer. Work during this phase involves filling patches where the initial vegetation cover failed. High rates of spot irrigation might be necessary to ensure that replacement plants grow in well. Once good cover is achieved, the 'Maintenance Period' begins with regular irrigation intervals and quantities, as well as mowing if required. As a guideline, tracks with relatively shallow vegetation base layers receive irrigation volumes of up to 5 L day^{-1} m^{-2} during peak summer in central Europe. Given the hot and dry summer conditions in Parramatta, irrigation volumes may need to be higher. The stipulation in the Draft Infrastructure Contract by TfNSW (2018) that "*the irrigation system must deliver the water volume required to completely irrigate the designated areas at a rate … 10mm per day for lawn areas*" seems very realistic and absolutely necessary.

It follows that designing irrigation systems that can handle distribution of such volumes is an important prerequisite. Design, installation, operation and maintenance of the required irrigation system must be handled by a team of experts. The irrigation strategy and feasible options of water supply for the system need to be rectified early during the design phase (Kappis and Schreiter 2016). Ultimately, the quantity and frequency of irrigation will depend on a range of factors, including (I) the vegetation type used, (II) thickness of the vegetation base layer, (III) water storage capacity of the top soil, (IV) water permeability of the vegetation base layer, (V) regional climate, (VI) and location specific weather conditions (e.g. exposition to sun, wind).

If water supply is insufficient, grass tracks can rapidly lose their positive visual attractiveness. Once scalping occurs as a result of water limitation, composition of the vegetation cover might change, leading to increased maintenance costs (Kappis and Schreiter 2016). As mentioned earlier, green track cover by the dominant and desired plant species should be at least 90 %, and spontaneous vegetation should only occur on less than 2 % of the green track bed. Lastly, it is advisable to request a water analysis of mains water to be used for irrigation to ensure its suitability for the selected irrigation system and vegetation cover. An example of a water analysis for water from the Prospect East catchment is attached at the end of the review (Appendix 3).

4.3 DRAINAGE

It is necessary to apply professional engineering solutions for appropriate drainage design of green track. This knowledge goes beyond the capacity of the authors of this report. Hence only a few suggestions about track drainage are provided. It is noted that defining the balance between sufficient drainage for stormwater and providing sufficient capacity for water retention to support green track vegetation is a balancing act that will vary according to track specific circumstances. An example of a track cross section with drainage is shown in Figure 4.3.

Drainage of green track is critical to reduce water damage to rails, slabs and other infrastructure, but also to limit the occurrence of stray currents and associated corrosion. Suitable capacity of drainage depends on expected rates of stormwater run-off and must be designed accordingly. With green track, however, additional issues must be considered, depending on the type of track used. If ballasted track is use, stormwater can simply drain through the sub-ballast and into the subgrade layer. Similarly, if a parallel grade beam system sits on compacted subgrade, water could just drain through the profile of the track.

However, if the green track is established using a continuous or twin concrete slab system, water might pool on the concrete surface and cause substantial damage of vegetation (anoxic conditions can cause dieback) and infrastructure (corrosion).

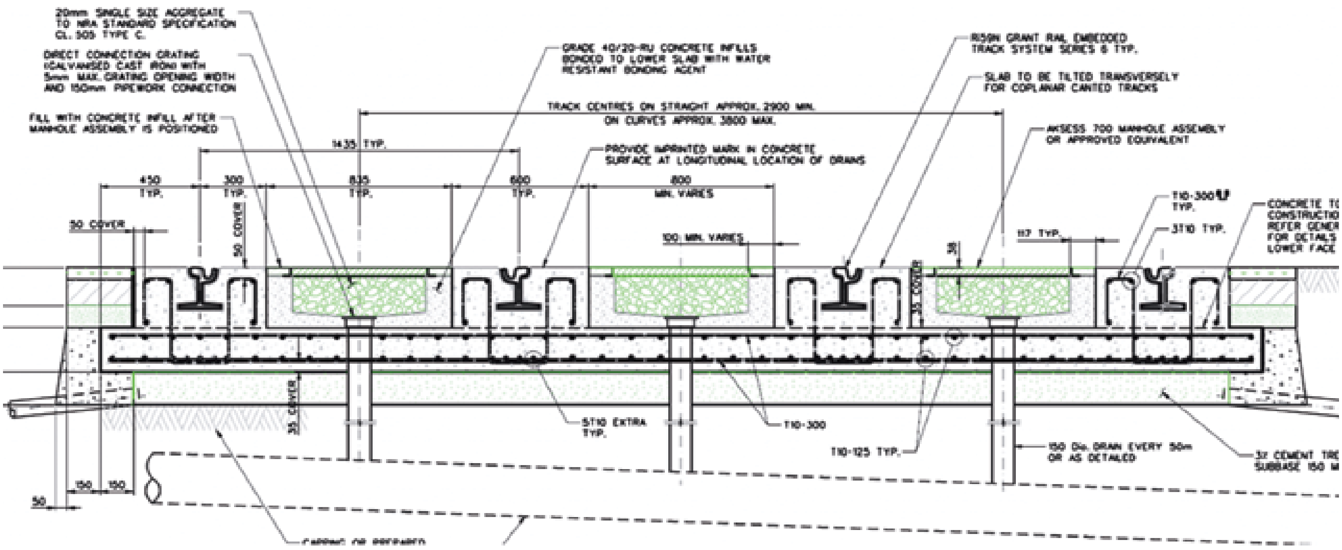


FIGURE 4.3: Example of a cross section of track type 'Luas 2004'. Clearly visible are vertical drainage shafts connecting to a tilted horizontal drain pipe to divert access stormwater away from the subgrade layer. It is advised that vertical drains should be filled with gravel and topped with geotextile material. (Image source: Corsi 2017)

4.4 IRRIGATION SYSTEMS FOR GREEN TRACKS

4.4.1 Mobile Irrigation with Water Tankers

Irrigation can be carried out with a special purpose rail mounted water tanker which is used for irrigation of public open spaces and parks in European countries. Rail mounted special purpose water cars are bespoke designs with corresponding higher investment costs.

This type of irrigation is very personnel-intensive since the tanker has to be filled (high-flow refill stations should be available), synchronized with regular tram operations and operated (Figure 4.4). The success of such measures is highly dependent on the technique used and frequency of irrigation. Irrigation with water tankers does not require any additional installation/construction works within the track area.

According to park management personnel of the City of Sydney, it is possible to operate green tracks without any irrigation system if the right plant species were selected. In such a scenario a water truck could be driven over the rails/tracks for a one-off watering if drought and/or heatwave conditions occur. However, timing of access for such operations is critical and undesirable if undertaken during engineering hours (time outside of operational hours). Reason is, there may not be sufficient time for irrigation and associated noise could be problematic in residential areas (TfNSW 2015).

FIGURE 4.4: Irrigation using a mobile water tank after installation of turf on a light rail track. (Image source: Schreiter 2012)

FIGURE 4.5: Pop-up sprinklers. Although the basic principle of the technology is similar among available models, differences exist in types of water dispersion (e.g. jet, mist or spray), if nozzle heads are stationary or rotate and materials individual sprinkler components are made of (e.g. plastic, brass). (Image source: variable, Google Images)

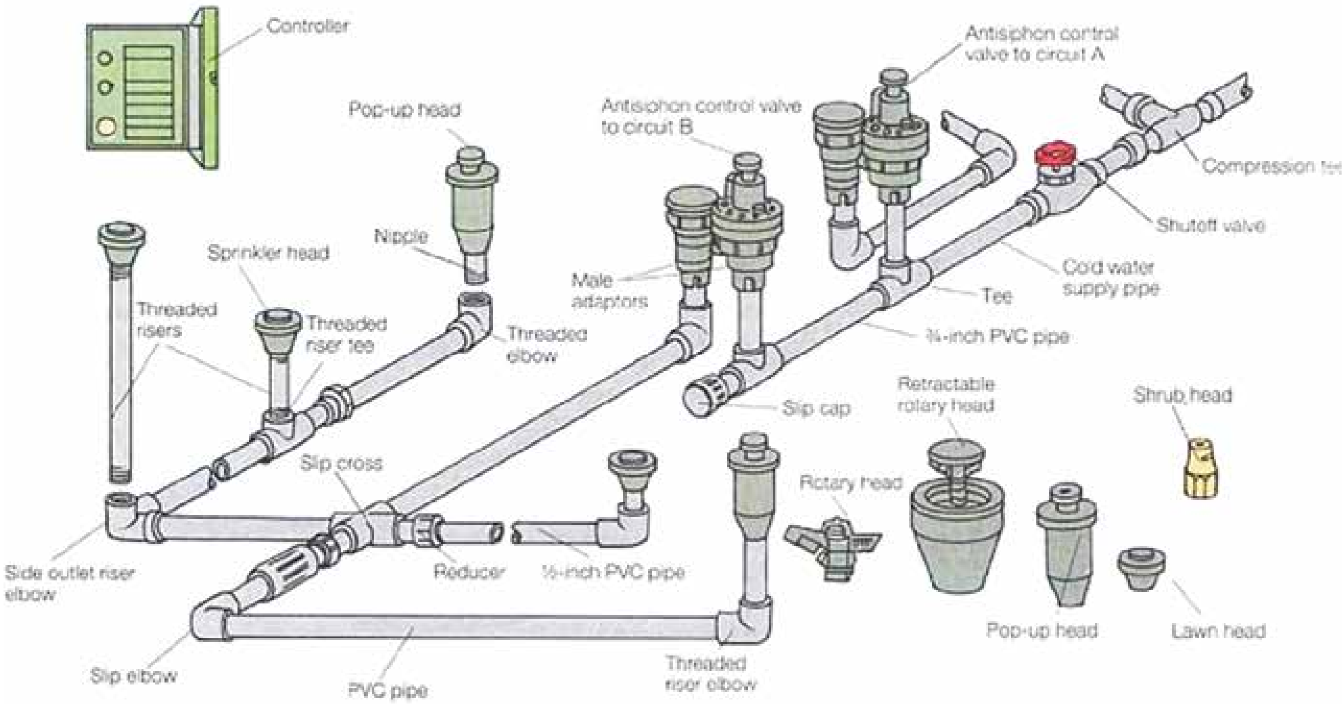


FIGURE 4.6: Schematic drawing of the components required for a pop-up sprinkler system. (Image source: mobos.com)

4.4.2 Pop-Up Sprinklers

Irrigation systems with pop-up sprinklers have been used successfully for a long time helping to maintain lawns and other urban green infrastructure in gardens, parks and small and large sporting grounds. Pop-up sprinklers are firmly installed into the ground. An electric impulse to the irrigation control system opens a valve that will fill an underground piping system. With increasing water pressure, the riser will emerge from the body and irrigate pre-defined areas. Once water pressure drops, the riser retrieves back under ground. Numerous designs of pop-up sprinkler systems exist on the market (Figure 4.5). The main disadvantages of pop-up sprinkler systems are high evaporative water loss, inefficient wetting of confined space and potential for vandalism.

For a complete system, it is necessary to install underground piping, include a network of safety- and solenoid shutdown valves. The entire systems will be operated centrally from a control unit (Figure 4.5). The pressure head and sprinkler model used will define reach of water jets, area covered and so on. Faulty sprinklers are easily detected, their repair mostly straight forward.

Basic requirements, installation and maintenance of pop-up sprinkler systems are briefly outline in Table 4.1. Typical service life of pop-up sprinklers is between 15 to 20 years provided that they are maintained on a regular basis. All components need to be checked, wearing parts such as nozzles have to be replaced if necessary, the sprinklers have to be adjusted and the irrigation control system has to be regularly tested. As shown in an example from Paris (Figure 4.7), pop-up sprinklers can successfully be used to irrigate green track; low-profile risers and positioning in the central space between parallel tracks ensures complete coverage of the track with minimal losses to adjacent areas. Sufficient drainage of grooved rails must be ensured to prevent potential negative effects of break performance of light rail vehicles.

TABLE 4.1: At a Glance – Irrigation with Pop-Up Sprinklers

REQUIREMENTS
» Trenching for water ducting system.
» Central control unit.
» Delivery of water to confined space must be ensured to minimize water loss, runoff and slip hazards.
INSTALLATION
» Installation depth of 15-20 cm.
» Need to be accurately placed to not interfere with electric installations.
» Heads should be encased in concrete rings for protection.
MAINTENANCE
» Subject to damage and vandalism.
» Misaligned sprinklers could spray on adjacent surfaces.
» Can impair tram traffic and should be operated outside of track use hours.

FIGURE 4.7: Pop-up sprinklers used for irrigation of grass track in Paris, France. (Hunter Industries 2018)

4.4.3 Drip Irrigation Lines

With their most frequent uses in agri- and horticulture industries, the market provides solutions for surface drip irrigation (SDI) and subsurface drip irrigation (SSDI). Either SDI or SSDI deliver water at high frequency and low flow rates to small target areas. Sustainable use of water is part of responsible urban design and drip irrigation systems can markedly contribute to water savings (Ayars, Fulton & Taylor 2015). These systems are highly efficient because they provide water directly to the root zone, minimizing evaporative loss, especially in hot and dry climate (Suarez-Rey, Choi, Waller & Kopec 2000). As SDI systems are not suitable for irrigation of green tracks, only SSDI systems will be discussed.

Benefits of SSDI include improved plant establishment, reduction in applied water and associated costs. A central water delivery pipe, laid into a 300-350 mm deep trench will feed water into drip lines that branch off into the side walls of the trench where they deliver water directly into the root zone of the vegetation (Figure 4.8). Installation costs of such systems can be high, depending on design and durability of materials used. The life expectancy for a SSDI is between 15 and 20 years. These type of SSDI systems are common in agriculture and provide efficient water supply to row plantings of a range of crops. However, due to the arrangement in distinct rows and limited reach of drip lines SSDI systems are not recommended for green track as spatial uniformity of wetting is difficult to achieve. Numerous images can be found on the internet that depict circular wetting patterns and patchy grass cover as result of drip irrigation (e.g. https://itc.tamu.edu/projects/drip-irrigation-of-turf/). Also, when used infrequently, dripper heads can become encrusted with soil resulting in blockage.

FIGURE 4.8: Sub-surface drip irrigation system. (Image source: Missouri Ruralist)

A better spatial distribution of soil moisture can be achieved using networks of sub-surface drip tapes (SSDT). These perforated tapes release water in the upper surface of soils and have successfully been used to maintain grass cover in urban settings (Figure 4.9). These systems are close-loop, low-pressure networks that can irrigate confined areas, including long narrow spaces like light rail tracks. Installation of drip tape networks is relatively simple as no trenching is required. The tape network is laid out, connected and tested on the surface before it is covered with an additional layer of top soil and turf. Care must be taken that spacing between parallel rows of tapes is not too wide, as this can result in uneven vitality of surface vegetation (see Figure 4.9).

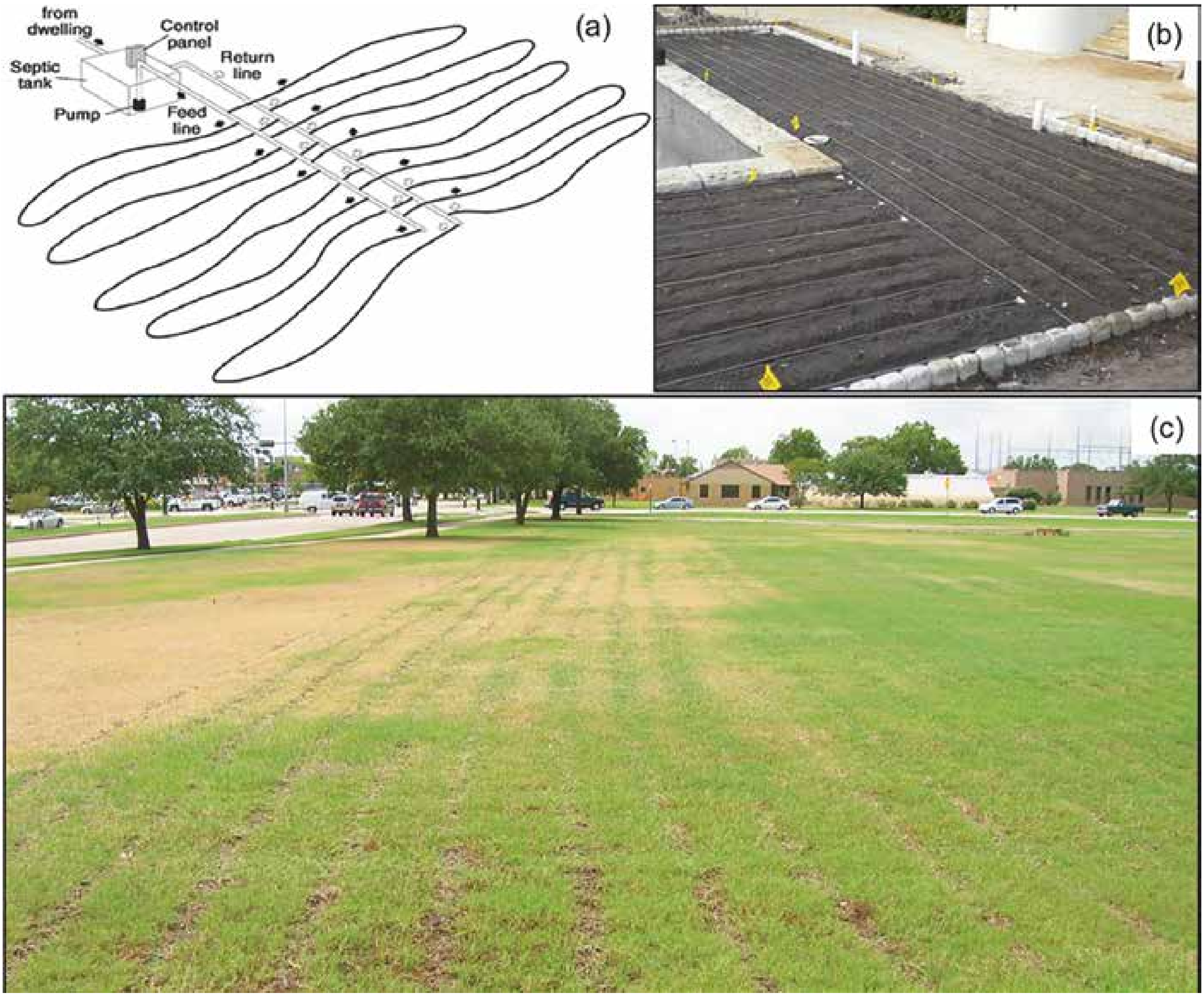


FIGURE 4.9: Sub-surface drip tape network. (a) Schematic diagram of principle operation and required components. (b) Construction of a subsurface drip line network in confined space with good spatial coverage. (c) Clearly visible impacts on grass vitality from subsurface drip line irrigation (Image sources: Water NSW, The Favorite, Texas A&M University)

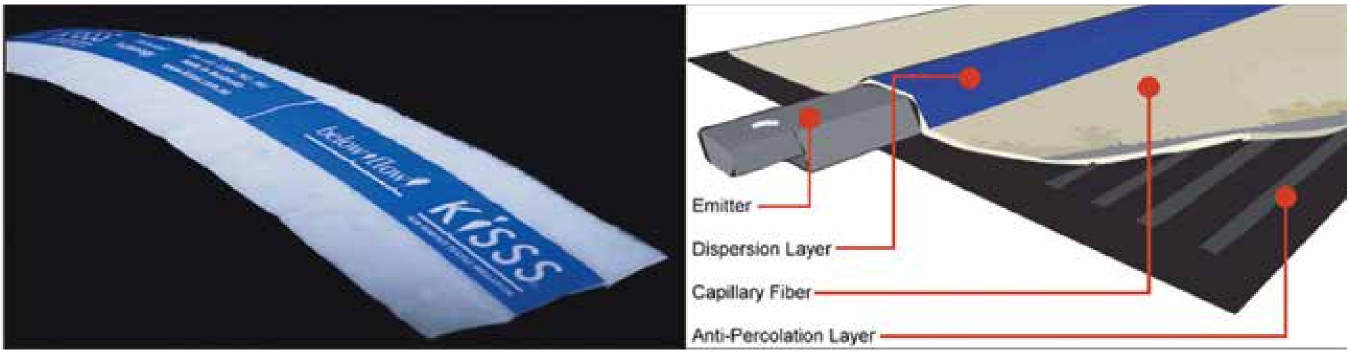


FIGURE 4.10: KISSS Flat irrigation system. (Image source: KISSS America)

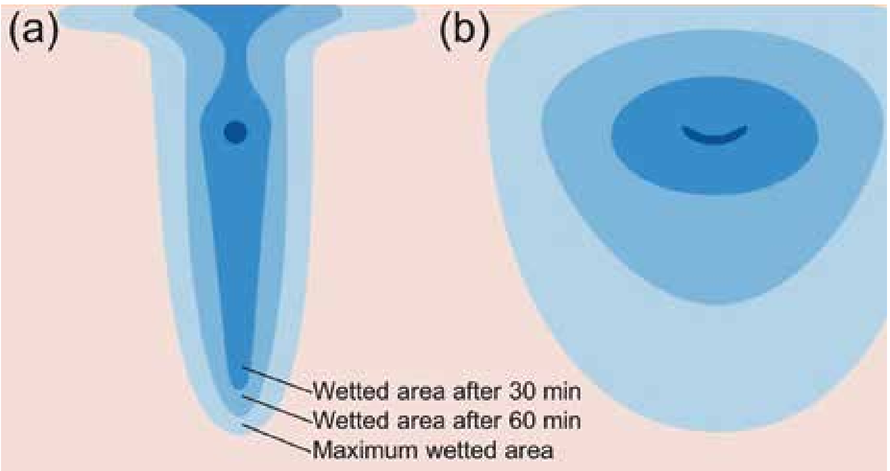


FIGURE 4.11: Typical distribution patterns of subsurface irrigation systems. (a Conventional SSDI system with strong downward seepage. (b) KISSS Flat with lateral and capillary wetting effect. Image modified from swanwatersolutions.com.

4.4.4 KISSS Flat Irrigation System

The Kapillary Irrigation Sub-Surface System (KISSS) takes drip irrigation to the next level of water saving performance. KISSS has been developed in Australia and is marketed globally as the world's most advanced sub-surface irrigation system, saving up to 50 % more water than conventional SSDI or SSDT systems and 75 % more effective than sprinklers. Performance of the technology has been subject of intensive research and development work for more than 10 years involving CSIRO, Western Sydney University, the University of Queensland and Charles Sturt University (e.g. Muirhead et al. 1998; Fuentes et al. 2004).

Two KISSS products are available, and KISSS Flat seems most appropriate for irrigation of green track.

KISSS Flat tubing is 100 mm wide and combines drip line with geotextile technology. A central drip tape is covered by a flat geotextile fabric on the top side and an impermeable layer on the bottom. The former wicks moisture laterally from the supply pipe, the latter prevents initial downwards escape of moisture (Figure 4.10). Water sitting in the geotextile is subsequently taken up by capillary forces of the soil. Typical installation depth of KISSS Flat is 150 – 200 mm below surface for crop species. This depth may be slightly decreased when irrigating shallow-rooting species such as grasses or groundcovers.

Benefits of this system over conventional SSDI and SSDT irrigation systems is the even distribution of water and the use of the capillary action of the fabric to transport water to points of use. Typical teardrop wetting patterns of other conventional drip systems are avoided (Figure 4.11). It thus provides greater control over root-zone conditions and ensures water is delivered uniformly at a rate consistent with rates of capillary absorption by the soil (IWT 2017).

FIGURE 4.12: Installation of a subsurface irrigation mat. (Image source: Hunter Industries 2018)

4.4.5 Subsurface Textile Irrigation

Subsurface textile irrigation (SSTI) systems consist of special Polyethylene drip lines that are embedded in several layers of geotextile fabric with low-density (Figure 4.12). The technology is predominately used in construction of green roofs but also for irrigation of green tracks in Germany (Kappis and Schreiter 2016). Similar to the KISSS principle, capillary forces will draw moisture from the drip line into the fabric from where it is taken up by soil or directly by plant roots. However, SSTI systems use mats that come at a far greater width than KISSS Flat. Mats are typically installed 100-150 mm below the surface. This location ensures little water is lost due to evaporation. Water supply to plant roots is up to 50 % more efficient compared to conventional surface irrigation systems.

SSTI systems require only low water pressure. This allows operation of the systems using smaller sized pumps, reducing power consumption and costs. In addition, SSTI do not affect tram line operations and the risk of vandalism is minimal. However, failing of SSTI mats can be very costly, as the entire mat has to be replaced for which also the entire vegetation and soil layer above the mat has to be removed. Typical lifespan of SSTI systems is between 15 and 20 years depending on maintenance, but rodents can substantially shorten this timeframe. Warranty times vary for products and manufacturers, so it is time well spent to compare them. See Table 4.2 for a brief summary of this irrigation technology.

TABLE 4.2: At a glance – Irrigation with Sub-surface Mats.

REQUIREMENTS
» Flat surface. » Calculate side overlap of 10-5 cm in material calculations. » A water analysis should be carried out in advance. » Design according to incoming water mains (i.e. end-feed layout, center-feed layout).
INSTALLATION
» Place single layer of geotextile on top soil as filter. » Lay out mats on top of this filter and stake down. » Interlink individual mats. » Connect to mains. » Program irrigation schedule into control unit.
MAINTENANCE
» Ducting system should be flushed seasonally. » Air should be released regularly from release valves installed at the higher point of the system.

4.5 SMART IRRIGATION SYSTEMS

Smart technology is becoming increasingly available to optimize irrigation scheduling. Three principles can be differentiated: 1. locally installed weather sensors (e.g. rain sensor), 2. Soil moisture sensors and 3. Irrigation computers that retrieve signals from specific internet pages. A rain sensor would interrupt irrigation schedule once a droplet hits the sensor and withhold any further scheduling until all rainwater from sensor has evaporated. Usually, these sensors have a small reservoir above them to capture larger amounts of rain to reflect realistic rates of evaporation. Similarly, a soil moisture probe would stop irrigation once soil moisture has surpassed a set threshold.

More sophisticated are package systems that access weather information online to hold off scheduled irrigation during and after rain events. Irrigation schedules and interruptions can be shared through mobile technology with contractors or maintenance crews. For example, the Rain Bird ST8 Smart Irrigation WiFi Timer allows remote scheduling and operation of multiple timers and individual irrigation zones within each timer via computer, tablet or mobile technology. A function, termed 'automatic seasonal adjust' allows matching irrigation schedules according to local rainfall, temperature and relative humidity information accessed via internet link. Similar products are the *SmartLink Landscape Network* by WeatherMatic or the cloud-based *WeatherTRAK* from HydroPoint. Many other products are available and should be discussed with local suppliers to identify optimal solutions for remote irrigation management of green tracks.

Staff at Western Sydney University have experimented with the irrigation control system *Hydrawise* (Figure 4.13). Analogous to products mentioned above, this system will adjust irrigation applications based on past, current and forecasted weather patterns by continuously accessing and analyzing data from Global Weather Monitoring Service (GWMS). Local weather station networks, for example all official weather stations operated by the Australian Bureau of Meteorology, can be added. Use of this technology seems beneficial for operating irrigation networks along a section of green track. This technology should be included in test design of the prototype to assess its practical use and advantages for the Parramatta Light Rail project (see Chapter 6).

The *Hydrawise Ready* controller though is quite advanced. It can monitor and provide information about flow meters, rain sensors and condition of wiring and master valves in the irrigation infrastructure. Inbuilt from master controls will inform automatically about blockages or leaks. Remote access to key components and regulation of timing and duration of irrigation can potentially reduce the frequency of site visits and associated costs. More importantly, faults in the irrigation system can be detected immediately and repaired before water deficits or flooding damages green track vegetation and infrastructure. A contractor dashboard function can allow site managers to check, monitor and regulate volumes of discharged water.

FIGURE 4.13: Hydrawise App. Example of a report screen showing detailed flow meter measurements for individually operated irrigation zones. This type of information can be highly informative when operating a multi-zoned irrigation network on a section of green track. (Image source: Hunter Industries 2017)

RECOMMENDATIONS FOR PARRAMATTA

Information from the following sources were used in this review:

- peer- and non-peer reviewed literature,
- grey literature,
- published and unpublished reports,
- climate data,
- web-based information and,
- communication with stakeholders and relevant experts.

Based on this information a number of recommendations are provided in best faith. In agreement with a previous assessment of green track viability in Sydney (Cox Richardson 2015), it is highly recommended to develop regular communication and knowledge exchange with green track operators in Adelaide (City of Adelaide) and Melbourne (Yarra Trams). To achieve the desired design and ensure good performance of green track beds, experts with relevant technical knowledge should support the design and tendering stages.

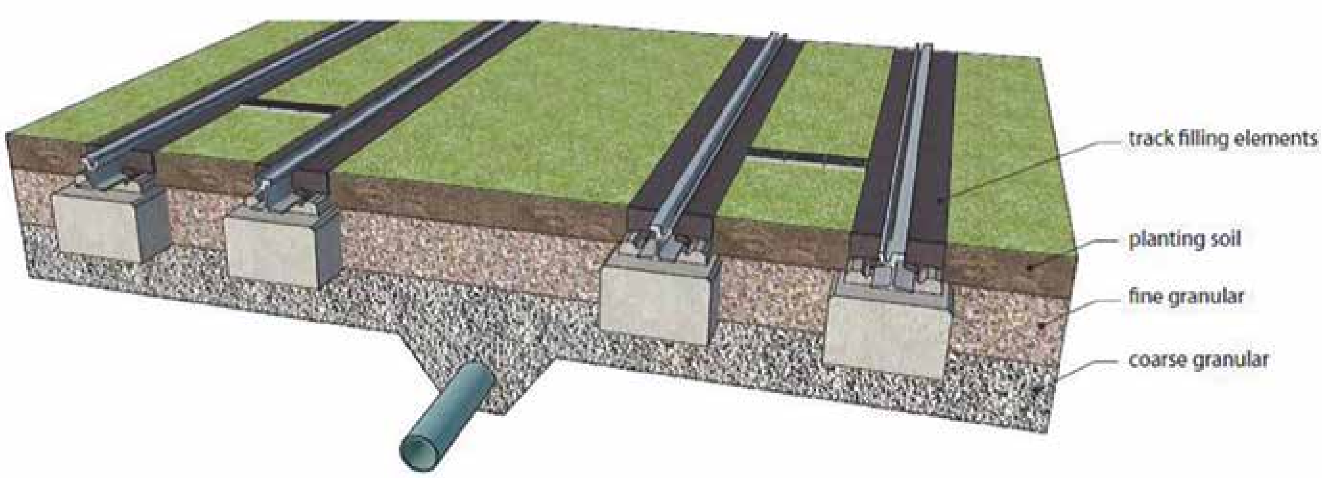
5.1 TRACK DESIGN

It is recommended to use a **parallel grade beam track system**, resting either on natural sub-grade or compacted granular material (Figure 5.1). Advantages for this track design are:

1. free draining of stormwater;
2. provision of sufficient depth for vegetation base layer that will provide good soil water storage characteristics;
3. good planting depth for green track vegetation between and alongside the two track lines
4. sufficient soil depth to position irrigation system at ideal depth (100-150 mm).

Either grooved or vignole rails are suitable for this track design, although the proposed track design displayed the Green Track Discussion Paper from TfNSW (2018) depicts a cross-section using vignole rails (Figure 5.2). However, grooved rails may be easier to incorporate into prefabricated concrete track beds, finishing flush with the surface. Figures 2.19 and 2.22 from Melbourne and Adelaide, respectively, exemplify possible examples of track finish. This **design would be beneficial for isolating the track from the vegetation**. However, it must be noted that several examples of green track designs outside Australia are provided in Chapter 2 (and also in Table 1.1) that use vignole rail profiles without any visible filling elements. Regardless of rail type and rail fastening infrastructure, isolation of rails and rail fastening infrastructure from soil must be ensured to reduce the risk of corrosion of track infrastructure as a result of stray currents.

FIGURE 5.1: Cross-section of a parallel grade beam track. (Image source: Sydney Light Rail)



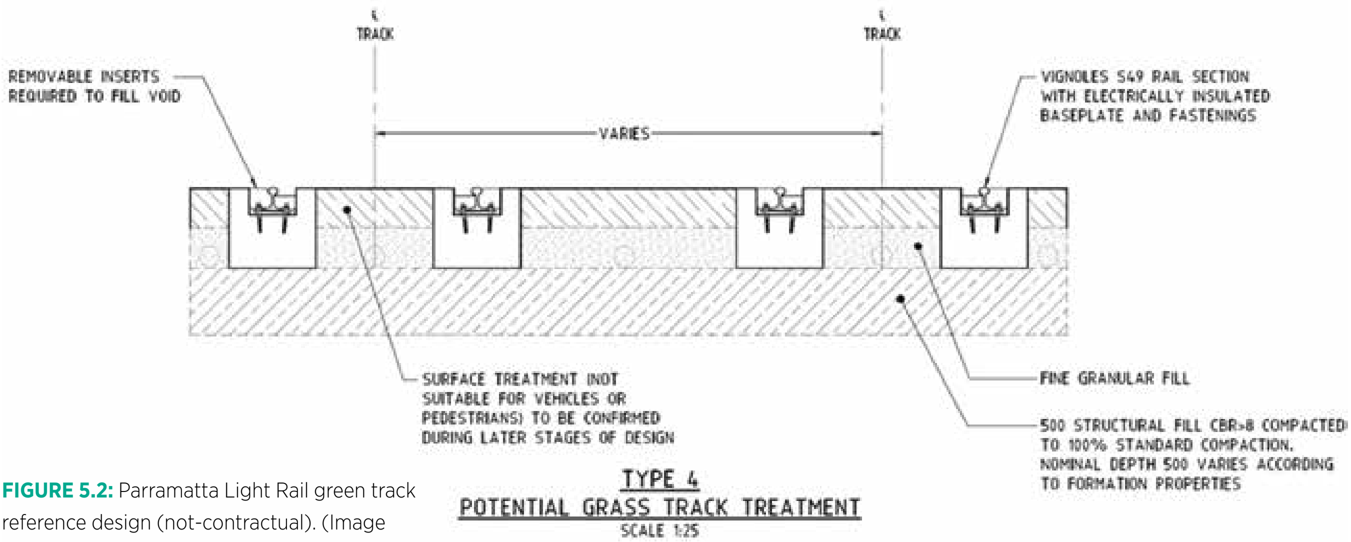


FIGURE 5.2: Parramatta Light Rail green track reference design (not-contractual). (Image source: TfNSW 2018)

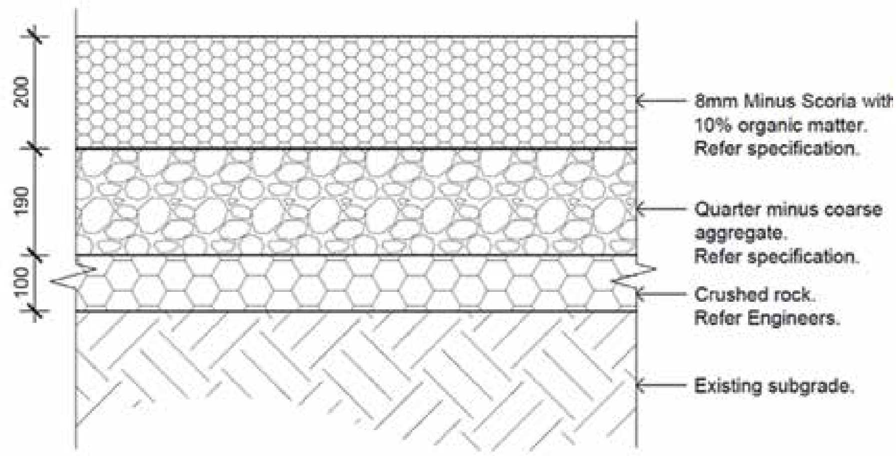


FIGURE 5.3: Schematic soil profile for Southbank green track. Drawing of anticipated thickness for vegetation base layer, filter layer and subgrade suggested for green track at Southbank, Melbourne. (Image source: Document M1733_TCL_Tram_Greening Rev B[2] provided by TfNSW)

The **vegetation base layer** should have a depth of **at least 250 mm**. The **filter layer** should have at least a thickness of **100 mm**. Melbourne's planning team for the Southbank Precinct is opting for a shallower vegetation base layer with very low water holding capacity (Scoria granulate) and a thicker filter layer (Figure 5.3). Reason for selecting these soil specifications may be that their selection of plant species can cope with drier and shallower top soils (similar to Sedum track beds), or specific irrigation techniques that ensure plant survival in 200 mm of top soil.

It is highly recommended to include a **geotextile layer between the vegetation base and filter layer** to prevent loss of top soil and associated decreases in drainage capacity. As shown in Figure 3.2, inclusion of geotextiles is also endorsed when depth of top soil is less than 100 mm. The schematic drawings from TfNSW (Figure 5.2) or Melbourne's planning team (Figure 5.3) do not explicitly indicate inclusion of a geotextile between the two soil layers, possibly an unintentional omission of detail in these sketches.

5.2 VEGETATION COVER

This review provides a *top-ten* list of suitable plant species for green track in Parramatta. Yet, for reasons listed in Table 3.1 and 3.2, the overall most suitable species are **Trailing Pratia** as native groundcover or **Zoysia tenuifolia** as native grass. Both species are perennial and should produce a thick mat of continuous green vegetation cover.

All suggested plant species will thrive in the climate of the region. When attempting a final selection, the following site-specific conditions should be considered to inform a species selection:

1. Potential thickness of the vegetation base layer
2. Environmental conditions (shade, sun, annual precipitation)
3. Maintenance (i.e. frequency of mowing, fertilizing)
4. Irrigation system and volume of water required
5. Water quality
6. Location (i.e. track or tram stop)
7. Access (i.e. pedestrians, bicycles, vehicles)

To ensure planting success, it is recommended that **planting takes place in early spring**. Cool temperatures and higher chance of sustained rainfall events at this time of year will provide optimal conditions for green track to pass through its Establishment and Rectification Period and reaches its Maintenance Period (see Chapter 4.1) before summer conditions may present periods of temperature and water stress (note that Parramatta also experiences dry winters, leaving autumn months for plant establishment as a less recommended planting season).

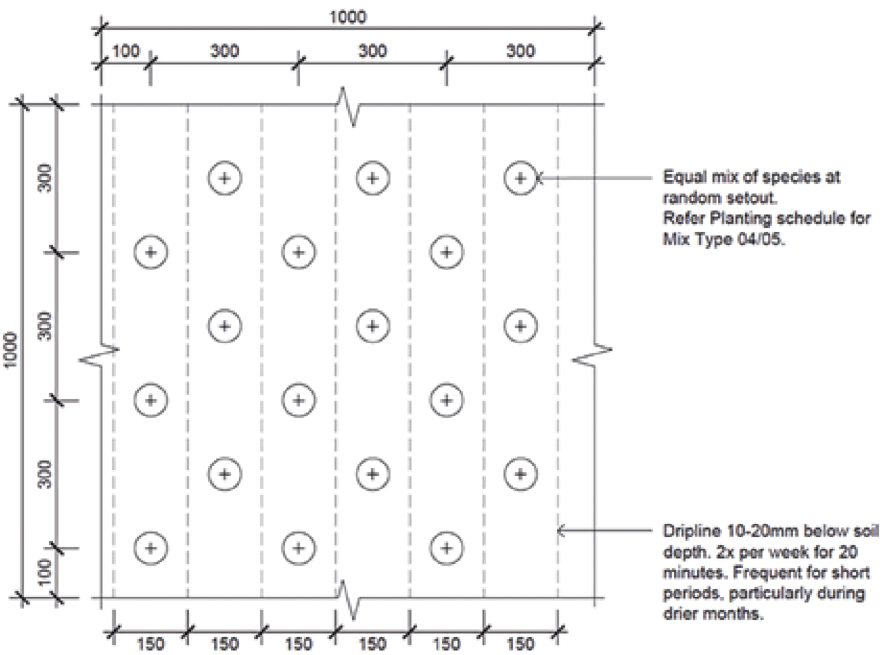
5.3 IRRIGATION SYSTEM

The **KISSS Flat irrigation system** appears most suitable for green track to thrive under climatic conditions, particularly hot and dry summers regularly experienced in Parramatta. This subsurface irrigation system will deliver sufficient amounts of water while minimising evaporative (towards the surface) and percolation losses (towards the filter layer). Pop-up sprinkler, although well-established as irrigation devices, are not recommended due to the high evaporative water loss, risk of damage, vandalism and potential interference with tram operations.

A diagram from the proposed Southbank green track system in Melbourne depicts separation of driplines by 150 mm, and an installation depth of 10-20 mm (Figure 5.4). While spacing seems appropriate, installation depth is surprisingly shallow. It is recommended to investigate optimal spacing of KISSS Flat irrigation lines using the green track prototype (see Chapter 5.5 below). Lateral capillary reach of water released from 100 mm wide geotextile may justify a wider spacing to achieve complete soil wetting, yet reduce up-front costs of the irrigation system.

Of the smart irrigation systems described in Chapter 4, **Hydrawise** seems most appropriate for automating irrigation of green track beds in Parramatta. From all products reviewed (more than listed in Chapter 4.4), *Hydrawise* provides the best developed resources for industrial-scale irrigation management.

FIGURE 5.4: Planting and irrigation schematic for the proposed green track at Southbank, Melbourne. (Image source: Document M1733_TCL_Tram_Greening Rev B[2] provided by TfNSW)



5.4 REFERENCE DESIGNS

Recommendations for green track in Parramatta provided here differ slightly from the track design that is suggested for green tracks at Southbank in Melbourne (Figure 5.5a) and the anticipated extension of the green track at Box Hill (Figure 5.5b). Most obvious is the selection of plant species for Southbank, moving away from turf towards meadow-type green beds composed of species like pig face, swamp daisy and vanilla lilies. These types of flowering plants will reach heights of up to 500 mm and reflects a current trend away from uniform urban green lawns to more biodiverse and dense vegetation mats (Ingnatieva and Hedblom 2018). As shown in Figure 5.5, taller plants will only be planted into the space between tracks. Notably, soil surface will sit 100 mm below the rail surface and within tracks plant heights of up to 135 mm above the rail surface will be tolerated. It could be expected that plant arrangements of this type will involve high-intensity maintenance. It is unclear how cross-seeding of taller plants into the space within tracks can be prevented or how wind from passing light rail vehicles will impact plant stature. The vegetation cover suggested for the Parramatta Light Rail project will be lower in height and uniform. This will help limiting costs for maintenance and focus on continuous green cover.

A second difference is the depth of the vegetation base and filter layer. The Southbank design indicates the use of a 200 mm thick top layer of Scoria (see Figures 5.3 and 5.5a). This material is a of volcanic origin, light weight, highly porous and with low water holding capacity. It is unclear if organic matter will be incorporated to support vigorous plant growth. The track design for the Box Hill extension depicts a 120 mm layer of top soil and vegetation cover within, and a 200 mm top soil layer between tracks (Figure 5.5b). The design specifies use of 'high quality turf'. Thickness of the vegetation base layer in both track bed designs is less than recommended for the green track at Parramatta (250 mm). A thicker layer of top soil will retain more water (stormwater and irrigation), which is expected to be an advantage during anticipated hot summer. Climate in Melbourne is significantly cooler, resulting in lower rates of evapotranspiration. This may allow for thinner top spoil layers or even the use of Scoria as planting medium. However, to successfully establish and maintain green track at Parramatta, track design must account for harsher summer conditions.

The use of geotextiles is not specified in either track design from Melbourne. Using such a fabric to prevent washdown of top soil into the filter layer is highly recommended. It will help maintaining a uniformly flat surface and retain the draining capacity of the filter layer.

In a report of TfNSW that assesses feasibility of green track for the CSLER project, the use of *Zoysia macrantha* is recommended (TfNSW 2015). This recommendation is based on the supposedly high drought tolerance of the species. The report advises that "Sydney's climate and the high drought tolerance of this species means that a watering system would not have to be installed". The present review does not support the statement, as it is unlikely that the green track will deliver all its functions and services, particularly during summer, if it is not supplied with additional water. Although the mentioned report advises that irrigation may be necessary if vegetation base layer is less than 300 mm thick, the information reviewed here suggests that even under circumstances where thickness of the vegetation base layer is increased, additional water will be required to maintain a healthy green track. This requirement is mostly owed to the high rates of evapotranspiration during summer in the climate of the Greater Sydney Basin (see Figure 4.1).

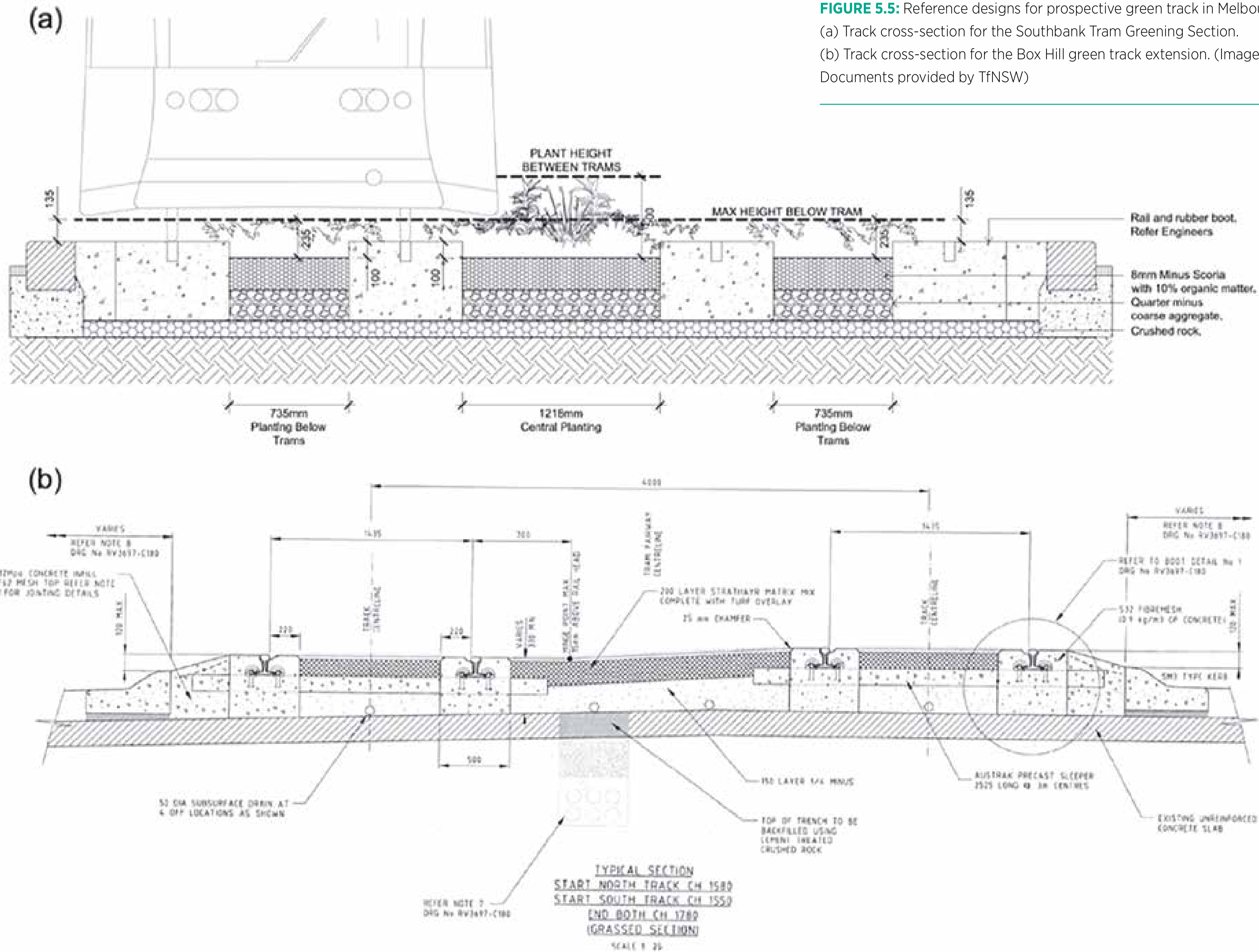


FIGURE 5.5: Reference designs for prospective green track in Melbourne.
(a) Track cross-section for the Southbank Tram Greening Section.
(b) Track cross-section for the Box Hill green track extension. (Image source: Documents provided by TfNSW)

CONCLUSION AND OUTLOOK

This report provides a comprehensive overview about the benefits provided by urban green track beds and how climate change may impact this highly specialized infrastructure. For the first time, environmental conditions and track designs were systematically assessed to determine how green track beds can be implemented into the Parramatta Light Rail project. Climate analyses revealed that green tracks are operated in cities that experience hotter average temperatures and less rainfall in summers compared to Parramatta. Provided that water will not become limited at any point in time, it is possible to operate green track in Parramatta.

A range of track bed designs suitable to accommodate green track beds have been assessed. **The most suitable design appears to be the parallel grade beam track.** This track type is used for green track in cities around the world, and offers sufficient flexibility to adapt to local conditions above and below ground. A range of local plant species have been identified to provide good groundcover of the track bed and withstand the pressures of urban life. Together, track and greening will offer a unique experience for tram passengers and residents alike.

As identified through this review, several important knowledge gaps must be addressed to help ensure green track is successful in Parramatta.

It is suggested to **establish a prototype** with dimensions of 35 m length and 8 m width (representative double tram line). The track should consist of 30 m green track and 5 m conventional concrete slab surface finish. Site access for heavy construction vehicles is necessary for construction and services (e.g. power and mains water) must be present on site to support research equipment and management applications (e.g. irrigation). The prototype should not be accessible to the public to reduce the risk of theft and vandalism.

1. Soil properties

Soil nutrient composition, pH, structure and water holding capacity must be investigated to provide optimal topsoil for the vegetation base layer. Particularly water holding capacity is an important parameter since a balance between holding onto moisture, yet at the same time allowing plants to extract sufficient volumes of water from soil space.

2. Plant performance

Although this review has identified three grass species and seven groundcovers, it remains unknown which of these 10 species is most suitable to withstand the harsh conditions of green track environment. The vegetation cover must remain dense to prevent establishment of weeds; it must cope well with different light conditions; particularly in summer, there will be very high surface temperatures, including radiated heat from metal rails. Testing plant performance against these parameters will help identify benefits and deficiencies of individual plant species.

3. Irrigation

Spacing and volumetric delivery of the subsurface irrigation system needs to be assessed. This will allow developing the most cost-effective layout of the system and reduce water losses due to oversaturation/drainage and associated expenses. In addition, defining optimal watering regimes will help minimize the risk of damage to track infrastructure from standing water. Optimised scheduling of irrigation and also fertilisation will be necessary on a species basis. All irrigation and fertilisation work must implement findings from soil-related work outlined above.

4. Maintenance

Once established, maintenance of the vegetation cover will be the largest expense to remain visually appealing. Assessments of a) frequency of mowing, b) time required for weeding and c) removal of debris, rubbish and litter to maintain the positive visual value of the track bed can help to develop cost analyses and forward projections for maintenance expenses.

5. Environmental benefits

As reported at the beginning of the review, green track provides a number of environmental benefits. Field testing can be used to assess several of these. For example, infrared thermography can be used to document effects of cooling; essays to calculate carbon sequestration capacity of green track can be established using plant and soil analyses in combination with measurements of biomass and maintenance activities.

6. CO_2 substitution effects

Little is known about substitution effects of green track on use of conventional track bed materials. Replacing concrete with vegetation cover will reduce the carbon footprint at construction. However, it is recommended to use life cycle analyses to develop a comprehensive impact analyses that accounts for additional benefits (e.g. soil carbon sequestration) and disadvantages (e.g. use of fossil fuels for mowing, nutrient leaching from fertilization). Moreover, carbon and environmental footprints of different types of concrete (Portland, Sulphoaluminate, Recycled, Geopolymer, etc.) potentially used in the construction of the green track should be compared. Research has demonstrated that the carbon footprint of steel-reinforced concrete can be reduced by more than 55% when using polypropylene fiber reinforced concrete (Cutright et al. 2013). Selecting 'smart' concrete for the construction of parallel grade beams will deliver significant environmental benefits.

Ideally, experimental work on the prototype will last for two consecutive summers. Construction and plant establishment should coincide with spring, as this time will provide good vigour of plants, and rapid establishment of green track. The necessary research will allow progressive development of designs and strategies how to operate green track under varying environmental conditions, including hot summers and heatwaves. Work on the green track prototype should also involve co-operation with industry partners that will establish and operate the green track for Parramatta Light Rail, ensuring engagement and communication of results among all parties involved. **This empirical work is the only means to develop best practices for green track operation** based on evidence currently not available in NSW or Australia.

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APPENDICES

Appendix 1: Different designs for green track beds

Grass track types include: 1. high-level vegetation (top-of-rail – TOR), where plant height reaches or exceeds the rail head; 2. low-level vegetation (foot-of rail – FOR) where plants only cover the base around rails; 3. mixed level type vegetation, where plants are growing at low (mostly between tracks) and high levels (mostly alongside tracks). See Table A1 for more details on advantages and limitations of the different track systems.

(1a) High-level vegetation

BENEFITS	DRAWBACKS
» Improved noise reduction due to fully encased rails » Good integration of green track into urban landscape » Improvement of urban climate due to high storage capacity of stormwater » No accumulation of debris and foliage » Good access for lawn movers and tractors to allow large-scale mechanised maintenance » Grass clippings can be removed easily	» Railway right of way is to a lesser extent perceived as danger zone » Increased crossing of tracks by pedestrians and possible vehicle incursion » Higher standard for rail encapsulation/ isolation to minimise stray current leakage » Reduced access for rail and track maintenance » Vegetation could be 'burnt' by radiating heat from light rail vehicle

(1b) Schematic diagram of a high-level vegetation track design.

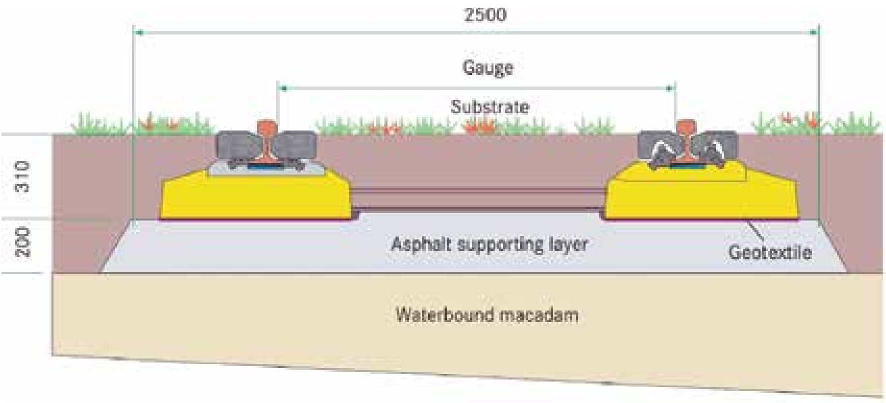


TABLE A1: *Benefits and drawbacks of different green track bed systems. Adapted from Kappis and Schreiter (2016). Cross-sections were adopted from Rail.One GmbH.*

(2a) Low-level vegetation

BENEFITS	DRAWBACKS
» Rails and fastenings are always accessible » Rails can easily be surveyed and replaced » Vegetation never overgrows the track » Minor risk of stray current leakage » No additional system components like encapsulation are necessary » Tracks are clearly visible, improving the perception of right-of-way » Pedestrians are more reluctant to cross exposed tracks and vehicle incursion is less likely » Radiant heat from underside of light rail vehicle is less likely to damage vegetation	» Increased noise levels due to noise emissions from exposed rails » Even green area is interrupted by clearly visible rails which is aversive to desired urban design » Increased surface storing heat in rail and concrete structures » Debris and leaves are trapped in the track reducing visual appeal » Regular cleaning of sleepers/concrete beams is required at rails and rail fastenings » Limited thickness of vegetation base layer depending on track structure » Limited capability for water retention as result of reduced thickness of vegetation layer » Increased effort for maintenance and ensuring safety of maintenance staff

(2b) Schematic diagram of a low-level vegetation track design.

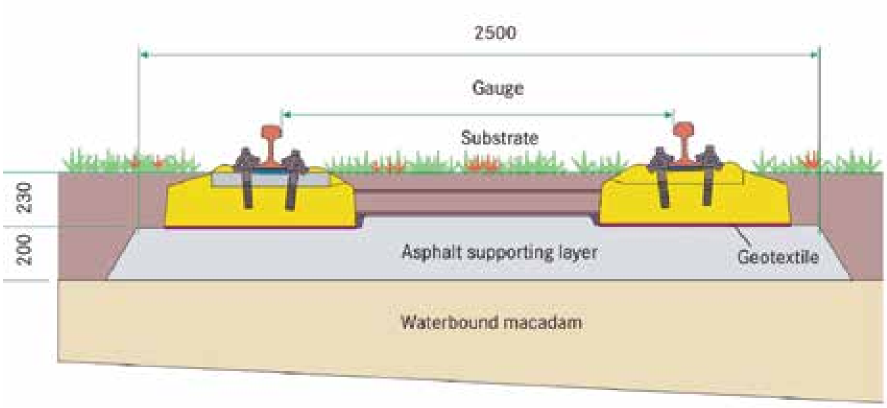


TABLE A1: *Benefits and drawbacks of different green track bed systems. Adapted from Kappis and Schreiter (2016). Cross-sections were adopted from Rail.One GmbH.*

(3a) Mixed-level vegetation

BENEFITS	DRAWBACKS
» While appearing like an even green area the track is clearly visible and recognised as light rail infrastructure » Rail and fastening elements are visible and accessible on one side of the rails » Heat radiation from passing light rail vehicles does not impact the low-level vegetation system between the tracks	» Debris and leaves can get trapped in the track » Depending on track construction, only limited thickness for the vegetation base layer between tracks » Limited capability for water retention as result of reduced thickness of vegetation layer » Effort for maintenance is similar to low-level track system » Vegetation cover could become patchy in and beside the track due to different thickness of the vegetation base layer

(3b) Schematic diagram of a mixed-level vegetation track design.

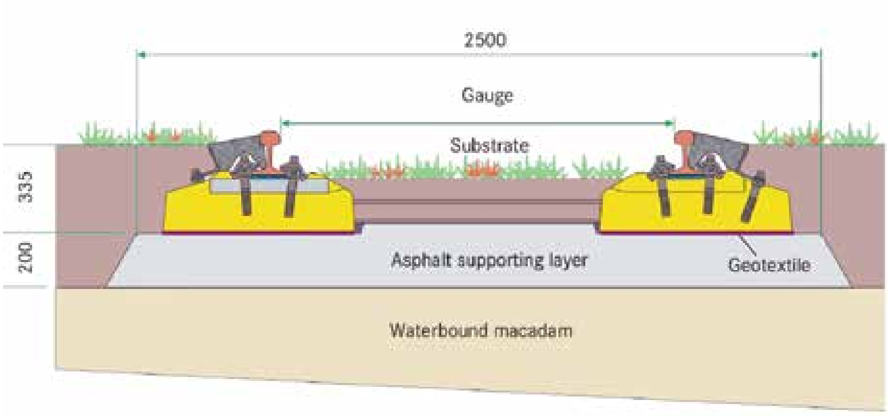


TABLE A1: *Benefits and drawbacks of different green track bed systems. Adapted from Kappis and Schreiter (2016). Cross-sections were adopted from Rail.One GmbH.*

Appendix 2

The Köppen Climate Classification System:

A – *Moist Tropical Climates* are known for their high temperatures year-round and for their large amount of rain year-round.

B – *Dry Climates* are characterised by little rain and a huge daily temperature range. Two subgroups, **S**– *semiarid or steppe*, and **W**– *arid or desert* are used with the B climates.

C – In *Humid Middle Latitude Climates, land/water,* differences play a large part. These climates have warm, dry summers and cool wet winters.

D – *Continental Climates* can be found in the interior regions of large land masses. Total precipitation is not very high and seasonal temperatures vary widely.

E – *Cold Climates* describes this climate type perfectly. These climates are part of areas where permanent *ice and tundra* are always present. Only about four months of the year have above freezing temperatures. *(NB: This climate category is will not be investigated in this review as it is not compatible with climate in Parramatta, Australia).*

Additional subgroups are designated by a second, lower case letter which distinguishes specific seasonal characteristics of temperature and precipitation:

f – Moist with adequate precipitation in all months and no dry season. This letter usually accompanies the **A**, **C** and **D** climates.

m – Rainforest climate in spite of short, dry season in monsoon type cycle. This letter only applies to **A** climates.

s – There is a dry season in the summer of the respective hemisphere (high-sun season).

w – There is a dry season in the winter of the respective hemisphere (low-sun season).

To further denote the variations in climate, a third letter us added to the code:

a – Hot summers where the warmest month is over 22°C. These can be found in **C** and **D** climates.

b – Warm summer with the warmest month below 22°C. These can also be found in **C** and **D** climates.

c – Cool, short summers with less than four months over 10°C in the **C** and **D** climates.

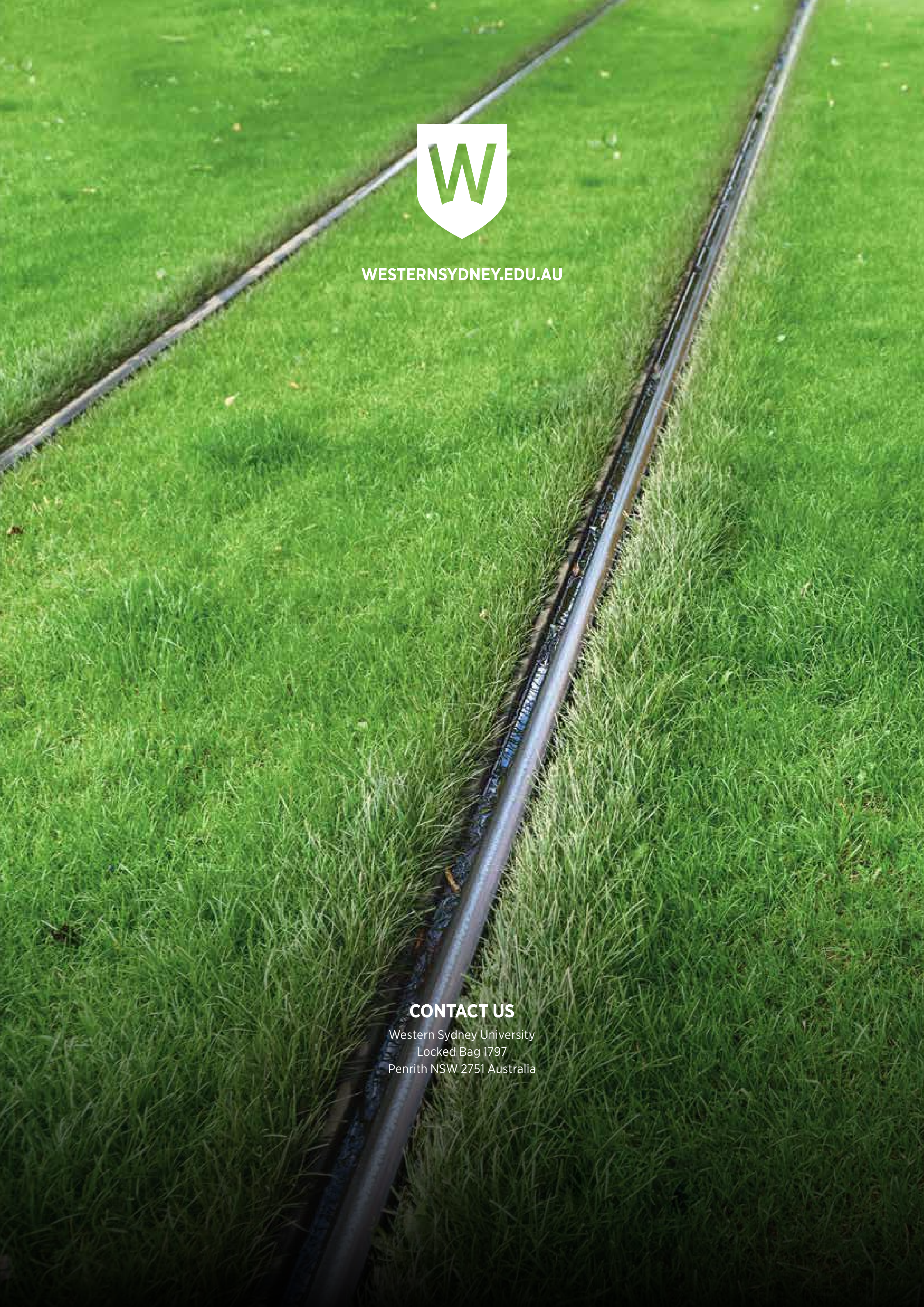
d – Very cold winters with the coldest month below -38°C in the **D** climate only.

Appendix 3

Water Quality Analysis of the Prospect East Water Supply System. Source: Sydney Water

Parameter	Units	ADWG* Health	ADWG* Aesthetic	Prospect East (10th – 90th percentile range)
Physical characteristics				
True colour	TCU or HU	na	15	<2 - 4
Turbidity	NTU	na	5	0.1 – 0.2
Total dissolved solids	mg/L	na	600	100 -136
pH	pH units	na	6.5 - 8.5	7.9 – 8.1
Conductivity	mS/m	na	na	18 – 20
Total hardness	mg $CaCO_3$ /L	na	200	48 – 62
Calcium hardness	mg $CaCO_3$ /L	na	na	29 – 40
Magnesium hardness	mg $CaCO_3$ /L	na	na	19 - 22
Alkalinity	mg $CaCO_3$ /L	na	na	32 – 41
Temperature	degrees C	na	na	14 – 23
Dissolved oxygen	% saturation	na	>85%	97 – 124
Disinfectants				
Free chlorine	mg/L	5	0.6	<0.04 – 0.04
Monochloramine	mg/L	3	0.5	0.98 -1.48
Disinfection by-products				
Trihalomethanes	mg/L	0.25	na	0.041 – 0.124
Inorganic chemicals				
Aluminium	mg/L	na	0.2	0.010 – 0.016
Ammonia (as NH_3)	mg/L	na	0.5	0.32 – 0.41
Arsenic	mg/L	0.01	na	<0.001
Cadmium	mg/L	0.002	na	<0.001
Calcium	mg/L	na	na	12.4 – 16.5
Chloride	mg/L	na	250	25.6 – 32.8
Chromium (Cr as VI)	mg/L	0.05	na	<0.0004
Copper	mg/L	2	1	0.007 - 0.028
Cyanide	mg/L	0.08	na	<0.005
Fluoride	mg/L	1.5	na	0.97 – 1.10
Iron	mg/L	na	0.3	0.010 – 0.021
Lead	mg/L	0.01	na	<0.001
Nickel	mg/L	0.02	na	<0.001
Magnesium	mg/L	na	na	4.2 – 5.5
Manganese	mg/L	0.5	0.1	<0.001 – 0.002
Mercury	mg/L	0.001	na	<0.0001
Nitrate (as NO_3)	mg/L	50	na	0.6 – 1.0
Nitrite (as NO_2)	mg/L	3	na	0.003 – 0.081
Phosphorous	mg/L	na	na	0.007 – 0.009
Potassium	mg/L	na	na	1.9 – 2.3
Reactive silica (as SiO_2)	mg/L	na	<80 mg/L	2.5 – 5.0
Selenium	mg/L	0.01	na	<0.003
Silver	mg/L	0.1	na	<0.003
Sodium	mg/L	na	180	12.7 – 15.5
Sulfate	mg/L	500	250	7.4 – 8.8
Zinc	mg/L	na	3	<0.005
Organic compounds				
Chlorinated, polynuclear aromatic, aromatic hydrocarbons		various	various	nd
Chlorophenols		various	various	nd
Pesticides		various	various	nd

Legend: na = no published health or aesthetic guideline value, **nd** = reported results are non-detectable (less than the limit of detection), ***ADWG** = *Australian Drinking Water Guidelines 2011*



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